51st Scientific and Technical Subcommittee – UN COPUOS
Vienna , 12 February 2014

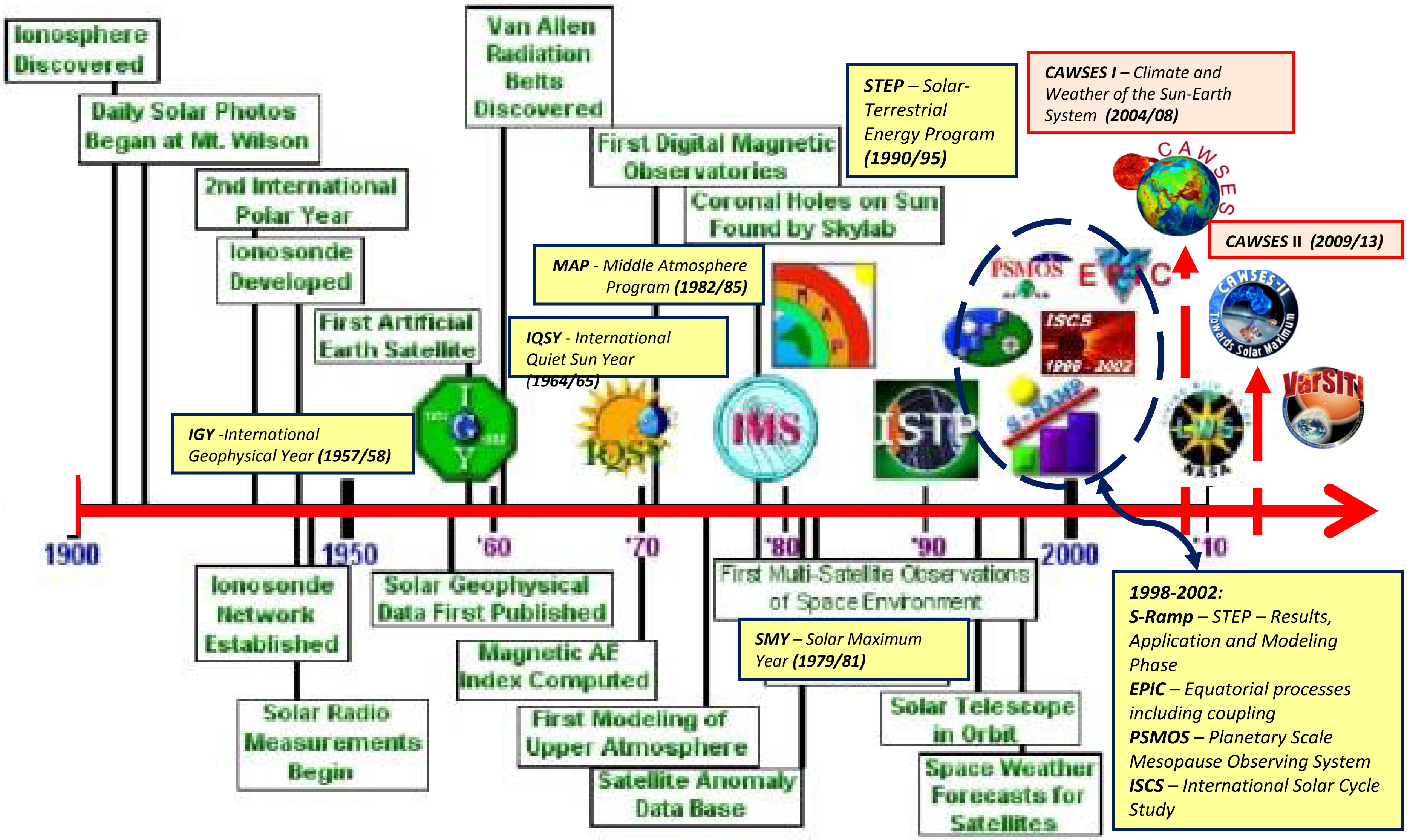
HIGHLIGHTS OF THE SCOSTEP CAWSES II SCIENTIFIC PROGRAM (2009-2013) - UNDERSTANDING THE CLIMATE AND WEATHER OF THE SUN-EARTH SYSTEM

Marianna G. Shepherd
Scientific Secretary
Scientific Committee on Solar-Terrestrial Physics (SCOSTEP)

SCOSTEP
Scientific Committee on Solar-Terrestrial Physics

CAWSES-II
Towards Solar Maximum

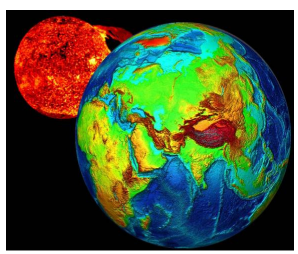
HISTORY OF SCOSTEP SCIENCE PROGRAMS



CAWSES: CLIMATE AND WEATHER OF THE SUN-EARTH SYSTEM

- CAWSES was established in 2004 as SCOSTEP's international program to link the world's scientists in a cooperative effort in improving our understanding of the Solar Terrestrial relations and their impact on life and society.
- Special emphasis was given on the short- (weather) and long-term (climate) variabilities of the solar activity and their effects/responses in Geospace and Earth's environment.
- CAWSES combined both purely scientific and application motivations for enhancing our understanding of variations in the Sun-Earth system.
- Ground-based and satellite observations, and numerical modeling.
- Capacity building activities involved researchers in developing countries, together with educational opportunities for students.

CAWSES
Phase 1: 2004-2008



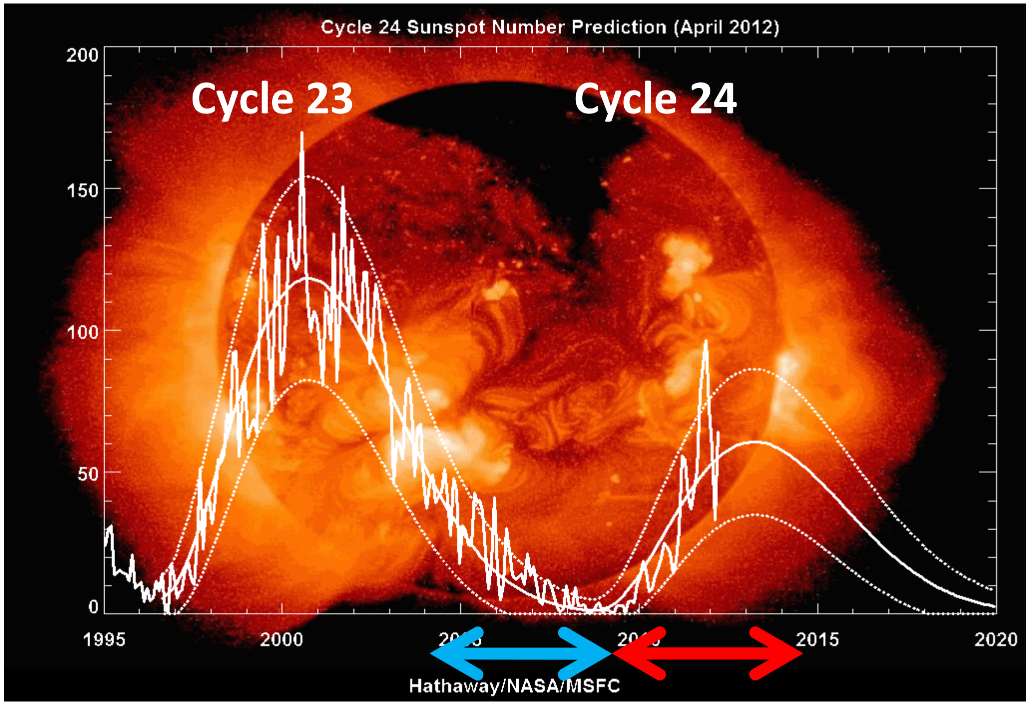
CAWSES II
Phase 2: 2009-2013

CAWSES II 2009-2013

- Fundamental questions of how the coupled Sun-Earth system operates on timescales of minutes to millennia
- Questions that require coordinated inter-disciplinary international effort

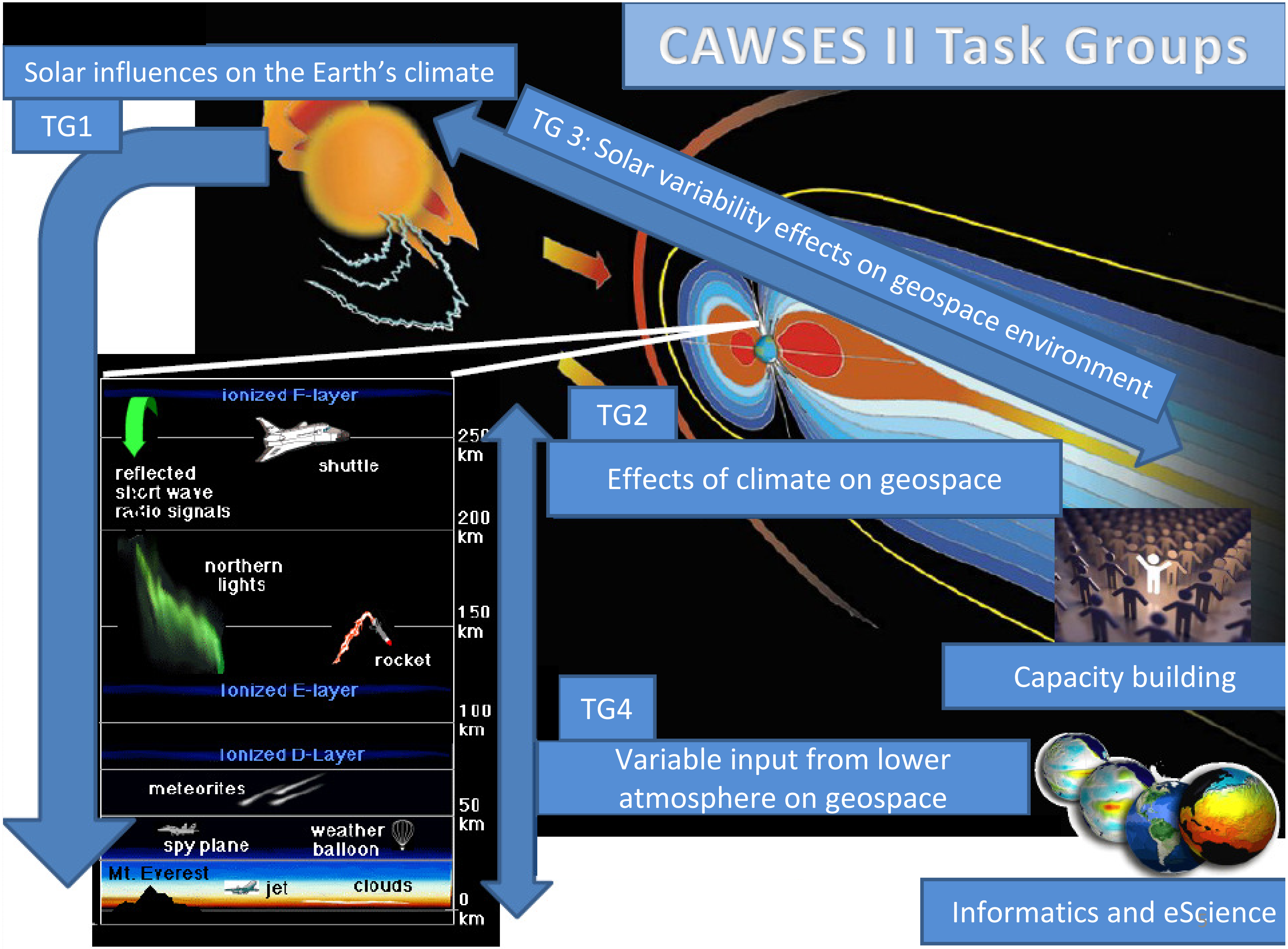
Four major tasks of CAWSES II:

- What is the solar influence on the Earth's climate?
- How will geospace respond to an altered climate?
- How does short-term solar variability affect the geospace environment?
- What is the geospace response to variable inputs from the lower atmosphere?



CAWSES CAWSES II

(during the rising phase of Cycle 24)


CAWSES II Task Groups
Solar influences on the Earth's climate
TG1
TG 3: Solar variability effects on geospace environment
TG2
Effects of climate on geospace
Capacity building
TG4
Variable input from lower atmosphere on geospace
Informatics and eScience
ionized F-layer
shuttle
reflected short wave radio signals
northern lights
rocket
ionized E-layer
ionized D-Layer
meteorites
spy plane
weather balloon
Mt. Everest
jet
clouds
250 km
200 km
150 km
100 km
50 km
0 km

WHAT ARE THE SOLAR INFLUENCES ON THE EARTH'S CLIMATE?

- Solar variability drives the Earth's environment on time scales ranging from minutes to millennia. Feedbacks are inherent in the Earth system and may amplify the direct forcing effects from the Sun.
- The influence of this solar variability on Earth's climate is a key issue of IPCC, and one that continues to be highlighted by policy makers, climate change skeptics, and the media.

OPEN QUESTIONS

- What is the importance of spectral variations to solar influences on climate?
- What is the effect of energetic particle forcing on the whole atmosphere and what are the implications for climate?
- How well do models reproduce and predict solar irradiance and energetic particle influences on the atmosphere and climate?

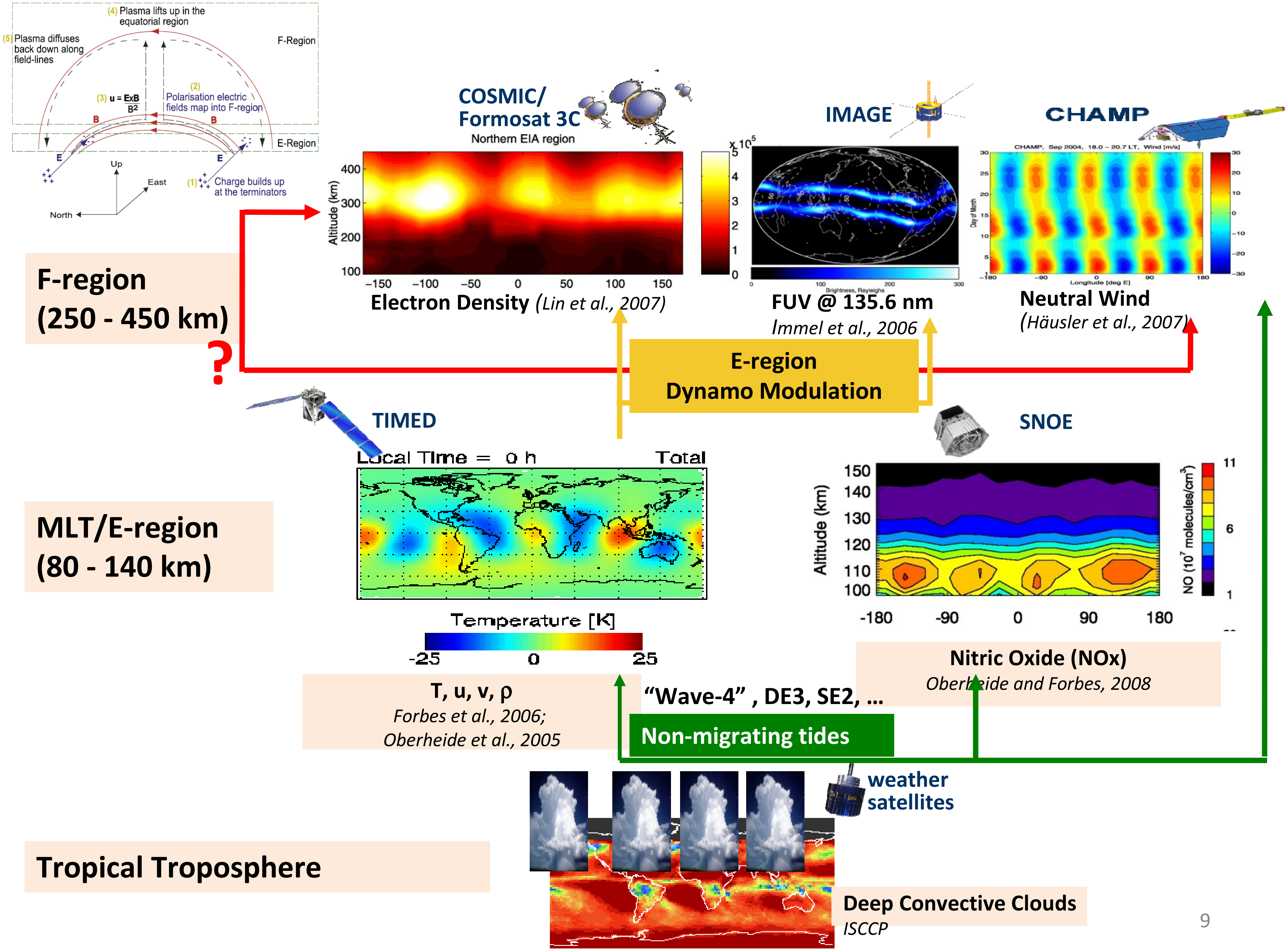
SCIENTIFIC PROGRESS

- **Importance of spectral variations to solar influences on climate**
  - Solar influence on climate - an important contribution to climate variability → Shift focus from global to regional response
  - Importance of top-down stratospheric UV mechanism accepted
  - Improved *Total Solar Irradiance* and *Solar Spectral Irradiance (SSI)* measurements: solar cycle variation estimates →New value of the "solar constant" (1361 Wm^{-2})
  - Direct effects of SSI – Ionization rates; Chemical changes: NOy, O_3, some other constituents; Radiative effects
- **The effect of energetic particle forcing on the whole atmosphere and its implications for climate**
  - Strong indirect effect of energetic particle precipitation (EPP) on stratosphere; studies of effects on troposphere and surface – inconclusive.
  - Solar protons impact polar chemistry, but no long-term (>years) effect
- **Modeling of solar irradiance and energetic particle influences on the atmosphere and climate**
  - Global models start including galactic cosmic rays (GCR) ionization - CERN CLOUD measurements show GCR stimulate aerosol nucleation at upper tropospheric temperatures → Coincident surface-based measurements of aerosol nucleation and ion contribution

WHAT IS THE GEOSPACE RESPONSE TO VARIABLE WAVES FROM THE LOWER ATMOSPHERE?

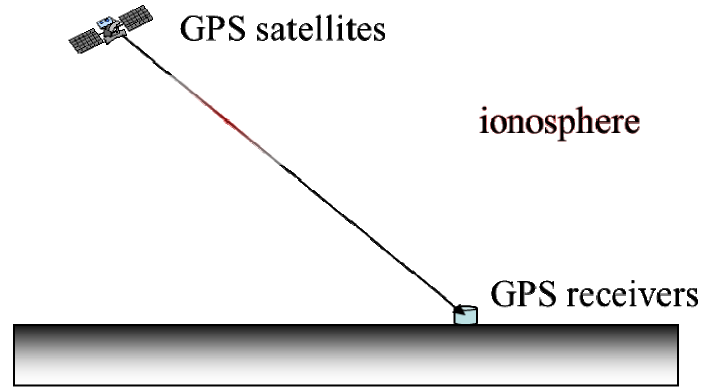
- A variety of new evidence suggests that tropospheric weather is an important ingredient in space weather. Equatorial ionospheric densities are modulated by atmospheric waves driven by persistent tropical rainstorms. Radio waves generated by lightning strokes in rainstorms interact with radiation belt particles to clear a "safe" zone between the inner and outer belts in the magnetosphere.
- Atmospheric gravity waves generated by hurricanes and typhoons may seed plasma bubbles in the low latitude ionosphere ➡ The extent to which the effects of this quiescent atmospheric variability are transmitted to the magnetosphere is yet to be resolved.
- **Overall GOAL:** Elucidate the dynamical coupling from the lower atmosphere to the geospace (upper atmosphere, ionosphere, and magnetosphere), for various frequencies and scales, such as gravity waves, tides, and planetary waves, and for equatorial, middle and high latitudes.

SCOSTEP Scientific Committee on Solar-Terrestrial Physics

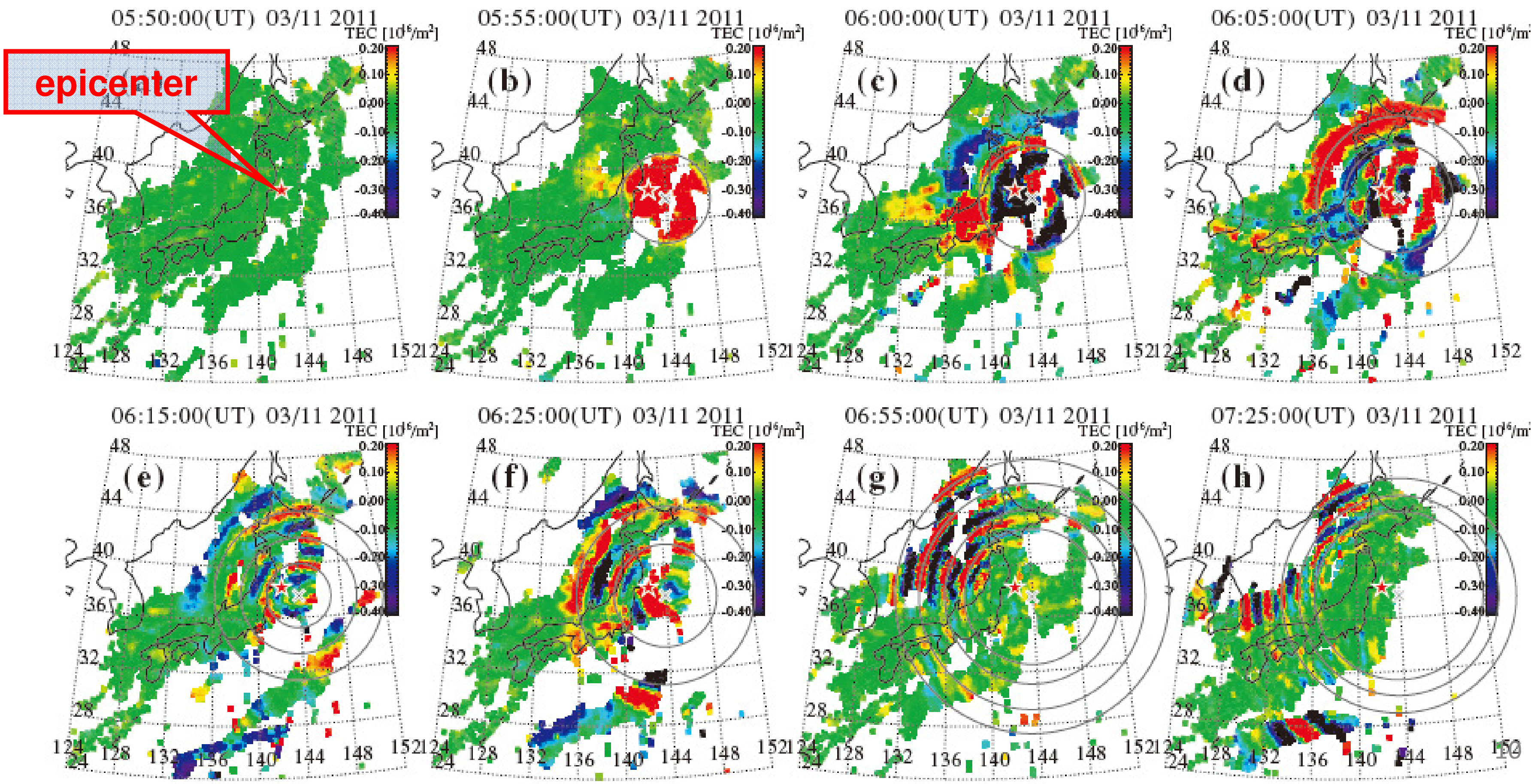


(4) Plasma lifts up in the equatorial region
(5) Plasma diffuses back down along field-lines
F-Region
(3) u = ExB / B²
(2) Polarisation electric fields map into F-region
E-Region
(1) Charge builds up at the terminators
Up
East
North
F-region
(250 - 450 km)
?
COSMIC/
Formosat 3C
Northern EIA region
Altitude (km)
Electron Density (Lin et al., 2007)
IMAGE
FUV @ 135.6 nm
Immel et al., 2006
CHAMP
Neutral Wind
(Häusler et al., 2007)
E-region
Dynamo Modulation
MLT/E-region
(80 - 140 km)
TIMED
Local Time = 0 h
Total
Temperature [K]
T, u, v, ρ
Forbes et al., 2006;
Oberheide et al., 2005
SNOE
Altitude (km)
Nitric Oxide (NOx)
Oberheide and Forbes, 2008
"Wave-4" , DE3, SE2, ...
Non-migrating tides
weather
satellites
Tropical Troposphere
Deep Convective Clouds
ISCCP

TEC Observations with GPS (GEONET; dense GPS network in Japan, 1300 stations)



Tsunami, occurred on March 11, 2011, generated sound waves and gravity waves, that propagated up to the ionosphere causing TEC perturbations.



WHAT WAS ACHIEVED?

- Collaborative effort by the neutral atmosphere and plasma communities leading to a much better understanding of how neutral dynamics originating in the lower atmosphere impact Earth's ionosphere.
- A significant progress in separating ionospheric variability introduced by the driving from below and from the Sun.
- The specific contributions were obtained from five observational campaignst and the support of dedicated workshops resulting in special issues in the peer-reviewed literature.
- **OVERALL OUTCOME :** ***Results show significant penetration of atmospheric waves into the ionosphere in all frequency ranges: acoustic waves, gravity waves, tides, and planetary waves***
- **Current Science Challenges (among others):**
  - Direct penetration of atmospheric waves into thermosphere and then into the ionosphere
  - Electromagnetic coupling from E (~100 km) to F (~300 km) region and then to thermosphere
- Impact of Low Solar Activity: *Enhanced wave effects, due to (i) cooler thermosphere and reduced wave dissipation, and (ii) less solar induced disturbances*

HOW WILL THE GEOSPACE RESPOND TO AN ALTERED CLIMATE?

- Radiative, chemical, and dynamical forcing from below contributes to disturbances of the upper atmosphere.
- Patterns of cooling and contraction of the upper atmosphere in response to rising greenhouse gas concentrations are emerging from model studies and observations, consistent with a strong connection to changes in the lower atmosphere.
- Rising greenhouse gas concentrations alter the ionosphere in a variety of ways and could be transmitted to the magnetosphere.
- These changes may have unforeseen consequences for space-related technologies and societal infrastructures.

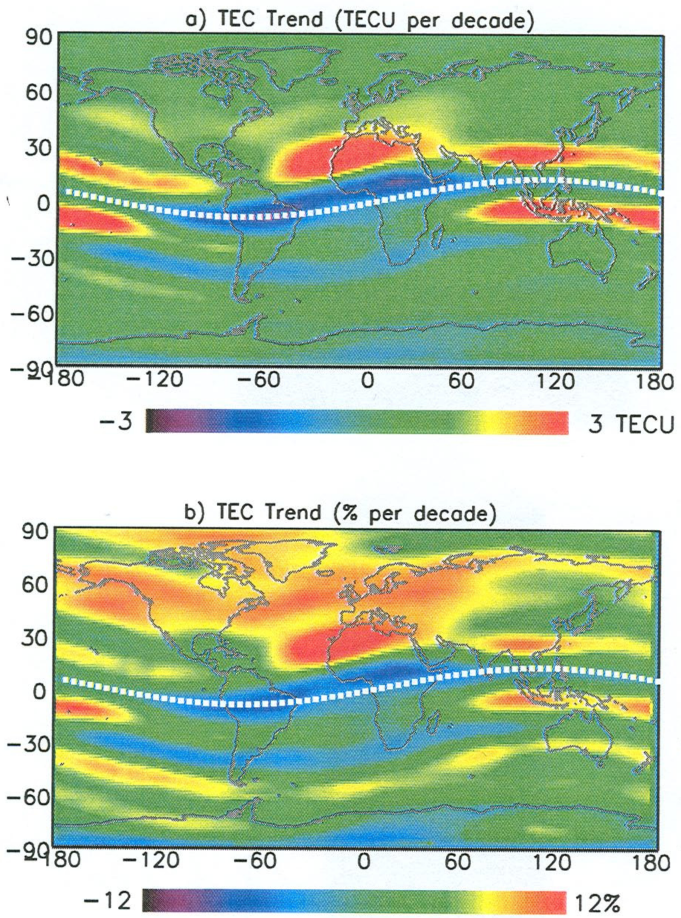
SCOSTEP
Scientific Committee on Solar-Terrestrial Physics

SCIENTIFIC HIGHLIGHTS

- 33-year PMC (Polar Mesospheric Clouds) data (at ~83 km) from the SBUV satellite → significantly smaller trends than previously reported. Long-term increases in PMC brightness, particularly in the Northern Hemisphere.
- 50-year data of NLC (Noctilucent Clouds, observed from the ground) → a weak positive trend (but statistically insignificant) in their appearance frequency - results consistent with satellite observations and models → the trend's magnitude increases with latitude.
- Models show that CO_2, CH_4 and CFCs drive mesospheric trends. Since ~1997, no significant trends are found in mesospheric temperature and PMC frequency, apparently due to the stabilization of stratospheric ozone (Montreal protocol).
- Onset of the Antarctic PMC season - highly correlated to the time of breakdown of the stratospheric winter vortex (*intra-hemispheric coupling*).
- Seven documented cases of impulsive increases of PMC resulting from poleward transport of water vapor from the exhaust of the U.S. Space Shuttle main engine.

TRENDS IN TOTAL ELECTRON CONTENT (TEC)

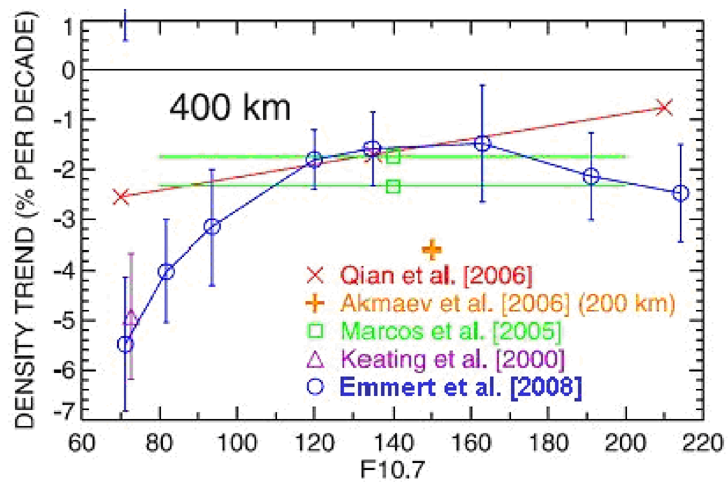
TEC trends from global GPS obser-vations over 1995-2010 (Lean et al., 2011).



Daily averaged global trend **+0.6 TECU/decade** (*if solar EUV flux in 2008 is the same as in 1996*) **or +3.2 TECU/decade** (*if solar EUV flux in 2008 is 15% lower than in 1996*). **The latter trend is not physically plausible; the former may be questioned** (*according to models and foF2 trends the expected trend should be negative*).

Impact of peculiar solar cycle 23?

Thermospheric neutral density trends near 400km derived from satellite drag over three solar cycles – *Emmert et al.* (2008).



Trends are negative for any level of solar activity but they are sub-stantially stronger under solar minimum conditions due to larger relative role of CO_2 in radiative cooling.

OPEN QUESTIONS

- Trend drivers (GHGs, solar/geomagnetic, ozone, water vapor) are changing → these need to be understood/quantified.
- What are the trends in the atmospheric dynamics (circulation and wave activity)?
- Improve accuracy in quantifying trends in various parameters, and to reduce the model-observation trend differences.
- On longer-time scale – to join upper atmospheric trends with long-term changes in the stratosphere into one scenario.

IMPACT OF LONG-TERM CHANGES & TRENDS ON SATELLITE-BASED TECHNOLOGIES

- Longer orbital life-time of satellites and of dangerous space debris (more collisions with satellites) in response to cooling and contracting thermosphere.
- Long-term changes in TEC and gravity wave activity could have impact on ionospheric influence on GNSS (GPS, GALILEO, GLONASS etc.) signal propagation + ionospheric corrections and signal stability.

HOW DOES SHORT-TERM SOLAR VARIABILITY AFFECT THE GEOSPACE ENVIRONMENT?

- CME-ICME connection
  - **Advanced modeling** for solar eruption and CME release
  - **Observed & modeled CME** - evolve with increasing heliocentric distance. 3-D MHD modeling of the solar wind structures associated with the 13 December 2006 coronal mass ejection event (Fig. 1).

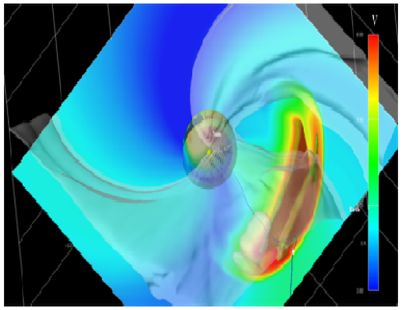
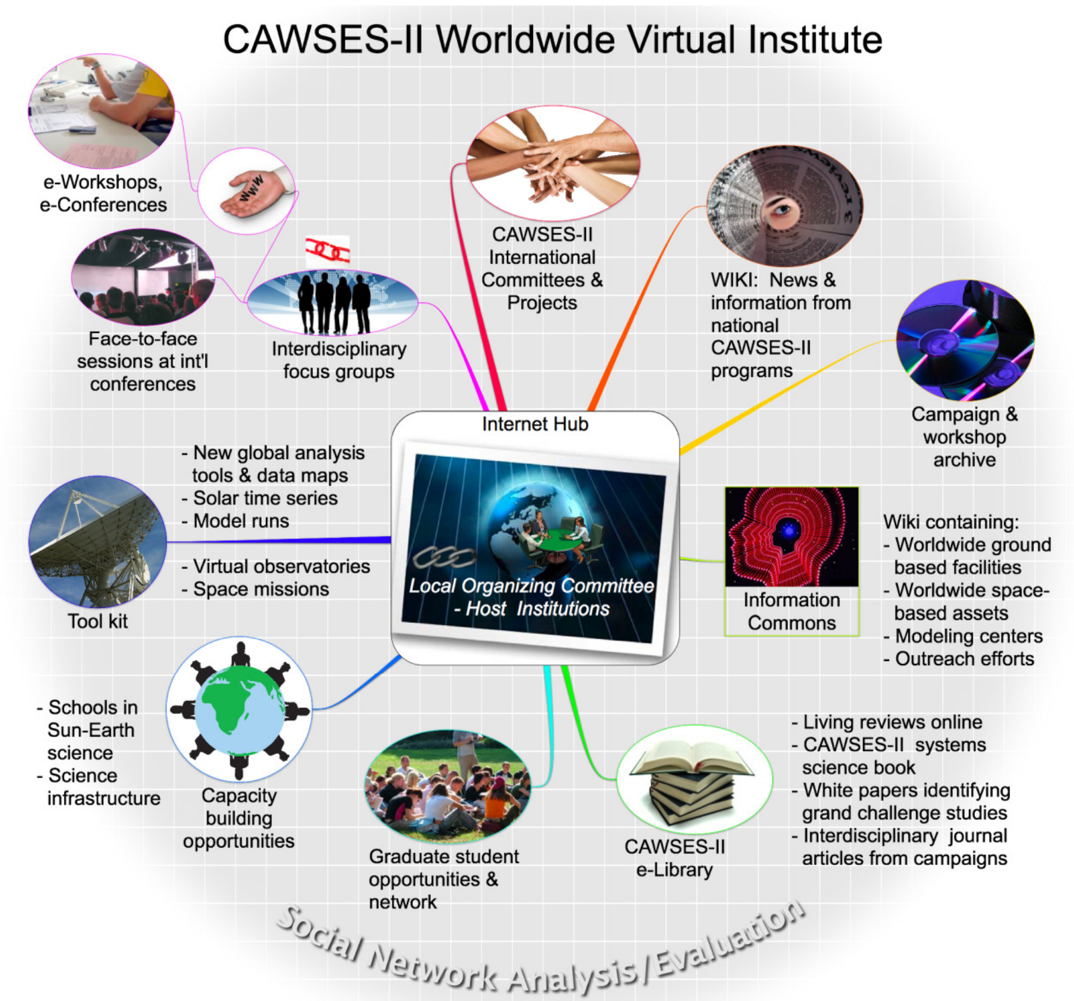


Fig 1: Kataoka et al. 2009

- 3D structure of ICME and solar wind
  - **ICMEs (Interplanetary Coronal Mass Ejections)** - sweep out interplanetary space plasmas and magnetic fields. ICMEs can coalesce with other ICMEs and high speed streams/CIRs.
  - **Multiple flaring and multiple CME** releases → a very complex solar wind → deflection and retardation of ICME propagation.
  - **Development of improved mean field solar dynamo models** taking into account multi-cellular and/or time varying meridional circulation, magnetic pumping, North-South asymmetry, irregularity in the cycles.

- Other Scientific Highlights
  - **Numerical Investigation of a Coronal Mass Ejection** from an Anemone Active Region: Reconnection and Deflection of the 2005 August 22 Eruption
  - **Magneto-thermal convection in solar prominences** observed by *Hinode* satellite.
  - **Superflares on solar type stars** - discovered by *Kepler* mission.

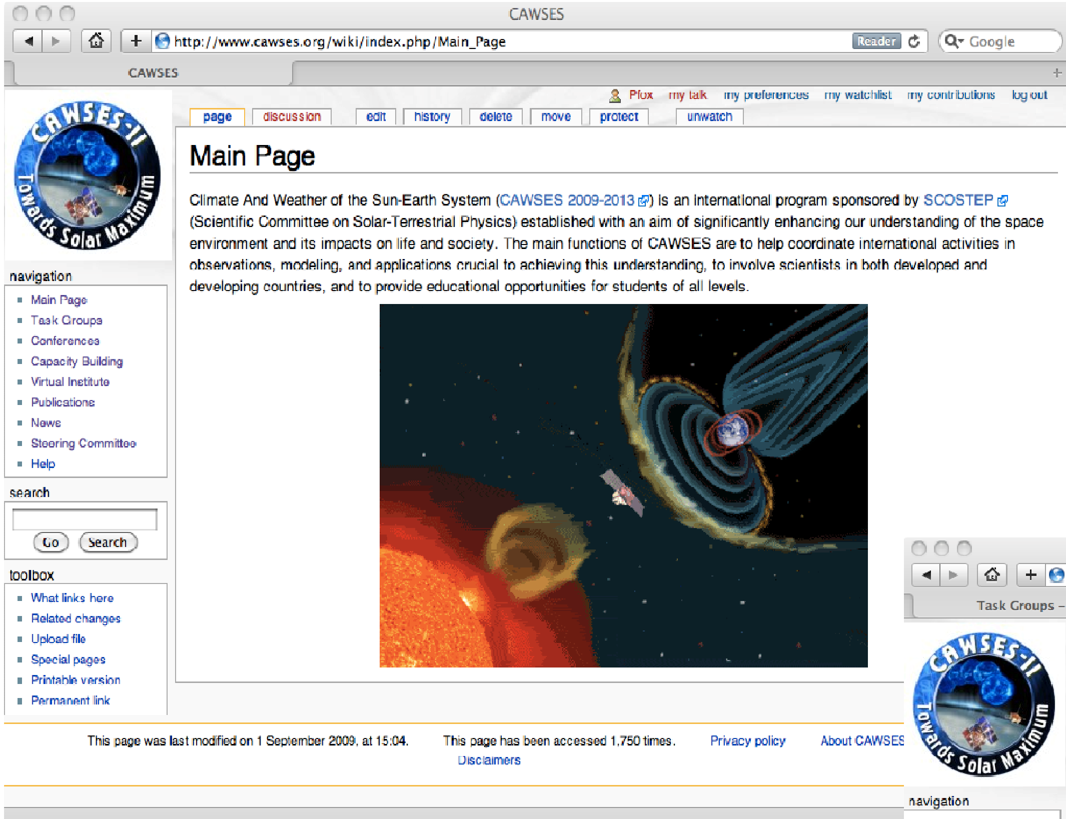
E-SCIENCE AND INFORMATICS



- Worldwide attention to data-aspects of international collaborations
  - good
- Relations to the World Data System
  - okay
- Use of virtual observatories as well as localized data sharing
  - very good

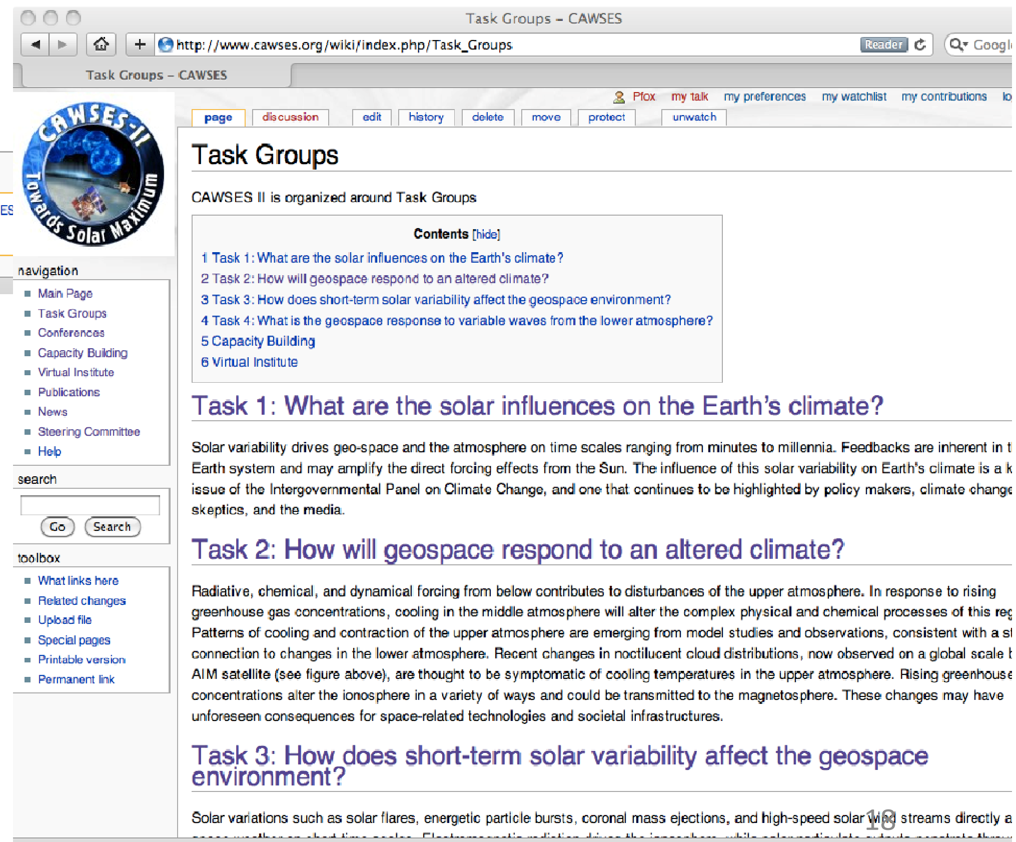
CAWSES Wiki

http://www.cawses.org/wiki/index.php/Main_Page



Wiki in place supporting science and outreach tasks – a place to collaborate

- 2 of 4 task groups made extensive use of the wiki
- Other 2 groups documented what they were doing




Thank You!