# OBSERVATIONS OF THE APRIL 2002 STORM EVENT BY THE GLOBAL INCOHERENT SCATTER RADAR NETWORK WITH COMPARISON TO THE ASPEN MODEL

M. Vigil, L. P. Goncharenko, J. E. Salah, S. P. Zhang *MIT Haystack Observatory, Westford, MA 01886*

G. Crowley *Southwest Research Institute, San Antonio, TX 78238*

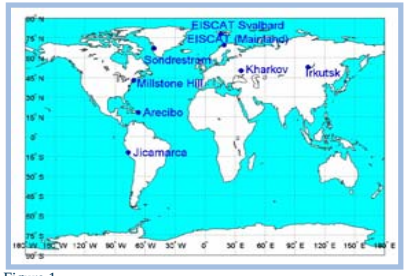



Figure 1

In this presentation, the results of the April 2002 world-day campaign are reviewed. Initiated by the Haystack Observatory, this campaign unites the efforts of eight incoherent scatter radars (ISR) to collect ionospheric data during a major geomagnetic storm event beginning on April 17, 2002 (fig. 1). Because of the sparse ionospheric storm data available, this collected data-set provides a major source of information for atmospheric studies. In addition, the participating ISRs are located along longitudinal and latitudinal sectors, an arrangement that makes this campaign unique and invaluable for studying spatial and temporal effects of ionospheric storms. Emphasis is given to describing pre-storm electron density depletions, correlations between electron density and kinetic temperatures, and comparisons between the ISRs and TIMEGCM/ASPEN, a first principle physical model.

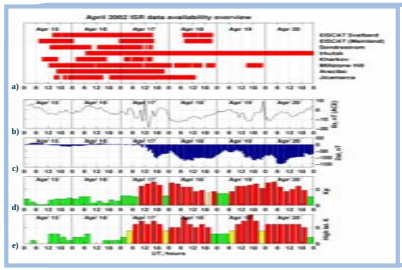
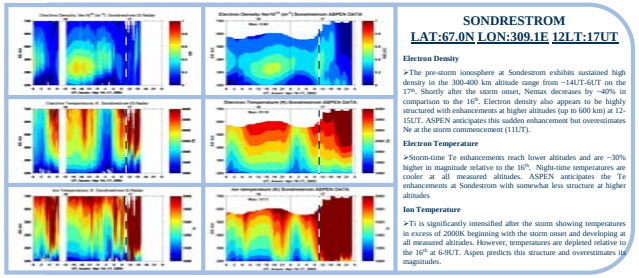


Figure 2

### ISR Data Availability and the April 2002 Storm

The eight IS radars involved in the world-day campaign operated from April 15-19 to monitor the ionosphere. Fig. 2a shows the data availability from this effort.

Fig. 2b-e shows several parameters measured during the campaign. Strong coupling between the IMF and the magnetosphere occur when the Bz component of the interplanetary magnetic field (IMF) is oriented southward (i.e. negative field strength, Fig 2b) resulting in the transfer of energy, mass, and momentum from the solar wind flow to the magnetosphere. Dst, a measure of ring current, is negative when the IMF is oriented southward and its magnitude corresponds to storm intensity. The K-index is directly related to the maximum amount of fluctuation (relative to a quiet day) in the geomagnetic field over three-hour intervals. The shown indices indicate that the geomagnetic storm commenced on April 17, 11UT.



### SONDRESTROM
**LAT:67.0N LON:309.1E 12LT:17UT**

**Electron Density**

➢The pre-storm ionosphere at Sondestrom exhibits sustained high density in the 300-400 km altitude range from ~14UT-6UT on the 17th. Shortly after the storm onset, Nemax decreases by ~40% in comparison to the 16th. Electron density also appears to be highly structured with enhancements at higher altitudes (up to 600 km) at 12-15UT. ASPEN anticipates this sudden enhancement but overestimates Ne at the storm commencement (11UT).

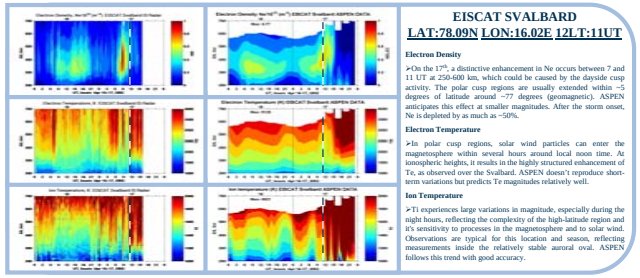
**Electron Temperature**

➢Storm-time Te enhancements reach lower altitudes and are ~30% higher in magnitude relative to the 16th. Night-time temperatures are cooler at all measured altitudes. ASPEN anticipates the Te enhancements at Sondestrom with somewhat less structure at higher altitudes

**Ion Temperature**

➢Ti is significantly intensified after the storm showing temperatures in excess of 2000K beginning with the storm onset and developing at all measured altitudes. However, temperatures are depleted relative to the 16th at 6-8UT. Aspen predicts this structure and overestimates its magnitudes.

Figure 3



### EISCAT SVALBARD
**LAT:78.09N LON:16.02E 12LT:11UT**

**Electron Density**

➢On the 17th, a distinctive enhancement in Ne occurs between 7 and 11 UT at 250-600 km, which could be caused by the dayside cusp activity. The polar cusp regions are usually extended within ~5 degrees of latitude around ~77 degrees (geomagnetic). ASPEN anticipates this effect at smaller magnitudes. After the storm onset, Ne is depleted by as much as ~50%.

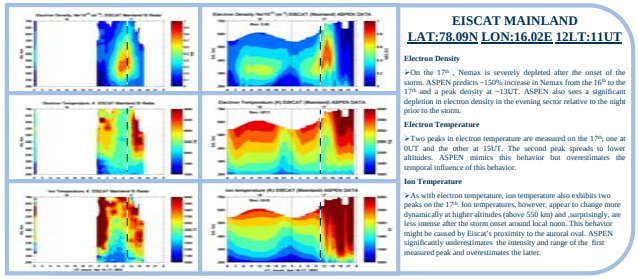
**Electron Temperature**

➢In polar cusp regions, solar wind particles can enter the magnetosphere within several hours around local noon time. At ionospheric heights, it results in the highly structured enhancement of Te, as observed over the Svalbard. ASPEN doesn't reproduce short-term variations but predicts Te magnitudes relatively well.

**Ion Temperature**

➢Ti experiences large variations in magnitude, especially during the night hours, reflecting the complexity of the high-latitude region and it's sensitivity to processes in the magnetosphere and to solar wind. Observations are typical for this location and season, reflecting measurements inside the relatively stable auroral oval. ASPEN follows this trend with good accuracy.

Figure 6



### EISCAT MAINLAND
**LAT:78.09N LON:16.02E 12LT:11UT**

**Electron Density**

➢On the 17th , Nemax is severely depleted after the onset of the storm. ASPEN predicts ~150% increase in Nemax from the 16th to the 17th and a peak density at ~13UT. ASPEN also sees a significant depletion in electron density in the evening sector relative to the night prior to the storm.

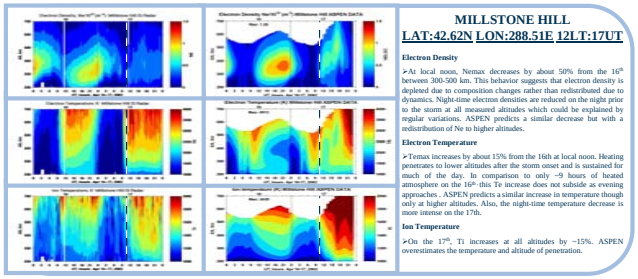
**Electron Temperature**

➢Two peaks in electron temperature are measured on the 17th: one at 01UT and the other at 15UT. The second peak spreads to lower altitudes. ASPEN mimics this behavior but overestimates the temporal influence of this behavior.

**Ion Temperature**

➢As with electron temperature, ion temperature also exhibits two peaks on the 17th. Ion temperatures, however, appear to change more dynamically at higher altitudes (above 550 km) and ,surprisingly, are less intense after the storm onset around local noon. This behavior might be caused by Eiscat's proximity to the auroral oval. ASPEN significantly underestimates the intensity and range of the first measured peak and overestimates the latter.

Figure 8



### MILLSTONE HILL
**LAT:42.62N LON:288.51E 12LT:17UT**

**Electron Density**

➢At local noon, Nemax decreases by about 50% from the 16th between 300-500 km. This behavior suggests that electron density is depleted due to composition changes rather than redistributed due to dynamics. Night-time electron densities are reduced on the night prior to the storm at all measured altitudes which could be explained by regular variations. ASPEN predicts a similar decrease but with a redistribution of Ne to higher altitudes.

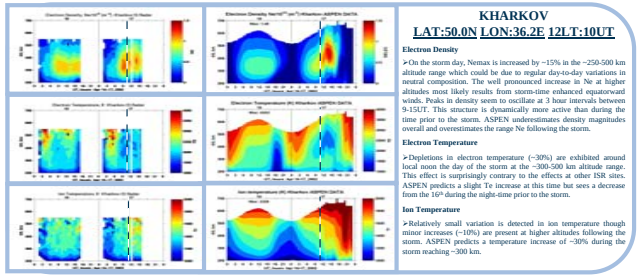
**Electron Temperature**

➢Temax increases by about 15% from the 16th at local noon. Heating penetrates to lower altitudes after the storm onset and is sustained for much of the day. In comparison to only ~9 hours of heated atmosphere on the 16th this Te increase does not subside as evening approaches . ASPEN predicts a similar increase in temperature though only at higher altitudes. Also, the night-time temperature decrease is more intense on the 17th.

**Ion Temperature**

➢On the 17th, Ti increases at all altitudes by ~15%. ASPEN overestimates the temperature and altitude of penetration.

Figure 4



### KHARKOV
**LAT:50.0N LON:36.2E 12LT:10UT**

**Electron Density**

➢On the storm day, Nemax is increased by ~15% in the ~250-500 km altitude range which could be due to regular day-to-day variations in neutral composition. The well pronounced increase in Ne at higher altitudes most likely results from storm-time enhanced equatorward winds. Peaks in density seem to oscillate at 3 hour intervals between 9-15UT. This structure is dynamically more active than during the time prior to the storm. ASPEN underestimates density magnitudes overall and underestimates the range Ne following the storm.

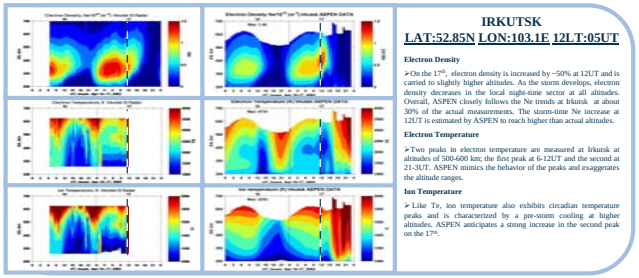
**Electron Temperature**

➢Depletions in electron temperature (~30%) are exhibited around local noon the day of the storm at the ~300-500 km altitude range. This effect is surprisingly contrary to the effects at other ISR sites. ASPEN predicts a slight Te increase at this time but sees a decrease from the 16th during the night-time prior to the storm.

**Ion Temperature**

➢Relatively small variation is detected in ion temperature though minor increases (~10%) are present at higher altitudes following the storm. ASPEN predicts a temperature increase of ~30% during the storm reaching ~300 km.

Figure 7



### IRKUTSK
**LAT:52.85N LON:103.1E 12LT:05UT**

**Electron Density**

➢On the 17th, electron density is increased by ~50% at 12UT and is carried to slightly higher altitudes. As the storm develops, electron density decreases in the local night-time sector at all altitudes. Overall, ASPEN closely follows the Ne trends at Irkutsk at about 30% of the actual measurements. The storm-time Ne increase at 12UT is estimated by ASPEN to reach higher than actual altitudes.

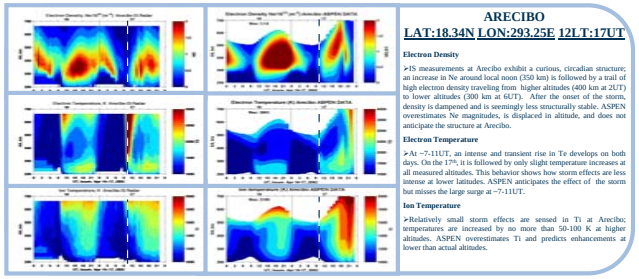
**Electron Temperature**

➢Two peaks in electron temperature are measured at Irkutsk at altitudes of 500-600 km; the first peak at 6-12UT and the second at 21-3UT. ASPEN mimics the behavior of the peaks and exaggerates the altitude ranges.

**Ion Temperature**

➢ Like Te, ion temperature also exhibits circadian temperature peaks and is characterized by a pre-storm cooling at higher altitudes. ASPEN anticipates a strong increase in the second peak on the 17th.

Figure 9



### ARECIBO
**LAT:18.34N LON:293.25E 12LT:17UT**

**Electron Density**

➢IS measurements at Arecibo exhibit a curious, circadian structure; an increase in Ne around local noon (350 km) is followed by a trail of high electron density traveling from higher altitudes (400 km at 2UT) to lower altitudes (300 km at 6UT). After the onset of the storm, density is dampened and is seemingly less structurally stable. ASPEN overestimates Ne magnitudes, is displaced in altitude, and does not anticipate the structure at Arecibo.

**Electron Temperature**

➢At ~7-11UT, an intense and transient rise in Te develops on both days. On the 17th, it is followed by only slight temperature increases at all measured altitudes. This behavior shows how storm effects are less intense at lower latitudes. ASPEN anticipates the effect of the storm but misses the large surge at ~7-11UT.

**Ion Temperature**

➢Relatively small storm effects are sensed in Ti at Arecibo; temperatures are increased by no more than 50-100 K at higher altitudes. ASPEN overestimates Ti and predicts enhancements at lower than actual altitudes.

Figure 5

*Figs 3-5 belong to a longitudinal chain of ISRs at about 60°W. Horizontally placed, the top and middle row of ISRs are part of chain along 45°E and 75°E latitudes respectively.*

## SUMMARY

- At all ISR sites, the geomagnetic storm creates a relative depletion in electron density after the onset of the storm.
- There is a clear correlation between electron density and temperatures. Namely, they are inversely proportional. This effect clearly exists at all locations; after the onset of the storm, temperatures are increased over all altitudes while density is, in general, decreased.
- These effects, however, do not take place at Kharkov (fig. 7) where post-storm measurements reveal a slight increase in electron concentrations and cooling of temperatures.
- These characteristics of increased geomagnetic activity appear to diminish in magnitude equatorwards (see fig. 3-5). This feature infers the rate and extent at which geomagnetic activity spatially influences the ionosphere.
- ASPEN forecasts generally anticipate enhancements and depletions of the above parameters but often overestimates their magnitudes.
- Further developments of this study are attempting to answer the many looming questions about ionospheric reactions to high geomagnetic activity.
  - What is the penetration in latitude and altitude of the variation of plasma parameters due to the storm effects?
  - What is the global morphology of large-scale plasma density variations during this storm?
  - Are there wave structures (e.g. TIDs) generated during this storm?