Community Coordinated Modeling Center

Climatology Assessment of Ionosphere/Thermosphere Models in Low Solar Flux Conditions for the CCMC CEDAR Challenge: Status, Lessons Learned, and Future Plans

BA Emery, JS Shim, D Anderson, P Bhaneja, D Bilitza, J Chau, G Crowley, M Codrescu, WR Coley , AJ Coster, E Doornbos, D Drob, JT Emmert, T-W Fang , M Fedrizzi, B Fejer, M Förster, B Foster, TJ Fuller-Rowell, LP Goncharenko , K Häusler, J Huba, M Jones Jr, J Klenzing L Lomidze, H Lühr, AJ Mannucci, A Maute, S McDonald, A Namgaladze, R Pfaff, X Pi, B Prokhorov, J Retterer, AD Richmond, P Roddy, L Scherliess, R Stoneback, Y-J Su, E Sutton, D Weimer, Q Wu, X Zhang

CCMC CEDAR-GEM Challenge, before Space Weather Week,
15 April 2013, Boulder, CO

CCMC Electrodynamic-Ionosphere-Thermosphere Challenge

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

. We examine solar minimum December solstice (07355) for +/-30 days

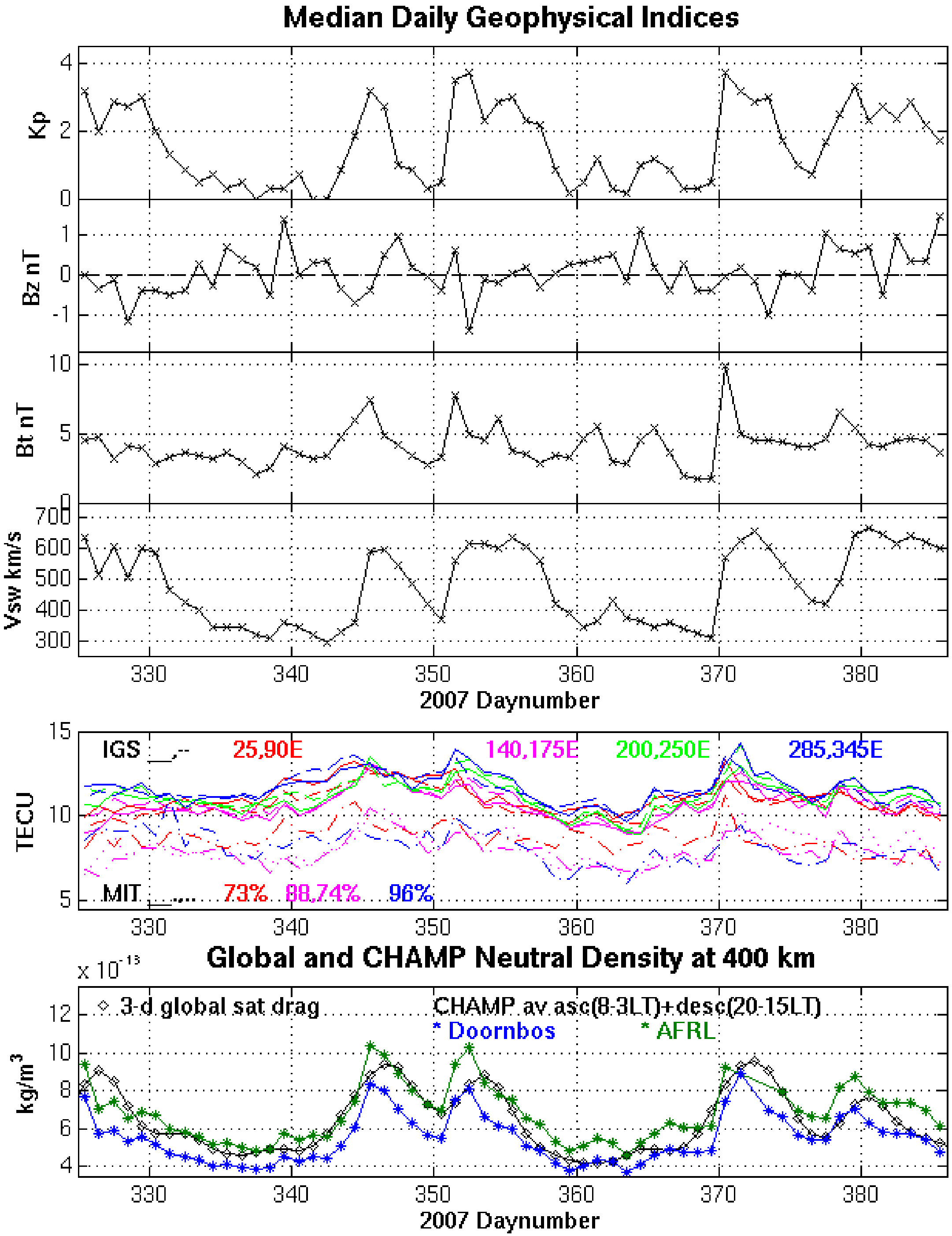
. Additional periods of solar min,med Dec, Mar from 2006-2012

. Data sets: MIT, JPL, 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 (mags, JULIA, ISR)

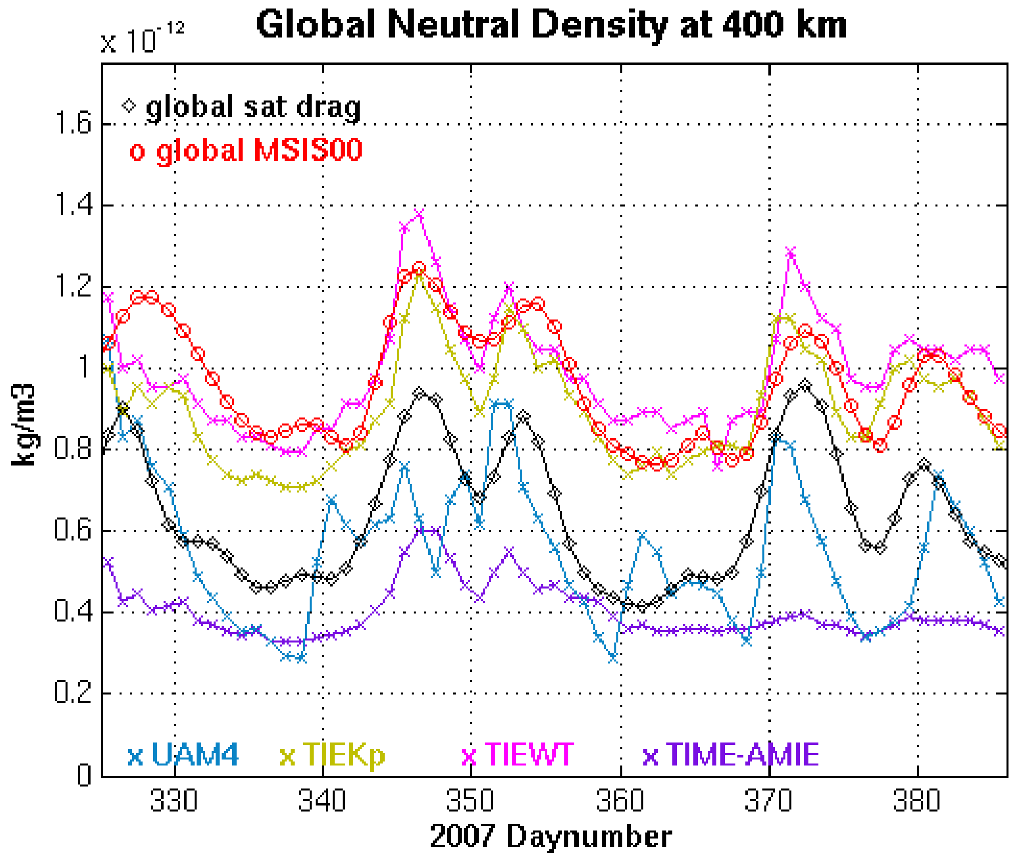
. Additional data sets from C/NOFS (IVM, VEFI, PLP) and CHAMP neutral zonal winds, Te and Ne.

. Models: CCMC runs of IRI2007, SAMI3_HWM93, USU_IFM, CTIPe, TIEGCM (Heelis Kp), USU_GAIM, and runs of TIEGCM (Weimer 2005 and TIMED lbs), TIME-GCM (AMIE), SAMI3 (MSIS tweaked), UAM4.

Solar Wind and Global TEC and Neutral Density at 400 km



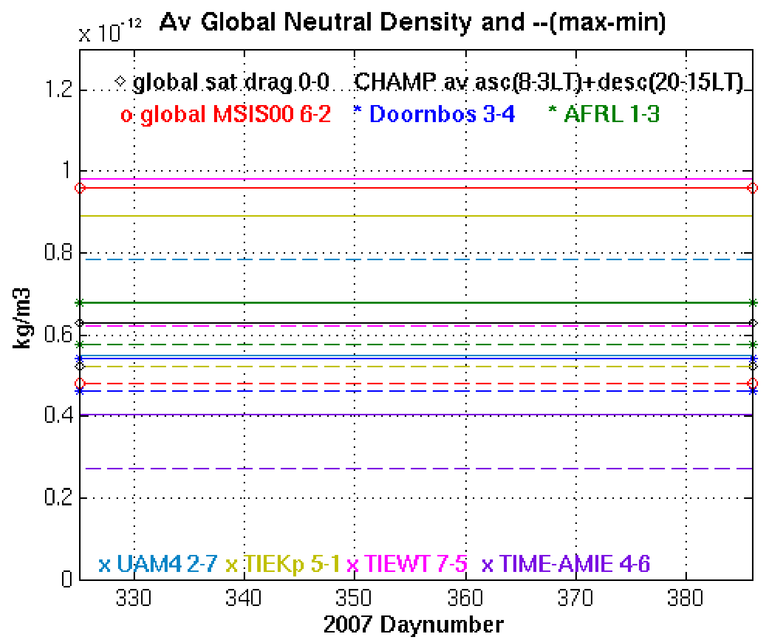
The conditions from 07325-08020 included 5 periods of High Speed Streams (HSS) in the solar wind velocity (Vsw). Kp values were usually >=2 for the HSS and <=1 for slow Vsw. The HSS prompted high daily TEC along 8 longitudes and high 400 km neutral densities in satellite drag data from Emmert [2009, JGR] and in two calibrations of the CHAMP satellite at 2 LTs.



Comparing with Global Models

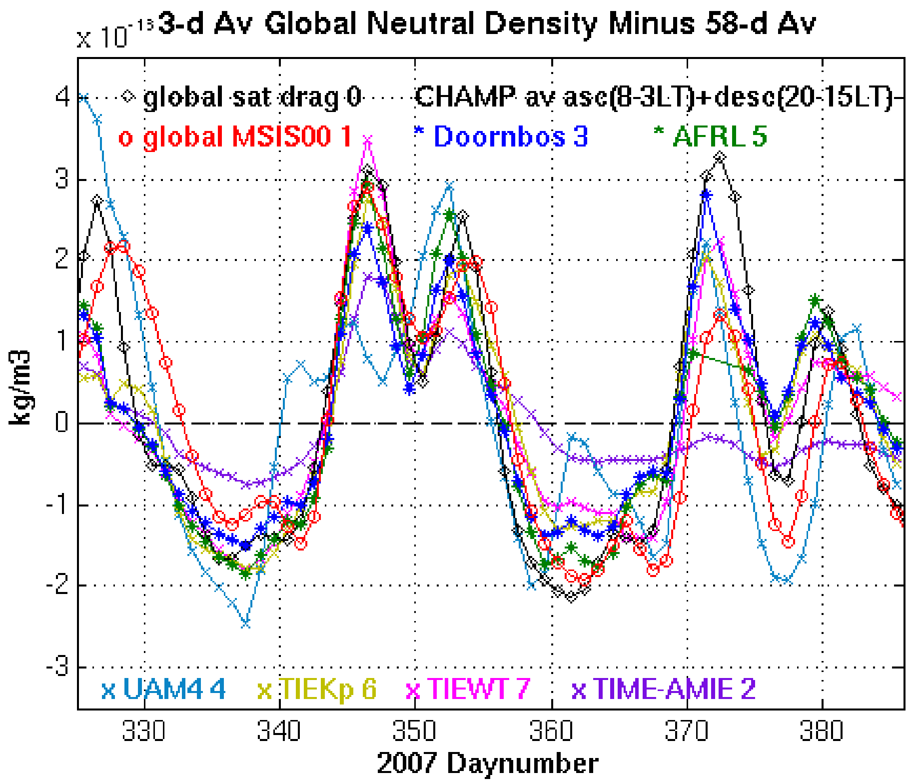
The sliding 3-day satellite drag observations at 400 km are compared with sliding 3-day empirical model MSIS00 estimates and daily global neutral densities from four theoretical models.

Four models are compared: (1) Upper Atmosphere Model (UAM) version 4 using MSIS00 temperatures as an empirical constraint and driven by IMF-dependent FACs from Papitashvili et al. [2002], (2) Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGCM) version 1.93 using Heelis [1982] convection driven by Kp, (3) TIEGCM using Weimer [2005] convection driven by IMF and lower boundary winds and temperatures driven by TIMED satellite SABER and TIDI observations, (4) Thermosphere-Ionosphere-Mesosphere-Electrodynamics General Circulation Model (TIMEGCM) driven by AMIE convection using observational inputs.



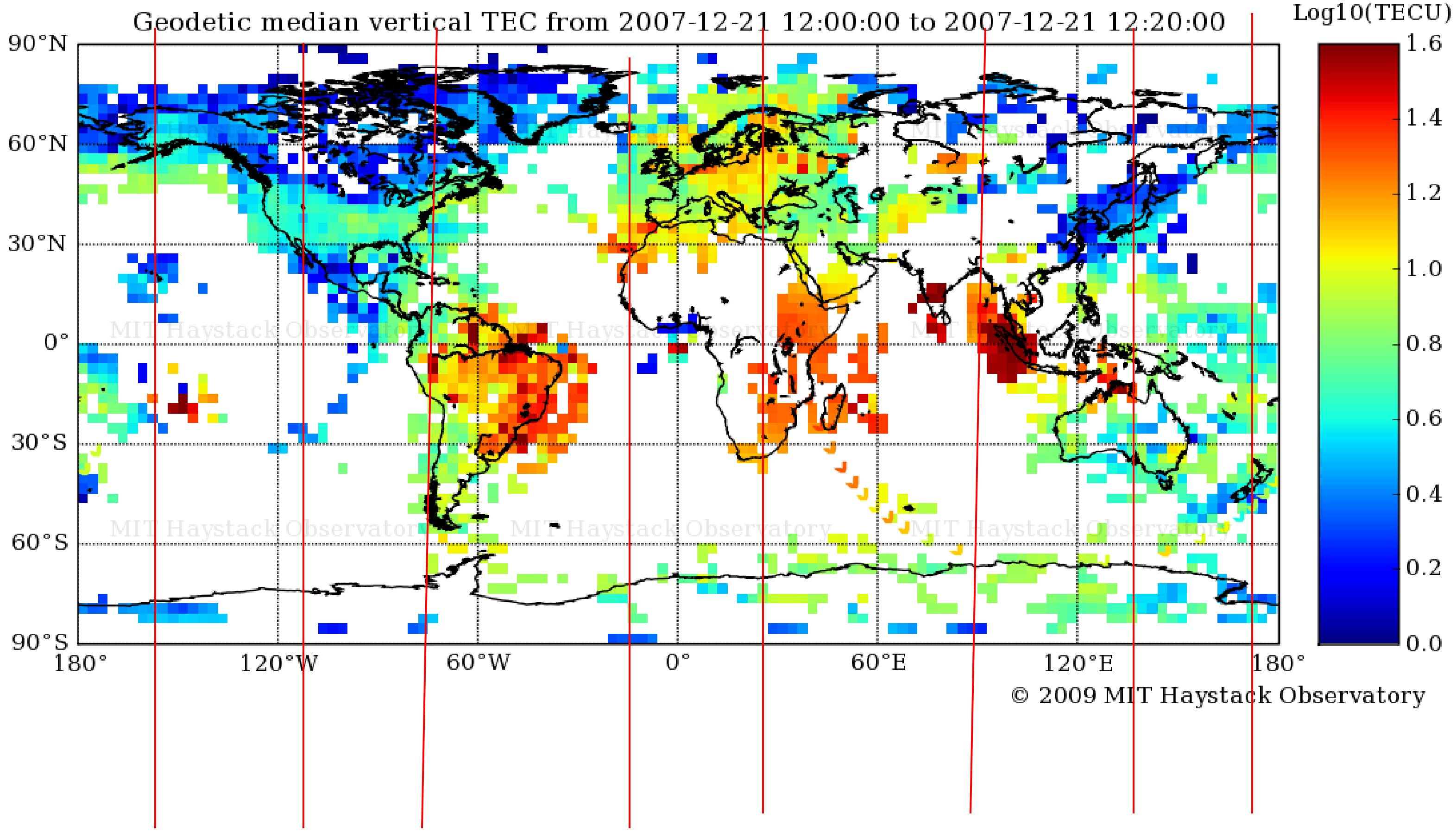
Metrics for Comparison

Because of the 26% increase in the baseline from Doornbos to AFRL CHAMP observations in 58-day averages (solid lines left figure), the first metric used is (1) the **baseline.** The other two metrics are (2) **max-min** (or the **range**), and (3) the **root mean square rms** from the satellite drag observations minus the 58-d averages.



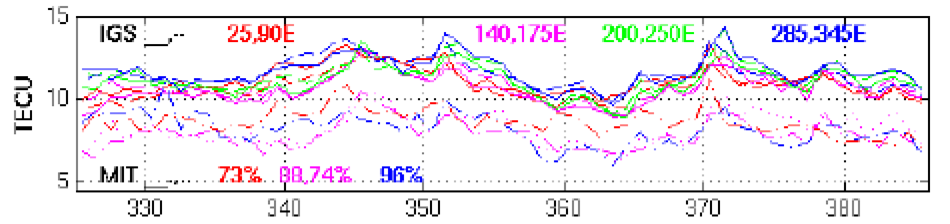
CHAMP obs and models were averaged over 3 days. The top figure gives two rankings from 0-8, where the first number is for the baseline, and the second is for the range. The bottom figure shows the sliding 3-day curves minus their 58-day averages (excluding the HSS peak at 371-373 to be able to compare with AFRL). Adding the 3 rankings together gives the best over-all comparisons to the satellite drag data as: (1a,b) AFRL obs and MSIS00, (3) Doornbos obs, (4a,b) TIEKp and TIME-AMIE, (6) UAM4, and (7) TIEWT.

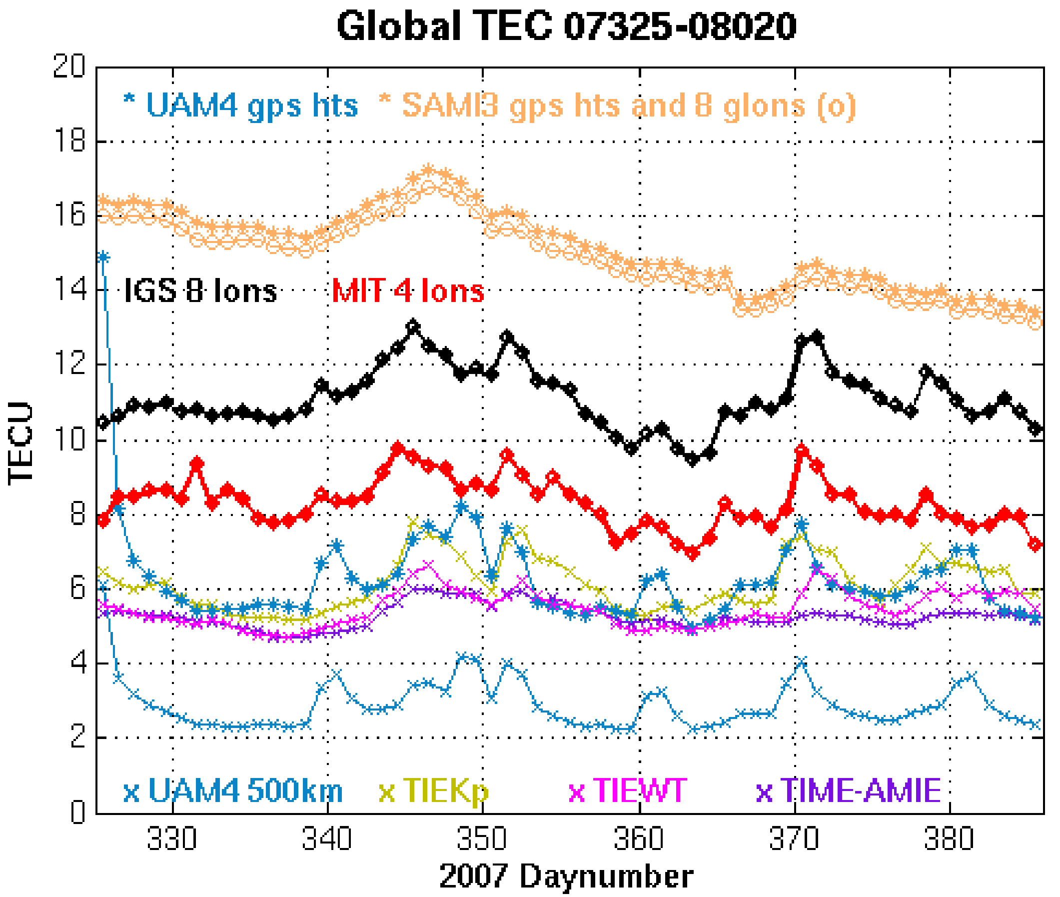
Choose 8 Longitude Slices from GPS TEC



5 deg lat and 5 deg lon bins for 20 min in December solstice 07355. Longitudes chosen: 25E, 90E, 140E , 175E, 200E (160W), 250E (110W), 285E (75W), 345E (15W).

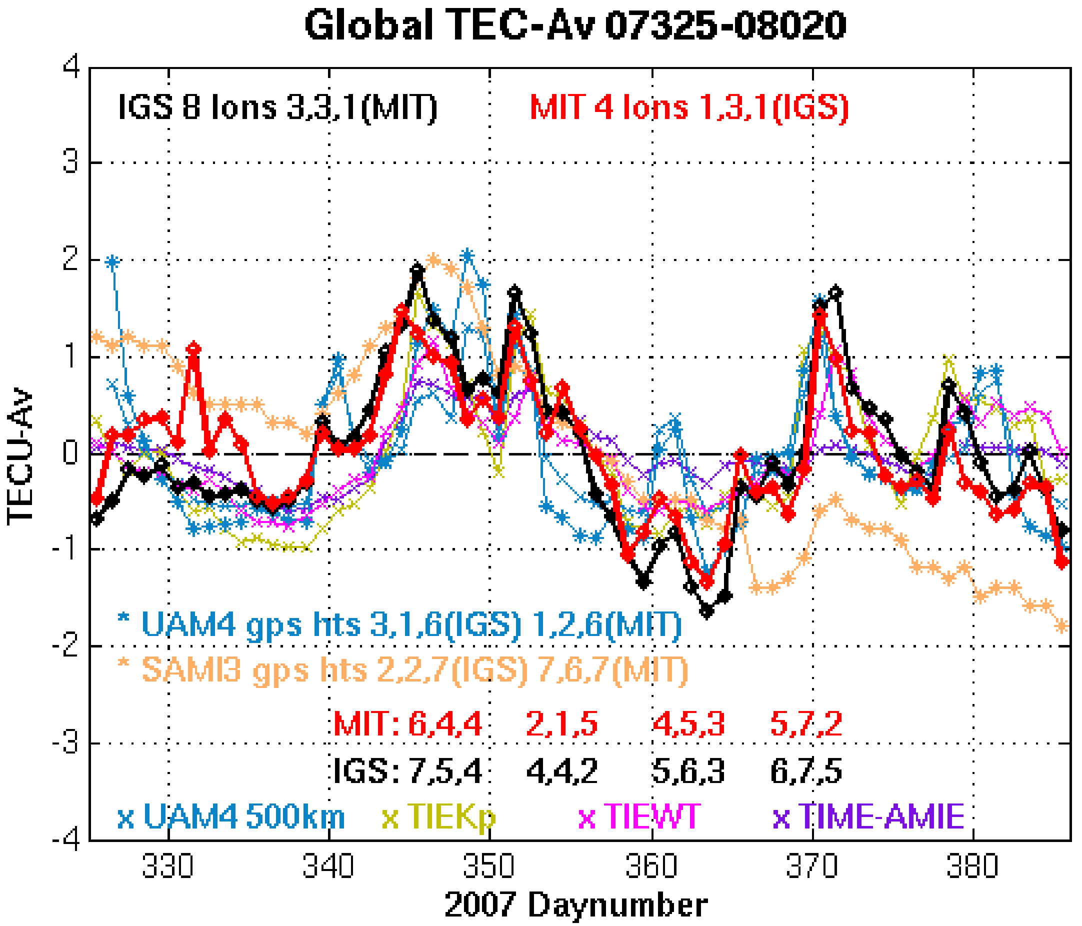
Global TEC





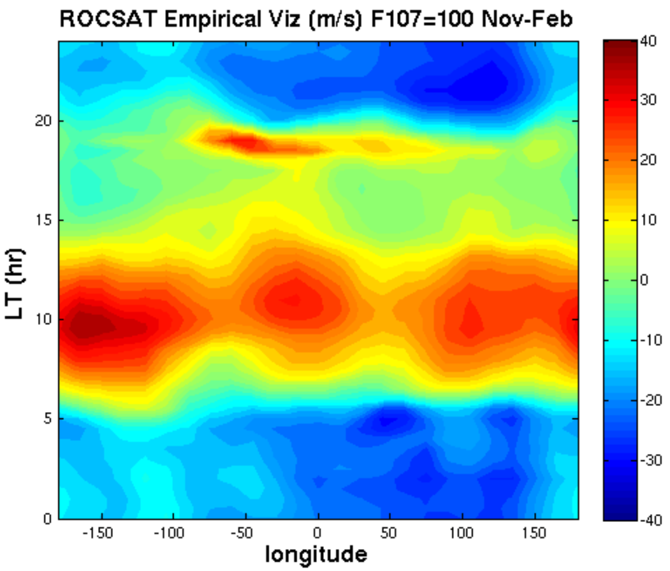
Average the 8 glons for IGS and the 4 'good' ones for MIT to get estimated global TEC from the data to compare with the models. There are obvious differences in TEC baselines, where the two UAM4 lines show approximately 3 TECU between 500 km and 20,100 km.

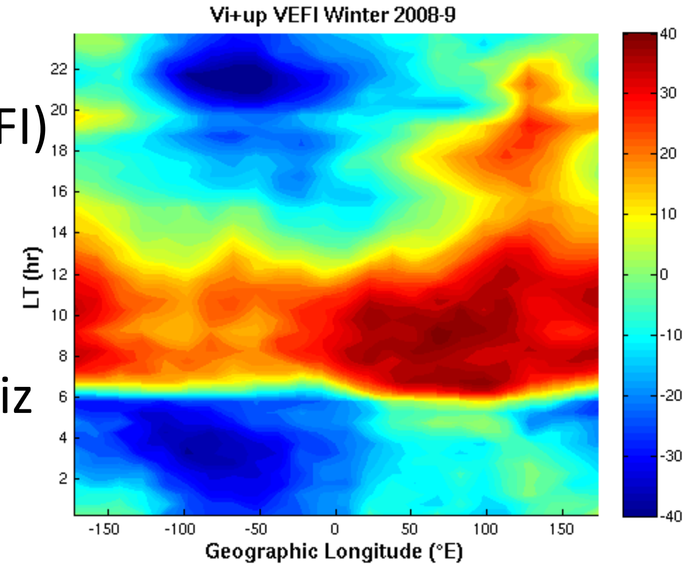
Global TEC Minus Averages



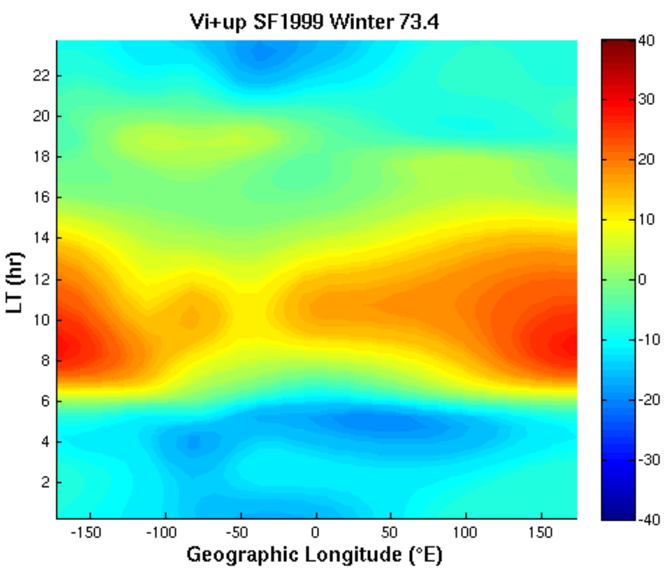
Using the metrics of baseline, range and RMS, the rankings for the 6 models and data are listed as before. For IGS, the total rankings are: (1) MIT obs, (2a,b) UAM4 gps and TIEKp, (4) SAMI3, (5) TIEWT, (6) UAM4 500km, (7) TIME-AMIE. For MIT, the total rankings are: (1) IGS obs, (2) TIEKp, (3) UAM4 gps, (4) TIEWT, (5a,b) TIME-AMIE and SAMI3, (7) UAM4 500 km. SAMI3 shows clearly a decrease in the magnitude over winter.

Low Latitude Vertical (Meridional) Ion Drifts from C/NOFS

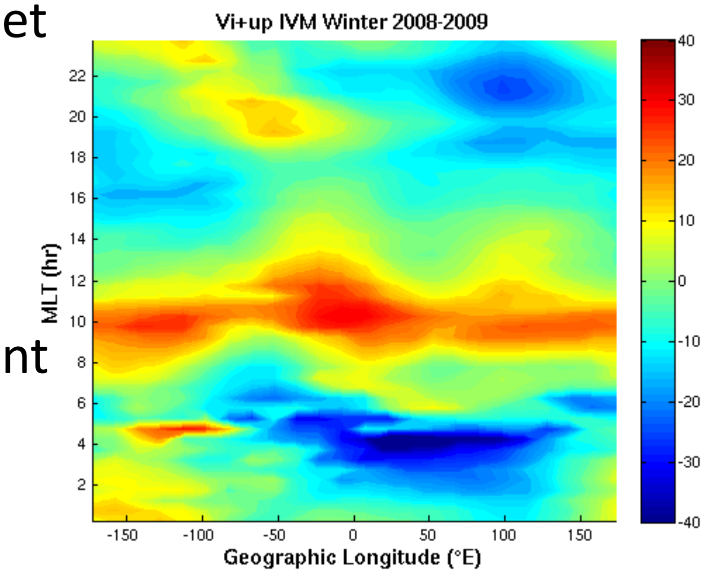




The Vector Electric Field Instrument (VEFI) and IVM both measure the upward (meridional to B or Viz) ion drifts. The Viz from VEFI is larger than from IVM, and previous work by Su et al [2012] shows PLP Ne observations are best matched using IVM Viz. The Pre-Reversal Enhancement (PRE) after sunset is not strong in these Nov-Jan solar minimum (F107~69) observations.



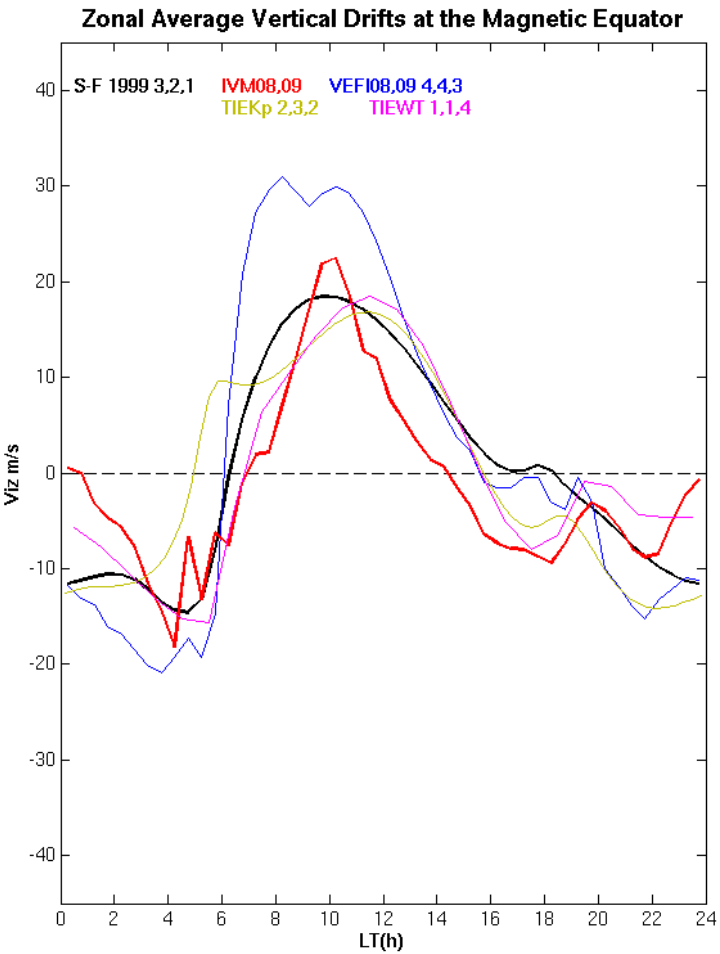
Scherliess and Fejer [1999] low-latitude model Viz.

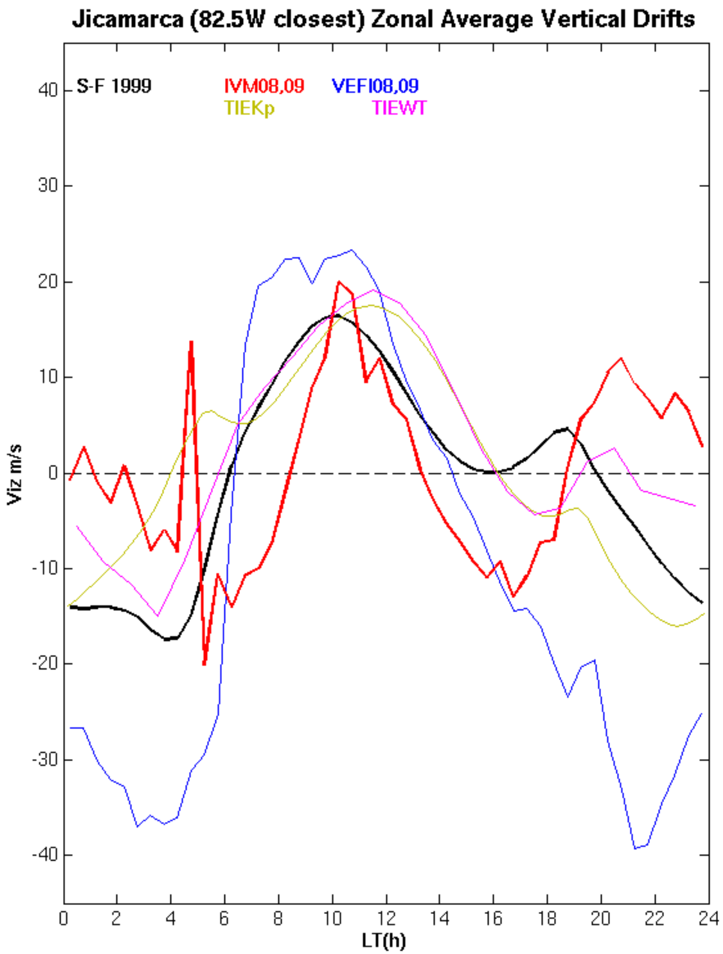


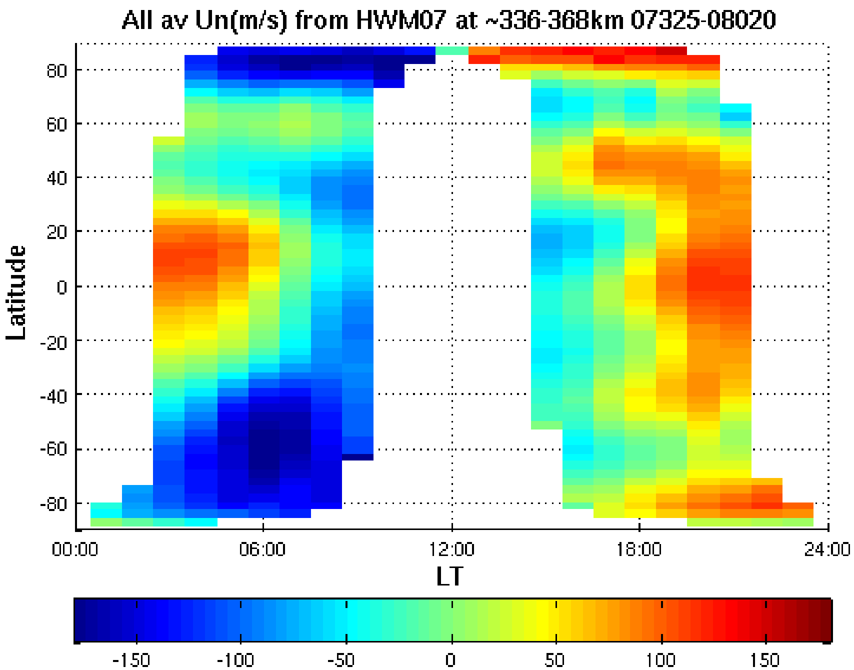
Low-Latitude Viz Metrics

The ranking for the metrics of baseline (close to zero), range and Viz-Av RMS are listed after each model where: (1a,b) SF 1999 and TIEWT, (3) TIEKp and (4) VEFI Viz obs. The order is unchanged with range corrections in the RMS.

Jicamarca at the magnetic equator and 76W has a stronger pre-reversal enhancement after sunset.

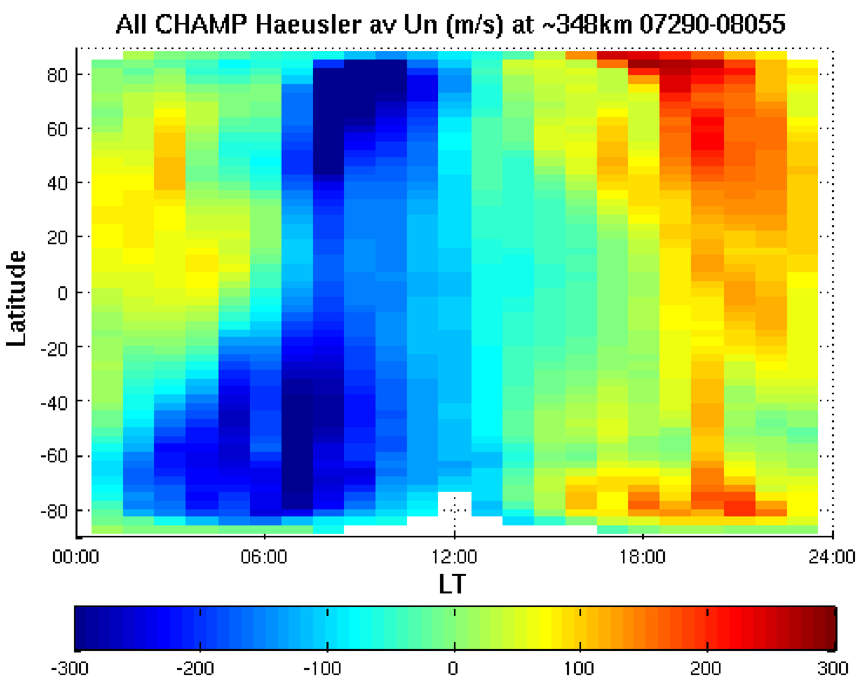




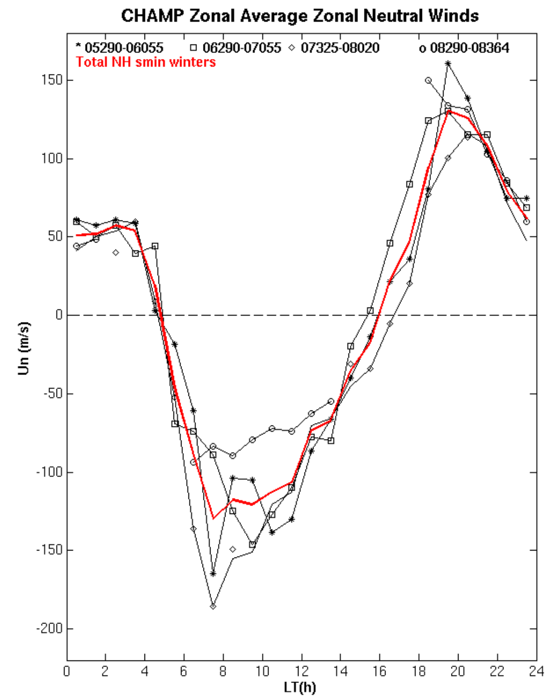


CHAMP Zonal Neutral Winds

The CHAMP satellite measures the cross-track neutral winds (~Un), which in legacy outputs, are good from 2001-2008. Here are the plots of the observed Un and those from HWM07 for 07325-08020 (61d), and CHAMP Un expanded 131 days.

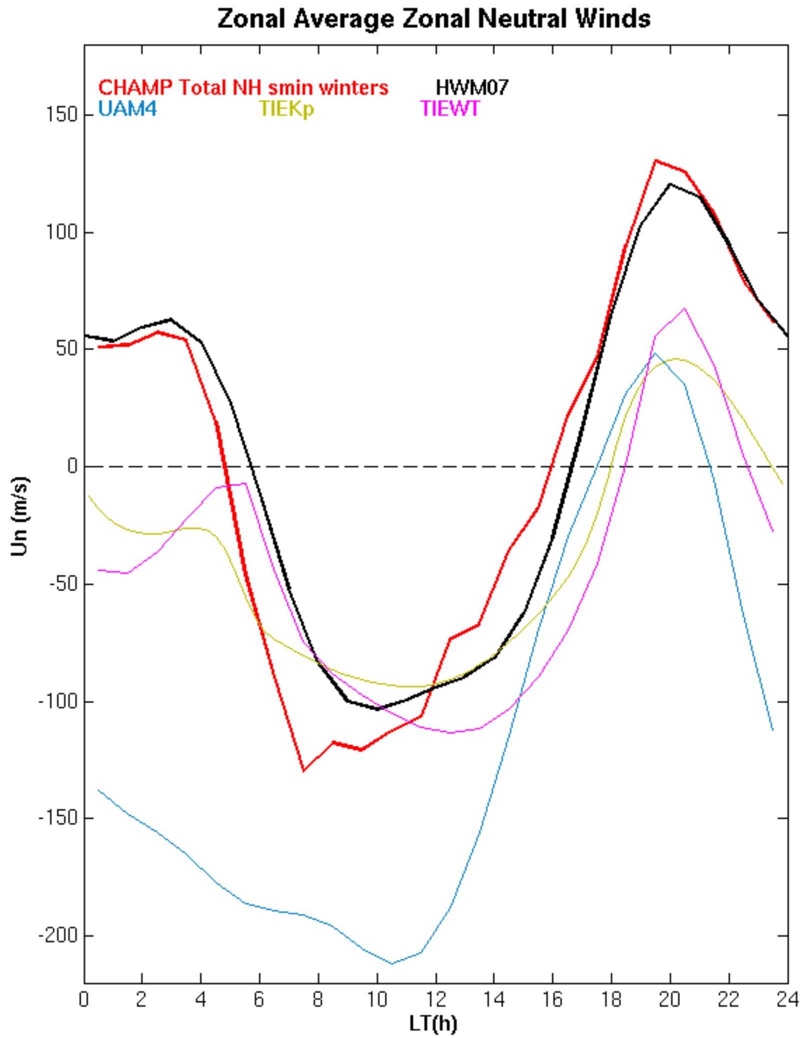


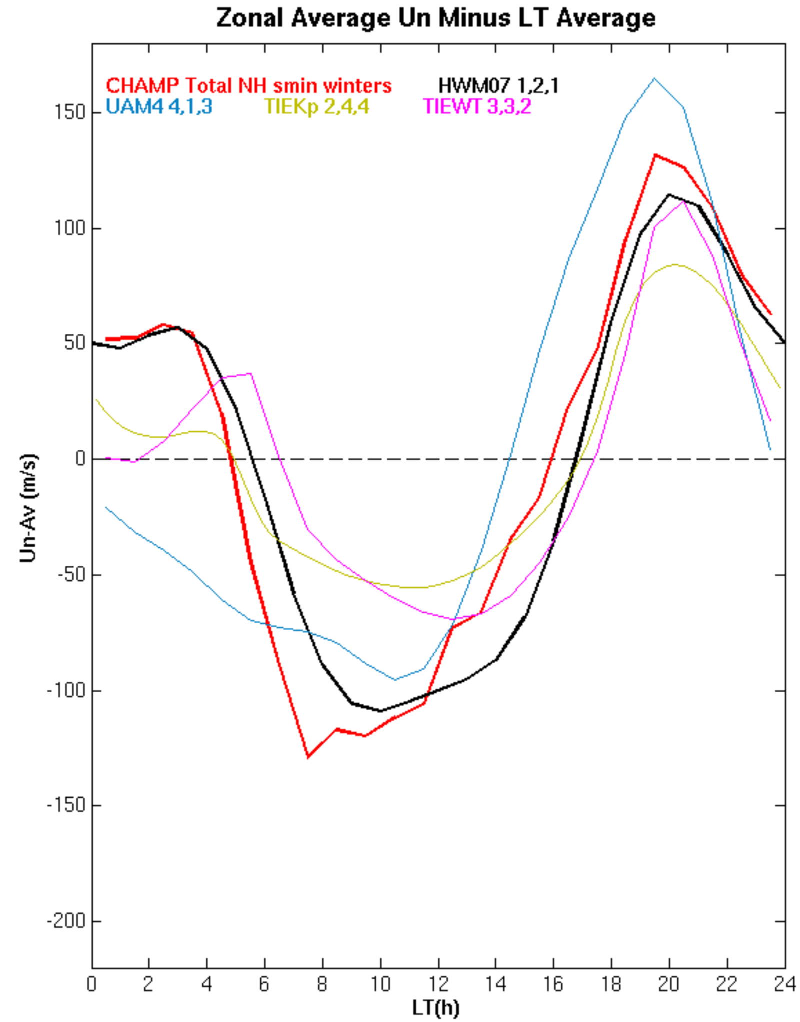
Four solar minimum winters from 2004-2008 from +/-13glat were averaged to compare with C/NOFS satellite observations.



Low-Latitude Un Metrics

The ranking for the metrics of baseline, range and Un-Av RMS are listed after each model where: (1) HWM07, (2a,b) UAM4 and TIEWT, (4) TIEKp





Dec 2012 Summary of the CCMC Climatology Study

- If there are baseline uncertainties, the metrics must compare values minus some average. The 3 metrics used were:
  - Baseline (ave over LT or 61-d becomes AV used in RMS)
  - Range (max-min can become R in RMS)
  - Root-Mean Square (RMS) sqrt[sum{(obs-Avob)*Rm/Rob-(mod-AVm)}^2/N] where Rm/Rob used for Viz did not change the ordering
- Count 3 metrics as:
  - Sum of rankings (not as precise)
  - Sum of abs values (emphasizes unknown baseline or poor range)
  - Sum of rel values |AVob-AVmod|/Avmod + |Rob-Rm|/Rm + RMS
- Model rankings changed with parameter studied or with different versions of the same parameter.
- The winter solar minimum study can include other NH winter solar minimum data since many ionospheric and thermospheric quantities remain about the same.
  - Used later C/NOFS satellite observations at low latitudes (2008-2009 IVM and PLP or 2008-2010 VEFI)
  - Used expanded CHAMP observations (2005-2008)

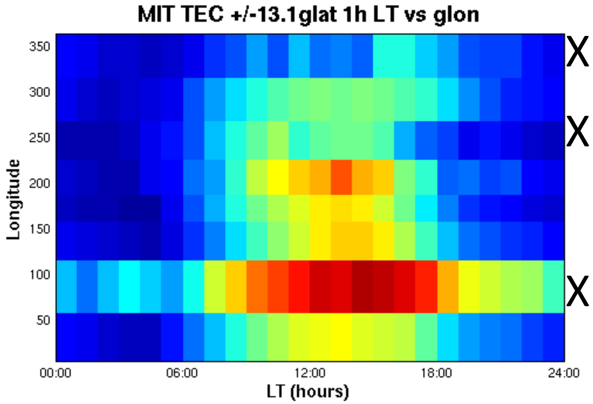
Low Latitude TIEGCM Climatology Studies

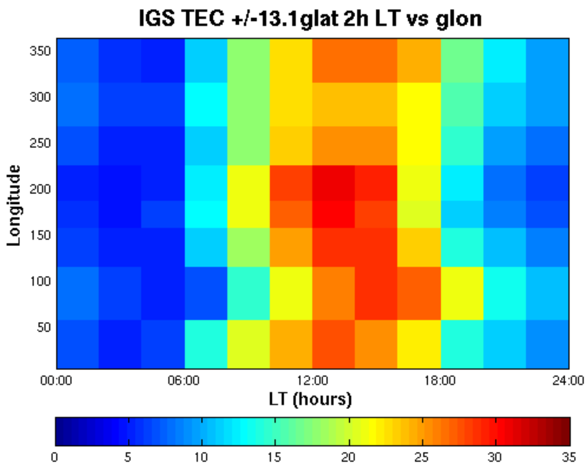
1) Expand data sets and add March and solar medium conditions.

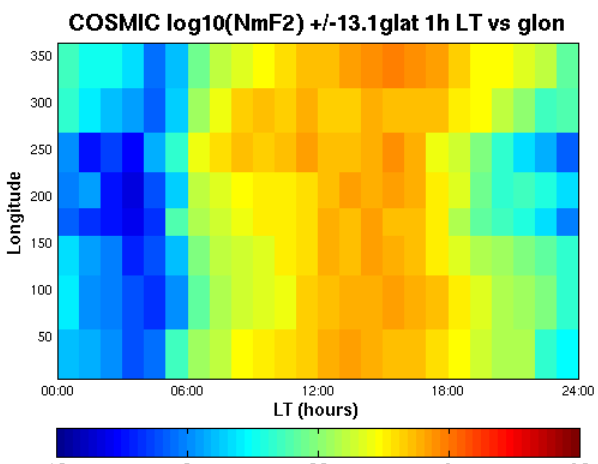
2) Look at zonal means of neutral zonal wind as a function of latitude.

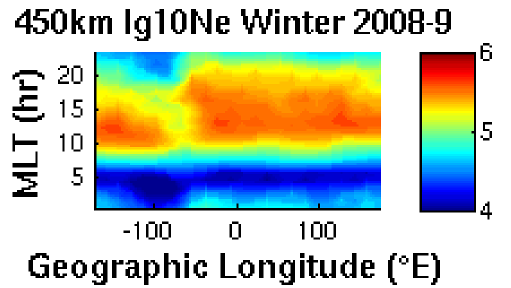
3) Look at different lower boundary conditions (lbc) where tides are especially important during low latitude, solar minimum, quiet conditions.

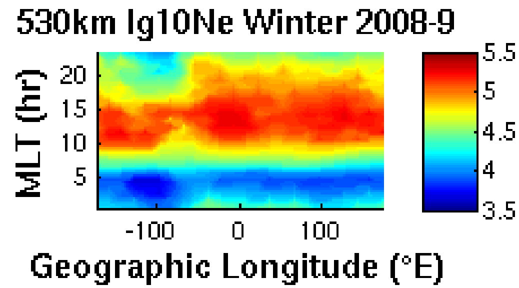
Average +/-13.1glat for LT vs Longitude and compare to C/NOFS PLP Ne with 3 peaks from DE2 waves from the lower atmosphere. The PLP Ne minimum at -80 (or +280E) shows in all but MIT TEC (but MIT is poor for 90, 250, 345E), but PLP peaks ~ 120E, 210E and 340E are best seen in hmF2.

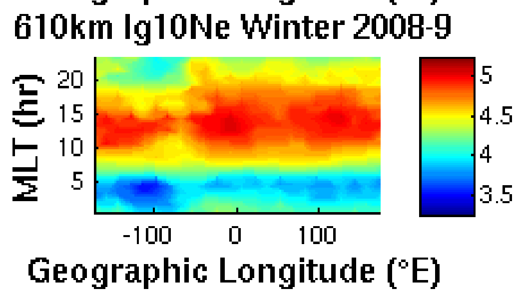


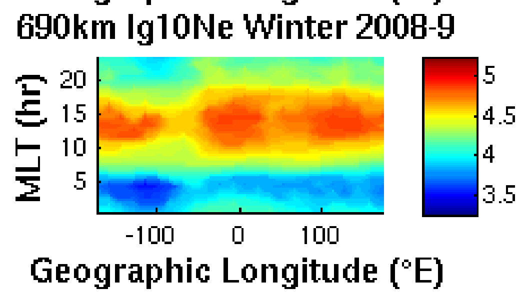


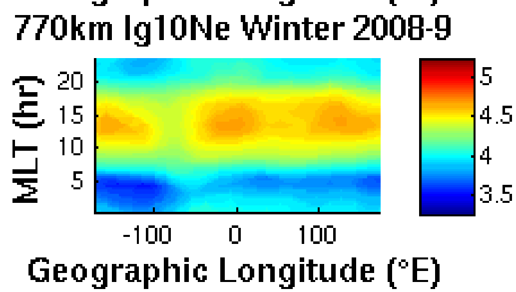


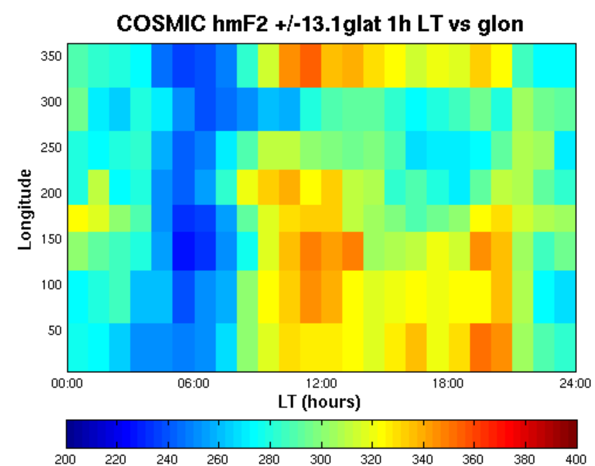




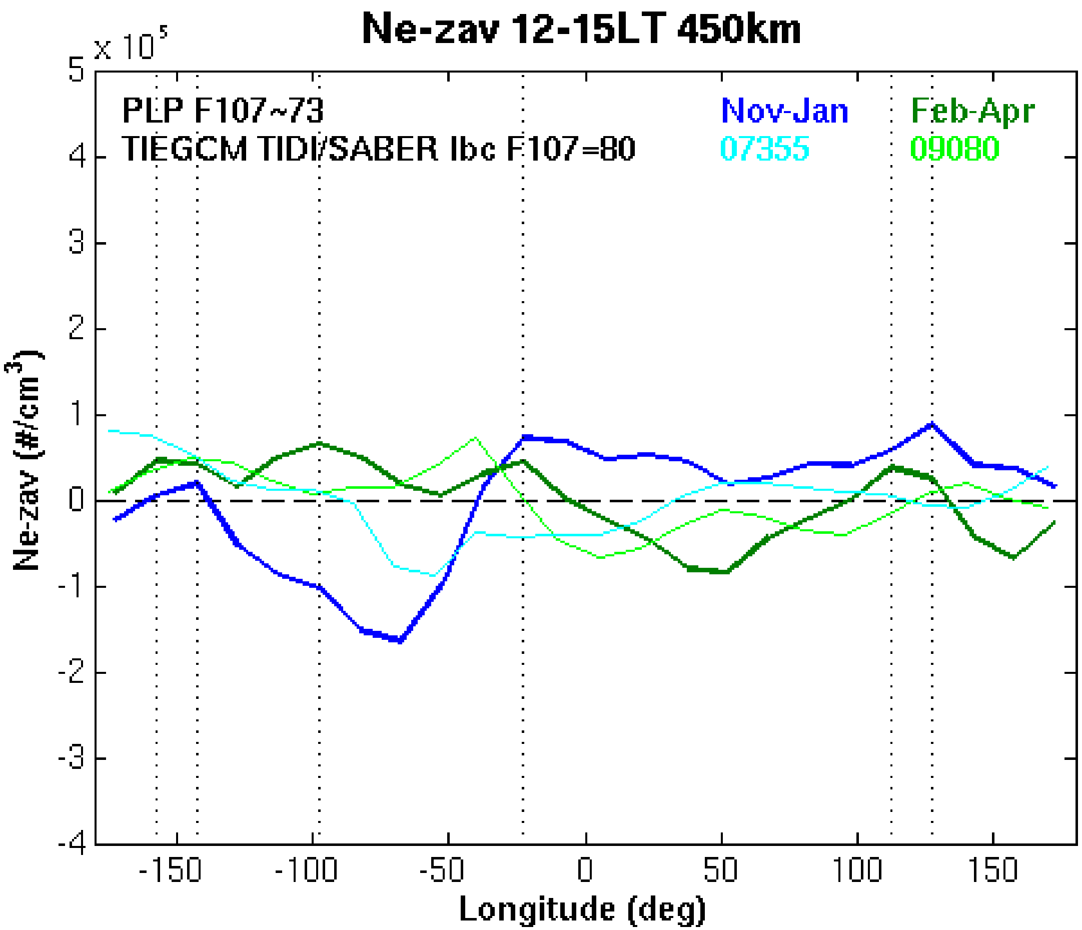








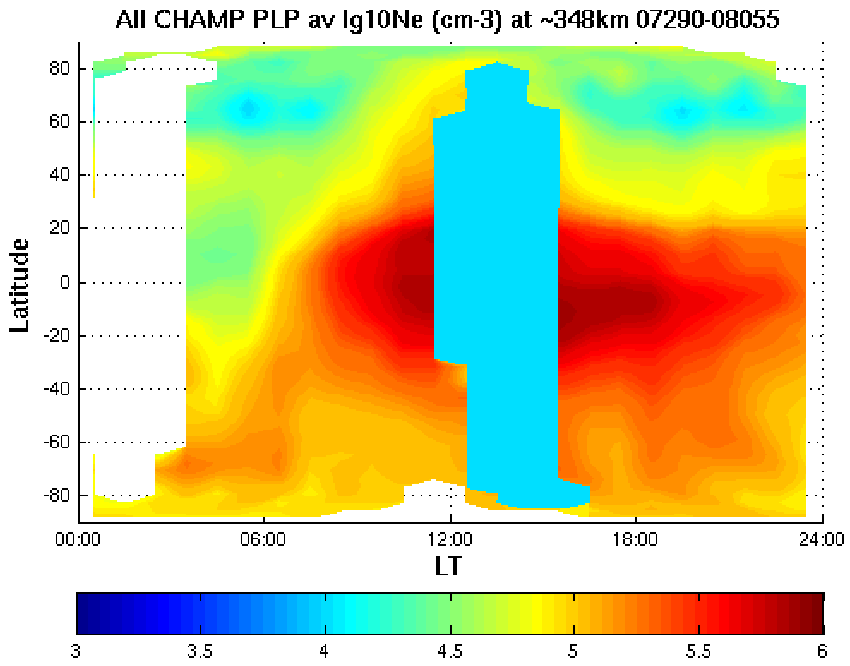
12-15 LT Ne minus zonal ave at 450 km from C/NOFS PLP and from TIDI/SABER LBC Tides

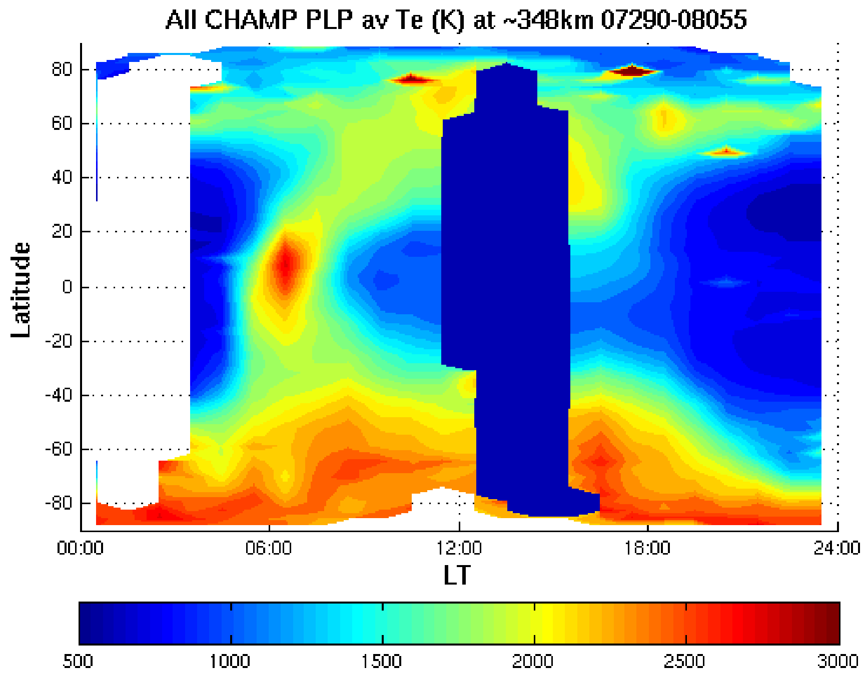


The TIEGCM can be run in double resolution using TIDI/SABER tides for the lower boundary condition (lbc) ~97km. These runs for specific solar minimum days similar to the C/NOFS PLP periods show 3 peaks in Ne ~450 km for December and 4 peaks in March similar to the data. However, the peaks at 50E in the TIEGCM are near a minimum in the C/NOFS data.

CHAMP Ne and Te

Oct 17 2007-Feb 25 2008

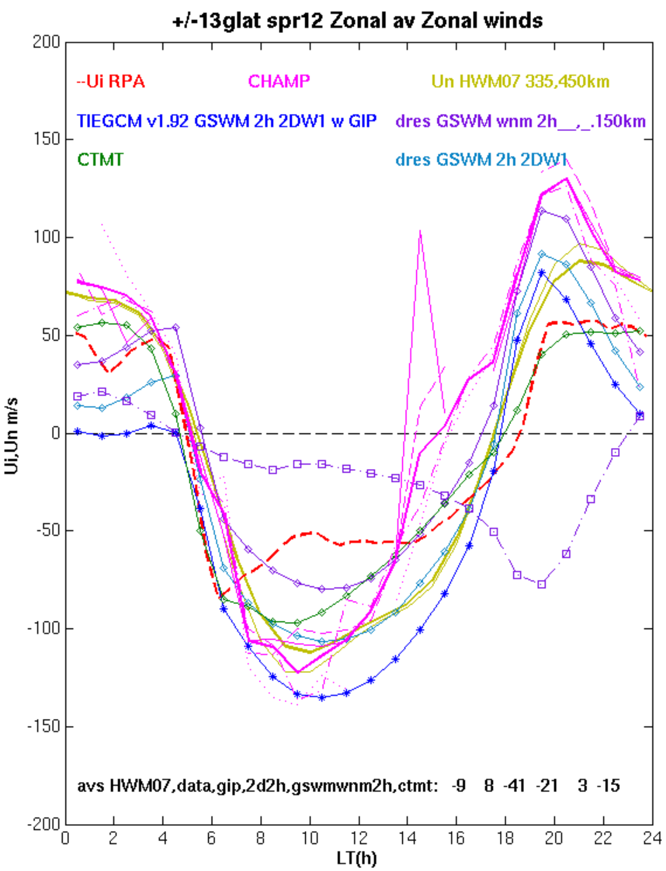


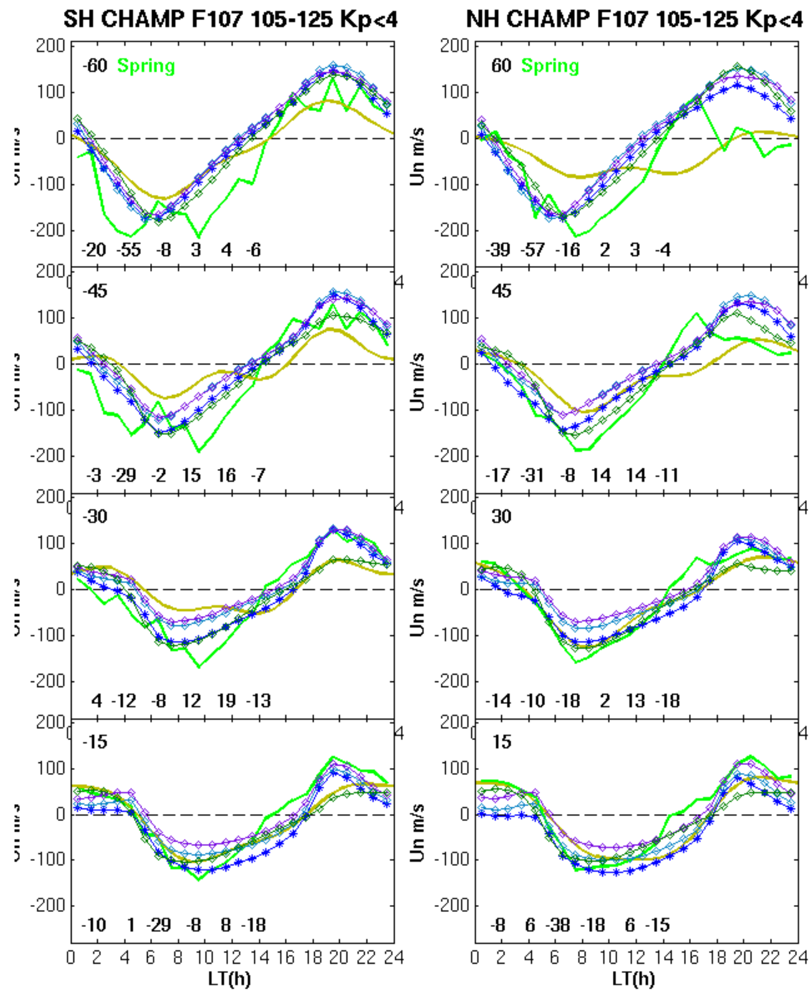


The CHAMP satellite requires 131 days to cover all local times. The PLP data here are for the 2007 December solstice solar minimum period. For the climatological studies, the data were separated into Kp bins (0-2 and 2-4), and into F107 bins. Zonal averages between +/-13 glat were used to compare with the C/NOFS data and TIEGCM results.

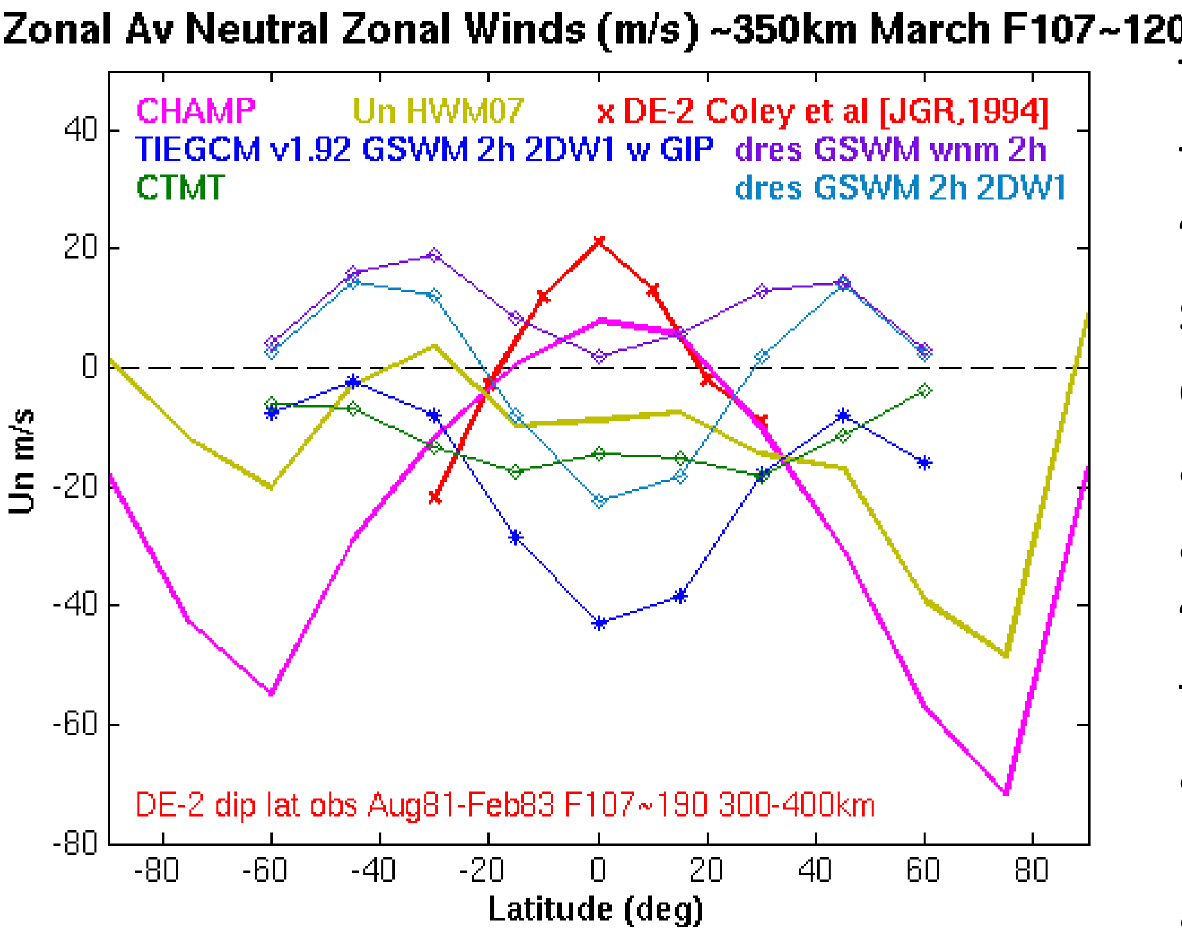
Feb-Apr 2012 Neutral Zonal Winds

The v1.92 GIP Un ~375km are the most westward +/-13glat, and v1.94 GSWM w nm most eastward, with 150km winds opposite sign post-sunset. The 97km (lb) geopotential heights need to give more westward winds at +/-45,60 glat.





March Un Zonal Means ~375km

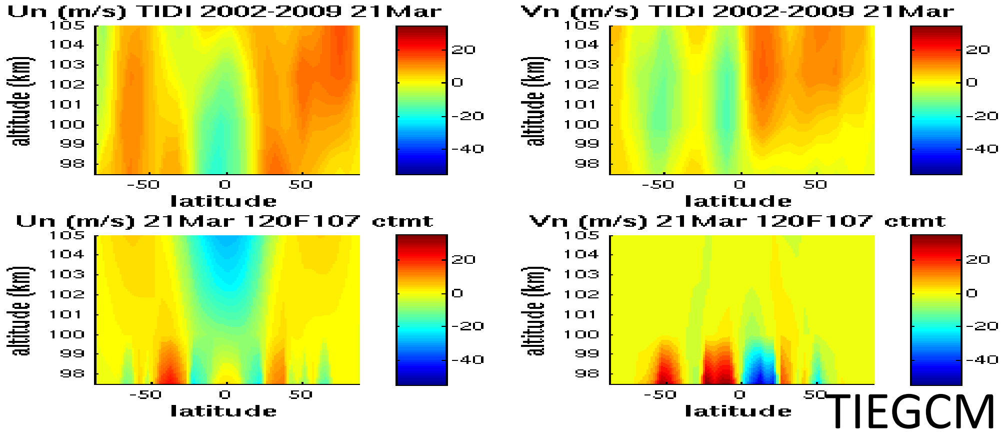


The CHAMP zonal means for the zonal neutral wind ~375km show superrotation (+E) at the equator and subrotation at higher latitudes (same as a Lieberman study to ~1.5m/s) and similar to the DE-2 study of Coley et al. [1994]. All the TIEGCM runs with GSWM tides show a minimum at the equator, while CTMT tides (dark green) have a secondary maximum at the equator.

The tides and mean winds near the lower boundary of the TIEGCM must change to get agreement.

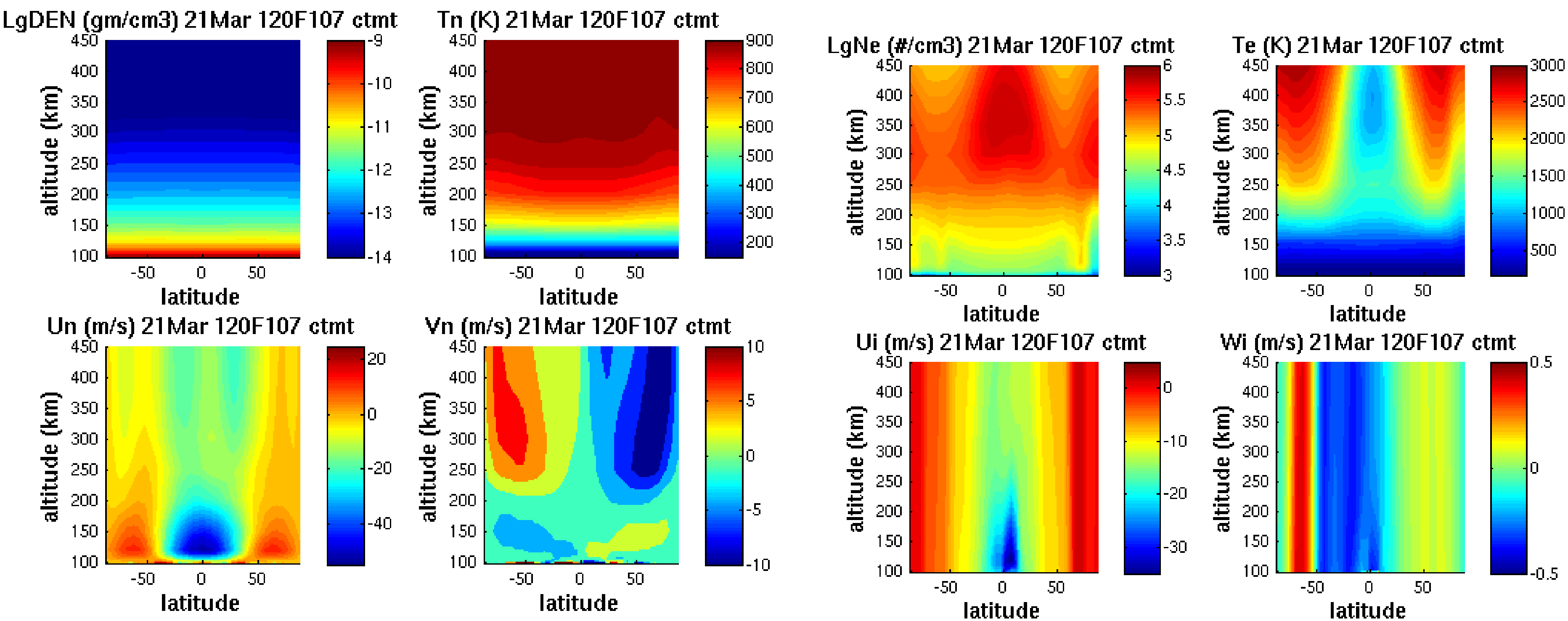
Nudging TIEGCM with CTMT Tides and Zonal Means in March

TIDI

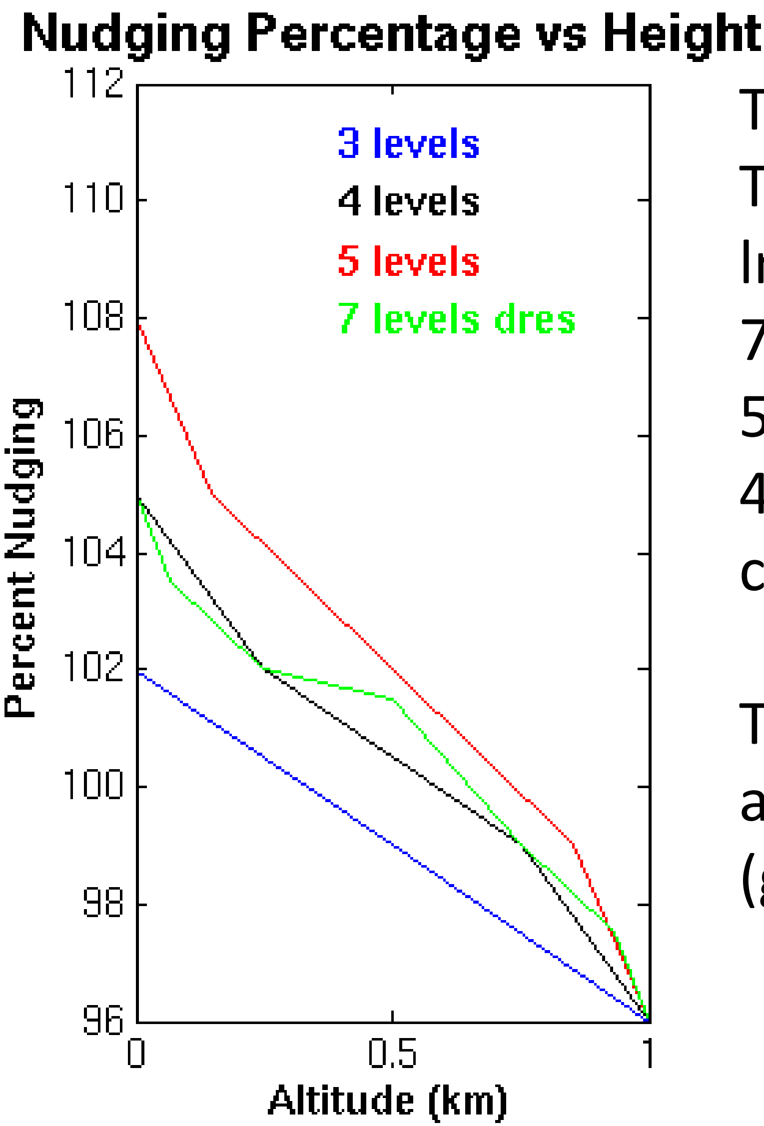


At equator using only lbc, Un and Ui are neg – unlike obs. Zonal means (zm) for nudging come from MSIS00 for density percent perturbations and Tn, and from TIDI for Un and Vn.

TIEGCM



Nudging Pressure Levels in the TIEGCM

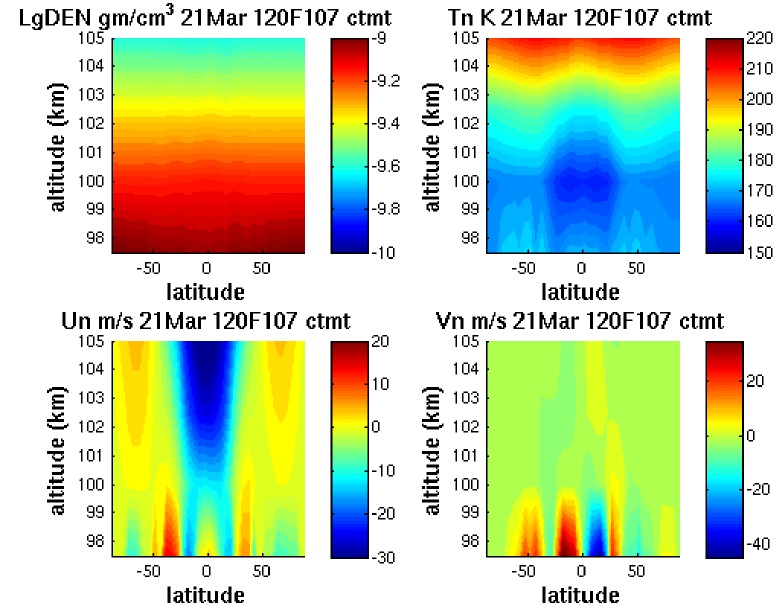


There are 29 pressure levels in the TIEGCM from -7 to +7 every 0.5 of ln(p/p0), where the first 7 levels are: -7.0 ~96km, -6.5 ~99km, -6.0 ~102km, -5.5 ~105km, -5.0 ~108km, -4.5 ~112km, -4.0 ~120km. The nudging parameter for ctmt_nlev pressure levels is:

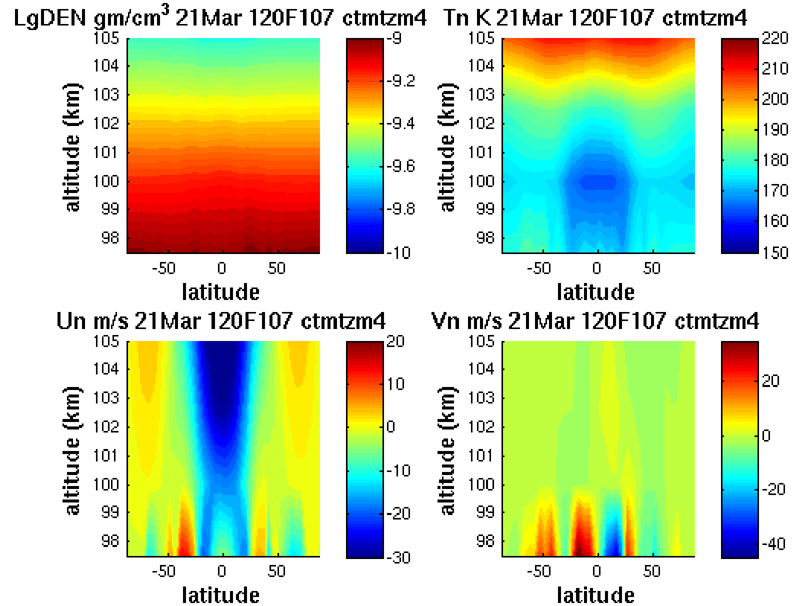
cos(90*(zp(i)+7)/(zp(ctmt_nlev)+7)

Tried ctmt_nlev=4 for single resolution and ctmt_nlev=7 for double resolution (green, dres).

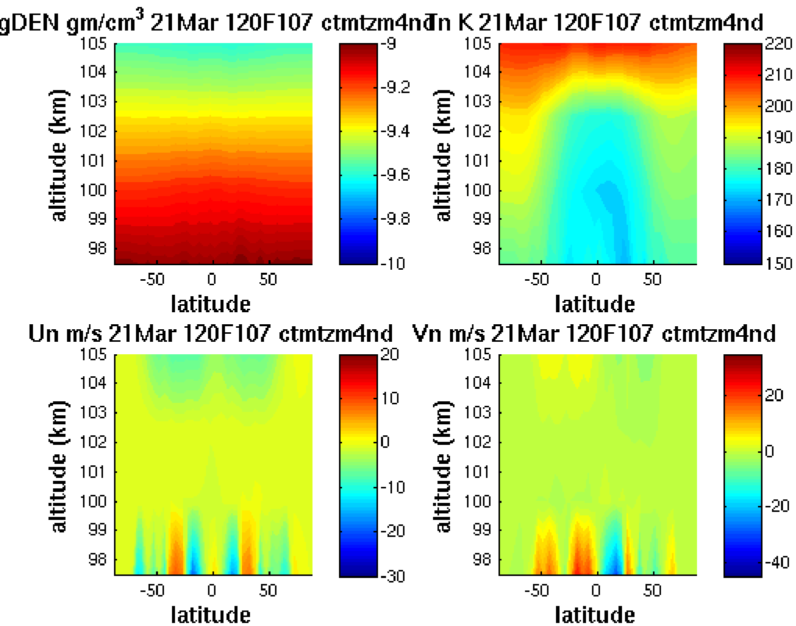
Zonal Means from TIEGCM-CTMT



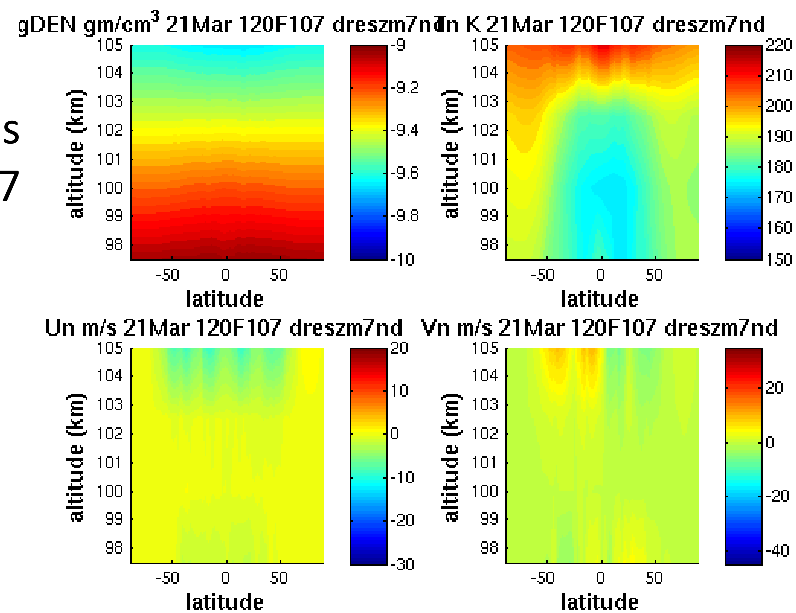
Reg lb



Lb+zm



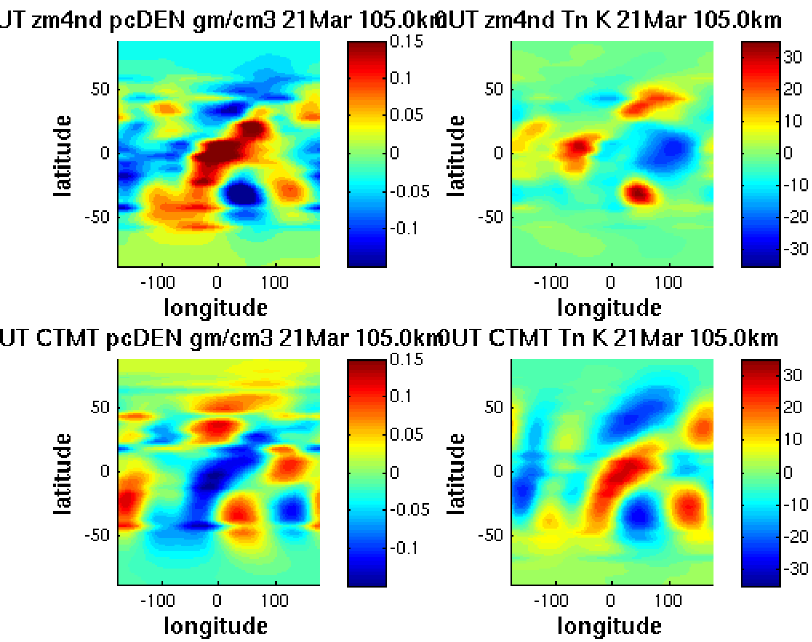
Dres
nlev=7



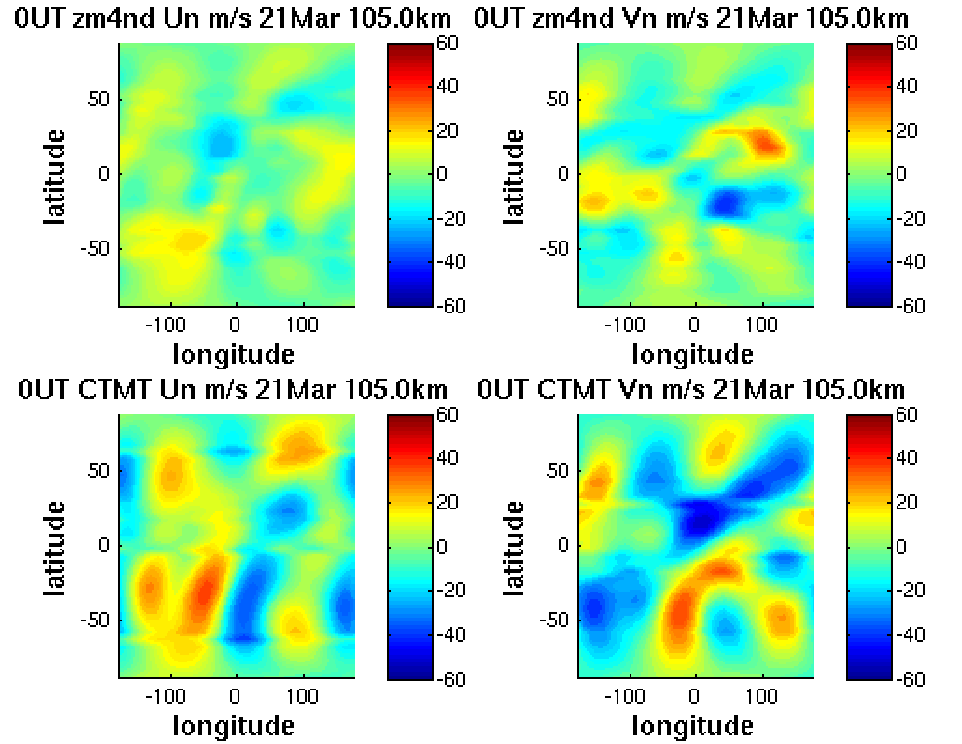
Nudging
nlev=4

Nudging 4 levels (actually 3)

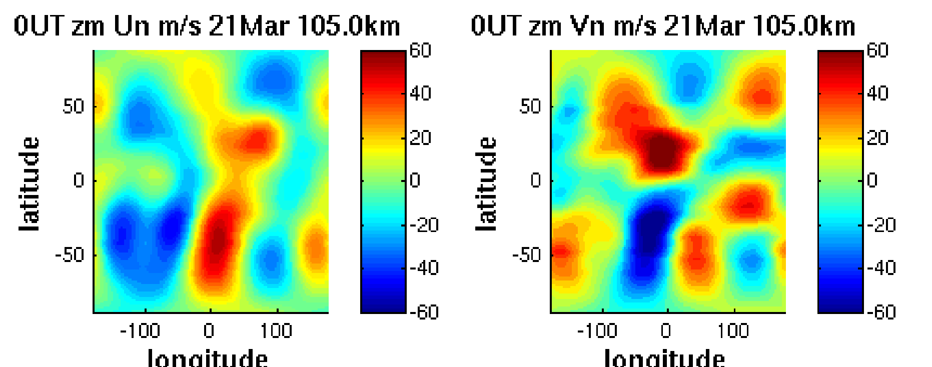
Density and Tn are still out of phase from CTMT at 105km.



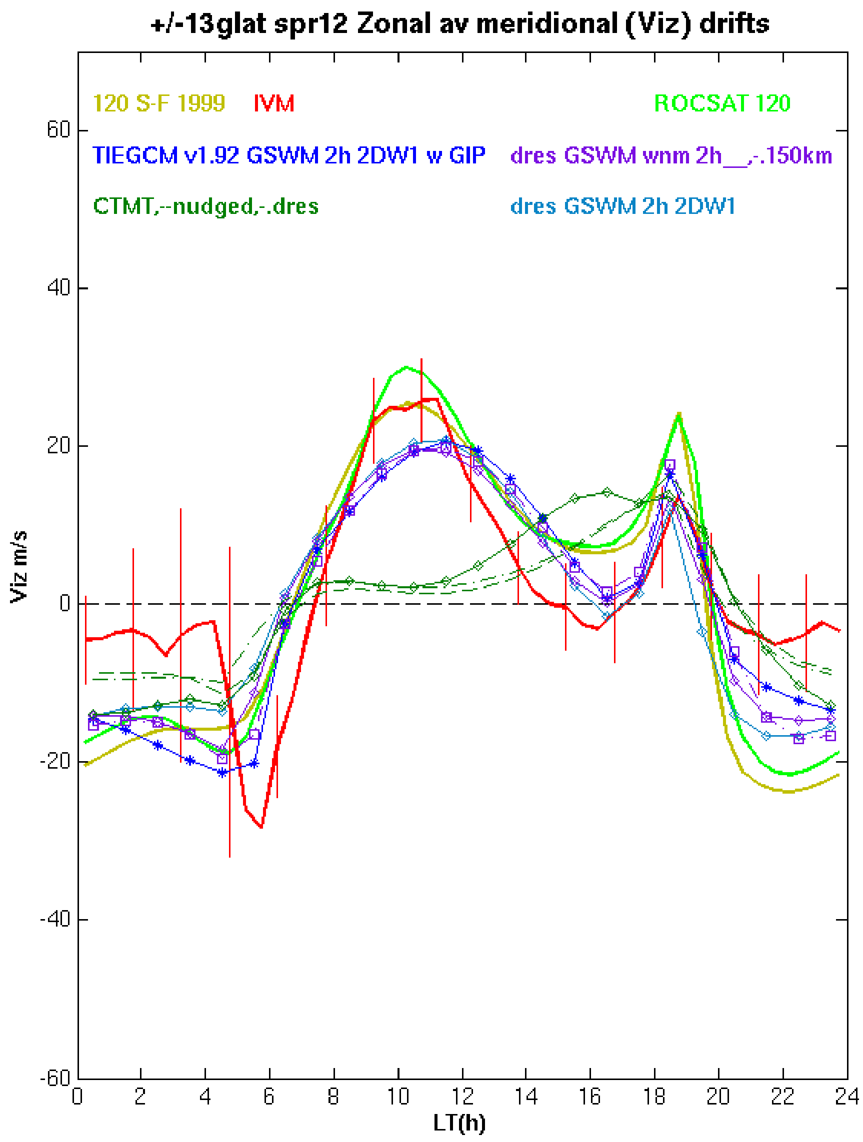
Un and Vn similar to CTMT at 105km



Lbc+zm from before shows Un and Vn 4-6 hours out of phase at 105 km from CTMT



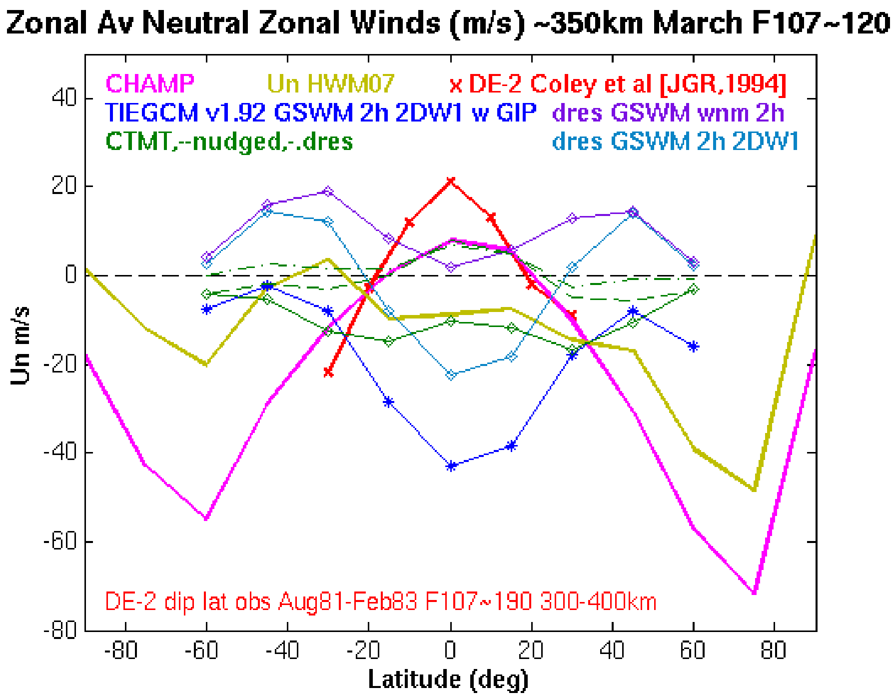
Zonal Mean Viz at Equator



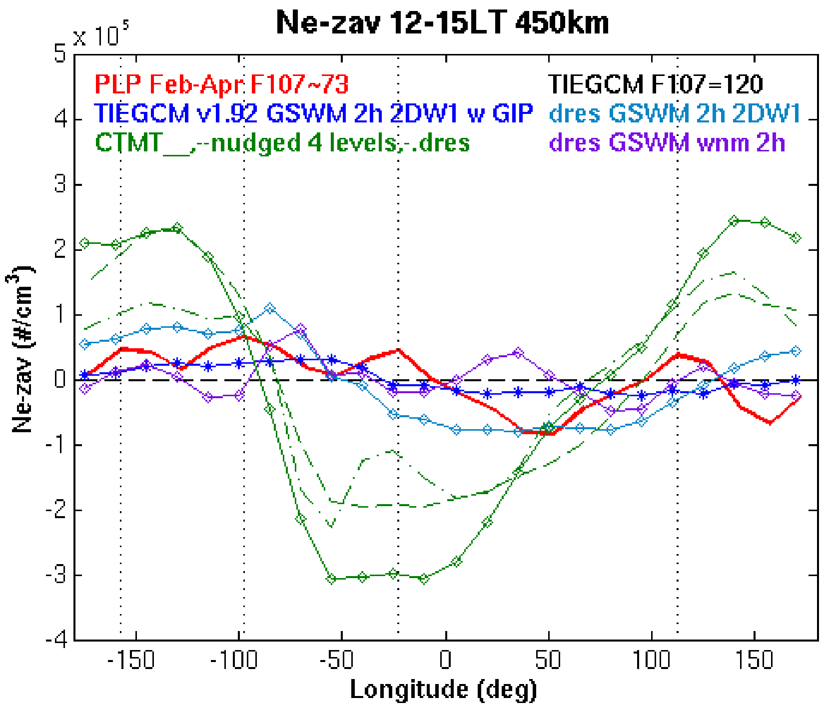
Need to get Viz right!

-Nudging with CTMT in dashed dark-green is improved from just lbc (solid green with diamonds) and double resolution (dres _.) to 105 km for ctmt_nlev=7 is nearly the same.

450km with Nudging



Un zonal means at 450 km are much improved with nudging to 105km where they match CHAMP in the low latitude superrotation.



Ne from 12-15LT between +/-15glat vs glon nudging to 105km is similar to the lbc CTMT for single resolution (5 deg grid --), but the 4 peaks in the data are present in the double resolution (2.5deg grid -.) solution.

Summary of Matching TIEGCM and Data in Low-Latitude Climatology

- “Seasonal” Climatology studies of quiet, low to medium solar flux can use data from different years, where “seasonal” means specific months, not “winter” or “summer”.
- If Viz is not matched at low latitudes, nothing else matches well.
- The TIEGCM-GIP results are similar to TIEGCM alone, but have a higher PRE (better match to data).
- It is hard to match both Te and Ne.
- Propagating tides (and geopotential heights) from the lower atmosphere help to drive Viz, produce low-latitude longitude peaks in Ne etc, and set the latitude structure of the neutral zonal wind.
    - Lower boundary GSWM with non-migrating tides or SABER/TIDI tides for specific dates are “best”.
    - TIEGCM does not propagate the tides properly between 97 and 105 km, where CTMT tides are 4-6 hours out of phase.
    - “Nudging” TIEGCM with Hough mode extensions of CTMT tides and mean values (MSIS,TIDI) has promise, but needs adjustment.

Future Plans

1) Compare low-latitude Ne in longitude for tidal signatures for other models in December.
2) Compare zonal means of the neutral zonal wind as a function of latitude for other models in December
3) Add GSWM 2009 for lower boundary and nudging for TIEGCM.
4) Consider expanding the CCMC climatology study to other months and solar fluxes to match the best data sources.