Ionosphere-Thermosphere Metrics

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Study of Metrics for the

National Space Weather Program

Executive Summary

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A "space weather metric" is a quantitative measure of the ability of a scientific algorithm or model to predict or nowcast the value of a physical parameter involved in space weather. A specific metric has three elements:

- A parameter defined at some position and time (for example, the F-region peak electron density at mid-latitude every hour for the next day);
- An observable to which a prediction can be compared (e.g., density measurement by an incoherent-backscatter radar facility);
- A criterion by which the metric is quantified (e.g., RMS difference between prediction and observation).

For the purpose of measuring the overall progress of the NSWP, it is useful for the scientific community to define a broad set of metrics, for the following reasons:

- Application metrics change as technologies change. Metrics for the NSWP must remain valid at least for the ten-year life span of the Program.

- Scientific metrics must be open to the scientific community, but application metrics often involve defense secrets (military) or trade secrets (commercial users).

- Although there is remarkable overlap between parameters that are important to the application community and scientifically important parameters, the overlap is not 100%.

- To measure progress, scientific metrics should have a scale that encompasses both presently available scientific algorithms and the best that we could hope for, by the end of the NSWP.

Ionosphere-Thermosphere

For each physical parameter, metrics should be defined that measure ability to forecast and nowcast

- climatological mean,
- one-sigma limits in the daily values ("day to day variability"),
- a particular time interval (e.g., one-day forecast),
- the departure from the climatological mean over a particular interval.

Table 1. Priority List of Key Physical Parameters for the Ionosphere and Thermosphere

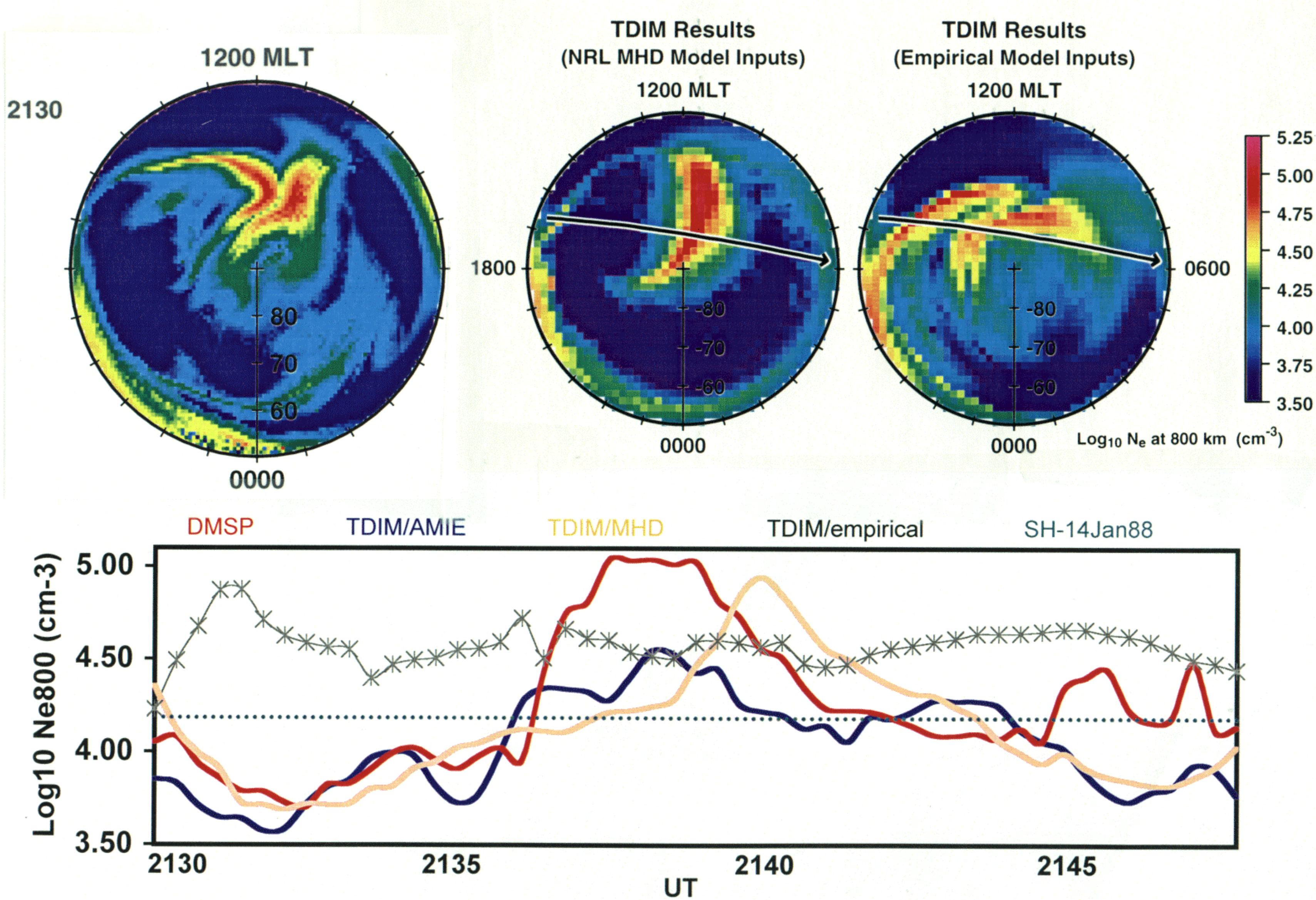
First Priority:
Electron density N_e, including intrinsic variability
Neutral mass density ρ, including intrinsic variability
$\delta N_e/N_e$, the amplitude of the electron density irregularities
Second Priority:
Neutral and ion composition
Thermospheric winds and temperatures
Low-latitude ion drifts
Third Priority:
Electron and ion temperature
Fourth Priority:
Minor species

Table 2. Top-Priority Ionosphere-Thermosphere Metrics

Category	Parameter	Place	Time	Cadence	Data	Criterion
F-region ionosphere	*Minimum:* NmF2 *Desired:* N_e(200-600), $\Delta h \sim 20$ km	Low, mid, and high latitudes	03-09LT 09-15 LT 15-21 LT 21-03 LT	Hourly	Ionosonde or Incoherent scatter radar (Jicamarca, Arecibo, Millstone Hill, and Sondre Stromfjord)	RMSE
High-latitude structure	N_e (800 km)	Orbit plane of polar satellite 45Þ-45Þmag. $\Delta x \sim 100$ km	Every orbit	Every orbit	DMSP-SSIES	RMSE
Pre-reversal enhancement	Vertical ion drift V_i(400 km)	Magnetic equator	N/A	Daily	Incoherent scatter radar (Jicamarca)	Obs-model or RMSE
Scintillation/ Ionospheric irregularities	S_4 250 MHz and 1GHz	Magnetic equator	18-24 LT $\Delta t \sim 1$ hr	Daily	Geostationary transmitter	RMSE
Electron content	Peak TEC and N/S latitude location of Equatorial Ionization Anomaly	N/A	Every orbit of observation	Every orbit of observation	TOPEX	(obs-model)/obs or RMSE

An additional set of metrics is needed to specify and forecast macroscopic features that can dominate certain regions of the ionosphere-thermosphere domain:

- Appleton anomaly,
- high-latitude features (subauroral trough, tongues and holes in polar-cap ionization, neutral-density holes),
- equatorial pre-reversal enhancement in vertical ion drift,
- transient ionospheric disturbances (TID's),
- the ratio of atomic oxygen to molecular nitrogen column abundance.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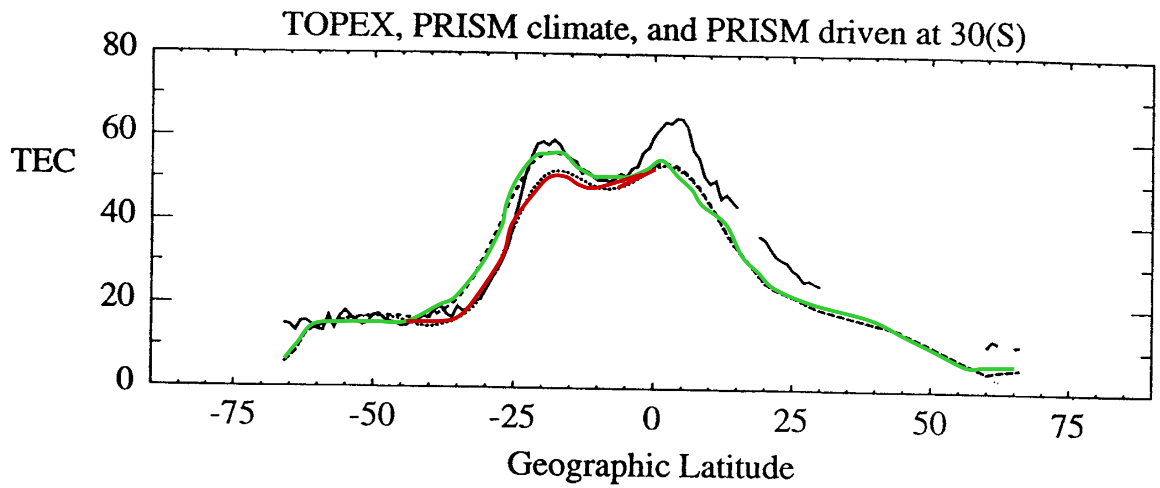
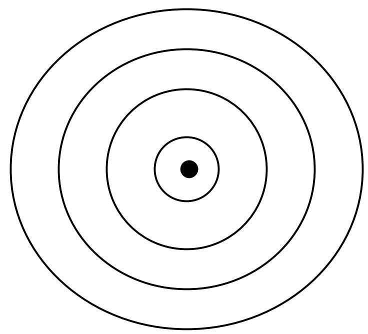
Ionospheric Effects

- OTH Radars
- HF Communications
- Surveying – GPS
- Navigation – GPS
- Surveillance
- Satellite Tracking
- Power Grids
- Pipelines
- FAA’s WAAS
- Solar Cells

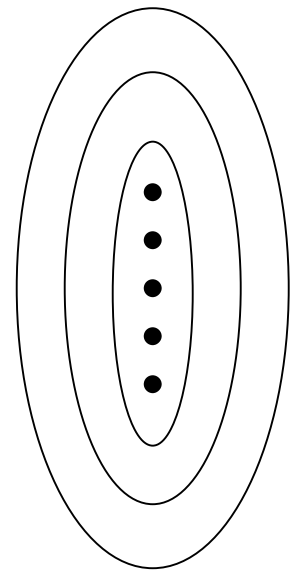


- Parameterized Real-Time Ionospheric Specification Model (PRISM)
  - TOPEX TEC Measurements
  - Data Adjustment at One Location

PRISM



Single Point



Multiple Points

Can introduce artificial N_e gradients!

Need Metrics for each application!

Table 4. Top-Priority Magnetosphere - Ionosphere Metrics

Category	**Parameter(s)**	**Place**	**Averaging interval**	**Data**	**Criterion***
High-latitude ionospheric electric field	Component of **E** along track of polar-orbiting spacecraft above 50Þ invariant latitude	~ 1000 km altitude, from dawn-dusk orbit	100 km along s/c track	Ion drift meter on DSMP spacecraft	Mean absolute error in component of **E** along satellite path
Auroral electron flux	Latitude-integrated energy flux, number flux. Latitudinal centroid of energy flux	~ 1000 km altitude, from nightside auroral zone crossings.	100 km along s/c track	Precipitating electron flux measured by DMSP or NOAA spacecraft	Mean absolute error
Magnetic indices	AE (electrojets) Dst (ring current) Kp (overall activity)	Ground stations	Time resolution of index	Ground magneto-meters	Mean absolute error
Magneto-spheric electron fluxes	Fluxes of > 10 keV and > 1 MeV electrons	Geo-synchronous orbit	15 minutes	LANL and NOAA spacecraft	Mean absolute error in log(flux)

*Mean absolute error = $\langle |F_{predicted} - F_{observed}| \rangle$

Table 3. Major Features of the Magnetosphere-Ionosphere Coupled System

Feature	Includes
Magnetic field configuration	Global magnetic structure, including dayside, tail; ground magnetic variations
Electric field configuration	Ionospheric and magnetospheric. Represents effects of solar-wind/magnetosphere coupling, magnetospheric convection
Auroral precipitation	Precipitation from polar cusp, polar cap, main auroral zones and plasma sheet
Trapped energetic particles	Includes ring current and inner and outer radiation belts, from ~ 1 keV to ~ 100 MeV
Cold particles	Plasmasphere, plasmapause, suprathermal ions
Plasma sheet, plasma-sheet boundary layer	Kilovolt electrons and ions that extend into the tail
Magnetopause	Shape and position, reconnection, transfer processes, boundary layers
Waves and small-scale effects	Cause particle loss by pitch-angle scattering, allow magnetic reconnection, accelerate auroral particles

We recommend that the following types of metric evaluations be undertaken as soon as possible to establish a regular program of scientific metrics for space-weather capabilities:

Type 1. Measurements should be made at a r egular cadence and compared systematically with algorithm or model predictions, to establish statistically valid baseline metrics. In addition to the overall averages, average errors should be recorded for different conditions (e.g., *Kp* levels in the case of magnetosphere-ionosphere metrics).

Type 2. When groups of scientists carry out event studies, comparing various models and other algorithms to observations, they should evaluate their models and algorithms in terms of the same standard metrics used in the statistical analyses of item 1. This would help to tie event studies and campaigns, which are a regular feature of cooperative research programs (e.g. CEDAR, GEM, SHINE) as well as some NASA spacecraft programs, to progress of the NSWP.