Looking at Low Latitudes – Remember the Tides

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Motivation

- Tides are produced by variations in water vapor and ozone in the lower atmosphere and propagate upwards to the thermosphere and ionosphere. Mean zonal westward winds can hinder their upward propagation.

- Longitudinal structure in low latitude vertical ion drifts, electron densities, neutral winds, ion drifts, and many other quantities are often caused by tides.

- Studies by Hanli Liu using MERRA/WACCM-X/TIME-GCM reproduced about 50% of the observed variability of NmF2 when day-to-day variations in the tides and mean winds were introduced in the lower atmosphere, nudging the TIME-GCM from 30-90km. Fuller-Rowell and Akmaev showed similar ionospheric variability caused by tides and gravity waves driving CTIPe with WAM.
Low Latitude Climatology

- Geomagnetic Quiet conditions in December (2008, 2009) and March 2012 in solar minimum (F107~73) and medium (F107~120) conditions

- NCAR Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGCM) was run with essentially no magnetospheric inputs, but variable tides (GSWM-Global-Scale Wave Model 2002 and 2009, CTMT-Climatological Tidal Model of the Thermosphere, TIDI/SABER) at the lower boundary around 94-99km (nominally 97km).

- Data sources:
  - 67-d Communication/Navigation Outage Forecast System (C/NOFS) satellite 400-800km electron density (Ne) and vertical ion drift (Viz)
  - 131-d CHAllenging Minisatellite Payload (CHAMP) 325-425km neutral zonal winds
Zonal Means in The Lower Thermosphere
(~Truth from MSIS00 and TIMED/TIDI)
There are 29 pressure levels in the TIEGCM from -7 to +7 every 0.5 of \( \ln(p/p_0) \), where the first 7 levels are: -7.0 \~ 96\,km, -6.5 \~ 99\,km, -6.0 \~ 102\,km, -5.5 \~ 105\,km, -5.0 \~ 108\,km, -4.5 \~ 112\,km, -4.0 \~ 120\,km. The nudging parameter for \texttt{ctmt\_nlev} pressure levels is:

\[
\cos(90\times(zp(i)+7)/(zp(\texttt{ctmt\_nlev})+7))
\]

Tried \texttt{ctmt\_nlev}=4 for single resolution and \texttt{ctmt\_nlev}=7 for double resolution (green, dres).

Nudged: \( T_n, V_n, U_n \) (not neutral density)
Compare ‘Nudging’ with ‘Truth’

CTMT temperature is ‘best’ and GSWM09 winds are ‘best’.
Nudging 4 levels (actually 3)

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

Un and $V_n$ similar to CTMT at 105km

CTMT Fit to obs

Lbc+z from before shows Un and $V_n$ 4-6 hours out of phase at 105 km from CTMT

Out zm4nd $U_n$ m/s 21Mar 105.0km

Out zm4nd $V_n$ m/s 21Mar 105.0km

Out CTMT $U_n$ m/s 21Mar 105.0km

Out CTMT $V_n$ m/s 21Mar 105.0km

Out zm Un m/s 21Mar 105.0km

Out zm $V_n$ m/s 21Mar 105.0km
GSWM02 migrating (DW1 and SW2) tides were used in the TIEGCM v1.94 (cyan) and adjusted (blue, *2 amp, -2h phase) at the 97km lower boundary (lb). The adjusted tides did not give a Pre-Reversal Enhancement (PRE) after sunset for F107=80.

Using TIDI/SABER tides at the lb (green), gave the best Viz.

Upward/downward Viz leads to increased/decreased Ne.
Use F107=120 and run TIEGCM v1.94 with 97 km tides for dres GSWM02 non-migrating tides with a 2 hour shift (purple), with 2*GSWM09 tides with a 2h shift (dark green), and with CTMT (TIDI/SABER) tides (cyan) with no shift. Dashed lines are the double resolution runs with nudging to ~105km.
C/NOFS PLP Ne for F107~73 shows 3 peaks ~13LT in Nov-Jan near 150W, 20W, 120E, with a fourth peak in Feb-Apr near 100W. 4 peaks are from DE3 from the lower atmosphere. In-situ non-migrating tides from the offset of the magnetic field and hence ion drag can give 2 peaks (DE1,S0), 3 peaks (DE2,SE1), and 1 peak (DW2,D0,SW3,SE1) from Jones et al. [JGR, 2013].
12-15 LT Ne minus zonal ave at 450 km from C/NOFS PLP and from TIDI/SABER

LBC Tides

The best tides are specific daily 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 3-5 peaks in Ne ~450 km for December and March similar to the data. However, the peaks at 50E in the TIEGCM are at a minimum in C/NOFS data, but close to a minor max at 22E.
12-15 LT Ne minus zonal av at 450 km

Only GSWM with non-migrating tides (purple) has 4 peaks in March and December from DE3 for Ne at 450 km. The single resolution CTMT (cyan) and GSWM09 (dark green) tides at the lower boundary have approximately 1 peak, where their double resolution nudged runs have multiple peaks where GSWM09 is ‘best’. DE3 is too big in the December GSWM02 run.
Zonal Neutral Winds - Superrotation at Equator

Average over +/-13glat of 4 solar minimum periods from Oct-Feb from 2004-2008 to compare with C/NOFS satellite observations.

Zonally averaged CHAMP winds as a function of latitude from Oct-Feb with F107 105-195 compared with DE-2 winds for 1.5 years F107 ~190.
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, similar to the DE-2 study of Coley et al. [1994]. All the TIEGCM runs show a minimum at the equator, and are mostly westward (subrotation).

Nudging the Un and Vn tides and mean winds to 105 km, show near zero zonal means, or slight superrotation – an improvement.
Summary of Tides in the TIEGCM to Match Data in Low-Latitude Climatology

- Propagating tides (and geopotential heights) from the lower atmosphere influence Viz and the latitude structure of the neutral zonal wind, and produce low-latitude longitude peaks in Ne etc for double resolution (2.5 deg) runs, but not for single resolution runs.

- Lower boundary double resolution GSWM09 with non-migrating tides doubled in amplitude and shifted 2 h earlier and nudged 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 and GSMW09 tides and mean values (MSIS,TIDI) improves the tides for Un and Vn at 105, but not Tn or density.

- Future: Use double resolution to investigate tides, nudge density also, and try nudging to 110 km.