Task Group 4: What is the geospace response to variable waves from the lower atmosphere?

1. Introduction

A variety of new evidence suggests that tropospheric weather is an important ingredient in geospace variability. Gravity waves generated by hurricanes or typhoons may propagate into the thermosphere and seed ionospheric instabilities, i.e., plasma bubbles, sporadic-E patches and traveling ionospheric disturbances. Atmospheric tides due to persistent tropical rainstorms produce large longitudinal and local time variations in bulk ionosphere-thermosphere-mesosphere (ITM) properties, i.e., temperature, wind, composition, airglow and plasma density, to name a few.

Oscillations of F-region plasma density and other ITM properties at planetary wave periods at least partly reflect the planetary wave activity and variability in the stratosphere. Thermospheric waves generated by high-latitude auroral energy input change the ionospheric and thermospheric environments even at low latitudes. All these waves may further interact with each other and the background atmosphere, i.e., when propagating upward through the stratosphere to the ionosphere, hence producing additional variability and/or secondary waves.

Studying the geospace response to variable waves from the lower atmosphere is particularly important since the induced variability competes with the solar and magnetic driving from above. Consequences for telecommunications, re-entry and satellite operations still need to be explored. The extent to which the effects of this quiescent atmospheric variability are transmitted to the magnetosphere is yet to be resolved.

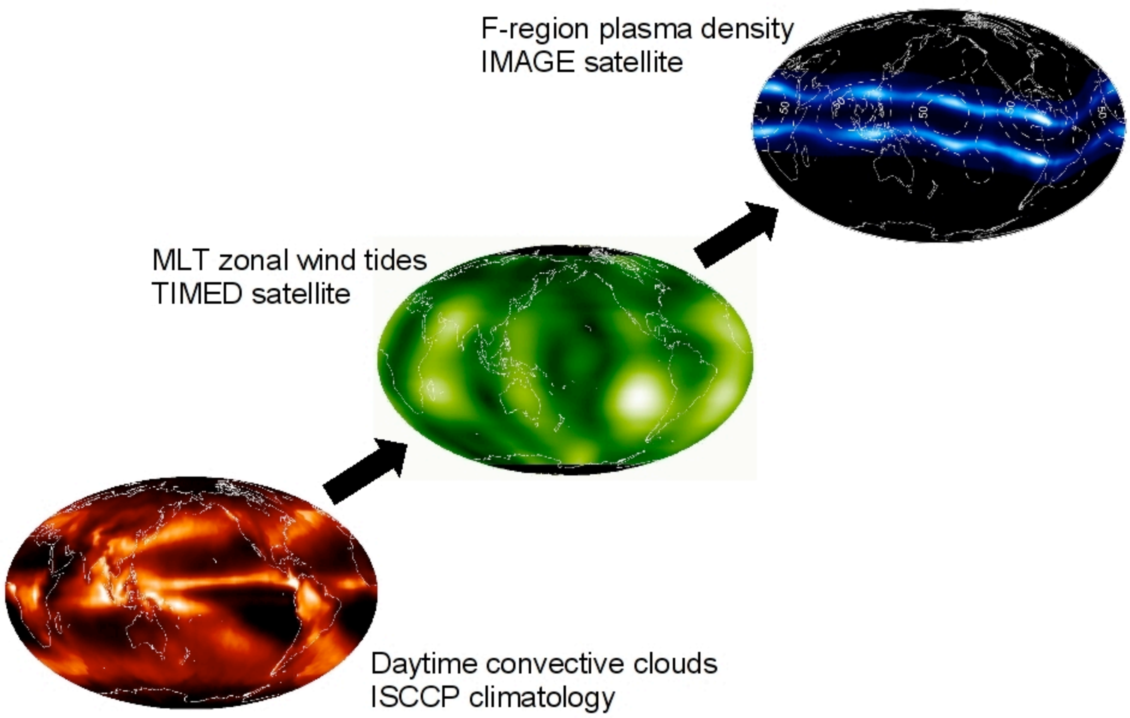

Figure 1. Persistent tropical weather systems can cause global wave structures throughout the ITM system.

2. The challenge

We thus stand right now at an exciting research frontier: understanding the cause-and-effect chain that connects tropospheric (weather!) and strato-/mesospheric variability with geospace processes. Task Group 4 will therefore elucidate the dynamical coupling from the low and middle atmosphere to the geospace including the 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. Attacking the problem clearly requires a systems approach involving experimentalists, data analysts and modelers from different communities. For that purpose, the most essential part of Task Group 4 is to encourage interactions between atmospheric scientists and plasma scientists on all occasions.

3. The scientific issues

The past few years have seen the development of basic ideas about the processes involved, including wave forcing, wave propagation and the neutral-electrodynamical coupling. Satellite and ground-based data sets to attack the problem are now of sufficient length and quality with even more becoming available soon. Mechanistic and first principle modeling results are encouraging and further improvements can be expected.

The following list of the scientific issues addressed by Task Group 4 gives a brief summary of what we know and what we do not know so far for (a) gravity waves, (b) tides, (c) planetary waves, and (d) thermospheric waves generated by auroral processes.

(a) Gravity waves

What we know: Gravity waves from convection and jets in the lower atmosphere propagate into the mesosphere, dissipate their energy near the mesopause region, and/or penetrate into the thermosphere.

- Basic knowledge about gravity wave forcing and propagation in the MLT region,
- Theory about penetration of gravity waves into the thermosphere, and
- Speculation about initiation of various ionospheric plasma instabilities by gravity waves.

What we do not know:

- Evidence of gravity wave seeding of ionospheric instabilities, such as
  - → MSTIDs: wavelength/propagation
  - → plasma bubbles: day-to-day variability, zonal separation
  - → sporadic-E patches: scale size and propagation
- How important is gravity wave forcing in the thermosphere/ionosphere dynamics?

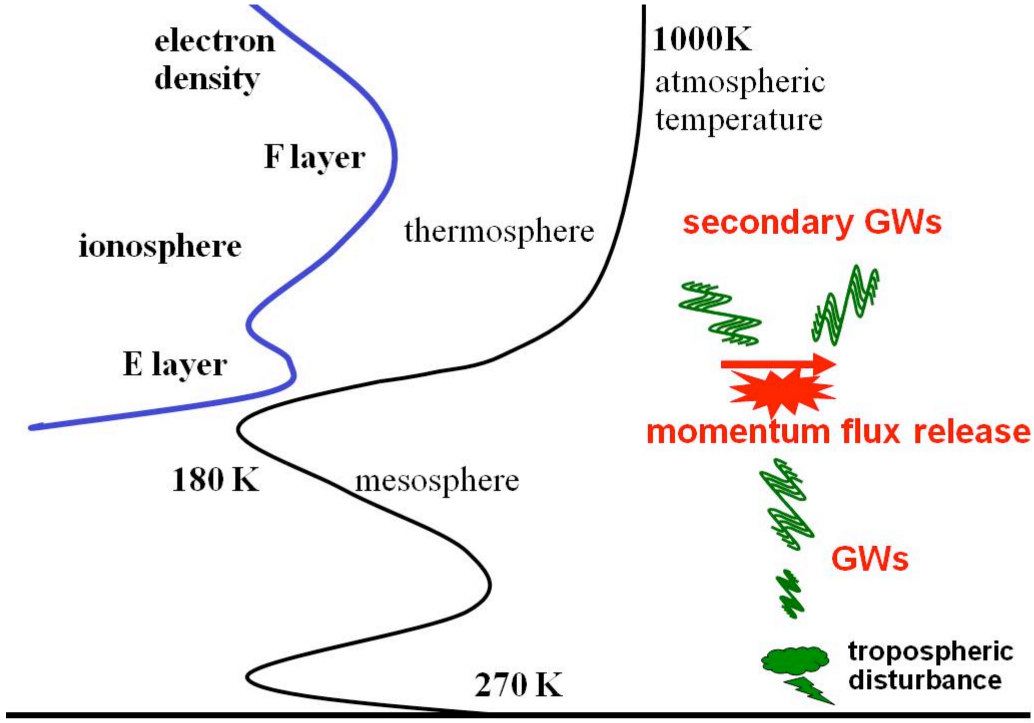

Figure 2. Gravity wave (GW) propagation and release of momentum flux in the thermosphere.

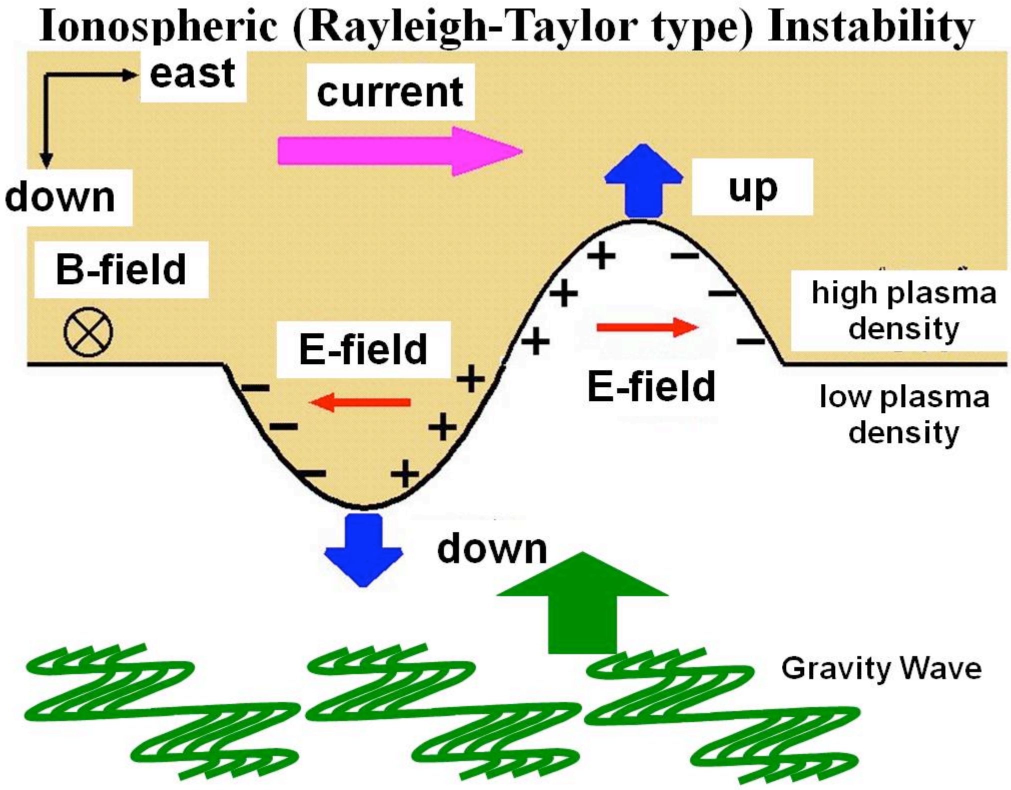

Figure 3. Gravity wave seeding of ionospheric (Rayleigh-Taylor type) instability.

(b) Tides

What we know: Nonmigrating (non Sun-synchronous) tides due to deep tropical convection produce large longitudinal and local time variations in bulk ITM properties.

- Temperature, wind, composition, plasma density, electron density perturbations
- 4-peaked longitudinal variations observed by satellites are the DE3 nonmigrating tide
- Basic quantitative knowledge of tidal forcing, propagation and morphology in the MLT region
- Basic qualitative knowledge of coupling into the F-region: E-region dynamo modulation,

due to satellite observations and model simulations since ~2006. Important contributions came from CAWSES-I.

What we do not know::

- What are the tidal structures in the ionosphere-thermoshere (IT), i.e., between 120 km (TIMED) and 400 km (CHAMP, GRACE)?
- What are the temporal variations: days, inter-annual, QBO, solar cycle?
- How much of the tropospheric influence is due to direct tidal upward propagation into the F-region and how much is due to E-region dynamo modulation?
- How important are tides forced by non-linear interactions in the stratospher and/or mesosphere? (for the IT)
- We know little about the coupling between the various waves (tides, GWs, PWs) and mean motions in the IT.
- There is no good understanding of the tidal effects on energy balance, composition, etc…

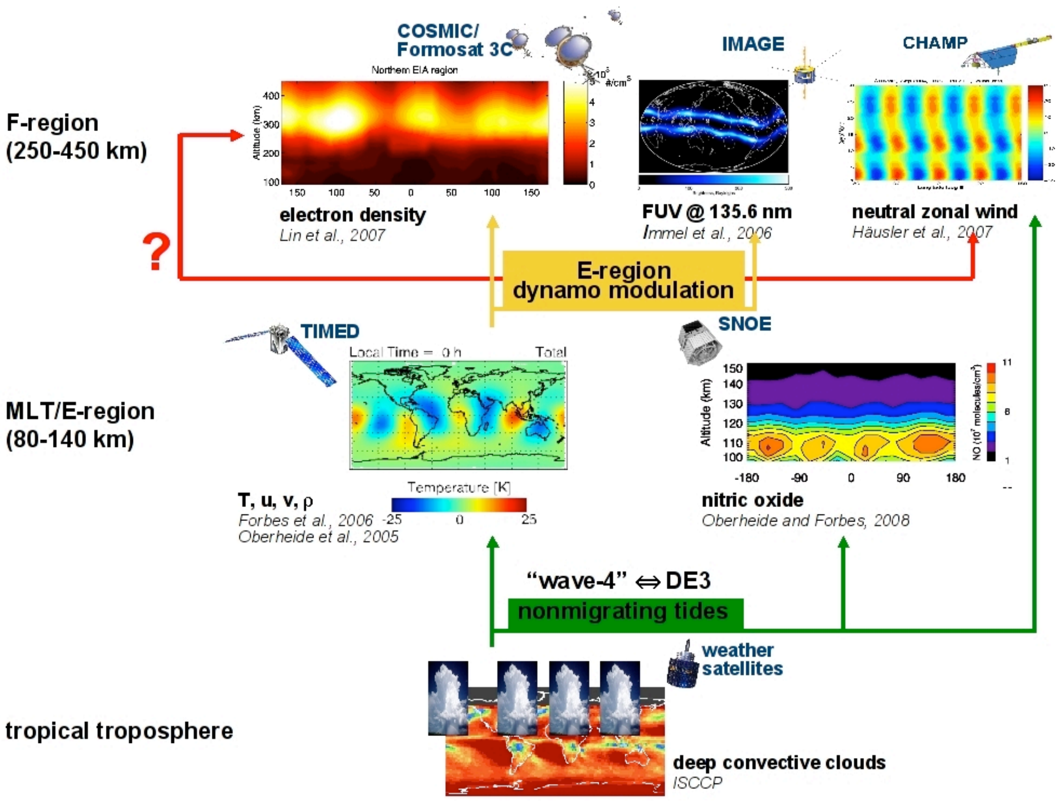

Figure 4. Coupling from the troposphere to the ionosphere through tides.

(c) Planetary waves

Much of the above about tides also applies to the planetary waves. Some specific questions are

- Stratwarm effects on the ionosphere and thermosphere.
- PW signatures in parameters of aeronomic interest, i.e., in O/N2 ratio, nitric oxide, dynamical fields, plasma density?, …
- Wave-wave interactions, interhemispheric coupling.

(d) Thermospheric disturbances generated by auroral processes

What we know: Traveling atmospheric disturbance (TADs) and gravity waves are generated in the high latitude ionosphere due to energy input from the magnetosphere. Related to these aurorally-generated neutral waves, we know

- They are reproduced on global scale by GCM
- We have large-scale views by global GPS-TEC map at middle and low latitudes
- We also have small-scale view by IS radars/SuperDARN radars in the auroral zone

What we do not know:

- How do storm-time neutral waves affect the formation of the equatorial ionization anomaly?
- How is the unusual vertical wind formed in the vicinity of aurora?
- Do thermospheric winds driven by high-latitude ionospheric plasma convection cause feedback to the plasma convection?
- How does the composition change (decrease of O/N2 ratio) of the thermosphere occur and

propagate on global scale to cause negative ionospheric storm

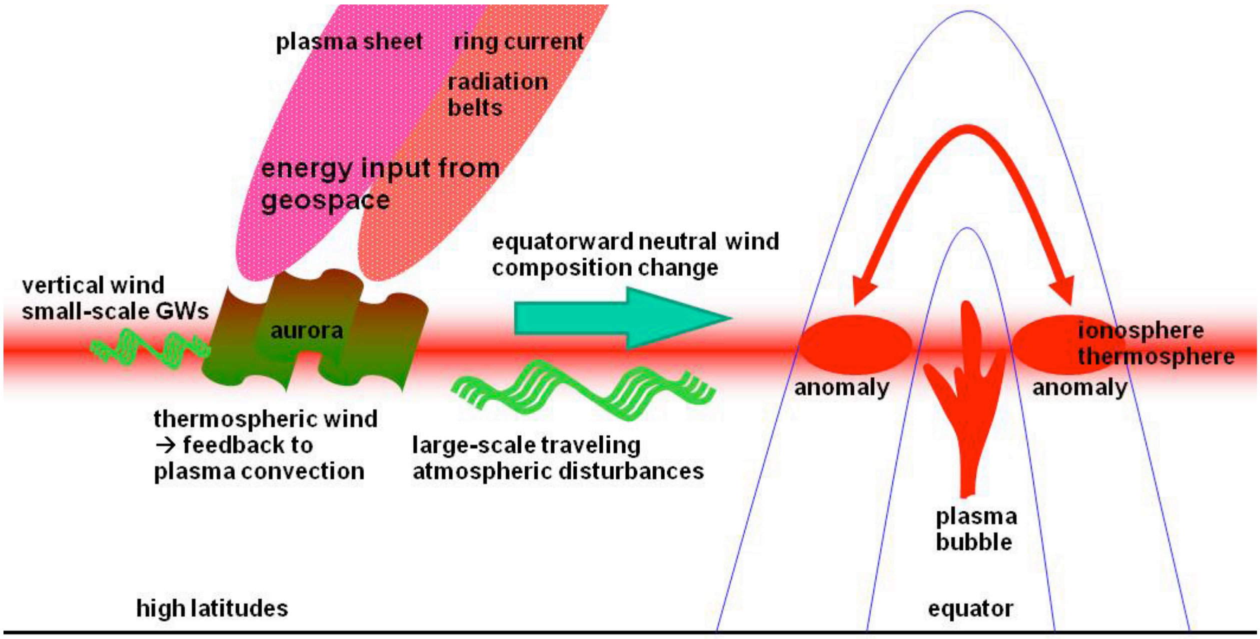

Figure 5. Cause and effects of thermospheric waves and disturbances generated by auroral processes.

4. Meeting the challenge

Task Group 4 has defined four projects to attack the overarching science questions:

Project 1: How do atmospheric waves connect tropospheric weather with ITM variability? (ITM=Ionosphere-Thermosphere-Mesosphere)

Project leaders: TBD (2-3)

Project Members: TBD

CAWSES-I Tidal Campaign will be continued here (with contributions to the other projects)

Project 2: What is the relation between atmospheric waves and ionospheric instabilities?

Project leaders: TBD (2)

Project Members: TBD

Project 3: How do the different types of waves interact as they propagate through the stratosphere to the ionosphere?

Project leaders: TBD (2)

Project Members: TBD

Project 4: How do thermospheric disturbances generated by auroral processes interact with the neutral and ionized atmosphere?

Project leaders: TBD (2)

Project Members: TBD

In addition, Task Group 4 has a joint project with Task Group 2:

Project 5: How does climate change affects atmospheric waves in the ITM?

Project leaders: TBD (2)

Project Members: TBD

- All projects are requested to make reports and workshops every 1-2 years in conferences.
- Task Group 4 will organize well focussd sessions at major conferences.
- It is planned to have focused conferences of Task 4 (like PSMOS-DYSMER) every 2 years. Alternatively, there may be multiple-day session at the SCOSTEP STP conferences.
- It is crucial that the different projects interact with each other.

5. Outcomes and Benefits -success criteria

Task Group 4 aims to get significant process understanding, and, to obtain closure towards a better quantitative understanding of the posted science challenge questions. The most important scientific needs towards this ambitious goal are:

(a) Gravity waves

- Penetration of GWs into the thermosphere and ionosphere
- Relation between gravity waves and various ionospheric instabilities
  → MSTIDs, plasma bubbles, and E-region patches
- Gravity wave forcing in the thermosphere/ionosphere dynamics?

(b) Tides and planetary waves

- What are the tidal structures and variability in the ionosphere and thermosphere?
- E-region dynamo altitudes, longitudinal and temporal
- How do they affect the thermosphere/exosphere?
  → Density, composition, energy balance, ...
- Understand the cause-and-effect chain that couples tropical convection with the F-region (tides)
- Quantitative, first principle modeling; data analysis
- What is the role of tides/GW/PW in plasma bubble seeding?
- Longitudinal and temporal modulation of GW propagation and/or GW-tidal interactions?
- How does climate change affect the tides? (closely related to Task 2)

(c) Thermospheric disturbances and storm-time winds generated by auroral processes

- Ionospheric plasma dynamics at middle and equatorial latitudes by (1) neutral winds from bottom and (2) electric fields from above.
  → Which is important for what cases?
- Coupling between thermospheric winds and plasma convection in the high-latitude ionosphere

- Composition change (O/N2 ratio) of the thermosphere. How does it occur and propagate on global scale to cause ionospheric disturbance?

The anticipated better process and quantitative understanding of the underlying physics will allow to assess the relative importance of the lower atmospheric waves to space weather and solar and magnetic driving from above. It will further provide the scientific fundament to explore consequences for key elements of today's technological society, i.e., telecommunications, GPS positioning, and satellite operations.

6. **Existing work and plans**

The "CAWSES Tidal Campaign" efforts from CAWSES-I will be continued (lead: Prof. Dr. William Ward, University of New Brunswick, Canada), as part of Task Group 4. Formally assigned to project 1, it will make contributions to projects 1-3.

More plans: tbd by project leaders.
A lot of facilities are available related to the Task Group 4 activities, as below.

Radars

- AMISR –Antarctica, Resolute Bay, Jicamarca, Poker Flat
- PANSY (IS radar in Antarctica) was just approved in Japan.
- EISCAT 3D: phased array antennas, imaging capability, under proposal
- German new type of radar for turbulence and winds in Andoya.
- SuperDARN radars: toward midlatitudes
  - → US: 6-7 new radars will be installed over next 3 years at Kansas, Azores up to Aleutian islands.
  - → Russia: four SuperDARN radars will be developed in a next few years
  - → Australia: Adelaide midlatitude site (part of TIGER network)
  - → Japan: Second Hokkaido radar is proposed for 2010 construction.

Optical instruments

- OMTIs – airglow imager/interferometer array – extension to lower latitudes
- US Fabry Perot Interferometer – US/Brazil
- Space –borne lidar – next steps?

Satellites

- ESA – SWARM satellite constellation – 3 CHAMP equivalent satellites (anticipated launch 2010)
- NICE, GOLD (NASA, in phase A): anticipated launch 2012-2015
- ISS – IMAP: launch 2013 (Japanese airglow imager on International Space Station)
- e-POP (Canada): launch 2009, ionospheric outflow

Magnetometers

- MAGDAS – Japan, magnetometer chains on global scale including Africa
- Chinese Meridian Project

VLF receivers

- AWESOME – VLF receivers network

7. Key linkages

- Priority program "CAWSES" of the German DFG (lead: Prof. Dr. F.-J. Luebken, IAP Kuehlungsborn, Germany), funded until 2011.
- CAWSES India?, other national CAWSES projects...
- Cross-task project with Task Group 2 (project 5 above)
- ISSI team 152 (lead: Dr. Peter Hoffmann, IAP Kuehlungsborn, Germany) addressing vertical coupling processes using EISCAT and CAWSES tidal campaign data.
- ISSI (International Space Science Institute, Bern, Switzerland) plans a workshop and subsequent review book publication for a topic of "The Energetic and Momentum Coupling between the Earth's Atmospheric and Plasma Environments".
- COSPAR, IAGA, AOGS, CEDAR ….

8. Milestones

- End of August: IAGA CAWSES session
- September 30: Project plan
- Autumn 2009: ISSI team 152 workshop in Bern, Switzerland.
- July 2010: STP-12 conference at Berlin
- July 2010: COSPAR sessions related to Task Group 4:
  - → C02 Advances in Remote Sensing of the Middle and Upper Atmosphere and Ionosphere from the Ground and from Space, including Sounding Rockets and Multi-Instrument Studies
  - → C11 Recent Advances in Equatorial, Low- and Mid-Latitude Mesosphere, Thermosphere and Ionosphere Studies
  - → C13 Ionosphere -Thermosphere Coupling to Magnetosphere and Solar Wind
  - → C22 Troposphere to Ionosphere Multi-Scale Wave Coupling Processes
- Autumn 2010: ISSI WS "The Energetic and Momentum Coupling between the Earth's Atmospheric and Plasma Environments" for review of current and future of topics related to Task Group 4.
- 2011?: Task 4 symposium (TBD)
- 2013?: Task 4/CAWSES symposium (TBD)

9. The next steps

Assign project leaders and team members (work in progress).