ISSI Proposal

'Towards more effective physics-based and statistical models of the polar ionosphere'

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Abstract

The proposers represent a combination of expertise in observational ionospheric measurements using world-class instruments, in physics based and empirical ionospheric and atmospheric modelling leading to the best currently available models, and a number of supporting observational and theoretical regimes.

The goal of the proposed work, with the aid of three workshops at ISSI, is to capitalise on the unique opportunity represented by the huge increase in data availability during the International Polar Year (IPY) of 2007-9 to dramatically improve the quality of models, and the underlying physical understanding, and in particular to develop their capabilities in now- and fore-casting.

The proposal is timely, not only because of the IPY but also because of the increasing reliance of mankind on technological systems which are vulnerable to space weather events, and their consequent impacts on GeoSpace, and for whose continuing safety we require adequate understanding of the physics of the interactions to predict, and take appropriate steps to mitigate, the effects.

The structure of a series of undisturbed, focused workshops offered by the present ISSI Call for Proposals would provide a very effective way to organise this work, enabling us to progress the studies rapidly and in a timely manner commensurate with the data collection efforts of the International Polar Year. It also provides a framework for the preparation of publications detailing the project development.

Scientific rationale, goals and timeliness of the project.

The International Polar Year will make quality high-latitude ionospheric data available in unprecedented quantities. The existence of a year-long continuous high-latitude data base of incoherent scatter radar (ISR) observations of the ionosphere provides an unprecedented opportunity for model/data comparisons. Physics-based ionospheric models such as the Utah State University Time Dependent Ionospheric Model (TDIM) are usually only compared with observations over restricted one or two day events or against climatological averages. In this study, using the ISR observations, the daily weather, day-to-day variability, and year-long climatology can be simultaneously addressed to identify modelling shortcomings and successes.

In the past, the TDIM has been driven by climatological representations of the magnetospheric convection, auroral oval, neutral atmosphere, and neutral winds, whose inputs are solar and geomagnetic indices, it is therefore not surprising that the daily weather cannot yet be reproduced.

In this project we will initially address the necessary underlying physics and this requires a multi- and inter-disciplinary approach involving not only the models themselves and the incoherent scatter data set, but also other space- and ground-based data characterizing conditions in the solar wind in the vicinity of the Earth and in interplanetary space between the Sun and the Earth.

This effort also represents enabling science which will support the utilization of spacecraft data to provide effective forecasting of the geoeffective consequences of solar events, which in turn allows suitable actions to be taken to mitigate the effects on mankind's technological infrastructure.

We propose to concentrate on two main threads, the first related directly to the development of the model-data comparison and model improvement, and the second related to understanding some of the important classes of phenomena revealed by the observational and modelling programs.

The plan is to use the year-long ISR runs not just to validate the physics of high latitude ionospheric models, but also as input data for assimilation models.

The primary model is the TDIM (Utah State University), which will be run in parallel with the radar throughout the IPY. Other team members will also the AMIE and TIMEGCM models throughout the interval, as well as the CMAT2 model - which covers the entire altitude range from 15km to exosphere and can be used particularly to investigate different gravity wave schemes as well as forming the lower boundary to much of the other work. At this stage, some of the models can already be run in real time to match the incoming observational data whilst others can be used to make "predictions" after the fact and can then be iterated towards the observations.

Field aligned currents (FACs) can also be derived routinely using AMIE using SuperDARN, ground-based magnetometers, DMSP, EISCAT, and satellite magnetometers as inputs and team members will attempt to interpret the FACs in terms of magnetospheric phenomena, and their effect on forcing of the atmosphere.

For the modelling work we will attempt to:

1. Create model predictions for the year-long observations
2. Compare these predictions with the observations and each other to identify model and theory challenges
3. Upgrade and improve the models and refine the observations during a series of focused ISSI workshops, allowing real improvements in repeats of the prediction-comparison cycle

Specific model related issues to be addressed include:

4. Improve the representation of tides in the models
5. Examine how global dynamics depends on gravity wave parameterizations
6. Examine what middle and low latitude effects (dynamic and chemical) depend on high-latitude storm time inputs
7. Better evaluate the effective Joule heating from magnetospheric inputs and the role ion drag plays in modifying that heating.
8. Evaluate the importance of global electrodynamical coupling to the response of the neutral atmosphere to auroral events.

9. Examine how well quantitatively current thermosphere-ionosphere models reproduce steady-state quiet time dynamics of the atmosphere globally

For the related studies, we intend to develop improved understanding of:

10. The relative importance of the sunlit, aurora precipitation ionization and ionospheric convection in the polar ionosphere, particularly with respect to the resulting variability in F2 region plasma dynamics
11. The day-to-day and seasonal variation of the polar ionosphere and the interaction between the thermosphere and ionosphere.
12. The role of cusp dynamics in the formation of polar cap patches.
13. The drivers and occurrence of polar cap patches in the northern and southern hemispheres, the latter using ionosonde observations made at Zhongshan station
14. The polar ionospheric response to Storms and Substorms
15. The role and importance of field-aligned currents in the high latitude ionosphere and magnetosphere.

The high-latitude F region ionosphere is driven by magnetospheric convection, particle precipitation, and solar ionization sources under the internal transportation and chemical processes in which interactions between the plasma and neutral components play an important role. The polar F region ionosphere undergoes structuring over a wide range of scales from the large scale of thousands of kilometers, to the smaller scale of several kilometers [Tsunoda, 1988] down to decameter irregularities serving as backscatter targets for the SuperDARN network of coherent HF radars [e.g. Moen et al., 2002]. These structures include the tongue of ionization (TOI), the polar hole, polar cap patches, the mid-latitude trough, and the smaller plasma blobs along the poleward aurora boundary etc. These structures constitute the high-latitude ionospheric space weather, with which the space community is especially concerned.

One of the main features of the polar ionosphere is the entry of lower-latitude higher density plasma to higher latitudes through the cusp region, where soft precipitation is expected to occur. The plasma entry serves as source for polar cap patches. The EISCAT Svalbard Radar (ESR) is located at cusp latitudes, near the magnetic conjugate point of Zhongshan Station, Antarctica, where the ionosphere has been monitored routinely by ionosonde (DPS-4) since 1995. The continuous ESR measurements provide opportunities to identify source of polar cap patches. Combined with numerical simulation and SuperDARN radar observations, it is expected to identify further the formation mechanism of polar cap patches.

The unprecedented long-term runs of the ISRs also give opportunities to study the day-to-day and seasonal variability of the polar ionosphere. Earlier studies showed that small changes in the high-latitude inputs cause dramatic changes in the high-latitude modelled ionospheric densities [Schoendorf et al., 1996]. Recent studies showed the importance of neutral wind in the understanding of the polar ionosphere [Sojka et al., 2005]. These studies showed difficulties in reproducing the ionospheric features, especially weather phenomena by using numerical models.

The high latitude ionosphere is known to be controlled by both solar EUV and magnetospheric precipitation and convection drivers, as well as the thermospheric responses to these drivers. In the past few years researchers have begun to reconsider the role of the neutral atmosphere, especially its high latitude representation by climatology models.

The high latitude neutral winds are most commonly observed by Fabry-Perot interferometers from the ground, or by satellite, of which the DE-2 observations produced the most extensive measurements of the thermospheric winds [Killeen et al., 1982; Hays et al., 1984]. These satellite winds have also been compared with ground measurements [Killeen et al., 4 1984] and together with seven FPI sites have been used to create mean neutral circulation patterns [Killeen et al., 1986]. These data sets form the core of the high latitude wind observations that were used to create the climatological horizontal wind model (HWM), which is used extensively throughout the ionosphere-thermosphere community [Hedin et al., 1991 and 1996]. At high latitudes the wind variability is strongly dependent on geomagnetic history and the coverage of observation is far from ideal. Both factors cause users of the HWM to have concerns when using it to represent specific events.

Most recently the wind issue has become further complicated by studies which have shown that vertical neutral winds are often large and associated with gravity wave dynamics [Ford et al., 2003; Innis et al., 1999; Johnson et al., 1995; McEwen and Guo, 2003]. The effects of such vertical winds can be considerable on the F-region [Sojka et al., 2001], because the vertical wind can readily move plasma along the near vertical high latitude magnetic field lines, rapidly affecting the plasma recombination rates and hence plasma density. The HWM, although having 3-D winds, does not include these large vertical winds generated during only special events.

Fifty years ago, the first International Geophysical Year (IGY) generated a huge step function increase in observations of ionospheric variability associated with the almost continuous geomagnetic activity experienced during the largest solar maximum of the modern era. In turn, these observations fuelled more than a decade of theoretical advancement of magnetospheric-ionospheric electrodynamics and geomagnetic storm physics.

This International Polar Year (IPY, 2007-8) will occur during what may well turn out to be the deepest solar minimum in 100 years. Potentially, it will be a very geomagnetically quiet period; a period during which ionospheric variability will be driven by processes in the troposphere and mesosphere. Since the variability of the ionosphere-thermosphere system associated with the upward propagating planetary, tidal, and gravity waves from the lower atmosphere is expected to be independent of the solar cycle, the IPY period is an ideal time to study the interchanges between the lower and upper atmospheric regions, including energy and momentum transfer from below the mesosphere, and related events in the stratosphere such as stratospheric warmings, polar vortex disruption, generation and propagation of planetary waves, etc.

In the Polar Regions, the coupling of the lower and upper atmospheres is usually negligible in comparison to the coupling of the magnetosphere and upper atmosphere. However, during the magnetically quiet IPY period, the lower-upper atmospheric coupling could, at times, dominate in the Polar

Regions. The stage is, therefore, set for "IGY" like fiduciary observations that will inevitably drive theoretical progress in understanding the coupling of the lower and upper atmospherics. Of particular importance in this regard are the two Incoherent Scatter Radars (ISR) located in the northern polar region that will measure the ionospheric state parameters (density, temperature, and velocity) simultaneously and almost continuously during the entire IPY.

The EISCAT Svalbard Radar (ESR), a powerful ISR in the European sector, can monitor the ionosphere parameters along the local geomagnetic field lines threading the polar cap, while the newly commissioned Advanced Modular ISR (AMISR) at Poker Flat, Alaska can similarly monitor the ionosphere on the other side of the polar region. At different times of the day, these radars sample the polar cap, auroral oval, and sub-auroral ionospheres. Both of these facilities will create a nearly year-long data set of ionospheric observations (ionization density, electron and ion temperatures, and line-of-sight ion velocity) that began on March 1, 2007.

Many other instruments that monitor the ionospheric and atmospheric regions will augment these two ISR data sets through their normal operational schedules. The Norwegian Research Council has provided incremental funding to allow the ESR to operate essentially continuously during the first year of the IPY. Meanwhile, the ISR facilities at Millstone Hill (Westford, MA) and Sondrestrom (Kangerlussuaq, Greenland) will operate for ~32 hours every two weeks to sample long-time scale variations not addressed by the previous long runs (~30 days duration) conducted by these radars.

In contrast to the situation during the IGY, the ionosphere can now be described with three-dimensional, time-dependent, physics-based models. However, these models still fail to capture the full variability, and often the climatology of the region. A recent example of this problem is the Sojka et al. [2005] comparison of the USU Time Dependent Ionospheric Model (TDIM) with a month-long ESR data set. Given that the described IPY observational campaign will focus on two ISRs operating almost continuously and complemented by extensive ground-based and satellite observations, a unique data base will be created that captures the seasonal and shorter term variability of the ionosphere.

In October 2002 the EISCAT Svalbard Radar (ESR) created a historic first: a full month of continuous operation, generating a high-resolution series of ionospheric profiles over Longyearbyen, Norway. Comparison with the TDIM model outputs shows that there is much scope for further development and improvements to the physical understanding of the ionospheric drivers, see figure 1.

Figure 2 shows a similar model prediction for the ESR for the first year of the IPY and illustrates dramatically that many features are generated, even without geophysical driver input, which are not observed in the real ionosphere and which indicate areas where both the understanding of the physics and the modelling can be improved during this study.

The IPY provides a major opportunity to advance the physical understanding of the high latitude ionosphere. The present ISSI call for proposals provides the means to exploit that opportunity effectively.

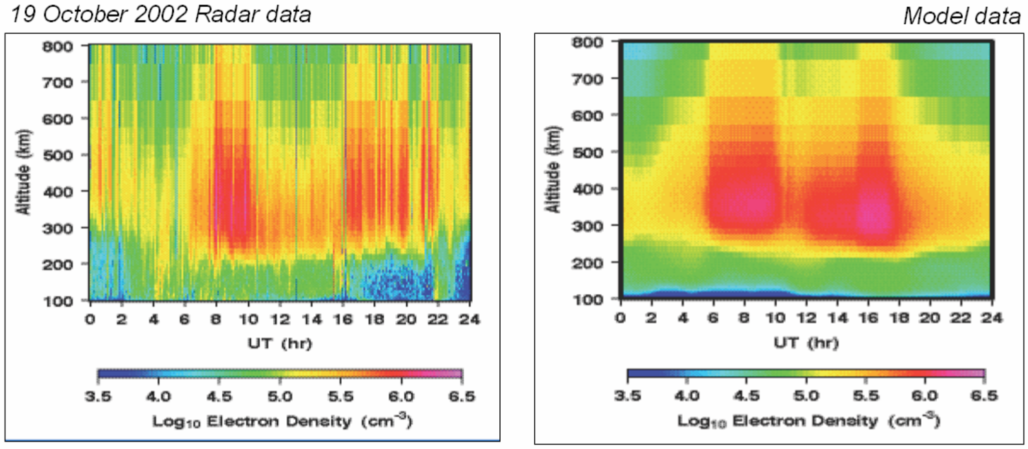

Figure 1: EISCAT Svalbard Radar (ESR) electron density observations for 19 October 2002 (left)). TDIM simulations for the Longyearbyen location on 19 October 2002, with the neutral wind set to zero. Altitude profiles of the ionosphere above Longyearbyen are shown for a 24 hour period; Ne is colour coded on a logarithmic scale.

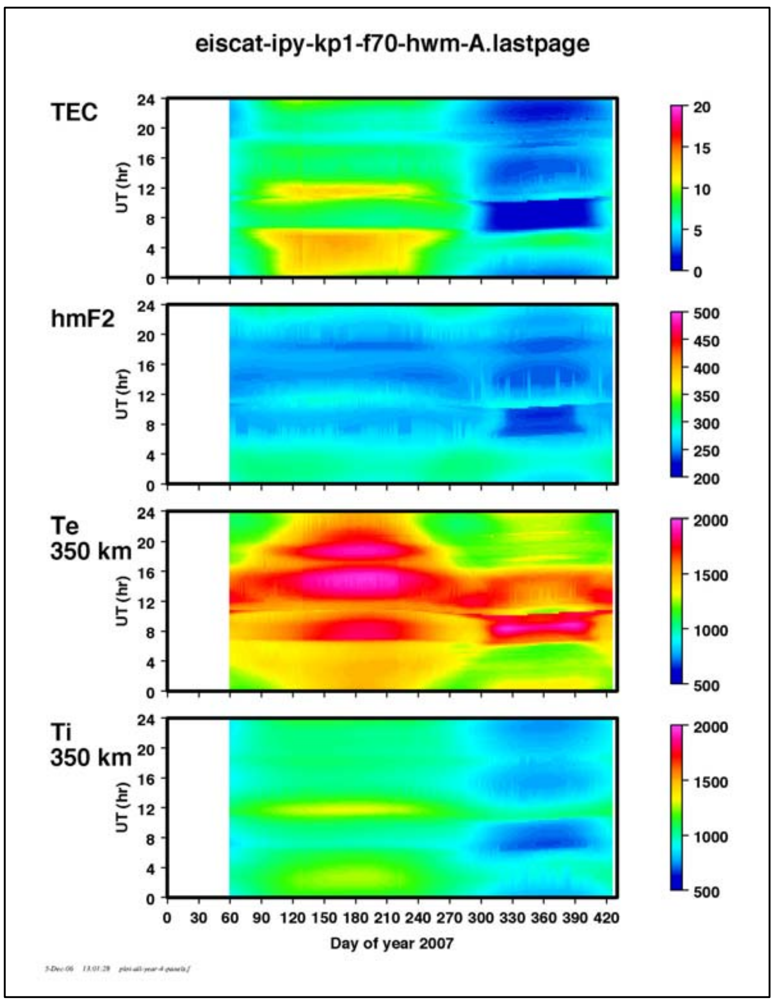

Figure 2: One year TDIM simulation for the EISCAT Svalbard Radar beginning 1 March 2007 derived from model computations of the vertical profile (F10.7 = 70, Kp = 1)

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