ROSMIC: Role Of the Sun and the Middle atmosphere/ thermosphere/ionosphere In Climate

The SCOSTEP VarSITI program and ROSMIC

William Ward (University of New Brunswick, Canada),

Franz-Josef Lübken (Leibniz Institute of Atmospheric Physics, Germany),

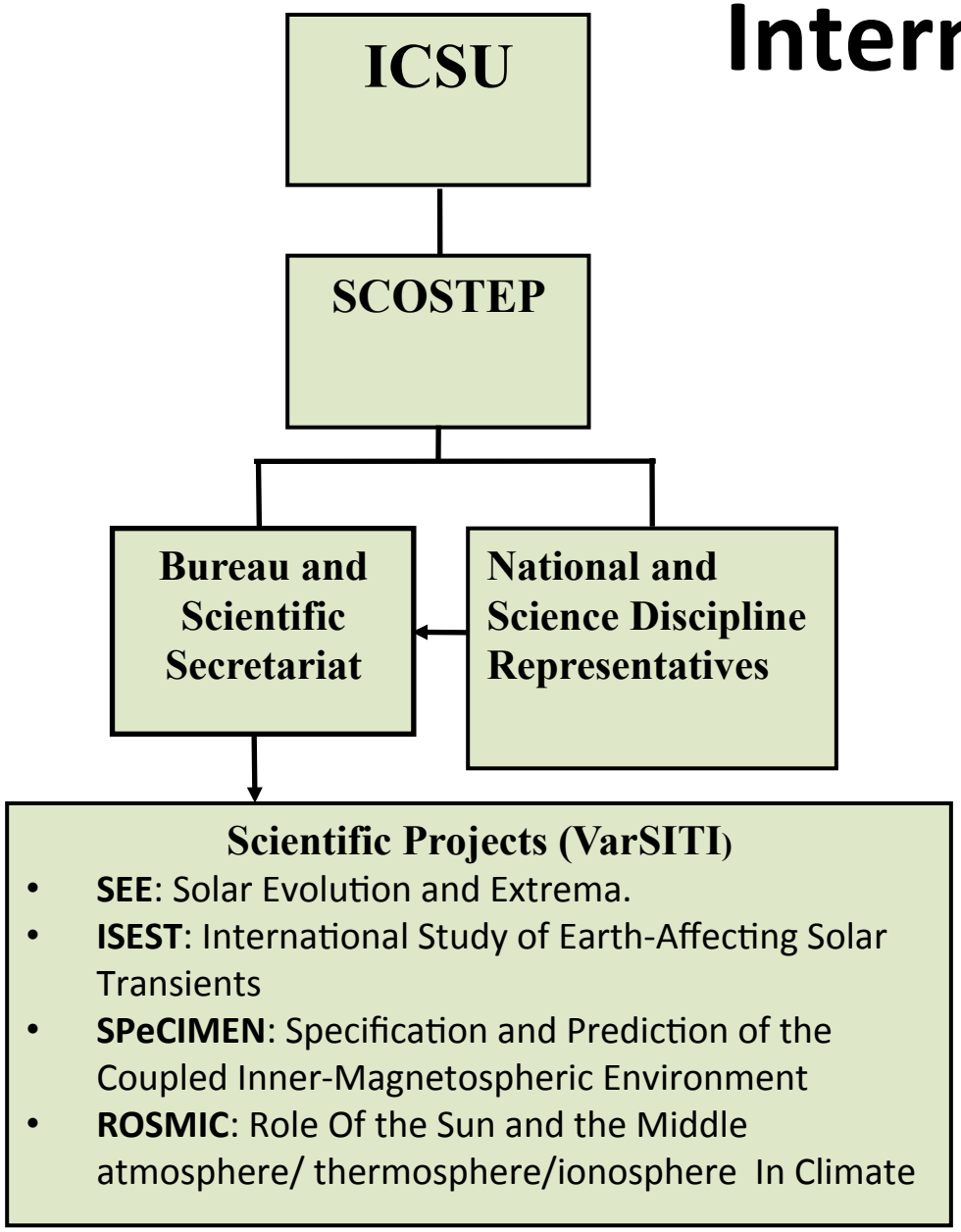
Annika Seppala (Finnish Meteorological Institute, Finland)

and the ROSMIC team

Aurora and airglow: iss029e007502 NASA

- ROSMIC is one of four projects comprising SCOSTEP's new program for the 2014 to 2018 period, Variability of the Sun and Its Terrestrial Impact (VarSITI).
- It supports scientific investigations which contribute to our understanding of
  - the impact of the Sun on the terrestrial middle atmosphere/ lower thermosphere/ionosphere (MALTI) and Earth's climate and
  - its importance relative to anthropogenic forcing over timescales from minutes to centuries.

International Structure



ICSU: International Council for Science, is a non-governmental organisation with a global membership of national scientific bodies (121 Members, representing 141 countries) and International Scientific Unions (31 Members). http://www.icsu.org/

SCOSTEP: Scientific Committee On Solar-TErrestrial Physics is an Interdisciplinary Body associated with ICSU and has the long-term responsibility to promote international interdisciplinary programs in solar-terrestrial physics. http://www.yorku.ca/scostep/

VarSITI: Variability of the Sun and Its Terrestrial Impact is the current SCOSTEP project and will run until 2018. http://www.varsiti.org/

Past SCOSTEP programs

IMS: 1976-79, "International Magnetospheric Study"
SMY: 1979-81, "Solar Maximum Year"
MAP: 1982-85, "Middle Atmosphere Program"
STEP: 1990-97, "Solar-Terrestrial Energy Program"
SRAMP: STEP-Results, Applications, and Modeling Phase
ISCS: International Solar Cycle Study
PSMOS: Planetary Scale Mesopause Observing System
EPIC: Equatorial Processes Including Coupling
CAWSES-I 2004-2008
CAWSES-II: 2009-2013

SCOSTEP
Scientific Committee on Solar-Terrestrial Physics

Organization of VarSITI

- A community meeting was held in Bern at the International Space Science Institute during May 7-8, 2013.
  - a number of proposal for future SCOSTEP activity were presented.
  - The proposal topics were collected together and four projects were identified and together form the SCOSTEP program, Variability of the Sun and Its Terrestrial Impact (VarSITI).
  - This program will last for the next 5 years.
- Co-Chairs for the program are Kazuo Shiokawa (STEL, Japan) and Katya Georgieva (SRTI, Bulgaria)

VarSITI Projects

- SEE (Solar evolution and Extrema)
- ISEST (International Study of Earth-affecting Solar Transients/MiniMax24)
- SPeCIMEN (Specification and Prediction of the Coupled Inner-Magnetospheric Environment)
- 4) ROSMIC (Role Of the Sun and the Middle atmosphere/thermosphere/ionosphere In Climate).

Solar Evolution and Extrema (SEE)

Are we at the verge of a new grand minimum ?

Project Co-Leaders:

Prof. Petrus C Martens, Montana State University, USA
Prof. Dibyendu Nandi, Indian Institute of Science Education and Research, Kolkata, India
Prof. Vladimir N. Obridko, IZMIRAN, Moscow, Russia

Goals & Objectives:

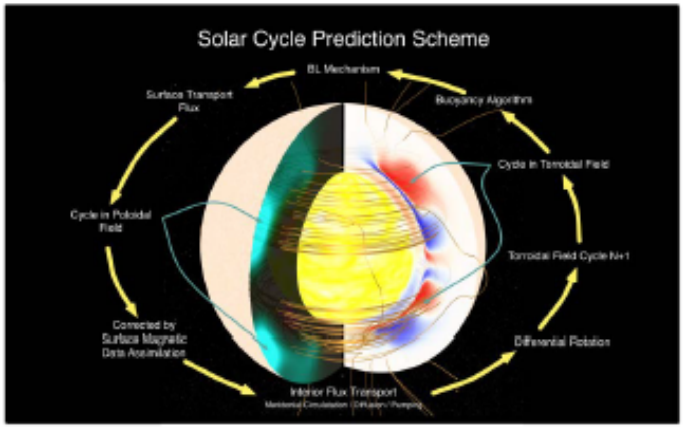
1) Reproduce magnetic activity as observed in the Sunspot record, including grand minima and extended minima in dynamo simulations,
2) Amalgamate the best current models and observations for solar spectral and wind output over the Earth's history,
3) Determine the size and expected frequency of extreme solar events.

Science Questions:

1) Are we at the verge of a new grand minimum? If not, what is the expectation for cycle 25?
2) Does our current best understanding of the evolution of solar irradiance and mass loss resolve the "Faint Young Sun" problem? What are the alternative solutions?
3) What is the largest solar eruption/flare possible? What is the expectation for periods with absence of activity?

Anticipated Outcome:

1) Dynamo Models for the near future or for an upcoming grand minimum,
2) A timeline of solar activity -- spectral radiation, wind - from the Earth's formation up to the present,
3) A frequency distribution and likelihood prediction of extreme events.



International Study of Earth-affecting Solar Transients/MiniMax24 (ISEST)

Can we predict the impact of solar transients on space weather?

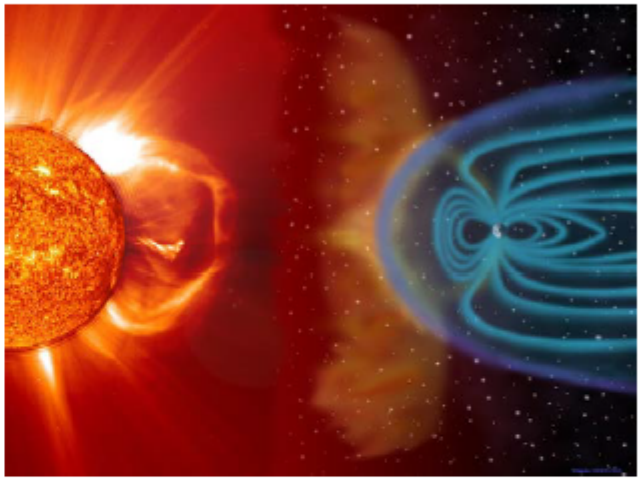
Project Co-Leaders:

Prof. Jie Zhang, George Mason University, USA
Prof. Manuela Temmer, University of Graz, Austria
Dr. Nat Gopalswamy, USA

Goals & Objectives: Understand the origin, propagation and evolution of solar transients through the space between the Sun and the Earth, and develop the prediction capability of space weather.

1) Carry out campaign study to integrate theory, simulations and observations in order to get a complete view and understand of the chain of cause-effect activities from the Sun to the Earth.
2) Use observations to Identify all Earth-affecting flares, CMEs, SEPs and CIRs during the STEREO era and their solar sources.
3) Use theoretical studies and numerical simulations to understand the structure, evolution and dynamics of CMEs and the global context of transient events.
4) Carry out campaign study to integrate theory, simulations and observations in order to get a complete view of the chain of cause-effect activities from the Sun to the Earth.

Science Questions: How do coronal mass ejections (CMEs) and corotating interaction regions (CIRs) propagate and evolve, drive shocks and accelerate energetic particles in the heliosphere?



Data/theory/modeling: Establish a database of Earth-affecting solar transient events including CMEs, CIRs, flares, and energetic particle events based on remote sensing and in-situ observations from an array of spacecraft, run observation campaigns such as MiniMax24, develop empirical, theoretical, and numerical models of CME propagation and prediction, validate models using observations.

Anticipated outcome: A comprehensive database of Earth-affecting solar transients will be created, and space weather prediction capability will be significantly improved. A significant improvement of space weather prediction to forecast the arrival time and expected intensity of solar transients.

Specification and Prediction of the Coupled Inner-Magnetospheric Environment (SPeCIMEN)

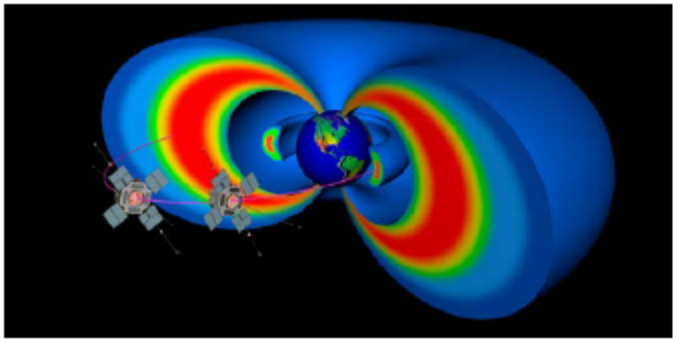
What is the physics behind radiation belt electron flux dynamics to enable the development of predictive models?

Project Co-Leaders:

Dr. Jacob Bortnik, University of California, Los Angeles USA

Prof. Craig J. Rodger, University of Otago, New Zealand

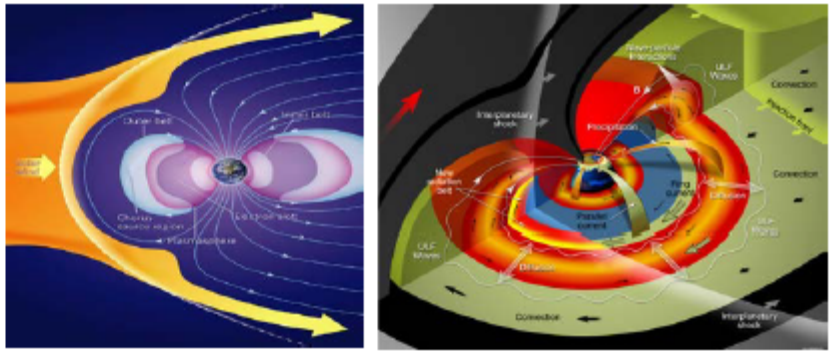
Goals & Objectives: The quantitative prediction and specification of the Earth's inner magnetospheric environment based on Sun/solar wind driving inputs.



The SPeCIMEN project is particularly timely given the recent launch of NASA's Van Allen Probes, the most recent mission to investigate the physical processes that control the dynamical behaviour of the Earth's radiation belts, eponymously named after its discovered, Prof. James Van Allen. During the 5-year VarSITI programme multiple additional satellites are expected to be launched, providing a constellation of spacecraft focused on the inner magnetosphere.

Science Questions:

Can the state of the Earth's inner magnetosphere be specified and predicted to high accuracy, based on inputs from the Sun and solar wind?



A schematic of the inner magnetosphere, showing the high velocity solar wind impinging upon the Earth's magnetic field (yellow, left), compressing it, and flowing around the boundary forming the magnetopause. Closer to the Earth are pictured regions of high energy electrons in two distinct zones of radiation (inner belt, outer belt, and slot region separating them), the cool, high-density plasma region known as the plasmasphere, and a region dominated by an electromagnetic wave known as chorus. The formation of the radiation belts is an active area of research which is intimately coupled with the dynamics of the solar wind, plasmasphere, and chorus region.

Anticipated Outcome: A series of coupled, related models that quantitatively predict the dynamical evolution of the inner magnetospheric state (radiation belts, ring current, cold plasma distribution, plasmasheet, convection electric field, and so on).

Role **O**f the **S**un and the **M**iddle atmosphere/thermosphere/ionosphere **I**n **C**limate (**ROSMIC**)

Goals & Objectives: To understand the impact of the Sun on the terrestrial middle atmosphere/ lower thermosphere/ionosphere (MALTI) and Earth ‘s climate and its importance relative to anthropogenic forcing over various time scales from minutes to centuries.

Anticipated Outcome: The development of a better understanding of the impact of solar activity on the entire atmosphere, relative to anthropogenic forcing and natural long term variability.

ROSMIC Co-chairs:

- Prof. Dr. Franz-Josef Lübken, Leibniz Institute of Atmospheric Physics, Germany
- Dr. Annika Seppälä, Finnish Meteorological Institute, Finland.
- Prof. William E. Ward, University of New Brunswick, Canada

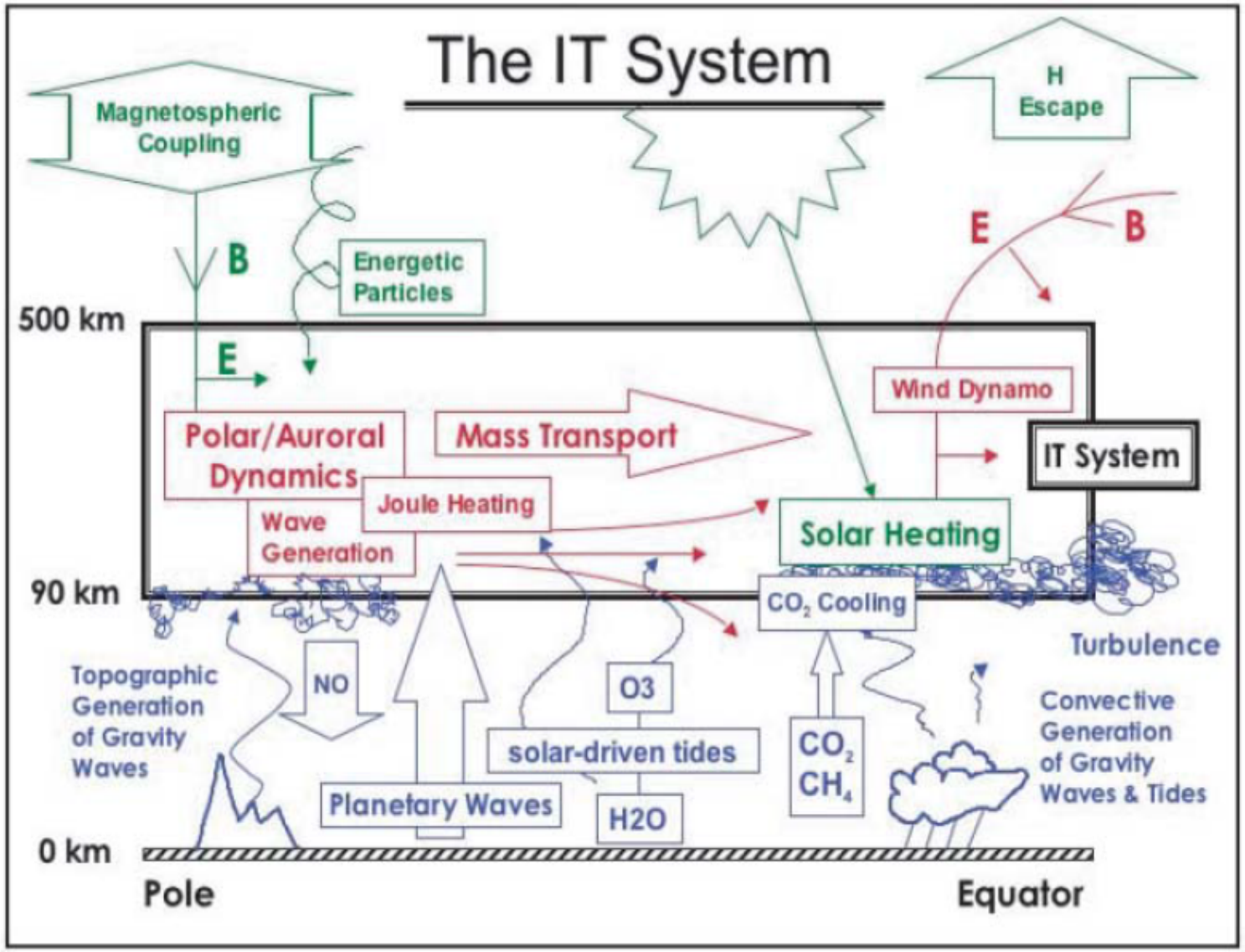
Context and Motivation

- The investigation of Earth-Sun interactions can now start to be undertaken from a systems perspective.
- Further advances in this field require the detailed **3D physical connections** between atmospheric regions/ ionosphere/ magnetosphere/solar wind to be addressed.
- The terrestrial atmosphere/ionosphere is the most extensively and intensively observed and analysed physical system in the natural world.
- It is a complex non-linear system which responds non-locally to external forcing and changes in its internal characteristics.

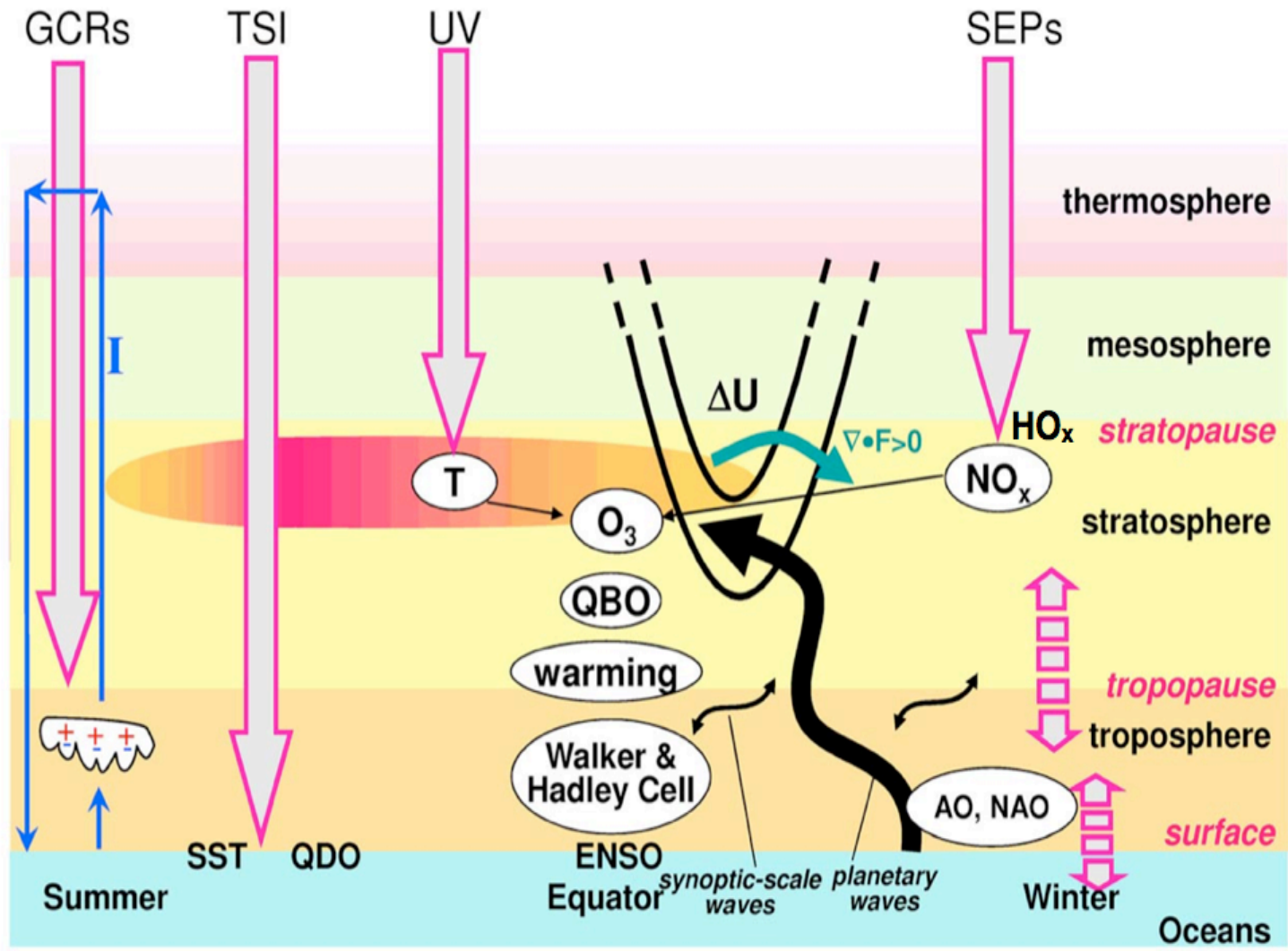
Key Issues

- The variability in the ionosphere and middle/ upper atmosphere is a combination of **upward** propagating disturbances from lower in the atmosphere and variability associated with the **downward** effects of short term solar influences.
- **What the relative roles of these various influences and their interactions?**

- The pathways whereby solar effects may influence the lower atmosphere are still poorly known. Changes to the composition of the atmosphere such as those currently taking place through anthropogenic activity may result in the atmospheric response to solar influences.
- **How stable is the structure of the atmosphere?**



Schematic of the processes relevant to the Ionosphere-Thermosphere system showing the upward and downward coupling processes which influence this region of the atmosphere (after Forbes, JMSJ, 2007).



Mechanisms of Solar Influence (after Gray et al, 2010)

Scientific Questions I

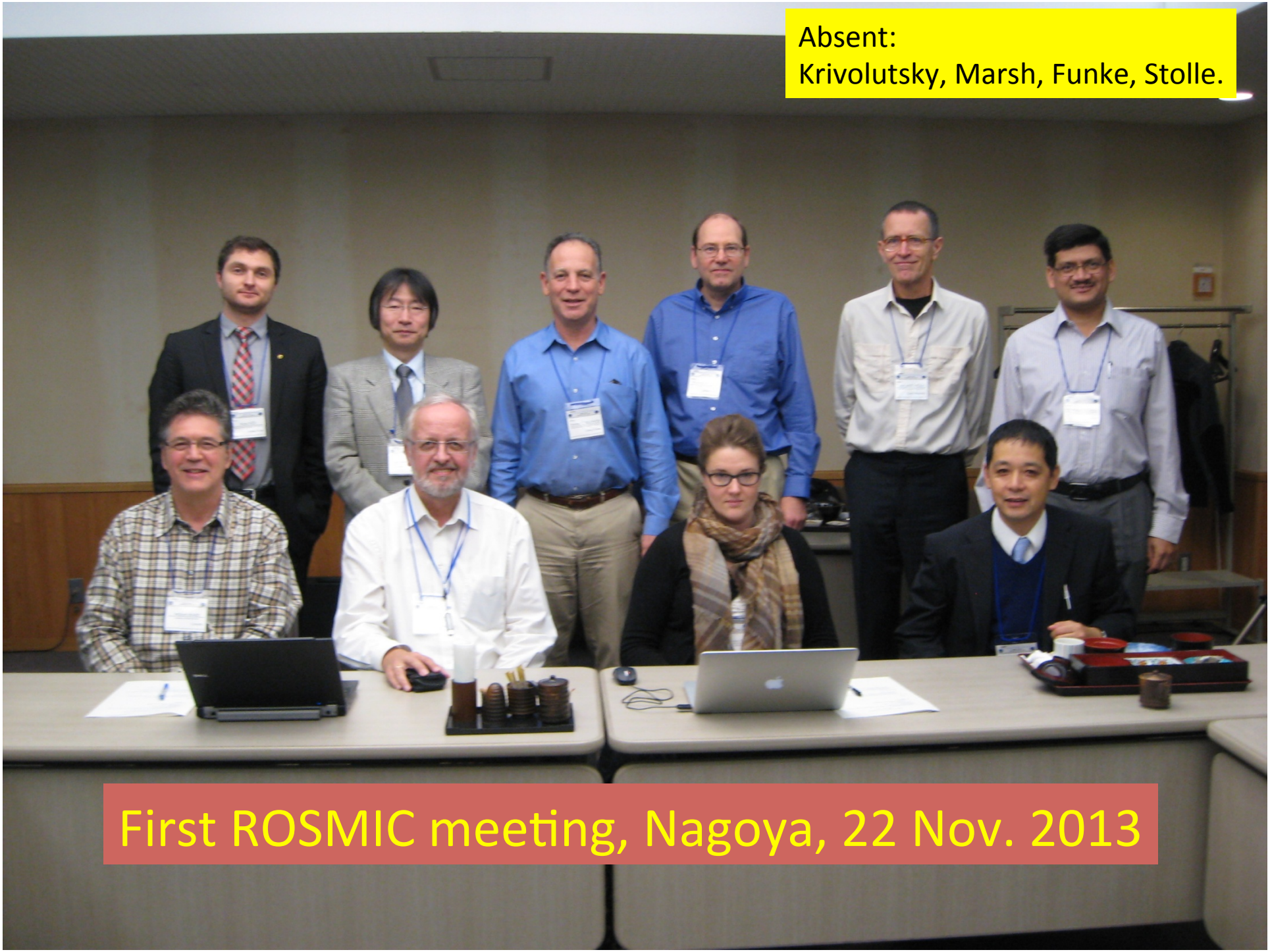
- What is the impact of solar forcing of the entire atmosphere? What is the relative importance of solar irradiance versus energetic particles?
- How is the solar signal transfered from the thermosphere to the troposphere?
- How does coupling within the terrestrial atmosphere through (e.g. gravity waves and turbulence) function?
- What is the impact of anthropogenic activities on the MALTI ?

Science Questions 2

- Which parameters in the MALTI show long term variations and why?
- What are the characteristics of reconstructions and predictions of TSI and SSI?
- What are the implications of trends in the ionosphere/thermosphere for technical systems such as satellites?

ROSMIC is organized into four working groups to address these questions. These groups and their leaders are:

- **Solar Influence on Climate**: Bernd Funke (Instituto de Astrofisica de Andalucia, Spain), Alexei Krivolutsky (Central Aero-logical Observatory, Russia), Tom Woods (LASP, USA).
- **Coupling by Dynamics**: Takuji Nakamura (National Institute of Polar Research,Japan), Claudia Stolle (GFZ German Research Centre for Geosciences, Germany), Erdal Yigit (George Mason University, USA).
- **Trends in the MLT**: Jan Lastovicka (Institute of Atmospheric Physics, AS CR, Czech Republic), Dan Marsh (NCAR, USA)
- **Trends and Solar Influence in the Thermosphere**: Duggirala Pallamraju (Physical Research Laboratory, India), Stan Solomon (NCAR, USA)


Absent:
Krivolutsky, Marsh, Funke, Stolle.
First ROSMIC meeting, Nagoya, 22 Nov. 2013

Solar Forcing

- Sources, mechanisms, response, feedback
- From 'abnormal events' to solar rotation to solar cycle to long term
- Long term development of TSI
- Solar spectral irradiance (SSI): morphology at various time scales
- Effect on trace gases (photochemistry)
- Relative importance of solar irradiance versus energetic particles ; geomagnetic effects
- Is there a regional (versus global) influence of the Sun ?
- Technical aspects of solar variability:
  - Satellite drag in the thermosphere
  - Space debris
  - Communication with satellites and via satellites
  - Global positioning systems
- Special attention to the current solar cycle 24
  For example: will we see unusually high ice layer activity ?

Coupling from Above to Below

- How does the solar signal transfer from the MA/LT through the stratosphere down to Earth's surface (role of QBO?) (still discrepancy between models and observations)
- Regional versus global effect: circulation patterns (e.g. NAM) ; role of mesosphere and stratosphere ?
- How do geomagnetic/ionospheric disturbances propagate downward and equatorward ?
- Transport of photochemically active species from the lower thermosphere down to the stratosphere.

Coupling from Below to Above

- Role of waves (planetary waves, gravity waves, tides)
  Modification by interaction of waves (e.g. tidal effects on gravity waves)
- New: wave mixing
- Role of small scale processes (turbulence) in neutral and plasma
  (detectable in ice layers + PMWE)
- Greenhouse gas increase: transport to MA/LT and modification (CH4,H2O)
  Future emission scenarios
- Ozone recovery: impact on the middle atmosphere/lower thermosphere
- How does the lower atmosphere structure the ionosphere, thermosphere, and plasmasphere ?

Trends

- Regional versus global scales
- Long term evolution of trace gases in the thermo/meso/stratosphere
  Examples: CO2, ozone, water vapor
- ... and their impact on the background (temperature, wind, wave propagation)
- Relative role of radiative versus dynamical forcing
- Trends in the thermosphere and impact on satellites
- Trends in ionospheric parameters
- Trends in waves due to changes in tropospheric (BD) circulation ?
- Long term effects in mesospheric ice layers (NLC, PMSE)
- What it is reason for the long term development of PW (not explained yet)
- Importance of long term natural variations in the atmosphere and ocean (incl. ENSO)

Science Tools

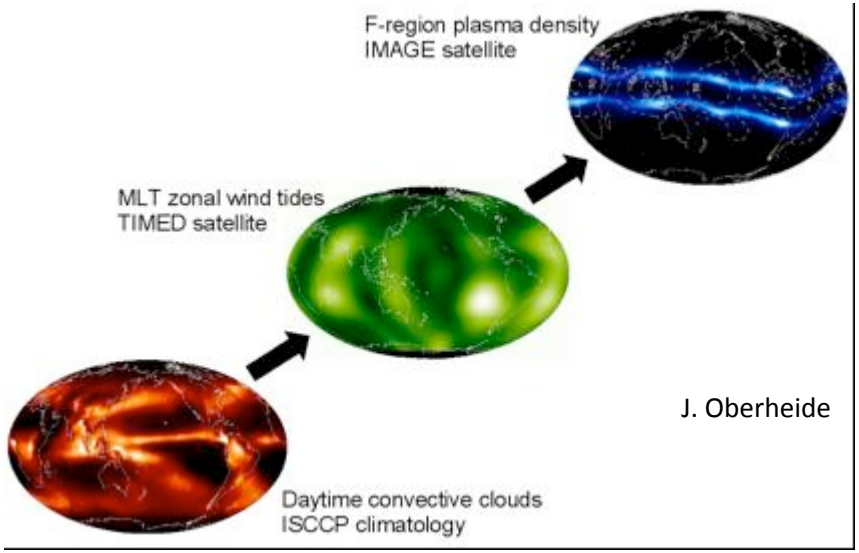
- Observations
  - Ground based (lidar, radar, passive, OH, mappers, ...)
    New: MAARSY, PANSY, equatorial MU-radar, DORIS, Fe-lidar, ...
    Increasing global coverage (GPS network)
  - Satellites (AIM, QB50, TIMED, SCISAT, AURA, ICON, ...)
    historical records over the last 20 years
  - Insitu (sounding rockets, balloons, airplanes): quasi 3D in the future (new)
- Theory and models
  - Study crucial physical processes, for example
    - Gravity wave breaking and turbulence (3d)
    - Layer formation in the mesosphere and relationship to background
  - ... and how to incorporate them into larger scale models
  - Global models (GCM, CTM), including coupling to the ocean, extending into the thermosphere, including electromagnetic coupling
  - General: try to minimize the difference between models and observations of trends
  - Data assimilation (?)
- Improve the interaction between solar and atmospheric scientists (terminology)
- Cooperation with other programs, e. g. SPARC, TOSCA, etc.

How Is ROSMIC Activity Supported?

- Workshops: *IAGA Workshop on Vertical Coupling – August/14; ANGWIN – October/14;*
- Conference sessions on specific topics at international conferences: *COSPAR 2.2- August/14; HEPPA/SOLARIS – July/14; EGU/15; IUGG/15;*
- International campaigns,
- Modelling comparisons;
- Establishing data archives, etc.
- The identification of science topics by an international organization can help justify funding applications. *ROMIC, Germany/14*

Participation

- Activities of the various groups is being organized.
- To express interest contact the group leaders the ROSMIC Co-PI's or the VarSITI project leaders.
- Small amounts of money are available to help seed activities associated with VarSITI. Information is on the VarSITI website under the tab, Organization.
- http://www.yorku.ca/scostep/
- http://www.varsiti.org/



Thank you for your Attention