REVISED: Low and Mid-Latitude Climatology Assessment of Ionosphere/Thermosphere Models During Solar Minimum

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Climatology Study for the Ionosphere-Thermosphere

The CEDAR Electrodynamics-Thermosphere Ionosphere (ETI) Climatology Challenge selected the year of ISR observations (March 2007 – March 2008) at the first CEDAR ETI Challenge Workshop in the summer of 2009.

This first Climatology Challenge centers on GPS Total Electron Content (TEC) around the solar minimum December solstice (07355) for +/-30 days to avoid a sudden stratospheric warming (SSW) January 22-23, 2008.

Data sets: MIT and IGS GPS TEC, USU COSMIC NmF2 and hmF2, NRL satellite drag daily global neutral density at 400 km, CHAMP neutral density at 400 km, Jicamarca ion drifts (magnetometers, JULIA, ISR)

Empirical model of the equatorial vertical drift (Scherliess and Fejer, JGR, 104, 6829-6842, 1999.)

Model runs: IRI, CTIPE, TIEGCM (Heelis Kp, double resolution Weimer 2005 with TIMED lower boundary)
The conditions from 07325-08020 were dominated by 5 periods of High Speed Streams (HSS) in the solar wind velocity ($V_{sw}$) and low solar wind. Kp values were usually >2 for the HSS and <1 for the low $V_{sw}$. The HSS prompted high global TEC and neutral densities at 400 km in satellite drag data (red) from Emmert [2009, JGR], MSIS (cyan) and TIEGCM Weimer05 with TIMED lower boundaries.
Separating HSS and Slow Speed Wind

Choosing $\text{Kp} \geq 2$ and $\text{Vsw} \geq 500 \text{km/s}$ and $\text{Kp} \leq 1$ and $\text{Vsw} \leq 450 \text{km/s}$ results in 25 days each of HSS (red) and slow speed wind (blue) conditions. Averages from daily values are: $10.7 \text{ cm}$ flux, $72.8, 74.3$; $\text{Kp}$ $2.79, 0.46$; $\text{Bz}$ nT $-0.08, +0.09$; $\text{Vsw}$ km/s $606, 359$. Neutral densities at 400 km are higher for HSS (*) than for slow Vsw (squares).
Have pronounced HSS peaks in the sunrise (ascending) and sunset (descending) ‘global’ densities over 1 day.
CHAMP, MSIS, TIE Neutral Densities at CHAMP Hts (~337-368km)
Ratios of neutral densities at CHAMP orbit

- Ratios of MSIS/CHAMP ~1.5, slightly higher for quiet periods than HSS with ratios ~0.1 higher for 8-3LT.

- Ratios of TIE/CHAMP ~same except for 8-3LT which are ~2 for quiet periods.
Drifts around the magnetic equator

Can calculate the median vertical ion drift from the models and compare it to the quiet-time model as a function of LT and longitude at the magnetic equator.

Results for TIEGCM Weimer TIMED lower boundary are fairly good. Usually active period (Kp~3-) larger magnitudes.
Daytime Jicamarca observations show Kp~3- Viz drifts are larger in magnitude before noon, and smaller in magnitude after noon. Model ViE ExB w/o neutral winds.
Choose 8 Longitude Slices from GPS TEC

Hourly coverage of the 8 longitude slices for 21 December 2007 from MIT GPS TEC analysis.

Minimum number of bins 446 for 345E, maximum 727 for 140E.

Can see daily low latitude maxima.
- Climatology medians for 61 days from MIT GPS TEC from 07325 (21 Nov) to 08020 (20 Jan).
- The winter (NH) anomaly expects daytime midlatitude NmF2 to be higher than summer (SH) as for 25E and 285E, but usually TEC is larger in the summer (SH) daytime midlatitudes.
- Low latitude night TEC and winter pole TEC lowest.
- Weddell Sea anomaly (~60-70S,~250-345E) shows night TEC larger than day.
- Possible bias problems with Indonesia (~0N, 90E) and Scandinavia (~70N, 25E).
Comparison of MIT and IGS TEC
HSS (Kp\geq2) and Slow Vsw (Kp\leq1)

The TEC for moderate Kp\geq2 (HSS) is slightly larger than for low Kp\leq1 (slow Vsw)
IRI model TEC and %model/data shows IRI overestimates morning day and summer night TEC and underestimates winter night TEC. %M/D for average model/data, and for absolute ratio average. Compare with average of 8 longitudes.
CTIPE TEC and %model/data shows CTIPE overestimates night TEC except in the winter high latitudes where TEC is underestimated.
TIEGCM Heelis Kp model and %model/data shows TIEGCM/Kp overestimates low latitude pre-dawn, high latitude winter, and underestimates midlatitude night TEC.
TIEGCM double resolution Weimer 2005 with TIMED lower boundary conditions and %model/data shows this TIEGCM is similar to the Kp TIEGCM.
1) All models show different regions of overestimation and underestimation of the ‘real’ GPS TEC.

2) All models did best for at least 1 lon (IRI 1-2 lons, TIE-Kp 4-5 lons)

3) Average absolute value percent deviations for 61 days total, or 25 days of HSS or slow Vsw: IRI 93, 99, 104%, CTIPE 94, 108, 99%, TIE-Kp 76, 77, 84%, TIE-WT 90, 90, 93%
For 15 min averages of 5x5 glat/glon bins on Dec 13, 2006, a 24-h Ion period has 96*36=3356 total bins. GPS TEC fills 34-79% of the bins, while COSMIC fills 1-2% (~60).
Use 5 deg lat by 25 deg lon bins over 61 days gives nearly complete maps with 1-20 points in each bin.

Similar to TEC plot showing 2 low latitude daytime maxima.
IRI NmF2 and %model/data shows IRI overestimates nighttime summer NmF2 and underestimates nighttime winter night NmF2.
CTIPE NmF2 and %model/data shows CTIPE overestimates night NmF2 (like TEC) and high lat winter and underestimates in night trough.
TIEGCM Heelis Kp model and %model/data shows TIEGCM Kp overestimates (as TEC) low latitude pre-dawn, high latitude winter NH, and underestimates midlatitude summer SH mostly at night.
TIEGCM double resolution Weimer TIMED lower boundary and %model/data shows this TIEGCM is similar to the Kp TIEGCM.
Summary of NmF2 Climatology

The regions of over- and under-estimates for NmF2 was sometimes the same as for TEC and often different.

1) IRI was the clear winner, with CTIPe doing next best.
2) Average absolute percent deviations: IRI 36%, CTIPE 61%, TIE-Kp 89%, TIE-WT 93%.
COSMIC Hmf2 Climatology

Hmf2 high at equator and night and low at dawn and winter day.
IRI model hmF2 and model-data shows IRI overestimates night high-lat winter NH hmF2 and underestimates midlatitude night hmF2.
CTIPe model hmF2 and model-data shows CTIPe overestimates high-lats and underestimates low-latitude hmF2 (except at pre-dawn).
TIEGCM Heelis Kp model hmF2 and model-data shows TIEGCM-Kp overestimates hmF2, especially in winter.
TIEGCM Weimer 2005 and TIMED lower boundary hmF2 and model-data shows TIEGCM-WT overestimates hmF2 in winter NH, and underestimates in high-lat summer SH pre-noon.
Summary of HmF2 Climatology

1) CTIPe and IRI were close, where CTIPe was best for 5 longitudes, while IRI was best for 3 longitudes.

2) Average absolute model-data deviations in km were:
   IRI 25km, CTIPE 23km, TIE-Kp 35km, TIE-WT 38km
Summary of the First CCMC Climatology Study

. NRL satellite drag daily global neutral density at 400 km varies with Vsw and Kp. TIEGCM Weimer/TIMED agreed better with MSIS at larger values where lo/hi ratios were 50% instead of 100%. CHAMP neutral densities similar in magnitude to NRL.

. TIEGCM Weimer/TIMED equatorial vertical drifts agree with the empirical quiet-time model of Scherliess and Fejer [JGR, 1999].

. Jicamarca vertical drifts show Kp~3- larger before noon and smaller after noon.

. 8 longitudes for 2 months work well for MIT or IGS GPS TEC and USU COSMIC NmF2 and hmF2

. The IRI TEC are no better than the first-principle models.

. Average differences for TEC are almost a factor of 2, with TIEGCM Heelis Kp ‘best’ for TEC with |model/data|-1 averaging ~77%.

. IRI was the clear winner for NmF2 with 36% average |model/data|-1, with CTIPe next with 61%, and the TIE-GCMs with ~90%.

. CTIPe and IRI had the best hmF2 with |model-data| differences of ~23 and ~25 km, with the TIE-GCMs ~35-40km.

. More data sets and models are welcome for the future climatology CCMC Challenge at the 2012 CEDAR Workshop.
Future Participants

* Geoff Crowley (gcrowley@astraspace.net) for TIME-GCM/AMIE runs
* Michael.David@aggiemail.usu.edu for TDIM USU runs
* Andrzej Krankowsi (kand@uwm.edu.pl) for IGS TEC (>=1994 5deg glon+2.5deg glat at 15min, 1h, or 2h intervals)
* sarah.mcdonald@nrl.navy.mil for runs of SAMI3
* Aaron Ridley (ridley@umich.edu) for GITM runs
* ludger.scherliess@usu.edu for COSMIC NmF2/hmF2 for different Kp and GAIM runs
* Eric.Sutton@kirtland.af.mil for eddylb + Weimer05 TIEGCM runs
* elsayed.talaat@jhuapl.edu for TIEGCM + SABER
* Dan Weimer (dweimer@vt.edu) for runs of his Weimer+Jacchia+Bowman models for 400 km neutral density
* Michael Wiltberger (wiltbemj@ucar.edu) for CMIT-TIEGCM model
* Shunrong Zhang (shunrong@haystack.edu) for ISR model runs