Highlights IN Space

PROGRESS IN SPACE SCIENCE, TECHNOLOGY AND APPLICATIONS, INTERNATIONAL COOPERATION AND SPACE LAW

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INTRODUCTION

This publication has been compiled from two reports prepared for the United Nations Committee on the Peaceful Uses of Outer Space, and covers the period from 1 November 1996 through 31 October 1997. The first part of the report, on space technology, applications, international cooperation and space law, was prepared by the International Astronautical Federation (IAF). The International Institute of Space Law (IISL) provided input for the section on space law. The second part, which focuses on space science, was prepared by the Committee on Space Research (COSPAR) of the International Council of Scientific Unions (ICSU). Many of the most prominent international experts from many countries have contributed to this comprehensive and authoritative survey. The infomation it contains reflects the wide range of space activities currently being conducted in many national and international space programmes. A list of contributors is located at the end of the report. This publication is being circulated only in the language in which the reports were prepared and submitted.

This review of recent developments in space science, technology, applications, international cooperation and space law is intended to provide information on these developments to a broad international audience. First published in 1992 as part of United Nations activities undertaken for International Space Year, the publication seeks to increase the awareness of all countries of the benefit of space activities.

It is hoped that this publication will make a significant contribution to the ongoing United Nations effort to disseminate information on space activities and to highlight the benefits they provide to all countries of the world.

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PART ONE:
1997 HIGHLIGHTS IN SPACE TECHNOLOGY AND APPLICATIONS

OVERVIEW

The two outstanding events of the year in space technology and applications were the successful landing and exploration of Mars by the U.S. Pathfinder mission, which was one of the first in the new "smaller, faster, cheaper" paradigm that is fast becoming the norm in science and exploration missions, and the long string of mishaps aboard the aging Mir space station, which have proven once more the importance and value of having people available in space to make on-the-spot decisions and resolve problems caused by unexpected events.

In addition to Pathfinder, 1997 also marked several other clear successes of the "smaller, faster, cheaper" approach. The Near Earth Asteroid Rendezvous (NEAR) spacecraft, launched last year as NASA's first cost-and-schedule-capped Discovery mission, snapped 500 photographs of an asteroid called Mathilde under extremely difficult conditions; the Mars Global Surveyor, launched in November 1996, was successfully inserted into Mars orbit and began its two-year survey of the Red Planet; and the Advanced Composition Explorer was successfully launched on its mission to the L-1 Earth-Sun Lagrange libration point to study the Sun's stream of particles and serve as a sentry to warn of impending solar storms. However, the Lewis Earth-observation satellite highlighted an inherent problem with the riskier smaller-cheaper concept when it lost orientation and power and could not be recovered due to the built-in autonomy that is an essential feature of low-cost systems.

The events of this year also showed, however, that spacecraft size and mass do not necessarily guarantee success. Mars 96, Spot-3, and the Advanced Earth Observation Satellite (ADEOS) also failed in 1997; Mars 96 during launch and the others after having operated successfully for some time on orbit. But the successful second repair mission to the Hubble Telescope, as fully effective as the first one in 1993, along with the truly remarkable information on Jupiter and its moons being returned almost daily by the Galileo spacecraft since its arrival in December 1995, demonstrated the clear benefits inherent in large, complex systems. The flawless launch this year of the largest space-exploration spacecraft ever built, the Cassini-Huygens mission to Saturn, is likely to provide further evidence of large-system potential. Hence the comparative values of small vs large spacecraft have yet to be established.

Nevertheless, confronted with strong evidence of success in NASA's vanguard of small science and space exploration missions, in combination with ever-tightening budgets, space agencies in Europe and Japan began this year to adopt the "faster, smaller, cheaper" philosophy. Agencies in Europe and Japan have sharply cut their budgets based on their projected ability to cut development costs and shrink spacecraft size. The new ESA plan for science missions, in particular, clearly reflects this trend.

The launch industry demonstrated its ability to recover from the string of failures described in this and prior reports, with the Ariane-5, Lockheed Martin Launch Vehicle (LMLV-1; now Athena-1), Pegasus XL, Long March 3B, and Delta-2 all posting post-failure successes. Several other failures, however, notably the first Zenit loss after 10 successes, gave notice that launch-system reliability continues to be a major concern. Development of the new generation of medium-to-large expendable launch vehicle derivatives, especially the Atlas IIAR, the Delta-3, the upgraded Proton, and the Evolved Expendable Launch Vehicle, continues to focus on improved reliability as well as lower costs.

1997 was once more marked by a major expansion of the international private-sector joint ventures and agreements that began burgeoning several years ago, with a host of major new projects launched among Russian, U.S., European, and Japanese firms as well as Chinese, Indian, Israeli, and other nations' companies. The proliferation of major corporate mergers, both national and international, also continued apace, with three major aerospace conglomerates created this year along with dozens of smaller but still significant ones.

A new era in satellite communications began with the launch of a major segment of the world's first low-Earth-orbit broadband communications constellation. Thirty-four spacecraft of the 66-satellite Iridium constellation were orbited by six launch vehicles, initiating not only a giant step in what appears to be the fastest-growing segment of the satellite communications industry—mobile communications—but also a potentially significant increment in the creation of orbital debris.

Space-segment growth in satellite communications, however, is likely to be exceeded by the ground-segment market, which is projected to more than double during the coming decade from about $18 billion annually in 1996 to over $46 billion in 2006. The mobile communications portion of that market is responsible for most of the growth, rising from 13 percent to 55 percent of the total market.

SPACE TRANSPORTATION

Current Launch Activities

The second launch attempt of the new Lockheed Martin Launch Vehicle (LMLV-1) was successful, placing NASA's 404-kg Lewis satellite (see below) into a 300-km polar parking orbit on 22 August. The two-stage LMLV-1, which failed on its maiden flight in August 1995, uses a Thiokol Castor 120 solid-propellant rocket for its first stage and a Pratt&Whitney Orbus 21D solid-propellant rocket for its second stage. The vehicle is also equipped with an orbit adjust module employing 10 Olin 220-N hydrazine monopropellant thrusters. It can place 650 kg into a 160-km 28.5-degree orbit at a price of $16 million to $17 million. The three-stage LMLV-2, whose first launch—of NASA's Lunar Prospector—is scheduled early next year from the new commercial spaceport at Cape Canaveral (USA), can orbit 1800 kg at a price of about $24 million. Following its first successful flight, the LMLV family was renamed Athena, after the mythical Greek goddess of wisdom. Lockheed Martin is seeking a patent on a mobile launcher for Athena to permit the "launch-on-demand" capability sought by U.S. military users.

A Pegasus XL launcher failed to deliver two science spacecraft into orbit on 5 November 1996, following a string of three successful launches. NASA's $26 million High Energy Transfer Experiment (HETE) and Argentina's $21.5 million Satelite de Aplicaciones Cientificas–B (SAC-B) both remained attached to the launcher's third stage after the explosive payload release mechanism failed to operate. The spacecraft were to study solar flares, X-ray sources, and other astronomical phenomena. The failure was later traced to the jolts resulting from separation of the first and second stages, which damaged the third-stage separation mechanism's electrical distribution system. Subsequent Pegasus XL flights, all successful to date, utilized a new shock mount for the system.

A Delta-2 rocket exploded just 13 seconds after being launched from Cape Canaveral on 17 January, destroying the first of a new series of U.S. Air Force Global Positioning System (GPS) spacecraft and causing $50 million in damages to the launch facility. The failure was subsequently traced to a vertical rupture in the graphite epoxy composite casing on one of the vehicle's nine solid-propellant booster rockets. The accident investigation panel concluded that the flaw was most likely caused by an impact during handling of the casing after its final structural testing had been completed. It was the first failure of a Delta launcher after 62 straight successes, although one prior launch had ejected its payload somewhat short of the desired orbit. Delta returned to service on 5 May with the successful launch of 5 Iridium satellites (see below), the first all-commercial launch from Vandenberg Air Force Base, and subsequently launched Telenor's (Norway) Thor-2 communication satellite from Cape Canaveral on 20 May. Several additional successful launches confirmed the Delta's return to routine operation.

The first Lockheed Martin Titan-4B launched a U.S. Air Force Defence Support Program satellite into a low Earth parking orbit on 23 February. The infrared sensing satellite was subsequently boosted to its geostationary orbit by a Boeing Inertial Upper Stage. The Titan-4B can launch payloads 25 percent heavier than those boosted by its predecessor, the Titan-4A, which has flown 20 times. The 4B variant gets its extra capacity from larger, more powerful solid-propellant boosters built by Alliant Techsystems. A Titan-4B/Centaur was also used to launch Cassini to Saturn on 15 October (see below).

Russia's first orbital launch from the Svobodny range was conducted on 4 March, when a Start-1 rocket placed a Zeya satellite, built by military students, into a polar orbit. The first Earthwatch (USA) commercial imaging satellite was launched into polar orbit from the same site by a Start-1 later in the year.

On 20 May the Ukrainian Zenit rocket suffered its first failure after 10 straight successes when the main booster engine shut itself down only one minute after launch from the Baikonur Cosmodrome. The payload, a Russian military satellite, was lost. Zenit is the launcher to be used by the Boeing-led international Sea Launch company (see last year's report).

Arianespace's tenth successful Ariane-4 launch of 1996 took place on 14 November, when an Ariane 44-L launched Arabsat 2B and Malaysia East Asia Satellite–2 (Measat-2), into geostationary orbit. They were the 14th and 15th satellites launched by Arianespace that year, setting a new record for the company. On 23 September 1997 an Ariane 42L lifted the Intelsat 803 satellite into a geosynchronous transfer orbit, marking the 100th Ariane flight and the 29th success in a row for Ariane-4.

Eurockot Launch Services (Russia and Germany) signed its first commercial launch contract in June, for three launches of two 210-kg E-Sat satellites each. E-Sat is a low-Earth-orbit data/messaging constellation owned by Echostar and DBS Industries (USA). The launches, from the Plesetsk Cosmodrome, will begin in 1998.

Japan's new M-5 rocket was launched on its maiden flight on 12 February, placing the Muses-B radio astronomy satellite in orbit for its five-year mission to observe celestial radio sources. Both the launcher and the spacecraft (see below) were built by the Institute of Space and Astronautical Sciences.

The first Long March launch this year took place on 12 May, when a Long March 3A rocket launched from China's Xichang Satellite Launch Centre placed the Dong Feng Hong-3 communications satellite into a geosynchronous transfer orbit. It was China Great Wall Industry's second successful operation in a row, following the October 1996 launch of a Long March 2D. China chalked up a third success on 10 June with the launch of a Feng Yun 2 weather satellite to its geostationary orbit slot aboard a Long March 3.

Resurgence of the Long March launch-system family received further confirmation on 25 June, when Hughes Space and Communications (USA) contracted with China Great Wall Industry for five launches, beginning in 1998 with a Long March 3 launch of an HS-376 satellite and continuing with annual flights of HS-601 and HS-702 spacecraft aboard more powerful Long March 3B vehicles. The contract also includes several options. China chalked up another success with the launch of two dummy Iridium payloads aboard a Long March 3C on 1 September, following which Iridium confirmed its plans to buy 11 of the 3C vehicles to launch 22 Iridium satellites beginning in December (see below).

Most important, the Long March 3B achieved its first successful flight on 20 August, launching Mabuhay Philippines Satellite's high-power (9 kWe) Agila-2 spacecraft into a geosynchronous transfer orbit (GTO). However, orbit insertion by the launcher was inaccurate, requiring the use of onboard propellant to move the spacecraft about 3,000 km. The additional propellant was within the planned reserve, and is not expected to reduce the 12-year lifetime of the satellite. Long March 3B uses a hydrogen-oxygen upper stage to lift 4,800-kg payloads to GTO, comparable to the performance of the Ariane 44L.

On 29 September the first operational flight of India's Polar Satellite Launch Vehicle (PSLV) launched the IRS-1D satellite into an 817 x 320 km orbit, somewhat short of the satellite's planned 817-km circular orbit. The spacecraft's onboard propulsion system is being used to boost IRS-1D into a 700–800 km circular orbit without any reduction in its three-year operational lifetime. The lower-than-planned orbit resulted from a slightly premature cutoff of the PSLV's fourth stage.

Development Activity

On 20 December 1996 the U.S. Air Force downselected the competitors for development of the modular Evolved Expendable Launch Vehicle (EELV; see last year's report) by awarding $60 million, 17-month Phase-2 design contracts to Lockheed Martin and McDonnell Douglas. The selection eliminated Alliant TechSystems and Boeing, but the recent acquisition of McDonnell Douglas (see below) keeps Boeing in the EELV picture.

Preliminary design reviews of the operations and ground-system segments of NASA's X-33 suborbital reusable launch vehicle technology demonstrator were completed on 18 December 1996, and the vehicle's critical design reviews were completed in January. Final design "freeze" and release of drawings for manufacturing were originally scheduled for July, but were postponed in June to later this year due to weight growth and aerodynamic instabilities discovered during wind-tunnel testing. This delay is likely to postpone the X-33's maiden flight several months beyond the original Spring 1999 schedule. System designs of the smaller X-34 were approved on 22 May, clearing the way for construction of the suborbital technology demonstrator's structures, avionics, and main propulsion system. The X-34's Fastrac oxygen-kerosene rocket engine was tested successfully in late August.

On 9 June NASA issued four contracts in its Low Cost Boost Technology Project for conceptual designs of a new small low-cost booster. Goals of this first $8 million phase of the Bantam System Technology Project, also called Bantam-X, are to develop designs for small-launcher flight demonstrators, analyse the small-payload launch market, and create business plans for post-2000 commercial small-payload launch operations. The four contractors are Universal Space Lines, Summa Technology, GenCorp Aerojet and Pioneer Rocketplane. Pioneer's design is a partly reusable air-launched vehicle; the other three are expendable rockets. NASA expects to downselect two of the awardees in 1998 to build flight-test vehicles, each under an estimated $30 million contract. The launches will use commercial spaceports.

On the basis of RD-180 engine test results (see below), Lockheed Martin removed some of the reserve payload capacity of its new Atlas IIAR (see last year's report) and upgraded the vehicle's maximum rated payload to a geosynchronous transfer orbit (GTO) from 3,820 kg to 4,045 kg. Stretching the Atlas tank would provide an additional upgrade to 4,318 kg, and the solid-rocket-boosted Atlas IIARS version, which employs two Thiokol Castor-4 strap-ons, is claimed to be able to lift 4,545 kg to a GTO, versus the current Atlas IIAS' maximum of 3,720 kg. On 17 June Lockheed Martin confirmed its commitment to the RD-180 for both the Atlas IIAR and the EELV (see above) by ordering 101 of the engines from the joint Energomash–Pratt&Whitney venture, RD Amross LLC, for about $1 billion. But because the EELV Air Force contract will specify transfer of any non-U.S. engine construction to the U.S. by 2002, Pratt&Whitney has committed itself to build a new manufacturing plant by April 1998 for the RD-180, as well as for Centaur upper-stage engines.

Space Systems/Loral (SS/L) announced on 29 January that it had contracted with Kistler Aerospace (USA) for 10 launches beginning in 1999. The contract, which exceeds $100 million, is contingent on successful development and flight testing of Kistler's two-stage reusable K-1 launcher. The K-1, whose first stage will use Russian NK-33 oxygen-kerosene engines provided by GenCorp Aerojet (USA), is claimed to be able to carry 3,600-kg payloads to low Earth orbit, sufficient for three of SS/L's Globalstar satellites. Both stages are to be recovered by parachutes and airbags. Aerojet took delivery of 34 NK-33 and NK-43 engines from Russia's ND Kuznetzov in August (see below). SS/L also contracted for an additional five launches of McDonnell Douglas's (now Boeing's; see below) new Delta-3 launcher in February, making a total of 18 SS/L Delta-3 launches under contract. Hughes has also reserved 13 Delta-3 launchers.

On 5 September the U.S. Air Force signed a $206 million contract with Orbital Sciences (USA) to convert up to 24 Minuteman-2 solid-propellant missiles to space launchers. The converted missiles can launch payloads up to 320 kg into low Earth orbit. The missions will include both small U.S. government payloads and technology development demonstrations.

The U.S. Air Force also awarded two contracts in September for conceptual designs of suborbital spaceplane demonstrators, including ground testing of critical-technology components. The $4 million 18-month contracts went to Lockheed Martin, which plans a vertical takeoff/horizontal landing design based on the X-33, and to Boeing North American, whose vertical takeoff/vertical landing design is derived from the McDonnell Douglas DCX. Boeing is also conducting technology studies and conceptual design of a small space manoeuvre vehicle called Refly, which is to be carried by the spaceplane demonstrator.

The X-Prize Foundation (USA) received 16 entries by 1 July for its $10 million award to the first private company or team that launches 3 people to an altitude of 160 km and repeats the flight within two weeks using the same vehicle. The concept is modelled after prior competitions that stimulated major developments in aviation, such as the $25,000 Orteig prize that was won by Charles Lindbergh for his 1927 New York-to-Paris flight. The 16 entries were mostly from the United States, with two from the United Kingdom, two from Germany, and one from Argentina.

International Launch Services announced on 17 April that it was upgrading the Baikonur Cosmodrome facilities by adding a second Proton launch complex to handle the expected increase in demand for large-satellite launches. The new Breeze stage being developed by Khrunichev will up the Proton's performance, beginning in 1998, from its current limit of 2,500 kg to 3,000 kg directly into the geostationary orbit, and up to 7,800 kg into a geosynchronous transfer orbit.

The Flight Readiness Review for Ariane 502, the second Ariane-5 launch, took place on 5–6 June; the vehicle arrived at the Kourou launch site on 13 June; and preparations for launch, originally scheduled for 30 September, began on 16 June. The vehicle incorporates corrective measures based on analysis of the Ariane 501 failure in June 1996. However, computer simulations of the flight trajectory revealed that Ariane-5 would use an excessive amount of the oil used to lubricate the thrust vector control actuators, so the launch date was postponed until the problem could be resolved.

The long-awaited Ariane 502 launch finally occurred on 30 October, injecting two "dummy" satellites into a geosynchronous transfer orbit. The Maqsat H and Maqsat B payloads, which weigh 2300 kg and 1400 kg respectively, simulate actual commercial payloads and measured vibration and other critical payload data. They were built by Kaiser-Threde (Germany). Maqsat H also includes instruments for a Dutch student experiment called Teamsat.

The launch was successful in all respects except for premature cutoff of the first-stage Vulcain hydrogen-oxygen engine, which left the payloads in a 525 x 27,000-km orbit instead of the planned 580 x 30,000-km orbit. This minor anomaly is not expected to create concern about future operational flights of the new vehicle, although ESA had decided prior to this flight to order an additional 20 Ariane-4 vehicles and extend the transition from Ariane-4 to Ariane-5 by two years, to 2002. Eutelsat became the first commercial Ariane-5 customer, reserving on 31 March a launch slot aboard Ariane 503 in the second quarter of 1998 for its Hot Bird 5 television satellite.

The first automatic parafoil flight test in support of the European Space Agency's Crew Transfer Vehicle (CTV) took place on 25 June, delivering a payload of 1700 kg to within 200 m of its target from an altitude of 1800 m. The CTV is a candidate for cooperation with NASA on the X-38 program (see below).

Japan announced on 16 May its plan to replace the solid-propellant J-1 launcher with an upgraded version, the J-1A. The J-1 can launch a payload of about 900 kg to low Earth orbit. The goal of the J-1A would be to reduce launch cost to $10,000 per kg and provide orbit insertion accuracy better than 30 km. Both liquid-propellant and solid-propellant designs are being evaluated.

UNMANNED EARTH ORBITAL ACTIVITIES

Telecommunications

Fixed-Base Communication Systems

Intelsat's board of directors voted during their 6–10 December 1996 meeting to procure and launch the organization's first dedicated direct-broadcast K-TV television satellite, planned for the South- and East-Asian market. The decision was strongly opposed by the U.S. signatory, who argued that it represented unfair competition with commercial firms by a subsidized international organization, but was supported by all the other Intelsat members, with Japan abstaining. The spacecraft contract, which was awarded in January to Matra Marconi Space (France) along with an option for two additional K-TV satellites, was the first Intelsat award to a non-U.S. manufacturer. The first of the 30-transponder, 3,250-kg, Ku-band satellites is to be launched to its 95-degree east longitude geostationary-orbit slot by an Ariane rocket in late 1998 or early 1999. In a separate action, the board decided to procure two follow-on satellites to replace aging Intelsat 6 spacecraft over the Indian Ocean. The order was placed with Space Systems/Loral (USA) in March, for two spacecraft each carrying 44 C-band and 10 Ku-band transponders.

The third Inmarsat-3 satellite, F-3, was launched successfully by a Lockheed Martin Atlas 2A rocket on 17 December 1996. It began operations from its orbital slot over the Pacific Ocean in January. Inmarsat F-4 was subsequently launched by an Ariane 44L on 3 June, along with India's Insat 2D. It went into service in August, bringing the Inmarsat-3 system into full operational status. An on-orbit spare is scheduled to be launched in December. Inmarsat also announced on 21 March its intent to build and fly a new $2 billion broadband multimedia system to deliver data, voice, and videoteleconferencing to portable computers. The new system, called Horizons, will use three or four geostationary satellites operating at frequencies below Ka-band.

Inmarsat's ruling council, at its meeting on 19 September, approved transition of the 81-nation international treaty organization to a private corporation, with a public stock offering planned for 2000. The final council vote on this action will be taken in April 1998. The new Horizons system will constitute the backbone of the new company's expanded service structure, but the current Inmarsat-3 system is expected to continue operations through 2010. Inmarsat also continues to hold a 15 percent share of its previous commercial spinoff, ICO Global Communications.

PanAmSat-5, the company's first HS-601 satellite, was placed in a geosynchronous transfer orbit on 28 August by an International Launch Services Proton rocket, and was subsequently moved to its 58-degree west longitude slot. It is the first commercial communications satellite to use xenon ion propulsion for stationkeeping. Its 24 Ku-band and 24 C-band transponders will provide direct-to-home broadcast services to the Latin American market, supplementing PanAmSat-6, which was launched by an Ariane-44P on 8 August.

A solar flare on 6 January was blamed for the failure of AT&T's Telstar 401 satellite, short-circuiting the spacecraft's main power bus when the resulting magnetic cloud reached Earth on 11 January. The three-year-old satellite, whose rated service life was 12 years, was insured for $132.5 million. It was later found that the failure occurred because faulty materials had been used in the satellite's electrical system. As a result, Lockheed Martin made several material modifications to the design of its Series 7000 satellite bus, which is used for the Intelsat 8 spacecraft. Another solar storm, whose cloud reached Earth on 11 April, is believed to have caused a partial power loss of TCI Satellite Entertainment's Tempo-2 satellite, built by Space Systems/Loral (USA). It was decided on 30 April to postpone the launch of PanAmSat-6, which uses the same power-system design, until the cause of the partial failure could be resolved (PanAmSat-6 was subsequently launched successfully on 8 August). The 11 April solar storm was the largest recorded in the past 5 years.

Space Systems/Loral (SS/L; USA) released design information in April on the company's new La Fayette high-power satellite bus (formerly designated Omega-2), the first of which is slated for use as Cyberstar-1, to be launched in 2000 as the first of a three-spacecraft geostationary-orbit broadband communications constellation. The 4,500-kg Cyberstar-1 will deliver 16 kWe, twice as much as its predecessor Telstar-5, which is built on the current SS/L FS-1300 bus. (However, to get a jump-start on the competition, Loral Space and Communications plans to use Telstar-5 to initiate CyberStar broadband communications services in mid-1998). Subsequent La Fayette spacecraft will have even higher power levels: 20 kW by 2001 and possibly as much as 30 kW shortly thereafter. The La Fayette, which is only 500 kg heavier than the FS-1300 spacecraft, uses advanced technologies such as lithium ion batteries rather than the current nickel-hydrogen ones and electric propulsion via Russian stationary plasma thrusters, as well as more efficient components and lighter waste-heat radiator designs.

The U.S. Federal Communications Commission (FCC) issued licenses to 12 companies on 9 May for broadband geostationary-orbit systems involving 73 satellites. The licenses, for Ka-band high-data-rate services, two-way video, and Internet access, went to EchoStar Communications, GE American Communications, Hughes Communications' Spaceway system, Ka-Star Satellite Communications, Lockheed Martin, Loral Space and Communications, Morning Star Satellite, Motorola, NetSat 28, Orion Network Systems, PanAmSat (see below), and VisionStar.

On 26 September a number of companies also filed applications for 18 new satellite system approvals by the FCC, primarily for the spectrum segments at 2 GHz, which is reserved for mobile communications systems, and the largely virgin high-frequency V-band (37.5 GHz to 50.2 GHz), which is best suited to broadband services such as Internet access and private data networks. Applications included systems with constellations ranging from low Earth orbit to the geostationary orbit, with investment estimates ranging from Orbital Sciences' seven-satellite $900-million medium-Earth-orbit Orblink to Lockheed Martin's $4.7 billion 40-GHz broadband constellation of nine geostationary-orbit spacecraft.

In a new application to the FCC filed on 11 June, the world's largest direct TV satellite broadcasting firm, DirecTV Enterprises, filed for a major system expansion involving six new high-power Ka-band geostationary-orbit spacecraft, two each to be located in slots at 96.5, 101, and 105.5 degrees west longitude. This $1.4 billion Direct-TV Expansion-1 fleet would supplement the company's three existing Hughes HS-601 spacecraft at 101 degrees west longitude, which currently serve nearly three million U.S. subscribers.

Hughes Communications, DirecTV's principal owner, subsequently filed an application with the FCC on 14 July for a new $4 billion high-capacity multisatellite broadband system designed to service global corporations. The 14-satellite Expressway system would use 10 geostationary-orbit slots worldwide to deliver nearly 600,000 high-speed lines at over 150 MB/sec. Expressway's capacity, claimed by Hughes to be the highest ever proposed, will result from the use of V-band (47-50 GHz), the highest frequency ever requested for a commercial satellite system. The satellites are projected to develop over 15 kWe end-of-life power, weigh about 5,500 kg, and have a lifetime of 15 years. Hughes says the new system picks up where Spaceway, its currently approved Ka-band system with about 6 MB/sec capacity, leaves off.

Hughes Space and Communications International received its first commercial contract with a Russian firm on 23 October, when Media Most bought Bonum-1, a Hughes HS-376 satellite, to provide 50 channels of digital direct-to-home television broadcasts to western Russia via eight Ku-band transponders. Launch is scheduled aboard a Boeing (formerly McDonnell Douglas) Delta-2 in November 1998, following which Bonum-1 will be placed in the geostationary orbit at 36 degrees east longitude.

The first satellite to be produced in Lockheed Martin's new Commercial Satellite Center (Sunnyvale, California) was launched by an International Launch Services Atlas 2AS rocket on 5 October. The A2100AX EchoStar-3, the first of the new AX series and the heaviest payload ever launched by an Atlas-Centaur, was subsequently placed in its 61.5-degree west longitude geostationary-orbit slot. EchoStar-3 weighs 3,700 kg, carries 32 120-W transponders, and will broadcast 300 television and data channels to the eastern United States

A series of Trans-Pacific High-Definition Video experiments was initiated on 28 March to establish a broadband asynchronous transfer mode (ATM) satellite link with ground-based fibre optic systems. The experiments, which were organized by the Japan–U.S. Science, Technology, and Space Applications Programme's Working Group on Satellite Communications, uses the U.S. Advanced Communications Technology Satellite (ACTS) and several transpacific fibre-optic cables. The tests'goal is to establish high-data-rate communications, comparable to those obtained with fibre optics (e.g., 45-155 MBs), to regions of the world not accessible by fibre-optic cables.

Telesat Canada ordered Canada's first direct broadcast satellite from Lockheed Martin in March, and its 91-degree west orbital slot was granted by Canada in April. The high-power satellite will carry 32 transponders, and is expected to be launched by December 1998. Capacity is already pre-sold to Telesat Canada customers.

Eutelsat's first of four next-generation Hotbird satellites, Hotbird-2, was launched to its 13-degrees-east geostationary orbit slot aboard an Atlas IIAS rocket on 12 November 1996. The 2,910-kg satellite, based on Matra Marconi's Eurostar 2000-Plus bus, provides direct television and radio broadcast services, both analog and digital, to a service area that extends to Kazakhstan and the Persian Gulf. Its two 28-m solar arrays deliver 5.5 kW of net power to the satellite's 20 Ku-band transponders, which are fully leased through 2008. Hotbird-2 has a design lifetime of 15 years. Hotbird-3, at 2,915 kg the biggest television satellite ever produced in Europe, was launched by an Ariane 44LP on 2 September, along with Meteosat-7 (see below). In addition to its 20 Ku-band transponders and two fixed transmit antennas, Hot Bird-3 is also equipped with Europe's first steerable-beam antenna.

Alcatel Espace (France) announced on 24 February that its subsidiary Skybridge LLC had developed a new technology that allowed the company to provide broadband services from its low-orbit 64-satellite constellation, formerly known as Sativod, using Ku-band rather than the higher-frequency but more troublesome Ka-band. The new approach, which uses twin fleets of paired satellites, is claimed to allow Skybridge to deliver broadband services without interfering with geostationary-orbit satellites using the now-congested Ku-band. Skybridge, which is seeking $3.5 billion in investment capital, subsequently teamed with Space Systems/Loral's Ka-band geostationary-orbit Cyberstar system on 18 June (see above).

Indonesia's Pasifik Satelit Nusantara (PSN) awarded Space Systems/Loral (USA) a $350 million contract on 5 December 1996 to build and launch the heaviest, highest-power C-band satellite ever produced. The improved FS-1300 bus will carry 84 transponders providing 4 million voice circuits, and will be able to support 200,000 simultaneous voice calls plus 100 television channels. This first of four Multi-Media Asia spacecraft marks the first civilian application of X-band, which will be used to downlink the satellites to communication gateways on the ground. Ku-band downlinks are not optimal for the south Pacific region due to occasional signal deterioration by the heavy rainfall that prevails there. The new spacecraft also employs onboard switching, pioneered and demonstrated in orbit by NASA's Advanced Communications Technology Satellite. Multi-Media Asia operations are expected to begin in mid-1999.

India's first direct-broadcast television service via satellite to individual homes was demonstrated on 26 March by Hong Kong's Star TV via C-band transmission from PanAmSat's PAS-4 satellite. The operational news and entertainment service, which is called Sky TV, uses Ku-band transponders transmitting to 65-cm and 85-cm dishes.

The Indian Space Research Organization's Insat-2D communications satellite suffered an electrical short-circuit in its main power bus on 4 October, causing failure of the spacecraft's propulsion and temperature-control systems. It was written off as a total loss on 5 October. The 2,100-kg, 25-transponder ISRO spacecraft had been placed in its geostationary orbit with Insat 2A at 74 degrees East longitude following its launch on 4 June by an Ariane-4 rocket.

On 1 July Australia opened its satellite telecommunications market to non-Australian firms, ending the monopoly formerly held by national carriers Optus Communications and Telstra Corporation. PanAmSat had been providing additional services through Optus' two geostationary-orbit satellites, but has now begun marketing those services directly via PAS-2 and will add more capacity next year with PAS-8.

Mobile Communication Systems

Inmarsat's ICO Global Communications signed a $616 million contract on 3 March with a three-company consortium, led by Japan's NEC, to build the ground system for the company's 12-satellite constellation. The system contract with NEC and its partners, Ericsson Ltd (UK) and Hughes Network Systems (USA), includes 12 satellite access nodes and two network management centres. Critical design review for the 2,750-kg satellites, which are based on Hughes' HS-601 bus, was completed the same week.

Teledesic received an operating license for its 840-satellite system from the U.S. Federal Communications Commission (FCC) on 14 March. The company subsequently contracted with Boeing on 29 April to build its constellation, with Boeing contributing $100 million for a 10 percent equity share in the company. Teledesic will offer broadband services beginning in 2002, including high-speed Internet links and videoteleconferencing, at Ka-band frequencies. Teledesic also announced on 29 April that it plans to reduce its constellation to 288 satellites (plus 36 on-orbit spares), increasing the mass of each from about 800 kg to 1,300 kg and raising their orbit altitude from 700 km to 1,375 km. Total system cost is still estimated at about $9 billion, including $2.5 billion for launch services.

On 1 July the U.S. FCC issued licenses to two applicants who had been denied them in earlier filings. Constellation Communications Inc. (CCI) has proposed a $600 million 12-satellite constellation in equatorial orbits. The system, called Ecco, would provide cellular-type telephone service to both fixed and mobile telephones in 100 equatorial countries. Matra Marconi Space (France) is building the spacecraft and Raytheon (USA) the ground systems. Mobile Communications Holdings Inc. (MCHI) has designed Ellipso, a $910 million 17-satellite constellation using elliptical orbits in three planes to maximize satellite visibility to ground stations. It, too, is designed to provide telephone service to rural areas worldwide. Lockheed Martin (USA) is building Ellipso's 16 Earth stations; Orbital Sciences (USA) is manufacturing the satellites, with Spectrum Astro (USA), Harris Corporation (USA), and Israel Aircraft Industries as subcontractors.

In February Qualcomm (USA) reported that the company had shipped 9,100 OmniTracs terminals during the last quarter of 1996. The Qualcomm system provides trucks and other mobile units with two-way communication via geostationary satellites. The company's sales to the end of 1996 have surpassed a total of 185,000 terminals.

On 26 September a Delta-2 rocket successfully launched five 670-kg Iridium satellites into low Earth orbit, following the prior launches of five satellites on 5 May by a Delta-2, seven spacecraft on 18 June aboard a Proton, five more on 20 August by a Delta-2, and another seven on 14 September by a Proton. One of the satellites launched on 9 July did not communicate properly from its parking orbit, and contact was lost with one of those launched on 14 September. The other 32 are operating normally in their 780-km orbit. Intersatellite links between spacecraft in different orbital planes were successfully tested early in October. Iridium reaffirmed its intent to launch 22 more satellites on eleven Chinese Long March 3C rockets beginning late this year.

The entire 66-satellite constellation is scheduled to be in orbit by mid-1998, and is expected to enter commercial service later that year. The company does not expect the two satellite failures to delay initial system operations. Two main control facilities are operational (in Arizona and Virginia, USA), as are 14 tracking, telemetry, and control (TTAC) sites around the world (eight in Canada, two in Iceland, two in Hawaii, and two in Arizona, USA). A third control centre is under construction in Rome, Italy, as are 11 gateways around the world. On 11 July Iridium raised the last increment of funding for its $4.7 billion revised capital investment needs.

Iridium's principal stockholder Motorola (USA) also filed an application with the U.S. FCC on 13 June for a wideband interactive, multimedia satellite communication system named Celestri. The $14.7 billion Ka-band system consists of nine geostationary-orbit satellites and a 63-spacecraft low-Earth orbit constellation. It replaces two previously announced Motorola systems, the 72-spacecraft low-orbit M-Star (1400-km altitude) and the four-satellite geostationary-orbit Millennium. Celestri is the first satellite communication enterprise to combine low-orbit and geostationary-orbit spacecraft in a single system. It will also incorporate advanced technologies such as arcjets for stationkeeping, high-speed onboard processing, high-efficiency solar cells and batteries, and optical links between the satellites in low Earth orbit.

Each of Celestri's LEO satellites will have six optical terminals running at 4.5 GB/sec, versus Iridium's 7 MB/sec; the entire Celestri system is being designed to transmit at 80 GB/sec. The LEO spacecraft will weigh about 3200 kg, four times as much as the Iridium satellites, and will develop 13 kWe of electric power, more than most large geostationary-orbit spacecraft. On 29 October, Motorola contracted with Matra Marconi Space (France) to build 70 satellite buses for the LEO constellation (including seven spares) and one bus for a geostationary-orbit satellite. The contract, which was in excess of $1 billion, includes investment participation by Matra Marconi Space estimated at somewhat less than 10 percent of the total space-segment cost.

Despite delays in launching its first four spacecraft from August to December due to the 17 January failure of a Delta-2 rocket (see above), Globalstar LP (USA) announced on 20 October that a $325 million loan completed the full financing of its revised $2.6 billion capital investment requirement. Following the failure of two Long March rockets last year, Globalstar had revised its launch campaign to use two Delta-2 rockets for eight satellites, three Zenit-2 launchers for 36 spacecraft, and three Soyuz rockets for 12 satellites. The Globalstar constellation of 58 satellites includes eight on-orbit spares.

The U.S. FCC issued two Digital Audio Radio Service (DARS) satellite radio system licenses on 1 April, to CD Radio, Inc. (for $83 million) and American Mobile Radio Corporation (for $90 million). The FCC subsequently issued CD Radio on 10 October the first-ever license for satellite-to-automobile radio services. CD Radio has contracted with Space Systems Loral for the three satellites in the company's $500 million system, which is aimed primarily at the automobile radio market, plus an option for a fourth satellite. First launch is expected in late 1999.

Navigation and Position Location

After reviewing five options for Japanese activity in satellite navigation, Japan's Science and Technology Agency on 1 April decided to conduct research aimed at the development of hydrogen maser atomic clocks and more accurate orbit determination techniques. The proposed $1.9 billion programme is not designed to lead to an independent Japanese satellite navigation system that would duplicate the capabilities of the U.S. Global Positioning System (GPS) and/or the Russian Global Navigation Satellite System (GLONASS); Japan will decide later whether or not to proceed in that direction.

The SLS-2000 aircraft landing system, which uses differential Global Positioning System signals to guide Special Category 1 approaches, received U.S. Federal Aviation Administration (FAA) Type Acceptance certification in August. Already in experimental use in Canada, Australia, South America, and Russia, the system costs an airport about $500,000 to install and has a range of about 40 km. It is manufactured by Honeywell (USA) and Pelorus Navigation Systems (Canada). Continental Airlines has installed systems at Minneapolis and Newark airports for initial use early in 1998.

Remote Sensing

Earth Observations

NASA announced the first two Earth System Science Pathfinder (ESSP) missions on 18 March. The $59.8 million Vegetation Canopy Lidar mission will map the global distribution of vegetation covered by forest canopies, using five pulsed lasers to measure the height of the canopy and the vertical density of the underlying vegetation. The spacecraft is being built by CTA Space Systems (USA) and will be launched by a Pegasus in 2000. The second ESSP mission, the Gravity Recovery and Climate Experiment, will use two spacecraft flying in tandem orbits separated by 500 km to model time-dependent changes in the Earth's gravitational field using precise microwave measurements of the spacecraft separation distance, which is affected by gravity anomalies. Onboard accelerometers will distinguish between gravity perturbations and those caused by drag, solar radiation pressure, and other forces. NASA is providing funding of $85.9 million for the mission, and Germany will contribute about $40 million in services, hardware, and launch aboard a Russian Kosmos. Space Systems/Loral (USA) is building the two spacecraft with support from Dornier Satellite Systems (Germany). Launch is scheduled for 2001.

NASA's $1.8 billion Earth Observation System Data and Information System (EOSDIS), whose data processing and distribution system is being built for the agency by Hughes Information Technology under an $865 million contract, passed a critical operational ground test on 14 May. The Hughes system, which has been criticized by both NASA officials and several independent review panels during the past year, successfully processed, distributed, and archived simulated EOS data of the type that will be generated by two instruments aboard EOS AM-1, which is scheduled for launch in mid-1998. The system also demonstrated its ability to notify scientists of the data's availability.

Following its launch on 22 August by the first successful Athena-1 rocket (see above), NASA's Lewis satellite began an uncontrolled spin at about 2 rpm and lost its power, apparently due to unbalanced thrusting by the spacecraft's eight 4.5-N hydrazine thrusters. The 404-kg spacecraft, built by TRW under a $65 million NASA contract, was one of the first projects under NASA's new "faster, smaller, better, cheaper" philosophy. It carried three imaging payloads: a Hyperspectral Imager that scans a narrow band of Earth in 384 spectral bands, a Linear Etalon Imaging Spectral Array that scans a wider swath in 256 bands, and an Ultraviolet Cosmic Background imager that studies the sky and cosmic background. Recovery of the satellite, which could have been easily accomplished if the off-axis thrust had been detected and corrected sooner, was hampered because its high degree of autonomous operations, which was one of the 40 new technologies Lewis was designed to evaluate, precluded constant monitoring of the spacecraft's status. The spacecraft plunged into the atmosphere and was destroyed on 28 September.

Management of disasters using a combination of satellite and aircraft capabilities was demonstrated by Project Wildfire in California (USA) on 4–5 June. Firefighters set fires, monitored them, and controlled them using NASA's Airborne Infrared Disaster Assessment System (AIDAS) aboard a Learjet, which transmitted images that were then overlaid on satellite-generated geographical information system maps and pinpointed by the Global Positioning System. Data obtained, in formats familiar to ground-based firefighters, included the type of vegetation burning, the boundaries of the fire, its direction of movement, the topography of the area (e.g., roads, residences, vulnerable power stations, forests, grasslands, etc.), and the location and extent of available water supplies.

The Canadian Space Agency rotated its Radarsat's antennae 180 degrees on 9–11 September to allow imaging of Antarctica, and began an 18-day mapping mission of the southern continent on 26 September. The images provided full radar coverage of Antarctica with a resolution of 25 m, and data processing can improve the effective resolution of certain details to about 8 m. The first high-resolution image of Antarctica, a calibration shot on 14 September, shows the mission's reference point at the South Pole, the U.S. National Science Foundation's Amundsen-Scott Station. Radarsat was launched in November 1995.

On 15 November 1996, all communications to and from France's Spot-3 satellite ceased, and after two weeks of fruitless attempts to restore communications, the three-year-old spacecraft was declared lost to service. Eleven-year-old Spot-1 was returned to service early in December 1996 to replace the failed Spot-3. However, the tape recorders on both Spot-1 and the still-operational Spot-2 are not operating, so all data from the two satellites must be transmitted only while in range of a ground station.

Spot-3's loss was subsequently traced to sequential failure of three of the six Sagem gyroscopes in the satellite's attitude control system, one in February 1996, the second on 9 November 1996, and the third on 15 November 1996. Although the spacecraft's attitude control system can operate with only three gyroscopes, the computer needs a fourth to serve as a reference for the three operational ones. The failure therefore started a string of events which caused the satellite to spin, eventually losing the solar panels' orientation toward the Sun and causing the batteries to run down. Because the same gyroscopes are used in ESA's two Earth Remote Sensing (ERS) satellites, new software was designed which orders them into an emergency mode, with their solar arrays oriented properly toward the Sun, in the event a gyroscope begins to show signs of failure.

On 5 February France announced a policy change that will allow the Spot-5 satellite, currently under development for launch in 2002, to market images having 2.5-m resolution. The technique involves ground integration of two 5-m-resolution images taken simultaneously by the satellite, permitting retention of Spot's large (60 sq km) field of view.

The Norwegian Space Centre's $3 million Svalbard Satellite Station was approved on 9 April and began data-reception services under a NASA contract in September. The Svalbard

Island station, whose far-north location in the Barents Sea allows it to contact polar-orbit satellites on every orbit, has a five-year, $6 million contract with NASA as backup tracking facility for the EOS-AM-1 and Landsat-7 spacecraft, and has a contract with ESA for the Proba minisatellite. The six-antenna station is also used by India's seven Earth observation satellites.

India's IRS-1D satellite was launched by a PSLV on 29 September (see above) into a somewhat lower orbit than planned, but is expected to operate for its full projected three-year lifetime. However, the orbit necessitated by the imperfect launch resulted in a revisit time different from that of IRS-1C's 22 days, so the planned 11-day revisit frequency cannot be achieved. However, the IRS constellation's swivelling 5-m resolution imaging cameras allow them to be pointed at targets off the satellite's track, so the irregular visit cycle will not affect the imaging frequency significantly. Both spacecraft together offer the capability for stereoscopic imaging. Data are marketed globally by Space Imaging Eosat (USA).

Atmosphere and Ocean Observations

NASA's Polar spacecraft, launched in February 1996, conducted a series of measurements in February of this year implying that tons of water are delivered annually to the Earth's atmosphere by cometary impacts. The results, released on 28 May, suggest that 20 small comets impact the atmosphere every minute, depositing 100 tons of water per year when they disintegrate at altitudes of 8,000 to 24,000 km. The direct evidence supporting this theory comes from dark spots in ultraviolet and visible-light imagery observed by Polar's Visible Imaging System, created by water vapour clouds averaging 50 km in diameter at altitudes of about 500 km. If verified, these data imply that comets add about 2.5 cm of water to the Earth's oceans every 10,000 years, which through the eons could have filled the oceans to their present level.

A series of measurements during March and April by two satellite instruments, the U.S. scatterometer aboard Japan's Advanced Earth Observing Satellite and the U.S.–French Topex/Poseidon spacecraft's radar altimeter, detected wind reversals and warm water surges in the southern Pacific that implied the development of the massive weather system known as El Nino. The El Nino condition, which affects weather all over the world but especially in the Western Hemisphere, was later confirmed by a number of other satellite and ocean-based instruments.

The U.S. GOES-10 (Geostationary-orbit Operational Environmental Satellite-10), launched on 25 April as a backup to the two GOES satellites already on orbit, suffered an inability to keep its solar arrays locked on the Sun. NASA controllers shut it down temporarily on 27 May, after the third such loss, until they could determine the source of the problem. In July the controllers discovered that the solar panels would rotate satisfactorily in the reverse direction, so in August they inverted the satellite's position with respect to the Earth and were able to get it back into operation with the panels rotating in reverse. However, ground station operations still have to be modified to allow them to collect data from the now upside-down spacecraft.

After a series of operational problems and equipment malfunctions following its launch in August 1996 (see last year's report), Japan's $475 million 3,200-kg Advanced Earth Observation Satellite (ADEOS) finally failed completely on 30 June following a power failure that resulted from excessive heating and expansion of the spacecraft's 24-m solar array during six planned exposures to direct sunlight, compounded by subsequent vibrations. Japan's largest and most complex satellite, ADEOS carried eight instruments, including several supplied by France and the United States. They were a key element in NASA's Earth Observing System, especially the scatterometer, which was vital to ongoing climate and weather prediction work (for example, see the accompanying discussions on the New Frontier programme and the detection of El Nino). The launch of Japan's Communications and Broadcasting Engineering Test Satellite (Comets) was postponed from its scheduled date of 18 August pending clarification of the cause of ADEOS-1's power failure. Comets uses a solar paddle of similar design. Japanese engineers are redesigning the tension control, attitude control, and reaction control systems for the solar paddles to be used on ADEOS-2, whose launch has now been postponed from February 1999 to late summer that year.

NASA (USA) and NASDA (Japan) announced on 9 June that they will cooperate on a 20-year New Frontier programme of Earth observations to monitor and predict global change phenomena, to begin late this year. The system will use both marine vessels and satellites. It was planned to begin with NASDA's Advanced Earth Observation Satellite (ADEOS), launched in 1996, and NASA's Tropical Rainfall Measuring Mission (TRMM) launched in August (see above), but failure of the ADEOS spacecraft on 30 June (see above) imposed a delay in programme initiation.

A Pegasus XL rocket finally launched Orbital Sciences' OrbView-2 (SeaStar) satellite from Vandenberg Air Force Base into a 310-km polar orbit on 1 August after over four years of delays caused by both satellite development and problems with the Pegasus XL launcher. Its main instrument, the Sea-Viewing Wide Field of View Sensor (SeaWiFS) built by Hughes, provides the United States with its first ocean colour monitoring capability since Nimbus 7 failed in 1986. Orbview-2's orbit was subsequently raised to its operational 705-km altitude, and the spacecraft began transmitting its first images on 4 September. The privately owned satellite was partly funded by NASA's 1991 advance "down payment" of $43 million for SeaWiFS data. The sensor generates global maps showing the biological productivity of sea vegetation every 48 hours, based on chlorophyll detection, and transmits its data to 38 ground stations in 18 countries. This type of capability, which was lost with the failure of ADEOS-1 on 1 July, is key to global climate modeling and to monitoring the effects of major ocean phenomena such as El Nino and "red tide" algae blooms, as well as being useful for commercial applications such as locating schools of fish. The first SeaWiFS global ocean-colour images were released by NASA on 16 September.

Eumetsat's 690-kg Meteosat 7, launched by an Ariane-44LP rocket on 2 September along with Eutelsat's Hot Bird-3 (see above), was manoeuvred so accurately into its geostationary slot at zero degrees longitude by ESA's Darmstadt Operations Control Centre that its expected lifetime was increased to seven years from five. It went into service in November, replacing Meteosat 6. Meteosat 5 was then reactivated and moved to an eastern slot to support forecasts for the Middle East and India. Meteosat 7 was built by Aerospatiale (France) with subcontractors Matra Marconi Space (France), Daimler Benz (Germany), and Alenia Spazio (Italy). It is the final element of the Meteosat Transition Program, to be followed by the three-satellite Meteosat Second Generation (MSG) constellation, whose first launch is scheduled for October 2000, and the Eumetsat Polar System (EPS), with three Metop spacecraft to be launched beginning in 2003.

Spacecraft Design and Development

The U.S. Air Force's Phillips Laboratory announced on 16 January a new programme called NexGen, to develop methods for building more affordable satellites by using standardized components, interfaces, and software that are compatible with both government and commercial spacecraft systems. The next-generation satellite project, a collaborative effort by the U.S. Air Force, NASA, the U.S. Navy, and the U.S. National Reconnaissance Office, will also explore methods for repairing and reconfiguring on-orbit satellites, possibly using the international space station as a parts depot and repair base.

On 3 February NASA awarded contracts to ten companies to identify, develop, and test advanced technologies for the New Millennium Program, joining the current 24 members of the Jet Propulsion Laboratory's Integrated Product Development Team (see last year's report). The technology categories of the new awards are autonomy, communications, instrument architectures and technologies, in-situ instruments, microelectromechanical systems, modular and multifunction systems, and microelectronics.

Commercial Developments

On 19 May NASA took the first step in the eventual privatization of its communications, command and control, and deep-space tracking operations, which are currently dispersed among a number of NASA centres, by issuing 8-month $4 million Phase 1 integrated architecture study contracts to Boeing North American and Lockheed Martin. NASA will select one of the two companies for a 10-year, $5 billion to $6 billion Phase 2 Consolidated Space Operations Contract (CSOC), whose goal is to improve efficiency and cut costs. This effort is patterned after the Shuttle operations contract issued last year to United Space Alliance (see last year's report).

On 19 November Lockheed Martin (USA) opened a new $65 million Commercial Satellite Centre in Sunnyvale California to produce all Lockheed Martin Telecommunications' commercial spacecraft. The 14,000 sq. m plant, which includes a 7,650 sq.-m-class 100,000 clean room, can produce up to eight satellites per year, with growth capability to 16. The new plant, which replaces the company's former facilities in East Windsor NJ, will reduce commercial satellite delivery time from 24 months to 18 months initially, and eventually to 12 months.

Immediately following finalization of Boeing's acquisition of Rockwell International's space division in December 1996 (see last year's report), Boeing announced plans to purchase McDonnell Douglas. The $16.3 billion acquisition was completed on 4 August, following approval on 1 July by the U.S. Federal Trade Commission (FTC). The major stumbling block to the merger, however, was securing the agreement of the European Commission, which contended that combining two of the world's three leading manufacturers of large commercial air transports would bias fair competition. Boeing, now the world's largest aerospace company, obtained the EC's approval in late July by granting a number of concessions in aircraft manufacturing and marketing. Space activities will be handled by the company's Information, Space, and Defence Systems Group.

Space Systems/Loral (SS/L) bought out its European partners for a total of $375 million in April, reducing their total holdings from 49 percent to about 2.3 percent. Loral Space and

Communications (USA) held the remaining 51 percent. Aerospatiale and Alcatel (France) each received a package of cash and Loral Space and Communications stock, as did Alenia Aerospazio (Italy). The three European companies remain on SS/L's board of directors. Daimler-Benz Aerospace (Germany) received cash for its share of SS/L, and will not hold a seat on the SS/L board.

Loral Space and Communications subsequently bought Orion Network Systems for $490 million on 7 October. Orion has one operational satellite (Orion-1) plus two more currently under construction, along with International Telecommunications Union authorizations for 11 additional geostationary-orbit slots, including several approved by the U.S. Federal Communications Commission for Ka-band service.

The merger of PanAmSat with Hughes' Galaxy division (see last year's report) was completed on 16 May, following the U.S. FCC's 4 April approval of transferring Galaxy's orbital slots to PanAmSat and the award of 7 new Ka-band slots to the newly restructured company on 9 May. Assets of the new PanAmSat were $6.2 billion at the time of the merger; aggregate revenues were $727 million in 1996. The new PanAmSat incorporated 10 Hughes Galaxy satellites into its system, which at the time of the merger totalled 14 spacecraft. Six more satellites are under construction for PanAmSat, and two more will be added in 1999.

Alcatel Alsthom (France) and Loral Space and Communications (USA) announced on 18 June an agreement to cooperate in financing, developing, building, and marketing Alcatel's 64-satellite Ku-band Skybridge system and Loral's geostationary-orbit Ka-band Cyberstar system (see above). Total capital cost of the two systems is about $7.5 billion. Cyberstar is scheduled for its first launch in 1998; Skybridge in 2001.

Spaceport Florida Authority received its commercial launch operator's license from the U.S. FAA's Office of Commercial Space Transportation on 22 May. The Authority has modified the former Cape Canaveral Air Force Station's Launch Complex 46 for commercial use in launching solid-propellant rockets.

On 7 May Germany's Daimler-Benz Aerospace (Dasa) and the Lagardere Group (France) agreed to merge Dasa's space division with Matra Marconi Space, 51 percent of which is owned by Lagardere and 49 percent by the General Electric Company (UK). The new company would be named Matra Marconi-Dasa Dornier, with aggregate 1996 sales of $3 billion annually. Reviews and approval of the merger are expected to be completed in 1998.

Lockheed Martin (USA) joined with Intersputnik (Russia) on 2 June to create a global satellite communications company, following approval of the venture on 30 April by Intersputnik's 22 member nations. The new company, which is called Lockheed Martin Intersputnik Ltd. (LMI), will compete with Intelsat and PanAmSat for the global market. Its first satellite, LMI-1, is a Lockheed Martin A2100 spacecraft having 44 C-band and Ku-band transponders. LMI-1 will be launched late in 1998 by a Proton rocket to serve Russian and eastern European markets. Three more launches are planned through 2000. Intersputnik currently operates 5 Gorizont, 2 Express, and two Gals satellites, but brings to LMI 15 geostationary-orbit slots.

On 2 September the largest satellite builders in Russia and the U.S. announced their intent to cooperate in a joint venture to develop and build a new generation of satellites to serve the Eastern European market, including the Russian government, from some of the 12 orbital slots now owned by Russia. These slots are currently occupied by 12 Express satellites and 10 aging Gorizont spacecraft, all built by NPO-PM. Following technical meetings in June and August, Hughes Space and Communications and NPO Prikladnoi Mekhaniki agreed to exchange key technologies, following similar priòr agreements between NPO-PM and Alcatel Espace (France), signed in June, and between Space Systems Loral (USA) and NPO Energia (Russia) to develop a new class of Yamal satellites.

Hughes Space and Communications International (USA) also announced the signing of an agreement on 11 September with Emirates Telecommunications Corporation (United Arab Emirates) to participate in the Thuraya Satellite Telecommunications Project, a $1.2 billion system of two geostationary-orbit satellites and associated ground facilities. Hughes will deliver the satellite system and has agreed to take a 2 percent share in the project, with a potential increase to 5 percent. First launch is planned for May 2000; Thuraya will service south and central Asia, the Middle East, eastern Europe, and North Africa. All previous Middle East satellites have been built by European manufacturers.

On 1 July Euroconsult released its report "Satellite Communications Ground Stations Market Survey: Worldwide Prospects, 1997 - 2006," predicting that the satellite communications ground hardware market will more than double, from its present $18.1 billion per year worldwide in 1996 to $46.2 billion in 2006. The largest growth will occur in mobile telecommunications, which is expected to surge from 13 percent of the total market in 1996 to 55 percent in 2006. Television ground stations will drop from their 1996 level of 82 percent of the market to 37 percent in 2006, although the dollar level for these systems is projected to increase by over $2 billion. Fixed-communication systems will remain at 5 percent of the market.

On 14 July Orbital Sciences (USA) announced plans to purchase the space and communications activities of CTA Inc., a manufacturer of small geostationary-orbit satellites (900–1150 kg, with power levels from 1.5–3.5 kWe), for $37 million. The acquisition, which was completed in August, gives Orbital Sciences access to the combined market for both low Earth orbit and geostationary orbit satellites.

HUMANS IN EARTH ORBIT

Space Station Development

On 20 November 1996 the first U.S. component of the international space station successfully passed its final pressure test. Node 1, which will connect other space station modules, sustained a four-hour pressurization to 1.5 times normal maximum operating loads. The test confirmed the successful correction by a new series of struts of the excessive strain observed in last year's tests.

After months of discussions fuelled by Russia's inability to generate sufficient funding to build the key space station service module, on 15 May NASA revised the space station launch schedule to accommodate the delay associated with late delivery of the Russian module. The first two elements, the Russian Functional Cargo Block (FGB), being built under contract to Boeing, and the U.S.-built Node 1 (both of which had met the original assembly schedule), will now be launched seven months late, in June and July 1998, and the service module launch will be delayed by eight months to December 1998.

The new schedule calls for the first crew to be launched in January 1999, followed by a replacement crew to be launched with the U.S. laboratory module in June 1999. A total of five three-person crews will live on the station through November 2000. On 31 May the revised plan was approved by all five of the participating national and international space agencies. It is estimated that assembly of the station and maintaining it through completion in 2003 will require over 1500 hours of extra-vehicular activity, about 400 by Russian crews and about 1100 by U.S. and other Western nations' astronauts.

NASA reported on 8 October that the invaluable experience gained during the Shuttle-Mir program, especially in dealing with unexpected emergency situations (see below), had instigated a host of procedural changes in International Space Station design, assembly, and operations. The modifications spanned improvements in docking practices, communications, onboard research facilities and operations, equipment stowage and inventory, attitude control, data handling for dual-control decision making, extravehicular activity, cable routing, ventilation systems, body restraints for researchers, involvement of crew members in research planning, crew training, and overall station management.

Flight tests of NASA's X-38 prototype crew rescue vehicle began in August, when aerodynamic characteristics studies were conducted with the fibreglass lifting-body vehicle fastened under the wing of a B-52 aircraft. Free flight glide tests were then initiated in September to further test the 7-m-long vehicle's aerodynamics and also its parafoil landing system. By using earlier data on the old U.S. Air Force X-24A, which flew 28 times from 1969 to 1971, NASA's designers believe they can design, build, and test-fly (in both air and space) four X-38 prototypes for $90 million. The currently projected X-38 design is an aluminum-and-composite 8.5-m-long lifting body weighing about 7,000 kg and able to return a crew of 6 people from the space station to Earth. It could also be modified for use as a space tug, to transfer crews and cargoes from an orbiting launch vehicle to the station.

On 6 March NASA and ESA signed an agreement under which ESA will provide two space station nodes and other equipment, including freezers for the ESA laboratory and software for a data-management system, in exchange for a Shuttle launch of the ESA laboratory in 2002. The nodes, built and manned by Italy, are to be used to connect space station modules and also to store support equipment for telecommunications and power distribution. Italy is also building several Mini Pressurized Logistics Modules under contract to NASA, in exchange for laboratory use by Italian experimenters. Daimler-Benz Aerospace (Germany) also signed an $11.8 million contract with ESA in March to provide a multipurpose minilaboratory, which includes a Microgravity Science Glovebox, for the U.S. section of the station. ESA will receive additional access to space station facilities in return.

On 31 July Spacehab (USA), RSC Energia (Russia), and Daimler-Benz Aerospace (Germany) signed a contract to develop and build an integrated cargo carrier (ICC) for Shuttle-transportable service to the international space station. Energia will build a 3 x 4.5-m pallet, reinforceable to carry up to 5400 kg, which can be loaded in Russia and shipped to Spacehab's payload processing facility at Cape Canaveral. Daimler-Benz will build the pallet support structure and will also integrate European payloads. Total capital investment to develop and produce the ICC is estimated at $30 million to $40 million. NASA has not yet agreed to use the ICC or to transport it on the Shuttle, although Spacehab's pressurized modules are currently used by the agency for both Shuttle experiments and transporting supplies and experiments to and from Mir.

Canada decided on 8 April to proceed with development of the two-armed Special Purpose Dexterous Manipulator, or "Canada Hand," for the 17-m Space Station Remote Manipulator System, which is the major subsystem of the international space station's $700 million Mobile Servicing System. Completing the Canada Hand in time for its scheduled launch in 2001 will add about $149 million to Canada's investment in the station.

Earth-Orbital Flight Operations

The U.S. Shuttle Columbia was launched on 19 November 1996 to re-test the Wake Shield Facility (WSF) that had flown with no more than partial success on two prior Shuttle flights (see previous reports), and also to test a number of procedures and components for assembling the international space station. The WSF was released on 22 November, and successfully processed seven semiconductor wafers in the ultra-high vacuum provided by the shield. It was retrieved three days later after experiencing only minor operational problems. The extra-vehicular activity needed to conduct the space-station procedural and equipment tests, originally scheduled to begin on 29 November, had to be cancelled due to a jammed airlock hatch, which was subsequently traced to a loose screw caught in the actuator. The cancelled tests were rescheduled for a subsequent mission in October.

Space Shuttle Atlantis, launched on 12 January, docked with Mir on 14 January to transfer U.S. astronaut Jerry Linenger to the Russian station, along with a stock of supplies and fresh water. Atlantis landed at the Kennedy Space Centre on 22 January, bringing back astronaut John Blaha after 128 days in space aboard Mir and the Shuttle.

The second Hubble Telescope maintenance and repair mission was accomplished by the crew of Space Shuttle Discovery during four spacewalks on 14–17 February. They replaced two old instruments with a new Near-Infrared Camera and Multi-Object Spectrometer and a new Space Telescope Imaging Spectrograph, and replaced worn or damaged equipment including optical sensors, electronic boxes, computers, and data recorders. The European-built solar panels, which had been installed in December 1993 to replace the original ones, were in excellent condition and had been distorted by no more than 5 cm in their three years of service. The top layer of the telescope's thermal insulation, however, was found to be cracked and peeling on the side of the spacecraft that normally faces the Sun. The crew placed spare insulation blankets over the two largest tears, but NASA plans to replace the insulation during the next repair mission in 1999. Discovery returned to Earth on 21 February.

Shuttle Columbia, launched on 3 April, carried the next-to-last Spacelab experiment capsule on a 16-day mission to study materials science, crystal growth, and microgravity combustion characteristics. Shortly following launch, however, failure of one of the spacecraft's three fuel cells forced termination of the mission, which landed on 8 April. The mission was subsequently launched again on 1 July and reflown successfully, completing the 33 experiments that had only barely been begun during the abbreviated April flight. The experiments featured racks and other equipment similar to those planned for use on the international space station beginning in 2000.

Shuttle Atlantis, launched on 15 May, delivered to Mir on 17 May a much-needed replacement of the Elektron oxygen-generating system (see below). Atlantis also delivered U.S. astronaut Michael Foale to the station and returned Jerry Linenger to Earth on 24 May after his having spent over 122 days aboard Mir. Atlantis also returned frozen blood and urine samples to German laboratories for analysis as part of the German Mir 97 mission.

Launched on 7 August, U.S. Shuttle Discovery deployed the German reusable platform carrying the Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere Shuttle Pallet Satellite (Crista-Spas), which for the next nine days measured 18 trace gases in the middle atmosphere (from 10 to 100 km altitude) that are believed to affect ozone depletion, and the concentrations of hydroxyl and nitrogen oxides, which are also known to affect the stratospheric ozone layer. Crista-Spas' data revealed more water than expected at northern latitudes, which may help support the multi-comet water delivery theory (see above). Discovery also tested a prototype Japanese robot arm in the Manipulator Flight Demonstration, demonstrating the viability of the 1.5-m long Small Fine Arm (SFA) slated for use on the space station's Japan Experiment Module (JEM), and used the Crista-Spas recovery process to practice space-station manoeuvres. Discovery landed at Kennedy Space Centre on 19 August, a day later than planned due to fog at the landing site.

Shuttle Atlantis was launched on 25 September to bring about 3200 kg of supplies to Mir, including a replacement computer (see below). Atlantis also carried U.S. astronaut Michael Foale's replacement, David Wolf, to the Russian station for a four-month stay, and returned Foale to Earth when it landed on 6 October. While Atlantis was docked to Mir, Russian cosmonaut Vladimir Titov (who rode to Mir on Atlantis) and U.S. astronaut Scott Parazynski conducted the third international spacewalk (the first ever staged from a U.S. Shuttle), removing several external experiments from the station and stowing a large cap that could be used to seal the leak on the Spektr module should a decision be made to remove a damaged solar panel from Spektr (see below).

On 10 February a Soyuz TM-25 launched a new crew to Mir, Vasily Tsibliev and Alexander Lazutkin, along with German astronaut Reinhold Ewald. Ewald returned to Earth on 2 March after completing his $17 million Mir-97 mission, together with the former Mir crewmen Valery Korzun and Alexander Kaleri. The same TM-25 launch carried a 7-kg experiment package, Japan's Microflora Investigation Experiment, which studied the characteristics of molds in a microgravity environment and was returned on 2 March along with Ewald and the Russian Mir crew. The purpose of the experiment was to learn how to prevent microorganism contamination of the space station's Japanese Experiment Module during long-term spaceflights.

On 29 April the Mir space station's commander, Vasily Tsibliev, and U.S. astronaut Jerry Linenger conducted the first joint spacewalk by citizens of two different nations. During the 5-hour excursion the two men tested the new Russian Orlan-M spacesuits and a tether package adaptable to both Russian and U.S. spacesuits, and installed and removed several external experiments.

Despite this success, 1997 marked a year of continuing problems with the 11-year-old Mir, which had a design life of five years. On 23 February a lithium perchlorate "candle," used as a backup source of oxygen for the crew, flashed into flame and filled the station with dense smoke, forcing the crew to move into the Soyuz return capsule for a brief period before they were able to extinguish the fire. The main oxygen generator subsequently failed in March, requiring the crew to rely totally on the "candles" for oxygen. In April, coolant began leaking from the temperature control system, which not only precluded maintaining proper temperature in the station but also required shutting down the main air purification system.

Then on 25 June, while the crew attempted a new manual procedure for docking the Progress supply ship, the Progress crashed into the Spektr module, punching a hole in it and damaging a solar panel and a radiator. To prevent pressure loss, the crew had to sever the power cables between the Spektr and the Mir in order to seal off the hatch between them, reducing by half Mir's available power. On 1 July the main oxygen system again lost power, and because the backup system had been powered by Spektr's power module, the crew had to return to burning "candles" for oxygen. Then on 3 July all 11 of Mir's attitude-control gyrodynes stopped temporarily, forcing the crew to maintain the space station's attitude with fuel-consuming rocket thrusters. On 14 July Mir commander Vasily Tsibliev reported irregularities in his heartbeat, and on 16 July one of the crew inadvertently disconnected the Mir's main computer, causing it to lose orientation and consequently the power generated by the remaining solar panels.

On 5 August, while a relief crew was on its way to Mir, the main oxygen generators failed once more, forcing the crew to rely on the "candles" for their oxygen. When the relief crew's Soyuz capsule reached Mir on 7 August, the automatic docking system failed, and the docking had to be performed manually. Finally, when Cosmonauts Vasily Tsibliev and Aleksandr Lazutkin returned to Earth in their Soyuz capsule, the retrorockets failed and the landing had to be accomplished by parachute only, a procedure they termed after their successful touchdown as "uncomfortable but not dangerous."

Mir's problems, however, did not end with the departure of Tsibliev and Lazutkin. On 18 August the space station's main computer failed due to a component malfunction during the docking of a Progress supply vehicle, which then had to be guided manually into the docking port. The failure also resulted in Mir's losing its orientation to the Sun and therefore all onboard power. The crew once more entered the Soyuz capsule and used its engines to restore attitude control and power.

Despite these difficulties, however, the new crew, along with U.S. astronaut Foale, manoeuvred their Soyuz capsule around Mir on 15 August and conducted a video-camera survey of the damaged Spektr exterior. Then, on 22 August Cosmonaut Pavel Vinogradov, the crew's flight engineer, overcame problems with a leaky spacesuit glove and successfully linked Spektr's 11 power cables via a new "hermaplate" junction panel on the Spektr hatch to the main Mir module during a six-hour "spacewalk" inside the damaged Spektr. But the saga of problems continued. On 25 August both the Elektron oxygen-generating system and the backup lithium-perchlorate oxygen system failed temporarily before being restored to service, and then on 7 September and 16 September the computer shut down, apparently due to breakdown of aging components, causing temporary losses of station orientation and consequent power degradation. The series of computer failures was finally brought to an end with the replacement of Mir's computer by a new one carried to the station by Shuttle Atlantis on 26 September.

In an external spacewalk on 3 September, Mir commander Anatoly Solovyev and U.S. astronaut Michael Foale toured the damaged area of the Spektr to study the damages so that they might be repaired on a subsequent spacewalk, and also to redirect the Spektr's solar panels, which had been displaced by the June collision. Unfortunately, their six-hour tour on 7 September was not successful in locating the puncture or punctures in Spektr, but Solovyev was able to move the solar panels to increase the power available to the station to about 80 percent of rated power. Because it was believed that the hidden leak was likely to be in the neighbourhood of the attachment point of the damaged solar panel, a large cap was brought to Mir by Atlantis on 26 September for possible future use in sealing off the leak if it is decided in the future to remove the damaged solar panel. The cap was attached to Mir's exterior during a spacewalk by Atlantis crew members on 1 October (see above). Then, as Atlantis was leaving Mir on 3 October Solovyev released two bursts of air into Spektr, and the Atlantis crew saw debris spewing from the module at the base of the solar array, confirming the source of the leak.

During a subsequent 6-1/2-hour spacewalk on 20 October, Solovyev and Pavel Vinogradov succeeded in routing new solar-array control cables into Spektr, reestablishing pointing control of the panels and thereby further boosting Mir's available power.

Life Sciences

NASA announced on 14 March the creation of a National Space Biomedical Research Institute Consortium to be led by Baylor College of Medicine. The consortium will conduct biomedical research and technology development relevant to long-term stays in space, and will seek to transfer applicable technologies to terrestrial uses, under a 20-year, $145 million NASA contract. Other consortium members are Harvard Medical School, Johns Hopkins University's Applied Physics Laboratory, Massachusetts Institute of Technology, Morehouse School of Medicine, Rice University, and Texas A&M University.

The agency subsequently announced on 8 August the formation of the NASA Astrobiology Institute at the Ames Research Centre. The notice asked for proposals from which it will select five to 10 Institute member teams in January 1998, to study a broad range of topics on both nonterrestrial life in the universe and on the future adaptability of terrestrial life forms to nonterrestrial environments. The Institute will also sponsor astrobiology education from grade school through graduate school to post-doctoral levels, and will serve as one of the test-beds for NASA's activities in the three- to five-year, $300 million multi-agency Next-Generation Internet (NGI) programme. NASA announced on 13 August its plans for the NGI are to connect up to 100 universities at speeds 100 times faster than the current Internet, and subsequently to connect about 10 sites at speeds another factor of 10 higher; i.e., up to 1 GB/sec.

On 27 March NASA's Office of Life and Microgravity Sciences and Applications awarded $6.7 million to 52 researchers (selected from 440 submissions) for both ground-based and space-based experiments in the life sciences. Most of the awards went to studies in space biology, space physiology and countermeasures, and advanced life support system research. Several of the experiments are devoted to the use of solar radiation for life support, for psychological purposes, and for food preparation. A subsequent $4 million grant was issued on 19 May to the Cleveland Clinic Heart Centre, which will work in cooperation with NASA's Johnson Space Centre to explore methods of monitoring the effects of long-term space flights on the human heart and to develop conditioning regimens to counteract those effects. Typical cardiovascular deconditioning effects that have been observed after long-term microgravity flights include lower blood volume, low blood pressure, and loss of blood-vessel tone.

Russia's Bion-11 experiment, launched aboard a Soyuz rocket from the Plesetsk Cosmodrome on 24 December 1996, was successfully recovered in Kazakhstan on 7 January. The spacecraft's primary payload consisted of two rhesus monkeys, but also included snails, flies, and other biological specimens. The mission's goal was to study the effects of weightlessness on bone and muscle tissue, neuromuscular reactions, and such disorders as anaemia, osteoporosis, muscular atrophy, and immune system dysfunction. Bion-11 was led by Russia's Institute of Biomedical Problems, with participation by NASA and the French space agency CNES. There had been major controversy, especially in the United States, about whether the mission's research was of sufficient value to warrant the exposure of the monkeys to the inherent risks of the experiment. The controversy was exacerbated by the unfortunate death of one of the monkeys, named Multik, following flight-related surgery the day after the landing. The monkey's death was later attributed to the use of general anaesthesia the day after the flight; monkeys on prior Bion flights had not been anaesthetized for at least seven days following reentry. NASA subsequently decided, on 22 April, to limit the agency's participation in future Bion flights to non-primate experiments.

SPACE EXPLORATION

Astronomy and Astrophysics

Eighteen-month, $3.5 million architecture study contracts were issued to TRW and Ball Aerospace (both USA) by NASA's Goddard Space Flight Centre on 24 July for the Next Generation Space Telescope (NGST). Original goals for the new telescope are that it be one-tenth the mass and one-tenth the cost of the currently operational Hubble Telescope, which it is scheduled to replace after 2007. Current plans call for a maximum cost of $900 million ($500 million for development and $400 million for launch and 10 years of operations), a mass of about 3,000 kg (vs the Hubble's mass of 11,000 kg), and a sensitivity a thousand times better than any space-based or ground-based telescope. NASA's Marshall Space Flight Centre also awarded two $5 million design and development contracts for prototype 1.5- to 2-m diameter NGST low-mass mirrors on 24 July to the University of Arizona's Steward Mirror Laboratory and Composite Optics Inc. The NGST's mirrors will be cryogenically cooled, for infrared observations. The prototypes, which are to weigh only 20 to 45 kg, must be able to operate down to 30 degrees Kelvin.

From 24 March to 5 April the U.S. Navy launched four NASA-funded Black Brant-9 sounding rockets from the White Sands Missile Range to study the composition of Comet Hale-Bopp, which was highly visible to most of the world during its closest approach late in April. Observations of Hale-Bopp, which was discovered on 22 July 1995, were also made by a number of operational spacecraft, including NASA's Hubble Telescope, ESA–NASA's Ulysses, ESA's

Solar and Heliospheric Observatory (SOHO), ESA's Infrared Space Observatory (ISO), the International Ultraviolet Explorer (until its mission ended in September 1996), and NASA's Polar.

From 1–5 April NASA reboosted the 15,300-kg Compton Gamma Ray Observatory (GRO), the heaviest civilian robot spacecraft ever launched, from its 430-km orbit to a 515-km orbit. The new orbit will allow GRO to operate through 2009 before it reenters the atmosphere. GRO has been studying gamma ray bursts, supernovas, pulsars, quasars, and black holes.

The Hipparcus Catalogue, which documents the precise positions and distances of 118,000 stars, was published by ESA in June. Results of the 18-year Hipparcus spacecraft programme, which is generally considered to be Europe's first major independent contribution to space science, is available to the public as ESA Special Publication SP-1200 in both printed form (its 17 volumes weigh about 17 kg) and as a set of six CD-ROMs. Hipparcus development started in 1980; it was launched in 1989 but was unable to attain its intended geostationary orbit when its apogee kick motor failed, and operated until August 1993. Because of its highly elliptical orbit, it suffered damage due to its regular passages through the Van Allen radiation belts, and also was unavailable to ground communications for 14 hours each day. Nevertheless, it was able to complete about 70 percent of its intended mission. Hipparcus also obtained less precise information on another million stars, as documented in the accompanying Tycho Catalogue.

It was decided in July to extend the mission of ESA's Infrared Space Observatory, whose planned 18-month period of operations was to end then (it was launched in November 1995). The decision was made possible by the remarkably efficient use of ISO's 2,140 litres of liquid helium coolant, which will allow the spacecraft to continue its observations until March 1998.

Italy's and Netherlands' BeppoSAX X-ray satellite, formerly called Satellite per Astronomia X (see last year's report), detected a major gamma-ray burst on 28 February, providing much new information on this mysterious astronomical phenomenon. However, two of its six stabilizing gyros began to show signs of deterioration on 13 March, following prior failures of two others in December 1996 and January. The gyros were manufactured by Sagem, the manufacturer of the gyros whose failure caused the loss of Spot 3 (see above), but are of a different design. BeppoSAX operators have tested a "safe mode" procedure for the satellite in the event the two additional gyros fail, and can then stabilize the spacecraft using its onboard star-trackers.

Spain's first Minisat-01 satellite was successfully launched by a U.S. Pegasus XL rocket from its L-1011 mother aircraft out of Spain's Gran Canaria island on 21 April. It was the first U.S. orbital launcher ever operated from European soil. The National Institute of Aerospace Technology's Minisat-01 carries three experiments: an ultraviolet radiometer built by Spain's Laboratory of Space Astrophysics and Fundamental Physics and the U.S. University of California at Berkeley, a gamma-ray telescope prototype, and an experiment to monitor the behaviour of liquids in microgravity.

Following its launch on 12 February on the maiden flight of Japan's M-5 rocket (see above), Muses-B, now called HALCA (Highly Advanced Laboratory for Communications and Astronomy), deployed its unique 8-m parabolic wire-tension-truss antenna on 28 February, after three perigee-raising burns placed the satellite in its planned highly elliptical 6-hour 560 x 21,400 km orbit. The root-mean-square shape accuracy of the antenna's reflector was measured at 0.8 mm during pre-launch testing.

HALCA's primary targets are super-massive black holes and masers. First images, confirming the operational readiness of the two lower HALCA frequencies (1.6 and 5 GHz), were received on 7 May, when the spacecraft (in combination with the 64-m ground-based ISAS antenna at Usudu) detected the fringe signal from quasar PKS 1519-273 in the constellation Libra. HALCA is also being used as one arm of a Very Long Baseline Interferometer (VLBI) in conjunction with a $5.1 million Canadian Space Agency digital recording and analysis system employing ground-based telescopes around the world in Sicily, South Africa, Puerto Rico, Japan, Green Bank (Virginia, USA), Madrid, Goldstone (California, USA), and Australia. The VLBI data are being used to study quasar cores, galactic features, cosmic gas clouds, and stellar magnetic fields.

Plasma Physics

NASA's 760-kg Advanced Composition Explorer (ACE), launched by a Delta-2 rocket from Cape Canaveral on 25 August, was subsequently placed in orbit at the L-1 Sun-Earth Lagrange libration point about 1.5-million km from Earth to study the chemistry of solar particles and also those coming from other sources in the universe. ACE can characterize about 30 elements with a sensitivity 10 to 1,000 times better than any previous spacecraft. The mission, originally budgeted at $141 million, was accomplished for $110 million plus the cost of the Delta launch. Besides studying solar and cosmic particles, the spacecraft's nine instruments will also serve as the world's first full-time sentry to warn of oncoming solar flares and magnetic storms, providing the U.S. National Oceanic and Atmospheric Administration (NOAA) and other centres in the United States and Japan with about an hour's advance notice of solar storms' impact on Earth's atmosphere.

On 3 April the European Space Agency's Science Programme Committee decided to re-fly the Cluster mission, which had been lost on Ariane-5's first flight attempt (see last year's report). The new mission, which is expected to cost only 214 million ECU (about $245 million), will not use instruments identical to those of the lost Cluster spacecraft, but will have essentially the same goals in conducting studies of Sun-Earth interactions via four identical, simultaneous measurements. The reduced cost (about half that of the original mission) is largely a result of the experience gained in designing and building the original spacecraft, as well as launching the four 1200-kg spacecraft on two of Starsem's Soyuz vehicles. The Dornier Satellitensysteme division of Daimler Benz Aerospace (Germany) is building the new spacecraft.

Brazil's sounding rocket payload Multifot-2, launched by a Sonda-3 rocket from the Alcantara Launch Centre on 11 November 1996, studied the sodium night glow chemistry and the vibrational dependence of the hydroxyl ion quenching rate. Signals from the longitudinal photometers were not able to be used due to a malfunction of the rocket's second stage, which did not spin the payload up to a speed sufficient to eject the nose cone fully, but data were obtained from the transverse photometers.

Solar System Exploration

Mars-96, a cooperative venture of 22 nations led by Russia, failed to reach its low Earth parking orbit subsequent to launch on 16 November 1996 and plunged into the Pacific Ocean near Chile about 4-1/2 hours after launch. The loss was subsequently traced to failure of the Proton launcher's Block D-2 upper stage to conduct its scheduled second burn. The 6700-kg spacecraft carried four Mars descent probes—two landing stations and two penetrators—equipped with radioisotope thermoelectric generators powered by a total of 0.27 kg of plutonium-238. No sign of any release of the fuel has been detected subsequent to the spacecraft's reentry.

The U.S. Pathfinder mission to Mars was launched by a Delta-2 rocket on 4 December 1996. After an uneventful flight, Pathfinder landed successfully on its scheduled date of 4 July within 30 km of its planned touchdown point (well within the 100-km specification) in the flood channel Ares Valles, which had been selected for the expected diversity of its mineralogy. The unconventional landing system involved aerobraking to a speed of 400 m/sec after Pathfinder's 7.6-km/second atmospheric entry, followed by further deceleration using a parachute and retrorockets, a rappel down a 20-m tether after jettisoning the aeroshell, and finally a free fall cushioned by inflated gasbags to bring the spacecraft to a stop after several high bounces that lasted for about two minutes. Gasbag deflation and subsequent unfolding of the Pathfinder's flower-petal-like solar panels on the Mars surface were successful, and the spacecraft ended its flight in an almost ideal level attitude, only 2.5 degrees from the horizontal. After returning the first photos of the Martian surface since two U.S. Vikings landed there over 20 years ago, Pathfinder's 11.5-kg solar-powered minirover Sojourner conducted a wholly successful survey and analysis of Martian rocks and soil in the neighbouring area within 500 m of the landing site.

Both the Pathfinder spacecraft (now named the Sagan Memorial Station, after planetary scientist Carl Sagan) and the Sojourner rover were still communicating with scientists on Earth when Mars Global Observer (see below) arrived in orbit on 11 September. However, contact with the Sagan Memorial Station was finally lost on 9 October after several previous communications blackouts (two months past its originally planned mission completion date), although the station's beacon signals indicated that it was still operating.

Mars Global Surveyor (MGS), launched by a Delta 2 rocket a month earlier than Pathfinder on 7 November 1996, arrived at Mars on 11 September and was successfully inserted into its planned highly elliptical 54,000 x 263-km orbit by a 45-minute burn of its main engine. The actual orbit period was within 26 seconds of the planned 45 hours. The $154 million spacecraft is using aerobraking, first demonstrated operationally in Venus's atmosphere two years ago by the Magellan spacecraft, to bring Mars Observer into its ultimate 380-km, 2-hour circular orbit over a 4-month period. The first five passes, conducted from 17–28 September, reduced the spacecraft's apoapsis from 54,000 km to about 52,000 km. These first aerobraking manoeuvres also revealed that the Martian atmosphere's high-altitude density is about double the expected value, and varied by about 30 percent during the passes.

Problems with one of MGS's solar panels, which had not locked into place following launch due to jamming of its hinge by a broken piece of its drive shaft, caused controllers to halt the aerobraking manoeuvres on 11 October. Instead of being forced into its proper locked position by the aerobraking drag forces, as had been expected, the panel appeared to have been pushed beyond the latch point due to buckling of the faceplate supporting the panel's hinge. A cautious programme of continued aerobraking, designed not to overstress the buckled plate, was resumed on 7 November. The final orbit that can be achieved with the new aerobraking programme has yet to be established.

The MGS spacecraft carries a high-resolution camera and five instruments duplicating those that were originally aboard Mars Observer, which failed to reach Mars in 1993, along with a French-built data relay for the 1998 Mars lander (see below). It will survey Mars' topography, magnetism, mineral composition, and atmosphere. The first series of data, taken during the aerobraking manoeuvres, confirm MGS's preliminary observation of 15 September that Mars has a weak magnetic field (about one-thousandth that of Earth's), and also detected the bow shock wave at about 6,800 km altitude, produced by the interaction of Mars' magnetosphere with the solar wind. Formal mapping of Mars is scheduled to begin in March 1998 and will last two years.

NASA first announced on 14 March, and subsequently on 19 June via an Internet posting, that its $300 million 2001 Mars Surveyor '01 Orbiter and Lander mission would consist of two spacecraft. The lander, which will probably be named the Mars In-Situ Propellant Production Precursor (MIPS), would be launched in April 2001 and land in January 2002, and the orbiter would measure space radiation, collecting data that were to have been taken by the Mars 96 mission. It is scheduled to be launched in March 2001 and arrive at Mars in December 2001. Preliminary designs for the MIPS lander include six experiments to test the effect of the Mars environment on propellant and oxygen production, to produce oxygen from the atmosphere using a zirconia cell, to manufacture carbon from the atmosphere with a zeolite sorption pump, and to test subscale hardware needed for a future sample return mission; e.g., advanced solar arrays, dust filtration and removal technologies, and temperature control systems. The lander will also carry a rover able to travel 10 km or more during its projected one-year lifetime, possibly a Russian Marsokhod, and will demonstrate new technologies for aerocapture and precision landing. Instruments aboard the Mars Surveyor '98 Orbiter and Lander spacecraft, currently being built by Lockheed Martin under a $187 million NASA contract, are designed to find and characterize water resources on Mars and will also deliver two soil microprobes being developed and built under a separate $26 million New Millennium programme contract. Subsequent orbiter and lander missions planned for 2003 and 2005 are likely to focus on sample-return technology and operations.

Further plans for exploration of Mars, announced at the International Astronautical Congress at Turin, Italy on 8 October, include ESA's Mars Express, an orbiter carrying a 120-kg payload to study the Martian atmosphere and possibly up to two 150-kg landers, to be launched in 2003 at a cost of about $130 million. France is also considering Mars 2001, which would refly five Mars-96 instruments to map Mars and study its atmosphere using a 1,000-kg spacecraft based on the CNES Proteus mini-satellite bus, along with a series of 180-kg "smaller, faster, cheaper" probes whose 40-kg payloads would study Mars' surface and atmosphere beginning in 2001 or 2003. Japan confirmed plans for a Planet-B Mars orbiter launch aboard an M-5 rocket in July 1998, to explore the interaction of the solar wind with Mars' atmosphere. The $100 million, 540-kg spacecraft will carry 14 instruments for a two-year mission beginning in October 1999.

Also announced at the Congress was a European plan for EuroMoon 2000, a joint government-industry programme to begin a series of return flights to the Moon. The first launch, by a Russian Molniya rocket in 2000, would map the proposed landing area. ESA also presented preliminary information on its Horizon 2000 cornerstone mission to Mercury, to follow up the U.S. Mariner-10 flight in 1974 by mapping the planet's surface, studying magnetic fields and particles around Mercury, and possibly landing a probe on the surface.

NASA'S $122 million Near Earth Asteroid Rendezvous (NEAR) spacecraft, launched in February 1996 to orbit asteroid 433 Eros beginning in January 1999 (see last year's report), took over 500 photographs of the asteroid 253 Mathilde, with resolution as fine as 100 m, during a 10-km/sec flyby on 27 June. NEAR's closest approach to the asteroid was within 1200 km. Mathilde is a 60-km-diameter C-class (carbon-rich) asteroid, the first to be observed by a spacecraft. It rotates once every 17.4 days.

Analysis of the results of the 1994 Clementine mission to the Moon, reported on 29 November 1996, suggest that there is a large body of frozen water, possibly of the order of 100 cubic metres, in a 2600-km wide, 12-km deep crater created 4.3 billion years ago by an asteroid impact at the Moon's south pole. The water was postulated to have been delivered there over a 3-billion-year period by cometary impacts. Earlier radar observations by the ground-based Arecibo Observatory in Puerto Rico, however, announced on 5 June, showed no indications of ice in the shaded areas. These images were made at the same wavelengths and viewing angles as the Clementine mission, but with much higher resolution. The discrepancy is expected to be resolved by NASA's Lunar Prospector, scheduled for launch next year.

Following Galileo's two encounters with Jupiter's moon Ganymede last year, the spacecraft successfully performed eight more encounters in 1997, two each with Europa and Ganymede and four with Callisto. The final two encounters of the mission will take place in November. The most notable recent findings of the spacecraft's eleven science instruments, which have been operating effectively with the five newly renovated Deep Space Network antennas in Australia and California, include strong inferential evidence of liquid water under Europa's ice crust, large variability of water content across Jupiter, and detection of a magnetosphere around Ganymede, the first moon in the solar system found to have one. NASA also approved this year the extension of Galileo's mission to December 1999, which will allow eight successive encounters with Europa and four with Callisto. These encounters will involve gravity-assist manoeuvres that may permit one or two subsequent encounters with Io.

The $3.3 billion 11-year Cassini/Huygens mission to Saturn completed ground testing at the Jet Propulsion Laboratory and ESA in March. The Cassini and Huygens spacecraft were transported to the Kennedy Space Centre in April and were mated in July. Despite the expected opposition to the launch by extremist groups who were concerned about the 32 kg of plutonium-238 in the radioisotope thermoelectric generators used to power Cassini's systems, the only delays in the launch were due to system "glitches" and weather. The first delay, from the originally scheduled date of 3 October to 13 October, was caused by an improperly set airconditioner flow which damaged Huygens' insulation and necessitated its replacement. The second delay, from 13 October to 15 October, resulted from a computer anomaly and marginal weather at Cape Canaveral.

Cassini was finally launched on its 3.5-billion-km journey by a Titan-IV/Centaur on 15 October, well within its "window." The initial trajectory was virtually perfect: the velocity was within 1 part in 5000 of the planned 11.2 km/s and the angular deviation was only 0.004 degree. Hence the first trajectory correction, on 9 November, required a velocity change of only 1 m/s instead of the planned 26 m/s. Cassini, at 5,700 kg the heaviest planetary exploration mission ever flown by NASA, will reach Saturn on 1 July 2004 after undergoing four gravity-assist manoeuvres, two using Venus, one employing Earth (in August 1999), and a final boost from Jupiter late in 2000. The big spacecraft, which involves the cooperative efforts of 17 nations, will then spend four years exploring Saturn and its moons.

On 23 April NASA awarded $350,000 mission definition contracts to each of five candidates for Discovery Programme missions: a Mercury orbiter, analysis of the material adjacent to three comet nuclei, a solar-wind sample return, sample return missions to the Mars moons Deimos and Phobos, and a Venus orbiter to study the planet's atmosphere. NASA subsequently selected two winners on 22 October. The $216 million Genesis mission proposed by Lockheed Martin and the Jet Propulsion Laboratory, orbiting at the L-1 Lagrange libration point between the Earth and the Sun, will collect samples of the solar wind for two years beginning in 2001 and return them to Earth for analysis in August 2003. The $154 million, 775-kg Comet Nucleus Tour ("Contour") spacecraft was proposed by Cornell University and the Johns Hopkins University's Applied Physics Laboratory. It will sample and analyse the dust emitted from comets Encke (in November 2003), Schwassman-Wachmann-3 (in June 2006), and d'Arrest (in August 2008), and will also take high-resolution images and generate spectral maps of the three comets from within 100 km of each of their nuclei.

NASA announced on 24 April its plan for a three-pronged exploration programme called "Ice and Fire," which would use advanced technologies to design, develop, and fly low-cost missions to make close-up observations of the Sun by flying through the corona to within 2-million kilometres from the Sun, to conduct radar studies of Jupiter's moon Europa to determine the thickness of its ice layer, and to explore Pluto, its atmosphere, and its moon Charon. Ice and Fire builds on prior work accomplished during Pluto Express mission studies and on technologies currently being explored in the New Millennium programme. Mission cost guidelines for the Discovery series would be used; i.e., a maximum development cost of $183 million plus launch and operations costs.

Planning for Human Exploration of Mars

On 22 November 1996 NASA Administrator Daniel Goldin announced the agency's intent to plan for an international mission to Mars carrying a human crew in the year 2012. Criteria he identified for the mission include: (1) a mission development time-scale of no more than eight years, (2) an annual budget averaging between $3 billion and $6 billion, of which the U.S. would commit no more than half, (3) adequate information obtained from precursor robot missions to identify areas on Mars having the required resources, and (4) existence of the scientific infrastructure for processing the data, along with compelling economic and inspirational reasons for sending humans to Mars. Mr. Goldin identified transportation as the key cost issue, noting that NASA's stated cost goal of $90 per kg of payload to low Earth orbit by 2010 would bring the mission costs into line with the programme criteria.

Goldin's criteria were crystallized in a specific reference mission plan completed in March by NASA's Johnson Space Centre, which proposed three flights by human crews between 2007 and 2014, each supported by two cargo-only flights, plus three initial cargo flights. This plan, however, titled "Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team," proposes the costly development of a new Shuttle-derived heavy-lift "Magnum Lifter" in the 80-tonne payload class, and hence has an overall budget that is probably not affordable in the current and projected future fiscal environment. Subsequent cost reductions through the use of inflatable crew transportation and habitation modules, released to the NASA Administrator on 9 July, offer some hope for cost reduction, but do not permit attaining Mr. Goldin's goal of an eight-year programme costing less than $25 billion.

Search for Extraterrestrial Intelligence

In October 1996, the SETI Institute's Project Phoenix began observations with the 42-m antenna of the National Radio Astronomy Observatory at Green Bank, Virginia (USA) and gradually phased in observations with the Georgia Tech 30-m antenna in Woodbury, Georgia (USA). These observations now utilize 50 percent of the observatories' time. The two telescopes work together as a pseudo-interferometer to discriminate against terrestrial and orbital interference. The Green Bank instrument covers the frequency range 1–3 GHz and the Woodbury telescope covers 1–7 GHz. Both systems were designed and developed by Australia's CSIRO. The feeds feature an innovative dielectric core that maintains nearly constant aperture illumination over a very wide range of frequencies.

The signal-processing subsystems have been optimized for detection of narrowband signals that would suggest the existence of an extraterrestrial technological civilization. All detected signals are compared against a dynamic database of previously detected signals from different directions. Those that match are classified as radio-frequency interference (RFI); those that do not are immediately re-observed with phase-coherent detectors at both telescopes. Only those signals seen by both telescopes and possessing the correct differential Doppler signature, associated with the direction of the distant star being observed, are considered to be candidates. For these few candidates, the observational pipeline is broken and additional observational verifications are automatically performed. To date, no signal has successfully passed this verification process. For 300 nearby solar-type stars (out to 155 light-years) observed in 1995 from Australia and now from Green Bank and Woodbury, within the frequency range 1–3 GHz, it has been concluded that there were no transmitters with powers exceeding 10^{12} W effective isotropic radiated power (EIRP) operating during the observations.

Because RFI is an increasing impediment to SETI and all ground-based radio astronomy observations, the designation by ITU treaty of a Shielded Zone of the Moon grows more important every year. An International Academy of Astronautics Cosmic Study, "Protecting and Establishing a Radio Astronomy Observatory on the Farside of the Moon," was initiated this year. It will be led and edited by Jean Heidmann (France).

TECHNOLOGY ADVANCEMENT

Propulsion

Earth to Orbit Rockets

NASA announced on 7 February that cracks in a developmental liquid hydrogen fuel pump delayed operational readiness of the improved Block 2 Space Shuttle Main Engines beyond their original operational date of December 1997. Although the cracking was not considered a serious problem in a developmental engine (five of 50 blades were found cracked after 11 test firings, but a second fuel pump had no cracks at all after 10 firings), the operational readiness delay to July 1998 was considered appropriate until the cause of the cracking could be established. Unfortunately, however, during a subsequent test on 27 August the fuel pump in the test engine was destroyed by an unrelated engine nozzle fire. Hence the six certification tests already completed will have to be repeated, along with the remainder of the certification testing, when a new pump becomes available in November. The first flight of the Block 2 engines therefore cannot occur until at least September 1998. The first three Block 2A engines, which still use Rocketdyne fuel pumps, were delivered to NASA in April for their January 1998 maiden flight aboard Shuttle Discovery.

The development-test model of the Russian RD-180 engine for Lockheed Martin's new Atlas IIAR derivative launcher (see above) was tested successfully by NPO Energomash at Khimky, Russia on 15 and 20 November 1996. Each test lasted 60 seconds at thrust levels ranging from 45 percent to 84 percent of rated thrust. Two subsequent tests operated for 6 seconds, to evaluate ignition transients, and for 186 seconds at 89 percent thrust, to duplicate the most demanding flight profile of the Atlas IIAR. The Atlas IIAR's nominal launch profile requires no more than 84 percent of the RD-180's rated thrust. The RD-180, which Lockheed Martin also plans to use for its EELV candidate (see above), is being developed and marketed by RD Amross LLC, a joint venture between Energomash (Russia) and Pratt&Whitney (USA).

Subsequent testing of the third test-model RD-180 was conducted in April, but a fire occurred during an attempt to run the engine under more stressful conditions than any expected on Atlas IIAR flights, damaging the engine beyond repair. The cause of the fire was subsequently traced to an improper mix between fuel and oxidizer, caused by a deliberately slower-than-normal engine startup sequence that was intended to test the limits of the engine rather than its operational sequence. The fourth test engine was run successfully on the same rigorous flight profile for 200 seconds on 29 May and again on 4 June, and once more for 230 seconds on 11 June, demonstrating that the valve adjustments made following the fire were successful and that there appear to be no design flaws in the new engine. The final two engines in this test series, scheduled for ground-testing late this year, are to be flight-type engines. One of them was delivered to NASA's Marshall Space Flight Centre on 6 August for ground testing mated to the Atlas IIAR tank and other flight-vehicle components. These tests are scheduled to begin in January 1998. The highly successful RD-180 test program is less than a month behind the schedule that was originally set up over two years ago, early in 1995.

On 23 August GenCorp Aerojet (USA) received from Russia 25 Kuznetsov NK-33 and 9 NK-43 engines, the second shipment of a total of 76 engines contracted by Kistler for its new

K-1 reusable launch vehicle (see above). 58 are NK-33s, three of which are to be used for each K-1 first stage, and 18 are NK-43s, which are to power the K-1's second stage. The first 12 NK-33 engines were shipped to Aerojet last year, and are being modified to the AJ26-NK33A designation by installation of a gimbaling mechanism, new wiring harnesses, electromechanical valve actuators, and other modifications to achieve reusability. They are planned by Kistler to be reused 20 times. The NK-43 is essentially an NK-33 fitted with a high-expansion-ratio nozzle, and will be designated AJ26-NK43A after modification. The engines were built in the 1960s and 1970s for the Russian Moon program.

Testing of the reusable X-33 Advanced Technology Demonstrator's linear aerospike engine was conducted at NASA's Marshall Space Flight Centre from 24–30 April. The tests studied the interaction of the exhaust plumes among three side-by-side hydrogen-fuelled thruster cells (the two X-33 engines will each have ten side-by-side thrusters), as well as the interaction and heating between the feed systems of cells. Full engine testing is to begin late this year, along with flight tests of a one-tenth scale half-span model aboard a NASA SR-71 supersonic aircraft.

The fourth and final flight test of a hybrid-rocket-propelled Hyperion sounding rocket was completed at NASA's Wallops Flight Facility on 25 April. Ground testing of a larger-scale hybrid rocket motor is continuing at the Marshall Space Flight Centre under NASA's Hybrid Propulsion Demonstration Program (see last year's report), which also funded the industry team responsible for the Hyperion flight-test programme.

The upgraded LE-7A first-stage engine for Japan's H-2A launcher (see last year's report) underwent its first test series in May. One prototype verified 80 performance characteristics during 50-second firings at Mitsubishi's Tashiro test site. The final 20 May test of the second prototype, of seven test firings conducted at NASDA's Tanegashima complex, was a full-duration 350-second firing. Unfortunately, post-test inspection revealed cracks in 10 of the 295 fuel-injector tubes and partial melting of four more, requiring redesign and additional testing. Although the technical problems associated with the redesign are not considered serious, their cost may severely impact the low-budget H-2A development effort. Testing of the LE-7A was resumed on 23 October.

Orbit Transfer and Upper Stages

Pratt&Whitney (USA) conducted test-firings in July of the modified RL-10 engine slated for use on the second stage of the new McDonnell Douglas (now Boeing) Delta-3. A 250-second test of the fixed section of the extended nozzle used to gain additional performance was completed successfully on 10 July at the U.S. Air Force's Arnold Engineering Development Centre, and all three sections of the new nozzle were test-fired on 25 July.

The U.S. Air Force Phillips Laboratory announced on 21 November 1996 a Solar Orbit Transfer Vehicle (SOTV) design study to evaluate and subsequently demonstrate the use of solar-thermal propulsion to transfer payloads from low Earth orbit to geosynchronous or Earth-escape orbits. Design specifications for the SOTV demonstration are a maximum mass of 135 kg, power consumption less than 300 W, and transfer time from low Earth orbit to the geostationary orbit less than 30 days. Advanced technologies could include inflatable mirrors and high-temperature materials. A $50 million 4-year contract culminating in a 60-day flight test is scheduled to be awarded in December. Testing of components for a related programme, the Integrated Solar Upper Stage (ISUS), which is jointly supported by the Phillips Laboratory, the Defence Special Weapons Agency, and NASA's Lewis Research Centre, were begun in June and completed in September. The ISUS uses thermionic converters, heated by radiation from a graphite receiver which in turn is heated by hot hydrogen from a solar concentrator, to generate 30–50 kWe. The power generated would be used in an electric thruster. The hot hydrogen working fluid is exhausted through a nozzle to provide additional thrust.

ESA completed in June a four-month preliminary mission feasibility study of a solar sail spacecraft called Daedalus, which is a candidate mission for the agency's Third Millennium celebration. Although heavy, the Daedalus sail concept would develop sufficient thrust to be propelled for about a year before the strength of the solar radiation drops to a level too low to sustain adequate propulsive force. If approved, the mission could be launched by December 1999.

Airbreathing Propulsion Systems

On 26 March NASA awarded a $33.4 million contract to Microcraft, Inc. to build and fly four unmanned 4-m flight-test vehicles for the Hyper-X programme. The goal of Hyper-X is to develop and demonstrate hydrogen-fuelled hypersonic airbreathing engines for reusable space launchers. The 55-month programme includes 20-second flight tests of a dual ramjet-scramjet (supersonic-combustion ramjet) at speeds of Mach 5 to Mach 10, following launch to 30-km altitude by a Pegasus rocket, beginning by the end of 1998. Other Hyper-X team members include Boeing North American, the General Applied Science Laboratory (GASL), and Accurate Automation Corp. (all USA).

The rocket-based combined-cycle propulsion test effort begun by NASA's Marshall Space Flight Centre under its Advanced Reusable Transportation Technologies programme late in 1996 proceeded this year under four $5 million to $8 million contracts with Boeing (Rocketdyne), Pratt&Whitney, and GenCorp Aerojet. On the basis of tests conducted at the GASL freejet test facility up to Mach 8, NASA will select one or two of the contractors late in 1999 to build flightweight engines for ground testing and possibly flight testing aboard Hyper-X (see above).

Pursuing a new technical approach to combined-cycle propulsion, NASA on 12 May awarded a $1.5 million contract to Astrox for design and simulation studies of a rocket-based combined-cycle propulsion system employing an inward-turning airstream to reduce drag and heating loads. By using three-dimensional axisymmetric compression rather than the more conventional two-dimensional configuration employed by the former National AeroSpace Plane, Astrox claims their design can improve specific impulse in hypersonic flight by up to 30 percent, in addition to the drag and heat-load reductions.

Russia's airbreathing launch research effort, conducted jointly by Russia's Central Institute of Aviation Motors and NASA's Dryden Research Centre, progressed this year with the flight on 1 August of a dummy hydrogen-fuelled axisymmetric engine, built by the Chemiautomatics Design Bureau, aboard an SA-5 missile launcher. Powered flights of the engine to Mach 6.5 are to begin late this year. The Russian Space Agency is also leading the Igla programme, aimed at the development of a 5-m flight-test vehicle similar to the U.S. Hyper-X, to be boosted by an SS-18 or SS-19 launcher to flight-test speeds of Mach 5–14. Russia's Moscow Aviation Institute is also cooperating with France on the Prepha follow-on programme, to develop experimental kerosene- and hydrogen-fuelled engines using ramjet, scramjet, and oblique detonation wave technologies and to conduct ground and flight tests in the Mach 3–12 range.

Germany's OHB-System purchased a demonstrator model of Russia's Raduga D-2 hypersonic test vehicle on 16 May. It will be used to test hypersonic technologies in a cooperative European-Russian programme. The 11.6-m D-2 expendable test vehicle built by MKB Raduga has flown over 500 times at speeds up to Mach 6.3.

An advanced airbreathing laser propulsion system conceived at Rennselaer Polytechnic Institute was flight-tested in September at the White Sands missile Range (USA), lifting a 50-gram, 14-cm diameter model about 2 m in altitude. The system uses a ground-based pulsed laser to ionize air in an annulus at the base of the vehicle, creating a plasma that produces thrust.

Power

In March the U.S. Department of Energy (DOE) initiated development of an Advanced Radioisotope Power System (ARPS) for deep space missions beyond 2002. The DOE will first build a 100W electrically heated prototype, scheduled for completion by July 1999, to be followed by flight-ready hardware powered by plutonium-238. The programme's goal is to improve the efficiency of current radioisotope thermoelectric generators (used on the Galileo, Ulysses, and Cassini missions) by a factor of three. The candidate conversion systems, one of which will be selected during the prototype phase, are alkaline metal thermal-to-electric conversion (AMTEC), thermophotovoltaic conversion, and a Stirling-cycle engine.

On 4 April NASA published the results of a two-year study, "Space Solar Power: A Fresh Look." It was the first major U.S. effort in 15 years, assessing approximately 30 diverse system concepts ranging from innovative architectural strategies such as the use of power relay satellites, to highly advanced system concepts such as integrated energy conversion/radio-frequency power generation "sandwich" designs, to specific technologies such as laser power transmission instead of a microwave link to the ground.

The study team focused on three design goals: (a) serve the global marketplace, not just the industrialized nations; (b) eliminate in-space construction infrastructure; and (c) use transportation and other infrastructure elements that are common to other markets, not unique to space solar power. The team examined various orbits, including not only the traditional geostationary Earth orbit but also an elevated low Earth orbit (LEO) and a middle Earth orbit (MEO). System design drivers included high levels of modularity and self-assembly. Several major technical strategies were developed and used to define seven architectures and four new system concepts.

One promising system concept is the "SunTower," a gravity-gradient-stabilized platform concept that would be deployed in constellations at approximately 6000 km altitude (MEO) or in Sun-synchronous orbits at approximately 1500 km altitude (LEO). The concept's modularity allows the use of both common-carrier launch systems and self-assembling spacecraft that entail little or no in-space infrastructure. A typical MEO SunTower architecture would provide about 250 MW of continuous power to globally dispersed markets and could be deployed for an investment of about \$10 billion to \$15 billion, with land use only 10–25 percent that of a comparable terrestrial solar power plant. Smaller-scale flight demonstrations could serve as prototypes for technology and systems at 50 MW power levels. Larger or advanced-concept systems than the SunTower require considerably more study.

The study also highlighted potential space applications for space solar power, such as solar-electric propulsion system stages for outer-planet robotic science missions and commercial GEO communications satellites, non-isotope power for Jupiter/Saturn robotic science missions, power systems for very large space observatories to find and study Earth-like planets around nearby stars, integrated radar and/or high-rate communications for science missions to asteroids, comets, or other small Solar-system bodies, high power for commercial GEO communications satellites and future space business parks, megawatt-class solar-electric space transfer vehicles for lunar cargos and human Mars-mission transportation systems, and wireless power transmission systems from lunar or Mars orbits to the surfaces of the Moon or Mars.

The study concluded that space solar power may be ready for reconsideration due to the availability of new technologies, significantly lower cost projections, and renewed environmental concerns associated with conventional terrestrial power-generating systems. Although its economic viability depends on many factors and the successful advancement of various new technologies, not least of which is the availability of low-cost access to space, the NASA "Fresh Look" study suggests that space solar power may well emerge as a serious candidate among the options for meeting the global energy demands of the 21st century. Continued work by NASA was strongly encouraged during testimony at a hearing of the US House of Representatives Space Subcommittee on 24 October.

Demonstrations held in conjunction with the international conference on Space Solar Power Systems (SPS 97) held in Montreal in August included new types of rectennas and retrodirective beam control devices from Japan and, from Canada, a microwave-powered roving vehicle such as might be used in lunar exploration.

Mars Pathfinder's cruise system, Sagan Memorial Station, and Sojourner rover (see above) were all powered by gallium arsenide solar cells. New technology advances in concentrator arrays and multi-bandgap arrays are being tested this year for NASA's New Millennium Deep Space 1 spacecraft (see last year's report), scheduled for launch in 1998. This will include the first use of a deployable modular concentrator array and 23 percent-efficient cells of gallium indium phosphide on gallium arsenide. These cells will power both the spacecraft electrical systems and an electrostatic (ion) thruster, the first such use for primary propulsion on a NASA spacecraft. NASA's Earth Observing System AM-1 spacecraft, to be launched next year, will see the first operational use of a flexible blanket array made with cells of gallium arsenide on germanium.

Materials and Structures

The first flight of a new Advanced Grid-Stiffened Composite Payload Shroud took place during a suborbital launch by Orbital Sciences from NASA's Wallops Flight Facility on 23 February, which carried a Midcourse Space Experiment payload to 390 km altitude. The new structure, which is claimed to be 60 percent lighter and three times stronger than conventional aluminum fairings, was developed by the U.S. Air Force Phillips Laboratory. It is made from a graphite-epoxy resin composite wound by a new automated process which Phillips is patenting. The shroud flown on 23 February was 3 m long and weighed only 37 kg, vs about 96 kg for an otherwise identical aluminum structure. It took less than a week to manufacture, compared with three to four weeks for a standard honeycomb-type composite fairing and six to seven weeks for an aluminum one.

NASA's Lewis Research Centre (USA) and the Keldysh Research Centre (Russia) signed a two-year contract on 2 July to measure flammability and flame-spreading rates of at least six different materials under microgravity conditions, using Keldysh's Skorost test facility on the Mir space station to conduct ignition tests at various air-flow velocities. Results will be correlated with those of comparable ground tests at NASA Johnson Space Centre's White Sands Test Facility in the United States.

This year DASA (Germany) successfully manufactured and tested the first ceramic composite hot-structure panels able to withstand temperatures higher than 1600 C, in conjunction with an adjacent control surface and accessory components such as hinge joints, seals, and fasteners. Flight-configuration components are being designed and fabricated for NASA's X-38 re-entry demonstrator. Aerospatiale (France) has also used ceramic composite materials for the first time in manufacturing and testing a highly stable telescope structure which is insensitive to moisture and has a thermal expansion coefficient less than 10^{-7} per degree C.

Automation and Robotics

On 7 January the U.S. Air Force's Phillips Laboratory announced a new programme, Microsystem and Packaging for Low-power Electronics (MAPLE), to develop and demonstrate microelectromechanical systems for miniaturized spacecraft. The Centre for Space Microelectronics Technology at NASA's Jet Propulsion Laboratory is collaborating with Phillips Laboratory in what the laboratories are calling "a big step toward the production of ultralight nanosatellites about 10 cm across or smaller," by using microelectromechanics technology to create integrated systems that merge information processing, communication, sensing, and control functions. The first flight demonstration, MAPLE-1, is scheduled for launch in December aboard MightySat-1. It will use miniature accelerometers to monitor the shocks created by explosive bolts. MAPLE-2 is scheduled for March 1998, to evaluate space radiation effects on microsensors and flight-demonstrate a miniature vibration monitor.

The 2,500-kg Nomad prototype planetary rover designed and built by Carnegie-Mellon University's Robotics Institute (USA) was put through a 45-day series of trials in Chile's Atacama desert beginning on 18 June. The tests, which involved remote guidance of the rover over desert terrain similar to that of Mars, were designed to evaluate its ability to navigate, explore, and perform scientific experiments during long-term lunar and Mars missions. The four-wheeled $1.6 million Nomad covered 215 km during the test, 20 km of which Nomad traversed by autonomous control using hazard-avoidance sensors.

Space Research Facilities

On 24 November 1996 Germany's 35th Texus sounding rocket was launched from Esrange in Sweden carrying 230 kg of German Space Agency experiments in fluid physics and molecular biology to an altitude of 267 km. The flight provided the experimenters with 6.5 minutes of microgravity conditions.

A Russian Photon-11 capsule returned four Russian-German materials science experiments to Kazakhstan on 23 October, following two weeks in orbit. A "piggyback" payload, the 90-cm-diameter, 155-kg German Mirka re-entry capsule with four hypersonic flight experiments aboard, had been separated from the Photon in orbit and landed separately via its own parachute. Mirka, built by Kaiser-Threde, is Europe's first return-to-Earth recoverable spacecraft. The Photon-11 had been launched by a Vostok rocket from the Plesetsk Cosmodrome on 9 October.

Novespace's (France) new Airbus A-300 microgravity test aircraft made its first commercial flights on 6 February. A series of 24 parabolic descents duplicated the conditions a Japanese solar panel manufactured by NEC would experience when deployed on orbit aboard the Comets technology testbed satellite.

On 24 June Japan's NASDA announced completion of its new $37 million, 6-m diameter spacecraft test chamber. The facility can control temperatures of spacecraft weighing up to 3500 kg from -100C to 300C. It was used this summer to test several instruments for ADEOS-2, scheduled for launch in 2000, and also systems for NASDA's first optical communications test satellite, the Optical Inter-Orbit Communications Engineering Test Satellite, scheduled for launch late in 2000

Environmental Effects of Space Flight

Space Debris

The U.S. National Research Council's report of 8 January, "Protecting the Space Station from Meteorites and Orbital Debris," warns that inadequate attention has been paid to the hazards of orbital debris. The report recommends additional shielding on the space station's modules, especially the service module being built in Russia, and also calls for additional protection on extravehicular space suits to resist debris punctures. The report also notes the changing nature of the debris hazard, which may require more shielding be retrofitted to the station in the future.

On 22 January two large fragments of a U.S. Delta second stage fell in Texas, USA: the 2.7 m x 2.1 m 250-kg stainless-steel propellant tank and a 30-kg titanium sphere. The Delta launch (of an MSX payload) took place from Vandenberg Air Force Base on 24 April 1996. The debris decayed from a 207 km x 860 km Sun-synchronous orbit that was established following a depletion burn of the stage.

U.S. Space Shuttle Discovery activated its reaction control system thrusters for 10 minutes on 15 February, during the Hubble Space Telescope repair mission (see above), to avoid a possible collision with a fragment of a Pegasus upper stage. On 17 July, ESA controllers moved their $800 million, 2,400-kg European Remote Sensing (ERS-1) satellite to a 2-km higher orbit just 60 minutes before a projected impact, at a relative speed of about 14 km/sec, with an abandoned 750-kg Russian Cosmos 614 military satellite launched in 1973.

Discovery of a new debris source in the 800–1000 km altitude range was announced at the Second European Conference on Space Debris 17–19 March. Measurements made by the radars at Haystack and Goldstone observed tens of thousands of metallic liquid spheres in the 1–3 cm diameter range. These measurements are consistent with a debris source of leaking coolant from one or more of the Radar Ocean Reconnaissance Satellite (RORSAT) nuclear power sources launched by the former Soviet Union in past years.

On 21 April a U.S. Pegasus XL rocket launched the cremated remains of 24 humans into low orbit as a secondary payload, along with Spain's Minisat-01 (see above). The containers' orbit is expected to decay in about 10 years, with the cremated remains burning up in the upper reaches of the atmosphere.

A new era of concern in the proliferation of potential space debris began on 5 May with the launch of the first five Iridium low-Earth-orbit communications satellites (see above). This class of constellations, especially their launch-vehicle stages and deployment hardware, represents a significant potential future debris hazard in high-traffic orbits. Although Iridium, Geodesic, and Globalstar had already announced (on 18 March) their intent to reserve sufficient fuel to deorbit spent or obsolete satellites (Iridium and Teledesic will drive their old spacecraft into the atmosphere; Globalstar will boost theirs into a higher, unpopulated orbit), there is still likely to be significant debris accumulation from spent upper stages and other hardware associated with the orbiting of these spacecraft.

EDUCATION

Teaching Programmes

The first United Nations graduate course in satellite communications and space technology began at the Indian Space Research Organization's offices in Ahmedabad, India on 10 February, with 14 students from nine Asian countries. The course, which coincided with a United Nations–European Space Agency workshop on tele-education and training via satellite, was completed on 25 April.

Space Explorers, Inc. (USA) announced on 22 April the availability of Moonlink, an Internet-based educational programme to bring data from the Lunar Prospector, scheduled for launch late this year, to classroom groups of 12 to 24 students. The programme receives the raw data and translates them into charts, graphs, and other readily understandable formats. Students can select a particular region of the Moon as "theirs," communicate with the spacecraft directly, and subsequently analyse their region's data over a long-term period such as a school semester or the life of the mission.

The Florida Institute of Technology (USA) received grants in April for student-built experiments to fly aboard the Shuttle in 1998. The two grants, $3,000 from the Florida Space Grant Consortium and $30,000 from the Florida Space Institute, are supporting two experiments, one to study upward-moving lightning and one to make thin films for solar cells.

NASA in May selected 18 institutions (from 61 proposals submitted by over 50 schools) to receive grants totalling $700,000 for undergraduate student research and teacher training in the

Earth sciences. It was NASA's first educational grant package devoted specifically to Earth system science.

In June NASA also selected 338 high-school students from 193 schools in 32 states and territories to work in science and engineering research in the agency's ongoing Sharp Plus Research Apprenticeship Programme. The students spent 8 weeks at 16 universities this summer.

A small student experiment named Falcon Gold was successfully launched on 24 October from Cape Canaveral Air Force Station by an Atlas 2A rocket, along with the primary payload, a large military communications satellite. It is a joint project between the University of Colorado and the United States Air Force Academy. The payload is in a 200 km by 35,200 km orbit, inclined 26 degrees to the equator. It receives Global Positioning System (GPS) signals and transmits the data back to ground stations to investigate the feasibility of using GPS for precise satellite orbit determination.

Fourteen students sent by the French and German space agencies spent nine days, from 14–23 February, in French Guiana to study the regional environment using maps generated by France's Spot, Europe's Meteosat, and U.S. Landsat and NOAA satellites. Results of the study are to be presented at a November symposium on space science and education being organized by the European space awareness organization Eurisy.

ESA and the Russian Space Agency signed an agreement in June to support a series of seminars at the International Space University (France). The seminars, which began in September, cover a broad range of space topics that include international space law, program management, industrial contracting, space transportation technology and systems, and manned space flight.

Public Awareness

On 21 May Canada's Imax Corporation released its film "Mission to Mir," which was produced in cooperation with NASA and Lockheed Martin. Public showings began in 22 countries in September. NASA also announced on 20 May its plans to have Imax document the on-orbit assembly of the international space station, scheduled to begin in October 1998.

INTERNATIONAL COOPERATION AND SPACE LAW

International Cooperation

On 24 July Hungary became the 81st member of Inmarsat, with the Hungarian Satellite Communications Association signing the Inmarsat treaty as the nation's designated representative. In Hungary's first use of the system, 50 trucks operated by the trucking company Hungarocamion were equipped with Inmarsat-C terminals.

On 7 November 1996 the Czech Republic and the European Space Agency signed a five-year agreement covering cooperation on space science, Earth observations, and ground support operations. The agreement provides for Czech participation in ESA programs.

On 8 November 1996 the United States and Mexico reached agreement to permit broadcasting entities in each country to transmit direct-to-home broadcasts into the territory of the other country.

On 3 December 1996 the Technological and Aerospace Committee of the Western European Union (WEU) Assembly approved a plan to strengthen ties between Europe and Japan in both civilian and military space programs. The proposals, adopted by the WEU Assembly, would be offered to the Japanese as means of accomplishing closer cooperation over a wider range of programs and projects.

The following day, on 4 December 1996 VTR Galaxy Chile, S. A. of Santiago announced that the Transportation and Telecommunications Ministry of Chile has issued a license approving provision of direct-to-home satellite television in Chile by Galaxy Latin America (GLA). GLA is a joint venture of American, Venezuelan and Brazilian telecommunication entities, with headquarters in Nassau, Bahamas.

On 6 December 1996 the Board of Governors of the International Telecommunications Satellite Organization (Intelsat) approved the procurement of a direct-to-home television broadcasting satellite for Asia.

Brazil and NASA signed an agreement on 6 December 1996 to fly a Brazilian camera aboard a Shuttle mission in 1999 and a humidity sounding instrument on an Earth Observing System spacecraft in 2000. This is the first agreement between the two countries which involves hardware contributions; prior agreements were limited to scientific data exchanges. It is expected to pave the way for Brazilian participation in the international space station program.

Also on 6 December several joint space programs were agreed between representatives of the European Space Agency (ESA) and representatives of Japanese organizations including the National Space Development Agency (NASDA), the Ministry of Posts and Telecommunications (MPT) and the Science and Technology Agency (STA) in a meeting at Tsukuba Science City in Japan. Projects will address cooperation in telecommunications, manned spaceflight and the international space station.

On 16 December 1996 ESA and a group of Japanese space agencies met to define a long-term program of cooperation. The ESA-Japan Ad Hoc Group agreed to design and test on-orbit a high data-rate communications system to transfer Internet-type information between satellites and ground computers at several gigabits per second. The system, called Gigabit, is to fly in 2002. The Group also agreed to lease Intelsat capacity for joint European-Japanese efforts in telemedicine, video conferencing, and sharing of Earth-observation data, and confirmed earlier agreements for cooperation on ESA's Artemis optical data-relay satellite (scheduled for launch in 2000), Japan's two Data Relay Test satellites (to be launched in 2000 and 2001), several cooperative projects on the international space station, and sharing of information on their crew-carrying demonstrators, Japan's Hope-X and ESA's Atmospheric Reentry Demonstrator.

France and Russia signed an agreement on 23 December 1996 under which French astronauts will visit the Mir space station in late 1997 and late 1999. The total price negotiated by the French and Russian space agencies was estimated at $40 million for a three-week visit in

1997 and a four-month stay in 1999. France subsequently signed an agreement with China on 16 May, to cooperate on space research and satellite construction for remote sensing and space science missions.

Also on 23 December 1996 space agencies in France and Russia signed an agreement providing for French astronauts to visit Russia's Mir Space Station, one in late 1997 and another in late 1999. France will pay Russia an undisclosed amount for the visits by French astronauts.

In December of 1996 it was announced that The Swiss Federal Institute of Technology in Zurich will deliver Radarsat data products in Switzerland for Radar International of Richmond, British Columbia. Radarsat International was established to deliver market radar imagery from Canada's Radarsat system. Also, the National Research Council of Thailand awarded a contract to MacDonald Dettwiler of Richmond, B. C., Canada, to upgrade a ground station near Bangkok, Thailand, to retrieve Radarsat imagery. MacDonald Dettwiler also received a contract from the Saudi Centre for Remote Sensing to upgrade a station near Riyadh, Saudi Arabia to work with Radarsat. Other agreements for Radarsat data distribution were announced naming NASDA as an image down loader and processor in Japan and Spot Asia Pte. Ltd., of Singapore, as distributor for Radarsat data in Southeast Asia. Spot Asia is a joint venture involving Spot Image of France and SSC Satellitbild of Sweden.

Also in December, Indian and Norwegian space agencies agreed to study the joint use of Norway's planned Svalbard Ground Station, possible use of Norway's Andoya Rocket Range for launch of Indian sounding rockets, and to study the possible use of Indian orbiting rocket capability for cooperative missions in the future.

Indonesia's Agency for the Assessment and Application of Technology signed a $10 million contract with Spotimage on 16 January to provide Indonesian government agencies with three years of training in the use of satellite imagery, along with a Spot satellite receiving station and over 250 satellite image maps.

ESA's science program was set on a whole new course following a 3 June meeting of the Science Program Committee. The Committee approved a 12-year plan based on flying a number of small technology-demonstration satellites to set the stage for the agency's larger science spacecraft. The plan's budget is based on the premise that two large missions, the Far Infrared Space Telescope and the Planck Surveyor, can be merged successfully. The approved ESA science mission profile now includes a small ($58 million) satellite to demonstrate electric propulsion in 2001, a $17 million imaging instrument to be launched to the Hubble Telescope in 2002, a Mars Express mission costing $173 million in 2003, a $200 million contribution to NASA's Next-Generation Space Telescope, tentatively planned for launch in 2007 (see above), and two more as-yet undefined small satellites in the 2009 time period. All these additions to ESA's science mission plan are based on the premise that national space programs will contribute to their costs.

On 17 January 1997, direct-to-home satellite television services were initiated in the Caribbean Region. Galaxy Latin America began serving Barbados, Trinidad and Tobago. These areas were added to services in place in Brazil, Costa Rica, Ecuador, Mexico, Panama and Venezuela.

From 27 to 30 January 1997, the United Nations and the Government of Austria co-sponsored a Seminar on "Space Futures and Human Security" in Alpbach, Austria. The seminar involved invited experts from 15 countries and from international organizations and national agencies involved in space activities. Proceedings of the seminar are to be published through the United Nations.

On 29 January 1997 the National Aeronautic and Space Administration (NASA) of the United States and Japan's major space agencies and universities completed meetings to strengthen collaboration on infrared astronomical research, meteorite studies and the exploration of asteroids and comets relating to the origins of life in the universe. The two countries will share and exchange information from their respective relevant space research programs. The countries also agreed to collaborate on guidelines for unmanned Mars exploration planned by both countries.

On the following day, on 30 January 1997 an Ariane launch vehicle placed Nahuel 1A, the first Argentine regional telecommunication satellite, and GE 2, an American communication satellite, into orbit from facilities in Kourou, French Guiana. GE American Communications Inc. (GE Americom) of Princeton, New Jersey, has taken an additional 10 percent ownership interest in Nahuelsat S. A. of Buenos Aires, making it the largest shareholder in the Argentine regional system with a 27.25 percent share of ownership.

Also in January 1997, a trade agreement between Thailand and Canada produced a Memorandum of Understanding by which Samart Cable Systems of Bangkok will distribute Norsat of Canada's electronic products throughout Southeast Asia and Thailand. At the same time, Telesat of Canada agreed to control and operate the Asia Broadcasting and Communications Network's L-Star satellites for 18 months following launch, and to provide training on satellite operations for ABCN personnel.

In early February it was announced that MacDonald Dettwiler & Associates Ltd., of Canada, would construct a remote sensing earth station in South Korea to receive, process and archive data from the Canadian Radarsat and from India's IRS-1C satellite. Terra-Systems of Honolulu, Hawaii and Spot Image Corp. of Reston, Virginia were licensed as non-governmental customer distributors of Radarsat imagery in the United States. Lockheed Martin of Bethesda, Maryland is the designated Radarsat data deliverer for US government customers.

Also in February it was announced that the French Spot Programme will begin in 2002 to sell imagery with a resolution of 2.5 metres on a commercial basis. The government of France will reserve authority to control high resolution imagery in instances involving political or military conflict. This policy of potential controls is not expected to adversely affect Spot commercial sales.

In February the German Aerospace Research Establishment (DLR) and the Aerospace Institute of the Technical University of Berlin announced a contract awarded in late 1996 to Cosmos USA for a satellite launch from Russia's Plesetsk Cosmodrome in late 1997. The satellite, the DLR-Tubsat, is a space and Earth observation platform with cameras for television and still pictures. The satellite can track objects in space, such as stars and orbital debris, and is capable of delivering ground imagery. The satellite will be a secondary payload being launched with a planned Russian military spacecraft.

On 6 February 1997 NASA and the Commonwealth Scientific and Industrial Research Organization of Australia agreed to use common computing and communication systems to exchange satellite data of the Earth collected by NASA's Mission to Planet Earth Program. The agencies will use a super library catalogue (the Information Management System) in compiling millions of data bits to help develop better climate prediction models. NASA is investing nearly $1 billion to provide communication and computing methods to confirm and transform data into useful information products to be available to scientists studying global climate change.

In February 1997, ESA and eight European space companies agreed to support a study of whether or not ESA can build a lunar lander to explore the Moon's south-polar region in 2001. The study is to be coordinated through the European Space Technology Centre in Noordwijk, Holland by ESA astronaut Wubbo J. Eckels.

Also in February it was announced that three Iranians and two North Koreans were among 14 graduate students from nine Asian countries arrived in Ahmedabad, India to participate in the first United Nations sponsored graduate study in satellite communications and space technology. The Indian Space Research Organization (ISRO) hosted the course, which coincided with a joint UN /ESA workshop on tele-detection and training via satellite. The training course ended in late April.

On 2 March 1997, NASA announced its 26 February selection of 16 new members of the Mars Pathfinder team from 60 proposals received earlier by NASA. The new team members will study the martian surface, composition of the atmosphere, and prevailing martian weather patterns. The new team members are from Denmark, Germany and the United States.

Expansion of the internationalization of launch services and the diversity of satellite system owners was manifest in the announced 1997 launch schedule of the Russian Proton launch vehicle. Planned launches, announced in March, included: national and international communication satellites, multi-satellite low earth orbit payloads, a direct broadcast satellite for a European customer, and later, additional national and regional communication satellites. One market analyst firm estimated in March that more than 250 satellites valued at more than US$35 billion would be launched to geostationary orbit from 1997 to 2006.

On 5 March 1997 ESA and NASA reached an agreement in principle for ESA to provide additional hardware and services for the International Space Station in exchange for NASA providing a launch of the European Laboratory Module, the Columbus Orbital Facility, on the Space Shuttle. In addition to committed elements, under prior existing agreements, ESA will provide Node 2, the interface between the European and Japanese laboratory modules, at the end of 1999 for launch in early 2000. ESA's Node 3 will be delivered in early 2002. ESA has also agreed to provide various types of freezers for use aboard the space station.

On 10 March 1997 the British National Space Centre signed a memorandum of understanding with the Indian Space Research Organization (ISRO) to collaborate on several areas of satellite Earth observations that are anticipated to lead to commercial benefits. The cooperative agreement was signed at the ISRO headquarters in Bangalore, India.

On 11 March 1997 WEU's 10-nation Assembly announced it had requested the WEU satellite centre in Torrejon, Spain, to monitor the armed rebellion in Albania. The request must be approved by the WEU Council. The Assembly asked the Council to give the centre the necessary means to accelerate its operating procedures.

The following day on 12 March 1997, the Société Europeenne des Satellites (SES) and the computer chip manufacturer Intel announced their formation of a joint venture named European Multimedia Satellite Services S. A. The company will deliver multimedia services to personal computers via satellite. The Luxembourg-based SES, which owns the Astra fleet of direct-broadcasting television satellites, holds a majority share of the new company.

At a meeting held in Washington, D. C. On 13 to 18 March 1997, the Intelsat Board of Governors approved a change of Intelsat policy to remove restrictions on Intelsat members working with private companies competing with Intelsat in international telephone services. To become effective the policy must be approved by a later meeting of the Intelsat Assembly of Parties.

On 14 March 1997, following a week of joint meetings in Toulouse, France, the Norwegian Space Centre announced that French and Norwegian space companies will begin cooperative projects on Earth observation, in telecommunications and in other areas of space activity. Both France and Norway have made Earth observation funding a priority in their respective national space programmes.

From 17 to 19 March 1997, ESA hosted the Second European Conference on Space Debris at the European Space Operations Center (ESOC) in Darmstadt, Germany. The conference was co-sponsored by Agenzia Spaziale Italiana, The British National Space Centre, Centre Nationale d'Études Spatiales, the Deutsche Agentur für Raumfahrtangelegenheiten, and the International Academy of Astronautics. Proceedings were published by ESA. The participants included 200 experts from 18 countries. The conference provided an opportunity for experts from around the world to exchange information about and their experience with the creation, tracking, management and mitigation of space debris.

China announced in March that it will use an American data processing system, to be built by Hughes STX Corp., of Vienna, Virginia, at its China Centre for Resources Satellite Data and Applications, in Beijing, to process data collected by the China-Brazil Earth Resources Satellite scheduled for launch in 1998.

Later that month, on 24 March 1997, a published programme notice announced that NASA will obtain four sounding rocket launches from Norwegian spaceports in December 1997. NASA's Goddard Spaceflight Center has arranged for launches of a Terrier Orion and a Black Brandt 12 from Norway's Andoya Rocket Range, and 2 Black Brandt 9 launches from the new Norwegian range at Ny-Alesund in Svalbard. Launch services will be provided by the Norwegian Space Centre of Oslo.

In early April, it was announced that Hughes Network Systems and Deutsche Telekom AG had joined European Satellite Multimedia Services S. A. of Luxembourg. Astra satellite system owner, Société Europeenne des Satellites retained a majority ownership share of the multimedia system planned to provide services via satellite to personal computers.

On 11 April 1997, French CNES officials said that in addition to the need for military awareness of satellites, the European community needs to have an independent capability to track orbital debris. France is proposing that Europe create an independent space surveillance system with the capability of tracking orbital objects. This would end a decades-long dependence on non-European space tracking and monitoring capabilities.

On 16 April 1997 Arianespace successfully launched two new communication satellites from the Kourou Space Centre in French Guiana. Thaicom 3, owned by Shinawatra Satellite Co. of Bangkok, and BSat-1a, a Japanese direct-broadcasting satellite, were launched on an Ariane 44LP, the 24th consecutive successful launch of the Ariane 4.

Later that month, on 18 April 1997, ESA announced that NASDA and ESA had agreed to cooperatively launch and use Europe's Artemis satellite, a data relay satellite, which will be used by Japan and ESA to communicate with low Earth orbit satellites and with the International Space Station. Japan will launch the Artemis satellite on an H2A rocket in 2000.

On 24 April 1997 space station managers from the United States and Russia met in Moscow for a critical design review of the Russian hardware contribution to the International Space Station. After several months of uncertainty about Russian funding of the project, Russian program personnel assured NASA that the program was funded and that the hardware would be delivered on time for a December 1998 launch.

In June, it was announced that the Commission of the European Union will help finance a program of cooperation between European and Russian space agencies. Information will be exchanged relating to international space law, space programme management and industrial contracts of interest to the parties. Russia will share expertise on space transportation and manned spaceflight. A series of joint seminars is planned to begin in the fall of 1997 at the International Space University in Strasbourg, France.

Also during June the 17-nation Eumetsat Organization, Europe's weather satellite organization, and Roshydromet of Moscow agreed to exchange data from their geostationary meteorological satellites. Eumetsat operates the Meteosat system and Roshydromet operates the GOMS-Elektro spacecraft along with three polar orbit Meteor satellites. The organizations also agreed to more frequent meetings to share scientific and technical data.

On 7 July 1997, a principal investigator of Canada's Thermal Plazma Analyzer (TPA) reported that the Canadian Space Agency will contribute the PTA experimental hardware to fly on Japan's Planet-B planned 1998 mission to study the Martian atmosphere.

The TPA will perform a series of measurements supporting Japanese and United States experiments on the Mars orbiter, expected to reach Mars in December 1999.

In early August it was announced that the 45-nation EUTELSAT Organization took charge of France's TDF-2 television satellite to transfer it to a more easterly orbital position where it will be used to serve the Russian satellite television market. The TDF-2, originally launched for France Telecom in 1990, is expected to remain in service until 1999.

On 2 September 1997, the US Information Agency announced plans to enter into a leasing arrangement with INTERSPUTNIK of Russia to broadcast Voice of America programming in the territories which comprised the former USSR. INTERSPUTNIK operates a system capable of reaching all of the former Soviet Republics. INTERSPUTNIK operates Russian satellites today, but starting in late 1998 INTERSPUTNIK's space segment is planned to be replaced with more advanced satellites built by the Lockheed Martin Corporation of the United States.

On 11 September 1997 Hughes Space and Communications International Inc. agreed to invest in the United Arab Emirates-based Thuraya Satellite Telecommunication project. Other owners include Abu Dhabi Investment Co., the ARABSAT Satellite Organization in Riyadh, Saudi Arabia, and state-owned telecom authorities in Bahrain, Egypt, Lybia, Morocco, Qatar and Tunisia. The Thuraya project is managed by the Emirates Telecommunications Corp. (Etisalat). On the same day, Hughes and Etisalat entered into a contract that requires Hughes to build an operational satellite system, including 2 satellites, necessary ground stations, launch support, and mobile telephones to work with the satellites. The contract is estimated to have a value of at least $1 billion. The first satellite launch is planned for May 2000 on a launcher to be selected.

On 19 September 1997 during a meeting on the island of Aruba, north of Venezuela, Inmarsat's Council reached a broad consensus on plans to privatize the treaty-based, 81-nation, global mobile satellite organization. The Council authorized hiring an investment banking firm in 1998 to prepare a public stock offering in 2000. The privatization plan will have to be approved by the Inmarsat Assembly of Parties, which will meet in April 1998.

From 6 to 10 October 1997, the International Astronautical Federation (IAF) of Paris, France, conducted its 48th International Astronautical Congress in Turin, Italy, with more than 1400 participants from more than 40 nations. Twenty-one agencies and companies were elected new members, bringing the Federation membership to 147 organizations. The next annual Congresses are planned to be held in Melbourne, Australia, in 1998, Amsterdam, The Netherlands, in 1999, and in Rio de Janeiro, Brazil, in 2000.

On 14 October 1997 NASA and the Brazilian Space Agency signed a Memorandum of Understanding which commits Brazil to contribute as much as US$120 million in hardware to the international space station over the next five years. Brazil will have the opportunity to send an astronaut to the station and a candidate astronaut could begin training with a NASA class as early as July 1998. Brazil could provide a Window Research Observational Facility, which would allow optical experiments to perform Earth observation, and an unpressurized logistics container to house experiments outside the space station.

On 23 October 1997 a Russian Photon capsule landed successfully in Kazakhstan to end a two-week mission in low Earth orbit. The mission included microgravity experiments from European, French and German space agencies. The mission included a German Mirka re-entry experimental capsule, which had separated from the Photon capsule while in orbit and landed near-by the Photon.

On 21 November 1997 the Brazilian Space Agency and the Russian Foreign Ministry signed an agreement to replace a 1988 agreement between Brazil and the former USSR. The agreement calls for cooperation in which the Russian experience in satellite launching and in space research could be used to help the Brazilian development of its national space programme. The new agreement is expected to play an important role in strengthening economic relations between the two countries.

On 26 November 1997 the ARABSAT Consortium sold one of its on-orbit satellites to the Indian Department of Space for a reported $40 million. ARABSAT 1C, launched in 1992, will be relocated by January 1998 to an orbital location reserved for an Insat satellite. The satellite has an estimated 5 years of operational life remaining. The Insat 2D, which was launched on 1 July 1997, failed in October. The ARABSAT satellite will restore the Insat service capacity lost in Insat 2D.

On 28 November 1997 Germany agreed to finance a share of a one year study of a possible future European military telecommunication system. Trimilsatcom would be backed by France, Germany and the United Kingdom to replace the existing French and British military communication satellites after 2000.

Space Law

On 18 July 16 space insurance companies filed suit against Canada's Spar Aerospace for the $66 million claim they paid for the AMSC-1 mobile communications satellite that failed in April 1995 a month after its launch, plus another $69 million in damages sustained by AMSC following the failure, plus unspecified punitive damages. The lawsuit alleges that Spar's tests of the automatic level control circuit in the satellite's power amplifier, conducted on 23 June 1992, revealed the circuit's inability to limit the power of the overdrive signals that are normally used by ground controllers during periods of heavy activity, which would cause the power amplifier to overheat and fail. The lawsuit further alleges that Spar's test report, filed on 29 June 1992, stated that the circuit met all the overdrive specifications. The claimants withdrew an earlier lawsuit in December 1996 to give Spar an opportunity to settle their claim out of court, but in May Spar refused any settlement on the grounds that the satellite's failure was caused by its ground controllers' excessive use of overdrive, and that Spar had no responsibility whatsoever for the failure.

On 11 December 1996 Equatorial Guinea became the 140th member nation of the Intelsat consortium. Equatorial Guinea, in west Africa, has used Intelsat services since 1985.

On 14 February 1997, at an International Telecommunication Union (ITU) convened workshop in Geneva, Switzerland, 42 nations and 20 industry representatives agreed to a Memorandum of Understanding (MOU) that calls upon states to minimize the regulation of satellite voice and data terminals, as a means of facilitating expansion of worldwide, integrated communication services via satellite. The MOU urges States to reduce the red tape and customs related to approving the manufacture, licensing, sale and use of satellite terminals used in international communications. The MOU is non-binding. A project team was formed to work further on means of facilitating travel with mobile terminals. The team will address standardization and certification of terminals, customs arrangements, licensing and other issues involved. The licensing team leader is Pekka Lansman of Finland's Telecommunications Administration Centre in Helsinki.

On 15 February 1997, at a meeting held at the World Trade Organization in Geneva, Switzerland, many of the world's largest and economically developed countries signed a trade agreement that is expected to increase competition in the telecommunications market. In November of this year, in Washington, D. C., the United States Federal Communications Commission Chairman, in announcing federal rules to implement the WTO agreement, stated "what these orders do is put a framework in place to make telecommunication services more available throughout the world."

Also in February 1997 Nahuelsat S. A. of Buenos Aires, Argentina announced signing of a landing rights agreement with Antelco, the telecommunications company of Paraguay, which will allow Nahuelsat to offer satellite communication services in Paraguay. Nahuelsat has similar agreements with Brazil, Chile, Mexico and Uruguay.

At a 4 March 1997 meeting in Paris, ESA's Member States agreed to relax the rules controlling contractor selection in ESA funded programs. Rule revisions will allow ESA management in the future to put greater emphasis on traditional contractor selection criteria of price, quality and timely delivery, and to be less constrained by considerations of the nationality and national locations of contractors. The members also agreed to measures to assure reasonable fairness in competition between smaller contractors and large aerospace conglomerates; and to urge ESA to invest in areas of commercial interest to Europe's space industry.

On 23 June 1997 Hughes Space and Communications International, Inc. filed a US$550 million lawsuit in Los Angeles, California alleging that Lockheed Martin Corp.'s commercial launch affiliates agreed to provide Russian Proton rocket launches for a fixed price, then later demanded a far higher price for the services. A Lockheed Martin spokesperson dismissed the claim as "without merit."

On the subject of litigation, on 21 July 1997 the Canadian company Spar Aerospace filed suit in Federal Court in Ottawa claiming the Canadian government owes the company more than $800 million (Canadian) in unpaid contract fees for work done on the MSat-1 mobile communication satellite programme. The Government claims it is withholding payment to Spar to offset funds owed to the Government by Spar for other work. There is a dispute over whether or not Canadian law allows such cross-charge fund withholding.

On 18 July 1997, at a meeting concluded at the ITU headquarters in Geneva, 120 industry and government representatives agreed to reduce constraints on international use of mobile telephones. Licensing telephone and data transceivers and carrying them across borders should be easier, as customs duties on satellite telephones will be phased out. Satellite system operators agreed to inform governments about the origin and receipt of calls in their respective national territories. More than sixty nations signed the agreement.

Later that month on 24 July 1997, at a signing ceremony in London, Hungary became the 81st member of the International Mobile Satellite Organization (Inmarsat). Inmarsat had already begun a project with Hungarocamion, a Budapest-based trucking firm, equipping 50 trucks with Inmarsat-C satellite Messaging terminals. The trucks operate throughout Europe, Russia and the

Middle East.

On 5 September 1997, Mongolia became the 142nd member of Intelsat. The Mongolian Telecommunications Co., Ulaanbaatar, the designated Signatory for Mongolia, has a .05 percent investment share.

Crowding of geostationary orbital slots in the Asian region in 1996 led to the jamming of a communication satellite by PT Pasifik Satelit Nusantara (PSN) of Jarkarta, Indonesia, in defence of an orbital position claimed by Indonesia. This incident focused global attention on a worsening problem of orbital crowding and caused the matter to be brought before the October-November 1997 World Radiocommunication Conference (WRC) of the 187 member-nation ITU in Geneva. The conference began in Geneva on 27 October and concluded on 21 November 1997. The conference decided to reduce the period for which orbital locations would be reserved for a notified satellite to seven years from nine years, but did not otherwise restrict current satellite filing practices. The Conference declined to establish a substantial filing fee as a means of defeating frivolous filing of satellite reservations.

Two other major conference issues involved sharing of radio frequencies between low Earth orbit (LEO) satellites and satellites in the geostationary orbit (GSO), and an effort to begin frequency sharing for and possible reduction of frequencies dedicated to global navigation satellites to accommodate more mobile satellite frequency usage. The issues were debated at length and ended in agreements to accept sharing of frequencies between LEO and GSO satellites, but preserving for the time being the frequencies allocated to global positioning system satellites. The latter issue will be revisited in 1999, when the decision to permit LEO and GSO sharing will also be reviewed.

In 1997, the International Institute of Space Law (IISL) continued both to develop the substantive law of outer space and to disseminate knowledge about space law. The major formal framework of the IISL's work is its annual Colloquium at which papers on space law matters are presented and discussed. The 40th Colloquium was held, as usual, in conjunction with the annual Congress of the International Astronautical Federation, which took place in Turin, Italy. The subjects covered at the Colloquium included the Background and History of the Outer Space Treaty, Concepts of Space Law and the Outer Space Treaty, the Applications and Implementation of the Outer Space Treaty and Future Applications of the Outer Space Treaty.

The Sixth Manfred Lachs Space Law Moot Court Competition held on 9 October at the IAF Congress and dealing with commercial Very High Resolution remote sensing systems was won by the team from the University of Paris XI, Sceaux.

In cooperation with the European Centre for Space Law (ECSL), the IISL organized a Symposium for the benefit of delegates to the 1997 session of the Legal Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS), on "Celebrating the 30th Anniversary of the Outer Space Treaty."

PART TWO: PROGRESS OF SPACE RESEARCH IN 1997

SPACE STUDIES OF THE EARTH'S SURFACE, METEOROLOGY AND CLIMATE

Satellite Programs

Meteosat-7, the last satellite of the first generation Meteosat series, was launched on 2 September 1997 aboard an Ariane-4 launcher. Commissioning activities started on 8 September 1997 and will take around three months before the satellite is declared operational. First image acquisition was successful on 18 September 1997. Meteosat-6 has been the operational spacecraft since 13 February 1997, replacing Meteosat-5, which is now used as in-orbit backup.

The National Oceanic and Atmospheric Administration (NOAA) Geostationary Operational Environmental Satellite 10 (GOES-10) was launched on 25 April 1997. After attaining orbit it was discovered that the mechanism for rotating the solar panel was not working properly. However, the array could be rotated in the reverse direction. By inverting the spacecraft, images of the Earth could be attained, indicating that the spacecraft could perform its mission with appropriate ground software modifications. GOES-10 is in storage as a backup to GOES-8 or -9.

NASDA launched the Advanced Earth Observing Satellite (ADEOS) on 17 August 1996 and acquired data from observations of land, ocean and atmosphere until 30 June 30 1997. ADEOS carried the AVNIR instrument (Advanced Visible and Near Infrared Radiometer), an instrument suited to land surface studies due to its high spatial resolution (multispectral band: 16m, panchromatic band: 8m). AVNIR has acquired 32,669 multi-images and 19,091 pan-images. NASDA has been developing thematic maps, such as digital elevation models, agricultural classification, urbanization and land use. These data will be used to retrieve evapotranspiration and surface water runoff. The other scanner, Ocean Colour and Temperature Scanner (OCTS), could measure the land surface with medium spatial resolution (700m) and high spectral resolution (10nm). OCTS covered the whole globe in three days, therefore these data are used to develop vegetation change/indices of seasonal and annual variations. Unfortunately, ADEOS operation was terminated by a solar paddle accident. Eight months of data (7,445 overpasses) are available, but this is not sufficient for these studies. ADEOS carried eight sensors and much scientific study has been conducted by using multiple sensor data for climate studies. A combination of OCTS (sea surface temperature and chlorophyll concentration) and NSCAT (NASA Scatterometer for ocean surface wind vector measurement) data can be used for climate variability studies by estimating air-sea interactions. NASDA and selected principal investigators are now keen to develop new data-sets for climate study researchers over the world.

The Geostationary Meteorological Satellite (GMS) series has been developed in Japan to contribute to meteorological service improvement. It plays an integral part in the world-wide program of the WMO, providing one of the five geostationary satellites implementing a meteorological satellite network for global observation. GMS-5 was launched by H-II rocket in March 1995 and is now operated routinely by the Japan Meteorological Agency.

TOPEX/Poseidon, the U.S.-French altimeter mission, is still fully operational more than five years after launch. It collects measurements of unprecedented accuracy on ocean topography, circulation, tides and mean sea level.

SPOT-3 failed in November 1996. CNES and SPOT IMAGE reacted to this situation by reactivating SPOT-1, anticipating the launch of SPOT-4 (March 98), and by special agreements with direct receiving stations.

The first Chinese geostationary meteorological satellite, FY-2 has been launched successfully and positioned in 105 degrees E, in June 1997. The major payload of FY-2 is a three-channel scanning radiometer observing Earth's disk in visible, micrometer and thermal infrared wavebands. The nadir resolution is 1.25, 5, and 5 km, respectively. FY-2 has also a space environment unit consisting of particle and X-ray monitors. FY-2 will distribute the cloud images and meteorological information to users.

Future Satellites

The Meteosat Second Generation (MSG) project is in Phase C/D (detailed design and building) with the first satellite, MSG-1, scheduled for launch in 2000.

The EUMETSAT Polar System (EPS) program is still in the approval process. The METOP satellites will form the space segment of this program. METOP Phase B studies have been completed under ESA responsibility, and a joint Request for Quotation for Phase C/D has been released by ESA and EUMETSAT.

As part of the EPS, EUMETSAT is including an Ozone Satellite Applications Facility, for which the Finnish Meteorological Institute has been chosen to coordinate a pilot project. EUMETSAT and ESA have agreed to fly an Ozone Monitoring Instrument (OMI) on the series of METOP satellites scheduled for the first decade of the next century. Finnish scientists have been involved in identifying and detailing requirements for OMI.

EUMETSAT's Microwave Humidity Sounder (MHS) is in Phase C/D (detailed design and building) with the first instrument to be delivered in 1998. MHS will fly on the NOAA-N, N' satellites and on the METOP series of spacecraft.

NOAA plans to launch the polar-orbiting satellite NOAA-K in February 1998. NOAA-K will for the first time fly an Advanced Microwave Sounding Unit (AMSU) instrument that will significantly improve atmospheric temperature and water vapour soundings in clear and cloudy regions and provide new surface and hydrological products. The Advanced Very High Resolution Radiometer (AVHRR) on NOAA-K has also been modified to include a 1.6 micrometer channel to provide improved discrimination between cloud and snow during the daytime.

The National Polar-orbiting Operational Environmental System (NPOESS) Integrated Program Office (IPO) announced the award of Phase 1 (Program Definition and Risk Reduction) contracts for five of the planned NPOESS payload sensors as follows: the Conical Microwave Imager Sounder (CMIS), Visible/Infrared Radiometer Suite (VIIRS), Cross Track Infrared Sounder (CRIS), Ozone Mapping and Profiler Suite (OMPS), and Global Positioning System

Occultation Sensor (GPSOS). NPOESS is the merged U.S. Department of Defence/NOAA polar environmental satellite programs planned for operation toward the end of the next decade.

The Tropical Rainfall Measuring Mission (TRMM) is a joint project between Japan and the United States. TRMM is the first space mission dedicated to quantitative measurements of tropical and subtropical rainfall which is one of the most important and least known parameters affecting the global climate system. TRMM was launched on 14 November 1997 by H-II Japanese rocket into a 350 km altitude and 35 degree inclination orbit. It carries five instruments: Precipitation Radar (PR), Visible Infrared Scanner (VIRS), TRMM Microwave Imager (TMI), Clouds and Earth Radiation Energy System (CERES), and Lightning Imaging Sensor (LIS).

SPOT-4 is planned to be launched in March 1998. Its primary high resolution imagery mission will benefit from and upgraded imager, the HRVIR, equipped with an additional 1.7 micrometer channel and from the doubling of the recording capacity. SPOT-4 will also carry a highly accurate positioning system, DORIS, an ozone instrument, POAM-3 (a follow-up to POAM-2), and the VEGETATION payload, a wide-field-of-view medium-resolution imager providing co-registered measurements in the same bands as HRVIR. VEGETATION is a cooperative program of the European Commission, France, Belgium, Sweden and Italy. The continuity of the SPOT service will be ensured with SPOT-5 scheduled for launch in 2002. Just like the previous four SPOT satellites, SPOT-5 is a cooperative effort between France, Sweden and Belgium and represents an improvement over SPOT-4 with an increased resolution (10 m multispectral and high resolution panchromatic mode, with a 2-3 m resolution).

In a move to develop operational oceanography, a series of small satellites dedicated to altimetry will be implemented through a CNES/NASA programme. It will ensure continuity of the TOPEX/Poseidon measurements at the same level of performance. The first one, Jason-1, is scheduled for launch in May 2000. Jason-2 is under consideration.

The Chinese polar orbiting meteorological satellite project FY-1 series is continuing. Following the previously launched FY-1A and -1B, FY-1C and -1D are actively being prepared. The channels of the scanning radiometer on board these satellites will be increased to 10: seven in the visible and near-infrared and three in thermal infrared.

The second generation of the Chinese polar orbiting meteorological satellite project, FY-3, is planned. FY-3 will have several payloads, including a modified Chinese-AVHRR atmospheric sounder, MW radiometers for cloud and rain as well as an Earth radiation budget unit and an ozone monitoring unit.

A Chinese Ocean Colour Satellite is being actively planned. It is a small satellite with an ocean colour sensor as the major payload.

Several Earth observing sensors are being developed for different space platforms in China. Among them are an L-band space-borne SAR (Synthetic Aperture Radar) with multi-observation modes, a space-borne multimode MW sensor consisting of an altimeter, a scanning scatterometer and a six-channel radiometer, and space-borne imaging spectrometers. Air-borne versions of these sensors have been developed and applied to various research and application projects in the last five to 10 years. In addition, space-borne sensors for the monitoring of solar input, Earth radiation budget and atmospheric ozone are being developed. A stratospheric balloon-borne observation with solar irradiance and UV (ultraviolet) sensors was successfully made in August 1997.

Pakistan is currently developing its second small experimental satellite, BADR-B, that is designed for Earth observations, cloud monitoring and some scientific experiments. It is expected to be launched by a Russian launcher sometime in the next two years.

Odin is a Swedish-led small satellite mission with a joint aeronomy and astronomy program, scheduled to be launched in the latter half of 1998. In addition to Swedish industry and research groups, Canadian, French, and Finnish groups are involved. In the aeronomy mode of operation, an UV-visible instrument (OSIRIS) and a sub-millimetre radiometer (SMR) are used in limb-viewing mode to study the upper atmosphere, especially processes related to ozone creation and destruction.

After the launch of its first satellite in February 1993, Brazil is now preparing for the launch of two other Data Collection Satellites, the SCD2 and the SCD2-A. They will replace the first satellite, SCD1, which continues to operate after having surpassed its expected life-time by more than three years. The SCD2-A was scheduled for launch in September 1997 and SCD2 in 1998. The main purpose of the SCD series is to receive and transmit environmental and meteorological data, which are collected from automatic platforms strategically placed at several remote sites within the country. The satellites and platforms are part of a larger program, called the Brazilian Complete Space Mission.

Within the same program, Brazil is also developing two small-range remote sensing satellites named SSR1 and SSR2. They should be completed by 2001 and 2003, respectively. These satellites will prove extremely valuable for continuous monitoring of the Amazon region.

Brazil is also developing a middle-range remote sensing satellite with China, which is programmed for launch in July 1998. This will be deployed in a Sun-synchronous orbit with an altitude of 778 km and an expected life-time of two years. It will offer global coverage in cycles of 26 days, with nine spectral bands and a maximum spatial resolution of 20 metres.

In the scientific field, Brazil is developing a micro-satellite called SACI-1, which was to be built and tested by the end of 1997. The payload is composed of four scientific experiments, which are being developed in cooperation with research organizations from the United States, Japan and France.

The Netherlands is preparing its first major satellite experiment on atmospheric chemistry, SCIAMACHY. In 1996 Space Research Organization Netherlands (SRON) completed its contribution to the SCIAMACHY instrument hardware, i.e. the detector modules covering eight spectral channels from the near ultraviolet into the near infrared. After assembly with the flight model spectrometer hardware, a lengthy process of calibration and characterization has commenced, running far into 1997. SRON also maintains the Instrument Simulation Software, which is a crucial tool for assessing the proper pre-flight and in-flight operation modes.

In 1996 SRON started efforts for the participation in the Gravity Field and Steady State Ocean Circulation Explorer (GOCE). SRON is presently preparing for involvement in the gradiometer readout system, a closed loop simulation system for the instrument/satellite/environment combination and elements for the GOCE science data centre. In this way SRON wants to become involved in the phase A study for this mission.

Preparations have been started at SRON to develop a far-infrared balloon-borne spectrometer for measurement of the important OH-radical and additional species like HCl, H_2O and possibly HBr. This experiment also serves as a test-bed for a high Tc-bolometer (90K) far-infrared sensor, which potentially offers an important advantage of a simple mechanical cooler for satellite applications.

Highlights of Scientific Results

Atmospheric Research and Applications

EUMETSAT's Foreign Satellite Data Relay facility at Lannion, France, was upgraded in May 1997 and now transmits image data from the neighbouring geostationary meteorological satellites GOMS, GMS and GOES-W. These data can be received via the Meteosat satellite.

Calibration of the visible channels of the Meteosat-5 and -6 satellites has been performed using the Matrix Operator Model radiative transfer code. Within the accuracy limits of the calculation, calibration coefficients were found identical for both satellites.

In autumn 1996 cloud motion winds derived from full resolution visible images were introduced as an operational Meteosat product. The high resolution visible winds are derived five times during daylight. This extends significantly the Meteosat wind products range and improves the low-level flow analysis, especially over trade-winds oceans. In December 1996 more than five times as many cloud motion winds were produced as in December 1995.

Also in autumn 1996, cloud-cleared water-vapour black-body radiances were introduced as an operational Meteosat product. The cloud-cleared black-body radiances are derived hourly. The hourly cloud-cleared radiances form the first truly asynoptic Meteosat product that presents a high potential benefit for numerical weather prediction, employing advanced data assimilation techniques.

Prototyping of a clear-sky winds product, derived from free atmosphere water vapour motions, was started in early 1997 and is expected to mature into an operational product.

Product extraction methods for the forthcoming MSG are being prototyped at EUMETSAT, with particular emphasis on radiation models for the short-wave and long-wave spectrum, atmospheric wind vector extraction and scene identification methods. These methods will be transformed into operational software by an industrial consortium. Data-sets from GOES-8 and -9, NOAA and other satellites are used to simulate MSG data.

Research work at the ECMWF on the "Use and Impact of Atmospheric Motion Winds on the Operational ECMWF System" and "Quality Controls for the Special Sensor

Microwave/Imager (SSM/I) Ice Concentration Data" has been sponsored through the EUMETSAT Research Fellowship program.

A EUMETSAT Users Conference was held in Brussels, Belgium, in September/October 1997 to discuss use of data from current satellites and from MSG.

EUMETSAT has become a co-convenor of the Science Groups of the GRAS, IASI and ASCAT instruments that are foreseen as METOP payload. These groups had initially been set up and convened by ESA.

Atmospheric measurements of vertical temperature profiles derived from Global Positioning System (GPS)/Meteorology (MET) observations have been compared with those from the NOAA operational instruments to evaluate the potential of GPS data in numerical weather forecast models. Global differences of about 2K in the altitude region 10–25 km are found when compared with satellite instruments and with ground-based radiosondes. Below 10 km, the differences increase as the surface is approached. This appears to be due to water vapour and horizontal variability in temperature and moisture and from decreasing GPS instrument signal/noise levels. This indicates that complimentary information will likely be needed to make use of GPS data in the troposphere.

The ozone data-set generated from the NOAA-11 Solar Backscatter Ultraviolet-2 (SBUV/2) instrument were reprocessed using the latest in-flight instrument performance history over its six-year lifetime. The data-set of total ozone amount, validated against a set of ground observations, demonstrated a stability of about 0.5 percent over this period. The data set was made available to the WMO UN Environment Program (UNEP) Trends Panel for their current assessment. The data from the NOAA-9 instrument covering the period 1984–96 underwent an initial reprocessing and validation is underway.

In preparation for the 1998 launch of NOAA-K, the current processing system for the Television and Infrared Operational Satellite (TIROS) Operational Vertical Sounder (TOVS) has been modified to eventually be able to process data from the AMSU, which will be on NOAA-K.

Observations of total ozone measurements from NOAA-14 SBUV-2 and/or NOAA-14 TOVS suite of instruments are used by the NOAA/National Weather Service (NWS) to predict the amount of ultraviolet radiation reaching Earth's surface. Forecasts of the amount of ultraviolet radiation reaching the surface with the added effects of elevation and clouds are issued daily as a UV Index. This product has been issued by the NWS since June 1994.

A 3-D global ozone analysis system has been developed by NOAA's NWS. Data to support this analysis were obtained from NESDIS. Ozone was incorporated into the global forecast model, allowing assimilation of the ozone analyses, prediction of ozone distributions and interaction of these distributions with radiative transfer parameterizations. Sources and sinks of ozone are parameterized using the NASA/GSFC algorithms.

The Global Ozone Monitoring Experiment (GOME) aboard ESA's ERS-2 satellite charts the world's ozone every three days, and can also detect the chemical agents that enter the stratosphere and damage the ozone layer. The ERS-2 satellite was launched by ESA on 24 April

1995, being a successor to ERS-1 which has observed the world's oceans, ice and terrain since 1991 using radar and infrared radiation. GOME facilitates the production of routine maps of global ozone and nitrogen dioxide, and images of the Antarctic ozone hole. Weather forecasters are studying the feasibility of issuing sunburn warnings on the basis of GOME's ozone data. However, GOME is only the forerunner of an even more searching atmospheric sensor. A scanning spectrometer SCIAMACHY is under construction and will be launched on ENVISAT in 1999.

Daily global mapping of Earth's ozone layer from space has resumed with the acquisition of the first image from the NASA Total Ozone Mapping Spectrometer (TOMS) aboard the Japanese satellite ADEOS on 12 September 1996. ADEOS continues the series of TOMS total ozone and volcanic sulphur dioxide observations that began with the Nimbus-7 satellite in 1978 and continued through the operation of a TOMS on a Russian Meteor-3 satellite, until that instrument ceased functioning in December 1994. Data from another TOMS instrument flying on the NASA TOMS-Earth Probe spacecraft complements the global ozone data from ADEOS by providing high-resolution imagery of atmospheric features related to urban pollution, biomass burning, forest fires, desert dust and small volcanic eruptions, in addition to ozone measurements.

In October 1996 TOMS instruments have again detected substantial depletion of ozone levels over Antarctica, commonly referred to as the Antarctic ozone hole. The average size of the Antarctic ozone hole during 1996 was almost as large as in the peak year of 1993, although ozone values were higher than the record lows seen in September 1994.

Real time experimental satellite products for Quantitative Precipitation Forecast (QPF) and flash flood prediction have been developed at NOAA. The family of experimental products include: (1) precipitation estimates that cover the entire GOES image, derived from the GOES Automatic Flash Flood Precipitation Algorithm, (2) precipitable water and precipitation efficiency analyses for detecting precipitable water plumes—a key ingredient for extreme precipitation events, and (3) soil wetness for detecting flooded areas and antecedent ground conditions prior to flash floods. New algorithm development includes multi-spectral techniques using GOES imager visible, infrared and near infrared data. These experimental products are undergoing development and validation, and are available on the NOAA/NESDIS Flash Flood World Wide Web Page at *http://orbit-net.nesdis.noaa.gov/ora/ht/ff/index.html*.

Validation of NOAA s GOES-8 Automatic Flash Flood Precipitation Algorithm (known as the Auto-Estimator), has shown that this algorithm works best for moving relatively small [smaller than Mesoscale Convective Complexes (MCCs)], cold top (colder than -62 degrees C) convective systems. Overestimates in both area and amount occur for quasi-stationary MCC-type systems. Planned improvements to the Auto Estimator include: (1) the ability for the analyst to adjust the rain rate-cloud top temperature relationship for warm top heavy precipitation systems, (2) the incorporation of visible imagery, (3) the use of Doppler radar data to discriminate between rain/no rain areas, and (4) implementation of an orographic adjustment factor.

Blended precipitable water products for detecting areas and plumes of moisture have been made available by NOAA for the continental United States. This blended product is composed of SSM/I, GOES-8/9, and Explosive Transfer Assembly (Eta) forecast model derived. A Precipitation Efficiency Factor that is computed by multiplying the blended precipitable water by the blended relative humidity (1000–500 mb) is also available. These products are being used with other data in the development of a quantitative precipitation forecasting technique.

GOES precipitable water data have been tested in the optimum interpolation analysis system at 80 km (GOES-8 only) and at 48 km (GOES-8 and GOES-9) in a parallel system to NWS's operational early Eta system. Positive results, though small, have justified the implementation of GOES-8 and GOES-9 precipitable water values in the early Eta. Precipitable water values for three layers and the total atmosphere are used.

NOAA NWS's new 3D-VAR (variationally based) analysis has also been used to successfully test GOES-8 and GOES-9 precipitable water. In addition, preliminary efforts are underway to test the direct use of GOES sounding radiances in the 3D-VAR.

Real-time experimental Microburst Image Products have been developed by NOAA. These products aid in the determination of conditions favourable for convective microbursts (or down bursts). GOES-8/9 temperature and moisture soundings are used in the derivation of these products, which include both an estimate of the maximum possible convective wind gusts, and one which estimates the likelihood of dry (low precipitation) microbursts. These products are available on the Internet at *http://orbit-net.nesdis.noaa.gov/ora/fpdt1/index.html*.

NOAA has developed real-time experimental GOES-8/9 soundings and high-density wind estimates. The sounding products provide hourly temperature and moisture information for much of North America and adjacent ocean areas. Each sounding represents a vertical atmospheric profile of temperature and moisture from Earth's surface through the stratosphere. High resolution atmospheric stability parameters are also derived from the soundings, which provide localized, regional guidance for severe weather forecasting activities at the NWS and other agencies. High-density wind estimates are produced from GOES-8/9 satellite data at three hourly intervals for the Northern and Southern Hemispheres, and represent the primary source of atmospheric wind flow data over the Atlantic and Pacific oceans, as well as much of Central and South America. These data are extremely useful in determining steering currents in the tropics, and have been shown to improve the accuracy of hurricane track forecasts in several cases. The GOES-8/9 sounding and wind products are available on the Internet at *http://orbit7i.nesdis.noaa.gov:8080/goes.html*.

Numerous Super Rapid Scan Operations (SRSO) data sets have been archived by NOAA for both GOES-8 and GOES-9 satellites. The imagery is being used in research projects involving severe storm and hurricane development and landfall, lake effect snow studies, volcanic ash detection and special experiments.

An extensive series of tests on GOES high density cloud-track and water vapour track winds has been conducted by the NWS, which resulted in improvements in satellite wind processing.

Since 1990, NOAA has been producing weekly composite maps of aerosol optical thickness over the global oceans. Aerosol optical thickness is a measure of the atmospheric content of fine particles. The larger the aerosol optical thickness, the greater the concentration of aerosol particles in the atmosphere. These particles interact with sunlight, producing a haze which reduces horizontal visibility at Earth's surface. They are created naturally by wind action on ocean and land surfaces, and by biological processes. They also are generated by man as a by-product of fossil fuel combustion and from biomass burning practices in agriculture. The latter example was prominent in the news in 1997 with the unprecedented numbers of fires burning out of control on the islands of Indonesia. The extensive smoke veil from these fires, covering an oceanic area, was successfully monitored by this satellite product.

Due to a good choice of spectral channels and high resolution, AVHRR data are used widely for different purposes. T. Nakajima, A. Higurashi and K. Kawamoto (Japan) have found that the retrieved cloud particle radius takes small values over large continents and large over ocean areas. This feature is, however, significant only with low warm water clouds with cloud top temperature larger than 270 K and not so noticeable with higher level clouds with top temperature between 250K and 270K. As for aerosol retrievals, it is found that the largest contribution in optical thickness field is from soil-derived aerosols from arid areas such as the Sahara and Middle East. It is found that the Angstrom exponent, which is a shape index of the aerosol size distribution, increases near large city areas. This suggests that the Angstrom exponent from AVHRR is a good index of small particles generated by gas-to-particle conversion in air masses affected by man-made pollution.

The NOAA operational single channel AVHRR optical thickness product has been validated against surface Sun-photometer data observed during the Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX) in July 1996. This is a project of the International Global Atmospheric Chemistry Program of the IGBP. The AVHRR product was within 10 percent of the surface observed optical depths at a wavelength of 0.63 microns. The experimental product of optical depth from channel 2 of AVHRR was biased high by up to 40 percent. Reasons for this high bias are being explored with aircraft in situ data.

The Clouds from the AVHRR (CLAVR) project has completed a one month demonstration of phase 3, which uses dynamic cloud/no-cloud thresholds to reclassify ambiguous classifications from CLAVR-Phase 1. Results from CLAVR-3 show that clear pixel populations are 80 percent larger than from CLAVR-1. All afternoon AVHRR data sets (five channel instruments) from 1981 to the present have been reprocessed by NOAA with atmospheric parameter retrieval algorithms. Products archived include cloud/clear radiances, total cloud amount, Earth radiation budget parameters, and aerosol optical thickness over oceans. Time series analysis of the aerosol optical thickness clearly depicts the El Chichon and Mt. Pinatubo volcanic eruptions, as well as the biomass burning over Indonesia in 1997. Time series of cloud amount show the influence of the El Niños during the past decade, which should help in the analysis of the 1997 super El Niño. The anomalies in Earth radiation budget components will be similarly studied, especially the outgoing longwave radiation flux. Evaluation of the 17-year data set is planned for 1998. Corrections will be applied where necessary, and a detailed analysis performed.

A vicarious technique to provide monthly calibration updates for the visible and near-infrared channels of the AVHRR on the NOAA-14 satellite was made operational by NOAA in November 1996. Previously, these channels had never been routinely calibrated after the launch of any AVHRR, because the AVHRRs do not carry calibration targets for them on orbit. The new calibration technique makes use of a combination of desert targets on Earth whose reflective properties are believed to be constant in time. It is termed vicarious because it relies on targets outside the satellite. Users of data from these channels of the AVHRR, primarily scientists studying Earth's land surface and atmosphere, have commented that the new calibration information has been very helpful.

AVHRR data are also used to retrieve thermal infrared emissivity of the land surface (Russia), surface insolation (Estonia), surface albedo (Finland) and soil moisture (China).

Substantial progress has been made at several centres on the application of TOVS data in numerical weather prediction. Direct use of radiance data has advanced considerably. Positive forecasts impacts were reported in all latitude zones, with substantial improvements in the tropics. The International TOVS Working Group of the International Radiation Commission plans to prepare and maintain a comprehensive list to document the use of TOVS data at operational numerical weather prediction centers, including the form of the data used (e.g. retrievals, clear radiances, raw radiances).

Inaccuracies in radiative transfer modelling are still significant sources of error affecting the use of TOVS data in numerical weather prediction. Radiation transfer models must be improved. Major numerical weather prediction centers and NESDIS co-operate on the evaluation and improvement of fast radiative transfer models.

Time series of radiance data are being employed to investigate tropospheric temperature and water vapour variability trends. Extensive use has also been made of TOVS data in re-analysis projects at ECMWF and NCEP, where they have been shown to contribute significant information. TOVS data are also being used to validate general circulation models.

Studies of ECMWF re-analysis products demonstrate that the accuracy of these products is dependent upon the volume of data available from the polar systems. Analysis errors are lower for these periods when data from two satellites are available.

Climate studies will benefit from easy access to TOVS level-1B data. These data should be made available via the Satellite Active Archive in a timely manner and at reasonable cost.

Polar-orbiting Operational Environmental Satellite (POES)/TOVS cloud-cleared radiances have been incorporated directly into the global analysis system by NOAA's NWS. This improved usage of TOVS data substantially improves forecasts in the Southern Hemisphere and, for the first time, produces major positive impact for Northern Hemisphere forecasts. Portions of the code were imported from the ECMWF.

NOAA's NWS has modified its use of TOVS sounding data to use level-1B radiances. Unlike the data previously used, these radiances have not been cloud-cleared, limb-corrected, surface emissivity-corrected or remapped. The nonlinear effects that were removed by the pre-processing are now handled directly within the analysis system. The assimilation of level-1B radiances rather than the NESDIS preprocessed data allows a more flexible and effective usage of the observed information.

Preparations are being made for the Advanced TOVS (ATOVS). ATOVS will be launched on the NOAA-K satellite.

The UARS data record exceeds six years now and questions of year-to-year variability can be seriously addressed. The first year, which was affected by Mt Pinatubo aerosols, can be contrasted with the later years. Any meaningful temporal trends were not expected to be seen in the UARS data, but the increase of HCl and HF are clearly seen in the HALOE (Halogen Occultation Experiment) observations.

SAGE II (Stratospheric Aerosol and Gas Experiment) is a successor to SAM, which operated from 1978–94, and SAGE, which operated from 1979–81. SAGE II became operational in October 1984 and measures attenuated sunlight at different wavelengths through Earth's limb during each sunrise and sunset. These measurements are converted to aerosol extinction profiles with a 1-km vertical resolution. A composite near-global view of stratospheric aerosol loading since late 1978 can be derived by combination extinction measurements from these three instruments. The data record includes perturbations due to the major volcanic eruptions of El Chichon (1982) and Mt Pinatubo (1991), as well as a number of minor eruptions.

Recently scientists from NASA have used visible to near-infrared optical depth spectra to construct a unified picture of the global to micro-scale evolution of the Pinatubo volcanic aerosol. Results suggested that when particle effective radius exceeded 0.4 micrometers, an upper bound on particle size could not be retrieved from optical depth spectra without employing wavelengths greater than 1 micrometer. To correct this problem, a combination of SAGE II and UARS measurements were used and changes in aerosol effective radius were followed for four years after the Pinatubo eruption.

The data-sets of the International Satellite Cloud Climatology Project (ISCCP) are still widely used in different investigations for different purposes. Alternative methods of cloud detection and classification have been elaborated at the University of Wisconsin, Dresden Technical University, Tartu Observatory (Estonia) and others.

At the 31st COSPAR Scientific Assembly, the Zeldovich Medal was presented to Franz H. Berger (Germany) for his achievements in satellite climatology. Franz Berger has elaborated a method to detect, characterize and classify clouds from satellite data and investigated the influence of cloudiness on the Earth radiation budget and the climate.

One of the major uncertainties in global climate models is still cloud feedback. A recent analysis of ISCCP data revealed an overall tendency for low cloud optical thickness to decrease with temperature, with the exception of cold high latitude cloud ensembles where low cloud optical thickness increased with temperature in accordance with the variation of the adiabatic cloud water content.

Clouds and water vapour affect not only the net radiation energy input to the climate system, but also its vertical and horizontal distribution. As a result, changes in cloud and water vapour variables can alter the dynamic and thermodynamic processes that determine the feedbacks in the response of the climate system to external perturbations. Information on the interaction between radiative and dynamic processes are gleaned by statistical analyses of multi-year data-sets, including ERBE, ISCCP, TOVS, SSM/I, and GEBA, combined with the output from data assimilation models (A. Arking, Johns Hopkins University).

The first model of ScaRaB (Scanner for Earth Radiation Budget) was operated on board the Russian Meteor 3/7 weather satellite from 24 February 1994 until 6 March 1995. The second model was to be launched on board the Russian RESURS-0 satellite in 1997. The objective of ScaRaB is to determine the Earth radiation budget components in terms of monthly regional averages and to study cloud-radiation interactions. These data provide a link between the NASA ERBE (1985–90) and CERES (1997) scanner missions. The interest of ScaRaB data is not only to extend the long-term Earth radiation budget history, but also to improve methods for estimating shortwave and longwave radiation budget and cloud forcing components. It must be remembered that accurate Earth radiation budget estimates depend on resolving difficulties not only in calibration, but also in angular, spatial and temporal sampling. ScaRaB offers new opportunities to test angular and time interpolation procedures and to check the general consistency of Earth radiation budget estimates. ScaRaB is a joint project of France, Russia and Germany.

The search for evidence of signals of climate change, and attribution to specific processes is being undertaken in a number of groups around the world. Special attention is paid to detection of human-induced effects on climate that is superimposed on the background noise of natural climate variability. The available evidence from proxy climate indicators suggests that the 20th century global mean temperature is at least as warm as in any other century since 1400 AD. More convincing evidence for the attribution of a human effect on climate should emerge from pattern-based studies. Usually these investigations are focused on the analysis of spatial patterns and time series in surface temperature. J.E. Harries, A. Geer, H. Brindley and A. Sinha (United Kingdom) have offered a new technique based on satellite data, in which patterns of spectral change in the outgoing planetary radiation are correlated with simulated changes in the spectrum bands for which long-term observations exist.

Terrestrial Research and Applications

Operational methods have been developed in China in which the Thematic Mapper (TM) data are used to extract the basic rice planting area in a given year, 1992, and then NOAA/AVHRR data are used to predict the change of the rice planting area. The results are acceptable. In crop yield estimation, NOAA/AVHRR data have been used to estimate global rice production based on statistical analysis between Normalized Difference Vegetation Index (NDVI) and rice yield. This method has been tested in Thailand, Vietnam,. the United States and China.

Based on the train of experimental MW active/passive data and ground truth, an Artificial Neural Network (ANN) model has been established in China to estimate the biomass of wheat. Based on the analysis of the feature of soil reflectivity and using the first derivative of spectral reflectance of vegetated area taken by the imaging spectrometer's observation, a method is used to retrieve Leaf Area Index (LAI) and Absorptive Photosynthetic Active Radiation (APAR).

Landsat data are being used in Estonia to study reflectance variations of forests and changes in agricultural land use. New methods of estimation of vegetation parameters from Landsat TM images have been developed.

Bi-directional reflectance function (BDRF) and polarization features of the Earth-atmosphere system and their influence on monitoring, identification and quantitative remote sensing is being studied in China. Numerical simulations of BDRF and polarization with a spherically-layered Monte-Carlo radiative transfer model of surface-atmosphere system of different structures are being systematically conducted. This is partly related to the ADEOS/POLDER retrieval study. At the same time, ground-based observations of sky radiance and polarization with a six-wavelength polarimeter are continuously being made at Beijing. Measurements and modelling of BDRF of different types of vegetation are made. Based on the analysis of the uncertainty and sensitivity matrix of inversion with BDRF data, a strategy of multi-stage, sample direction dependent, target-decision (MSDT) is suggested.

NOAA is using GOES observations to monitor cloudiness, surface skin temperature, and the solar radiation reaching Earth's surface over the continental United States. These measurements are being compared to the same variables produced by the NWS regional Numerical Weather Prediction (NWP) model—the Eta model. The GOES measurements provide unique data not available from conventional observations and will be used to improve land surface and cloud modeling.

NOAA ahs developed a new drought monitoring product it is being produced on an experimental basis. This drought index is based on a combination of the Vegetation Condition Index, a measure of vegetation health and vigour, and the Temperature Condition Index, a measure of surface temperature anomalies, from AVHRR. The U.S. Department of Agriculture is using the drought index to monitor agricultural production in the world's lay regions.

The operational NDVI from AVHRR has been transformed by NOAA to a quantity representing the fraction of each grid box of Earth covered with green vegetation. A climatology of this quantity has been developed based on six years of global AVHRR observations. The climatology represents the average fractional vegetation cover for each grid box for each month of the year. These values are now being used as boundary conditions in NWS NWP models, leading to more accurate surface temperature forecasts.

On 4 April 1997, the U.S. Air Force Defence Meteorological Satellite Program (DMSP) successfully launched satellite F-14 into a day-night polar orbit. On 28 April, the NOAA-NESDIS National Geophysical Data Centre (NGDC) began receiving DMSP sensor data from F-14. NGDC receives tape recorded DMSP data via a dedicated T-1 data line to Offutt Air Force Base in Omaha, Nebraska. NGDC serves as the nation's long-term archive for DMSP data. NGDC currently receives 7.8 gigabytes of DMSP data per day, coming from satellites F-10, F-11, F-12, F-13 and F-14. The DMSP suite of passive microwave instruments includes the SSM/I, Special Sensor Microwave/Temperature (SSM/T1) and Special Sensor Microwave/Temperature-Moisture (SSM/T2), which are widely distributed and used for meteorological applications. In addition to the passive microwave data, DMSP operates a unique set of space environment sensors and the Operational Linescan System (OLS) that is designed for global cloud imaging. The visible band data of the OLS is intensified at night for detection of clouds using moonlight. NGDC uses the light intensified OLS data to detect visible band emissions sources present on Earth's surface, such as fires or city lights. NGDC has completed a five-year nightly inventory of fires for Madagascar and is producing the first global satellite derive mapping of human settlements.

A chain of impact craters in Chad has been identified from radar images of Earth taken by the Spaceborne Imaging Radar C/X-band Synthetic Aperture Radar (SIR-C/X-SAR) that flew on the Space Shuttle Endeavour in April and October 1994. The images reveal two new craters adjacent to a previously known impact site. The images suggest that Earth may once have been hit by a large, fragmented comet or asteroid similar to the Shoemaker-Levy 9 comet that slammed into Jupiter in 1994. Scientists in China are using space radar images to locate and study two generations of the Great Wall of China that have been eroded and buried in places by centuries of blowing sand. The Spaceborne Imaging Radar project is managed by the Jet Propulsion Laboratory for NASA's Office of Mission to Planet Earth. The radar project is a joint mission of the United States, Germany and Italy.

Oceanographic Research and Applications

The AVHRR instruments carried aboard the NOAA polar orbiting satellites are used to produce weekly composite global sea surface temperature maps. These products were used by NOAA to monitor the development of the 1997 El Niño, which exceeded any past El Niño event of the modern record. In addition, AVHRR-derived sea surface temperature data are being used to produce an experimental product of "Potential Coral Reef Bleaching". The 1997 high sea surface temperatures (31-32 deg C) off Mexico's Pacific coast were some of the highest temperatures seen since satellite records began in the early 1980s and are independently confirmed sites of coral bleaching.

NOAA is currently producing a near-real-time, satellite-derived, marine wind product to support forecast centres. The product merges SSM/I wind speed estimates with scatterometer-derived vector wind data to produce a synoptic picture of the near-surface wind field. Currently, only data from the European scatterometer (ERS-2) are used to support this product owing to the untimely demise of the NASA scatterometer.

The current generation of geostationary satellites is now being used by NOAA to produce experimental sea surface temperature products. Using data from near time-coincident, AVHRR data, sea surface temperature equations were developed that are similar in structure to current operational equations used to compute sea surface temperature from the AVHRR. The geostationary sea surface temperatures are being used to examine diurnal fluctuations in sea surface temperature, something not currently possible with data from polar orbiting satellites.

New results from the ocean-observing TOPEX/Poseidon mission reveal the features of interseasonal oscillation in the tropical Pacific. In addition to 30-day oscillation in the eastern equatorial Pacific, there are quasi-90-day and quasi-60-day oscillations in the western tropical Pacific. TOPEX/Poseidon is a joint program of NASA and CNES.

In early 1997, NOAA began assimilating near-real time altimeter data from the TOPEX/Poseidon satellite in the operational ocean model used for El Niño/Southern Oscillation (ENSO) prediction. These data are available with a delay of only two days and yet have an accuracy of approximately 5 cm. It has been shown that assimilation of these sea level measurements produces better forecasts of sea surface temperature in the tropical Pacific with lead times of up to six months. As a result of this development, NOAA had more confidence in the oceanic and atmospheric predictions during the dramatic 1997 El Niño.

NOAA has published a series of articles on its maps of high resolution gravity fields from the Geodesy Satellite (Geosat) and ERS-1 altimeter data. Discussion of the method of production of the high-resolution gravity field maps and the demonstration of their resolving power are published in D.T. Sandwell and W.H.F. Smith, *J. Geophys. Res.*, vol. 102, no. B-5, pp. 10,039-10,054, May, 1997. The estimation of global sea floor topography from a combination of these gravity data with conventional shipboard sonar depth soundings is described in W.H.F. Smith and D.T. Sandwell, *Science*, vol. 277. pp. 1956-1962, 26 September 1997. The maps are available from the NOAA/NESDIS/NGDC, which is World Data Centre A for Marine Geology and Geophysics. The efforts now under way to include depths from this grid in ocean circulation models include the work of the Scientific Committee on Oceanic Research (SCOR) Working Group on Improved Global Bathymetry.

A high resolution marine gravity field covering the southern-most sea, i.e., all ocean offshore West Antarctica, from the Ross Sea east to the Weddell Sea, has been derived by NOAA using satellite altimeter data, including ERS-1 Geodetic Phase data. Gravity over large portions of these often ice-covered seas was, until now, unsurveyed by satellite or ship. Satellite marine gravity in these areas was degraded or lost due to ice cover. Analysis of the ERS-1 waveform data over these ice-covered seas has enabled us to derive a high-resolution gravity field which covers all of these poorly charted seas. This new gravity field reveals tectonic fabric of seafloor adjacent to West Antarctica which allows one to see how the two continents, New Zealand and West Antarctica, fit together approximately 80 million years ago. This work is described in detail in the paper "Antarctic Tectonics: Constraints from a new ERS-1 Satellite Marine Gravity Field" (by D. McAdoo and S. Laxon) in the 25 April 1997, issue of *Science*. Comparable gravity fields have also been derived for the ice-choked Arctic Ocean by Laxon and McAdoo.

Neural network algorithms have been created by NOAA and evaluated for use in the retrieval of ocean surface wind speed, water vapour, cloud liquid water and sea surface temperature from SSM/I data and for the simulation of SSM/I radiances from the above physical quantities. Impact of these algorithms on global analyses and forecasts shows definite advantages over other methods.

A procedure has been developed for assimilation of ERS-2 wave height data in the NOAA operational global ocean wave model. This procedure will be generalized for other types of wave data over the oceans.

A 25 km resolution sea ice concentration analysis based on SSM/I passive microwave data has been developed and is undergoing operational implementation. NOAA's National Marine Fisheries Service (NMFS) is using altimetry data from TOPEX/Poseidon to infer the dynamics of surface currents in the North Pacific near the Northwest Hawaiian Islands. The current information is used to estimate the distribution of planktonic larval spiny lobster (*Panulirus marginatus*) from their spawning grounds. With better knowledge of larval distribution, scientists are able to estimate recruitment success to the atolls where the lobsters settle, thereby improving forecasts of lobster abundance.

NOAA's NMFS has used Coastal Zone Colour Scanner (CZCS) colour imagery to correlate chlorophyll concentrations with densities of the toxic phytoplankton Gymnodinium breve in surface waters of the eastern Gulf of Mexico. The minimum detection level of G. breve blooms from CZCS imagery is approximately 10 times more sensitive than that from visual detection. This offers hope for the development of early warning systems for harmful algal blooms using the higher resolution sensors of Sea-viewing, Wide-Field-of-View Sensor (SeaWiFS). The capability for such sensitive, remotely-sensed detection of blooms could lead to early warnings for coastal communities and resource managers, providing time for mitigation actions.

NOAA's NMFS and National Ocean Service (NOS) are using Landsat TM digital multispectral imagery and large format natural colour aerial photography to monitor changes in coastal ecosystems through the Coastal Change Analysis Program (C-CAP). C-CAP is investigating the potential for use of acoustic imaging sensors for mapping benthic features in deep and coloured waters, and airborne imaging systems for accurate assessment of TM-derived land cover data. The C-CAP program is imaging all U.S. coastal areas on a one- to five-year interval to detect changes in coastal upland and wetland land cover and submersed vegetation.

Composite Dataset Programs

The Committee on Earth Observation Satellites (CEOS) began to implement the Integrated Global Observation Strategy (IGOS). Its objective is to pave the way to an optimal and operational use of space and in situ data for global modelling, mapping and prediction purposes. The following six IGOS projects were defined as case studies to implement such a strategy:

1. Global Ocean Data Assimilation Experiment (GODAE)
2. Long-term continuity of ozone measurement
3. global observations of forest cover
4. ocean biology
5. disaster management support
6. upper air measurements for numerical weather prediction

NOAA's archive of GOES data, one of the oldest and largest collections of meteorological satellite data in the world, is being transferred from the video cassettes that have been used to store these data for more than 20 years to the IBM 3590 cassette, a magnetic tape with 10 gigabytes (GB) of storage capacity, and an access rate 24 times faster than the current technology. This new system is expected to provide faster, less expensive access to these data for climate research. NOAA is making plans to begin transferring the existing archive of almost 40,000 video cassettes in 1998. During this transition a backup archive will be created for off-site storage, while the primary archive will be maintained at the National Climatic Data Centre (NCDC).

Some 28 countries participate in the 1 km Landcover Data Base of Asia Project, which is based on data acquired by NOAA satellites. The project is organized by the Asian Association for Remote Sensing and coordinated by the Remote Sensing Department of Chiba University, Japan. The results obtained from this project will be integrated to the 1 km Landcover Data Base of the World.

The Desertification Studies in Iran and Turkmanistan Project is presently under its initiation stage and is proposed to be carried out on the basis of space-taken remotely sensed data and GIS.

The national basic GIS of 1:1,000,000 has been finished and that of 1:250,000 is at work in China. Based on this, a synthetic fast response system of flooding analysis has been completed. A snow disaster monitoring and assessment system based on GIS and AVHRR is now established and has been applied to the national (pastoral area) snow disaster forecasting and assessment.

International Cooperation

The European ATOVS group continued its efforts to develop the software for processing direct readout High Resolution Picture Transmission (HRPT) data from the forthcoming NOAA-K, -L and -M satellite series. The group is coordinated by EUMETSAT. The complete package was planned to be ready in late 1997.

Negotiations between NOAA and its key European partners—EUMETSAT, with involvement as appropriate of ESA—are almost complete for a joint polar satellite system, taking into account, on the U.S. side, the converged civil-military U.S. system. This agreement is expected to be signed in 1998, the end result of which will be the operation of a joint U.S.-European environmental satellite system that provides greater and more accurate instrumentation, achieves higher coverage, and distributes data more rapidly, reliably, and at lower cost.

On 31 March 1997, NASDA, NASA, and NOAA signed a Memorandum of Understanding (MOU) on Japan's Advanced Earth Observing Satellite-II (ADEOS-II) Program. ADEOS-II will provide NOAA with access to enhanced ocean surface wind and ocean colour data for the purposes of near-real time environmental monitoring. The satellite will also carry an improved French Argos Data Collection System, for timely relay of in-situ environmental data. ADEOS-II will be a follow-on to Japan's ADEOS mission, which was launched on 17 August 1996, and suffered a premature failure on 30 June 1997.

Another significant accomplishment was the further development of the IGOS with international counterpart space and Earth observing agencies. NOAA and NASA organized and hosted an initial meeting of an IGOS Strategic Implementation Team in February 1997 in Irvine, California. Senior officials commissioned development of six prototype projects to test the IGOS concepts. NOAA is leading two of these projects, Upper Air Measurements and Disaster Management Support.

In addition to the cooperation with China, recent major international cooperation efforts of Brazil include: (1) participation in the International Space Station, presently under discussion with NASA, (2) development of a scientific satellite with France, and (3) development of a remote sensing satellite, named SABIA3, with Argentina, which will focus on applications related to water, agriculture and environment.

In Finland techniques have been developed for using TOMS/TOVS ozone data to produce global and regional maps of ozone vertical density and UV-B radiation at the surface. In cooperation with the Argentine Weather Service, instruments on simultaneous, conjugate balloon flights from Marambio (Antarctica) and from the Meteorological Observatory in Sodankylä (Finland) have measured ozone profiles, which have been compared with corresponding satellite measurements.

As part of the ESA ENVISAT-1 Ground Segment, a GOMOS (Global Ozone Monitoring by Occultation of Stars) data processing centre is under development at Sodankylä. Along with its French partners, Finland has been heavily involved in the GOMOS instrument from the very beginning. On the scientific side, activities include characterization of instrument performance, development of retrieval algorithms and processing, development of mission planning tools, development of in-flight calibration tools, and development of higher order products.

Cooperative research on remote sensing of wetland vegetation by imaging spectrometer observation has been conducted between NASDA and the Chinese National Remote Sensing Centre. The cooperative research included vegetation type identification, biomass estimation and dynamic monitoring.

Satellite Observations Problems

Speakers of the Panel Discussion on Satellite Observations for Earth System Science at the 31st COSPAR Scientific Assembly highlighted the importance of continuous long-term global measurements of atmospheric, oceanic and terrestrial variables, which can only be accomplished by remote-sensing satellite techniques, and particularly the expected gaps in remote sensing measurements—either due to lack of appropriate techniques or to lack of planning by space agencies, while excessive duplication occurs in some areas. They stressed that in the design of satellite missions scientists must consider the applications of results for the benefit of society.

Whether the speaker focused upon atmosphere, land or ocean, the scientific emphasis was on seasonal-to-interannual variability. This requires global observations, many years in duration, and uniform data processing procedures. Accurate long-term measurements of simultaneous variables is the goal. All agreed that this situation has only recently improved, but with only a handful of variables.

The world-wide in-situ network of data collection platforms is decreasing at an alarming rate. Concern was expressed that because remote sensing satellite data require ground truth data for calibration and validation, the deterioration of the in-situ network should be slowed until it is proven that satellite data will replace in-situ data. Furthermore, increased attention must be given to the integration of satellite, both operational and research, and in-situ measurement networks, recently named the integrated observing system.

Public Education and Awareness

EUMETSAT, in cooperation with WMO, convened the second User Forum in Africa, in Harare, Zimbabwe, in mid December 1996. It focused on training issues and raising the awareness of regional users on the future capabilities of MSG and the needs to prepare for the transition from the current to the future satellite generation. A Task Team with representatives of sub-regional groupings of the African user community was set up to develop a strategy of preparation and resource mobilisation for the transition to MSG.

NOAA's NCDC has completed a series of Web pages that provide access to information about and data from NOAA's satellites. Among these pages are approximately 3000 images of significant environmental events; links to images with narrative descriptions of the events shown, and ancillary information about the meteorological phenomena taking place, and access to over five years of daily GOES imagery. These pages average an estimated monthly total of 10,000 users, with 100,000 files containing 9 GB of data downloaded. In addition, on-line access has been added to several of NOAA's most popular user's guides, providing researchers with instant access to NOAA documentation. All of these pages may be accessed from the NCDC Web page at *http://www.ncdc.noaa.gov*, by choosing "satellite".

SPACE STUDIES OF THE EARTH-MOON SYSTEM, PLANETS AND SMALL BODIES OF THE SOLAR SYSTEM

Terrestrial Planets

Mercury

A mission to Mercury is included in the ESA long-term program, with a launch date of 2009. Scientific and technical studies have been carried out which have led to the definition of a preliminary baseline mission based on the use of solar electric propulsion. The spacecraft would consist of a main orbiter for high resolution multi-wavelength observations and fundamental physics studies, and a subsatellite dedicated to particles, fields, and radio sciences studies. As a further support, the SMART-1 mission has been proposed in 1997 to be launched in 2001, as a test flight for solar electric propulsion.

Moon

Lunar Prospector, NASA's first competitively selected Discovery-class mission, is scheduled for launch in January 1998 and will go into a 100-km-altitude lunar polar orbit for a year of geochemical mapping of the lunar surface. It will carry six instruments that are designed to map the Moon's surface composition, gravity and magnetic fields, and to search for the possible release of volatiles from the lunar interior.

Japan's ISAS is planning a lunar penetrator mission (Lunar-A) for launch later this year. By implanting three scientifically equipped penetrators at widely separated sites (one on the far side) across the lunar globe, this mission will examine the Moon's heat flow and seismic activity.

Mars

The International Mars Exploration Working Group (IMEWG), set up in 1993, now harmonizes the programs for the exploration of Mars within NASA and ESA, and also Austria, Canada, Finland, France, Germany, Italy, Japan and Russia. Despite the failure shortly after the November 1996 launch of Mars-96, the ambitious international mission to Mars led by the Russians, the situation looks now quite favourable, with a program of explorations exploiting all the ballistic opportunities, avoiding duplications, and keeping missions as open as possible to all contributors. It may be added that a considerable controversy continues to surround the 1996 announcement that a meteorite known to have come from Mars might contain signs of ancient martian life.

Using innovative engineering, Mars Pathfinder landed on 4 July 1997 in Ares Vallis (19N, 34W) at the mouth of an ancient catastrophic flood basin. A wide variety of rocks and geological formations were apparent. Pathfinder carried a multi-spectral stereoscopic camera, a miniature meteorological station, and several simple experiments. It also unloaded a small rover, called Sojourner, which crawled around the martian surface imaging and sampling rocks with its alpha-proton-X-ray spectrometer. The latter chemical analysis identified various volcanic rock types and suggested more internal processing of martian material than had been anticipated. Just as remarkable as the technical and scientific feats of this mission was the considerable involvement of the public worldwide in the mission: on one day alone, 47 million hits were recorded on the various World Wide Web sites that carried the publicly posted images.

Mars Global Surveyor was placed into a highly elongated orbit in September 1997, and is presently using aero-braking to move toward its planned Sun-synchronous circular orbit. The spacecraft, which carries a magnetometer/electron reflectometer, a thermal emission spectrometer, a laser altimeter and a high-resolution visible imager, has a nominal two-year mission lifetime. Already the orbiting spacecraft has found a few regions on Mars that are locally magnetised.

In its future Mars Surveyor program, NASA plans to launch a pair of spacecraft, usually a lander and an orbiter, to Mars every 26 months. During the 1998 window, the orbiter will carry a small integrated wide- and medium-angle imager and a pressure-modulated infrared radiometer. It will be joined by a lander targeted to carry out meteorological observations just off the polar cap. A gamma-ray spectrometer will be among the instruments on the 2001 orbiter. The ultimate goal of this campaign to study Mars is a search for possible life and the return to Earth of a 1 kg martian rock in 2008.

Planet-B is being developed by Japan for launch next year. It is designed to study martian aeronomy and the interaction of Mars with the solar wind, including studies of the plasma flow in the planet's vicinity.

As part of JPL's technology-development program New Millennium, a series of microprobes for Mars is under consideration for launch very late in this century.

Mars Express has been introduced in the ESA Horizon 2000 implementation plan. Launched in 2003 by a Molnya/Soyuz, it will consist of an orbiter carrying a scientific payload, and possibly up to four mini lander modules. It will operate for at least one martian year.

Asteroids

The NEAR spacecraft, en route to a January 1999 rendezvous with the near-Earth asteroid Eros, flew past the large C-class main belt asteroid Mathilde on 27 June 1997 and found it to be pock-marked with many large deep craters and to have a surprisingly low density.

MUSES-C, a Japanese mission to another near-Earth asteroid Nereus, will be launched in January 2002 and will land a small rover to crawl across the surface of this tiny asteroid.

Rosetta, a cometary mission (see below), will fly past two asteroids on its way to its cometary rendezvous.

Comets

The payload for Rosetta, ESA's international mission to visit comet P/Wirtanen toward the end of the first decade of the next century, was confirmed by ESA in June 1997. The project consists of an Orbiter and a Lander. The orbiter will fly alongside the comet for three years, a period that will include the comet's perihelion passage, studying the nucleus with remote-sensing instruments while simultaneously investigating the coma with mass spectrometers, dust detectors and plasma instruments. The lander will be deployed by the orbiter after the first year of operation and will make in-situ studies of the nucleus for a period of one to several months.

Deep Space 1, a JPL's first interplanetary technology-development mission, is due for launch in the summer of 2000 on a mission to comet West-Kohoutek-Ikemura.

The Discovery-class Stardust mission, which is designed to fly past comet P/Wild 2 in early 2004 capturing samples of dust to be returned to Earth in January 2006, is under development for a launch in early 1999.

CONTOUR, another Discovery-class mission, has been selected for development. It will be launched in 2002 and, over the period November 2003-August 2008, it will study the diversity of comets, by flying past three comets (Encke, d'Arrest and Schwassmann-Wachmann 3) and perhaps at the end of the mission being redirected to visit a new comet.

Outer Solar System Space Probes

Jupiter

Galileo has been in orbit around Jupiter since late 1995, observing the planet's atmosphere, dramatically different satellites and rings at visible, infrared and ultraviolet wavelengths. The spacecraft, which also carries a dust detector and instruments to study the planet's energetic magnetosphere, had dropped an atmospheric probe that reached a pressure level of more than 10 bars, measuring wind speeds and composition.

Observations of the large Galilean satellites have found them to be remarkably diverse. The volcanically active Io is covered with variable colourful flows and exhibits atmospheric emissions/airglow. Imaging of Europa reveals a sparsely cratered surface, suggesting a youthful surface, and a complex array of dark and bright bands, ridges and troughs; the satellite may be geologically active today. Speculation has arisen as to whether this moon has a water ocean below (but near to) its icy crust and even whether that ocean might harbour some form of life. The outer Galilean moons Ganymede and Callisto are dark, colourless heavily cratered bodies that are surprisingly smooth at small scales. Ganymede exhibits its own magnetic field and magnetosphere.

Infrared and multispectral observations have determined that the Jovian atmosphere is, for the most part, laterally homogeneous; the vertical structure is an upper tropospheric haze overlying a thicker cloud deck which in turn overlies a deep haze. The planet is violent as well, with huge thunderstorms in the vicinity of Jupiter's Great Red Spot, lightning bursts associated with thunderheads in latitudinally restricted high-shear regions, and powerful aurorae. Galileo has greatly refined Voyager's description of the Jovian ring system, showing a system with wave-like features.

Galileo's nominal mission was to have ended on 31 December 1997, but an extended mission, lasting two years with support from only a skeleton work force, has been approved. Its primary focus will be the detailed investigation of the satellite Europa during nearly 10 new flybys; the mission will end with two close encounters of Io.

Saturn

The Cassini-Huygens mission, a joint program between ESA and NASA, was launched on 15 October 1997. It will arrive at Saturn on 1 July 2004. The Huygens probe, containing instruments to sample Titan's atmosphere and a lander, will be dropped onto the satellite on 27 November 2004. The Cassini orbiter carries a comprehensive set of a dozen instruments to study the planet's atmosphere, ring system, magnetosphere and satellites. Special emphasis will be placed on the study of Titan during numerous flybys with the surface being probed by a radar system.

Uranus, Neptune and Pluto

NASA continues to study a possible flyby of Pluto that, if approved, would occur in the early years of the next century.

Observations from Near-Earth

Observations of planets, satellites, rings, asteroids and comets taken by HST have been very productive in the last year. Synoptic observations have been made of weather patterns on Mars, Jupiter, Saturn and Neptune, while aurorae on Jupiter and Saturn have been studied. Faint atmospheres have been found on several Galilean satellites. Observations taken during Saturn's ring-plane crossings have shown features in the outer ring system to form and disappear. An enormous impact crater on Vesta is seen to be mineralogically distinct. Flows in the near-nucleus regions of comets have been observed with HST's excellent resolution.

Numerous discoveries of Sun-grazing comets have been made by the Solar and Heliospheric Observatory, launched on 2 December 1995. Also, Lyman-alpha mapping of the circum-cometary hydrogen clouds has provided cometary water production rates.

The Infrared Space Observatory satellite, launched by ESA on 17 November 1995, is devoted to the study of all classes of astronomical sources from 2 to 200 microns. Solar-system studies have greatly benefited from ISO observations.

Observations of infrared HD lines have led to new determinations of the D/H ratio in Jupiter, Saturn and Neptune. Stratospheric water has been discovered on all giant planets, showing evidence for an external oxygen source which might be either local (rings and/or icy satellites) or interplanetary (icy/dust grains). With comet Hale-Bopp, ISO has obtained the first CO_2 identification in a distant comet; in addition, a complete infrared spectrum of Hale-Bopp, obtained at 3 AU, has demonstrated the presence of forsterite, a magnesium-enriched type of olivine. New results have also been obtained on Mars, Titan, Io, asteroids and the zodiacal light.

SPACE STUDIES OF THE UPPER ATMOSPHERES OF EARTH AND PLANETS, INCLUDING REFERENCE ATMOSPHERES

Earth's Middle Atmosphere and Lower Ionosphere

The middle atmosphere and lower ionosphere, the region between 20 and 110 km in altitude, continues to be the focus of extremely active research which involves all the major nations of the world who engage in solar terrestrial physics (STP) research.

This region is critically important for an understanding of interactions between the Sun and Earth. In particular, studies of climate change and of anthropogenic influences upon composition and dynamics require research of continuity and depth in this region. Much of the research has been coordinated with, or consistent with, the 1990-1997 Solar Terrestrial Energy Program (STEP), and with the Coupling, Energetics and Dynamics of Atmospheric Regions (CEDAR)program being conducted in the United States. There are now in place strong SCOSTEP post-STEP programs 1997-2002: SRAMP (STEP Results, Applications and Modelling Phase) will provide the structure and opportunity for studies appropriate to events (1990-1997), demonstrating coupling within the entire Solar Terrestrial environment, to be studied; PMOS (Planetary-scale Mesopause Observing System) will provide and develop a global network of observing systems (optical and radar) to study the global scale chemical and dynamical influences of planetary waves/tides, and gravity waves upon the MLT (mesosphere and lower thermosphere); and EPIC (Equatorial Processes Including Coupling) will study the coupling processes throughout the middle atmosphere and lower atmosphere of the equatorial regions, and consider extra-tropical coupling (with PSMOS). There have also been continuing developments within CEDAR (Phase III), which include strong linkages with the NASA-TIMED satellite program (2000), and with the "Space Weather" initiatives in the United States and internationally. Both of these major programs place considerable emphasis upon the middle atmosphere and lower ionosphere; this led to significant research meetings during 1997 (see below). The Upper Atmosphere Research Satellite (UARS) continued to provide unique data on constituents, temperatures and winds during 1996–97, providing opportunities for collaborations with many ground-based observing systems. Collaborations with scientists and administrators in the various Space Agencies, e.g. NASA, CSA and ESA, have been particularly fruitful in 1996–97.

The development and operation of ground-based optical and radar systems is a fundamental factor in the success of continuing and new programs of research. The first operation of the new EISCAT Svalbard radar (1996–97; at 78 degrees N) opened a new era for ionospheric and thermospheric investigations in the Arctic and polar regions. The existing EISCAT system (70 degrees N) has been the 1996–97 focus of E-region wind studies over the last solar cycle (Japan and Norway), and of turbulence effects upon dynamics, aeronomy and tides (United Kingdom, Norway, Germany, Canada). Another Incoherent Scatter Radar (ISR), at Millstone Hill (MIT, 42 degrees N) has provided for the analysis of 15 multiple-day observational campaigns spanning 10 years (1987–97), under the CEDAR program. This analysis has resulted in a determination of the climatological average of winds and temperatures in the 100–130 km region of Earth's atmosphere. The variability in the tidal parameter for winds and temperature has been characterized, and seasonal effects have been studied. Comparisons of the observations with general circulation and tidal models has been made, indicating the improvements necessary for such models.

New radars are being developed in the Pacific Rim nations, e.g. the operation of a meteor wind radar (6 degrees S, 107 degrees E) and an MF radar (0 degrees, 109 degrees E) in Indonesia is a collaborative project between Indonesia, Australia and Japan. The Japanese MU radar has also been operated in a meteor-mode (35 degrees N, 136 degrees E), and winds compared with simultaneous measurements with a sodium lidar and a CCD imager. There is also considerable activity in Antarctica. In 1996 the British Antarctic Survey developed and tested software to operate a dynasonde, based at Halley (75 degrees S, 26 degrees W), as an Imaging Doppler Interferometer (HIDI). Routine IDI soundings began in December 1996 making measurements of the mesospheric winds above Halley at five minute intervals. The data are now being assessed to characterize the mean mesospheric wind and tidal motions above Halley. Observations of winds (USA, Russia) using a meteor radar at the South Pole Station have provided a number of new and unexpected results: e.g. a strong (20 m/s) westward-propagating semi-diurnal wind oscillation exists during non-winter months with zonal wavenumber s=1; and divergence events (as evidenced by zonal mean meridional winds) occasionally occur over the South Pole, implying extreme vertical winds (adiabatic heating/cooling) or meridional heat fluxes. In addition an updated global empirical semi-diurnal migrating tide model has been developed and has been compared with numerical models European MLT radars have provided a rich variety of winds analysis and results. For example, the continuous measurements at Collm (52 degrees N, 15 degrees E) have provided 14-year mean wind profiles, also seven-year means in combination with the Kuehlungsborn MF radar wind data, as well as the estimation of long-term trends. A long-term decrease of the semi-diurnal tidal amplitude was found. The quasi 2-day wave showed strong inter-annual variability and a possible dependence on the mean circulation; while planetary waves at other time scales (5, 10, 16 day) also showed strong inter-annual variability, but in a more irregular manner. Related planetary wave studies have used the Sheffield Meteor Radar winds-data set.

The Canadian optical and radar systems have operated productively in North America, and new systems are being developed for PSMOS and future satellite programs. There are MF and VHF (tropospheric turbulence-scatter and meteor-detection) radars in southern Canada, but also increasingly in the north (Resolute Bay, 75 degrees N), alongside optical systems and the co-located US observatory. Lidars are being increasingly used, e.g. at Eureka (80 degrees N) for studies of ozone depletions associated with dynamical, chemical and seasonally varying processes. The MLT research studies, linked with SRAMP and CEDAR activities, have emphasized the interactions between various scales and types of atmospheric waves.

Planetary and tidal wave modulations of gravity wave fluxes are being demonstrated, which emphasize the complexity of MLT dynamics. These processes can lead to planetary wave signals being transferred into the lower and upper thermosphere. The U.S. CEDAR research has been rich and diverse. For example, there have been studies of the non-migrating diurnal tide in the equatorial region using meteor observations and the "Global Scale Wave Model" results; comparisons of meteor and MF radar winds, and also UARS (WINDII/HRDI experiments) winds; and reverse ray tracing of gravity waves in the mesopause region to determine potential tropospheric sources. As an example of international collaboration, routine spectroscopic measurements of the near-infrared hydroxyl nightglow have been used to monitor the mesospheric temperature at Stockholm, Sweden (59 degrees N, 19 degrees E) since 1993 as part of a U.S.-Swedish cooperative project. This temperature time-series has been used to identify and monitor the presence of Rossby normal-modes with periods less than two days in the high latitude mesosphere, and to correlate their summer occurrence to non-blocking QBO flows in the equatorial stratospheric wave-guide. Optical studies involving FPI, and all-sky imagers, have been used in the United States (Michigan), at Resolute Bay (Canada, 75 degrees N), and at Sondre Stromfjord (Greenland) alongside the ISR there, to study the linkages between chemistry, winds and wave motions. Increasingly there is interest in MLT neutral dynamics and ionospheric (E-, F-region) perturbations, i.e. coupling between atmospheric and ionospheric regions.

Rocket investigations, especially alongside ground-based systems, continue to provide unique and essential high resolution and multi-parameter data. The Norwegian ALOMAR facility is the best illustration of this. There is a large set of ground-based lidar, radar and passive optical instruments that can monitor the state of the atmosphere in the height range 2–100 km. The parameters measured are density, temperature, winds, momentum transport, and concentrations of minor constituents such as ozone, water vapour and aerosols. The EISCAT is also important for such studies. A very small instrumented payload for launch with meteorological rocket systems has been developed. This Mini-Dusty payload was successfully flown in May 1997, and opens up new opportunities for inexpensive investigations of the middle atmosphere. Middle Atmosphere Dynamics and Structure (MIDAS) is also a new Norwegian–German middle atmosphere project, combining ground-based and rocket techniques. MIDAS includes the construction of four new payloads to be launched 15 times in five campaigns over the period 1999–2004. The prime objectives of MIDAS are to study turbulence, gravity waves and layered structures (NLC and PMSE) with a combination of in-situ and ground-based instruments. Scientific highlights are many, but include the identification of positively and negatively charged noctilucent cloud particles by means of rocket instruments.

Indian scientists have also been active with rockets. Ionization layers in the equatorial E-region 90–120 km were studied by rocket-borne probes. The results were compared with a mid-latitude station. Thin layers of 1–2 km thickness were seen in the daytime more frequently over the mid-latitude compared to the equatorial latitude. Balloon-borne results of vertical electric field and polar conductivity from the Indian zone in the 15–35 km region were also compared with the high and mid-latitudes. Latitudinal effects were observed. Brazilian scientists launched rockets from near the equator. The MULTIFOT II experiment measured a number of OH and oxygen airglow emissions from the 75–120 km region, with simultaneous ground-based measurements of the atmospheric sodium layer.

Satellite systems, in particular UARS (HRDI/WINDII instruments), continue to have an enormous impact upon our understanding of chemical aeronomy and dynamics. Increasingly there are comparisons with ground-based systems, whose high time resolution and ability to follow wave interactions in time, complement the spatial coverage of satellites. Focusing briefly on WINDII; operations have continued over 5.5 years now, and no degradation in instrument performance has been detected. Upper mesosphere and lower thermosphere tides have been characterized, and an empirical model developed. The influence of dynamics on emission rates has been studied, including that of the two-day waves for O(1S), and also for OH. Mesospheric temperatures from Rayleigh scattering have been determined, and the morphology of polar mesospheric clouds studied, as well as observations of polar stratospheric clouds and stratospheric airglow. Longitudinal effects on O(1S) have been studied and its long term trend.

The NASA Shuttle experiments CRISTA/MAHRSI (Germany) had a successful flight from 4–11 November 1994, with spatially well-distributed accompanying aircraft, balloon, rocket and optical system measurements. The Wuppertal team in 1996–97 evaluated 18 trace gases measured during the first CRISTA flight. Very pronounced small scale structures (streamers) were seen in horizontal tracer distributions in the lower stratosphere. They are discussed in the context of the tropical diffusion barrier. Fairly strong small scale structures were also present in the mesosphere. For instance, temperatures at low latitudes showed a pronounced diurnal tidal wave. In the lower thermosphere atomic oxygen was seen to sensitively react to geomagnetic activity. The Wuppertal team was also busy with the preparations for the second CRISTA flight on STS 85 (August 1997).

Czech scientists showed that the period of the CRISTA experiment/campaign (October–November 1994) was very representative of normal climatological conditions in the upper middle atmosphere over central Europe, based on night-time radio-wave absorption measurements in the lower ionosphere and the inferred gravity wave activity. They also showed that the very strong negative trend in the overall ozone content (a decrease by 50 percent over 20 to 25 years) was only slightly dependent on latitude (75–36N).

Preparations for future satellites continue. The US-TIMED system has been mentioned already. The work toward achieving well-calibrated and well-characterized instruments is advanced. This system will provide unique and global information on dynamics, thermal state, minor constituents and energy deposition rates for the middle atmosphere and lower ionosphere. The Swedish-led Odin satellite program (Canada, Finland, France) is proceeding well, with a launch date of mid-1998. Using also the Canadian OSIRIS systems (Odin Spectrograph Infrared Imaging System), this satellite will provide global data on aeronomy/minor constituents and structures, allowing for study of the ozone "holes", PMCs and stratospheric warming influences. Collaborations with ground-based systems capable of validating the Odin data, and of providing necessary wind and waves measurements for global modelling, are now being planned.

Theoretical studies are essential to a complete study of the middle atmosphere and lower ionosphere. There are several middle atmosphere models in existence, but the new Canadian MAM is an excellent example. There was continued 1996–97 development of this 3-D troposphere-stratosphere-mesosphere general circulation model. The climatology of the first-generation is about to appear; this represents the first published climatology of a middle atmosphere model that includes the entire mesosphere. Another important first is the identification of realistic tidal structures in the upper mesosphere of the model, whose annual variation agrees well with WINDII observations. Current work is focusing on performing long-term climate integrations, improving the treatment of stratospheric chemistry, and raising the model lid into the lower thermosphere. This will allow simulation of large-scale phenomena in the critical upper mesosphere/lower thermosphere region. The Canadian MAM is intended to be used to attempt the first-ever assimilation of mesospheric data, using a variational system applied to WINDII wind data. There is, and will be, considerable collaboration and linkages between MAM and the ground-based systems discussed above.

Chemical aeronomy must also have strong theoretical underpinnings. A preliminary United States study of the influence of electrical charging on the growth of aerosol particles in the upper mesosphere was completed. Growth by coagulation was found to be inhibited for moderate to high ionization rates, since the particles all tend to be negatively charged, but greatly enhanced for low ionization rates, when both positive and negative charges can become equally abundant. The results are important from the point of view of understanding the aerosol content of the middle atmosphere.

The major 1996 meeting on Solar Terrestrial Physics was the July COSPAR General Assembly in Birmingham, United Kingdom. There were symposia on many topics important to upper atmosphere research; and these were mentioned in the 1995–96 report. The major international meeting in 1997 will have been the "IAGA 8th Scientific Assembly, with ICMA, and the STP Symposia". The latter is the concluding event of the STEP Program (1990–97). The "IAGA Division II: Aeronomic Phenomena" symposia are of most significance to the upper atmosphere, and have been organized by people active in COSPAR, SCOSTEP and CEDAR. They include the following sessions: Upper Atmosphere Structure, Dynamics and Electrodynamics; Equatorial Ionosphere and Thermosphere Coupling Processes; Layered Phenomena in the MLT; Equatorial Atmosphere-Ionosphere Interactions; Gravity Wave Parameterization in the Middle Atmosphere. There will also, during the weeks of the IAGA conference, be meetings of SCOSTEP, the Steering Committees of SRAMP, PSMOS and EPIC; and General Meetings of those three latter groups to plan the campaigns, events, and data archiving and analysis required for particular studies. These post-STEP programs will have a profound effect upon this research area. The first results coming from these new initiatives will be reported upon in 1997–98.

Earth's Ionosphere, Thermosphere and Mesosphere

The Ionosphere, Thermosphere and Mesosphere (ITM), comprising regions between about 90 and 800 km in altitude, continues to provide an intensive focus of international research. This region has been studied for many years using a combination of ground optical and radio wave diagnostics, sounding rockets and satellite platforms. Much of the current research has been coordinated with the 1990–97 Solar Terrestrial Energy Program (STEP), and with the Coupling, Energetics and Dynamics of Atmospheric Regions (CEDAR) program (sponsored by the U.S. National Science Foundation). There are also SCOSTEP post-STEP programs planned for the 1997–2002 period: SRAMP (STEP Results, Applications and Modelling Phase); PMOS (Planetary-scale Mesopause Observing System) which will provide and develop a global network of observing systems to study the global scale chemical and dynamical influences of planetary waves/tides, and gravity waves propagating upwards into the ITM region; and EPIC (Equatorial Processes Including Coupling) will study the ITM coupling processes at low latitudes.

The 1996–97 period has seen the CEDAR program move into its mature (or "third") phase, utilizing networks of state-of-the-art instruments and coordinated data analysis programs. There have also been strong linkages developed with the upcoming NASA-TIMED satellite program (planned for launch in 2000), and with the "Space Weather" initiatives in the United States and internationally.

The National Space Weather Program (NSWP) in the United States is devoted to improve predictive services for the Near-Earth Environment. The "integrative" work (now in its second year of funding) is related to identifying, assessing and predicting the risks to ground-based and space based technological systems-as diverse as the risk of damage due to space-craft charging, to the possibility of disruption to electricity distribution systems and damage to extended oil distribution pipe-lines. It is expected that this effort will move from initial assessment into prediction followed by prompt circulation of near-term hazards within the next 12–24 months. The NSWP program derives particular benefit from the GEM (Geospace Environment Modeling) program of the U.S. National Science Foundation, which continues to develop methodologies for the accurate modeling a space weather events in the magnetosphere and the ever more accurate measurement/modeling of important inputs to the ITM region (aspects as critical as ion convection patterns, hemispheric heating rates, solar wind and interplanetary magnetic field configurations).

The Polar Cap Initiative of the U.S. National Science Foundation has established the Early Polar Cap Observatory (EPCO) at Resolute Bay, Northwest Territories, Canada. A combination of optical and H-F radio instruments have been used to investigate the mesosphere, thermosphere and ionosphere in the central portion of the geomagnetic polar cap. Plans for the deployment of an advanced Incoherent-Scatter Radar at EPCO have been adopted and the new radar and associated optical and radio instruments will be built and commissioned over the next three years.

The new EISCAT-Svalbard Radar (500 MHz, incoherent scatter radar) was commissioned, using a single antenna, in early 1996, and was officially opened in a ceremony in August 1996. Japan has joined the EISCAT Consortium, and as the result, the equipment for a second antenna is now in preparation. The ESR Facility will observe the polar ionosphere and magnetosphere in the vicinity of the polar cusp as well as the polar cap. Considerable facilities for optical observations of the aurora, thermosphere and ionosphere, already existing at Longyearbyen (Kjell Henriksen Auroral Observatory, formerly the Nordlysstasjonsen), will be used for joint studies with the ESR.

The Norwegian Space Centre has approved and implemented plans for launches of sounding rockets from Nye-Aylsund, Svalbard. Initial flights of NASA payloads are planned for late 1997 and 1998, which will explore the regions of the polar cusp and central polar cap.

The UARS satellite continues to provide important new measurements of upper atmosphere data - the most relevant being the upper atmosphere dynamics data sets obtained from the WINDII and HRDI wind-measuring instruments. A recent "Winds Workshop", held in Michigan, presented important new findings from the Inter-comparison Campaigns (Ground-based Radar and Optical comparisons with UARS). The UARS descriptions of diurnal and seasonal variations of winds, airglow intensities, and the altitude variations of airglow layers, are unique and provide a particularly exciting view of the variable upward propagation of tides and other waves through the lower part of the ITM region.

The NASA Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics (TIMED) Mission is being prepared for launch with a complement of four-instruments—UV Imaging Spectrophotometer, Fabry-Perot Interferometer, IR limb-Scanning Instrument and a Solar EUV Spectrophotometer—in January 2000. The mission will study the physical and dynamical processes of the Thermosphere-Ionosphere-Mesosphere regions, and the important interactions which occur throughout these regions.

The joint IAGA/SCOSTEP Assembly in Uppsala, Sweden, was the most important international meeting to be held during 1997. The meeting included sets of tutorial review papers and a full range of sessions devoted to special topics. Of particular interest were sessions devoted to emerging Space Weather predictive capabilities, a topic of increasing interest and challenge. Other sessions discussed polar cap and equatorial phenomena. Important new techniques to map the global ionosphere using data from the Global Positioning System (GPS) satellite array are under development.

The SuperDARN network (Super Dual Auroral Radar Network) of HF radars take advantage of backscatter power from ionospheric irregularities at high latitudes. This network consists of international collaborative activities between the USA, Canada, Iceland, and Finland in the northern hemisphere and various international collaborators in the Antarctic. During the past year, SuperDARN has participated in several international ISTP campaigns and UARC (Upper Atmospheric Research Collaboration) efforts at providing real-time diagnostics of high latitude convection. Efforts continue at stream-lining the product for easy visualization employing Internet capabilities. Several of the current difficulties are encountered by the very placement of the radars at remote inhospitable locations, but these problems are slowly being surmounted. Data from SuperDARN are being used in conjunction with model ingestion schemes, such as the U.S. Assimilative Mapping of Ionospheric Electrodynamics (AMIE) approach and similar studies based in Japan and Europe. These model ingestion schemes provide improved global inputs to existing ITM general circulation models.

ITM General Circulation models have continued their development, though extension to altitudes as low as 30 km for the NCAR Thermosphere-Ionosphere-Middle-Atmosphere-Electrodynamics General Circulation Model (TIMEGCM) code, and to higher spatial and temporal resolution. Ionospheric models have been used successfully to study aspects of ionospheric weather, such as polar cap patches, auroral features, etc.

The INTERBALL project consists of a pair of satellites which monitor the cause-effect relationship between the solar wind and the near terrestrial environment. One satellite orbits deep in the magnetotail providing a monitor of solar wind perturbations on the magnetosphere. The other satellite monitors the effect of these perturbations on the auroral region and ionosphere. These activities are conducted by an international team including Russian and Canadian scientists.

Equatorial aeronomy is experiencing a renewed phase of scientific interest by both the experimental and theoretical communities. A number of MISETA (multi-instrument studies of the equatorial thermosphere aeronomy) campaigns have been held to concentrate researcher's efforts at defining the state of the low latitude thermosphere and its coupling with the ionosphere. The results of the first MISETA activities have appeared in a special issue of the Journal of Geophysical Research in December, 1996.

The Upper Atmospheric Research Collaboration (UARC) continues to provide the community with a forum for conducting campaigns and sharing discussions of real-time data sets. The scope of UARC has increased substantially in the past year and now incorporates three NSF incoherent scatter radars, the EISCAT radar, Polar and Wind satellite data, one-hour Kp data, and several real-time space weather models. Intensive campaigns have been held which collected thermospheric and ionospheric data into a convenient multi-viewer display permitting researchers and students to exchange comments and discussions: a particular example is the April 1997 geomagnetic storm period. Continuing activities will also include efforts at post-campaign analysis and "electronic workshops".

Several coordinated data analysis activities are underway which are focusing on geophysical observations of the January and April 1997 space weather events associated with coronal mass ejections. Coverage of these events by instruments on the ISTP spacecraft and from the ground have provided unprecedented information on the response of the near Earth space environment to large perturbations.

As part of an NASA-sponsored data restoration effort, a large amount of topside ionospheric sounder data from the ISIS-2 satellite have recently been made available for Internet retrieval and viewing at the Web site *http://nssdc.gsfc.nasa.gov/space/isis/isis-status.html*. The data were digitized from the original telemetry tapes, which were selected from 23 ground stations from the years 1972–84. Most of these data are "new" data since they had not previously been processed into higher level data products.

Planetary Atmospheres and Aeronomy

The Galileo spacecraft reached Jupiter in early December 1995. It successfully deployed an atmospheric entry probe and then went into orbit around Jupiter. This mission is providing new, extensive and exciting measurements of the atmosphere and magnetosphere of Jupiter and its moons. Examples of these new results are the discovery of an intrinsic magnetic field of Ganymede, the likelihood of frozen ice on Europa, an atmosphere and ionosphere around Europa, enhanced (compared to solar) elemental abundances of the heavy elements in Jupiter's atmosphere and the near absence of clouds near the probe entry region, just to name a few.

Mars-Pathfinder one of the first two NASA Discovery missions, landed successfully on the surface of Mars in July of this year. It is nominally an engineering demonstration test of the landing system, but it also carried the following instruments: an imager, an atmospheric structure cluster and an alpha-proton-X-ray spectrometer, which is carried by a mini-rover called Sojourner. The Mars Global Surveyor spacecraft is headed to Mars and will begin orbiting the planet in September 1997. It carries the same instrument complement as Mars Observer did, except for the pressure modulated infrared radiometer and the gamma-ray spectrometer.

In Japan the ISAS Planet-B mission to Mars was initiated in 1992 and is on schedule for a July 1998 launch. The main scientific aim of this program is to study the martian upper atmosphere/ionosphere and its interaction with the solar wind. It has a very extensive and ambitious scientific payload; some of the instruments are being developed in collaboration with Canada, Germany, Sweden and the United States.

The other Discovery mission, NEAR (Near Earth Asteroid Rendezvous), flew by the asteroid, Mathilde, on 27 June of this year and made measurements on its bulk (e.g. size, shape, volume, spin state), surface (e.g. elemental and mineral composition, geology, structure) and internal properties (magnetic field, mass distribution).

NASA is preparing the Lunar Prospector, its third Discovery mission, for launch later this year. It will carry out low altitude mapping of the moon, as well as make measurements of surface composition, magnetic fields, gravity fields and gas release events. Work is also progressing in readying Stardust the next Discovery, which is a cometary/interstellar dust sample return mission.

Five other potential Discovery missions have been selected for further study; these are Genesis (solar wind sample return), Vsat (Venus atmosphere), Contour (Comet nucleus tour), Aladdin (Phobos/Demos sample return) and Messenger (Mercury orbiter).

The Cassini mission was readied for launch in October 1997 by NASA. It will carry the Huygens Probe, built by ESA, which will make measurements of the atmosphere of Titan. The Cassini Orbiter will make comprehensive measurements of the atmospheres and plasma environment of Saturn and Titan.

The Rosetta mission is a joint one between ESA and NASA and is now in its early development phase. The plans call for the Rosetta spacecraft to rendezvous with a comet and also to deploy a surface lander. The successful completion of this mission would lead to a major advance in our understanding of comets.

A vigorous program of theoretical studies of planetary atmospheres and plasma environments is continuing. Some of the activities are associated with the interpretation of past data sets as well as predictive studies associated with future missions.

Task Groups for Trace Species and the International Reference Ionosphere

COSPAR International Reference Atmosphere for Trace Constituents

The COSPAR International Reference Atmosphere for Trace Constituents was published in 1996. This was immediately followed by a successful meeting in July 1996, during the Birmingham COSPAR Assembly. During that meeting, many new results on trace and minor constituents models for the middle atmosphere, obtained from the UARS and other recent missions, were presented and discussed. The proceedings of that meeting will be published by Elsevier in Autumn 1997. The 1996 COSPAR meeting also started the planning for a new empirical modelling activity, incorporating all these new results, with the intention of producing an updated (1990s) CIRA for trace constituents of the Middle Atmosphere before the COSPAR Assembly in 2000.

The community involved in NASA's UARS is currently developing a middle atmosphere trace constituent climatology model, and a further important symposium will be held during the 1998 COSPAR Assembly in Nagoya as part of the process of developing the next generation of empirical and semi-empirical CIRA model, reflecting the enormous improvement in this area during this current decade.

International Reference Ionosphere

The International Reference Ionosphere (IRI), the standard ionospheric model developed by a joint Working Group of COSPAR and URSI, can now be accessed and run on the Internet at *http://nssdc.gsfc.nasa.gov/space/models/iri.html*.

The model continues to be very popular with more than 300 hits per month on the Web site and about 500 accesses per month to its ftp directory.

Progress in improving IRI was reviewed during the 1997 IRI Workshop at the Institute of Atmospheric Research in Kuehlungsborn, Germany from 27–30 May. The meeting was held jointly with the European Union Cooperation in Scientific and Technical Research (COST) project 251 (Improved Quality of Service in Ionospheric Telecommunication System Planning and Operations).

COST 251 is a follow-up project to the earlier COST project on Prediction and Retrospective Ionospheric Modelling over Europe (PRIME). The meeting provided an excellent forum for the exchange of expertise and ideas between these European and international ionospheric modelling teams.

Storm-time modelling is now a prime focus of the IRI project. Several teams are using theoretical models and/or the long record of ionosonde measurements (from the two CD-ROMs produced by NOAA's National Geophysical Data Centre) to establish updating algorithms. But even with the inclusion of storm effects in IRI, using IRI for predictions of 'Space Weather' on a daily basis will require updating with near real-time data. Of special interest is the updating with GPS measurements since these satellites provide the most evenly distributed data source for ionospheric information. A special IRI team including scientists from Canada, USA and Spain is now working on this problem.

The IRI Task Force Activity at the Laboratory for Atmosphere and Radio Propagation of the International Centre for Theoretical Physics (ICTP) in Trieste, Italy was continued in 1996 and 1997 with great success. The very focussed, hands-on activity has resulted in major improvements of the bottom-side and F1 region electron density profile for IRI.

SPACE PLASMAS IN THE SOLAR SYSTEM

COSPAR Scientific Commission D is responsible for monitoring the study of plasmas in the solar system, from the Sun's corona and solar wind to the magnetosphere and ionized atmosphere of each of the planets, including also the extended plasma environments of comets. Our knowledge of the physics of plasmas in space comes mainly from in-situ and remote sensing measurements made by space probes, but important information has also come from balloons, rocket probes, and ground based facilities.

The joint ESA/NASA heliospheric mission, called Ulysses, is successfully continuing its exploration of the inner heliosphere, with all instruments fully operational. Some important discoveries have been firmly established. There is a transition from the familiar gusty slow solar wind at low latitudes to a relatively smooth and constant fast wind at around 750 km/s at high latitudes. The composition of the wind differs markedly from one flow regime to the other and the transition is sharp. The dipolar nature of the magnetic field known to exist at the surface of the Sun has not been found at Ulysses altitudes (around 2 AU over the poles). Cosmic ray intensity over the solar poles is only a little greater than the intensity at low latitudes. This finding confounds beliefs held for many years. There are indications that the cosmic ray intensity at the north pole may be slightly higher than at the south, and that the "symmetry" equator for cosmic radiation in the 1994–95 time frame may have been around ten degrees south solar latitude.

In October 1995 Ulysses embarked on a second six-year orbit of the Sun, which will make possible an examination of the solar poles at a time of maximum solar activity, when the solar atmosphere will differ greatly from its 1994–95 quiet configuration.

The ICE spacecraft started life as ISEE 3 (International Sun Earth Explorer) in 1978. In recent times the radio signal from the spacecraft has been used to probe the content of the interplanetary medium, and especially in the period when the spacecraft-Earth line was passing close to the Sun.

The SAMPEX spacecraft, the first of NASA's small explorers, launched in 1992 into a near-Earth polar orbit, has studied the arrival and storage of anomalous cosmic rays in Earth's radiation belts. It was believed that all anomalous cosmic rays were singly charged, and indeed this feature helped separate them from the real cosmic rays which have been stripped of all available electrons. Recent observations, using Earth's magnetic field as an analyser, indicate that the higher energy anomalous cosmic rays may carry several electronic charges. This complicates the picture, but helps explain why the charged particles are accelerated to such high energies in the heliosphere.

The Solar and Heliospheric Observatory (SOHO) was launched on 2 December 1995. SOHO is part of the first "cornerstone" of ESA's Horizon 2000 program, and is carried out jointly with NASA. On 14 February 1996 it was inserted into its halo orbit around the sunward Lagrangian point and on 2 May it began its fully commissioned operational mission. With its mix of remote-sensing and in-situ measurements, SOHO investigates solar and interplanetary processes, many of which are closely related to those pursued by the IASTP missions. All instruments are working well and already excellent results are being obtained.

The "background noise" in the global solar surface velocity is much lower than expected and as a result helioseismology measurements are extremely sensitive. Flows under the photosphere, in the convection zone, have been measured for the first time. The Sun, now at minimum activity, maintains an unexpectedly high level of activity when observed in extreme ultraviolet light. Polar plumes, which connect to the polar solar wind, have been observed over a very wide temperature and space range, together with the photospheric magnetic field.

NASA's Galileo mission is continuing its study of the giant planet Jupiter's magnetosphere, moons and atmosphere. After the atmospheric probe was released in July 1995, orbiter and probe have reached Jupiter separately in December 1995. The orbiter flew close by the moon Io and made its closest approach to Jupiter, to record the probe signals as the latter descended through Jupiter's atmosphere. The orbiter then used its main engine to go into orbit around Jupiter to study its magnetosphere. Among the surprising results is the finding that the moon Ganymede seems to have a tiny magnetosphere of its own.

The ambitious program to study solar-terrestrial physics, referred to as the Inter-Agency Solar-Terrestrial Physics Program (IASTP), is now in its main phase. IASTP comprises a globally distributed fleet of satellites and ground-based instruments, all directed at studying the chain of plasma processes that govern the transfer of mass, momentum and energy from the Sun's atmosphere to the Geospace environment.

The Japanese contribution to IASTP, the Geotail spacecraft, is the oldest member of the satellite fleet and has been providing exciting data since its launch in 1992. Geotail's first goal was to explore Earth's magnetotail, up to distances of 220 Re, and has shown a richness in structure and dynamics which have changed our views of this region. After Geotail started descending to a its present 10 Re times 30 Re orbit, it started skimming Earth's magnetopause and bow shock and is ideally suited to study those boundaries. This orbit also traverses the source regions of the magnetic substorms.

NASA has contributed two satellites to the IASTP program, Wind and Polar, launched in November 1994 and February 1996, respectively. Wind's main goal is to study phenomena in the solar wind and to monitor conditions upstream of the magnetospheric system. For this purpose, Wind will be placed in a halo orbit around the L1 libration point between Earth and the Sun. So far it has used periodic encounters with the Moon to maintain a variable size orbit around Earth which allowed for studies of Earth's magnetopause, bow shock and foreshock regions, in addition to those of the solar wind. Polar was placed in a 90 degree inclination elliptical orbit with a 9 Re apogee initially located over the north pole. Polar is carrying out in-situ studies of the distant polar magnetosphere, but with its set of imaging instruments also investigates the auroral region.

Also part of IASTP, the program called INTERBALL is led by the Russian Space Agency, but involves a large international community of Russia together with Austria, Bulgaria, Canada, the Czech Republic, ESA, Finland, France, Germany, Hungary, Italy, Kirgizia, Poland, Romania, Slovakia, Sweden, United Kingdom and Ukraine. INTERBALL-Tail, a satellite-subsatellite pair in an eccentric orbit with 63 degree inclination and 200,000 km apogee, has been operating successfully since its launch in August 1995. Another such pair, INTERBALL-Aurora, was launched recently (August 1996) into an orbit with the same inclination, but lower (20,000 km) apogee. The configuration is particularly suited to study the cause-and-effect relationships between the plasma processes in the geomagnetic tail and in the auroral acceleration region.

Related to IASTP is the Fast Auroral Snapshot (FAST) satellite, the second in NASA's small explorer program. FAST was delayed two years because of launcher development problems, but was finally launched in August 1996. FAST will study the auroral acceleration region at altitudes of several thousand km with unprecedented time resolution, thus complementing the lower altitude measurements obtained earlier with the Swedish-German Freja mission.

In 1997 NASA launched the Advanced Composition Explorer (ACE) mission to study the composition of heliospheric plasmas and superthermal particles. This mission is still in its early phase and we anticipate major scientific contributions from the instrument complex onboard ACE.

As is apparent from the list of active or recently launched missions, the next few years should provide a great advance in our understanding of space plasmas, in spite of the loss of Cluster (in 1996). Ground based observations of various kinds are planned in conjunction with those missions and will contribute significantly to our understanding, particularly with regard to global questions, as will instruments carried on balloons and sub-orbital rocket flights.

RESEARCH IN ASTROPHYSICS FROM SPACE

Astronomy

The needs of Astronomy can only be met by access to the entire electromagnetic spectrum from the radio to the gamma-ray range. This makes the presence in space of appropriate instruments essential because 1) large parts of the spectrum do not penetrate the atmosphere of Earth and so observations are literally impossible unless the relevant instruments are placed in space above Earth's atmosphere, while 2) even for wavelengths that can reach Earth, the distorting effects of the atmosphere mean that substantial performance gains can be achieved with space-based instruments e.g. the HST. A considerable degree of complementarity is thus implied between ground-based and space-based astronomy. However given the current high cost and extreme shortage of finance for instruments in the space area, it is increasingly important to establish that access to space is absolutely essential and that the proposed observations cannot be pursued with ground-based facilities. In addition, there is increasing emphasis on the possibility of using small spacecraft with reduced launch and operations costs. While this approach can not always be successful for astronomy given the strong requirement to increase sensitivity through the use of larger apertures, it is clear that in future, consideration will increasingly be given to more modest scale missions.

Worldwide Astrophysical Space Programs

As in previous reports, an updated overview of world-wide space programs in Astronomy and Astrophysics is summarized in Tables 1 and 2. The tables list the missions which are operating in space and those which are approved and either awaiting a start or already under construction.

Tables 1 and 2 include the main responsible agency or nation; launch dates (actual or scheduled), and brief description of the main characteristics of the mission.

A large number of projects and proposals have been submitted to the various agencies. ESA has selected the Cobras-Samba microwave background mission - now known as Planck, for the M3 opportunity while an advanced astrometry mission will form part of the extended Horizon 2000 Plus program. Several interesting mission proposals in all areas of astronomy were submitted for the NASA Medium Explorer (MIDEX) program. This now includes the Microwave Anisotropy Project (MAP) mission. A far UV sky survey mission—Galaxy Evolution Explorer (GALEX), has recently been selected in the NASA Small Explorer (SMEX) program.

Comments on the content of the tables and on the situation in each of the principal spectral regions are given below.

<u>Gamma-ray</u>

With the continued success of Compton, the importance of this spectral domain is strikingly emphasized. Thus the start of the ESA Integral program, which includes high energy imaging and spectroscopy instruments along with context instruments for X-ray and optical monitoring, is particularly timely in enabling a strong and complementary follow-up mission.

X-ray/Extreme UV

The NASA Rossi-XTE mission devoted to temporal studies and broadband spectroscopy of X-ray sources (1-200 keV) has been producing new and exciting results on QPOs, neutron stars, pulsars and candidate black holes. The Beppo-SAX X-Ray telescope (Italy/Netherlands/ESA) devoted to imaging, broad-band spectroscopy and long term monitoring of X-ray sources (0.1-200 keV) has identified a fading X-ray source just after the occurrence of several gamma-ray bursts. This source has made possible a follow-up in the optical (ground based telescopes and HST). After 30 years of searches it appears that the elusive gamma-ray bursts are now identified with extragalactic counterparts at other wavelengths. The NASA HETE (High Energy Transient Experiment) mission to follow up gamma-ray bursts was tragically lost in November 1996 when it failed to separate from the launching rocket's third stage. The characteristics of the NASA AXAF (Advanced X-Ray Astrophysics Facility) have been measured and shown to lead to sub arcsecond X-ray images. The instruments have also been fully tested and the mission is due for launch in 1998. The ESA XMM is also progressing well. The X-ray mirrors also perform better than specification. The mission is due for launch in 1999. In the mean time German astronomers are developing ABRIXAS (A Broadband Imaging X-ray All-Sky Survey) as a follow-up to ROSAT. Also for launch in 1999, ABRIXAS will extend the sky survey conducted by the latter to energies up to 10 keV. Japan's ASCA mission is still fully operational while ASTRO-E, which includes a novel high resolution X-ray microcalorimeter, is progressing well through its development.

The NASA EUVE mission continues in operation while Spain's Minisat-1, carrying a UV spectrometer and a hard X-ray detection system, has been successfully launched and is operating in orbit.

Visible/UV

HST is fully operational and has been fitted with two new instruments in 1997. The ESA Hipparcos has completed its astrometry task with major findings while an advanced interferometry mission has been chosen for study as a cornerstone in the ESA Horizon 2000-plus program. In parallel, very large ground-based projects are underway in several countries. IUE operations finally ceased in February 1997. This ends an extremely productive mission which operated for more than 18 years and resulted in an output of more than 3400 publications in refereed journals. No successor to this enormously successful UV observatory is foreseen at present and continued weakness in this area will prove detrimental to astronomy. However the NASA Lyman, a specialist high-resolution UV spectroscopy mission due for launch in 1998, will have a significant impact in the areas of cosmic abundance studies and interstellar physics.

Infrared

ISO continues to operate extremely successfully after 18 months with several important findings emerging from observations in the 2.4 to 240.0 micron band. More than the two-year operational lifetime is anticipated before the liquid Helium is exhausted. SIRTF (NASA) is still being planned and a Japanese IR mission (IRIS) will be flown at the turn of the century. A small cooled IR telescope (IRTS) has been flown by Japan's ISAS on the Space Shuttle and successfully surveyed about 10 percent of the sky during its three week mission.

Sub-millimetre/Microwave

Approved missions are RELICT-2 (Russia) and the US SWAS, a small Explorer. ODIN is in phase B. FIRST, the largest mission approved in this frequency band, is the fourth of the ESA cornerstones. PLANCK (ESA) and MAP (NASA) have both been selected for the important field of microwave background anisotropy studies. ESA is presently studying the possibility of combining the FIRST and PLANCK missions on the same spacecraft.

Radio

HALCA (previously VSOP), the first operational space VLBI system, has been launched by ISAS on their latest M5 vehicle. Successful operation of this challenging mission has been achieved with the first maps demonstrating a resolution of 0.3 milliarcseconds at 5 GHz. RADIO-ASTRON, an additional VLBI mission which will further enhance the capability of ground-based VLBI arrays.

Complementary Research

In addition to the information from the analysis of photons, astronomers have seriously considered the possibility of using other particles such as neutrinos, gravitons, and charged species (Cosmic Rays). While neutrino detection, for the time being, appears to be an exclusively Earth-based activity, gravitational wave astronomy from space may have considerable potential. A space-based interferometer system (LISA) is being considered as a future cornerstone mission in the ESA Horizon 2000-plus program while the exciting OMEGA project is being studied as a possible future Medium Explorer in the NASA program. For successful gravitational wave missions, there is an urgent need to test critical technologies and small missions are being considered for this purpose. At present no missions are approved for Cosmic Ray studies. However ASTROMAG, which includes a large superconducting magnet, is being considered by NASA as an attached payload for the space station.

Conclusions

The same conclusions may be drawn as in recent years:

1. The state of astrophysical research in general and of the ever increasing part of it performed with space-based instruments continues to be healthy.

2. Increasingly severe budgetary pressures rather than scientific or technical reasons are leading to reductions in scope and eliminations of missions.

3. Most of the wavelength bands require further space investigation. The electromagnetic spectrum from UV to gamma-ray and including parts of the IR and sub-mm cannot be explored without continued access to space.

4. New missions tend to be bigger and more costly. Hence international collaboration and cooperation continue to increase in importance - both to contain costs for individual funding agencies and to avoid duplication in the implementation of large facilities.

5. Increasing consideration is being given to the role of small missions. While much of space astronomy requires intrinsically large facilities, technical advances - particularly in on-board data processing and storage, now allow modest scale missions to play an increasingly important role.

Table 1: *Missions in Operation*

Year	Radio	Sub-mm	IR	Visible/UV	EUV/X-ray	Hard X/Gamma-ray
1978			Kuiper			
1987						Mir/KVANT
1989						Granat
1990				HST	ROSAT	Ulysses
1991						Compton
1993					EUVE, ASCA	
1995			ISO, IRTS	IEH/UVSTAR		
1996					Rossi-XTE, Beppo-SAX	Rossi-XTE, Beppo-SAX
1997	HALCA				Minisat-1 (EURD)	Minisat-1 (LEGRI)

HALCA (ISAS)	10 m antenna for orbiting VLBI imaging 1.3, 6, 18 cm
Kuiper (NASA)	Airborne IR Observatory with 91 cm telescope.
ISO (ESA)	60 cm cooled Cassegrain telescope for spectrophotometry and imaging of IR sources. Observatory mission with contributions from NASA and ISAS.
IRTS (ISAS)	15 cm cooled telescope for imaging and spectroscopy of galactic and extragalactic sources. PI mission; Flown in 1995.
HST (NASA/ESA)	2.4 m telescope for imaging and spectroscopy of galactic and extragalactic sources. Observatory mission. NICMOS (IR) and STIS (Optical/UV) instruments now installed.
MINISAT-1 (Spain)	(EURD (E)) UV spectrometer on to monitor the diffuse background from 30 to 100 nm
EUVE (NASA)	Sky survey for broad band spectroscopy of bright sources in the range 8-50 nm. EUV spectroscopy. Now in observatory phase.

IEH/UVSTAR (NASA)	UV spectroscopy (60-125 nm) from the Shuttle. Two 30 cm diameter telescopes. Successfully flown.
ROSAT (D/NASA/UK)	Imaging Soft X-ray/EUV telescopes for surveys and pointed observations (0.03 - 2.5 keV). Guest observer program will continue to 1998.
ASCA (Japan/NASA)	High sensitivity imaging and spectroscopy of X-ray sources.
Rossi-XTE (NASA)	Temporal studies and broadband spectroscopy of compact X-ray sources (1 - 200 keV).
Beppo-SAX (I/NL/ESA)	Imaging broadband spectra and long-term monitoring of X-ray sources (0.1 - 200 keV). PI mission including a contribution from ESA Space Science Department.
MINISAT-1 (Spain)	(LEGRI (E/UK)); Low energy Gamma-Ray instrument 15-150 KeV.
Mir/KVANT (Russia)	Imaging, spectroscopy and timing studies in the band 2-200 keV. PI mission with guest observer program.
GRANAT (Russia/F)	Monitoring and localization of X-ray sources and low energy gamma-ray imaging. PI mission with French guest observer program for the gamma-ray telescope SIGMA.
Compton (NASA)	Imaging and broad band spectroscopy (0.1 MeV - 30 GeV).
Ulysses (ESA/NASA)	French gamma-ray burst experiment HGS-OGRE.

Table 2: *Approved Projects*

Year	Radio	Sub-mm	IR	Visible/UV	EUV/X-ray	Hard X/Gamma-ray
1998		ODIN			AXAF	
1999		SWAS		Lyman, Spectrum-X	XMM, Spectrum-X, ABRIXAS	
2000	Radio-Astron	RELICT-2			Astro-E	
2001	MAP			Spectrum-UV, GALEX		Integral
2004		FIRST/PLANCK				

Radio-Astron (Russia/Eur/USA)	10 m antenna for orbiting VLBI at 1.3, 6, 18 and 92 cm. Observatory class mission in phase C.
RELICT-2 (Russia)	Study of anisotropy/spectrum of 2.7 K cosmic background radiation.
MAP (NASA)	Microwave Anisotropy Project. Study of anisotropy of 2.7K microwave background. Medium Explorer mission.

PLANCK (ESA)	Previously COBRAS/SAMBA. Study of anisotropy of 2.7K microwave background. ESA medium mission (M3) in Horizon 2000 plus program.
SWAS (NASA)	55 cm off-axis Cassegrain warm telescope for spectroscopic survey of the galactic plane in lines of H_2O, O_2, CI, CO (480-550 GHz).
ODIN (S/F/Canada/SF)	1.1 m telescope for mm (119 GHz) and sub-mm (420-580 GHz). Interstellar chemistry and atmospheric ozone.
FIRST (ESA)	3 m warm Cassegrain telescope for high throughput hetrodyne and far IR spectroscopy and imaging. Observatory class mission.
SPECTRUM UV (Russia/I)	Optical/UV telescope - 1.7 m, 90-900 nm, for spectroscopy and WFI
GALEX (NASA)	Galactic Evolution Explorer. UV all-sky survey mission.
SPECTRUM X	Spectroscopy, imaging, monitoring and polarimetry (Russia/NASA/EUR) of X/gamma-ray sources. PI mission in phase C/D.
AXAF (NASA)	High res. X-ray imaging/spectroscopy. Observatory facility.
XMM (ESA)	High throughput spectroscopy and imaging in the soft X-ray range. Observatory in phase B.
ABRIXAS (Germany)	High energy all-sky X-ray survey in the 1 - 10 keV range.
ASTRO E (ISAS/NASA)	High throughput imaging X-ray spectroscopy facility - including a microcalorimeter and CCDs, for the range 0.1 - 10 keV.
Integral (ESA)	Imaging and spectroscopy from about 5 keV to 10 MeV. In phase B.

Solar Physics

The high temperatures reached in the upper chromosphere and corona dictate that the solar atmosphere is best observed at shorter wavelengths—ultraviolet (UV), extreme ultraviolet (EUV), X-ray and gamma-ray. Work at these wavelengths must be undertaken from space since the radiation cannot penetrate the atmosphere of Earth. However even at visible and IR wavelengths, observations from space eliminate the distorting effects of Earth's atmosphere thus allowing imaging of fine structures on the Sun's surface or photosphere at size scales of approximately and eventually below, 100km.

The transfer of mechanical energy from below the photosphere and the conversion of this energy to forms that are responsible for the heating and activity of the corona and the acceleration of the solar wind remains the focus of considerable effort for space-based solar physics. Both problems require observations of the solar atmosphere on the smallest possible scale since it is clear that some of the crucial physical processes are very localized. In addition a new channel for solar information is being developed thanks to recent work from the SOHO spacecraft in particular. These observations allow us to probe in detail for the first time the operation of convective energy transfer from the interior to the surface. The emerging magnetic flux is also being studied in detail from SOHO. Thus in the future emphasis will shift to coordinated studies of how the Sun's interior is magnetically coupled to its high atmosphere and how the convective dynamo in particular transfers its energy and initiates the violent events e.g. Coronal Mass Ejections (CME), solar flares, which can lead to consequences of major economic importance for spacecraft operating in near-Earth orbits and occasionally for power distribution systems on the surface of Earth itself.

Understanding the outer layers of the solar atmosphere and the transfer of energy to these regions from the interior represents a major intellectual challenge which is of substantial cultural significance. It also has a huge potential impact on both our economics and, through the Sun's influence on climate, our quality of life on Earth. The past major solar space missions have made significant contributions to this understanding by allowing coordinated studies over a wide range of wavelengths including visible, UV/EUV, X and gamma-ray photons. This emphasis on coordination is one of the key elements in most of the major programs for solar physics. Furthermore, from lengthy experience in solar observing and the need for collaboration with colleagues in many nations, the solar physics community has a long and successful history of international collaboration which is fully exploited in planning space missions.

Currently Operating Solar Programs

Current solar programs are directed at three broad areas of solar-terrestrial science, the solar interior, the solar atmosphere and the influence of the solar wind and of large solar events, such as CMEs and solar flares, on Earth and on the interplanetary medium. Thus in addition to the important fundamental aspects, this work has the ultimate goal of enabling us to forecast CMEs and other facets of solar activity which can strongly influence the interplanetary and terrestrial environment. Studies of the Sun's interior, undertaken from SOHO with the techniques of helioseismology, are allowing us to establish values for the fundamental parameters density, temperature, rotation rate and composition. Measurements of emerging magnetic flux, in addition to providing information on the nature of the solar dynamo, are beginning to permit examination of the most probable sources of energy for the hot solar atmosphere. This atmosphere is being studied directly by X-ray, EUV and visible light observations with imaging telescopes, spectrometers and coronagraphs on the Yohkoh and SOHO spacecraft. These instruments address a broad range of scientific questions regarding the Sun's magnetic activity cycle, solar flares, the nature of the inner and extended corona, CMEs and the acceleration of the solar wind. Useful progress is being made in explaining the high temperature of the solar corona while investigation of the sources of the solar wind, crucial for the understanding of mass loss from the sun and ultimately for clarifying important features of stellar evolution, is also making good progress. Mass ejections have impact throughout the interplanetary medium and have an especially important role on the magnetic configuration of Earth. Study of these important events is being enormously advanced by SOHO coronagraph observations of the disturbed corona and by both SOHO and Ulysses studies of the material and energy transported into interplanetary space as a result of these events.

SOHO is a joint ESA–NASA mission launched successfully on 2 December 1995. The SOHO spacecraft arrived at the L1 Lagrangian point between Earth and the Sun on 14 February 1996. From this unique vantage point, 1.5 million km in front of Earth, SOHO observes the Sun continuously, overcoming the day/night cycle in gathering the data. Moreover at the Lagrangian point it can avoid the effects of orbital velocity present in low Earth orbiting missions and of the geocorona ultraviolet emission. SOHO therefore has an unprecedented view of solar phenomena and detects with minimum noise, solar oscillations and the solar ultraviolet emission. Because of its smooth trip to the Lagrangian point and the excellent performance of the scientific instrumentation, SOHO has a long operational life ahead of it.

SOHO is one of the most ambitious solar physics missions so far deployed. Its scientific payload consists of 12 instruments, including six built by ESA countries in collaboration with groups in the United States. These instruments study the Sun, from the centre by helioseismology, to the outer atmosphere by remote sensing in the visible and in the ultraviolet. The solar wind is simultaneously probed by in-situ measurements. The twelfth instrument observes Hydrogen Lyman alpha emission from the interplanetary medium to monitor the solar wind mass flow. The ESA-NASA cooperation in SOHO includes the staffing of a common operations centre at the NASA/Goddard Space Flight Centre for day-to-day operational decisions and collaborative research. The performance of the SOHO instruments has so far been excellent and a wealth of new results has been gathered in the first year and a half of scientific observations.

The white light and UV coronagraphs are providing dramatic images of CMEs. In these phenomena the Sun is releasing large amounts of hot material into the heliosphere. The mass input in the solar wind during mass ejections has been found to be much larger than expected. Also the frequency of such phenomena is greater than anticipated for the current phase of low solar activity. Such events disturb the whole solar system and can affect Earth's own space environment. Coronal mass ejections can also have dramatic effects on telecommunication satellites.

SOHO has mapped for the first time the fast and slow solar wind flows in the outer solar atmosphere thus enabling us to relate the flows to the topology of the solar magnetic fields. It is now possible to trace the solar wind acceleration up a few solar radii from the solar surface. The acceleration of the solar wind turns to be much more effective at the solar poles and in other regions where magnetic fields are open. Here the solar wind speed reaches 800 km/s at about three solar radii out from the solar surface. Acceleration is less effective near the solar equator where closed magnetic field lines underlie the streamers which are probably the source of the slow solar wind.

The surface of the Sun turns out to be highly dynamic even in periods of low solar activity, with continuous emergence and cancellation of magnetic fields, as shown by the high resolution telescopes observing the solar disk and the inner corona. A new class of phenomena, named blinkers, has been identified which along with other new variable phenomena, may provide an important input to the problem of heating the solar atmosphere. These instruments are also able to localize the emergence of coronal mass ejections near the solar surface. Large global disturbances caused by flares have also been identified. They are in the form of waves propagating from the site where the flare occurs throughout the entire solar atmosphere.

One of the SOHO instruments surveys the sky around the Sun to examine the ultraviolet glow from hydrogen atoms. It is clear from the UV sky maps obtained so far that the solar wind blowing from the poles is less strong than that from lower latitudes. Earth is also visible in the maps produced with this instrument, because a cloud of hydrogen gas called the geocorona envelopes it and glows in the ultraviolet. As SOHO sees the geocorona from the outside, it will be able to monitor the effects of solar activity on Earth's outer atmosphere.

SOHO is successfully probing the interior of the Sun. It does so with several instruments that observe the solar surface oscillations that can be detected almost completely free of noise. The measurements are of small periodic variations in emission intensity or in surface velocity. The detection of short-range oscillations due to sound waves has already allowed us to trace the gas motions occurring just below the solar surface as well as solar rotation in and below the convection zone. Rotation has been found to be less dependent on latitude than on the solar surface.

In August 1991, the Japanese Institute for Astronomical Science and Aeronautics (ISAS) launched Yohkoh, the only long duration mission totally devoted to solar observations during the current cycle. The four-instruments on Yohkoh were designed to study high energy solar flare activity, the global coronal structure and the irradiance variations of the Sun. Yohkoh is carrying: the Soft X-Ray Telescope, a U.S.-Japanese collaborative experiment, which is imaging the soft X-ray corona and a Bragg crystal spectrometer developed jointly by experimenters in the United Kingdom, United States and Japan. The Japanese instruments include an advanced Fourier-synthesis hard X-ray telescope providing much better sensitivity and resolution than the imaging detectors previously flown on the Hinotori and Solar Maximum Mission satellites. Higher energy X-rays and gamma-rays are also monitored by the Yohkoh instruments provided by Japanese groups.

After six years of operation, Yohkoh has produced a wealth of dramatic new results. Its excellent spatial and temporal resolution have revealed the highly dynamic nature of the solar corona with changes of the coronal magnetic structures taking place very suddenly. With Yohkoh the process of magnetic reconnection was for the first time actually observed to occur in solar flares and active regions. Yohkoh has discovered active region brightenings with a frequency of occurrence as a function of their energy which is a continuous extension of the similar distribution for flares. This implies that small events ("microflares") are not over-abundant. A new explosive coronal phenomenon—Jets—has been discovered. The energy release mechanism again involves magnetic reconnection. With the decline of the current solar cycle, much new information has been obtained on the evolution of coronal streamers, the related occurrence of CMEs and on the nature and evolution of coronal holes - the sources of the high speed solar wind streams. Novel observational techniques for the detection of CMEs are proving particularly successful.

Since the launch of SOHO, an increasing volume of joint observations is being carried out. Active region evolution, coronal bright points, streamer development and CME observations have all benefited from this joint approach which is set to continue and develop further. In addition to work with SOHO, simultaneous observations of the Sun which include Yohkoh, U.S. and Japanese sounding rockets and several ground-based observatories are continuing. Support for Yohkoh operations is planned at least through 2002 when spacecraft reentry is predicted. Thus observations will cover an entire solar cycle and enable detailed study of the impact of the cyclic rearrangement of magnetic field in the solar corona. In addition, with the return of Ulysses to the solar neighbourhood in 2001 and the anticipated continuing operation of SOHO, all of the elements will be in place for a major study, at solar maximum, of the Sun's outer atmosphere and its influence on Earth.

The NASA solar physics program uses flight opportunities from the Space Shuttle to conduct investigations of the corona with Spartan—a retrievable, autonomous satellite that permits up to two days of solar observing time. A white light coronagraph and an ultraviolet coronal spectrometer study bulk flow patterns and acceleration mechanisms of the inner solar wind. The instruments undertake UV spectroscopy and white light polarimetry of the extended solar corona from 1.5 to 6 solar radii from Sun-centre, thus allowing measurement of temperature, densities and bulk outflow velocities of electrons, protons and several minor ions. The resulting description of the extended corona can be used together with theoretical studies to identify and understand the physical processes involved in solar wind acceleration.

Three Spartan missions have been flown while a further mission has undertaken joint observations with the SOHO spacecraft. NASA also pursues a program of sounding rocket launches for the purpose of verifying the calibration of several of the SOHO instruments.

Coronas is a series of Russian satellites designed to observe the solar atmosphere from near-Earth orbit, and to observe solar activity and magnetospheric solar effects. They will carry a number of instruments developed by groups from Russia, in collaboration with workers from many other countries. The instruments include X-ray spectrometers, multi-layer imaging telescopes and coronagraphs, as well as detectors for helioseismology.

Coronas-I was launched on March 1994. The 11 instruments of the scientific payload covered a wide region of the electromagnetic spectrum from radio to gamma-rays. Particles were also detected. The main instruments are an imaging X-ray telescope and spectroheliograph (6 intervals in 2-304 Angstrom spectral range) having spatial resolution a few arcseconds, an optical photometer for measuring solar oscillations, a radio-spectrometer and a set of hard X-ray and gamma-ray spectrometers from 1-2 MeV.

Currently operating missions of special importance for solar studies are Ulysses and the Compton Gamma Ray Observatory.

Ulysses, launched in October 1990, is an exploratory mission carried out jointly by the European Space Agency and NASA. Its primary objective is the study of the interplanetary medium and solar wind as a function of heliolatitude. The solar physics objectives of Ulysses encompass the study of the structure of the interface between the Sun and the solar wind/interplanetary magnetic field, solar radio bursts, solar X-rays and solar cosmic rays out of the ecliptic plane. On September 1994 after a journey of almost four years Ulysses reached its maximum latitude during the first-ever pass over the south pole of the Sun. Ulysses has spent a total of 234 days above 70 degrees latitude during its first polar pass. The second polar pass, over the north pole, occurred on 31 July 1995. The spacecraft has already sent back a wealth of extremely valuable information from the polar regions on the properties of the high-latitude solar wind and interplanetary magnetic field. The acceleration of energetic particles, at large radial distances and high latitudes in regions where co-rotating solar magnetic fields interact, has been studied in detail. Continued operation of Ulysses for a second complete orbit has been approved by both NASA and ESA. Thus the spacecraft will return to the neighbourhood of the Sun in 2001 to make a new series of observations over a wide range of solar latitudes but this time under solar maximum conditions.

The Compton Gamma-Ray Observatory (GRO), launched in 1991, is well-suited for observations of the solar X and gamma radiation which are the most energetic emissions from solar flares. Flare emission is observed in the energy range 50 to 1000 keV and above 20 MeV. GRO data allow extremely accurate measurement of the spectrum of the Sun's non-thermal radiation. Many important results have emerged including the direct demonstration by timing that non-thermal electrons move from the coronal flare release site to impact the Chromosphere. Compton continues to provide valuable observations of high energy phenomena on the sun.

Missions Currently Under Development

Coronas-F is under development in Russia and is scheduled for launch in late 1998. The payload will include improved versions of the instruments of Coronas-I. Coronas-F will also observe spectral lines in the region 3-7 Angstrom. The third solar mission in the Coronas program is Foton which will include a large solar gamma-ray telescope.

The Transition Region and Coronal Explorer (TRACE) spacecraft, a NASA small Explorer mission, has had some delays due to launch vehicle development problems. It is now scheduled for launch in March 1998 into a Sun-synchronous orbit to allow eight months of continuous solar observation. It will be operated in coordination with Yohkoh and SOHO. The objective of the TRACE mission is to observe directly the connections between the small-scale features that characterize the photospheric magnetic field and the larger scale structures that are seen in the solar corona thus pursuing the discovery by Yohkoh that the corona is a continuously dynamic atmosphere which is responding to impulses from the photosphere. TRACE will survey this connection from the photosphere into the corona, with unsurpassed temporal and spatial resolution. Thus TRACE is expected to make major contributions to our understanding of the mechanism of coronal heating. The TRACE instrument is designed to isolate narrow UV and EUV spectral bands containing emission lines formed in the chromosphere, transition region and corona. The spacecraft is now in the final stages of integration and calibration. TRACE is an open mission—all data and related analysis software will be freely available to the entire solar physics community.

The U.S. Air Force is building an instrument called the Solar Mass Ejection Imager (SMEI). Its goal would be to provide advance warning of the arrival at Earth of solar transient disturbances. It would also be able to map mass ejection in three dimensions. This mission will fly in the Yohkoh and SOHO time frames for complimentary studies of the extended solar corona.

Future Solar Programs in Planning

Future solar space missions continue to focus on understanding the problem of chromospheric and coronal heating namely the coupling of sources of energy in coronal activity with structures and changes of magnetic fields and plasma motions in the solar outer atmosphere. Significant advances in this field require major improvement in the resolution of the instruments and the use of stereoscopic techniques to define the geometry of the magnetic confinement of the plasma in the solar atmosphere. In addition, the study of CMEs is assuming a much increased importance because of the impact of these events on the near-Earth environment.

Following the highly successful solar missions Hinotori and Yohkoh launched by ISAS, the Japanese solar physics community plans a further Sun-observing satellite. The mission, Solar-B, has been selected by ISAS and, given Japanese government approval, will be launched in

February 2004. The mission is expected to involve teaming between the Japanese, American and British solar physics communities. The model payload includes an optical telescope capable of making photospheric images with a spatial resolution of 200 km on the solar surface and of measuring vector magnetic and velocity fields in the photosphere. There is also an X-ray imager for the diagnosis of plasmas having temperature of 0.5 to 10 million K. Line broadening in transition region and coronal emission lines, which may be manifestations of energy input into the corona, will be observed with an EUV imaging spectrometer. A Sun-synchronous orbit will be chosen to minimize the effects of observing time gaps and of line shifts due to the spacecraft motion, thus an eight month period of continuous observation will be available from the start.

Recently selected for flight in the NASA Small Explorer program, the HESSI mission will employ cooled Germanium detectors with coded mask imaging systems to observe solar flares with unprecedentedly high non-dispersive energy resolution. Operating in the energy range up to 500 keV, the mission is scheduled for launch in 2000.

The Space Solar Telescope was proposed in China in 1992. The telescope system will consist of a diffraction limited optical telescope with 1 metre aperture size, spectrographs, and attached telescopes for the UV, soft and hard X-rays. The satellite carrying the telescope will be placed in a circular polar orbit of 500 km. Launch is planned in the years 2001–02, around the maximum of the next solar cycle. The major scientific targets are to achieve a breakthrough in solar physics by coordinated high-resolution observations of the magnetohydrodynamic processes in the solar atmosphere. The telescope will obtain two-dimensional spectra, magnetic vector fields, velocity fields and images in the visible, UV and X-ray spectral ranges.

The Solar Interferometric Mission for Ultrahigh Resolution Imaging and Spectroscopy (SIMURIS) was studied by the ESA in the framework of the Space Station Attached Payloads and recommended for a second phase of study in 1992. Uncertainties on the Space Station Program have delayed the work though studies were undertaken for accommodation of a reduced version on the External Viewing Platform of the Columbus Module. SIMURIS will provide ultra-high spectral, temporal and spatial resolution to investigate the very fine structure of the Sun. Thus it would be a unique mission capable of observations at scales smaller than 0.1 arcsec or 70 km which are appropriate for many of the processes occurring in the solar atmosphere. Besides its temporal and spectral coverage, the SIMURIS Mission also proposes a UV imaging interferometer from 1175 to 2800 Angstrom with ultrahigh spatial (~ 20 km), spectral and temporal (50 ms) resolutions.

Cooperation between the United States, Russia, Europe and Japan is proceeding toward the approval of a heliospheric probe mission consisting of two spacecraft, Solar Probe and Plamya, to graze the Sun's corona at about 4 and 10 radii. These spacecraft would carry a variety of very small in-situ instruments and imagers for testing all of our current beliefs concerning the Sun's outer atmosphere some time after 2000. Progress continues towards the realization of these interesting missions.

Studies are beginning in Europe, the United States and Russia for a program which would place three or more spacecraft in orbit around the Sun so as to view it from additional directions to that represented by the Earth-Sun line. Methods for placing one spacecraft in a solar-polar orbit with plane at 90 degrees to the Earth-Sun line are also being discussed. Such a mission would provide a tomographic view of solar atmospheric structures and of the surface magnetic fields. It would produce a major advance in the understanding and forecasting of CMEs. Detailed study work will begin in the NASA program during 1998 while a stereo mission is a leading candidate for selection within the future ESA program.

ESA is studying the possibility of flying several solar instruments, some of which have been developed for the Eureca platform, on the ISSA. They include systems devoted to the study of solar variability at UV wavelengths which is of particular importance for Earth's atmosphere and the evolution of climate.

Conclusions

Solar physics activities in space include extensive international cooperation and a rich variety of research goals over the next decade. These involve both the continued operation of existing spacecraft and preparation and planning for future missions. Studies of the Sun have a dual importance in that the Sun is not only a prototypical object for much of astrophysics but also has the driving role in defining the heliosphere, in influencing Earth and in controlling the near-Earth environment. With the advent of new communications technology, the long-standing tradition of international cooperation in solar research will be strengthened still further as we enter the new millennium.

LIFE SCIENCES AS RELATED TO SPACE

Radiobiology

Two important reports have been issued by panels in the United States in the past two years outlining the problems of assessing radiation risk to space travellers outside the confines of the geomagnetosphere and suggesting the research necessary to lower the uncertainty in present risk estimates. In particular, effects on humans from high energy particles with charge equal to or greater than 2 (i.e., HZE particles) were singled out as being the most important to be studied, as our knowledge about them is notably incomplete thus leading to high uncertainties in the estimates of risk.

One report, entitled "Radiation Hazards to Crews of Interplanetary Missions—Biological Issues and Research Strategies," was prepared by a Task Group of the Space Studies Board of the National Research Council of the National Academy of Sciences (1996). Of the several conclusions of this report, the following appear to be the most important:

1. The effects of the highly ionizing component of the galactic cosmic rays to human health is largely unknown. A more thorough understanding of cancer induction, central nervous system changes, cataract formation, heritable effects and early effects on body organs and function is necessary for the rational design of shielding to be provided by space vehicles for interplanetary missions.

2. Although cancer risk appears to be the most important late effect to crew members, the central nervous system may also be of concern due to traversal of the very highly ionizing component of the galactic cosmic rays, HZE particles. Further

experimentation is essential to determine if damage from such radiation poses a significant risk.

3. It appears to make sense from an economic point of view to increase research budgets to decrease the uncertainty in risk estimates rather than to provide possibly unnecessary additional shielding on the spacecraft to protect space travellers from the higher design risks occasioned by the high uncertainty in the present estimates.

4. Unless access is obtained to a reliable source of high-energy heavy ions (HZE particles) for a significant fraction of each year, it will take over 10 years, perhaps 20 years or longer, to reduce the present large uncertainties in cancer risk. This would "postpone the design of necessary shielding or may result in the use of excess shielding (at a higher cost) and possibly delay any planned Mars mission beyond the next quarter century." Even if the necessary facilities, expertise, and funding were available now, it would take about 10 years to provide the data to assess the best way to provide adequate safeguards for the flight crew.

5. To carry out the required research, a number of possibilities should be explored, including international collaborations, more running time at existing accelerators, expansion of existing facilities, commissioning of new beam lines, and the construction of a new dedicated high-energy heavy ion facility.

The second report, entitled "Modeling Human Risk: Cell and Molecular Biology in Context," was prepared by a panel selected to "evaluate the extent to which experiments with animal models are essential for the development of new and more accurate predictions of the risks associated with exposure to HZE particles" (1997). This will "provide a basis for a research agenda to be developed and implemented well before a mission to Mars". The major conclusions were:

1. Our current knowledge of health effects of exposure to galactic cosmic radiation is inadequate.

2. Neither existing in vitro and culture models nor theoretical and computational biology can substitute for in vivo studies.

3. Animal experimentation utilizing state-of-the-art cell and molecular biology techniques is "most emphatically" needed. "The Panel unequivocally endorses the ethical, informed and optimal use of animals". Although the mouse has particular advantages as a model system, other species and systems should be considered where a model has clear experimental advantages for answering a specific question. Genetically engineered mice can be used to evaluate mechanisms of radiation-induced cancer and neurodegenerative damage.

4. Because many radiation effects become apparent months or years after exposure, longitudinal studies are desirable to distinguish early and late health effects. Age of the animal is an important variable.

5. The impact of HZE particles on individual neurons and neuronal networks in model organisms must be studied to determine whether neurodegeneration in humans might be of concern.

Planetary Biology and Origins of Life

Mars is of particular interest to COSPAR's exobiology researchers and to its planetary protection program. Because of the general similarities between Mars and Earth, in particular their early history, and because mission and observational data still suggest the potential for Mars to harbor life under its surface, plans for the exploration of Mars are subject to strict planetary protection requirements. These requirements affect both the spacecraft which may land on the surface of Mars, and those spacecraft which may return samples of Mars to Earth.

In 1992, the U.S. National Research Council's Space Studies Board (SSB) conducted a study published in the report, "The Biological Contamination of Mars: Issues and Recommendations". Using the best information available at the time, this report provided advice on a new, relaxed, planetary protection implementation that the Board felt would meet long-established planetary protection requirements for Mars lander missions. The key findings of the report were that the probability of growth of terrestrial organisms on present-day Mars is essentially zero, and that a reduction of the biological load carried by all missions to the surface would minimize the chances of jeopardizing future experiments. The report stipulated biological cleanliness requirements for landers, and made orbital lifetime and probability of impact requirements for orbiters optional, depending on the cleanliness of the spacecraft. It also defined the period during which Mars should be protected in terms of a relative timeframe, rather than specifying dates, as did the earlier policy.

In 1994, COSPAR reviewed the new recommendations for Mars landers at its meeting in Hamburg. At that meeting, the resolution that the SSB requirements be adopted as COSPAR Planetary Protection policy was adopted by COSPAR. In late 1996, three spacecraft (two U.S. and one Russian) were launched toward Mars in compliance with these new requirements (and the recent Pathfinder mission to Mars would not have been possible within the cost/performance targets without the new implementation procedures), though the Russian spacecraft, Mars-96, failed to achieve Earth orbit.

Given the goal NASA had established to eventually return a sample from Mars to Earth, the 1992 SSB report was contemplated as the first in a series that would also provide advice on how NASA should treat such a sample-return mission. Accordingly, NASA requested the continuation of the SSB's work, and in 1997 the NRC published the report, "Mars Sample Return: Issues and Recommendations", which reported the results of their study. This report proved to be quite timely, as it was published as NASA was examining opportunities to conduct an early sample return mission to attempt to follow-up on the circumstantial evidence for life on early (~3 byr) Mars that had been found in the Martian meteorite, ALH84001.

The findings of this second SSB report were consistent with the growing realization that the results of the Viking missions with respect to life represent knowledge about Mars that, in the case of the life detection package, may be limited to the very surface of the planet. While the Viking missions represented the best thinking about life on Earth at the time of their development, later findings about life at hydrothermal vents in Earth's ocean and in volcanoes, as well as evidence of thriving ecosystems several kilometres below the surface of Earth, have caused a reexamination of the paradigms associated with planetary life forms. In view of this new knowledge, the SSB found that, 1) there remain plausible scenarios for extant life on Mars, 2) the contamination of Earth is unlikely to pose a risk, but the risk is not zero, and 3) that uncertainties with regard to the possibility of extant life can be reduced through research and exploration. These findings then were mapped onto recommendations that, 1) samples returned from Mars should be contained and treated as though potentially hazardous until proven otherwise, 2) if sample containment cannot be verified en route to Earth, the sample and spacecraft should either be sterilized in space or not returned to Earth, 3) the integrity of sample containment should be maintained through reentry and transfer to a receiving facility, 4) that controlled distribution of unsterilized materials should only occur if analyses determine the sample not to contain a biological hazard, and 5) that planetary protection requirements for the first sample return should not be relaxed for subsequent missions without thorough scientific review and concurrence by an independent body.

To ensure that these recommendations could be carried out, the SSB also recommended that a research facility for receiving, containing, and processing should be established as soon as serious planning for a Mars sample return begins, and that it should be operational at minimum, two years before launch. This facility was recommended to have a multidisciplinary science staff for development of the appropriate sample-handling procedures, and an advisory panel of scientists established for oversight responsibility. The SSB also recommended that there be formed an interagency panel of experts to coordinate responsibilities and advise NASA on implementation of planetary protection measures. Finally, the SSB recommended that an administrative structure be established to verify and certify adherence to planetary protection requirements at each critical stage throughout any sample return program, and that the public should be openly informed of NASA's efforts in planetary protection.

These recommendations will be brought before COSPAR at the 1998 meeting in Nagoya.

With the likely acceptance of virtually all of the 1997 SSB recommendations on Mars sample return, much additional work needs to be accomplished prior to a mission being approved. Technology requirements include the reliable sealing and preserving of the Mars sample (no accidental release, no terrestrial biological contamination) and a means whereby to break the contact chain between the outside of the sample container and the surface of Mars. Perhaps most critically, a protocol must be developed for quarantining and testing the returned martian sample for signs of life, while preserving other science objectives.

Meanwhile, NASA has requested a new SSB study to address sample returns from bodies other than Mars. This study, Chaired by Professor Lesley Orgel, recognizes the variety of worlds that have been opened by small, relatively inexpensive missions, such as Muses-C and missions of the NASA Discovery series, as well as acknowledging the reshaping of our ideas about life in the solar system that have been occasioned by the Galileo spacecraft's discovery that an ocean under the ice on Jupiter's moon Europa might, indeed, exist. Such an ocean would present a compelling target for the further exobiological exploration of the solar system beyond Mars, and a particular challenge for planetary protection.

Natural and Artificial Ecosystems

Continued development and testing of light-emitting diodes (LEDs) for plant lighting systems (developed by Quantum Devices, Inc.) have produced LEDs with longer operating life spans than arc discharge and incandescent lamps, and can now be explored as an intense visible light source to replace lasers for photodynamic therapy for cancer treatment.

The use of microwave-driven lamps for growing plants is also under development, and holds potential for substantial improvements in electrical conversion efficiencies if solid-state magnetrons can be developed.

The use of recirculating hydroponic systems to grow potatoes has stirred interest in some commercial groups who are interested in producing disease-free "seed" potatoes for seed expansion programs. It usually takes about five years to produce enough seed potatoes from disease free stock before providing this product to growers to produce the final product, and use of controlled environment techniques could save a year or two of seed expansion in the field, which risks the introduction of diseases, e.g. viruses, from insect vectors.

CELSS studies with cropping systems have provided interesting information regarding yield potential, which in turn may help gauge field production practices. For example, Bugbee and Salisbury have obtained wheat yields several times that of world record field yields, and Tibbitts and Wheeler obtained potato yields nearly twice that of world records, both examples of which suggest that yield improvements are still possible if environmental factors can be optimized.

Finally, the use of atmospherically closed systems to track crop community development in CELSS studies has allowed tracking of biogenic gases which may have implications for global atmospheric chemistry. In Kennedy Space Centre studies with the Biomass Production Chamber, researchers have been able to monitor ethylene production by crop stands, along with numerous other volatile organic compounds. Perhaps one of the most prevalent biogenic gases that has been seen is nitrous oxide (N_2O), presumably as a result of bacterial denitrification of the nitrate-rich nutrient solutions.

MATERIALS SCIENCES IN SPACE

Microgravity research is scientific investigation conducted in a gravitational field that is a small fraction of the gravitational acceleration on Earth. Gravity is certainly a weak force compared, for example, to atomic binding forces. Therefore, the role of gravity in physical phenomena is important only when stronger forces are in equilibrium or when special circumstances arise. The goal of materials science research in space is to use the unique experimental environment to study fundamental phenomena during solidification of melts, crystal growth and combustion, and to determine thermophysical properties of fluids.

Materials Science Research

The particular interest in this field is the understanding of the roles of buoyancy-driven convection, sedimentation, and hydrostatic pressure in the processing of alloys, composites, ceramics, and polymers. NASA, ESA, DARA, CSA and NASDA have continued to support vigorous programs involving solidification and materials property measurement in ground-based experimental programs and short duration microgravity experiments carried out in drop tubes and rockets. In addition, continuous access to the Russian space agency's Mir station is providing a unique, long term, low-gravity environment for NASA supported investigators.

The STS-79 flight included two materials science experiments for transfer to the Mir space station. First was the Mechanics of Granular Materials (MGM) experiment, which studied what happens to granular materials under low stress condition. The MGM research results could lead to improved selection and preparation of building sites in earthquake-prone areas, and in the study of erosion, mining and offshore engineering. The other experiment, the Material in Devices as Superconductors (MIDAS), will gather data on superconductor materials during its four month stay on Mir.

The free-flying Wake Shield Facility (WSF-3) made its third flight into orbit on STS-80. The Facility is a 12-foot diameter, free-flying stainless steel disk designed to generate an "ultra-vacuum" environment in space in which to grow semiconductor thin films for use in advanced electronics. Wake Shield was designed, built and is operated by the Space Vacuum Epitaxy Centre at the University of Houston—a NASA Commercial Space Centre—in conjunction with its industrial partner, Space Industries, Inc., also in Houston. During its first flight on STS-60, WSF, although experiencing a hardware problem that resulted in the vehicle remaining attached to the robot arm, proved the vacuum wake concept, and realized the space epitaxy concept by growing the first-ever crystalline semiconductor thin films in the vacuum of space. These thin films of aluminum gallium arsenide could be used to make the next generation of semiconductors for use in computer chips and other advanced electronic devices.

The STS-81 shuttle flight to Mir transported additional samples for the QUELD-II binary and ternary diffusion studies as well as the Liquid Metal Diffusion (LMD) experiment. The LMD experiment determined the self-diffusivity of In metal.

STS-83 and it's reflight, STS-94, saw a major emphasis in materials science research within the Microgravity Science Laboratory (MSL-1). MSL-1 was a collection of microgravity experiments housed inside a European Spacelab Long Module (LM). It built on the cooperative and scientific foundation of the International Microgravity Laboratory missions (IML-1 on STS-42 and IML-2 on STS-65), the United States Microgravity Laboratory missions (USML-1 on STS-50 and USML-2 on STS-73), the Japanese Spacelab mission (Spacelab-J on STS-47), the Spacelab Life and Microgravity Science Mission (LMS on STS-78) and the German Spacelab missions (D-1 on STS 61-A and D-2 on STS-55).

MSL-1 featured 19 materials science investigations in four major facilities: the Large Isothermal Furnace, the EXpedite the PRocessing of Experiments to the Space Station (EXPRESS) Rack, the Electromagnetic Containerless Processing Facility (TEMPUS) and the Coarsening in Solid-Liquid Mixtures (CSLM) facility.

The Large Isothermal Furnace was developed by the Japanese Space Agency (NASDA) for the STS-47 Spacelab-J mission and was also flown on STS-65 IML-2 mission. It housed the Measurement of Diffusion Coefficient by Shear Cell Method Experiment, the Diffusion of Liquid Metals and Alloys Experiment, the Diffusion in Liquid Lead-Tin-Telluride Experiment, the

Impurity Diffusion in Ionic Melts Experiment, the Liquid Phase Sintering II Experiment (LIF), and the Diffusion Processes in Molten Semiconductors Experiment (DPIMS).

The EXPRESS rack replaces a Spacelab Double rack and special hardware will provide the same structural and resource connections the rack will have on the Space Station. It housed the Physics of Hard Spheres (PHaSE) experiment and the Astro/PGBA Experiment.

The Electromagnetic Containerless Processing Facility (TEMPUS) is used for the Experiments on Nucleation in Different Flow Regimes, Thermophysical Properties of Advanced Materials in the Undercooled Liquid State Experiment, Measurements of the Surface Tension of Liquid and Undercooled Metallic Alloys by Oscillating Drop Technique Experiment, Alloy Undercooling Experiments, the Study of the Morphological Stability of Growing Dendrites by Comparative Dendrite Velocity Measurements on Pure Ni and Dilute Ni-C Alloy in the Earth and Space Laboratory Experiment, the Undercooled Melts of Alloys with Polytetrahedral Short-Range Order Experiment, the Thermal Expansion of Glass Forming Metallic Alloys in the Undercooled State Experiment, the AC Calorimetry and Thermophysical Properties of Bulk Glass-Forming Metallic Liquids experiment and the Measurement of Surface Tension and Viscosity of Undercooled Liquid Metals experiment.

"TEMPUS researchers whose samples were processed during the minimum duration flight in April learned how their samples performed in the microgravity environment of space. Using this knowledge, they were able to fine-tune their experiments for this flight," said Dr. Jan Rogers, TEMPUS project scientist with Marshall Space Flight Centre.

In the German levitating furnace, known as TEMPUS, a sample of a glass-forming metallic liquid performed just as planned, according to principal investigator Dr. William Johnson of the California Institute of Technology in Pasadena. This experiment is measuring the thermophysical properties—heat capacity, thermal conductivity, nucleation rates, surface tension, viscosity and thermal expansion—of a complex alloy of titanium, zirconium, copper and nickel.

The TEMPUS levitating facility, also investigated the nucleation, or the point at which solidification from the melted state begins, in undercooled liquid zirconium. Undercooling is when a liquid remains fluid when cooled below its freezing point. Researchers on this material were Dr. Robert Bayuzick of Vanderbilt University in Nashville, Tenn., with Dr. Merton Flemings and Dr. Gerardo Trapaga of the Massachusetts Institute of Technology in Cambridge, Mass.

TEMPUS experiments to investigate the maximum amount that a sample of aluminum-copper-iron and aluminum-copper-cobalt melts could be cooled below their freezing point and remain liquid were performed for Dr. D.M. Herlach of the German Aerospace Research Establishment in Cologne, Germany. Dr. Herlach also studied the solidification velocity of dendrites.

The Large Isothermal Furnace was used to process multiple samples for diffusion studies. The materials included; tin and lead-tin-telluride (Dr. Shinichi Yoda of the National Space Development Agency of Japan in Tsukuba, Japan), germanium, an element widely used as a semiconductor and alloying agent (Dr. David Matthiesen of Case Western Reserve University in Cleveland, Ohio), lead-tin-telluride (Ms. Misako Uchida of Ishikawajima-Harima Heavy Industries in Tokyo, Japan), and molten salts (Dr. Tsutomu Yamamura of Tohoku University in Sendai, Japan).

Biotechnology Research

Application of biotechnology research results range from the design of new drugs, to protein engineering, synthetic vaccines, and biochip technology for the electronics industry. Biotechnology under microgravity conditions has focused on the study of isolated biomacromolecules, such as proteins and the study of cells in controlled fluid and chemical environments. In particular, protein crystal growth has been the subject of many space experiments. Proteins are complex molecules responsible for many biochemical functions essential to life on Earth. Scientists use protein crystals to determine the structure and function of proteins. The pharmaceutical industry uses such information for the design of drugs that bind to a specific protein which can block chemically active sites. Such drugs are able to "turn off" the protein's activity, thus regulating metabolic processes. Protein crystal growth is a recurring Space Shuttle experiment because there are over 300,000 proteins in the human body and scientists know the structure of less than 1 percent of them. The three-dimensional structures of proteins are determined by X-ray analysis of protein crystals. However, many proteins that interest medical researchers have not produced crystals of adequate size and quality to allow X-ray data to be collected. Crystals grown in space, where they are virtually free from the distortions of gravity, often provide better structural information than their counterparts grown on Earth.

Biotechnology continues to be an a major part of STS microgravity missions with essentially every shuttle flight this year having at least one biotechnology experiment(er).

On STS-79 an investigation to study the long-term development of cartilage cells in microgravity, was transported to Mir. During the planned four-month stay on Mir, weekly samples of the culture were taken which was to provide researchers with information on engineering cartilage cells for possible use in transplantation. In addition a Commercial Generic Bioprocessing Apparatus was transferred to Priroda.

STS-80 flew the National Institutes of Health NIH-R4 Experiment, a series of bone cell experiments known as CCM-A (formerly called STL/NIH-C-6), the Biological Research in Canister (BRIC - 09) Experiment, the Commercial MDA ITA Experiment (CMIX-5). The CMIX-5 hardware conducted research in areas including diabetes treatment, tissue replacement and the growth of crystals for research into breast cancer inhibitors.

Shuttle flights (STS-81 and STS-84), to the Mir station, provided sample exchanges for the, Biorack multipurpose facility designed to investigate the effects of microgravity and radiation on plant, tissue, cell and fungus growth, the Biotechnology System (BTS), and replacement of the growth media in the Cartilage in Space (CART) experiment. In addition during STS-84 the PCG dewar was returned to Earth.

A major thrust of STS-83 MSL-1 (reflown as STS-94) was in the area of protein crystal growth. Grown in space, proteins ranging from insulin to HIV-Reverse-Transcriptase have been produced as larger, purer and new, never-before-seen crystal structures. The Protein Crystal Growth Experiments on this mission attempt to grow a record number of nearly 1,500 protein crystal samples. The Observable Protein Crystal Growth Apparatus was used to characterize proteins and determine the differences that exist in crystal growth processes in microgravity and on the ground. The experiment hoped to ultimately optimize growth procedures and conditions for application in the biochemical field. A major goal of this experiment was to improve the design and loading procedures and to eliminate bubble formation, which interferes with crystal growth. MSL's provided a reflight opportunity for the Second Generation Vapour Diffusion Apparatus. The experiment is led by Dr. Larry Delucas of the Centre for Macromolecular Crystallography at the University of Alabama in Birmingham.

The ASTRO/Plant Generic Bioprocessing Apparatus, was a plant growth experiment studying the effect of space on certain types of plants. The investigation was to examine the production of lignin, essential for the formation and joining of woody cell walls in plants; the production of secondary metabolites, essential for generating energy needed to sustain vital life processes; and changes which occur in the sugars and starches of vegetable plants. The research was to help determine if these plant processes are interrelated and how they might be manipulated to improve plant growth and production on Earth. The findings may also verify evidence that plants grown in microgravity require less metabolic energy to produce lignin, permitting greater production of secondary metabolites, a source of many medicinal drugs. Secondary metabolites may also be used to attract, repel or poison insects. Plants studied aboard Space Shuttle Columbia, included *Artemisia annua*, a species of sage native to Southeast Asia and a source of the antimalarial drug artemisinin; *Catharanthus roseus*, which produces vinca alkaloids, used in chemotherapy treatment of cancer; *Pinus taeda*, or loblolly pine, used widely in the paper and lumber industries; and *Spinacia oleracea*, a variety of spinach.

STS-85 (86) reflew the Bioreactor Demonstration System (BDS). This payload was to study the effect of gravity on the development of cells and tissues. The BDS is designed to perform cell biology experiments under controlled conditions on small samples of material. Although his work with the Bioreactor Demonstration System is effectively complete, more than 30 data runs with human colon cancer cells were completed. Future research on the ISS may reveal a way to halt the growth of these cells or kill them in the human body.

Fluid Physics

Fluid and interfacial transport processes are common to both materials and biological systems. Under terrestrial conditions, the effect of gravity on inhomogeneous fluids generally results in internal phenomena such as buoyancy-driven convection, particle sedimentation as well as the distortion of fluid interfaces. These effects can add complexity to fluid systems. For example, the effects of other contributing processes (such as diffusion) can be masked or substantially modified. Thus, the microgravity environment affords the opportunity to study these other processes without the complicating influence of gravity.

The Visualization in an Experimental Water Capillary Pumped Loop (VIEW-CPL) experiment on STS-80 studied alternate methods for spacecraft thermal management. VIEW-CPL, is an investigation of capillary pumped loop equipment in weightlessness designed by University of Maryland students. Such technology may one day be used in cooling systems for future spacecraft, allowing fluids to be pumped without the use of moving parts.

STS-83 (Microgravity Science Laboratory-1) and its reflight, STS-94, was host to three fluid physics experiments, all utilizing the Middeck Glovebox. The Middeck Glovebox allows the astronauts to work with fluids that would normally be required to have several "containment layers", complicating experiment design and operation.

The Internal Flows in a Free Drop experiment examined techniques for controlling the position and motion of liquids in low-gravity. This study is to enable researchers to assess a potential method of mixing which could lead to improvements in chemical manufacturing, petroleum technology, and the cosmetics and food industries.

The Bubble and Drop Nonlinear Dynamics experiment is led by Dr. L.G. Leal of the University of California at Santa Barbara. The results could lead to techniques that eliminate or counteract the complications that bubbles cause during materials processing. This experiment was flown to help scientist better understand how bubbles respond to ultrasonic radiation pressure - possibly leading to a technique that could eliminate or counteract the complications that bubbles cause during materials processing. During the experiment, bubbles are deployed into a water-filled chamber within the Glovebox. Scientists assessed their ability to control bubble location, manipulate double bubbles and maximize bubble shape. Shape deformation was studied as a function of size and ultrasonic pressure. The effect of ultrasonic radiation pressure on bubbles was also to be assessed by bringing two single bubbles together to form one.

On STS-94 the Capillary-driven Heat Transfer Device was also operated in the Middeck Glovebox. This study examined the device's ability to transfer heat away from a particular location. In the future, these devices may be used to transfer heat from electrical equipment to radiators on spacecraft. The benefits of these systems are that they weigh less than conventional units because they operate on evaporation and condensation, and are more economical because they do not require power. This study has already provided insight into how these devices work and is offering explanations as to why they occasionally fail in spacecraft applications. The experiment's lead investigator, Dr. Kevin Hallinan of the University of Dayton, Ohio, reported that the during flight operations they were able to characterize boundaries of what is called unstable operations which accelerates this transition to this failed - or disrupted state. He also noted that this is the same failure mechanism that was seen previously. However, they were able to characterize the conditions that cause a violent instability in the evaporator portion of the device. This instability immediately causes the entire device to fail. This may lead to understanding another 'failure mechanism' and closer to the goal of understanding why the Capillary-driven Heat Transfer devices have failed in space yet succeed in 1-G (on the ground).

Mission STS-85 flew two fluid physics experiments; the Two-Phase Fluid Loop Experiment, or (TPFLEX), which was to study how cooling systems operate in low gravity, and the Critical Viscosity of Xenon (CVX).

Combustion Research

The availability of improved low-gravity facilities such as drop tubes and towers, parabolic flights and manned space missions offers unique opportunities and challenges to combustion science and technology. The reduced gravity levels afforded by these low-gravity environments enable the study of combustion phenomena that, under terrestrial conditions, are obscure or substantially modified by gravitational effects. These research opportunities facilitate work toward the challenging task of developing strategies for the prevention and control of fire and explosion hazards for spacecraft, as well as improved fire detection, prevention and extinguishing methods on Earth.

Microgravity conditions for experimentation in combustion offer a variety of simplifications compared to terrestrial experimental conditions. These include a reduction in dimensionally, the inhibition of settling effects for multiphase phenomena, and a substantial reduction of buoyancy forces. Studies focus on the processes of ignition, flame spreading, flame extinction, flamefront instabilities, smoldering, flammability limits of gaseous pre-mixed flames, and soot processes in non-pre-mixed flames. In addition, materials synthesis in heterogeneous pre-mixed flames has also been considered. In many cases these experiments are of short duration. Short duration combustion experiments have been performed in 1996-7 in microgravity facilities such as the drop shafts at NASA Lewis Research Centre in Cleveland, USA, and at Kamisunagawa in Japan and the drop tower in Bremen as well as on parabolic flights.

Multiple combustion research experimentation was flown on STS-83 and its reflight, STS-94. In many cases the earlier flight allowed experimenters a preliminary experiment which could be "improved" on STS-94.

The Droplet Combustion Experiment (DCE) investigated the fundamental combustion aspects of single, isolated droplets under different pressures and ambient oxygen concentrations for a range of droplet sizes varying between 2 and 5 mm. The DCE apparatus was integrated into a single width MSL-1 Spacelab rack in the cargo bay. During the experiment an n-heptane fuel droplet is burned in an atmosphere of helium and oxygen. The droplet is formed and deployed in the apparatus. Igniter wires are brought close to the sides of the droplet then retracted to create a free burning droplet. Researchers learned that achieving non-buoyant, or steady, flames is a lot more difficult than anticipated and so was predicting some of the flame burning characteristics. According to Dr. Forman Williams of the University of California in San Diego "The crew had a tougher time igniting the droplets at the lower pressure; we expected that, but, when the fuel droplets did ignite, they burned stronger and more vigorously than we expected". This experiment also showed the first complete burn of a 3 mm diameter heptane droplet. Additionally, as a fuel droplet burned in a spherical shape, the heat dissipated outward, and actually extinguished the flame before all the fuel vapour was completely burned away. This gave researchers a very pure look at the combustion process. In a novel twist to this experiment, scientists decided to run a test using two droplets instead of one. This provided a bonus to researchers as they observed the interaction of the droplets.

The Combustion Module-1 (CM-1) facility from the NASA Lewis Research Centre houses the Laminar Soot Processes Experiment and the Structure of Flame Balls at Low Lewis-number Experiment (SOFTBALL); the Principal Investigator is Paul Ronney (UCLA). This study is designed to determine under what conditions a stable ball of flame can exist and if heat loss is responsible in some way for the stabilization of the flame ball during burning. Most of the fuel mixtures used for this experiment were so weak—resulting in flames that are about one hundred times weaker than a common match flame—that they will not burn on Earth.

STS-85 provided an additional flight opportunity for the Solid Surface Combustion Experiment (SSCE). This experiment is designed to understand how flames behave in space and increase basic understanding of the combustion process. The SSCE is a continuation of the combustion investigation efforts that were performed last month by the STS-94 crew on the re-flight of the Microgravity Sciences Laboratory mission having previously flown on STS-63.

Vibration (g-jitter) Isolation

A g-jitter is the residual acceleration that exists in (large) free-flying space platforms. It is caused by oscillatory vibrations and random disturbances either due to the structure itself or mechanical equipment operated on the platform. Materials science experiments are typically not sensitive to vibrations above 50–100 Hz. However, 1–10 milli-g vibrations at frequencies below 10 Hz can induce fluid flows stronger than the expected diffusive-only flux. Thus, experimenters are requiring both a more detailed knowledge of the local acceleration environment and hardware for g-jitter reduction.

During STS-79 (Spacehab/Mir) flight the Active Rack Isolation System (ARIS) was evaluated. ARIS is a prototype of an International Space Station payload system designed to eliminate vibrations or disturbances caused by crew activity or engine firings.

STS-81 (also a Mir flight) tested the Treadmill Vibration Isolation System (TVIS) experiment while the shuttle was attached to Mir and while flying alone.

Finally, STS-85 provided an opportunity to test an updated Microgravity Vibration Isolation Mount (MIM), designed to isolate small experiments from disturbances on the International Space Station. An earlier version of MIM has been used on the Mir space station for over a year.

NASA continues to provide experimenters with measurements of the local acceleration environment from the Space Acceleration Measurement System (SAMS), the Microgravity Measurement Assembly (MMA), the Quasi-Steady Acceleration Measurement System and the Orbital Acceleration Research Experiment (OARE). Data for particular missions is typically available on the Internet.

FUNDAMENTAL PHYSICS IN SPACE

Projects under Development

Gravity Probe B (GP-B) is a NASA Project aimed at testing two predictions of Einstein's theory of General Relativity to an unprecedented high precision. According to this theory a gyroscope in a polar orbit at 650 km altitude will experience two relativistic precession effects: (1) in the orbital plane a geodetic precession of 6.6 arcsec/yr and (2) at right angles to the orbital plane a frame-dragging precession (or Lense-Thirring precession) of 0.042 arcsec/yr due to Earth's rotation. GP-B aims at measuring each of these effects in each of four independent gyroscopes to an accuracy of 0.0002 arcsec/yr per gyroscope. The resulting overall measurement of the frame-dragging effect after combining the results will be accurate to 1 part in 400 and of the geodetic effect to about 1 part in 100,000. In addition, the experiment will provide a re-measurement of the relativistic deflection of light to a few parts in 1,000. Proper motion of the guide star with respect to the remote inertial frame is being determined to better than 0.0001 arcsec/yr in separate VLBI observations of the selected star with respect to a nearby quasar.

The GP-B scientific payload comprises four gyroscopes, a drag-free proof mass, and a star tracking telescope all held together with a fused-quartz block and four DC SQUID packages for the gyro readout. Each gyroscope independently measures the geodetic and frame-dragging precessions, thus giving both measurement and failure redundancy. The payload is accommodated in a superfluid helium dewar which maintains a temperature of about 2.5K during the mission lifetime of 17 months. Construction of the GP-B instrument is now almost complete. A prototype instrument probe containing the four gyroscopes and telescope has been integrated with the flight dewar and has successfully passed the electromagnetic interference tests. First turn-on of spacecraft power to engineering electronic systems is expected in January 1998.

GP-B has a launch mass of 3000 kg. It will be launched by a Delta II launch vehicle from Western Test Range at Vandenberg, California in March 2000.

CRONOS is an experiment to test Einstein's "clock gravitational frequency shift" to a precision of 1 part in 1,000,0000, an improvement by two orders of magnitude over the most precise experiment up to now, the suborbital flight of the GP-A rocket in 1976. CRONOS is a hydrogen maser clock in space (weighing only 35 kg) which is under development in Switzerland and intended for flight on the Radioastron mission, an international space VLBI mission led by the Astro Space Centre in Moscow. On Radioastron, CRONOS is mainly used as a high precision local oscillator of the space radio telescope receiver. The redshift experiment is made possible by comparing two identical hydrogen maser clocks, one on the ground, the other on Radioastron whose apogee is 80,000 km, thereby exploiting the large gravitational potential difference available in space.

Projects under Study

MiniSTEP aims at testing the Equivalence Principle to 1 part in 10^{18}, six orders of magnitude better than has been achieved on the ground. MiniSTEP is a NASA/ESA collaborative project; the payload will be provided by Stanford University and a large number of European institutes.

MiniSTEP is the "minimal-cost" version of STEP (Satellite Test of the Equivalence Principle), which was studied in 1992 as an ESA/NASA collaborative project at Phase A level as a candidate for ESA's second medium-size project (M2) and as a European-only project in 1995 again at Phase A level as a candidate for M3. Although STEP was in both cases not selected it stirred up quite some interest in the scientific community and led to parallel studies of three low-cost tests of the Equivalence Principle in space: the NASA-led MiniSTEP, the CNES-led GEOSTEP and the ASI-led GG (Galileo Galilei). GEOSTEP and GG, both with a lower target sensitivity than MiniSTEP, are no longer being pursued.

MiniSTEP carries a cryogenic payload consisting of four differential accelerometers accommodated in a superfluid helium dewar. The test masses are pairs of concentric hollow cylinders of different materials "freely falling" around Earth. Any violation of the Equivalence

Principle would show up as a periodic variation of the force that is exerted to keep the test masses centred on each other. Much of the MiniSTEP technology can be inherited from GP-B. Like GP-B, MiniSTEP is a drag-free spacecraft using the boil-off from the helium dewar to feed a number of proportional thrusters on the spacecraft to compensate for the drag from the residual atmosphere at orbital altitude and from solar radiation pressure. Like GP-B, position sensing is done with ultrasensitive SQUID magnetometer circuits. The launch of the 400 kg MiniSTEP spacecraft into a Sun-synchronous, circular orbit at 400 km altitude is planned for late 2004; mission lifetime is six months.

The LISA Project is a Laser Interferometer Space Antenna for the detection and observation of gravitational waves in the frequency range 10^{-4} to 10^{-1} Hz which is inaccessible to ground-based detectors. It is included as the third cornerstone project in ESA's long-term space science program "Horizon 2000 Plus".

LISA consists of six identical spacecraft, forming an equilateral triangle in interplanetary space with two closely spaced (200 km) spacecraft at each vertex. In principle, one spacecraft at each vertex would be sufficient, but the optical system and attitude-control requirements would be more complicated. The distance between the spacecraft pairs is 5×10^6 km, which defines the interferometer arm length. Each spacecraft sends out a 1 W laser beam (at 1 micro-m wavelength) to its corresponding 'far' spacecraft, and a 10 mW laser beam to its neighbouring 'near' spacecraft. The lasers at each pair of near spacecraft are phase-locked together, thus behaving effectively as a single laser. Each spacecraft receives the laser light through a f/1 Cassegrain telescope with a 30 cm aperture and sends out a beam of its own through the telescope. For the two main arms of the interferometer, the far spacecraft transmits back beams which are phase-locked with a small frequency offset from the incoming beam. When a gravity wave passes through the system, it causes a strain distortion of space, which is detected by measuring the fluctuations in distance between proof masses that are floating freely inside the spacecraft. The incoming light from the telescope is reflected off the proof mass and superimposed with the local laser on a phase-measuring diode. The distance fluctuations are measured to sub-Angstrom precision. Each proof mass is shielded from external disturbances (e.g. solar radiation pressure) by the spacecraft in which it is accommodated. The position signals from capacitative sensors are used in a feedback loop for drag compensation using FEEP (Field Emission Electric Propulsion) thrusters to enable the spacecraft to follow its proof mass precisely. LISA is designed to detect gravitational-wave strains with a signal-to-noise ratio of 5 down to a level of order 10^{-23} in one year of observation.

The six spacecraft, including three propulsion modules for the transfer from Earth orbit to the final position in interplanetary space, can be launched by a single Ariane 5. The three pairs of spacecraft are positioned in individual heliocentric orbits at 1 AU from the Sun; their orbits have a specific inclination and eccentricity such that the three spacecraft pairs move relative to each other on a circular orbit inclined at 60 degrees to the ecliptic. This keeps the distances between them (the interferometer arm lengths) constant. To ensure that the gravitational perturbations stay small enough for this, the system is placed at least 20 degrees behind Earth. As this configuration orbits the Sun in the course of one year, the observed gravitational waves get Doppler-shifted. For periodic waves with sufficient signal-to-noise, this allows the direction of the source to be determined. The three arms give two almost independent interferometers and also provide redundancy in case of the failure of up to two spacecraft (not at the same vertex).

More recently, NASA has begun studies of a three-spacecraft LISA mission, also in a heliocentric orbit, with a payload very similar to that of the ESA LISA cornerstone project. The NASA-led LISA is envisaged in collaboration with ESA and European institutes. Under consideration in the USA is also a gravitational wave project with six spacecraft in a geocentric orbit, called OMEGA, with a slightly reduced sensitivity.

Given a moderate amount of funding for technology development the technology for a first gravitational wave project in space could reach maturity within a few years. A convincing way to demonstrate this maturity would be through a low-cost technology demonstration mission in space. Three such projects with launches in the 2000–02 timeframe are now under discussion: two (ODIE and DS-3) in the United States and one (ELITE) in Europe. If these missions are successful, a first gravitational wave project in space could be launched in the 2005–10 timeframe.

SATELLITE DYNAMICS

The COSPAR Panel on Satellite Dynamics is concerned with the orbital and attitude motion of artificial satellites and space probes and with techniques for the determination of these motions. The following brief report highlights a few representative activities where advances have been made in the past year, in particular: the exploitation of precise tracking systems in support of Earth observation missions; applications connected with GPS; and advances in gravity field modelling and preparations for future missions for gravity field improvement.

Precise Tracking and Earth Observation Missions

The ERS-1, ERS-2, SPOT and TOPEX/Poseidon missions have continued to yield valuable data (altimetry, SAR) which could take advantage of highly precise orbital solutions based on laser, PRARE, Doris and/or GPS measurements.

TOPEX/Poseidon and the ERS spacecraft have played an important role in identifying and monitoring the development of El Niño Southern Oscillation (ENSO) events in the Pacific Ocean (1993, 1997). The gradual movement of warmer water from west to east (and vice versa) can be seen as a clear signal in altimeter height measurements.

Following the very successful tandem mission with ERS-2, the ERS-1 spacecraft has been put into hibernation, but the tandem orbit configuration (1 day separation and narrow window in the cross-track component of the ground track) has been maintained and used for further SAR interferometry campaigns in 1997.

The PRARE system onboard ERS-2 has continued to function well and the tracking network has been further expanded. The performance as well as orbit and ionospheric product quality have been presented at a number of meetings (3rd ERS Symposium in Florence, during a dedicated PRARE session at the EGS in Vienna, etc.). Meanwhile a furthermore improved data release is in preparation.

For a period of six months SLR tracking was re-initiated to the two Diademe satellites D1-C and D1-D (launched in 1967) after an interruption of more than 20 years. This high quality tracking data will be included in the releases of new improved Earth gravity models, e.g. GRIM, due to the important orbital characteristics. In general a good tracking record has been achieved from about 20 stations of the global SLR network with orbital fits in the order of a few dm.

New results were presented from the global DORIS (Doppler) network for site velocities on nine major tectonic plates, showing good agreement with geological models, and with solutions derived by laser and GPS techniques. Of special interest were the estimates of vertical motions and motions of sites close to plate boundaries.

GPS and other Constellations

New developments in the framework of the International GPS Service for Geodynamics (IGS) included consideration of support needed for future Earth orbiters carrying GPS receivers, the use of the IGS ground network for rapid and estimation of tropospheric water vapour with high temporal resolution (1 or 2 hours), discussions with the oceanographic community on setting up a permanent tide gauge survey using GPS, and the consolidation of the pilot project aiming at incorporating regional GPS networks into routine weekly solutions for the positions of points fundamental to the definition and maintenance of regional and global geodetic reference frames.

The experiments on the generation of IGS predicted orbits for the GPS satellites have led to routine products being made available to the user community on a continuous basis, with accuracy normally significantly better than that of the broadcast ephemeris. The accuracy of the final orbits is in the region of 4–8 cm per component. A daily IGS combined solution for UT1 is likely to be added to list of IGS products in the near future after considerable preparations already carried out.

Several centres have generated multi-year solutions for tectonic motions of the stations of the network covering some or all of the period since the start of the IGS (1992). Combination of GPS and laser data strengthens such solutions.

A laser tracking campaign of the GPS-35 and -36 spacecraft was organised in autumn 1996 and extended into 1997 following a LAGEOS eclipse season in December. Poor weather caused a disappointing data return, and results till now on calibrating IGS orbits through laser are not conclusive.

Analysis of GPS (and also DORIS) data is being carried out for investigation of the geocenter variations (constant, bias, annual, semi-annual) as a contribution to the IERS Geocenter Campaign.

For orbit determination and gravity improvement, the data from the GPS flight receiver on the GPS/MET has been processed using the EPOS (GFZ) software. An accuracy of about 30 cm in position (6.5 cm radially) has been demonstrated. As a test, three days of GPS data from GPS/MET were incorporated into the global gravity field model GRIM4. Further improvements are expected in gravity modeling with more GPS/MET data.

In support of the MOMS-2P optical camera project onboard the Mir space station, precise orbit ephemeris from one frequency GPS receiver observations have been computed, resulting in orbital accuracies of some dm.

In the framework of the ESA ATV Rendezvous Predevelopment project (ARP) post-flight analysis of relative navigation using GPS is being carried out. Submetre accuracies have been obtained for a first Flight Demonstration (Shuttle-ASTROSPAS) and data have been collected from two subsequent Shuttle-Mir rendezvous missions.

GPS measurements collected during the Japanese spacecraft mission OREX (Orbital Re-entry Experiment) have been processed, using various orbit determination approaches (stand-alone GPS, IMU-augmented GPS, differential GPS between OREX and ground receivers). After separation from the H-II launcher, OREX made one revolution round Earth at 450 km altitude before making a de-orbit manoeuvre and planned re-entry.

An important application of GPS is the determination of a unified vertical datum for Europe (European Unified Vertical Network EUVN). This network covers 33 countries. The field campaign was organised by the EUREF Subcommission of IAG in the period from 21–29 May 1997, and 195 sites were observed, including tide gauge stations, levelling nodal points and EUREF permanent stations.

Discussions have been initiated by the U.S. Departments of Defence and Transportation on the selection of a second civil frequency for GPS to allow easier access to precise measurements, though removal of ionospheric delay terms. User inputs were being requested.

Efforts are being undertaken to develop orbit determination software that will run on parallel computers. This in view of future constellations of many satellites, like Iridium, but also already GPS and GLONASS, for which massive amounts of tracking data are foreseen to be collected. In addition, for low-flying satellites equipped with a GPS receiver, it might be necessary to make use of "massive parallel computing" when estimating large amounts of unknowns, e.g. many gravity field parameters in addition to the orbit parameters. Another (complementary, operational) aspect of this is the study of increased autonomy in the on-board orbit and attitude control systems.

New ground was broken during the period under review with the collocated control of six ASTRA spacecraft in a longitude window 0.2 degrees wide in geostationary orbit, with inter-satellite distances of some tens of km.

Gravity field models

The most accurate determinations of Earth satellite motion were, until recently, based on use of the JGM-3 gravity model. The need for a better geoid model for processing altimeter data was the driver for the development of a new combined model EGM96 to degree and order 360 by NASA/GSFC and NIMA (formerly DMA). For EGM96 DMA made available new and improved gravity data over regions of the globe that previously had not been available, such as China, the former Soviet Union, South America and Africa. Altimeter derived anomalies from the GEOSAT geodetic mission were used to help define the high degree portion of the field. The field also incorporates data from recent airborne gravimetry campaigns undertaken over Greenland and the Arctic. New satellite tracking data were added to the satellite data used in JGM-2, including GPS tracking to three GPS satellites: EUVE, GPSMET, and TOPEX; TDRSS tracking of EUVE; Tranet tracking to several satellites (D1C, D1D, BEC, Hilat, and Radcal - all valuable because of their unique altitude and inclinations); SLR tracking to Stella, and GFZ-1. The solution also includes two years of TOPEX SLR/DORIS tracking. It is expected that EGM96 will be a major improvement over previous solutions such as JGM2/OSU91A or JGM3/OSU91A.

An important new data source now being introduced into the models is from the laser tracking of the GFZ-1 spacecraft, flying in a relatively low orbit (400 km). Major efforts are being made in modeling of non-conservative forces for POD and gravity field model evaluations. The SLR network continues successful tracking campaign of this low altitude target. Future LEO missions (e.g. CHAMP) will benefit from these experiences and the new procedures developed.

A multiplicity of satellite missions has been envisaged to seek improvements in the modelling of the gravity field and the geoid. These have included Aristotles, Champ, Games, GP-B, GRACE, GRM and GOCE. Of these missions, GRACE (Gravity Recovery and Climate Experiment) is a newly approved mission, scheduled for launch in March 2001. It will consist of two satellites flying in a tandem formation, 100 to 400 km apart. It will permit a solution for Earth's gravity field every 12 to 25 days. Its objective is to study both the static and time variable gravity field with unprecedented accuracy. Participants include the University of Texas at Austin, the Jet Propulsion Laboratory, the GeoForschungsZentrum (GFZ) and DLR in Germany, Loral Space Systems, the Johns Hopkins University Applied Physics Laboratory (APL) and Dornier SatellitenSysteme, Germany.

Champ is another mission that will be launched before GRACE (mid-1999). It will include GPS tracking, and an microaccelerometer, which will be used to directly measure and remove the effects of disturbances on the tracking data caused by nonconservative forces such as drag, thrusting, and solar radiation pressure. CHAMP's mission objectives are: (1) global long to medium wavelength gravity field mapping, (2) global Earth magnetic field mapping, and (3) atmosphere and ionosphere limb sounding using GPS. A GPS nadir antenna has been accommodated in addition for a GPS altimetry experiment.

GOCE (Gravity Field and Steady-State Ocean Circulation Explorer) is a candidate ESA mission that proposes to fly a satellite gravity gradiometer for gravity field measurements, and a GPS/GLONASS receiver for orbit determination and long wavelength gravity field determination. The mission, if approved, would be implemented in the post year 2000 time frame as an ESA Earth Explorer mission.

Finally, the very successful navigation of the recent NASA Mars missions should be highlighted. The Mars Pathfinder landed softly on the planet in July 1997 and proceeded to carry out its task of exploration, while the Mars Global Surveyor was inserted into orbit round the planet in September 1997 taking advantage of an aero-braking technique for circularisation, and soon obtained measurements from its laser altimeter. Considerable advances in modelling of the Martian gravity field can be expected.

SCIENTIFIC BALLOONING

One major international conference on balloon technologies and observations was held in the past year, the 13th ESA Symposium on European Rocket and Balloon Programs and Related Research at Oeland, Sweden, in May 1997. In the meeting significant progress and efforts were reported from various countries. It can be seen with satisfaction that the success rate in scientific ballooning has continued to stay at nearly 100 percent in recent years. This is certainly due to the improvement of the balloon material and manufacturing technologies, in which areas efforts have been made in various countries.

NASA's Balloon Program

NASA's balloon program, which is implemented by the Goddard Space Flight Centre/Wallops Flight Facility (GSFC/WFF), have conducted 26 scientific balloon flights from five launch sites, including Fairbanks, Alaska, Juazeiro do Norte, Brazil, and Lynn Lake, Canada. The program had a 96 percent success rate for balloon performance and 85 percent for science missions in financial year 1997.

The balloon program research and development activities included: 1) the first phase of study of the Ultra Long Duration Balloon (ULDB) Project which could allow balloon flight durations up to 100 days; 2) completion of development of a balloon rotator for pointing of photo-voltaic arrays for long duration balloon (LDB) missions; and 3) the completion of a development effort with NASA/Lewis Research Centre for a balloon borne 200 W fuel cell for LDB missions.

The Ultra Long Duration Balloon System development effort has been formally organized and initiated. The effort consists of two parallel activities; an 18- to 24-month balloon vehicle technology development activity which will demonstrate the balloon material and superpressure design, and a 36 month ULDB Mission development effort which will demonstrate the feasibility and viability of a prototype, 100-day, integrated balloon payload science mission. A technology workshop was conducted as part of the ULDB effort to identify existing and relevant technologies that could be transferred from spacecraft programs to the balloon program. An integrated management team has been established and the initial conceptual design phase has begun. Scale model hangar testing of the balloon structures from the most promising candidate composite balloon films have been conducted with very encouraging performance. Development of additional higher strength to weight composite materials continued during 1997.

Final development, integration, and testing of a balloon rotator for pointing of photo-voltaic arrays for LDB missions was completed during 1997. The rotator is capable of supporting a 3200 kg payload at balloon float altitudes. The initial flight test was conducted on 30 March 1997. The test was very successful and provided validation of the specified power draws; less than 5 W average and less than 20 W peak, and demonstrated typical pointing accuracies of +/- 1 degree. This development culminated with the highly successful long duration flight test conducted from Fairbanks, Alaska in June–July 1997.

The development of a prototype balloon borne 200 W fuel cell which was initiated with LeRC in 1996 has been completed in 1997. This is the first stage in the possible development of a 2 kW fuel cell power system for LDB missions where science instruments, such as super-conducting magnets, require higher than average power draws. The system testing has been completed at LeRC and flight testing is scheduled for late fall 1997 or early 1998.

The LDB development effort completed its final milestone in 1997 with the first nearly global flight of the mid-latitude LDB System. The flight which was launched from Fairbanks, Alaska on 23 June, flew west around the globe, and impacted in northern Canada on 6 July. This flight served to demonstrate technologies that will allow scientists to fly payloads for long durations in the northern hemisphere, the global capability of TDRSS for suborbital applications and the performance of automated flight systems including a ballasting system and the newly developed solar pointing rotator.

More Activities in Long Duration Ballooning

The French group is currently implementing a campaign involving about 200 small super-pressure balloons in the Antarctic area around the year 2000. The objective is to observe the global motion of the atmosphere at stratospheric altitudes in this polar region. Technical development of this program is being undertaken.

Another interesting report by the French group concerned long duration flights at the turn-around period of high altitude winds at Esrange, which was performed in the fall of 1996. They succeeded in recovering the payloads quite near the launch site after about 40 hours. They estimated that such a turn-around period continues for 10 to 14 days at Esrange. It was well known that the turn-around period of high altitude winds in E-W direction is suitable for a long duration balloon flight. However, in other locations a certain balloon drift was still observed in the North–South direction, which limits the flight duration. Further studies in this area will be important.

Trans-Mediterranean flights, performed in a collaboration of Italy, France and Spain, were also scheduled for summer 1997 with launches from Sicily and payload recoveries in Spain.

The Russian group has also been operating long duration flights from Kamchatka to Ural lasting for about five to seven days. Continuing from 1995, collaborative observations of extremely high energy cosmic rays were carried out by a Russian and Japanese group in 1997. The flight performances in terms of height of level altitude and change of balloon altitude were improved. The balloons were launched from Kamchatka, Russia, in July 1997, and two balloons were successfully recovered near Volsk after flights of about five days each.

Indian groups have been pursuing a feasibility study of long duration, trans-oceanic flights from Andaman Island to mainland India, as well as from the mainland to South Africa.

Many countries have been making efforts to develop new balloon systems and facilities to meet the requirement of long-duration flights and sophisticated observations. Among these a French group has reported the successful operation of a balloon-borne large infra-red telescope of 2 m in diameter. The wavelength range is from 100 to 1000 micrometres, and some exciting results were obtained. A similar, but smaller telescope of 30 cm in diameter was developed in Sweden.

Arctic and Antarctic Flights

In the past several years two long-duration flight campaigns have been operated in

Antarctica, taking advantage of the absence of sunsets, and thus no or minor ballasting requirement, in the summer season. The Arctic flight performed by NASA in June–July 1997 was already been mentioned above. Another campaign is conducted in a collaboration of the National Polar Institute and ISAS with balloons being launched from Syowa Station and flights lasting for 15 to 20 days with circum-polar trajectories. NASA has continued the series of a few flights per year to observe the extremely high energy cosmic ray spectrum and for other scientific subjects with zero-pressure balloons. In this year, the Japanese group has also scheduled flights for the recovery of atmospheric sampling payloads near the launching site, based on tests in 1995.

New Balloon Systems

The term over-pressurized balloons describes less pressurized balloons compared to super pressure balloons. This type of balloon has a great capability to save ballast particularly in the polar region where the effect of the sunset observed in the summer season is naturally minor compared to mid-latitude flights. After several test flights of short duration by the U.S. group, the over-pressurized balloon is now in a stage of practical application. The key point is to develop the most suitable and reliable systems to keep the desired over-pressure during the flight. NASA has developed an automatic gas pressure control system combining the newly developed large exhaust valves with differential pressure sensors. Japanese groups have proposed more simple and passive systems with normal horse-tail ducts closed by smaller permanent magnets. The duct is to open when the over-pressure becomes larger than the magnet force acting to close the duct. The test flight of this system was performed in 1997, and further test flights in the Antarctic campaign are being planned in 1998. Another approach to save ballast is to minimise the change of the gas temperature inside the balloons during the day and night excursions. The French group has been continuing to improve the Mongolfière Infrarouge (MIR), which is a hot air balloon heated by the infra-red radiation emitted from the ground. The CNES group is going to use this system in the scheduled campaign THESEO to study the details of the bulk air motion in the stratosphere of the polar region.

The French group has also proposed to use minimal ballast drop systems for zero-pressure balloons allowing a slight change of the floating altitude during the night. This is a revised version of the RACCOON system used by the U.S. group almost 10 years ago, and used to perform flights from Australia to Brazil. However, the new proposal is to control the ballast more accurately to achieve longer flight duration. The estimated two to three-weeks flights are possible at mid-latitude by putting moderate amounts of ballast on the balloons.

Another item to be reported is the development of high altitude balloons with light payloads by the ISAS group. This was achieved by a balloon of 120,000 m^3 made of thin polyethylene films of about 6 micrometres. With this technical implementation of an old idea an altitude of 50.2 km was accomplished. Thereby some sounding rocket experiments can be replaced by balloon-borne observations, gaining extended observation time and reducing the costs.

Research Using Balloon Platforms

In addition to technological demonstrations, a large number of primarily scientific launches and campaigns took place in 1997.

As a successor of the successful European Arctic Campaign, SESAME, in 1994 and 1995, another large campaign was organized and successfully performed in 1997 to observe the atmospheric constituents in conjunction with satellite observations. About 20 balloons were launched from Esrange in February and March 1997. The main objective of this campaign was the in-situ validation of satellite observations of atmospheric constituents such as Ozone, NO_2, HNO_3, N_2O, CH_4, CFC-11, and others. The related satellite observations were made by ILAS (Improved Limb Atmospheric Spectrometer) on board the Japanese satellite ADEOS (Advanced Earth Orbiting Satellite) launched in August 1996. The campaign was organized within an agreement between CNES and EA (Environmental Agency, Japan). The balloon observations were made by various instruments including a chemiluminescence detector, Fourier transform infrared spectrometer, cryogenic sampler, UV-visible spectrometer, and grab sampler.

As a follow-up program of the SESAME campaign, the "Third European Stratospheric Ozone Campaign" (THESEO) was organized by France to start in 1998, involving a collaboration with various European countries and Russia. In co-ordinating the observations on board of satellites, sounding rockets and ground based experiments in the polar region, the atmospheric minor constituents such as Ozone as well as the global motions of atmosphere shall be studied.

International collaboration is indispensable for balloon-borne observations. In a collaboration between the United States and Japan, a balloon experiment of a super-conducting magnetic spectrometer was also performed from Lynn Lake, Canada, in 1997 as a follow-up of the successful flights of 1993–95. Because of the large size of the super-conducting magnet (1 m x 1.3 m), almost 50 anti-protons were detected in this experiment, which was an unprecedented achievement in this low energy region. The flights are planned to continue for a couple of years. At the same time the detectors will be developed to cater for higher energies.

The Chinese Balloon Program

In 1996, China constructed a new major ballooning facility at Gu Cheng (37° 47' N, 116° 08' E), which is located about 250 km southwest of Beijing. Because of the busy air traffic in this area the move to another location in the northern part of China as a permanent station is being considered in the near future.

The Chinese group performed several flights last year, using balloons of 50,000 to 400,000 m^3. The launching capability is for payloads of up to 2 tons. The observations include solar ultra-violet, solar magnetograms, hard X-rays, atmospheric composition, and microgravity. International collaboration exists between China and Japan for atmospheric composition measurements, and a micro-gravity experiment with German participation is in the planning stage.

Scientific Ballooning Activities in Other Countries

Indian scientists also have long experience in balloon-borne observations and have performed many measurements. They have also improved their facilities and are now extending the observations into infra-red astronomy.

In the COSPAR Assembly of 1996 Australia, Brazil, China and India reported on their recent developments in scientific ballooning. These countries have developed capable balloon-borne detectors, performed balloon flights with scientific instrumentation, and show progress of balloon technology. The instruments developed include large area X-ray and gammy-ray telescopes and a coded-mask telescope.

Balloons for Other Planets

Last, but not least, balloons floating on other planets are becoming one of the exciting items in scientific ballooning. Balloons on other planets have continuously been studied. JPL have been performing comprehensive studies for planetary balloons, and feasibility studies have been made of balloons floating in the atmosphere of Titan to observe its atmosphere. The balloon altitude is stabilized by using the phase change of gas to liquid with temperature. Plans are for a mission in 2008 after the Cassini/Huygens mission which arrives at the Saturn-system in 2004.

SPACE RESEARCH IN DEVELOPING COUNTRIES

Promotion of Space Research Activities in Developing Countries

The COSPAR Panel on Space Research in Developing Countries (COSPAR-PSRDC) has been making continuous efforts to help initiate, encourage and promote the participation of scientists from developing countries in space research and its applications for national development. As a first step, a scientific meeting was organised by PSRDC during the 30th COSPAR Scientific Assembly, 16–19 July 1994, in Hamburg. The main purpose of the meeting was to discuss, review and identify suitable ground-based experiments which could be developed, deployed and operated by the developing countries in the context of the validation, analysis and interpretation of satellite based data. Such initiatives would help in the utilisation of global satellite data which is presently available in plenty but cannot be used to its full potential without adequate and corresponding support of ground-based observations. Based on the outcome of the Hamburg meeting, COSPAR adopted a resolution with the following recommendation that the "National members of COSPAR, ICSU unions and associated members should encourage and support programs and activities involving ground-based and space techniques, particularly related to global and regional change studies and facilitate increased participation of scientists from developing countries."

Considering the fact that space science has been a major source of inspiration in various scientific endeavours for national development and taking into account the ground realities that many developing countries are yet to benefit from a full opportunity to share or participate in the current excitement of space sciences as a means of improving the quality of human resources, PSRDC organised another meeting to discuss these issues during the 31st COSPAR Scientific Assembly on 19–20 July 1996, in Birmingham, United Kingdom. During this meeting PSRDC members further discussed various approaches and means in promoting space science education and research activities in the developing countries.

In view of the deliberations of PSRDC during the past few years and the COSPAR resolution in this context, it is felt that one possible effective way would be that the developing countries may select suitable ground-based experiments for regular observational data with an integrated approach involving space based observations/data for initiating a modest space research activity in the country. To assist in this endeavour of the developing countries, PSRDC has recommended that a compendium of information of typical ground-based experiments which are complementary to space based observations/data should be prepared and widely distributed to the individual scientists and the concerned scientific agencies. Such a data base is presently not available.

In order to prepare this Compendium of information on typical ground-based instruments which are complementary to space based observations/data, it is necessary to collect scientific and technical information from a large number of scientists and space agencies of the world. In view of this, a detailed form has been designed to collect such information, and this has been sent to a large number of individual scientists as well as space agencies all over the world. The data collection is likely to be completed by the end of December 1997. After suitable analysis and grouping of the data, the compendium will be finalised and made available as a source of information particularly for the scientists in developing countries. (For more details and requesting a copy of the form or report, the reader may contact Dr. S.C. Chakravarty Program Director, Space Science Office, Antariksh Bhavan, New BEL Road, Bangalore-560094, India, Telephone: +91 80 3416271, Fax:+91 80 3419190, e-mail: scc@isro.ernet.in).

Out of the 22 papers presented at the PSRDC scientific meeting on "Problems of space science education and the role of teachers" held during the 31st COSPAR Scientific Assembly, 16 papers have been received in the final form and these have been sent to the official publishers of COSPAR. These papers will be compiled and brought out as a single volume of the Advances in Space Research.

Space Science and Applications Activities of Different Countries Related to PSRDC

Islamic Republic of Iran

The Iranian Remote Sensing Centre (IRSC) is the government organisation responsible for co-ordinating and supervising all national remote sensing activities in the country. IRSC has taken responsibility for upgrading the satellite ground receiving station at Mahdasht situated about 50 km from Tehran. In recent years, 12 different projects have been carried out by IRSC at local, provincial and national levels including an applied project for the monitoring of renewable resources of the country. Applied projects carried out using remotely sensed space data within the country cover a wide spectrum such as, land use, hydrological, geological, tectonic, seismotectonic, and mineral mapping, geotechnical, geological, geomorphological and landform features, image-map production (at the scale of 1:50000 and 1:100,000), sea surface temperature and chlorophyll concentrations, environmental pollution (oil-slicks), natural disaster monitoring and prediction (sea surface undulation, landslides, etc.), crop area estimation (including tea, rice, barley, wheat and cotton), rangeland green biomass estimation, desertification and dedesertification.

A satellite receiving station for Meteosat and NOAA APT data is located in Tehran. The data are used to monitor local instabilities, flood situations, diurnal heat cycle of land and sea surfaces, dust and sand movement. There are plans to upgrade the facilities in order to receive and process data from NOAA AVHRR, Meteosat and Russian meteorological satellites, to install a VSAT terminal and a new switching system, and a radar network for the country.

A comprehensive program in satellite communications including launching three identical satellites called Zohreh (Persian equivalent for Venus) allocated for Iranian domestic communication needs by ITU is being undertaken. Each satellite will carry 14 Ku-band transponders and one L-band transponder. The system will allow the use of small and inexpensive Earth terminals for television reception, rural telephone services and business communications. The ground segment will include the installation of two tracking, telecommunication, telemetry and command stations and the establishment of a network of Earth stations.

Other major activities carried out by different government agencies of Iran are as follows: (1) use of Global Positioning System (GPS) for rescue and relief operations and accurate positioning of marine vehicles used for a national levelling project and for triangulation networking over the country and its subsequent linkages with the regional network and the international GPS networks, (2) use of satellite-based positioning systems for accurate positioning of marine vessels, resource and relief operation, navigation and geodetic projects, crustal movement studies etc., (3) a project on sustainable development "Landcover Assessment and Monitoring of Iran" is under execution using technical, educational and financial support provided by UNEP, and (4) the 1 km land cover data base of Asia which is developed using the data acquired by NOAA satellites has been taken up as a regional project. The results obtained from this project which covers 28 countries of the region will be integrated into a 1 km land cover database of the World.

There are more than 10 universities engaged in conducting graduate and post-graduate courses in different areas of space science varying from aeronautics to space remote sensing technologies. To establish computerised data-bases accessible to national users, while the Internet is used for regional and international accessibility, a national Network for Public Information Services has also been successfully established. To access data related to space science and application, presently two databases have been initiated. These databases are Earth Resources Satellite Data of Iran and Remote Sensing Education Courses in Iran. Other databases under preparation will be on space science documents, oceanography and natural disasters.

China

Numerical simulations and theoretical modelling have been the main activities in the field of space physics in China. Space science exploration has been carried out mainly with balloon and satellite borne experiments. Practice-4 is the first large elliptical orbit (apogee at geostationary height) scientific satellite for the exploration of space charged particle environment. During its initially designed half-year lifetime the main objective of this satellite is to study the spectrum and spatial distribution of charged particles in the near-Earth environment, the single event upset (SEU), single event latch (SEL) and satellite surface plasma charging effects. Among the six detectors onboard the satellite, five were designed and manufactured by the Centre for Space Science and Applied Research, of the Chinese Academy of Sciences (CAS). The satellite platform and the other detectors were designed and manufactured by the China Aerospace Corporation.

Measurements have been made on stratospheric aerosols and ozone using indigenous 30,000 -50,000 m^3 high altitude scientific balloons. Five launches were made in 1994. CAS has taken up the design and manufacture of high technology balloons for launching a solar telescope for photographing the diffraction limited (0.2 arc sec) solar magnetic vector fields and velocity fields, from a vantage point above the majority of Earth's atmosphere. Chinese experts are having discussions with experts from Germany and other countries and are making an assessment on a program and key techniques for the design and manufacture of a satellite borne space solar telescope on the basis of the experience in balloon borne solar telescope project.

During the past two years, using ground-based simulation facilities, experiments on the solidification of eutectic alloys, containerless levitation techniques, and casting techniques have been used to investigate microgravity and gravity effects. Also in July 1994, the alpha-LiI03 crystal growth experiment was made on the indigenous recoverable satellite.

In the field of space based life science research, the Institute of Space Medico-Engineering, have carried out space experiments on mice and silkworm respectively using an indigenous recoverable satellite and a Russian biology satellite. Also on the ground, a simulated weightlessness state has been used to investigate the influence of space motion sickness and weightlessness on organisms.

A Chinese multifunctional real-time operational ground-based system for Meteosat includes a satellite operation control centre, a command and data acquisition station, data processing system, turn around receiving system, a data collection platform, medium scale and small scale data utilisation stations, facsimile or cloud image receiving station and 140 Mbps optical fibre communication system. The ground stations of CAS have been upgraded to be capable of receiving ETM data of Landsat-6 and SAR data of JERS-1 and ERS-1. The comprehensive utilisation of space and related ground based data has been widely applied in the study of soil erosion, urbanisation, forest monitoring, disaster surveillance, natural water/soil conservation and lakes.

Indonesia

The Indonesian National Institute of Aeronautics and Space (LAPAN) conducts space research to understand the natural phenomenon of aerospace and its characteristics in relation to Indonesian climate prediction and environmental condition.

A number of facilities established so far include ground-based equipment, meteorological stations, a balloon launching station, a rocket launching station, an atmospheric chemistry laboratory, an ionospheric research station, and a laboratory and software for climate modelling.

The climate related research has been focused on using the climate models such as the Global Circulation Model (GCM) and the Limited Area Model (LAM). Both models use a similar basic theory in describing the dynamical and physical states of the atmosphere. The use of LAM is aimed at making more detailed climate simulations for certain regions which cannot be done by GCM due to its course resolution.

In the field of solar physics, sunspot numbers are being observed from the solar observation station at Watukosek (7.57 degrees S, 112.65 degrees E) and Sumedang (6.5 degrees S, 107.47 degrees E) while solar radio burst observations have been made from Sumedang using a radio spectrograph. The observational data have been used in supporting frequency prediction for HF radio communication.

Possible relations between solar variability and total ozone over Indonesia has been studied on the basis of data obtained from the TOMS experiment on board NIMBUS satellites during the period October 1978 to December 1992. Data used in this study represented the region between 7 degrees S and 7 degrees N and between 95 degrees E and 140 degrees E. The total ozone variation was clearly dominated by the effects of SAO and QBO (with a periodicity of 22–34 months), both causing variation of the order of 8 percent (~20 Dobson unit). The residual time series obtained after removing those two effects indicated the presence of an 11-year variation in phase with the oscillation of solar activity in the same period. The solar activity index employed here was the core-to-wing ratio at 280 nm based on observations with the Solar backscatter Ultraviolet (SBUV) version 6 and the Stratospheric Aerosol and Gas Experiment II (SAGE II).

Medium Frequency (MF) radar has been in full operation at Pontianek (0.5 degrees, 109.1 degrees E), West Kalimantan, as a collaborative project between LAPAN (Indonesia), University of Adelaide (Australia) and Kyoto University (Japan). By using 1.98 MHz frequency with a power of 25 kW, the three MF antenna radar observe the two components of the wind up to 60–100 km in altitude during the day time and 70–100 km at night, every 2 km with a time resolution of 2 minutes. The analysis of the observations taken between November 1995 and September 1996 has shown that zonal and meridional wind velocities at 78–98 km reached a maximum (more than 50 m/s) during the equinox (March and September) directed to the west and south, respectively. In the mesosphere/lower thermosphere it was found from spectral analysis that there were some periodicities: a longer one of 2–10 days and the shorter one of 5 minutes to 24 hours. These are indications of the existence of Kelvin waves (longer period), and tides and gravity waves (shorter period).

India

The fourth of the second generation Indian communications satellites, INSAT-2D, was lunched successfully on 4 June 1997 and after a series of in-orbit testing of the payload the satellite was declared ready for use. The indigenously developed Polar Satellite Launch Vehicle (PSLV-1C) successfully launched the fourth operational Indian Remote Sensing Satellite (IRS-1D) on 29 September 1997 from Sriharikota. IRS-1D is the first operational remote sensing satellite to be launched by India's own launch vehicle. Like its predecessor, IRS-1D also contains three on-board cameras: a Panchromatic camera (PAN), with a spatial resolution of 5.8 m and a swath of 70 km, a Linear Imaging Self -scanning Sensor (LISS-III) operating in four spectral bands and a Wide Field Sensor (WiFS) with a swath of 810 km.

Application of remote sensing technology has been set up in vital areas such as crop inventory, landuse mapping, ground water targeting, forest cover mapping and change detection, mineral targeting, snow melt predictions, flood mapping, drought management, ocean and marine fisheries. In the area of space sciences, the IRS-P3 satellite, launched from Sriharikota on 21 May 1996, has been providing valuable data related to X-ray astronomy and oceanography. The SROSS C-2 satellite launched on 4 May 1994 from Sriharikota is still providing data on the ionospheric parameters and on possible gamma-ray burst sources. A national-level training workshop for the utilisation of SROSS-C2 data was held in 1996 to expose scientists from various universities and academic institutions to the satellite data processing, analysis and interpretation. As a result a number of groups from these institutions have initiated activities in the area of space based research of Earth's upper atmosphere, ionosphere and high energy astronomy. Indian scientists are participating in the international co-operative projects such as the Indian Solar Terrestrial Energy Program (STEP) and the Indian Ocean Experiment (INDOEX). A boundary layer radar has been installed at Gadanki near Tirupati (13.5 degrees N, 79.2 degrees E) collocated with the Indian Mesosphere Stratosphere Troposphere (MST) radar which has been operational since 1993. Indian climatologists, aeronomers and astronomers are presently having a number of discussion sessions to define proposals on national satellites dedicated for space science research.

Taiwan

The space science activities in Taiwan includes the research fields related to ionosphere, magnetosphere, interplanetary medium, meteor event, and solar physics.

In addition to numerical simulation studies by means of high speed computer, the existing experimental instruments for ionospheric studies in the Taiwan area include an ionosonde, a digisonde, a magnetometer, and a facility for total electron content (TEC) measurement, the Chung-Li VHF radar, CW-HF Doppler sounding system, and an ionospheric tomography network along Taiwan meridian. In-situ ionospheric measurements by means of the Ionospheric Plasma and Electrodynamic Instrument, which will be mounted on-board ROCSAT-1 and scheduled for launch in the spring of 1999, will be another important tool to investigate the behaviour of the ionosphere in the equatorial anomalous region. In addition, a program of sounding rocket experiments and space payload development for the purpose of ionospheric observations are under way. The related research topics include the dynamics and 3-dimensional spatial structures of the sporadic E (Es) and spread F plasma irregularities, the ionospheric response to solar activity, the reconstruction of the electron density profile from the TEC data observed with the ionospheric tomography network, gravity wave propagation in the ionosphere, the behaviour of geomagnetic and ionospheric storms, the coupling between the ionosphere and magnetosphere, and plasma instability in the ionosphere.

The primary tools for magnetopheric research in the Taiwan area are the numerical simulation and the analysis of in-situ satellite based observations. The main topics related to the megnetospheric research are: the coupling between solar wind and magnetosphere, the investigation of magnetospheric substorms by constructing a nonlinear steady-state convection model, investigating the current system of the magnetosphere-ionosphere coupling using a theoretical electric current system to model the coupling process, applications of magnetohydrodynamics to the space environment, studies of the characteristics of the magnetosheath and magnetopause in the space environment, investigation of the generation mechanism of high/low-latitude magnetic pulsations by using a magnetic meridian network, and the study of ULF waves in the magnetosphere.

The dynamics of coronal mass ejection and interplanetary magnetic clouds are investigated by analysing in-situ satellite based measurements and numerically simulating theoretical magneto-hydrodynamic equations.

The interaction of MHD discontinuities in the space plasma environment by using numerical simulation techniques with a hybrid code, interaction of interplanetary disturbances with

Earth's magnetosphere, the effects of interplanetary disturbances on the bow shock, magnetosheath, magnetopause and geomagnetic substorm, and the discontinuities and the thin current sheets in the solar wind and Earth's magnetosphere.

The capability of observing meteor trails occurring in the height range 80–120 km has been implemented at the Chung-Li VHF radar located on the campus of the National Central University in Taiwan. The mesospheric and lower thermospheric winds and waves, including gravity waves and tidal waves, can be measured by using this radar. Furthermore, the diffusive coefficient of the mesosphere and lower thermosphere can also be derived from the life-time of the echo signal from the overdense meteor trail. Moreover, the electron density can be estimated from the fading pattern of the radar returns of the overdense meteor trail, provided the diffusive coefficient is obtained beforehand.

Pakistan

The main elements of the Pakistan space program, initiated in 1961–62, includes the launching of sounding rockets for upper atmospheric research, low Earth orbit satellites for scientific and technological applications, the operation of ground stations for tracking, telemetry and control, acquisition of data from remote sensing and meteorological satellites, collection of data from unmanned Data Collection Platforms (DCPs) in remote areas under the Argos program, and receiving distress signals under the COSPAS-SARS project. The space program is being implemented by the Space and Upper Atmosphere Research Commission (SUPARCO) under the policy guidelines laid down by the Space Research Council under the Prime Minister. So far, about 200 sounding rockets have been launched to collect data on the upper atmosphere and related phenomena. These rockets have been designed and fabricated indigenously at SUPARCO. APT images received from NOAA Satellites are used to monitor cloud types and the build-up of fronts, storms and cyclones. They are used in real time to track cyclones in the Arabian Sea and Bay of Bengal. NOAA-TOVS data are used to derive vertical profiles of many atmospheric parameters from the ground to a height of about 35 km for tropospheric and stratospheric studies.

A large number of research studies covering diverse disciplines such as hydrology, agriculture, forestry, geology, etc., using data from Landsat, SPOT and NOAA satellites have been conducted at the Remote Sensing Applications Centre, Karachi. Increasing use is now being made of GIS (Geographical Information System) as a complement to satellite remote sensing data in resource/environmental studies. SUPARCO has prepared a land cover database of Pakistan using NOAA data as part of a regional project of a 1 km land cover database of Asia.

Ionospheric data collected through ionosondes operating at Karachi, Multan and Islamabad are analysed to study ionospheric conditions. Geomagnetic data of Karachi are acquired in analogue and digital forms. The digital data are used to compute hourly ranges, mean hourly values and monthly mean of the total scalar magnetic field and its components. The analogue data are used to determine the occurrence of principal magnetic storms, solar flare effects, local K and C indices etc. Monthly bulletins of geomagnetic data are provided to various data users, including the World Data Centre, Boulder, Colorado, USA and the Institute of Geophysics, Beijing, China.

Pakistan's first experimental small satellite, Badr-1, was designed and fabricated by SUPARCO scientists and engineers, and was successfully launched in 1990 on a Chinese Long March 2E vehicle. Its payload includes a digital communications experiment with data store and forward capability. The next satellite Badr-B, is currently under development. It will be placed in a low-Earth, Sun-synchronous, near circular orbit at an altitude of about 800-1,000 km in the next two years. Work on satellite structure, various sub-systems and payloads, including a CCD camera and radiation dosimeter is progressing.

CONTRIBUTORS

The report submitted by the International Astronautical Federation (IAF) for Part One was prepared by J. Grey (for G. Hovmork and Lin Jin, Co-Chairmen of the International Programme Committee for the 48th IAF Congress) and was approved by K. Doetsch, IAF President. The International Institutue of Space Law (IISL) contribution on space law and international cooperation was prepared by S. Doyle.

For the report submitted by the Committee on Space Research (COSPAR) for Part Two, each of the organization's Interdisciplinary Commissions and Panels contributed a chapter in response to a request from the Scientific and Technical Sub-Committee of the United Nations Committee on Peaceful Uses of Outer Space. The report provides an overview of the progress in the various disciplines of space research science during 1997. Although many people contributed to this report, the major part of the scientific input was provided by the following scientists:

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ACRONYMS, ABBREVIATIONS, AND DEFINITIONS

ABRIXAS	A Broadband Imaging X-ray All-Sky Survey
ACE	Advanced Composition Explorer
ADEOS	Advanced Earth Orbiting Satellite
ALOMAR	Arctic Lidar Observatory for Middle Atmosphere Research
AMIE	Assimilative Mapping of Ionospheric Electrodynamics
AMSU	Advanced Microwave Sounding Unit
ANN	Artificial Neural Network
APAR	Absorptive Photosynthetic Active Radiation
APL	Applied Physics Laboratory (Johns Hopkins University)
APT	Automatic Picture Transmission
ARIS	Active Rack Isolation System
ARP	ATV Rendezvous Predevelopment project
ASCA	Advanced Satellite for Cosmology and Astrophysics
ASCAT	Advanced Wind Scatterometer
ASI	Agenzia Spaziale Italiana (Italy)
ASTRO-E	High throughput imaging x-ray spectroscopy facility
ASTROMAG	A large superconducting magnet
ATOVS	Advanced TIROS Operational Vertical Sounder
ATV	Automated Transfer Vehicle
AU	Astronomical Unit
AVHRR	Advanced Very High Resolution Radiometer
AVNIR	Advanced Visible and Near Infrared Radiometer
AXAF	Advanced X-ray Astrophysics Facility
BDRF	Bi-Directional Reflectance Function
BDS	Bioreactor Demonstration System
BRIC-09	Biological Research in Canister experiment
BTS	Biotechnology System
C-CAP	Coastal Change Analysis Program
CART	Cartilage in Space experiment
CAS	Chinese Academy of Sciences
CASSINI-HUYGENS	A joint ESA/NASA mission to study Saturn
CCD	Charged Coupled Device
CCM	A series of bone cell experiments
CEDAR	Coupling, Energetics and Dynamics of Atmospheric Regions
CELSS	Controlled Ecological Life Support System
CEOS	Committee on Earth Observing Satellites
CERES	Clouds and Earth Radiation Energy System
CHAMP	Challenging Mini-satellite Payload
CIRA	COSPAR International Reference Atmosphere for Trace Constituents
CLAVR	Clouds from AVHRR
CM-1	Combustion Module
CMEs	Coronal Mass Ejections
CMIS	Conical Microwave Imager Sounder
CMIX-5	Commercial MDA ITA Experiment

CNES	Centre National d'Etudes Spatiales (France)
COMPTON	A NASA imaging and broad band spectroscopy mission
CONTOUR	A Discovery-class mission designed to study the diversity of comets
COSPAR	Committee on Space Research
COSPAS	Russian acronym meaning Space System for Search of Vessels in Distress
COST	Commission on Science and Technology
CRIS	Cross Track Infrared Sounder
CRISTA	Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere
CRONOS	Clock Relativity Observations of the Nature of Spacetime
CSA	Canadian Space Agency
CSLM	Coarsening in Solid-Liquid Mixtures
CVX	Critical Viscosity of Xenon
CW	Continuous Wave
CZCS	Coastal Zone Color Scanner
DARA	Deutsche Agentur für Raumfahrtangelegenheiten (Germany)
DARN	Dual Auroral Radar Network
DCE	Droplet Combustion Experiment
DCPs	Data Collection Platforms
DEEP SPACE 1	JPL's first interplanetary technology-development mission
DLR	German Aerospace Research Establishment
DMA	Defence Mapping Agency (USA)
DMSP	Defence Meteorological Satellite Program
DORIS	Doppler Orbitography and Radio-positioning Integrated by Satellite
DPIMS	Diffusion Processes in Molten Semiconductors experiment
DS-3	Deep Space 3
EA	Environmental Agency (Japan)
ECMWF	European Center for Medium-range Weather Forecasting
EGM	Earth Gravity Models
EGS	European Geophysical Society
EISCAT	European Incoherent Scatter Facility
ELITE	European LISA Technology demonstration satellite
EMI	Electromagnetic Interference
ENSO	El Niño Southern Oscillation
ENVISAT	Environmental Satellite
EPCO	Early Polar Cap Observatory
EPIC	Equatorial Processes Including Coupling
EPS	EUMETSAT Polar System
ERBE	Earth Radiation Budget Experiment
ERS	ESA Remote Sensing satellite
ESA	European Space Agency
ESR	EISCAT-Svalbard Radar
ETA	Explosive Transfer Assembly
ETM	Enhanced Thematic Mapper

EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
EURD	European UV spectrometer on MINISAT-1
EUV	Extreme Ultraviolet
EUVE	Extreme Ultraviolet Explorer
EUVN	European Unified Vertical Network
EXPRESS	EXpedite the PRocessing of Experiments to the Space Station
FAST	Fast Auroral Snapshot explorer
FEEP	Field Emission Electric Propulsion
FIRST	Far Infrared Sub-mm Telescope
FREJA	Swedish/German scientific satellite carrying instruments for research of the aurora
GALEX	Galaxy Evolution Explorer
GALILEO	NASA's Jupiter orbiter
GB	GigaBytes
GCM	Global Circulation Model
GEBA	Global Energy Balance Archive
GEM	Geospace Environment Modelling
GEOSAT	Geodesy Satellite
GEOSTEP	Gravity Experiment in Orbit Satellite Test of the Equivalence Principle
GEOTAIL	Satellite to study the Earth's magnetotail
GFZ-1	First satellite of the GeoForschungs Zentrum (Potsdam)
GG	Galileo Galilei
GIS	Geographical Information System
GLOBAL SURVEYOR	A NASA orbiter carrying several experiments from the failed Mars Observer Mission
GLONASS	(Russian) Global Navigation Satellite System
GMS	Geostationary Meteorological Satellite
GOCE	Gravity Field and Ocean Circulation Explorer
GODAE	Global Ocean Data Assimilation Experiment
GOES	Geostationary Operational Environmental Satellite
GOME	Global Ozone Monitoring Experiment
GOMOS	Global Ozone Monitoring by Occultation of Stars
GOMS	Geostationary Operational Meteorological Satellite
GP	Gravity Probe
GPS	Global Positioning System
GPS-MET	GPS Meteorological (experiment)
GPSOS	Global Positioning System Occultation Sensor
GRACE	Gravity Recovery and Climate Experiment
GRANAT	A Russian/French mission for monitoring and localization of x-ray sources and low energy gamma-ray imaging
GRAS	Global Navigation Satellite System Receiver Atmospheric Sounder
GRIM	German/French Global Earth Gravity Models
GRO	(Compton) Gamma-Ray Observatory
HALCA	Antenna for orbiting VLBI imaging observatory
HALOE	Halogen Occultation Experiment

HESSI	High Energy Solar Spectroscopic Imager
HETE	High Energy Transient Experiment
HF	High Frequency
HIV	Human Immunodeficiency Virus
HRDI	High Resolution Doppler Imager
HRPT	High Resolution Picture Transmission
HRVIR	High Resolution Visual and Infrared
HST	Hubble Space Telescope
HZE	Particles of high change and high currency
IAG	International Association of Geodesy
IAGA	International Association of Geomagnetism and Aeronomy (IUGG)
IASI	Infrared Atmospheric Sounding Interferometer
IASTP	Inter-Agency Solar-Terrestrial Physics Program
ICE	International Cometary Explorer
ICMA	International Commission on the Middle Atmosphere
ICSU	International Council of Scientific Unions
ICTP	International Center for Theoretical Physics
IDI	Imaging Doppler Interferometer
IEH/UVSTAR	A NASA UV spectroscopy mission
IERS	International Earth Rotation Service
IGBP	International Geosphere-Biosphere Program
IGOS	Integrated Global Observing Strategy
IGS	International GPS Service for Geodynamics
ILAS	Improved Limb Atmospheric Spectrometer
IMEWG	International Mars Exploration Working Group
IML	International Microgravity Laboratory
IMU	Inertial Measurement Unit
INDOEX	Indian Ocean Experiment
INSAT	Indian communication satellite
INTEGRAL	ESA imaging and spectroscopy program
INTERBALL	InterCosmos Fireball
IPO	Integrated Program Office
IR	Infrared
IRI	International Reference Ionosphere
IRIS	International Radio Interferometric Surveying
IRS	Indian Remote Sensing satellite
IRSC	Iranian Remote Sensing Center
IRTS	Infrared Telescope
ISAS	Institute of Space and Astronautical Science (Japan)
ISCCP	International Satellite Cloud Climatology Project
ISEE	International Sun Earth Explorer
ISIS-2	International Satellites for Ionosphere Studies
ISO	Infrared Space Observatory
ISR	Incoherent Scatter Radar
ISSA	International Space Station Alpha
ISTP	International Solar-Terrestrial Physics Program

ITA	Instrumentation Technology Associates
ITM	Ionosphere, Thermosphere and Mesosphere
ITU	International Telecommunication Union
IUE	International Ultraviolet Explorer
JERS-1	Japanese Earth Remote Sensing Satellite
JGM	Joint Gravity Model
JPL	Jet Propulsion Laboratory
KUIPER	NASA airborne IR observatory with 91 cm telescope
LAGEOS	Laser Geodynamic Satellite
LAI	Leaf Area Index
LAM	Limited Area Model
LAPAN	Indonesian National Institute of Aeronautics and Space
LDB	Long Duration Balloon
LEDs	Light-Emitting Diodes
LEGRI	Low Energy Gamma-ray Instrument
LEO	Low-Earth Orbit
LeRC	Lewis Research Center
LIF	Liquid Phase Sintering II experiment
LIS	Lightning Imaging Sensor
LISA	Laser Interferometer Space Antenna
LISS	Linear Imaging Self-scanning Sensor
LM	Long Module
LMD	Liquid Metal Diffusion
LMS	Life and Microgravity Science
LUNAR-A	An ISAS lunar penetrator mission
LUNAR PROSPECTOR	A NASA Discovery-class mission
LYMAN	A specialist high resolution UV spectroscopy mission (NASA)
MA	Middle Atmosphere
MAGELLAN	A radar-mapping mission to Venus
MAHRSI	Middle Atmosphere High Resolution Spectrograph Investigation
MAM	Middle Atmosphere Model
MAP	Microwave Anisotropy Project
MARINER 10	A Mercury-exploring spacecraft
MARS EXPRESS	An orbiter and a series of microlanders ESA is considering for liftoff in the early part of the 21st century
MCCs	Mesoscale Convective Complexes
MDA	Materials Dispersion Apparatus
MET	Meteorology
METOP	Meteorological Operational satellite
MF	Medium Frequency
MGM	Mechanics of Granular Materials
MHD	Magneto Hydrodynamics
MHS	Microwave Humidity Sounder
MIDAS	Middle Atmosphere Dynamics and Structure
MIDAS	Material in Devices as Superconductors
MIDEX	NASA Medium Explorer
MIM	Microgravity Vibration Isolation Mount

MINISAT-1	A mission carrying EURD and LEGRI
MiniSTEP	A minimal-cost version of STEP
MIR	Russian space station
MIR	Mongolfière Infrarouge
MIR/KVANT	Russian imaging, spectroscopy and timing studies mission
MISETA	Multi-Instrument Studies of the Equatorial Thermosphere Aeronomy
MLT	Mesosphere and Lower Thermosphere
MMA	Microgravity Measurement Assembly
MOU	Memorandum of Understanding
MSDT	Multi-stage, Sample Direction dependent, Target-decision (strategy)
MSG	Meteosat Second Generation
MSL	Microgravity Science Laboratory
MST	Mesosphere/Stratosphere/Troposphere
MSX	Mid-course Space Experiment
MU	Middle Atmosphere-Upper Atmosphere radar
MULTIFOT II	Proper name of experiment (Multiphotometer)
MUSES-C	A Japanese mission to the near-Earth asteroid Nereus
MW	Microwave
NASA	National Aeronautics and Space Administration
NASA/GSFC	NASA Goddard Space Flight Center
NASA/WFF	NASA Wallops Flight Facility
NASDA	National Space Development Agency of Japan
NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center
NCEP	National Centers for Environmental Prediction
NDVI	Normalized Difference Vegetation Index
NEAR	Near Earth Asteroid Rendezvous
NESDIS	National Environmental Satellite, Data, and Information Service
NEW MILLENNIUM	JPL's technology development program
NGDC	National Geophysical Data Center
NIH	National Institutes of Health
NIMA	National Imagery and Mapping Agency
NIMBUS	Weather satellite
NLC	Noctilucent Clouds
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NPOESS	National Polar-orbiting Operational Environmental System
NRC	National Research Council
NSCAT	NASA Scatterometer
NSF	National Science Foundation
NSWP	National Space Weather Program
NWP	Numerical Weather Prediction
NWS	National Weather Service
OARE	Orbital Acceleration Research Experiment

OCTS	Ocean Color and Temperature Scanner
ODIE	Orbiting Drag-free International Explorer
ODIN	Swedish Middle Atmosphere satellite
OLS	Operational Linescan System
OMEGA	Orbiting Medium Explorer for Gravitational Astrophysics
OMI	Ozone Monitoring Instrument
OMPS	Ozone Mapping and Profiler Suite
OREX	Orbital Re-entry Experiment
OSIRIS	Odin Spectrograph Infrared Imaging System
PAN	Panchromatic camera of 5.8 m resolution
PATHFINDER	A small rover which landed on Mars on July 4, 1997
PCG	Protein Crystal Growth
PGBA	Plant Generic Bioprocessing Apparatus
PhaSE	Physics of Hard Spheres
PI	Principal Investigator
PLANCK	An ESA project to study microwave background anisotropy
PLANET-B	ISAS program aimed at clarifying the structure and dynamics of the Martian upper atmosphere and its interaction with the solar wind
PMC	Polar Mesospheric Clouds
PMSE	Polar Mesospheric Summer Echo
POAM	Polar Ozone and Aerosols Measurements
POD	Precise Orbit Determination
POES	Polar-orbiting Operational Environmental Satellite
POLAR	NASA spacecraft to study polar magnetosphere
POLDER	Polarization and Directionality of the Earth Reflectance
PR	Precipitation Radar
PRARE	Precise Range and Range-rate Equipment
PRIME	Prediction and Retrospective Ionosphere Modelling over Europe
PSLV	Polar Satellite Launch Vehicle
PSMOS	Planetary Scale Mesopause Observing System
PSRDC	COSPAR Panel on Space Research in Developing Countries
PW	Planetary Waves
QBO	Quasi-biennial Oscillation
QPF	Quantitative Precipitation Forecast
QUELD	Queen's University Experiment in Liquid Diffusion
RADIO ASTRON	Observatory with antenna for orbiting VLBI
RELICT-2	A Russian study of anisotropy/spectrum of 2.7 K cosmic background radiation
ROSAT	Röntgen Satellite (German X-ray satellite)
ROSETTA	ESA's international mission to visit comet P/Wirtanen
SAGE	Stratospheric Aerosol and Gas Experiment
SAM	Stratospheric Aerosol Measurement
SAMPEX	Solar, Anomalous, Magnetospheric Particle Explorer
SAMS	Space Acceleration Measurement System
SAO	Semi-annual Oscillation
SAR	Synthetic Aperture Radar

SARS	Search and Rescue Satellite
SAX	X-ray Astronomy Satellite
SBUV	Solar Backscattered Ultraviolet
ScaRaB	Scanner for Earth Radiation Budget
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Cartography
SCOR	Scientific Committee on Oceanic Research
SCOSTEP	Scientific Committee on Solar-Terrestrial Physics
SeaWiFS	Sea-viewing, Wide-Field-of-View Sensor
SEL	Single Event Latch
SESAME	Second European Stratospheric Arctic and Mid-latitude Experiment
SEU	Single Event Upset
SIGMA	Gamma-ray telescope
SIMURIS	Solar Interferometric Mission for Ultrahigh Resolution Imaging and Spectroscopy
SIR	Spaceborne Imaging Radar
SIRTF	Space Infrared Telescope Facility
SLR	Satellite Laser Ranging
SMART-1	A test flight for solar electric propulsion scheduled for launch in 2001
SMEI	Solar Mass Ejection Imager
SMEX	NASA Small Explorer
SMR	Sub-Millimeter Radiometer
SOFTBALL	Structure of Flame Balls at Low Lewis-number experiment
SOHO	Solar and Heliospheric Observatory
SPECTRUM X-GAMMA	PI mission for spectroscopy, imaging monitoring and polimetry of X-ray sources
SPECTRUM-UV	Optical/UV telescope for spectroscopy and wide field imaging
SPIRIT III	A cryogenically cooled infrared sensor
SPOT	Satellite pour l'Observation de la Terre
SQUID	Superconducting Quantum Interference Device
SRAMP	STEP Results, Applications and Modelling Phase
SROSS	Stretched Rohini Satellite System
SRSO	Super Rapid Scan Operations
SSB	Space Studies Board
SSCE	Solid Surface Combustion Experiment
SSM/I	Special Sensor Microwave Imager
SSM/T1	Special Sensor Microwave/Temperature
SSM/T2	Special Sensor Microwave/Temperature-Moisture
SST	Sea Surface Topography
STARDUST	A Discovery-class mission designed to fly past P/comet Wildt 2
STEP	Solar Terrestrial Energy Program
STEP	Satellite Test of the Equivalence Principle
STL	Space Tissue Loss
STP	Solar-Terrestrial Physics
STS	Space Transportation System

SUPARCO	Space and Upper Atmosphere Research Commission (Pakistan)
SURVEYOR	A NASA program which plans to launch a pair of spacecraft to Mars every 26 months
SWAS	Submillimeter Wave Astronomy Satellite
TARFOX	Tropospheric Aerosol Radiative Forcing Observational Experiment
TDRSS	Telemetry and Data Relay Satellite System
TEC	Total Electron Content
TEMPUS	The electromagnetic containerless processing facility
THESEO	Third European Stratospheric Ozone campaign
TIMED	Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics
TIMEGCM	Thermosphere-Ionosphere-Middle-Atmosphere-Electrodynamics General Circulation Model
TIROS	Television and Infrared Operational Satellite
TM	Thematic Mapper
TMI	TRMM Microwave Imager
TOMS	Total Ozone Mapping Spectrometer
TOMS	Total Ozone Monitoring Scanner
TOPEX/POSEIDON	Oceanic Topography Experiment
TOVS	TIROS Operational Vertical Sounder
TPFLEX	Two-Phase Fluid Loop Experiment
TRACE	Transition Region and Coronal Explorer
TRMM	Tropical Rainfall Measuring Mission
TVIS	Treadmill Vibration Isolation System
UARC	Upper Atmosphere Research Collaboration
UARS	Upper Atmosphere Research Satellite
UCLA	University of California at Los Angeles
ULDB	Ultra Long Duration Balloon
ULF	Ultra Low Frequency
ULYSSES	A joint ESA/NASA heliospheric mission
UNEP	United Nations Environment Program
URSI	International Union of Radio Science
USAF	United States Air Force
USML	United States Microgravity Laboratory
UV	Ultraviolet
UVVISI	Visible UV Imager/Spectrometer System
VHF	Very High Frequency
VIEW-CPL	Visualization in an Experimental Water Capillary Pumped Loop
VIIRS	Visible/Infrared Radiometer Suite
VIRS	Visible Infrared Scanner
VIS	Visible
VLBI	Very Long Base Interferometry
VSAT	Very Small Aperture Terminal
VSOP	VLBI Space Observatory Program
WiFS	Wide Field Sensor
WIND	NASA spacecraft to study solar wind and terrestrial plasma
WIND II	Wind Imaging Interferometer

WMO	World Meteorological Organization
WSF	Wake Shield Facility
WWW	World Weather Watch
WWW	World Wide Web
XMM	X-ray Multi-Mirror
XTE	X-ray Timing Explorer

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