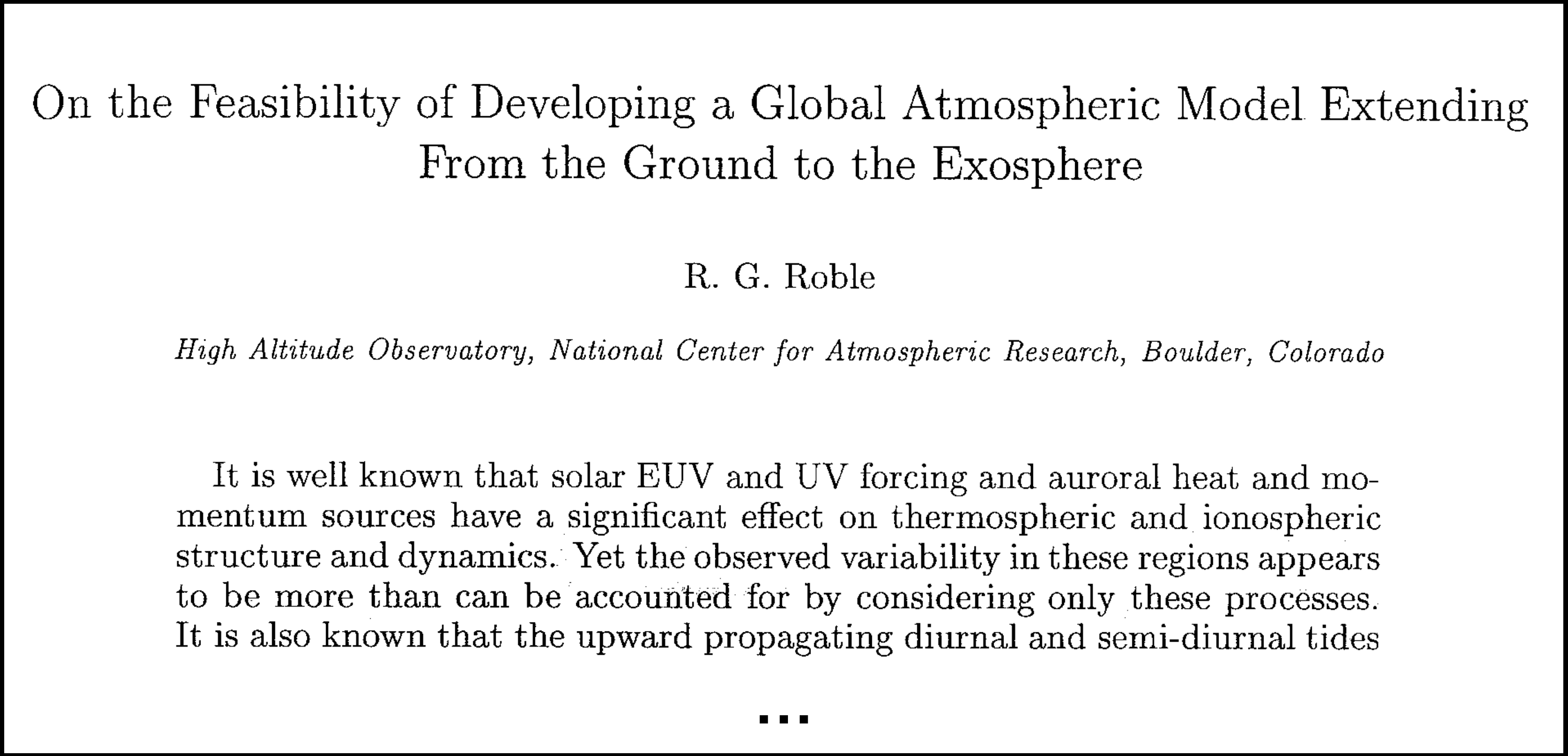
Towards Numerical Space Weather Prediction with Whole Atmosphere Models

R. A. Akmaev
(NOAA SWPC)
T. J. Fuller-Rowell, F. Wu, H. Wang, and T.-W. Fang
(U. Colorado, CIRES)

Sponsored by

- NASA LWS and Heliophysics Theory programs
- AFOSR MURI program

It all started with …


On the Feasibility of Developing a Global Atmospheric Model Extending From the Ground to the Exosphere

R. G. Roble

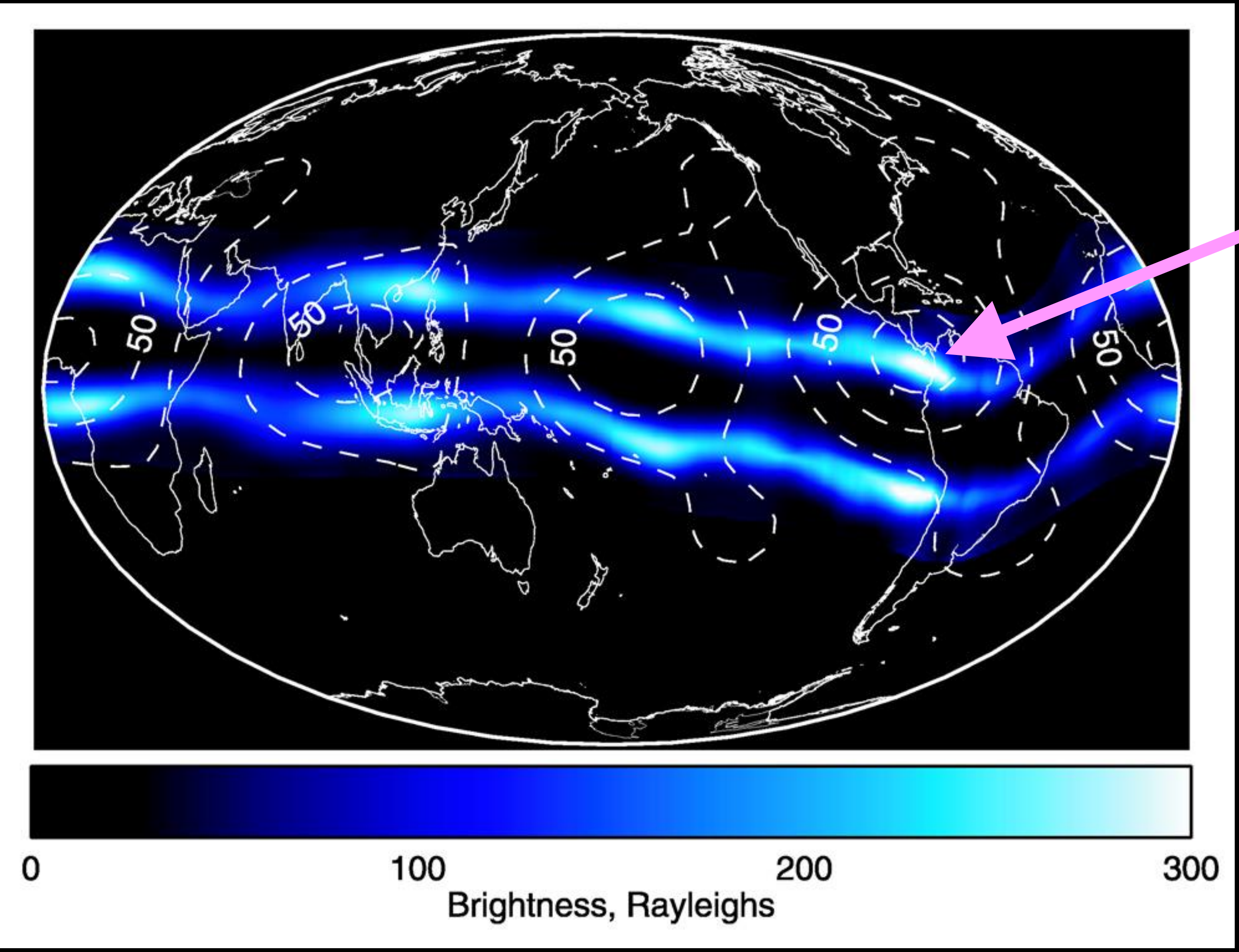
High Altitude Observatory, National Center for Atmospheric Research, Boulder, Colorado

It is well known that solar EUV and UV forcing and auroral heat and momentum sources have a significant effect on thermospheric and ionospheric structure and dynamics. Yet the observed variability in these regions appears to be more than can be accounted for by considering only these processes. It is also known that the upward propagating diurnal and semi-diurnal tides

…

Roble, in "Atmospheric Science Across the Stratopause," AGU Monograph 123, 2000.

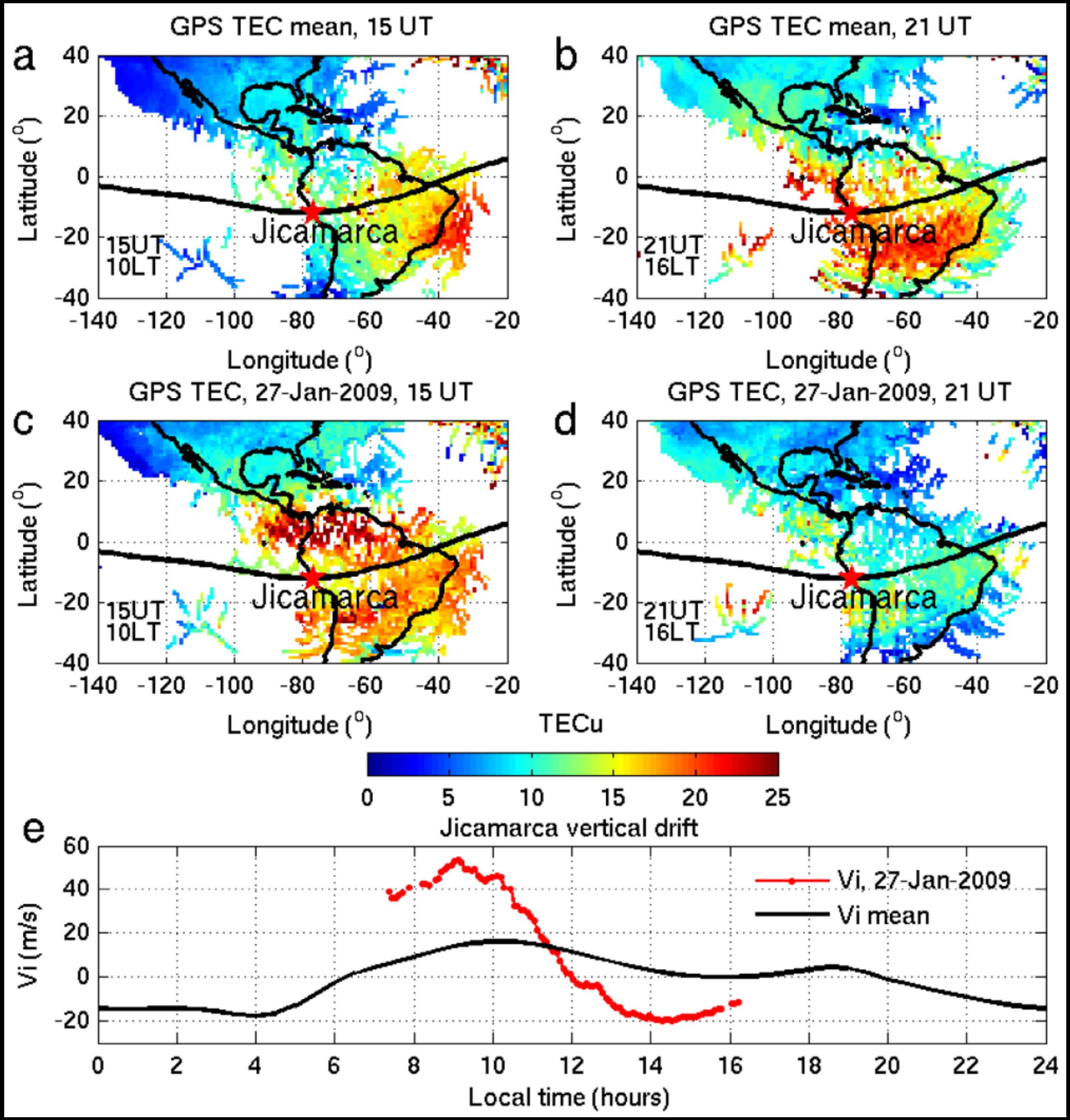
Motivation: “nonmigrating” structures in post-sunset Equatorial Ionospheric Anomaly (EIA)



The four peaks in diurnal temperature amplitude result from superposition of the migrating (to the west) tide (DW1) and nonmigrating eastward mode with zonal wavenumber 3 (DE3).

IMAGE composite of 135.6-nm O airglow (350–400 km) in March–April 2002 for 20:00 LT and amplitude of modeled diurnal temperature oscillation @ 115 km (Immel et al., 2006).

Motivation: January 2009 Stratospheric Warming in EIA



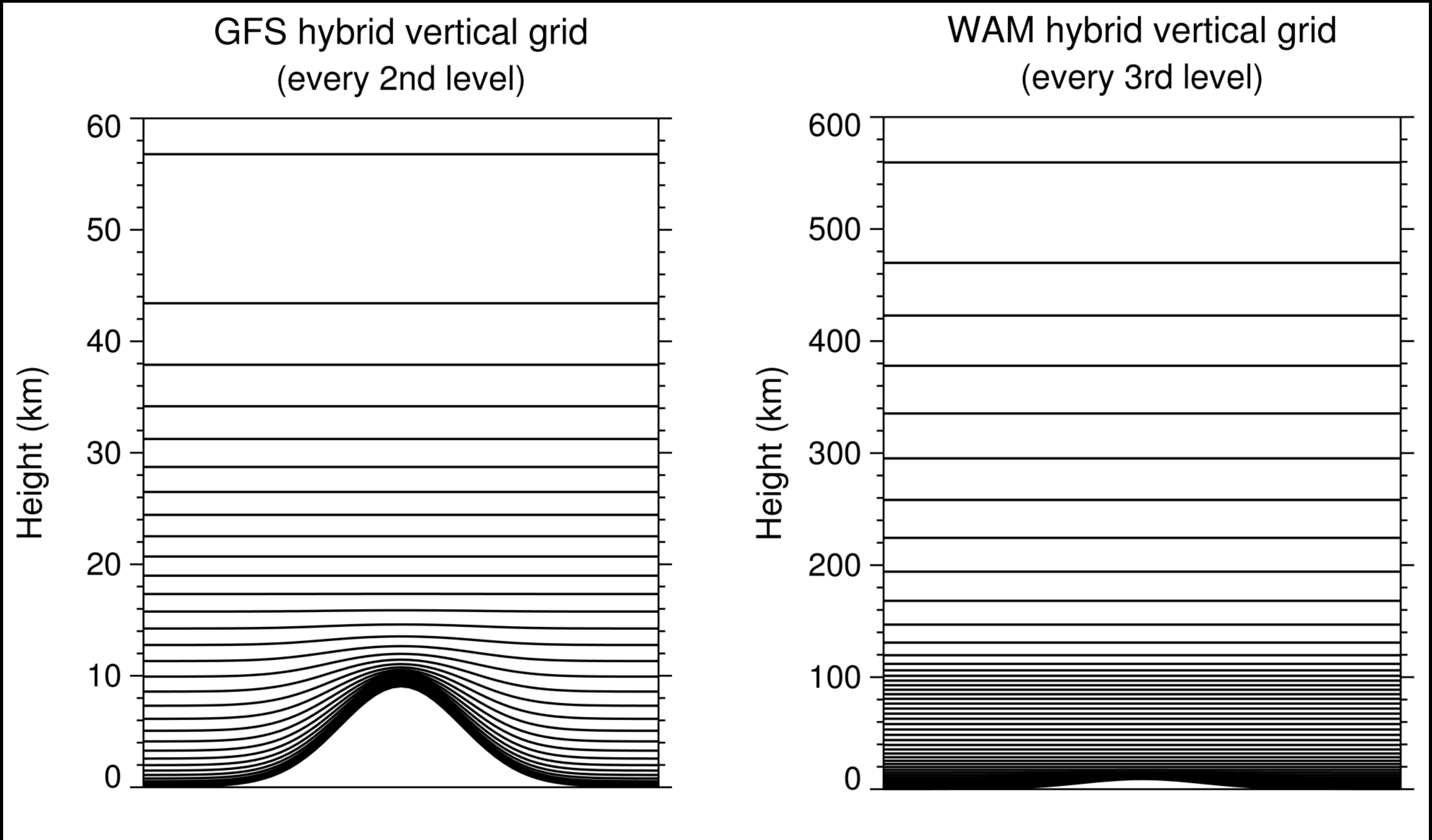
Goncharenko et al. (2010):

Climatological TEC @ 10 and 16 LT from ground GPS observations.

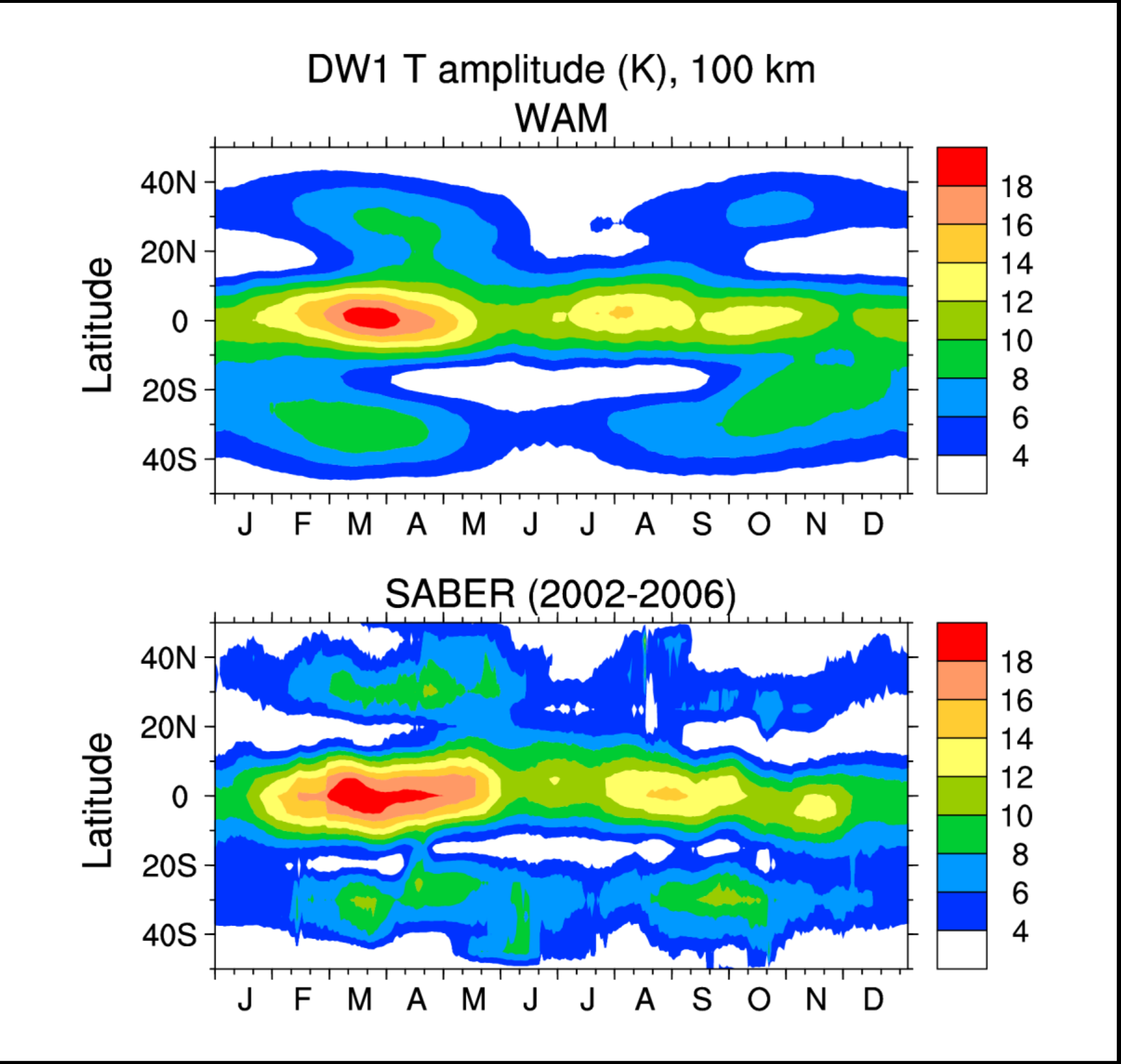
Same on January 27, after the peak of the warming.

Comparison of plasma drift climatology with observations on Jan. 27.

WAM = Extended GFS

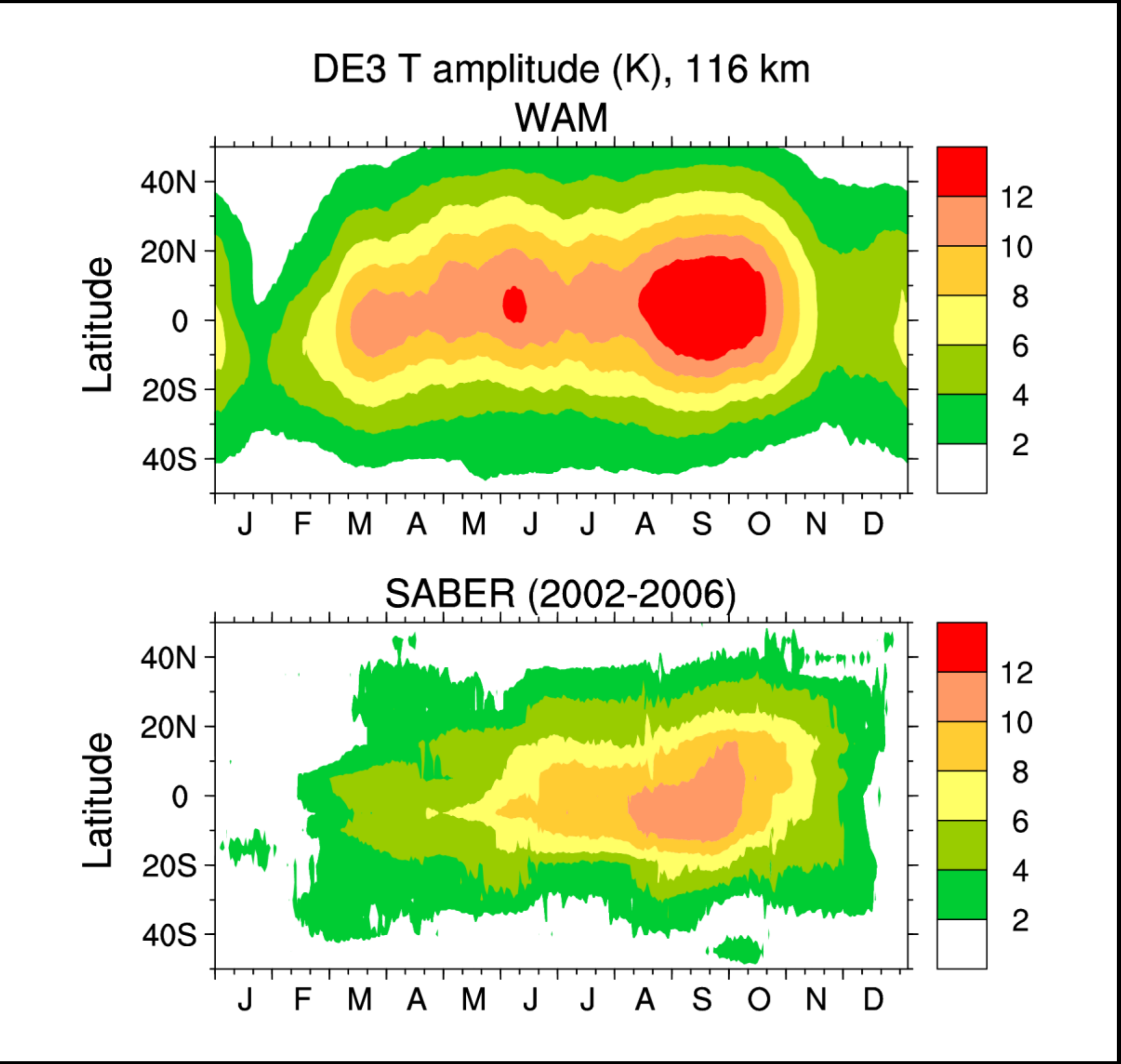


Validation: DW1 tide @ 100 km



Example: DW1 migrating tidal temperature amplitude compared to TIMED/SABER data analysis (Forbes et al., 2008) @ 100 km.

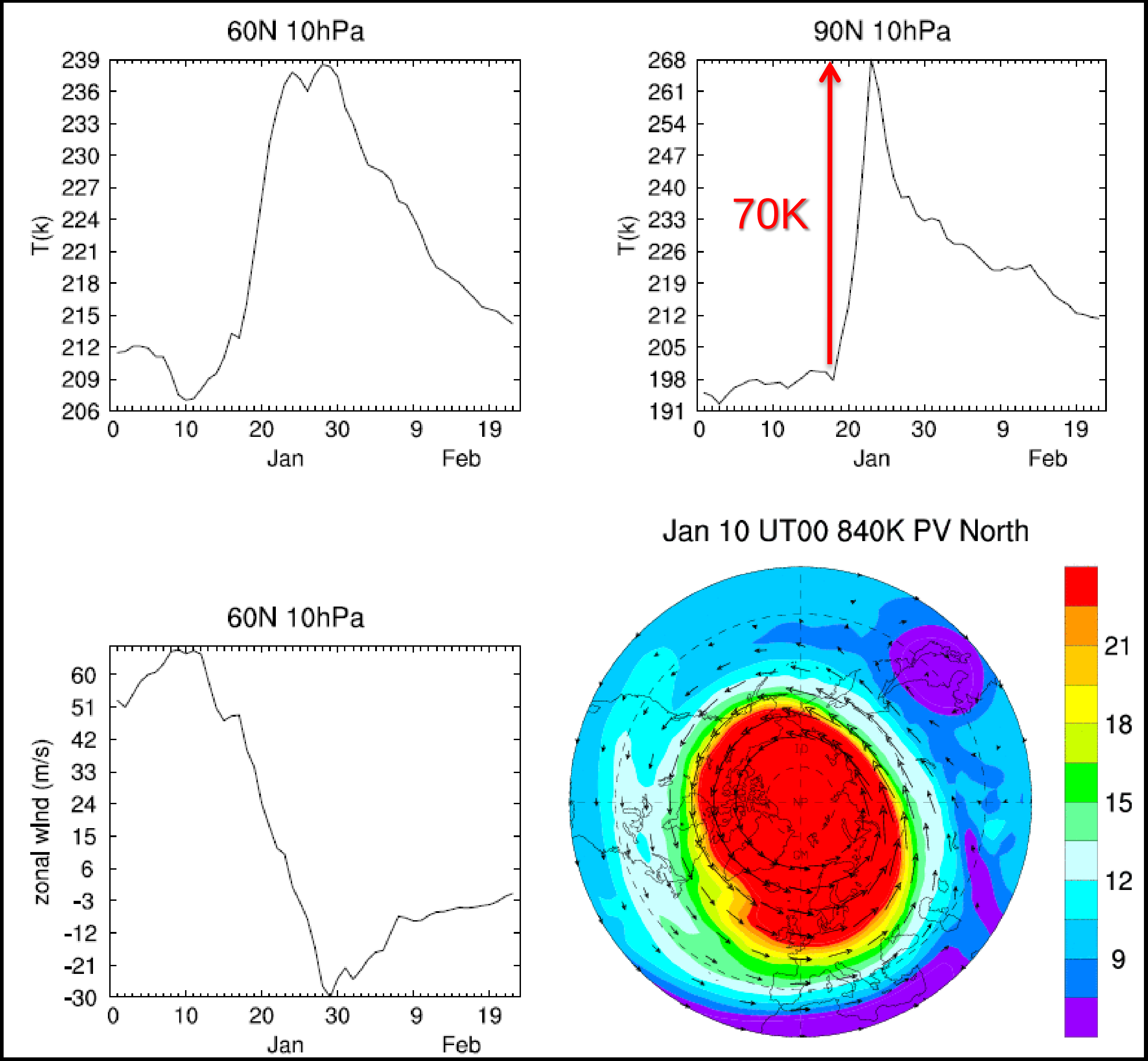
Validation: DE3 tide in the E-layer



Example: DE3 nonmigrating tidal temperature amplitude compared to TIMED/SABER data analysis (Forbes et al., 2008) in the E-layer dynamo region.

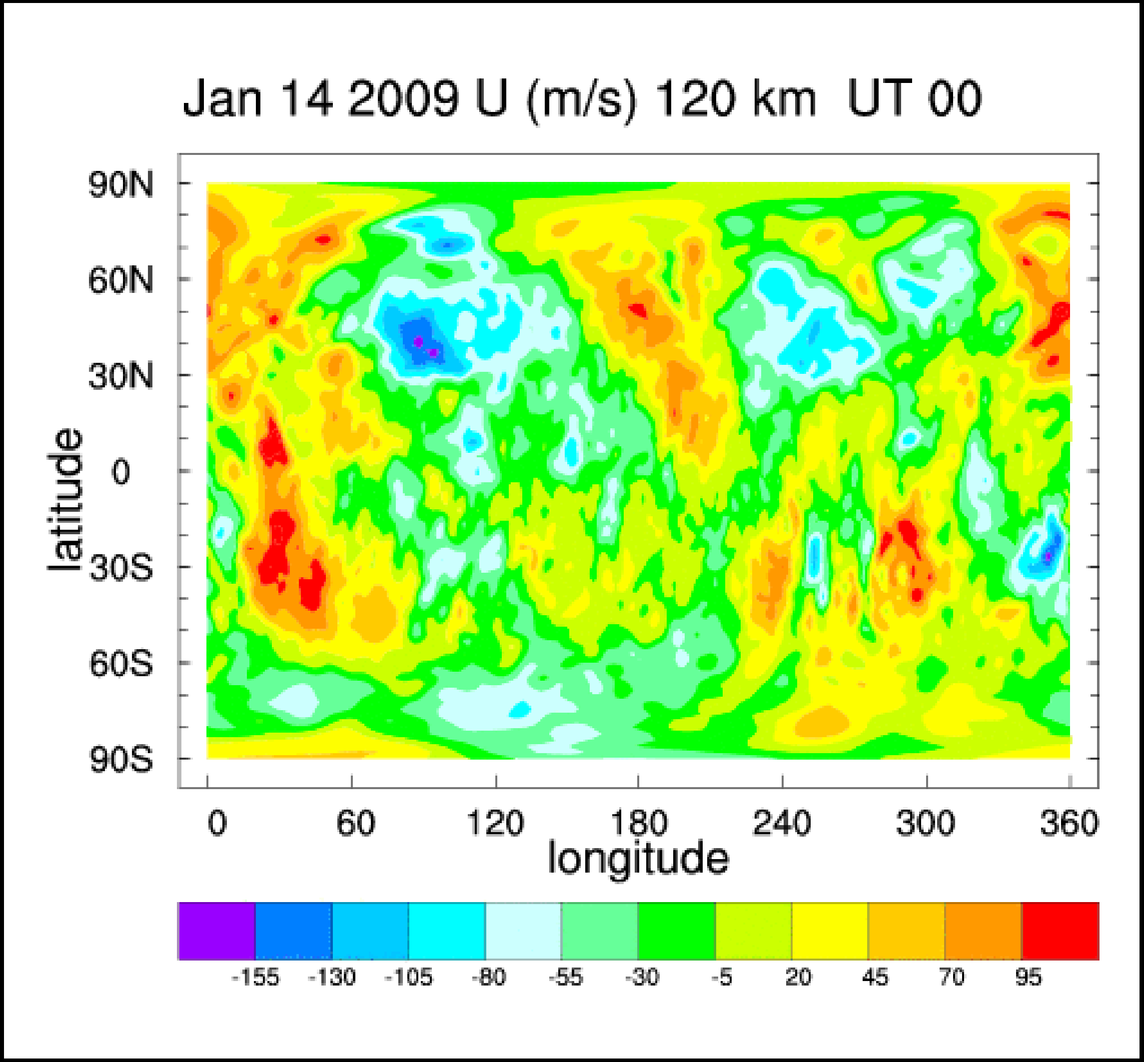
Other tides (e.g., SW2) and variables (winds) validated as well (Akmaev et al., GRL, 2008).

January 2009 stratospheric warming



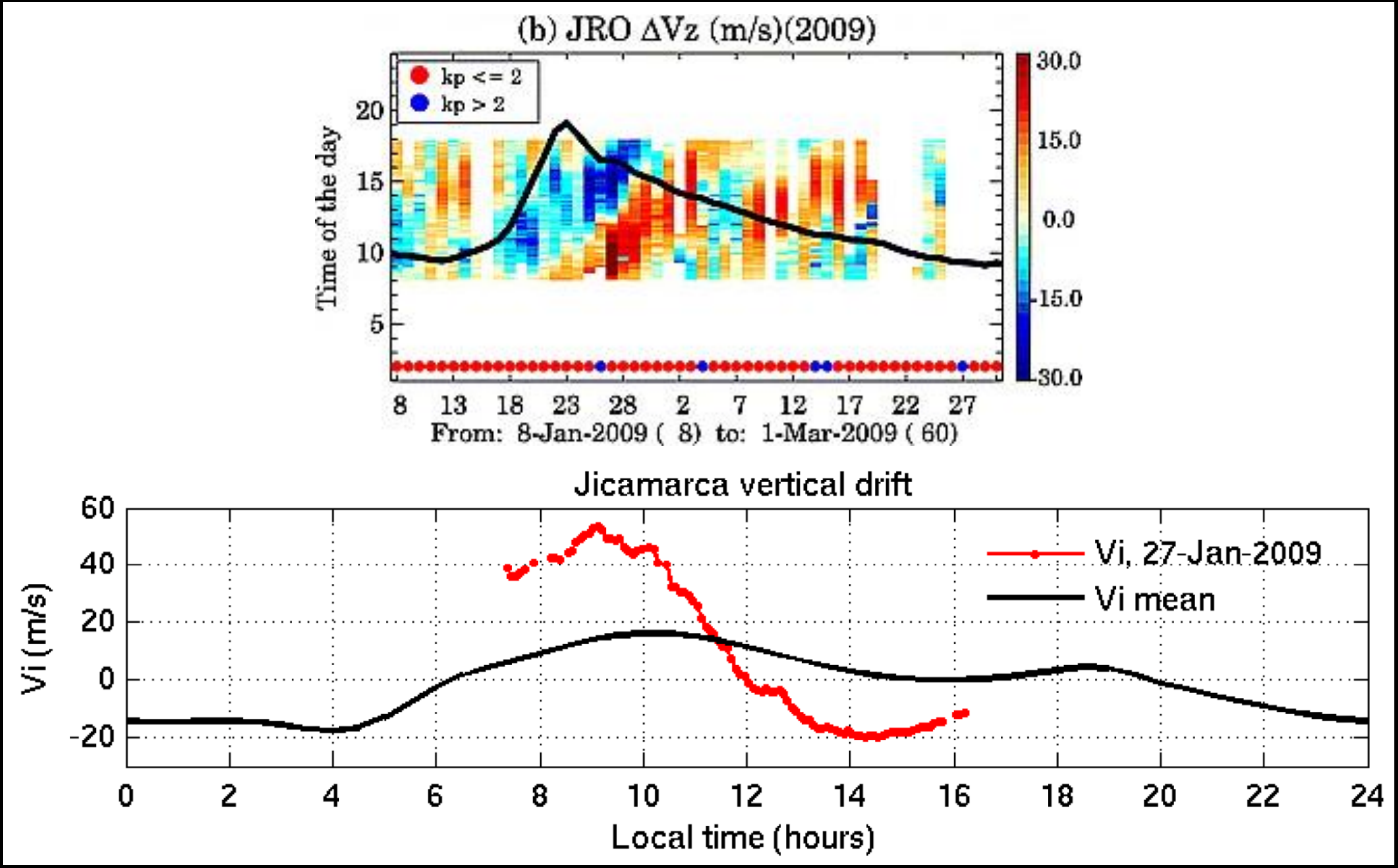
Fuller-Rowell et al. (2011); Wang et al. (2011).

Zonal wind in the E layer



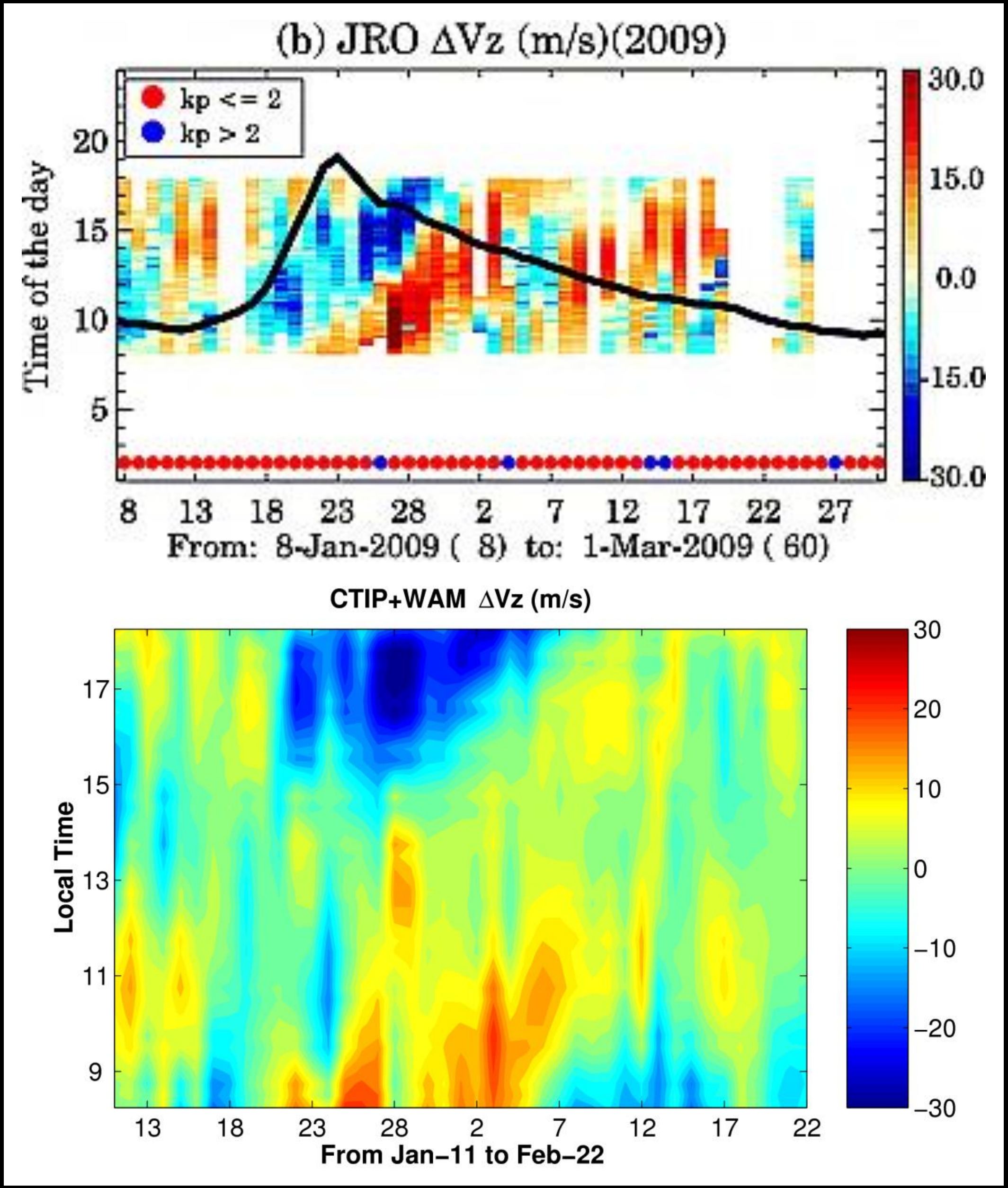
Wave 2 (semidiurnal) pattern ⇒ Wave 3 (terdiurnal) pattern

Electrodynamics: Observations



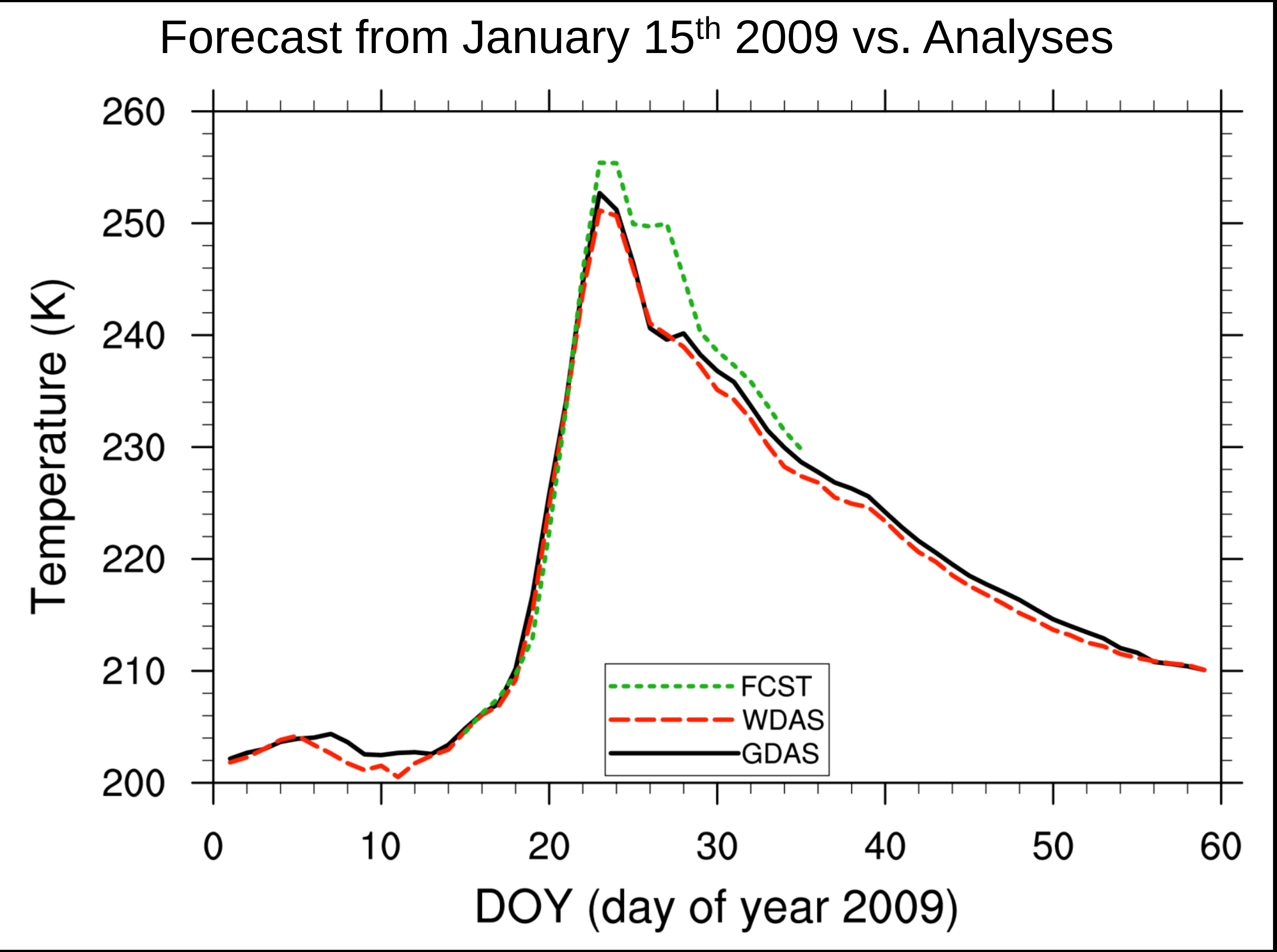
Vertical plasma drift @ Jicamarca (Chau et al., 2010; Goncharenko et al., 2010)

Comparison with WAM⇒CTIPe



CTIPe simulations with WAM winds appear to reproduce the main features in vertical plasma drift during an SSW, including the earlier and stronger peak, the timing of the perturbation and of the recovery (Fuller-Rowell et al., 2011).

Predictability: Polar cap T @ 10 hPa



Initialized with operational data WAM forecasts SSW several days in advance (Wang et al., 2011).

Summary of results to date

- WAM has been validated on tides deemed important in interactions between the lower and upper atmosphere.

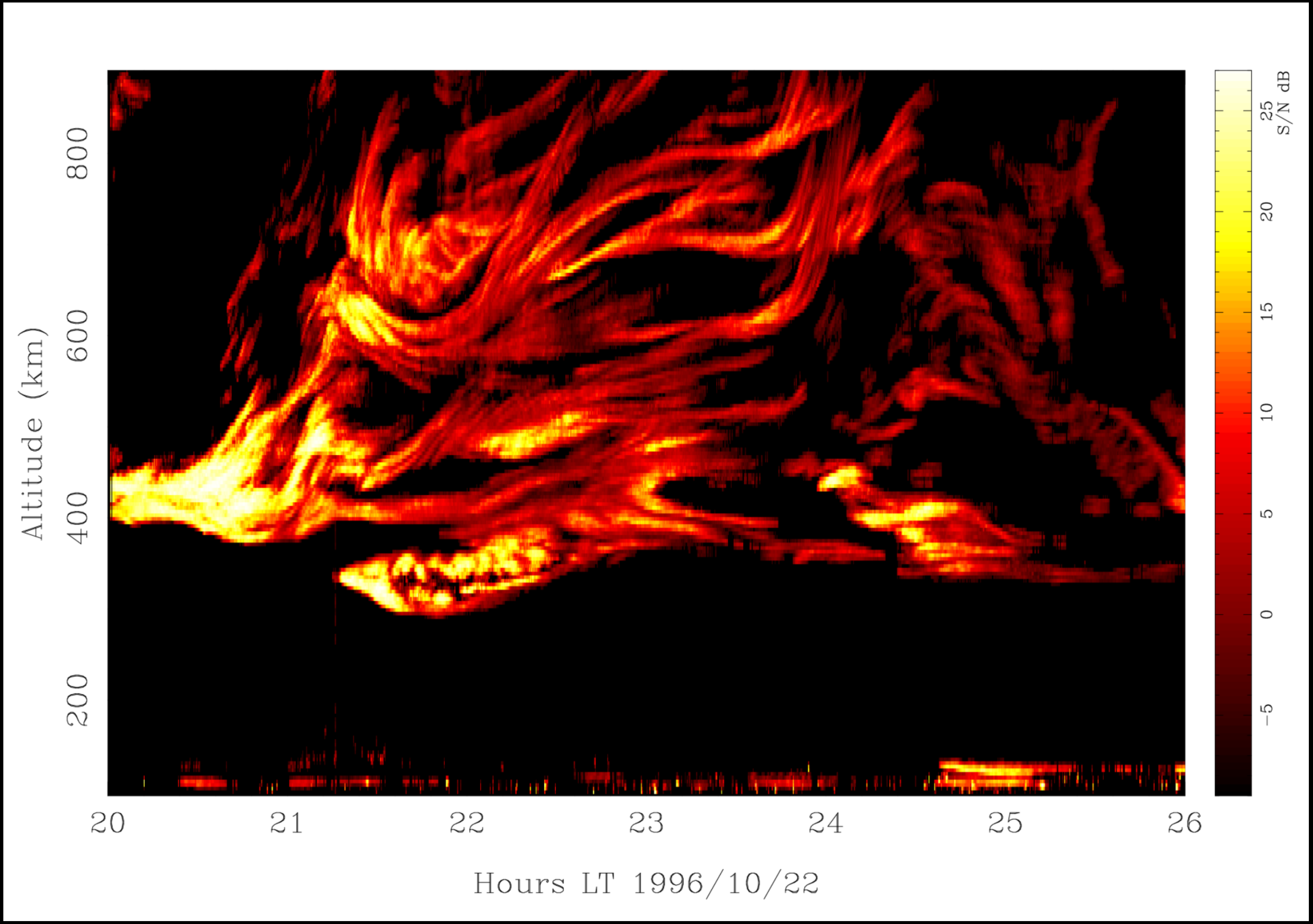
- SSWs are internally generated by WAM in free runs and well reproduced in a “weather prediction” mode:
    - Substantial changes in upper atmosphere dynamics include enhanced terdiurnal tidal amplitudes and related increases of MDM and MTD magnitudes. Noticeable increases in global mean mass density are registered at satellite altitudes.
    - First coupled WAM-CTIPe simulations reproduce the main features of equatorial electrodynamics observed during SSWs.

- Initialized with operational data WAM potentially offers the capability to forecast the effects of SSWs and meteorological on the upper atmosphere and ionosphere several days in advance.

Future model development

- High-resolution simulations (cf. GFS T574, or ~60-km wavelength, vs. WAM T62)
  - Potentially generate QBO, SAO, etc., internally w/out GW parameterizations.
  - Seeding of ionospheric plasma irregularities?
- High resolution requires nonhydrostatic dynamics.
- True “deep-atmosphere” dynamics needed.
- Implications/lessons for further GCM development, including lower-atmosphere models
  - Numerical schemes (e.g., semi-implicit).
  - More accurate thermodynamics.
  - No need for “sponge” layers.
  - Interactive coupling to IPE, then to geospace models, etc.

Future challenges: Application to plasma irregularities



JULIA radar observations (Hysell & Burcham, 1998)