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REPORT ON THE UNITED NATIONS/EUROPEAN SPACE AGENCY WORKSHOP ON MICROWAVE REMOTE SENSING APPLICATIONS ORGANIZED IN COOPERATION WITH THE GOVERNMENT OF THE PHILIPPINES

(Manila, Philippines, 22-26 April 1996)

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INTRODUCTION

A. Background and objectives

1. In its resolution 37/90 of 10 December 1982, the General Assembly endorsed the recommendations of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82) and decided, among other things, that the United Nations Programme on Space Applications should promote the dissemination of information on advanced space applications and new systems developments among Member States, particularly for the benefit of the developing countries.

2. The United Nations/European Space Agency Workshop on Microwave Remote Sensing Applications, held from 22 to 26 April 1996, was one of the activities of the Programme on Space Applications for 1996 that could further that objective. Those activities were endorsed by the General Assembly in its resolution 50/27 of 6 December 1995. The Workshop was organized in cooperation with the Government of the Philippines and hosted by the National Mapping and Resource Information Authority (NAMRIA) of the Philippines for the benefit of participants from developing countries.

3. The objective of the Workshop was to expose the participants to various aspects of current and future microwave remote sensing systems, as well as to applications of radar data to natural resource exploration and environmental monitoring. The Workshop featured the experiences and programmes of a number of countries, especially those from the region of the Economic and Social Commission for Asia and the Pacific (ESCAP), in the development and application of microwave remote sensing. The Workshop concluded with working group deliberations that focused on three major areas: data availability and accessibility; practical applications of radar data; and required education and training.

4. The present report, which covers the background, objectives, organization, observations and conclusions of the Workshop as well as a summary of the lectures presented, has been prepared for the Committee on the Peaceful Uses of Outer Space and its Scientific and Technical Subcommittee. Participants will report to the appropriate authorities in their respective countries.

B. Organization and programme of the Workshop

5. The participants were professionals with several years of experience in the field of remote sensing, the management of natural resources and other related programmes that can benefit from microwave remote sensing applications. The Workshop was attended by 68 participants from the following States, United Nations entities and international bodies: Afghanistan, Australia, Bangladesh, Canada, China, Fiji, India, Indonesia, Iran (Islamic Republic of), Japan, Malaysia, Nepal, Palau, Philippines, Republic of Korea, Singapore, Sri Lanka, Thailand, United States of America, Vanuatu and Viet Nam; United Nations Environment Programme (UNEP) and the Office for Outer Space Affairs of the United Nations; and the European Space Agency (ESA) and SPOT Asia (Satellite pour l'observation de la Terre (SPOT): French Earth observation satellite).

6. Funds allocated by the United Nations and ESA for the organization of the Workshop were used to defray the cost of international air travel and living expenses (hotel accommodation and daily subsistence allowance) of 20 participants from the region of Asia and the Pacific. The Government of the Philippines, through NAMRIA, provided conference facilities and equipment, local transportation and midday meals for all the participants.

7. Opening addresses were made by J. Solis, Administrator, NAMRIA, on behalf of the Government of the Philippines; by J. Lichtenegger on behalf of ESA; and by A. A. Abiodun, United Nations Expert on Space Applications, Office for Outer Space Affairs.

8. The programme of the Workshop was developed jointly by the United Nations and ESA and covered the following major areas: (a) national programmes (presentations made by M. Nur, Indonesia; S. Park, Republic of

Korea; V. Phan, Viet Nam; L. Posadas, Philippines; K. Osman Salleh, Malaysia; M. Sebastian, India; and C. Keng Yew, Singapore); (b) spaceborne radar remote sensing in the 1990s (presentations made by S. Ahmed, Canada; Y. Bechacq, SPOT Asia; J. Guifei, China; J. Lichtenegger, ESA; E. Paylor, United States of America; P.V.N. Rao, India; and H. Wakabayashi, Japan); (c) radar data processing and calibration (presentations made by M. Higashi, Japan; J. Lichtenegger, ESA; and R. Schumann, ESA; (d) radar data applications (presentations made by S. Kanchanasutham, Thailand; M. Khan, Bangladesh; J. Lichtenegger, ESA; E. Lopez, Philippines; N. Mahmood, Malaysia; A. Milne, Australia; M. Bin Seeni Mohd, Malaysia; M. Nur, Indonesia; A. Pineda, Philippines; and R. Punongbayan, Philippines); and (e) international cooperation (presentations made by A. A. Abiodun, Office for Outer Space Affairs; D. Pradhan, UNEP; and R. Schumann, ESA). The programme of the Workshop also included a visit to NAMRIA facilities at Manila.

9. The Workshop was conducted through a number of plenary and working group sessions. During the working group sessions, the participants discussed the issues associated with microwave remote sensing. Their observations and recommendations are summarized in section I of the present report. The participants also noted that the recommendations should be pursued in conjunction with the international exchange of ideas, which were nurtured by the collaborative nature of the Workshop. To further such collaboration and to evaluate the implementation of recommendations made by the working groups, the participants agreed that a follow-up workshop should take place within two years.

10. At the conclusion of the Workshop, the participants expressed their appreciation of the scientific and technical quality of the programme and the presentations delivered. In addition, they expressed their thanks to the co-sponsors for the support received, making possible their participation in the Workshop, and also to NAMRIA for the cooperation and support of its administrative and technical personnel.

I. OBSERVATIONS AND RECOMMENDATIONS OF THE WORKSHOP

11. The proceedings of the working group sessions focused on the following three major areas of microwave remote sensing: data availability and accessibility; practical applications of radar data; and required education and training. The discussions included references to the experience acquired in satellite microwave remote sensing by the international scientific and user communities.

A. Data availability and accessibility

12. Based on the in-depth discussions of the working group, the participants noted that various sources of data could be provided by current technology. At the same time, the working group observed that the issue of data availability and accessibility could be an obstacle to the successful utilization of microwave remote sensing data in developing countries. The working group noted the following problems associated with the acquisition of data:

(a) Product catalogue: lack of information on the availability of data; and complexity of data accessing;

(b) Processing and delivery time: lack of publicized delivery standards; need for near real time (NRT) data cannot be met in many cases; and lack of standardized naming of product processing levels;

(c) Programming requests for data acquisition: conflicts in handling programming requests, especially in cases of emergency;

(d) Data format: data could be difficult to read.

13. On the basis of the working group discussion, the Workshop made a number of recommendations in order to inform the data providers on the fundamental needs of the users. The recommendations have been summarized as follows:

(a) Ground receiving station (GRS) operators should make information on data received available within 24 hours after reception through a catalogue browsing system on the Internet;

(b) GRS operators should make high-quality quick-looks or small subscenes available within three hours after reception for downloading via public networks;

(c) Earth observation satellite (EOS) operators should develop a centralized worldwide catalogue database and make metadata and quick-looks available to all users free of charge. The Committee on Earth Observation Satellites (CEOS) should encourage the preparation of a master catalogue on data availability for all EOS;

(d) GRS operators should commit themselves to meeting product delivery times, recommended by the Workshop as follows:

(i) Regular service - 10 days;
(ii) Rush service - 48 hours;
(iii) NRT service - 3 hours.

(e) GRS operators should standardize the naming and specifications of data products;

(f) In emergency cases, countries in the region of South-East Asia should have an agreement to disseminate data taken within the footprint of their operational GRS;

(g) In emergency cases, GRS operators should give programming priority to users that would handle disasters with an environmental and social impact;

(h) EOS operators should coordinate conflicting programming requests, especially in emergency cases, and CEOS should provide required guidelines on the prioritization of programming requests;

(i) GRS operators should provide users with software which is able to read data from different platforms. The digital product should contain:

(i) Description file in ASCII codes of all information pertinent to the data;
(ii) Files containing source codes for reading the header for different platforms (UNIX, VMS, PC etc.);
(iii) Header file;
(iv) Data file.

14. The participants in the Workshop also emphasized that CEOS should play a leading role in the coordination and synchronization of activities of all EOS operators in order to optimize the availability of microwave remote sensing data.

B. Practical applications of radar data

15. The participants noted that the following major application areas were of particular interest and relevance to developing countries in the region of Asia and the Pacific:

(a) Hazards mapping (natural and man-made), including: volcanic and seismic hazards; earthquakes; tsunamis; oil spills monitoring; flooding vulnerability, assessment and monitoring; and disaster management;

(b) Base mapping, including: photogrammetry/topographic mapping; preparing terrain profiles for the design of communication systems; geological structure mapping; and bathymetric mapping;

(c) Agriculture and forestry, including: forest inventory and monitoring (especially mapping of old growth forests and forestry on hilly areas); crop identification and monitoring; harvest forecasting; crop suitability; soil classification (with emphasis on soil moisture and soil suitability measurements); mangrove cover; and land cover;

(d) Marine and meteorology, including: sea-surface temperature mapping; ocean wastes mapping; coastal management (especially erosion assessment of coral reefs); wave height assessment; forecasting of wave conditions on shipping routes; fisheries (with emphasis on mapping of coastal habitats and location of fishing grounds); tides and currents (patterns, measurements and observations); and wind speed;

(e) Environmental monitoring, including: air/water pollution monitoring; preparation of environmental impact assessments (EIA); epidemiological studies (breeding grounds of disease-bearing insects); and monitoring of mining environments related to requirements of environmental clearance certificates (ECC);

(f) Resource inventory and planning, including: coastal changes related to urbanization; geological hazard studies for urban planning; ground-water identification; geological structure/mineralization studies (modelling); land-use studies; analysis of rehabilitation measures for disaster areas; landfill site selection; and terrain analysis for radio propagation applications.

16. The participants agreed that microwave remote sensing technology had reached a level that could contribute significantly to activities of economic importance. With the exception of meteorological applications, however, the majority of application areas still required considerable research and support, through modelling, in order to improve interpretation of the data.

17. Since remote sensing technology utilizes radiation from the ultraviolet spectrum to microwaves, the potential benefits of the appropriate complementary and additive use of all wavelength data and acquisition techniques were advocated at the Workshop.

18. It was noted by the working group that the required frequency of observation for many of the parameters greatly exceeded that obtainable from a single platform. The working group recognized that development of the necessary multi-platform system would not be feasible for a single agency. However, given the number of systems proposed for the coming decade, cooperation and coordination between both the providing agencies and the ground reception facilities could enable the repeat coverage required. The working group noted that this subject is on the agenda of CEOS.

19. It was also stated by the working group that data delivery in many cases needed to be improved considerably from the current situation. This is specifically the case for those applications which require a rapid response to a given situation. The participants also observed that there was a real need for the development of proven methodologies for data analysis.

20. Members of the working group indicated that the majority of users in developing countries experienced difficulties in acquiring and upgrading the hardware and software required for data processing and analysis. There was also inadequate technical and financial support to pursue the applications.

21. The participants observed that inadequate education and training did not allow users in developing countries to fully utilize microwave remote sensing data and to integrate this information into the regional, national and local decision-making processes.

22. With the above in mind, the working group made a number of recommendations that have been summarized as follows:

(a) Present and potential users should be given more training in microwave technology applications to facilitate full implementation of the technology and utilization of acquired data. It would also enable the users to successfully implement demonstration projects that might subsequently provide the basis for decision makers to expand the use of such data in order to address national and regional needs;

(b) The Centre for Space Science and Technology Education for the region of Asia and the Pacific region should place more emphasis on teaching and training programmes in microwave technology;

(c) Active cooperation and collaboration of ESCAP countries in information exchange should be encouraged in order to share experiences in practical applications of radar data, as well as information on project proposals, funding opportunities and available resource persons;

(d) To achieve extensive utilization of the data, a multi-tier pricing policy should be introduced whereby the cost of the data would depend on the particular need of the user. Data sharing among the users within one country should be encouraged;

(e) A worldwide inventory of resources related to microwave remote sensing, which would include information on experts, projects, organizations involved and their activities, should be prepared and made available on-line via the Internet.

C. Required education and training

23. The working group acknowledged that the present and forthcoming radar systems for Earth observation were very relevant to Member States in the Asian region. This new technology requires that an extensive education and training programme should be set up to enable Member States to obtain the full benefits from airborne and satellite synthetic aperture radar (SAR) systems.

24. Some of the key issues addressed by the working group pertaining to education and training were: who needs to be trained (e.g. decision makers, professionals, technicians and educators); what should be taught (e.g. principles, techniques, applications, data processing and interpretation and software training); where the training should take place (e.g. in-house, on-the-job, locally, nationally, regionally or internationally); and how the training should be conducted.

25. The participants also addressed the issues of maintaining international and regional links between national educational and research institutions, as well as international information and scientific exchanges, technology transfers, and availability and sharing of data and equipment.

26. After discussing the above-mentioned issues in some detail, the following recommendations were formulated by the working group:

(a) Dissemination of information on fellowships, training and research opportunities in microwave remote sensing should be improved. The information should be available on-line via the Internet;

(b) The United Nations, in cooperation with the Centre for Space Science and Technology Education for the region of Asia and the Pacific, should undertake a survey to determine current local training requirements and priorities for bilateral and multinational collaboration in microwave technology education, research and applications;

(c) The possibility of incorporating short-term training courses, workshops and seminars into a programme for providing participants with credit toward a certificate or diploma in remote sensing or any other certification leading to a formal academic degree should be considered;

(d) Donor countries should be encouraged to increase the number of fellowship, training and research opportunities available for scientists, researchers and professionals from developing countries;

(e) Recognizing the important role of the Centre for Space Science and Technology Education for the region of Asia and the Pacific established in India, the participants called upon Governments in the region to sign the relevant agreement with the Centre as soon as possible and to actively participate in all the activities of the Centre.

II. SUMMARY OF PRESENTATIONS

A. Earth Observation Programme of the European Space Agency

27. Monitoring of the Earth environment and effective management of its natural resources are the necessary elements of sustainable development. ESA, through implementation of its Earth Observation Programme, supports those activities by providing a range of remote sensing technologies and support infrastructure that are under continual development, and by encouraging the application of those systems through varied and expanding training activities. The main objectives of the ESA Earth Observation Programme include the following elements:

(a) Monitoring the Earth environment at various scales;

(b) Monitoring and management of Earth resources;

(c) Continuation and improvement of services in operational meteorology;

(d) Improved understanding of Earth dynamics;

(e) Serving and responding to user community needs.

28. In order to ensure that the above-mentioned objectives are met, the Earth Observation Programme comprises a variety of activities that range from satellite and instrumentation development and operation to data utilization and training. The activities are aimed at encouraging the adoption of remote sensing techniques for a wide range of applications, including the Earth Observation Satellites mission, the Meteorological Programme (METOP) and the Meteosat Second Generation (MSG) missions, future Earth Observation missions, the Earth Observation Preparation Programme, the Data User Programme and the development of the Earth Observation Data Policy.

29. The most visible current activity of ESA in the area of Earth observation may be the European Remote Sensing Satellite (ERS) programme. ERS-1 was launched on 17 July 1991, and has operated in orbit for over four years, continually providing a wide range of high-quality microwave data about the Earth and its environment. This satellite was joined in orbit by its near twin, when ERS-2 was launched on 21 April 1995. With the Active Microwave Instrument (SAR and Wind Scatterometer) and Radar Altimeter remaining unaltered from ERS-l, modifications to the second satellite payload involved the addition of a completely new instrument, the Global Ozone Monitoring Experiment, modification of the Along Track Scanning Radiometer and the upgrading of the Precise Range and Range-rate Equipment for determining orbital position.

30. The ERS programme should provide an overlap with the next major ESA development, the Environmental Satellite (ENVISAT), currently scheduled for launch in 1998/99. This is important since it will provide data continuity into the next century, thus bridging the gap between the technology in orbit today and that now under development. Instruments on board ENVISAT include: Advanced Synthetic Aperture Radar; Radar Altimeter; Medium Resolution Imaging Spectrometer; Michelson Interferometer for Passive Atmospheric Sounding; Global Ozone Monitoring by Occultation of Stars; Advanced Along Track Scanning Radiometer; Scanning Imaging Absorption Spectrometer for Atmospheric Cartography; Scanner for Radiation Budget; and Doppler Orbitography and Radio-positioning Integrated by Satellite.

31. ENVISAT is expected to have a five-year life-span, and will incorporate the possibility of utilizing data relay satellites in addition to ground stations for the downlink of its data.

32. Meteosat operations, handled by Eumetsat from 1 December 1995, are now entering into a transitional phase between the current Meteosat Operational Programme and the MSG Programme. Meteosats 3 and 4 were de-orbited in November 1995, leaving Meteosat 5 to continue to support the nominal mission. Meteosat 6, remaining on standby, will be followed by a transitional satellite in mid-1997, with the first of the MSG satellites scheduled for a launch in the year 2000.

33. METOP-1 is the first of a series of three satellites that are to be employed primarily for meteorological and climate monitoring operations. METOP-1 is expected to be launched in 2001. These polar orbiting missions will enhance, and eventually replace, the current meteorological satellites of the National Ocean and Atmospheric Administration (NOAA) of the United States of America flying in the so-called morning orbit.

34. The space segment and part of the payload for METOP-1 is being developed and provided by ESA, while Eumetsat will be responsible for its operations and for subsequent satellites in the series. The remainder of the payload is to be provided by NOAA, Eumetsat and European national space agencies.

35. Improvements over the existing systems include higher spatial and spectral resolutions in both the visible and infrared portions of the electromagnetic spectrum, more frequent imaging, air mass analysis and more timely data dissemination. Additionally, there is the possibility of including scientific and search and rescue packages as a payload option. The programme, consisting of three satellites, will mean that the provision of data can be expected to continue until well beyond the turn of the century.

B. Advanced Land Observing Satellite mission

36. The Advanced Land Observing Satellite (ALOS) is a Japanese high-resolution Earth observation satellite that is to be used for cartography and for environmental and hazard monitoring applications. To meet user requirements and future regional observation needs, the National Space Development Agency (NASDA) of Japan has decided to equip the satellite with both optical and microwave high-resolution sensors. A high-resolution Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) as well as a Phased Array L-band Synthetic Aperture Radar (PALSAR) were chosen as the mission instruments of ALOS. ALOS is currently scheduled to be launched in 2002.

37. In order to accommodate high-performance sensors, the ALOS satellite system will have several outstanding capabilities, among which are precise determination of position and attitude and the capability to handle large volumes of data. ALOS will carry a star-tracker instrument for accurate attitude determination and phase-tracking Global Positioning System (GPS) receivers for precise position determination. To handle the large volume of data generated by AVNIR-2 and PALSAR, ALOS will have mass storage on board. The memories will have a storage capacity of 706 gigabits and a data-handling capability of 240 megabits per second. Optical data recorders and solid-state memory recorders are the most probable equipment for the mass memories. ALOS will also provide a high-data-rate transmission capability through the Data Relay Technology Satellites scheduled for launch before ALOS. This will make it possible to receive ALOS data in real time for hazard monitoring.

38. PALSAR is the second Japanese spaceborne SAR which uses L-band frequency. The instrument has three modes of observation, identified as fine resolution, ScanSAR, and low-data-rate modes. The fine-resolution mode, a strip SAR, is a conventional mode, used mainly for detailed regional observations and repeat-pass interferometry. The goal for this mode is to achieve 10 metres of spatial resolution, both in the range and azimuth directions, and 70 kilometres of swath width. PALSAR will have another attractive observation mode, the ScanSAR mode, which will make it possible to image strips with widths of more than 250 kilometres by sacrificing spatial resolution. This width is about three times wider than current SAR (e.g. Japanese Earth Resources Satellite (JERS-1/SAR) images, and should be useful for determining the coverage of sea ice and rain-forest monitoring.

39. In the low-data-rate mode, data can be transmitted directly to ground stations using X-band frequency. Because of narrow band width in the X-band downlink frequency, the maximum data rate in this band is limited to 120

megabits per second. By sacrificing spatial resolution in range direction, dynamic range and swath width found in the fine-resolution mode, the observation data can be transmitted at either 120 or 60 megabits per second.

40. The PALSAR system will be jointly developed by NASDA and the Japan Resources Observation System (JAROS) organization. NASDA is responsible for PALSAR integration and developing the antenna unit, including the radiation panels. JAROS is responsible for the development of an electronics unit, as well as transmitting/receiving modules of the antenna unit.

C. Applications of radar remote sensing technology in the Philippines

41. In the Philippines, microwave remote sensing data are widely used by a number of government institutions and organizations, as well as by users in the private sector. Activities in space technology development and in applications are coordinated by a multi-agency body called the Committee on Space Technology Applications, under the Science and Technology Coordinating Council (STCC). STCC is a cabinet-level body chaired by the Department of Science and Technology, and serving as the highest science and technology policy-making body in the country.

1. Completed projects

42. The use of radar satellite data in the Philippines was spurred by the need to implement a programme for rehabilitation of areas in northern and central Luzon that had been severely damaged by the July 1990 earthquake. This was known as the Earthquake Reconstruction Project. The project was funded by the International Bank for Reconstruction and Development and the Asian Development Bank, and jointly implemented by NAMRIA, the Philippine Institute of Volcanology and Seismology and the Department of Public Works and Highways. The project utilized SAR data provided by INTERA, a Canadian company, to assess earthquake damage and map potential geologic hazard zones.

43. Another project, entitled "Interpretation of SAR Data and Preparation of Geologic, Seismic Zonation, and Geohazard Maps for Portions of Luzon, Philippines", utilized interpretations of conventional aerial photographs, detailed geotechnical investigations and reviews of geologic and geophysical information, and combined them with interpretations of SAR data that had been collected by INTERA. The project team included the participation of the private sector. Among other very important outputs, the project team using SAR data prepared digital base maps showing drainage and transportation networks, and digitized available geological maps for all of Luzon. SAR mosaics in the 1:100,000 scale were prepared and analysed to produce maps showing physiography, structures and lineaments.

44. These projects had a training component, in the form of intensive participation by local professionals in data review and analysis, field mapping, drilling, report writing, preparation of map layouts and hazard mapping. Seminars on such topics as "engineering seismology" and "estimating characteristics of earthquake ground motions and evaluating liquefaction potential", a short training course on SAR data interpretation and field trips to selected study areas were also included.

45. With funding from the European Union, a number of projects using ERS-1 data were undertaken in 1994. One of these is the project entitled, "Mount Pinatubo Environmental Degradation Assessment Using ERS-1 SAR Data", which produced land cover maps of Mount Pinatubo and vicinity. This project was implemented by the University of the Philippines Training Center of Applied Geodesy and Photogrammetry. An integral part of the collaboration with ESA was the training component, which included a national radar training workshop for 32 persons from different government agencies and regions.

2. Ongoing projects

46. The Philippine Institute of Volcanology and Seismology has started a three-year project, entitled "Mitigation of Volcanic Hazards in the Philippines using ERS-1 Data". Four active volcanoes, namely Pinatubo, Taai, Mayon

and Ragang, were selected for investigation and monitoring of changes using the technique of interferometry. Important outputs of this project consist of geologic and hazard maps, as well as knowledge of interferometric techniques. The project is sponsored by the United Nations Educational, Scientific and Cultural Organization and the International Union of Geological Sciences.

47. At present, two agencies are implementing projects in which Radarsat data are utilized. NAMRIA is conducting a study to examine the feasibility of using Radarsat SAR data to produce orthoimages. The project goal is production of a low-cost 1:100,000 orthoimage on the basis of fine-resolution (10-20 metres) data by designing and developing an appropriate digital elevation model. Radarsat provides data only, while the Government of the Philippines, through NAMRIA, provides funding for the operating expenses and equipment.

48. The Bureau of Soils and Water Management is conducting a project entitled, "Flood Vulnerability Assessment of the Central Luzon Basin using Radarsat". The project output will be presented in the form of monthly flood situation maps (1:250,000) for 1996 and 1997, pointing out flood duration, depth and spatial extent.

D. Rice monitoring in Thailand using synthetic aperture radar data from the European Remote Sensing Satellite

49. The objective of the study was to evaluate the capabilities of ERS-1 SAR data for monitoring rice-planting acreage and its growth. The study area was about 100 square kilometres in the Tha Muang district, Kanchanaburi province, in western Thailand. The rice-growing area was irrigated, flat, homogeneously managed, and had large individual fields, of at least 1 hectare each.

50. Multi-temporal ERS-1 SAR data were available on 12 acquisition dates, between November 1991 and December 1994. The analysis of ERS-1 SAR data was supported by aerial photographs and a SPOT panchromatic image.

51. Within the study area, 10 sample areas of approximately 10 hectares each were selected for detailed backscattering studies of rice fields. Extensive ground measurements were taken in conjunction with ERS-1 data acquisitions during the main growth period from August to December 1993. Plant height, moisture content and plant density, the number and size of leaves, stalk net weight and the height of standing water were measured, along with more general observations of the state of the water and soil surface and plants, as well as weather conditions at acquisition time.

52. GPS was used to locate and register test-site boundaries and calculate the area of each test site. The ERS-1 data were geometrically corrected using a topographic map at scale 1:50,000. The field boundaries of all the surveyed test sites were digitized and superimposed on the geometrically corrected and filtered data. The results of the study can be summarized as follows:

(a) Multi-temporal ERS-1 SAR data are highly suitable for rice-field mapping. The achieved mapping accuracy in the study was 89 per cent for rice fields against any other land cover;

(b) At least three images should be available during the growth cycle. The optimum acquisition dates are during the flooded vegetative phase, at the end of the reproductive phase and shortly before harvesting. An additional post-harvest image may be useful for better discrimination from other land cover classes in the surrounding areas;

(c) The use of a pixel-based, standard maximum-likelihood classifier is sufficient, although more sophisticated methods may provide better results. Speckle filtering of the input data is essential;

(d) Multi-temporal ERS-1 SAR data are highly suitable for rice-crop monitoring;

(e) The radar backscattering coefficient is well correlated with rice-plant height; consequently, the use of radar data allows determination of the approximate stage of plant growth;

(f) The radar signal shows a potential correlation with rice yield. However, this relation may be indirect, assuming that radar backscattering is more sensitive to parameters such as biomass, moisture and geometry of rice plants rather than to grain yield itself;

(g) If an operational rice-monitoring system is developed, it is strongly recommended to include multi-temporal radar data as a primary data source.

E. Use of synthetic aperture radar data from the European Remote Sensing Satellite for land-use and coastal zone monitoring in Indonesia

53. Indonesia is an archipelago country with approximately 17,000 islands and a coastline of more than 81,000 kilometres in length. The coastal zone is a vital living space and an area of intense economic and social activity of great importance to the country. Planning and management of land use and coastal resources should be based on a sound knowledge and understanding of the physical and biological processes involved. Remote sensing data could be a very important source of information for that purpose. In optical remote sensing, however, one of the major constraints that limits the use of this tool is cloud cover. Microwaves are able to penetrate cloud cover and allow the monitoring of land use and coastal areas on a weather-independent basis.

54. The main objective of the project was to study the potential of ERS-1 SAR data to derive information that would be useful for land-use and coastal zone management. The detailed objectives of the project included the following:

(a) Over land, to investigate the potential of ERS-1 SAR for mapping areas used for fish ponds, harbours, coastal infrastructures, settlements, rice fields and other land-use categories, and its relevance for coastal zone management;

(b) Over sea, to investigate the potential of ERS-1 for detecting oil spills, wave studies, underwater features and man-made objects in the sea;

(c) To compare the information content of ERS-1 SAR data with that of other remote sensing data;

(d) To integrate information derived from ERS-1 into coastal zone management models.

55. The study area was located along the northern coast of Central Java. Three data sets of ERS-1 SAR data were available, acquired on 23 January, 16 February and 6 March 1994. Analysis of the multi-temporal data was complemented by field observations and existing maps. Both visual and digital analysis of ERS-1 SAR imagery was carried out.

56. The result of the study may be summarized as follows:

(a) Multi-temporal ERS-1 SAR images are very useful for land-use and coastal zone management, including monitoring of changes in the coastal land cover and coastline at high and low tide and detection of oil spills;

(b) Complementary use of multisource imagery (ERS-1 SAR, Landsat Thematic Mapper and SPOT), as well as application of multisensor data fusion techniques is recommended for more accurate interpretation and classification of data, especially with respect to land-use monitoring.

F. European Community/European Space Agency/Association of South-East Asian Nations project

57. In November 1992, the European Community, in partnership with the Association of South-East Asian Nations (ASEAN) and with the technical support of ESA, embarked upon an ambitious project to upgrade remote sensing facilities in South-East Asia in order to assist the developing countries of the region in the development of microwave remote sensing programmes and applications of ERS-1 and NOAA advanced very high resolution radiometer (AVHRR) data. Such development was to be achieved through hardware and software upgrades for both ERS-1 and AVHRR data acquisition, processing and archiving and, in the case of ERS-1, through the establishment of a pilot project and training programme to be conducted over a two-and-a-half-year period. The structure of the project comprised three elements: two bilateral agreements (with Thailand and Malaysia) aimed at providing the necessary hardware and software resources to support new developments in remote sensing within ASEAN; and one regional component addressing the pilot project and training needs required.

58. The European Community made available to the project a grant of 3.9 million European currency units (ECU), with an additional contribution of 1.52 million ECU from ESA in the form of data and training facilities.

59. Upgrading of existing acquisition facilities in support of ERS-1 in Thailand was completed, and operations commenced at the beginning of March 1993. Since then, approximately 145 high-density digital tapes have been acquired, each one containing data from an average of three to four satellite passes. In addition to the precision processor capable of producing a variety of ERS-1 products, the processing chain incorporated the first operational installation of a quicklook processor. This processor enables even the longest passes to be processed to image form in less time than it takes to produce a single precision product. The quicklooks so produced provide a valuable visualization within the cataloguing facility that is also provided as part of the overall system.

60. In Malaysia, an extension to the existing AVHRR acquisition facilities at the Malaysian Meteorological Service was made in order to include processing of higher-level products using the ESA-developed software packages. Additional Universal Interface Terminal systems and stand-alone SAR geocoding systems were also installed.

61. Eight pilot projects were selected from the large number of proposals submitted and distributed between the four countries participating in the project (Indonesia, Malaysia, Philippines and Thailand). The pilot projects addressed applications issues that were of specific relevance to the South-East-Asian experience.

62. The pilot projects were:

(a) INDO-1: land-use assessment and monitoring using ERS-I SAR data;

(b) INDO-2: application of ERS-1 SAR data for coastal zone management;

(c) MAL-1: complementary nature of SAR and optical data for land cover mapping;

(d) MAL-2: coastal zone information from ERS-I SAR satellite data;

(e) PHIL-1: application of ERS-I SAR data to environmental degradation assessment in the Mount Pinatubo area;

(f) PHIL-2: application of ERS-1 SAR data in flood hazard assessment of fluvial and coastal environment;

(g) THAI-1: rice monitoring using ERS-l data in Thailand;

(h) THAI-2: application of ERS-1 SAR data for coastal studies in Khlung District, Thailand.

63. In support of the above-mentioned pilot projects, the project also provided an opportunity for appropriate training to the project personnel. Training programmes also helped facilitate the dissemination of information among the participating countries on the capabilities of the relatively new technology of microwave remote sensing.

Extremely important within this element was the need to promote an awareness among high-level decision makers about the potential advantages to be gained from using remote sensing technologies, in particular, microwave applications in support of policy and other vital decisions. The training programme of the European Community/ESA/ASEAN project was therefore structured into a series of layers, each targeted at a different audience:

(a) *Seminars for decision makers*. These were one-day events designed to provide both decision and policy makers with an overview of the possible application areas in which microwave data could be useful. Each participating country hosted one of the events;

(b) *Regional training workshops*. These were for a period of two weeks each, introducing an audience of 24 researchers to the principles and practice of microwave remote sensing. Each event addressed a different applications area.

64. In addition, provision was made for two researchers from each project to spend up to three weeks in Europe at facilities of the European Space Research Institute (ESRIN) in order to address issues that were important to the ERS programme, and also at the partner institutes of their respective projects to work on pilot project data using hardware, software and expertise that may not be readily available within ASEAN.

65. In November 1995, the Project Advisory Board held a meeting which evaluated the project and discussed future trends of cooperation between the European Community/ESA and ASEAN. The meeting concluded that most of the pilot projects had been successful, and other activities were completed as planned. Participants at the meeting also discussed the problems experienced during implementation of the pilot projects.

G. Imagery distribution at SPOT Image

66. SPOT Image is a member of the ERS consortium and the distributor of ERS data for users in France and around the world (not including Europe and North America). Singapore-based SPOT Asia, a subsidiary of SPOT Image, responds to SPOT and ERS data inquiries for customers in South-East Asia.

67. In order to understand user needs and to provide better technical advice to customers, SPOT Image undertook a certain number of projects on the application of ERS SAR data. One of those activities was the analysis of ERS SAR data applications to determine which would have the highest potential in terms of relevance to regional user needs. In collaboration with ESA/ESRIN, SPOT Image is currently conducting a comprehensive evaluation of SPOT-ERS data complementarity in European Community/ESA/ASEAN pilot projects in tropical and equatorial regions, with a particular focus on applications concerning cartography, interferometry and agriculture.

68. SPOT Image has also gained expertise in the use of microwave data in the preparation of maps on the basis of SAR data, in flood monitoring using SPOT and SAR imagery, in geocoding SPOT and ERS SAR data and in development of interferometric digital elevation models (DEM).

69. The use of combined SPOT and SAR imagery opens a door to many opportunities in the field of geographic information. Complementarity of the data is due to the type of information delivered by each sensor as well as to the access to information over cloudy regions. Multi-source data products can provide end-users with more accurate and reliable information on agriculture and crop area identification, deforestation monitoring, oil and mineral exploration and geological interpretation, flood monitoring and DEM production, as well as with more complete solutions for production of up-to-date geographic information.