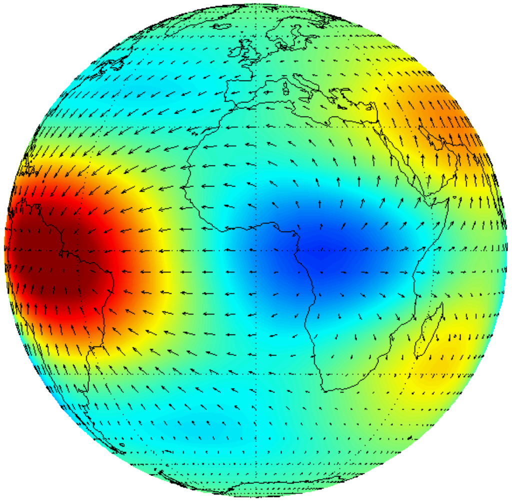
Climatological Tidal Model of the Thermosphere – CTMT



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With significant contributions from Jeff Forbes and others

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Climatology of upward propagating diurnal and semidiurnal tides in the thermosphere

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[1] A major challenge in delineating and understanding the "space weather" of the ionosphere-thermosphere system is the lack of global tidal observations in the 120–400 km "thermospheric gap" between satellite remote-sensing and in-situ tidal diagnostics. This paper aims to close this gap by presenting an observation-based Climatological Tidal Model of the Thermosphere (CTMT) of self-consistent upward propagating migrating and nonmigrating diurnal and semidiurnal tides from 80–400 km and pole-to-pole for moderate (F10.7 = 110 sfu) solar flux conditions. CTMT includes the 6 (8) most important diurnal (semidiurnal) tidal components for temperature, density, and zonal, meridional and vertical winds and is based on Hough Mode Extension fits to 2002–2008 mean TIMED satellite tidal diagnostics in the mesosphere/lower thermosphere (MLT). Validation with independent 2002–2008 CHAMP tidal diagnostics (F10.7 = 105 sfu) around 400 km proves that the approach captures nonmigrating tides well, indicating that these waves propagate directly upward without significant tidal forcing occurring in the thermosphere. Notable exceptions are the DW2 and D0 components that are most likely generated in-situ by nonlinear interaction forcing in the upper thermosphere. CTMT is suitable for driving upper atmosphere models that require self-consistent tidal fields in the MLT region as a lower boundary condition. It does not include migrating tides due to in-situ EUV absorption in the upper thermosphere but allows us to quantitatively assess thermospheric variability due to tides from the lower atmosphere. This is done by discussing longitude/latitude maps of reconstructed diurnal and semidiurnal tidal variations as function of altitude and local time.

Tidal "space weather" in thermosphere based on SABER and TIDI tides in MLT region

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CTMT – Basics

- **Arguments:** Position, time, solar radio flux
- **Output:** Upward propagating diurnal and semidiurnal migrating and nonmigrating tides; amplitudes and phases of temperature, density, horizontal & vertical wind; monthly mean climatology for 110 SFU and individual years; DW2, DW1, D0, DE1, DE2, DE3, SW4, SW3, SW1, S0, SE1, SE2, SE3
- **Domain:** Ground to exosphere, pole-to-pole
- **Physical constraints:** Thermospheric tidal equations with dissipation, mode coupling, no tidal forcing in thermosphere
- **Formulation:** Hough Mode Extension (HME) fits to observed temperature and wind tides from SABER and TIDI in the mesosphere/lower thermosphere
- **Validation:** CHAMP, WINDII, SABER IR emissions, GB data

http://myweb.clemson.edu/~joberhe/articles/ctmt.html (until July 1, 2016)
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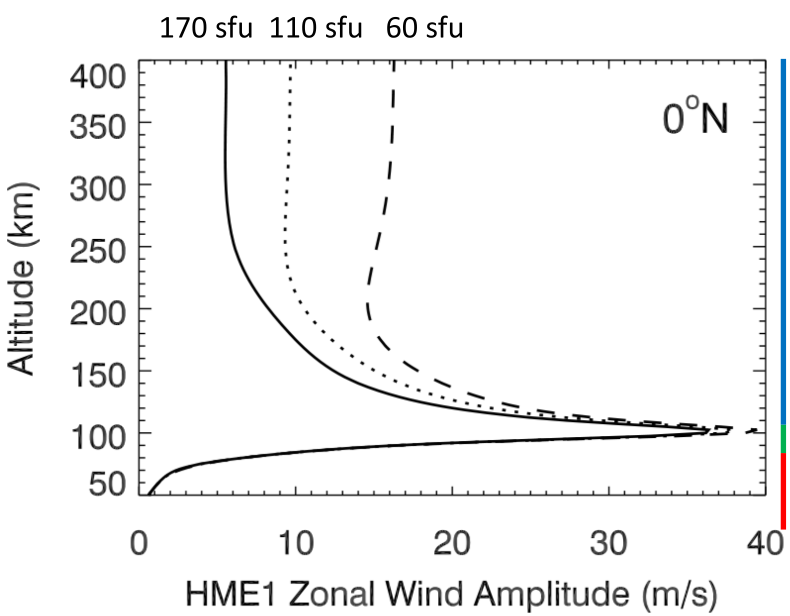
CTMT – History

- HME concept by Richard Lindzen et al. in mid-1970s
- Improved HME modeling by Jeff Forbes and Maura Hagan in 1982
- Comparison of theoretical HMEs with mainly radar obs in the 1990s
- First fits to satellite winds (HRDI @ 95 km) and demonstration of consistency with GCM results in 2005 by Svoboda, Forbes & Miyahara
- HME fits to SABER T and TIDI u,v DE3 tide in 2008 by Oberheide and Forbes -> consistency of SABER and TIDI DE3 tides
- CTMT formulation and validation with CHAMP in 2011 by Oberheide, Forbes, Zhang and Bruinsma
- ~130 citations of 2008 & 2011 papers

CTMT – Physical constraints

- Fitted to observed SABER T and TIDI u,v tides in MLT
- All tides forced below the MLT region, no tidal sources above MLT
- Tidal dissipation described by Rayleigh friction for GW drag, eddy diffusivity, Newtonian cooling, thermal conductivity, ion drag
- Distortions of tidal structures due to mean winds can be viewed as “mode coupling”, i.e., the excitation of higher-order tidal modes which combine together in a linear sense to approximate the distortion



No tidal sources in thermosphere

Large solar flux dependence due to molecular thermal conductivity ~$T^{2/3}$

Fit range to SABER & TIDI

Tidal sources

Effects of mean winds: mode coupling

CTMT – Formulation I

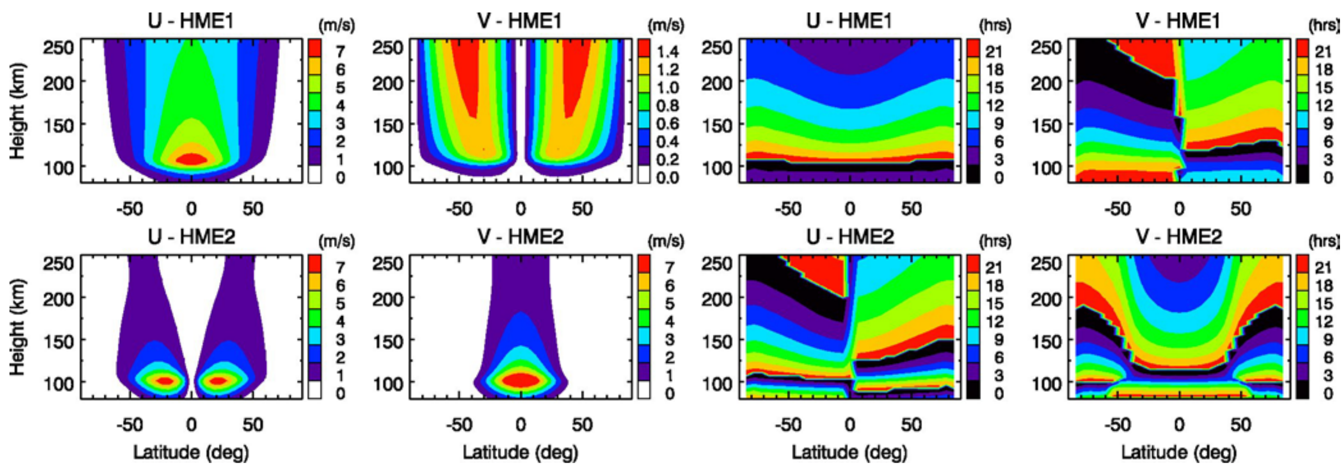
Hough Mode Extensions (HME) from "stripped-down" GSWM

- Replace forcing with arbitrarily calibrated classical Hough Mode
- Set background wind to zero, use solar flux dependent global mean T-profile from MSIS
- Keep tidal dissipation scheme
  -> 2-dimensional HME (lat/height) for T, u, v, w, neutral density
- Either 2 or 4 HME per tidal component

Example: Hough Mode Extensions for the DE2 tide

HME-1

HME-2



amplitude

phase

CTMT – Formulation II

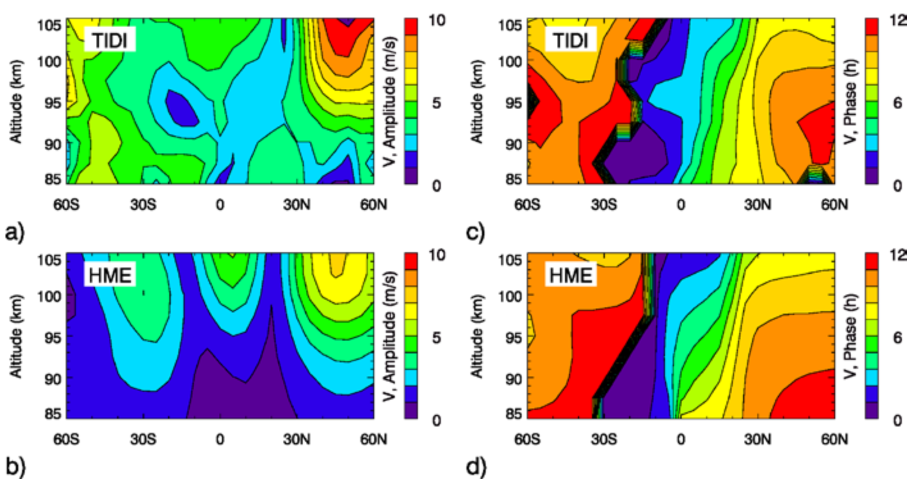
Fit HMEs to observed tides from SABER (T) and TIDI (u,v)

- Use 2 HME (1st sym, 1st asym), add 2 more (2nd sym, 2nd asym) if needed (DE1, semidiurnal)
- 85-105 km, 45°S-45°N (partly extended), monthly mean tides
- Use time-dependent fit-coefficients to reconstruct amps and phases from pole-to-pole and 0-400 km.

S0 component

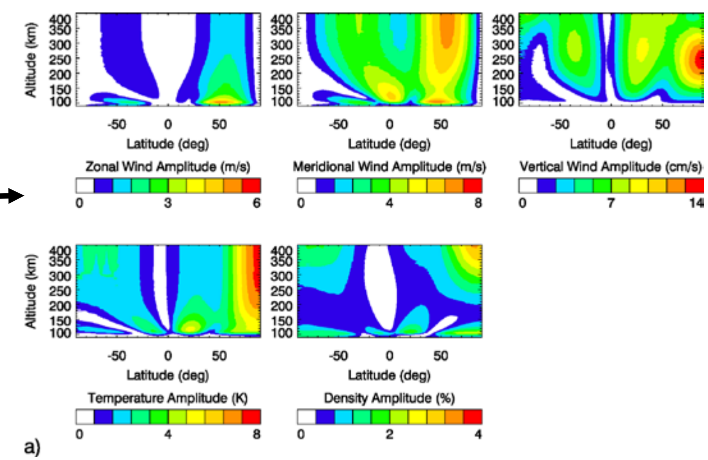
TIDI

CTMT



amplitude

phase



reconstructed amplitudes

CTMT – Data

SABER (T) and TIDI (u,v) monthly mean tides

- DW2, DW1, D0, DE1, DE2, DE3, SW4, SW3, SW1, S0, SE1, SE2, SE3
- Standard CTMT version: SABER v01.07, TIDI v03.07a (Qian Wu's HAO TIDI winds)
- CTMT versions with SABER v2 and Michigan TIDI winds: no big differences to standard CTMT within the limits of an empirical model

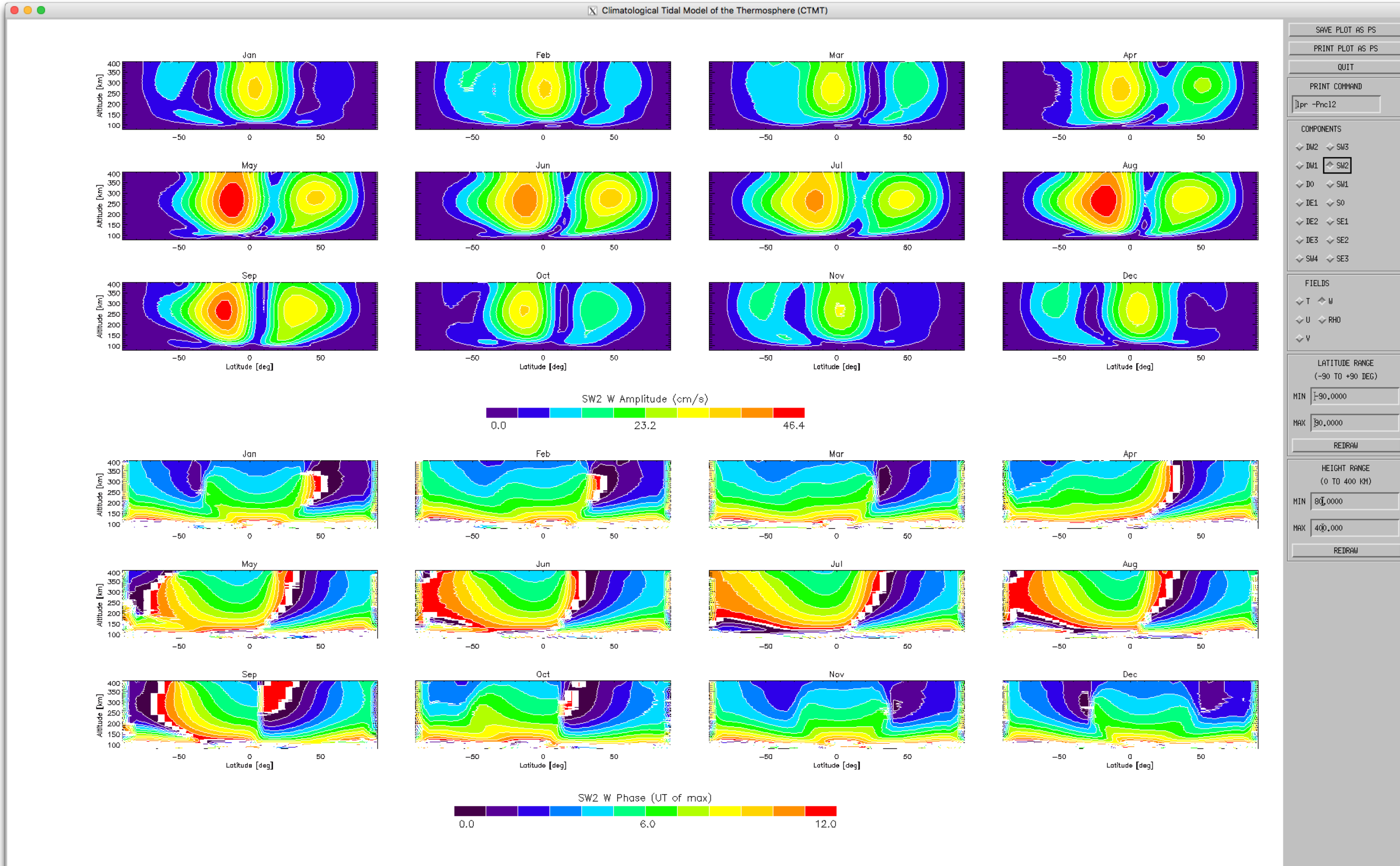
Climatological CTMT – standard version

- Multi-year, monthly mean averaged SABER & TIDI tides using HMEs for 110 sfu: 2002-2008, 2002-2013

CTMT for individual years

- Monthly mean SABER & TIDI tides for individual years using 110 sfu HMEs -> good in MLT region, less useful in thermosphere
- Also special version for DE2, DE3, SE2, SW2 that use solar flux dependent HMEs

CTMT – Operation

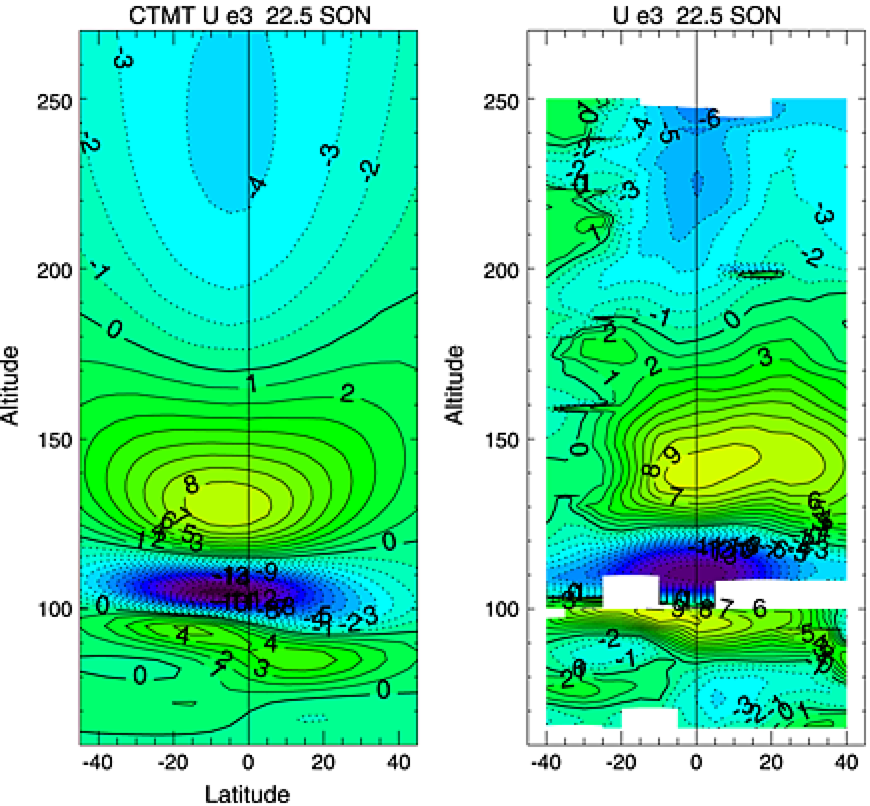


CTMT provided as 2 netcdf files (diurnal, semidiurnal), idl viewer software (tested on Mac)

CTMT – Validation

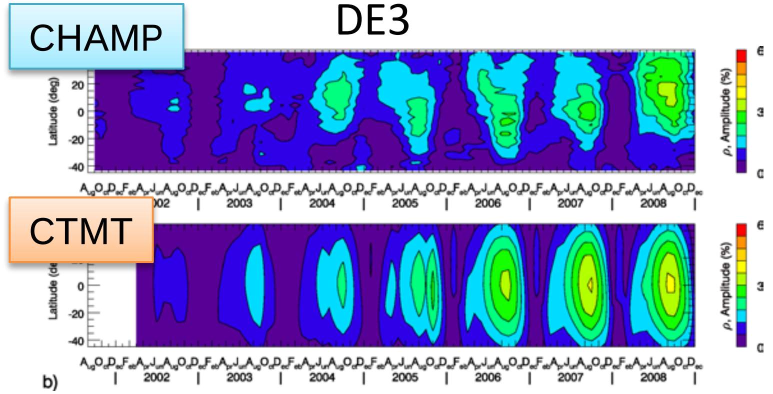
CTMT model, DE3, zonal wind
17h – 7h difference @ 22.5°E

WINDII, DE3, zonal wind
17h – 7h difference @22.5°E

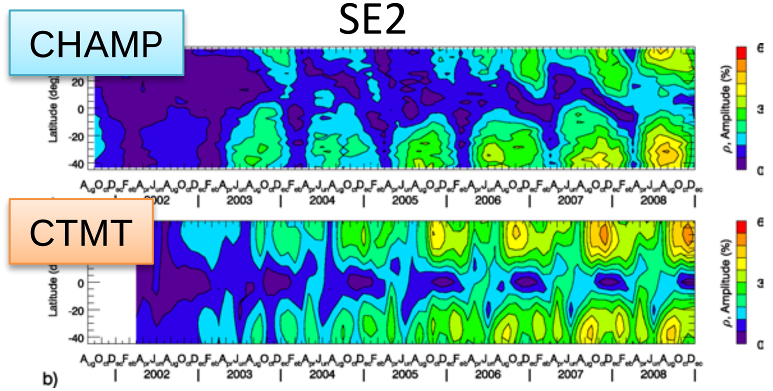


Lieberman et al., 2013JA018975

DE3



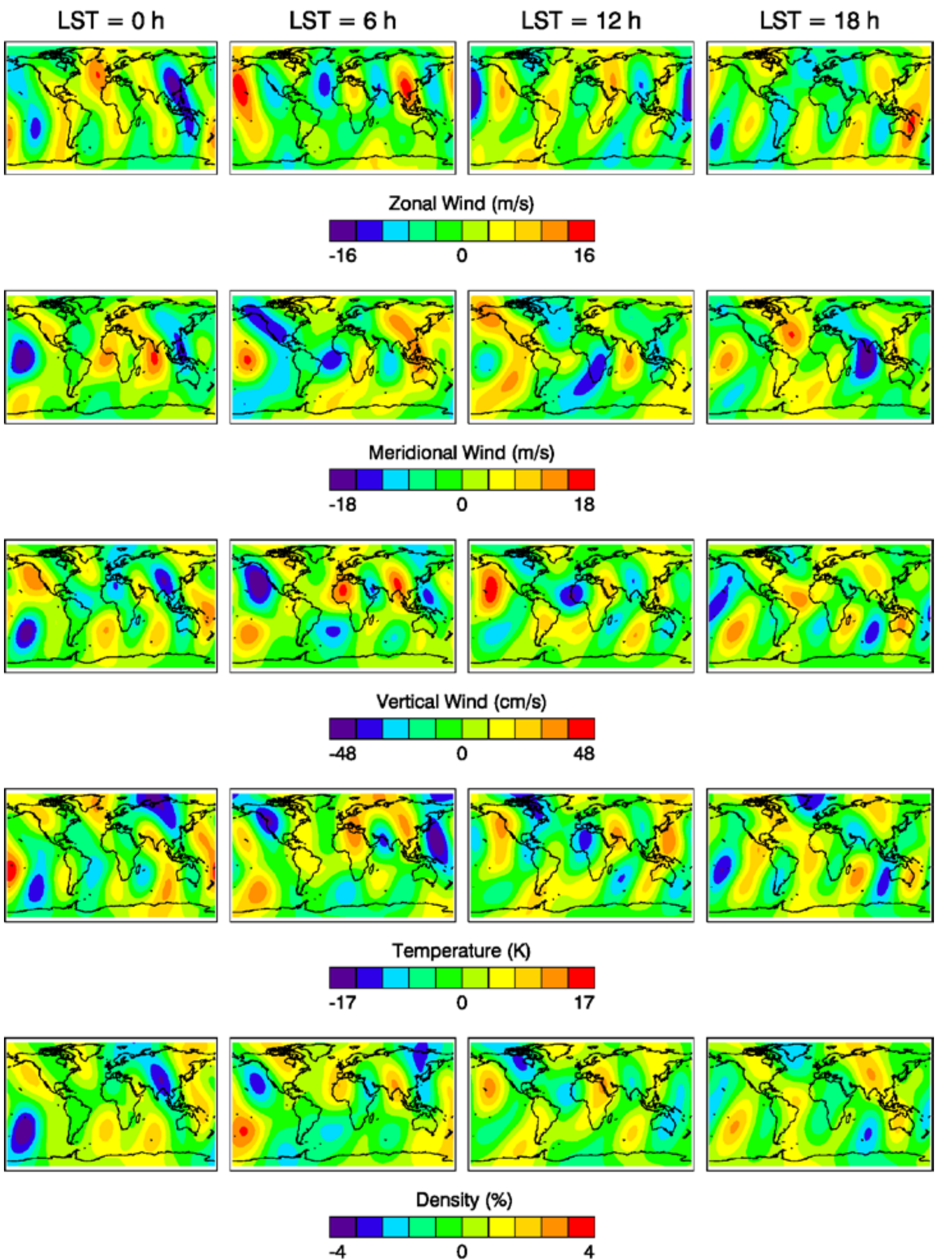
SE2



Neutral density, 390 km

Many more: lidar, radar, satellites (other components)

CTMT – Thermosphere

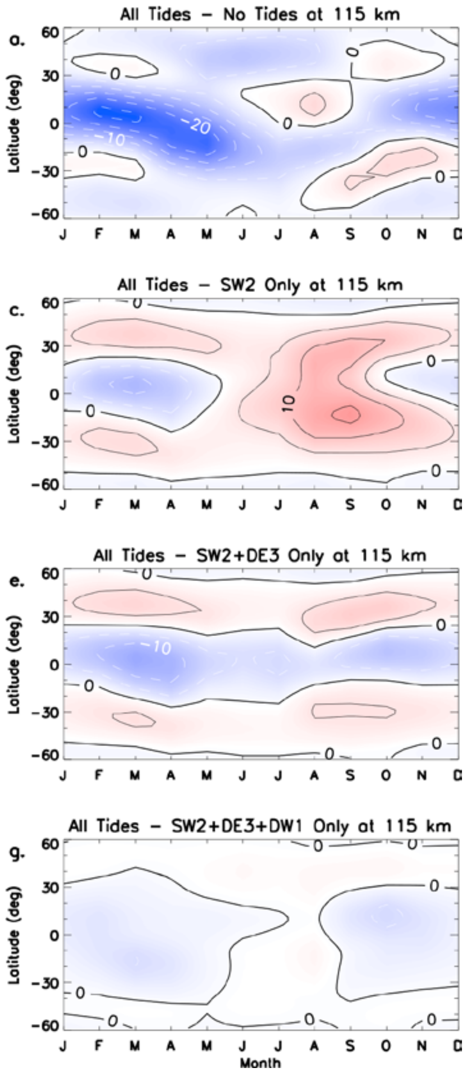


250 km
September 2008

Superposition of
DW2, DW1, D0, DE1, DE2, DE3,
SW4, SW3, SW1, S0, SE1, SE2, SE3
at given lon/lat/local time

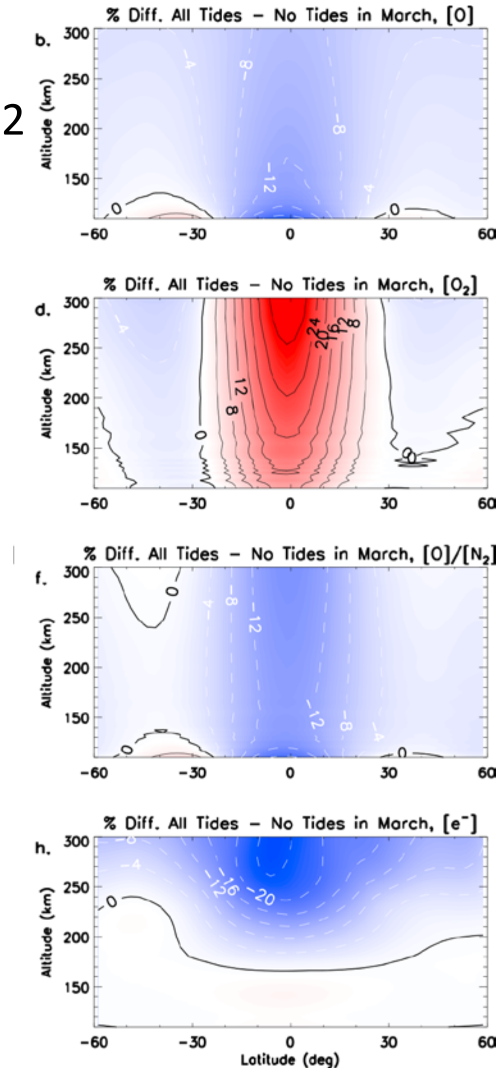
Straightforward to compute from
CTMT amps and phases.

CTMT – Lower boundary for GCM's



Mainly DW1 & SW2

Noticeable impact of
DE3 on mean zonal wind



Driving GCMs requires
self-consistent tidal fields

Mean zonal wind
115 km

TIE-GCM driven by CTMT @ 97 km
Jones et al., 2013JA019744

Constituents

CTMT – Major Applications & Limitations

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Observation-based, self-consistent MLT tides in all dynamical param.

- Close to reality in MLT -> lower boundary for GCMs
- Tidal density variations in re-entry region
- Tidal impact on constituents (T, advection)

Upward propagating tides in thermosphere

- Closes gap between 110-400 km (TIMED, CHAMP, Swarm,…)
- Interpretation of GB obs (e.g., FPI) at different locations

Limitations

- Tides forced above the MLT not accounted for: in-situ migrating tides and nonmigrating tides with known thermospheric sources (e.g., DW1+SPW1 -> DW2)
- It cannot reproduce tides for a particular day! We won’t be able to do that before we have satellite constellations like DYNAMIC.

CTMT – Updates & Upgrades

Updates

- Processing more years of the continuing TIMED mission
- Fits to short-term tidal variability from SABER (deconvolution approach), no TIDI, experimental

Upgrades!?

- Will try approach with GOLD data
- ICON team plans to use HME fits (at least that's my understanding)

CTMT – Summary

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