A Data assimilation model for determining the mean state and migrating tide structures in the mesosphere and lower thermosphere using satellite measurements of wind and temperature

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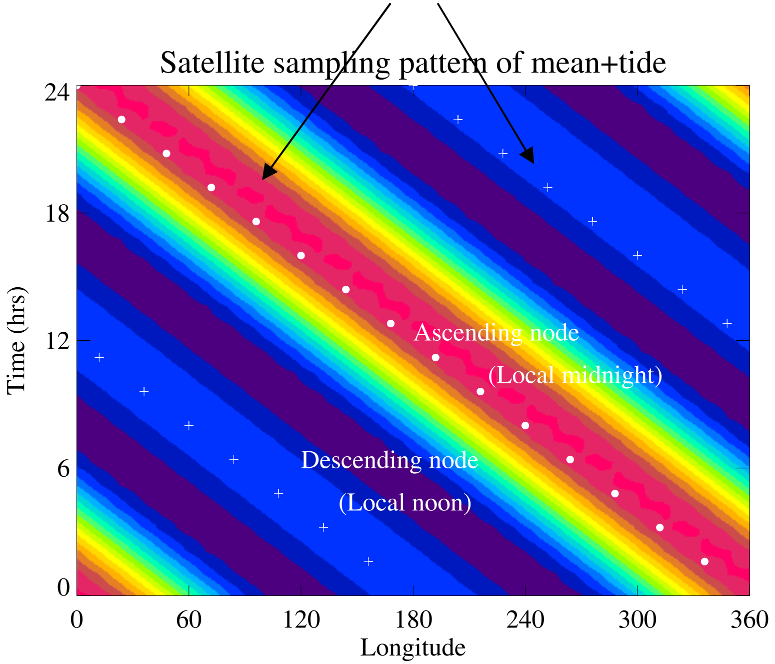
Outline

- Review difficulty with standard approach to tidal analysis of satellite data.
  1. Harmonic fitting to the local time sampling that occurs as the satellite precesses, (illustrated with TIMED data)
  2. Sums and differences of ascending and descending node data
- Present a new method that employs fitting a mechanistic tide model to measured wind and temperature fields simultaneously
- Validation test
- Show results of the method applied to HRDI/UARS data
- Discuss relevance for assimilation of MLT data into time-dependent models

Satellite measurements provide a global but asynoptic view of the atmosphere

- In the mesosphere and lower thermosphere the dominant dynamical features in the wind and temperature fields consist of the mean flow and migrating tidal structures.
- These flow components are almost perfectly aliased in satellite measurements, making difficult to determine the separate mean, diurnal and semidiurnal tide contributions.
- Sum/difference method requires day/night data, is not applicable at all latitudes, and cannot resolve mean, diurnal and semidiurnal tide

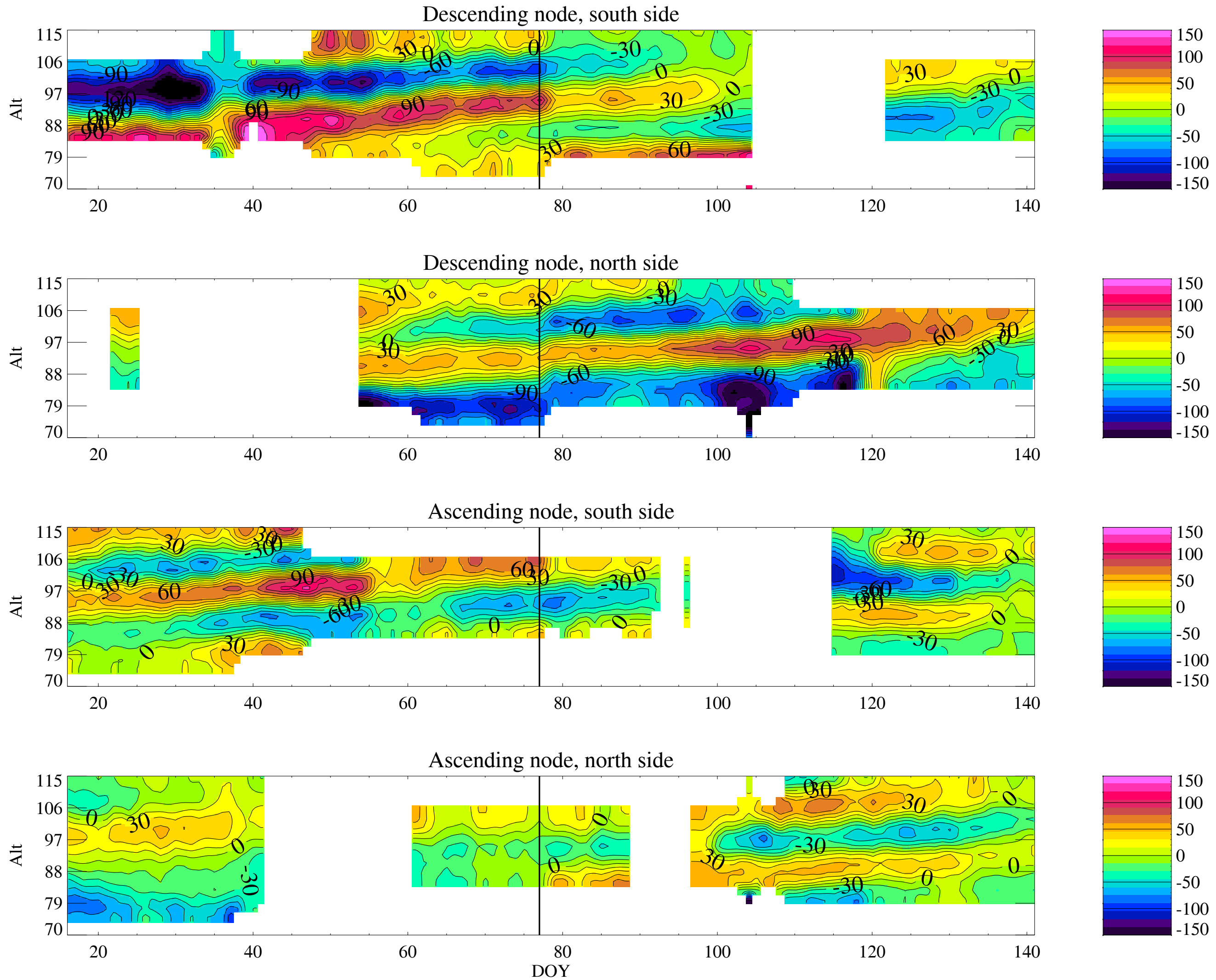
Analysis begins with separately averaging all data from ascending and descending nodes



At the equator

TIDI meridional winds at 18S

coverage over two yaw cycles from Jan-May 2004
multiple coverage from two tracks and ascending/descending nodes



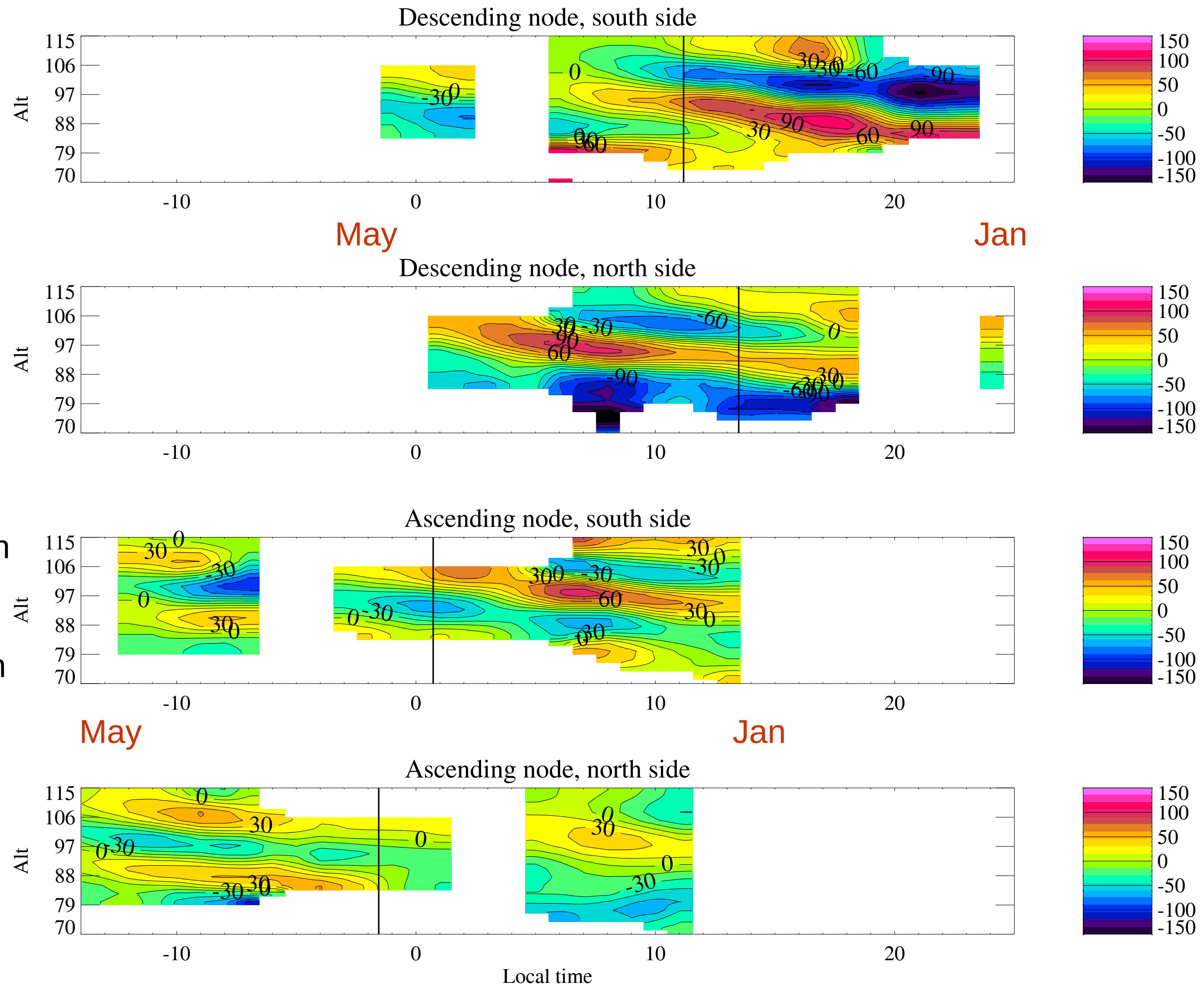
TIDI meridional winds at 18S

binned by local time (4 local times sampled per day)

Jan-May 2004

March yaw marked with vertical line

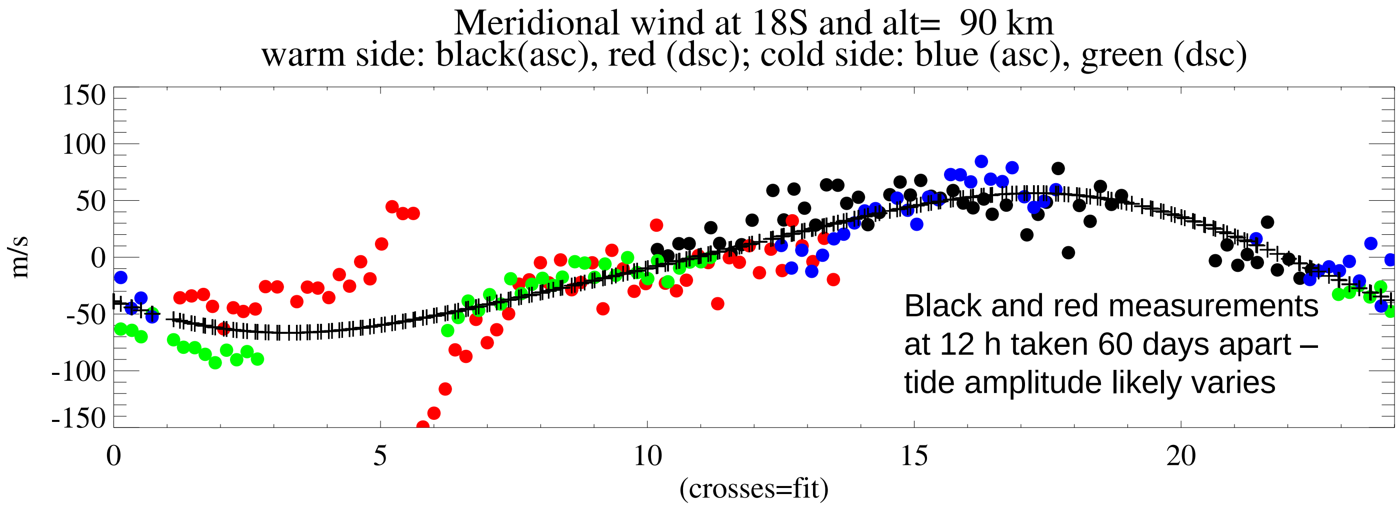
Note that each yaw cycle gives 24 hour coverage from both nodes



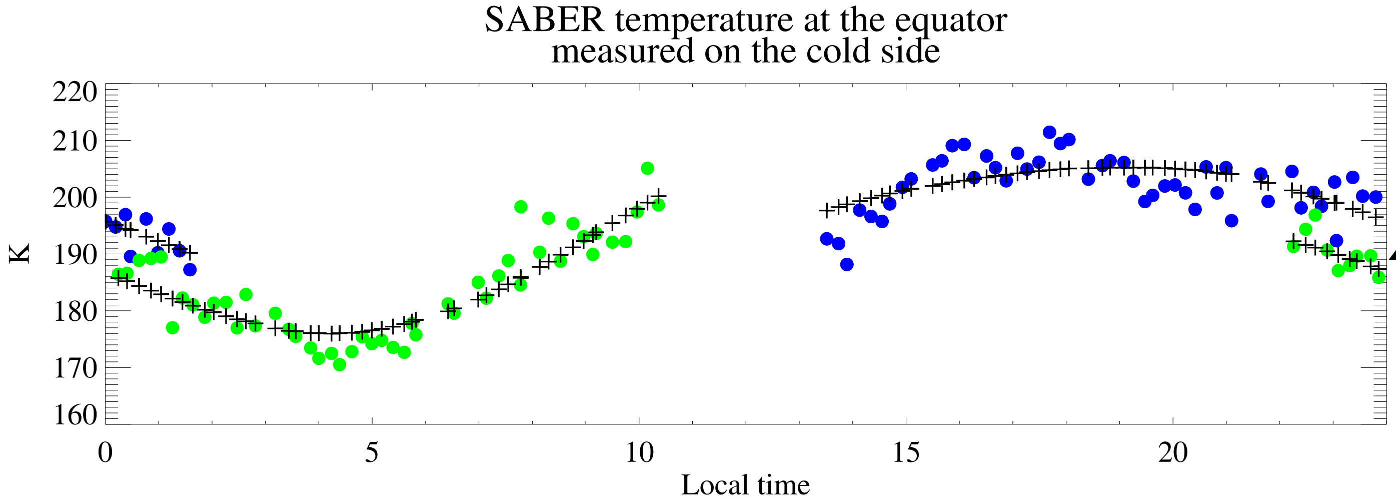
Harmonic model fit:

include mean, secular variation of mean, diurnal and semi-diurnal components

$$y(t) = a_0 + a_1 t + d_0 \sin(t) + d_1 \cos(t) + s_0 \sin(2t) + s_1 \cos(2t)$$



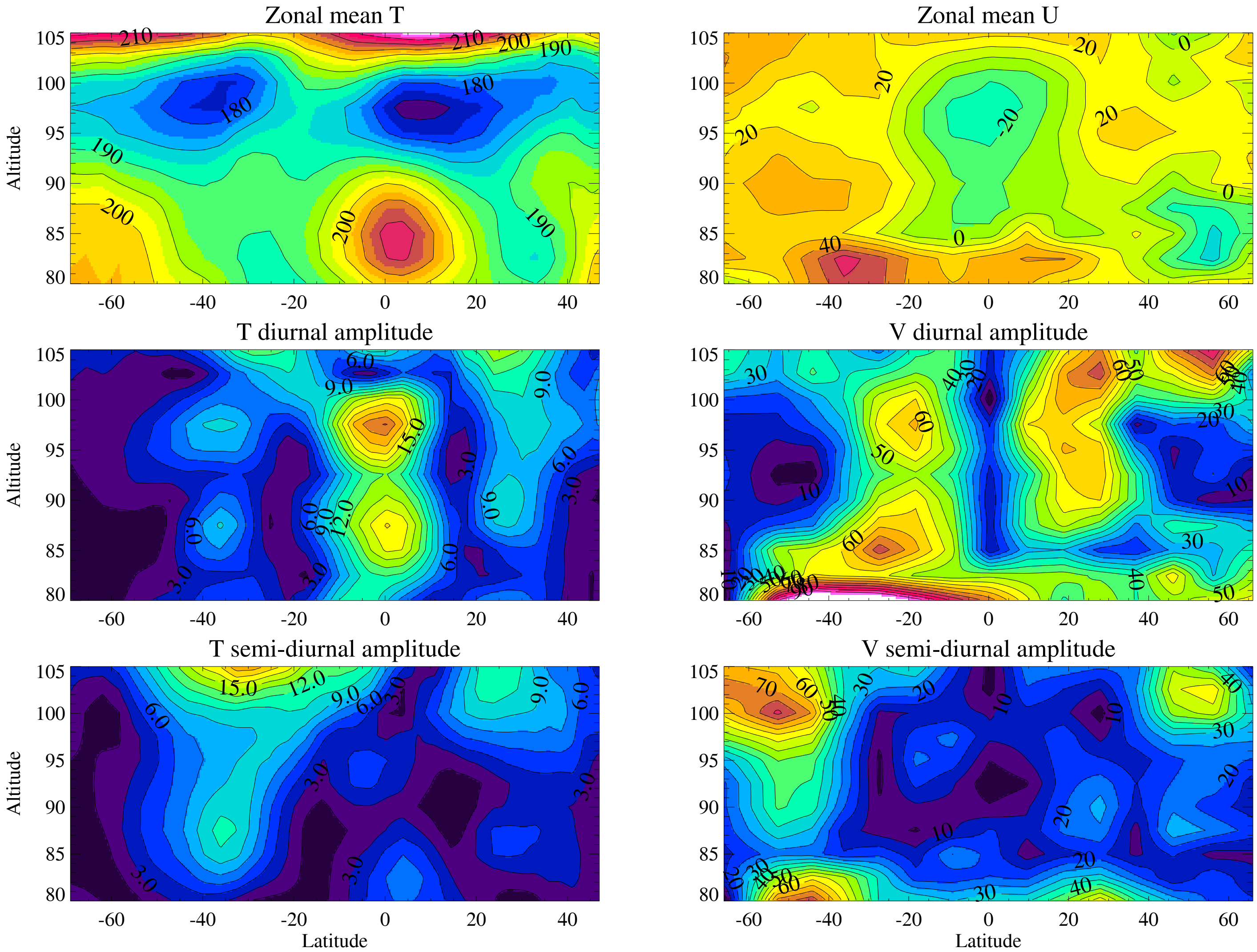
Data for yaw cycle from March-May 2004



Measurements taken 60 days apart force inclusion of the secular term

Harmonic fit to TIMED data:

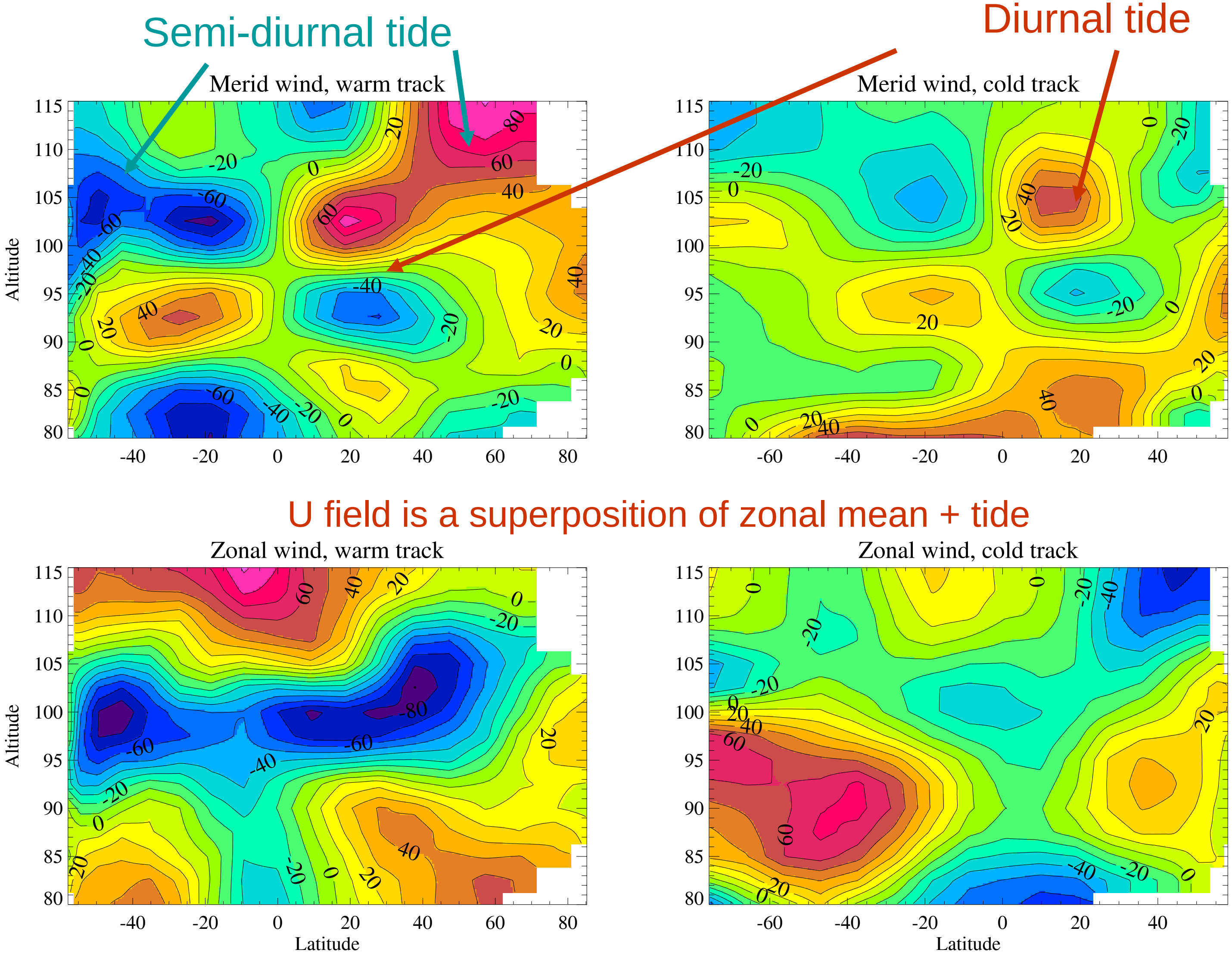
Zonal mean wind and temperature; tidal amplitudes



TIDI wind components

March 20, 2004, descending node

The tide is evident in daily cross sections of the winds and temperatures. The next few slides show these three fields contain enough information to derive information on the tides and mean flow



Assimilation model: basic ideas

- Advantages of this technique include:

1. ability to estimate daily variations in mean fields and tidal amplitudes;
2. Test bed of techniques for bringing tide models or GCMs into agreement with observations

Basic Ideas:

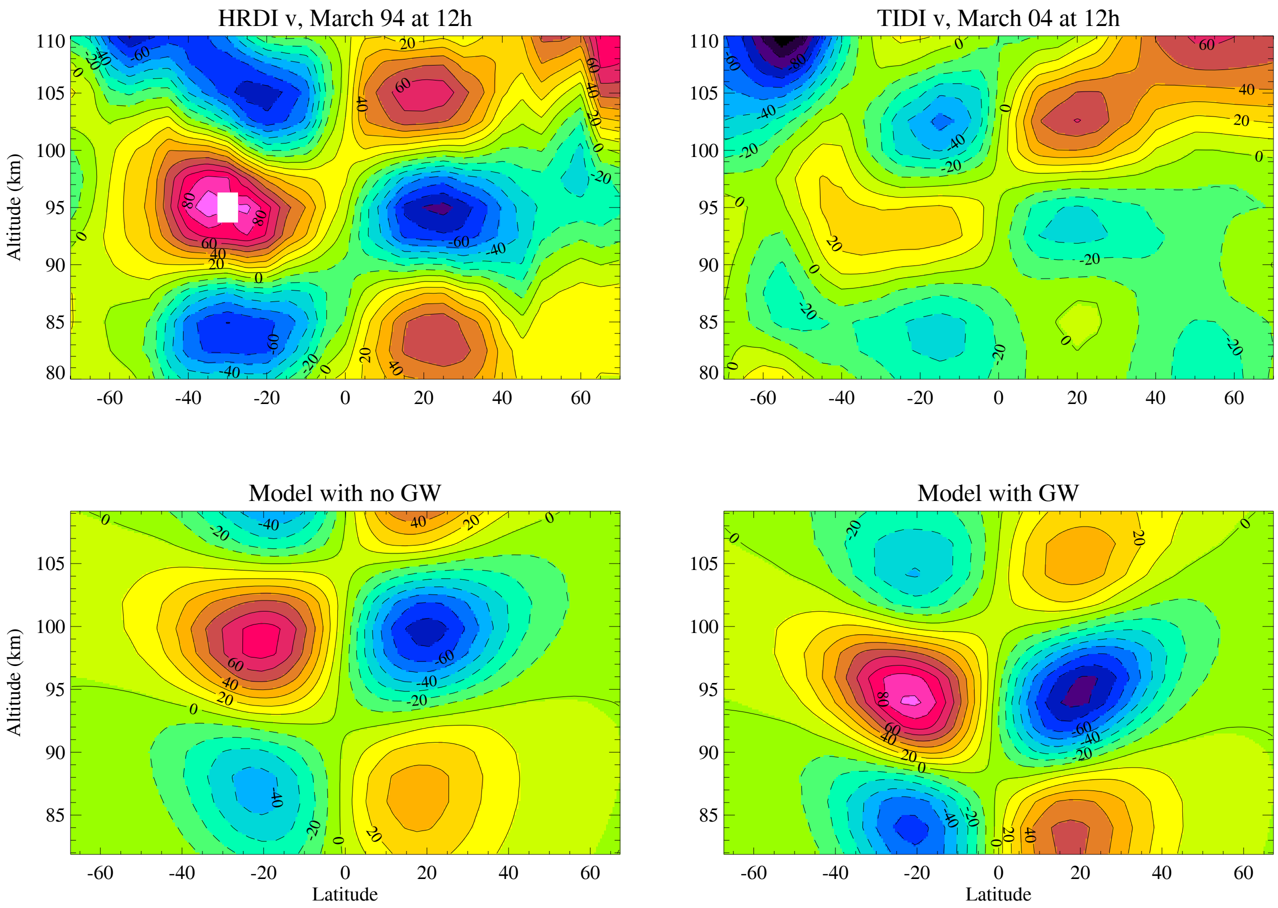
- Dynamical constraints vastly limit the number of relevant degrees of freedom when considering wind and temperature simultaneously – the latitude altitude structure is not completely arbitrary
- Mean flow is expanded in terms of ‘geostrophic modes’ . These are determined by the zonal mean geopotential, which is represented as a 2-dimensional expansion in terms of Legendre polynomials;
- Tidal forcing is assumed to be negligible in the MLT. It follows that the tidal response in the MLT is uniquely specified by conditions at some lower boundary (e.g. 70 km);
- Lower boundary condition is represented as a Hough function expansion. Five modes used for each of the diurnal and semi-diurnal tides (more may be required for the semi-diurnal modes);
- Tidal structure is controlled by the background mean flow, dissipation mechanisms and interaction with gravity waves as well as by the tide heating

Assimilation method

- May be viewed as a generalization of balanced initialization – temperature, geopotential and wind fields of tides (and other forced modes) must satisfy certain relations (polarization relations)
- Assimilation should involve adjustment of wave source and other forces in addition to modifying the dynamic fields
- Use nonlinear least-squares fit to determine 113 coefficients:
  1. mean flow expansion coefficients;
  2. tide expansion coefficients (parameters describing tide source)
  3. Eddy diffusion coefficient
  4. GW source parameters for the Alexander-Dunkerton scheme.
- The model is a linear combination of modes. The tide modes depend on the mean flow and the GW forcing

Why GW forcing is necessary:

Model simulations of the tide reproduce the observed vertical wavelength only if gravity waves are included



GW forcing of the tide

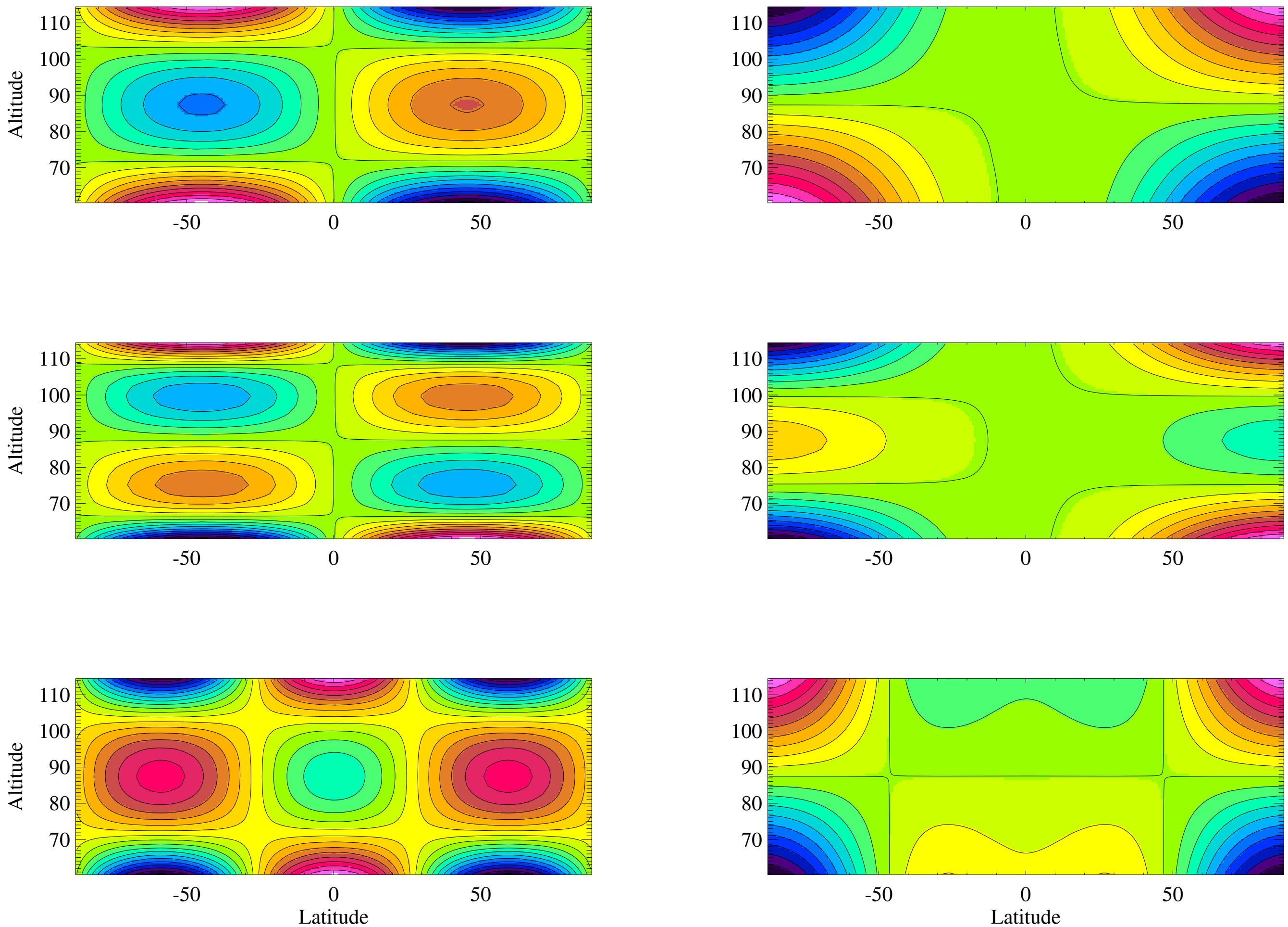
- Vertical structure of the tide is sensitive to the GW source structure
- Source spectrum confined to the tropics
- Spectral shape for momentum flux given by $B(c)=B_w \exp(-(c/c_w)^2)$
- Eddy diffusion represented by a simple profile ramped up to K_{eddy} above 80 km
- B_w, c_w, K_{eddy}, and intermittency are adjustable parameters determined using a non-linear least-squares fit

Geostrophic basis functions

generated using a double Legendre polynomial expansion for the geopotential in latitude and altitude (3 out of 89 'modes' shown)

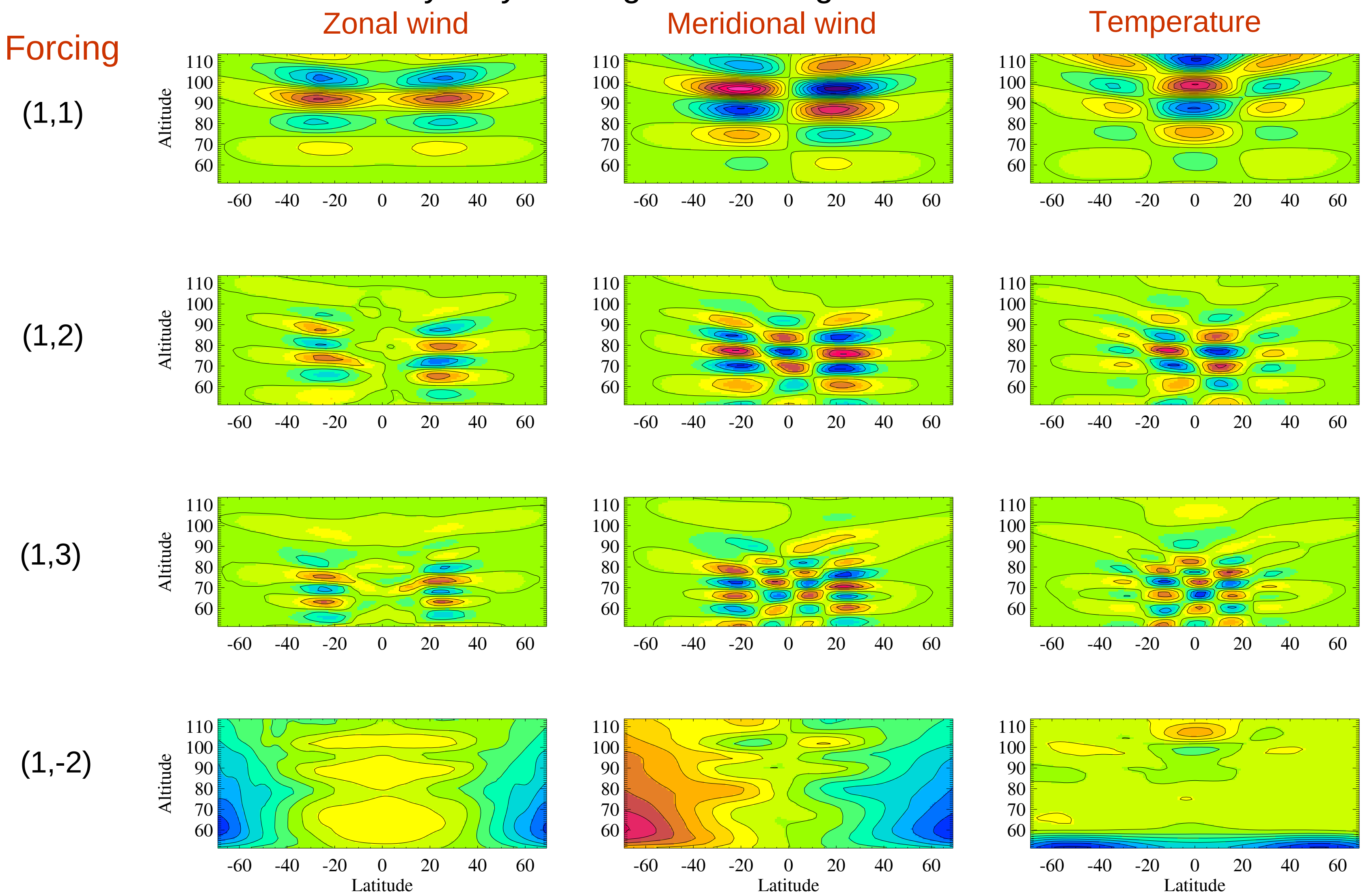
Zonal mean zonal wind

Zonal mean temperature



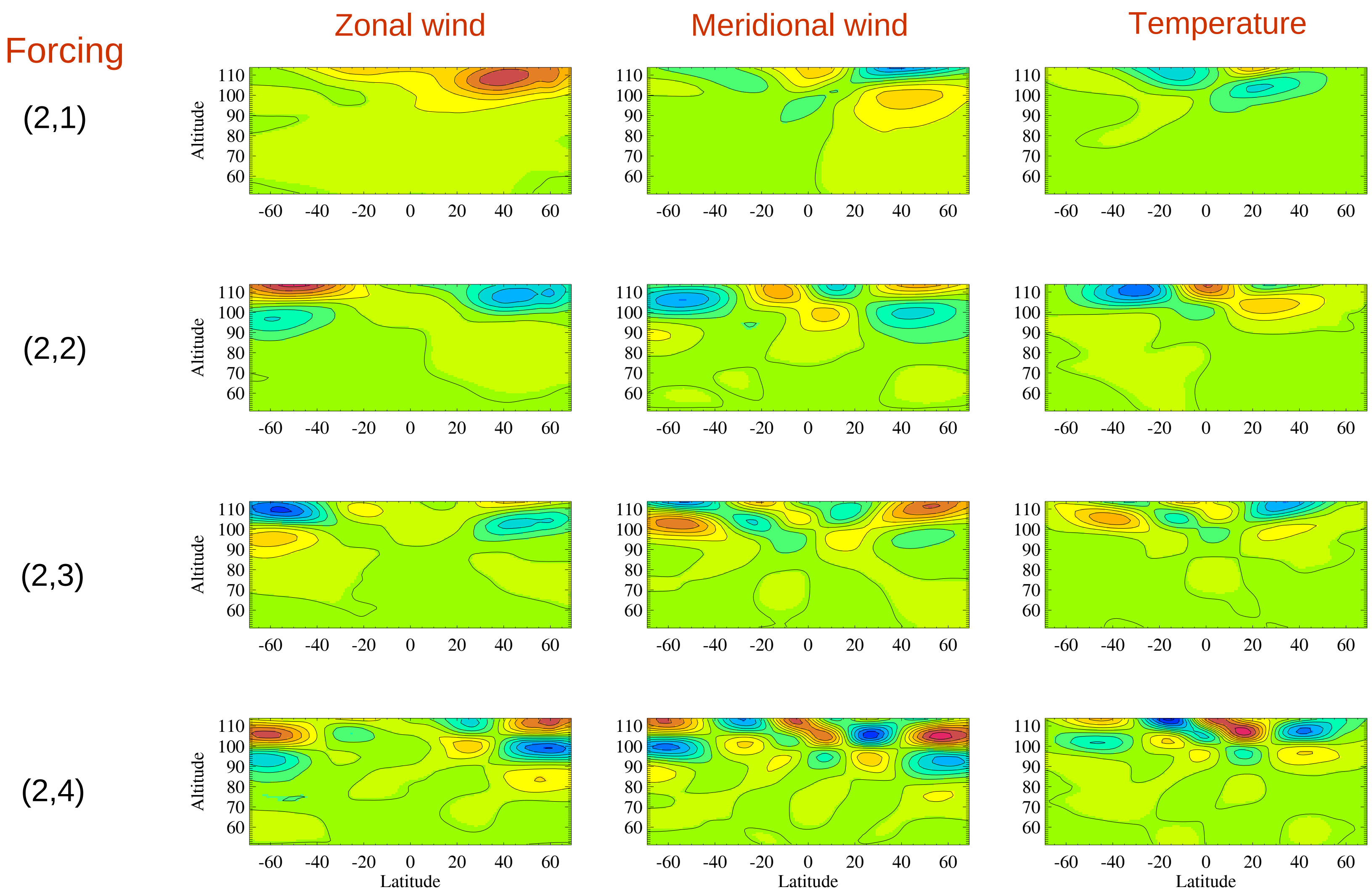
Diurnal tide basis functions

Generated with a linear tidal model, GW forcing, eddy, molecular diffusion;
URAP March wind/temperature background;
Forced in a thin layer by heating with a Hough function horizontal structure



Semi-diurnal tide basis functions

Tide patterns are distinct from each other and from the geostrophic modes



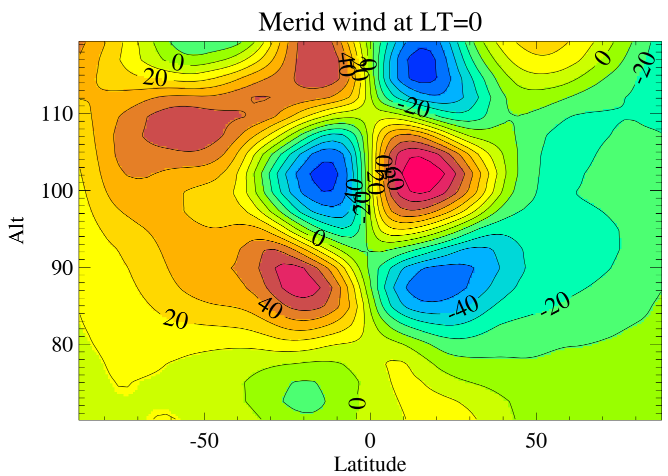
Validation experiment: proof of concept

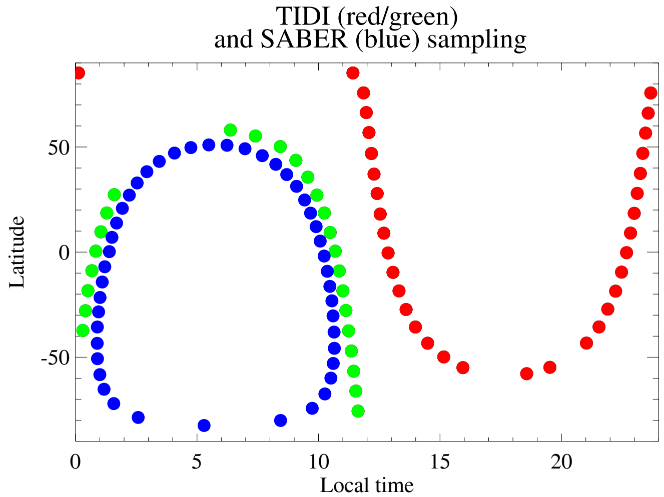
- Tide and mean flow are simulated with a nonlinear model forced with solar heating of water vapor (NVAP) and ozone (UARS) ;
- Model results sampled by TIMED observation pattern for March 1, 2004;
- Linear tide modes are calculated with a linear model using same mean flow used in the nonlinear simulation
- Eddy diffusion and GW forcing are solved for
- This experiment shows there is enough information in data from a single day to reproduce the tide and mean flow of the control run.

Construction of the simulated data

meridional wind segment

Synoptic view

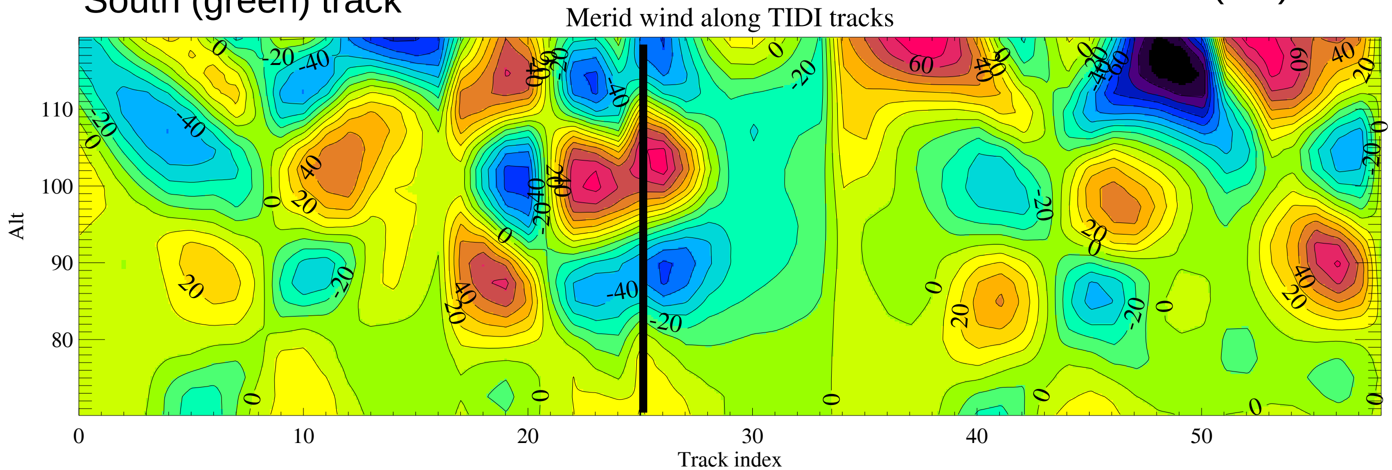




South (green) track

North (red) track

TIMED view



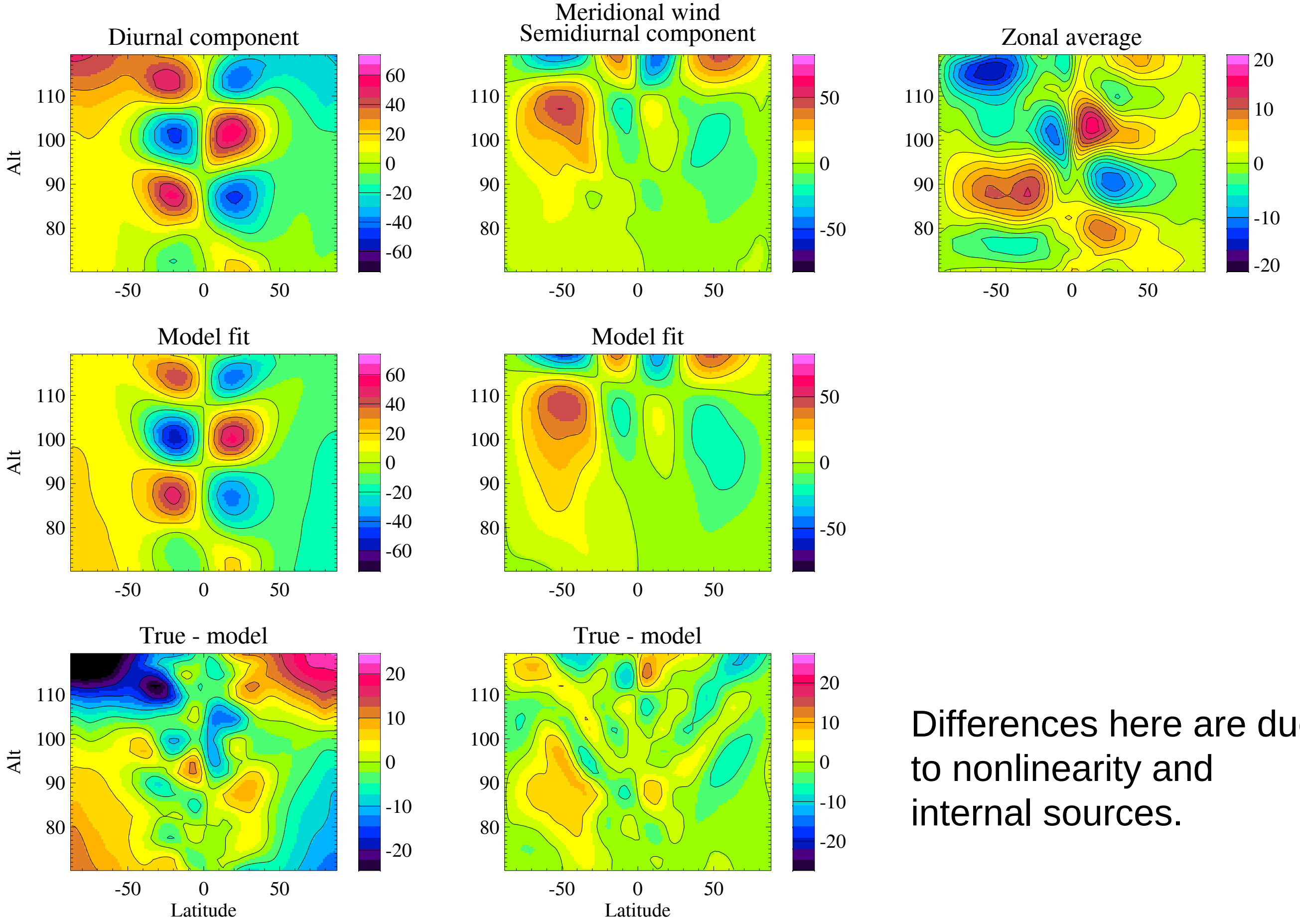
Assimilation results: Meridional wind component

Assimilation determines complex coefficients in a Hough mode expansion, allowing reconstruction of results at all local times; reconstructed here at local time=0h

“Real” Atmosphere (control run)

Assimilation results

Difference



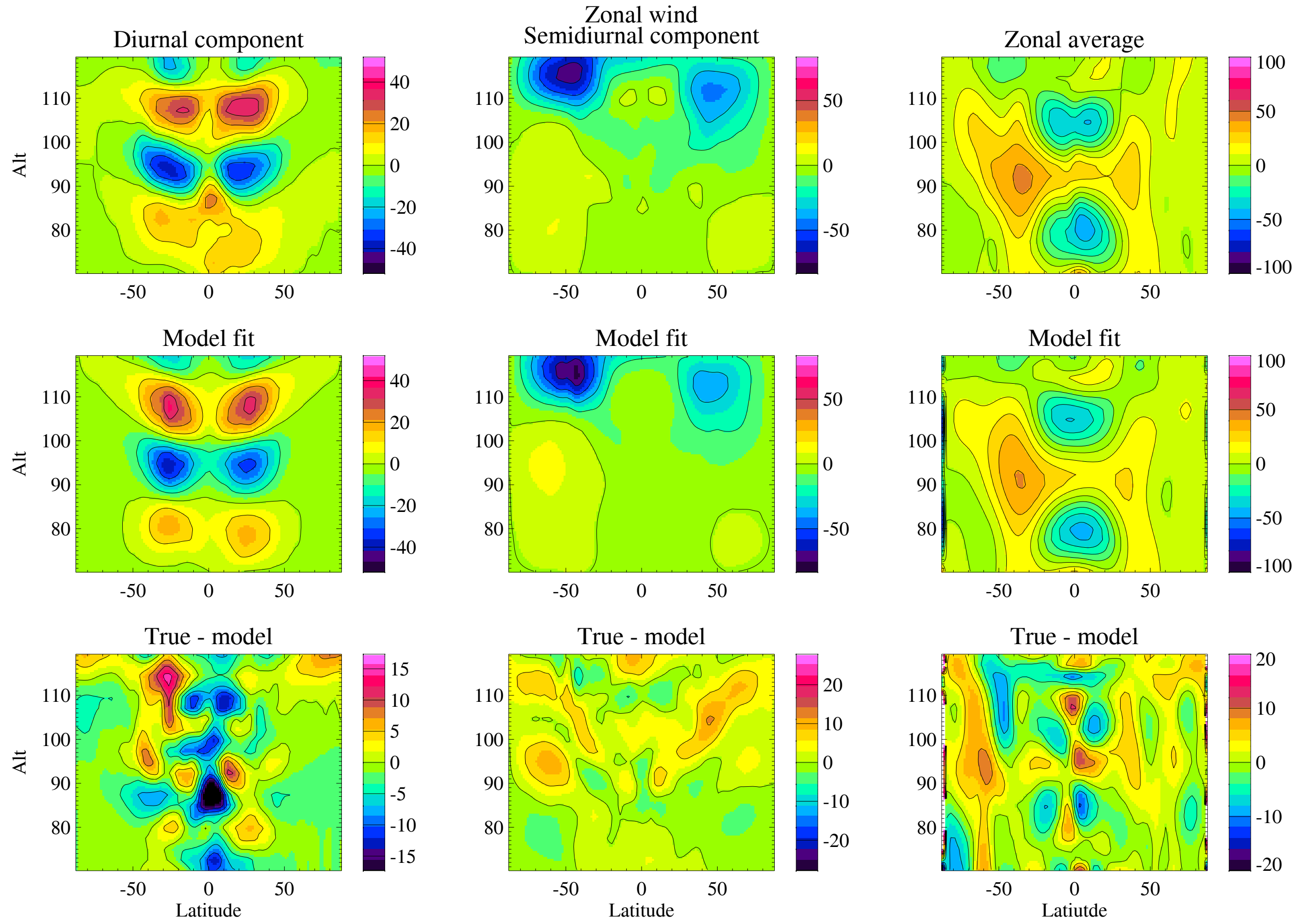
Differences here are due to nonlinearity and internal sources.

Assimilation results: Zonal wind component
reconstructed at local time=0h

"Real" atmosphere

Assimilation results

Difference

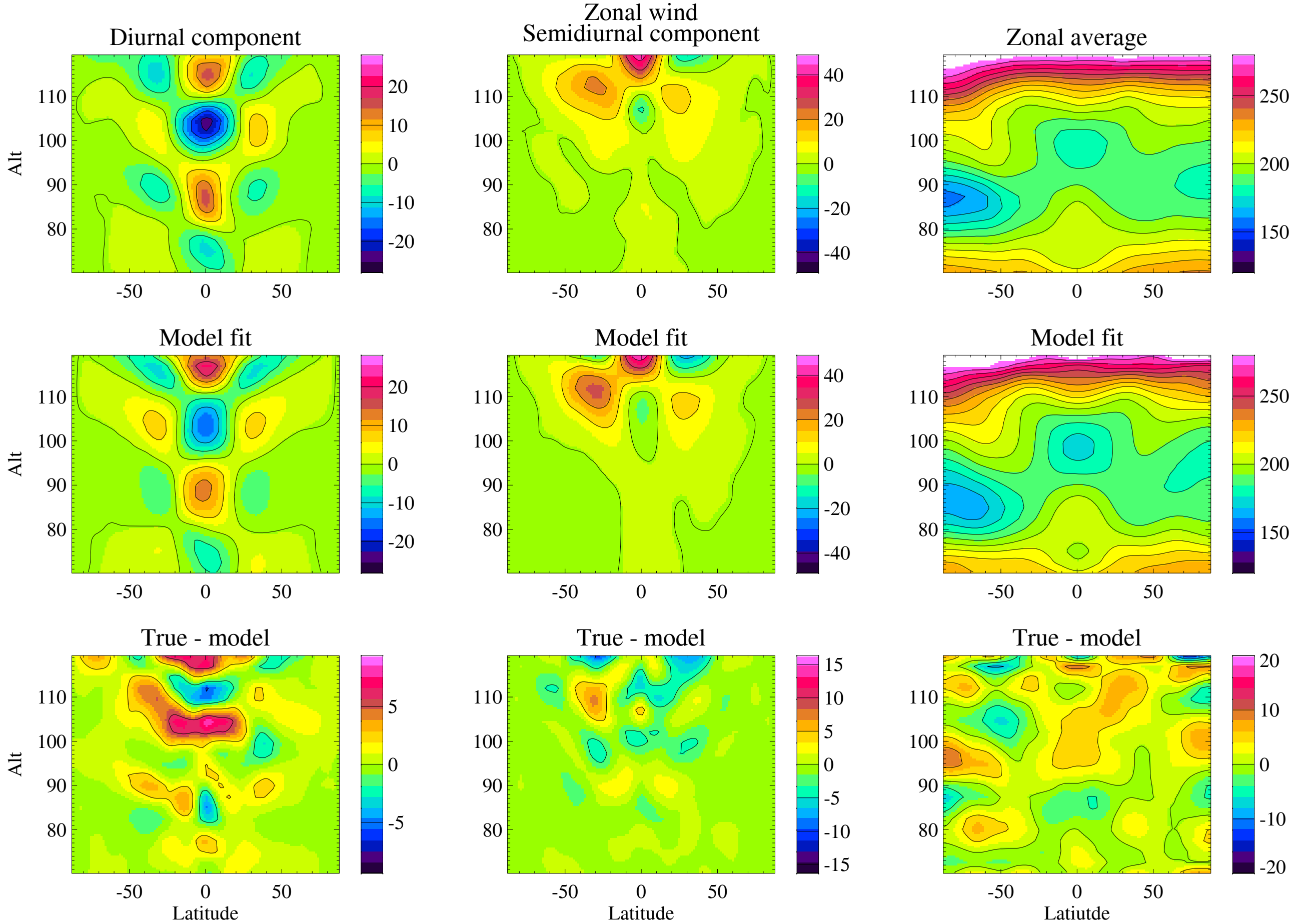


Assimilation results: Temperature component
reconstructed at local time=0h

“Real” atmosphere

Assimilation results

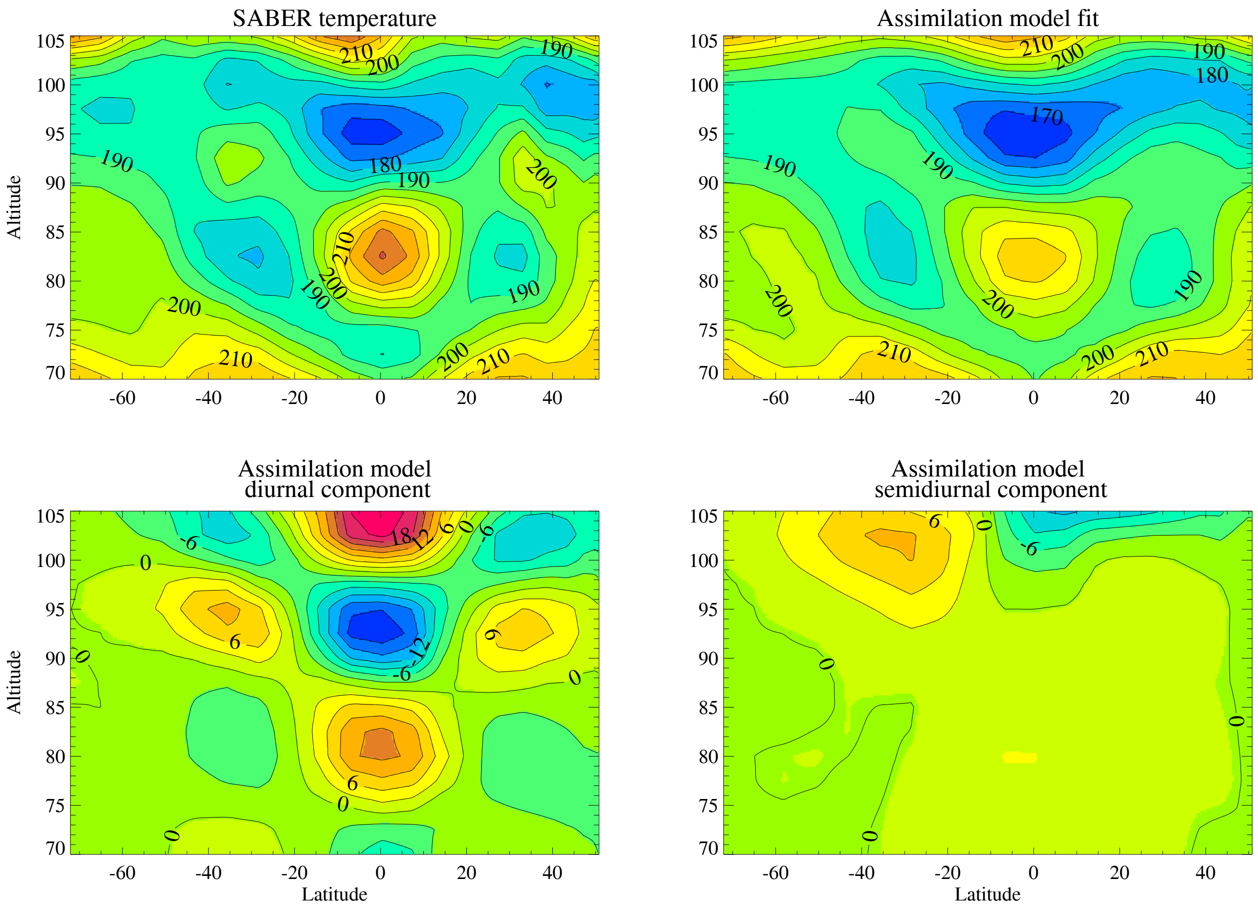
Difference



Assimilation model fit to TIMED data:

(March 20, 2004)

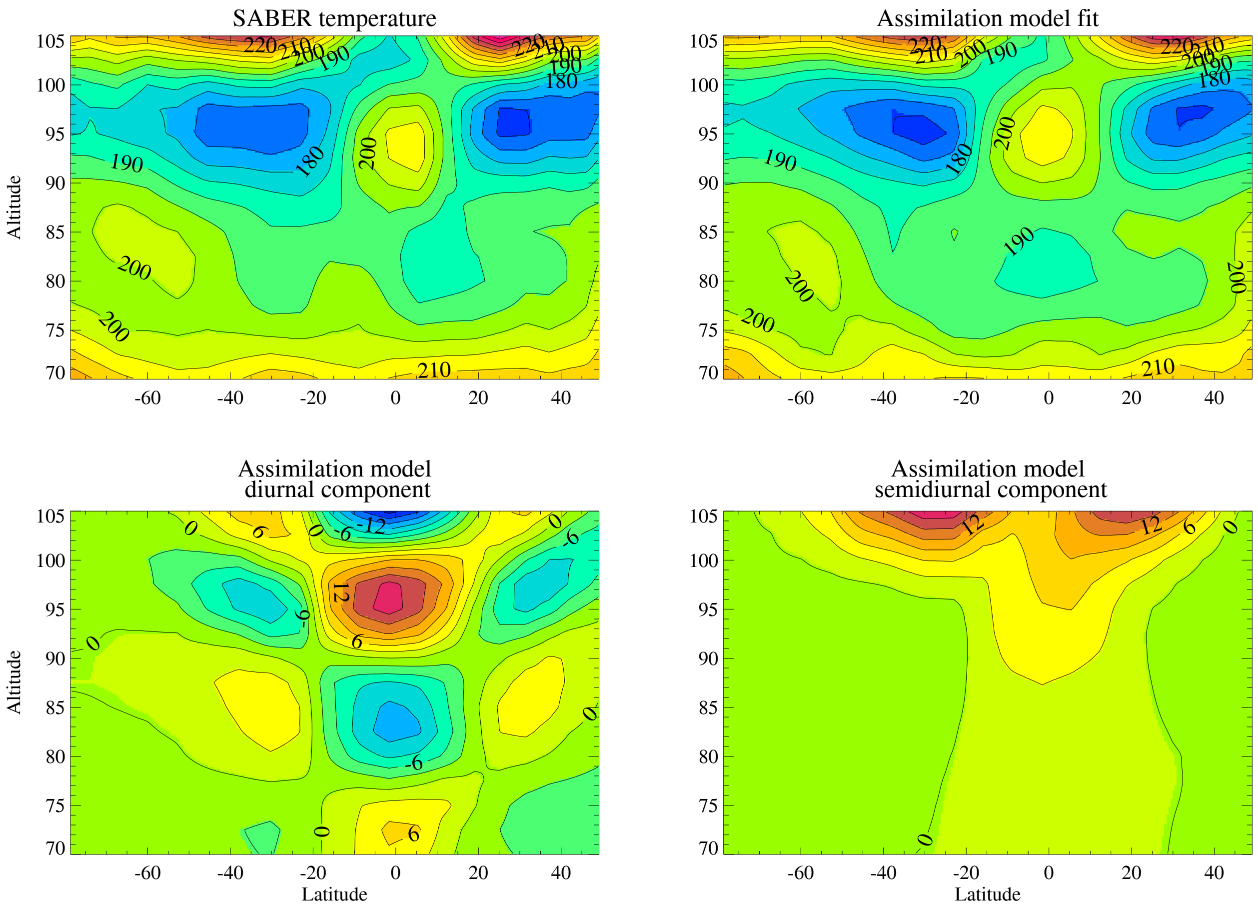
SABER temperatures, ascending node



Mean +
tides

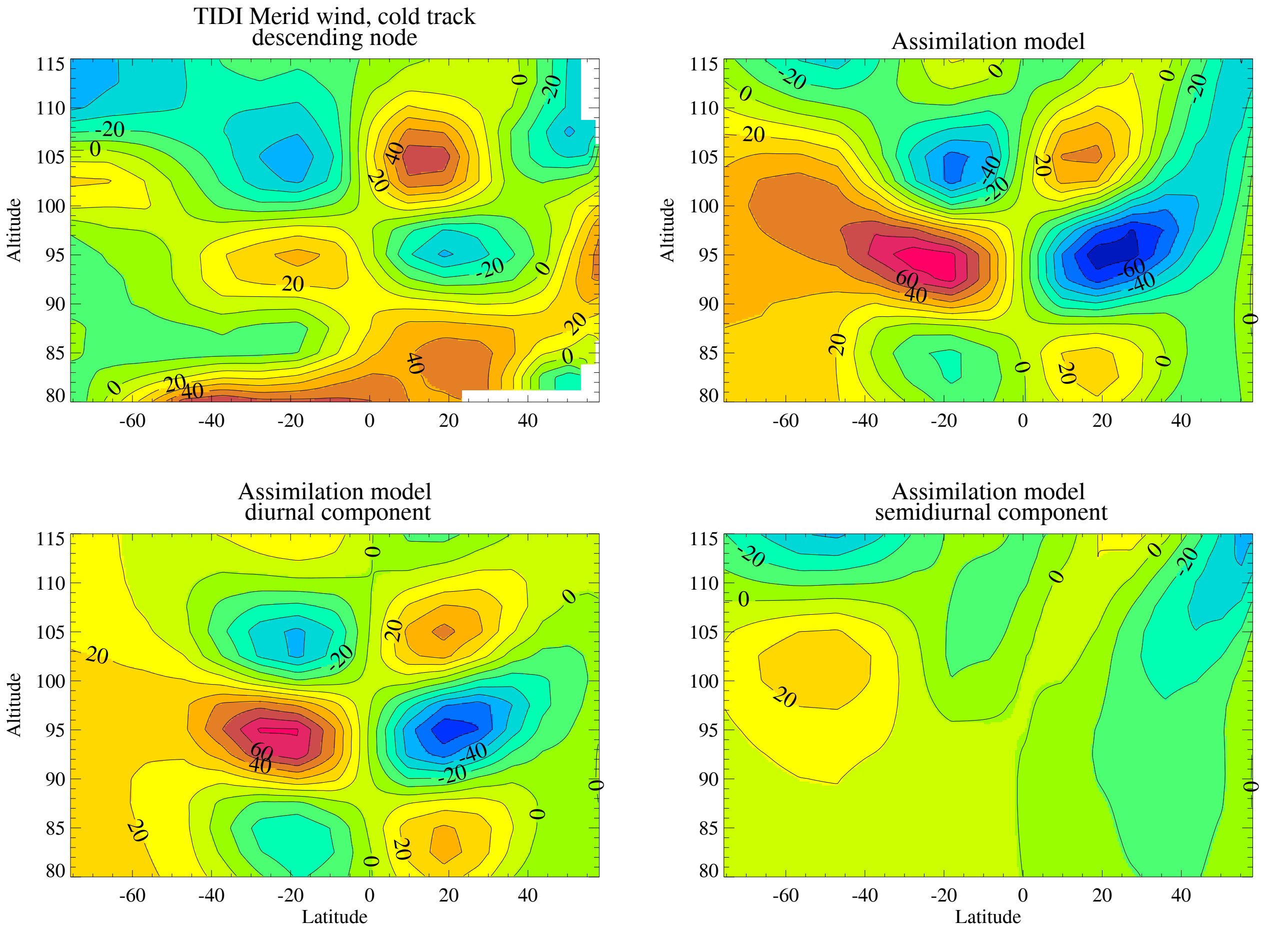
Assimilation model fit to TIMED data:

SABER temperatures, descending node



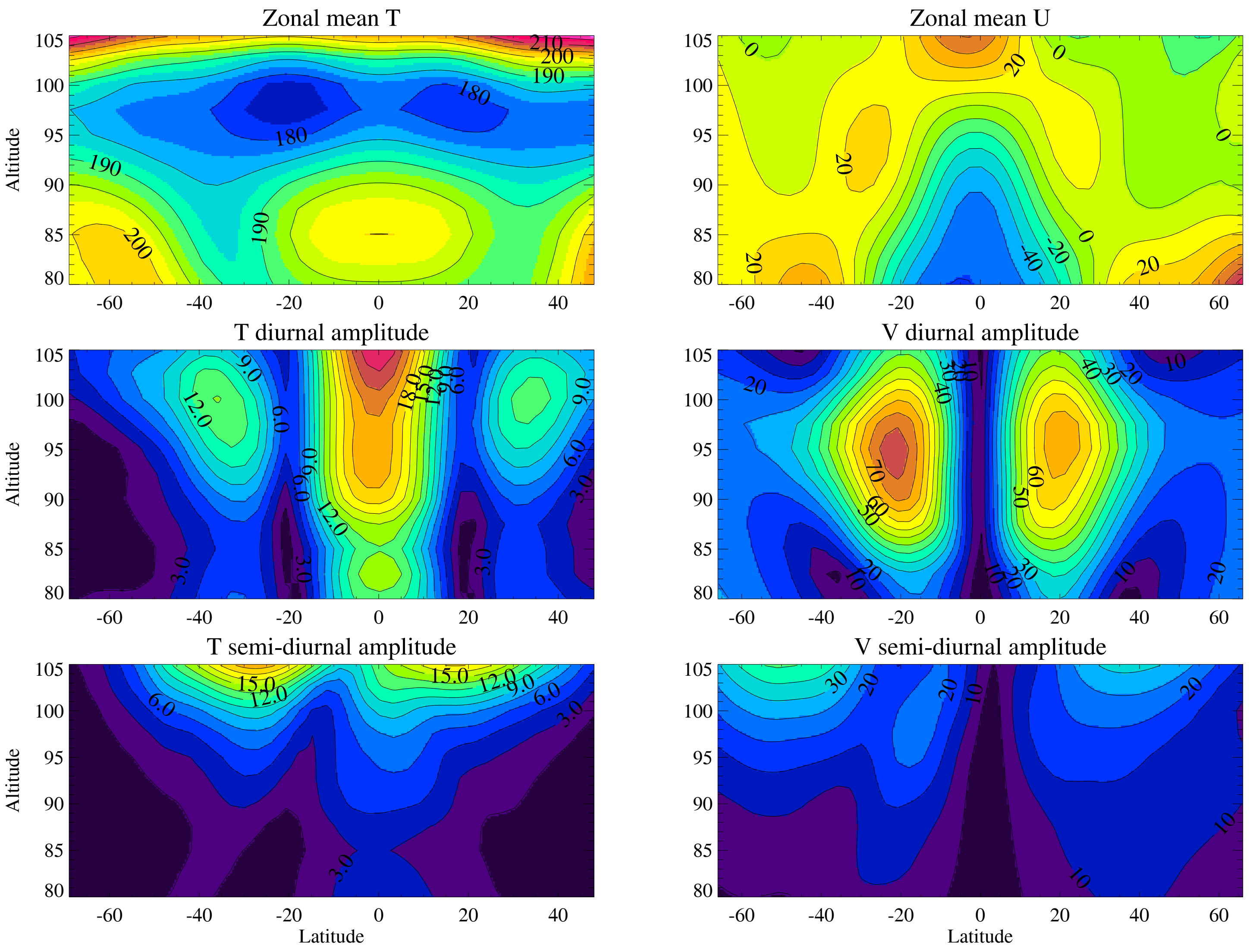
Assimilation model fit to TIMED data:

TIDI meridional wind, descending node, cold track



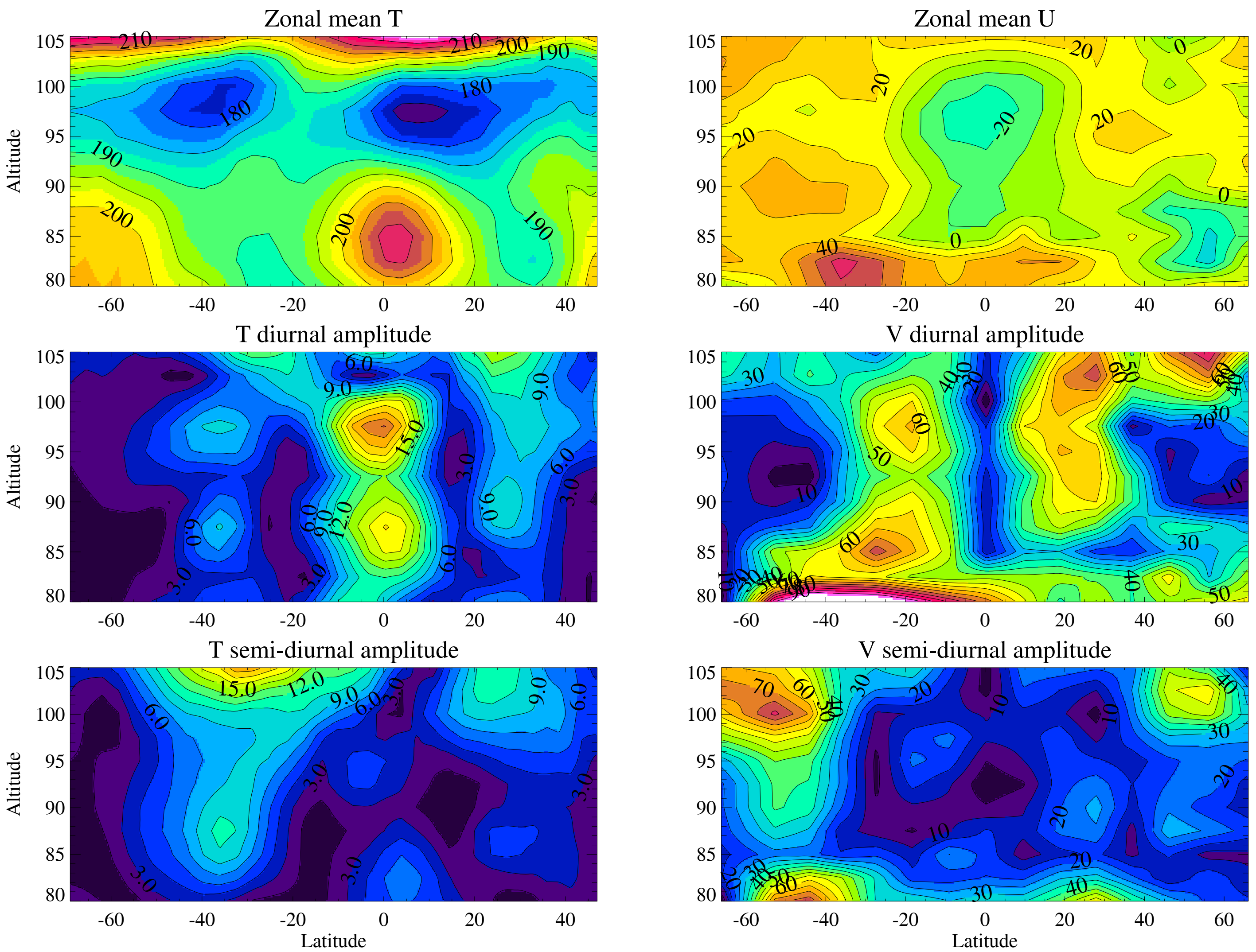
Assimilation model fit to TIMED data:

Mean flow and tidal amplitudes

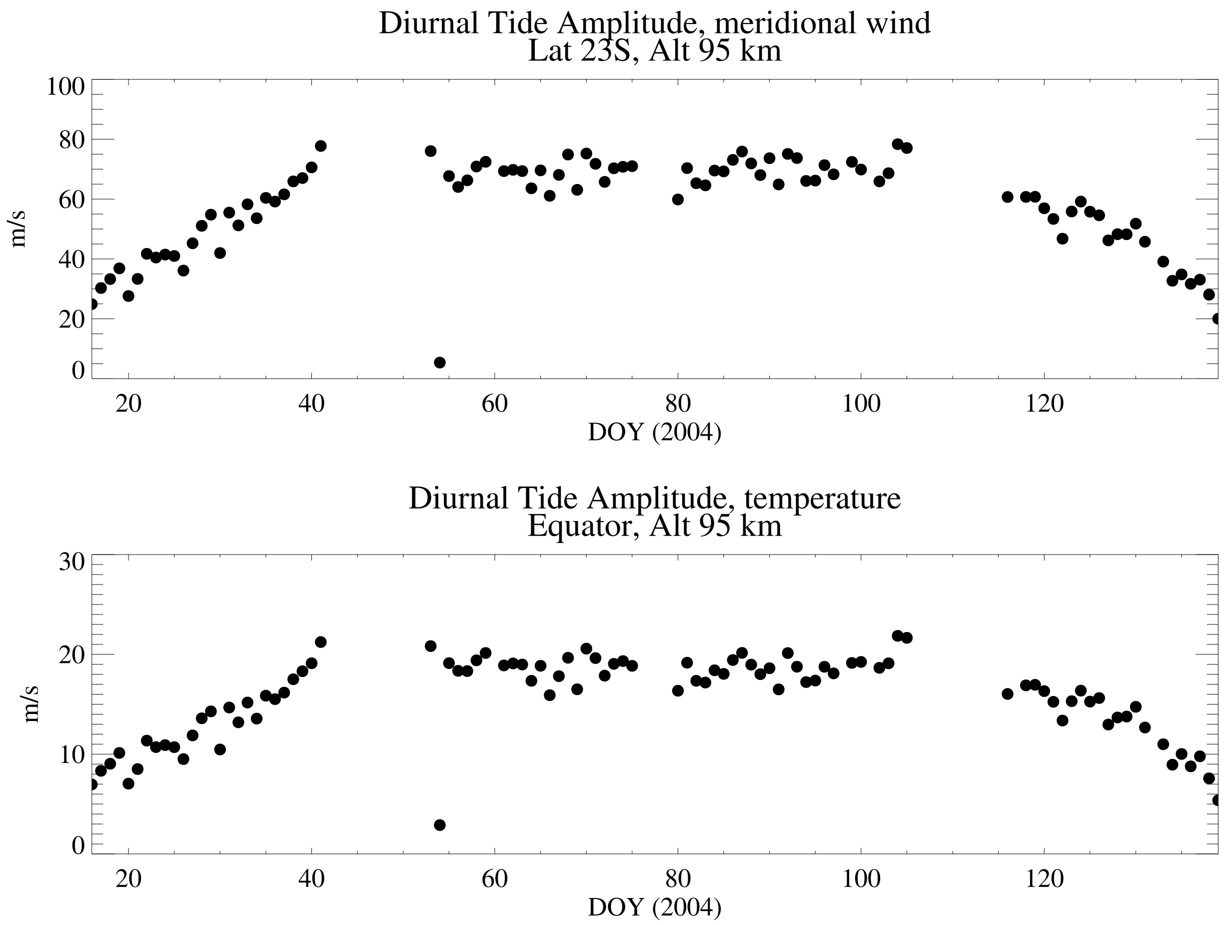


Harmonic fit to TIMED data:

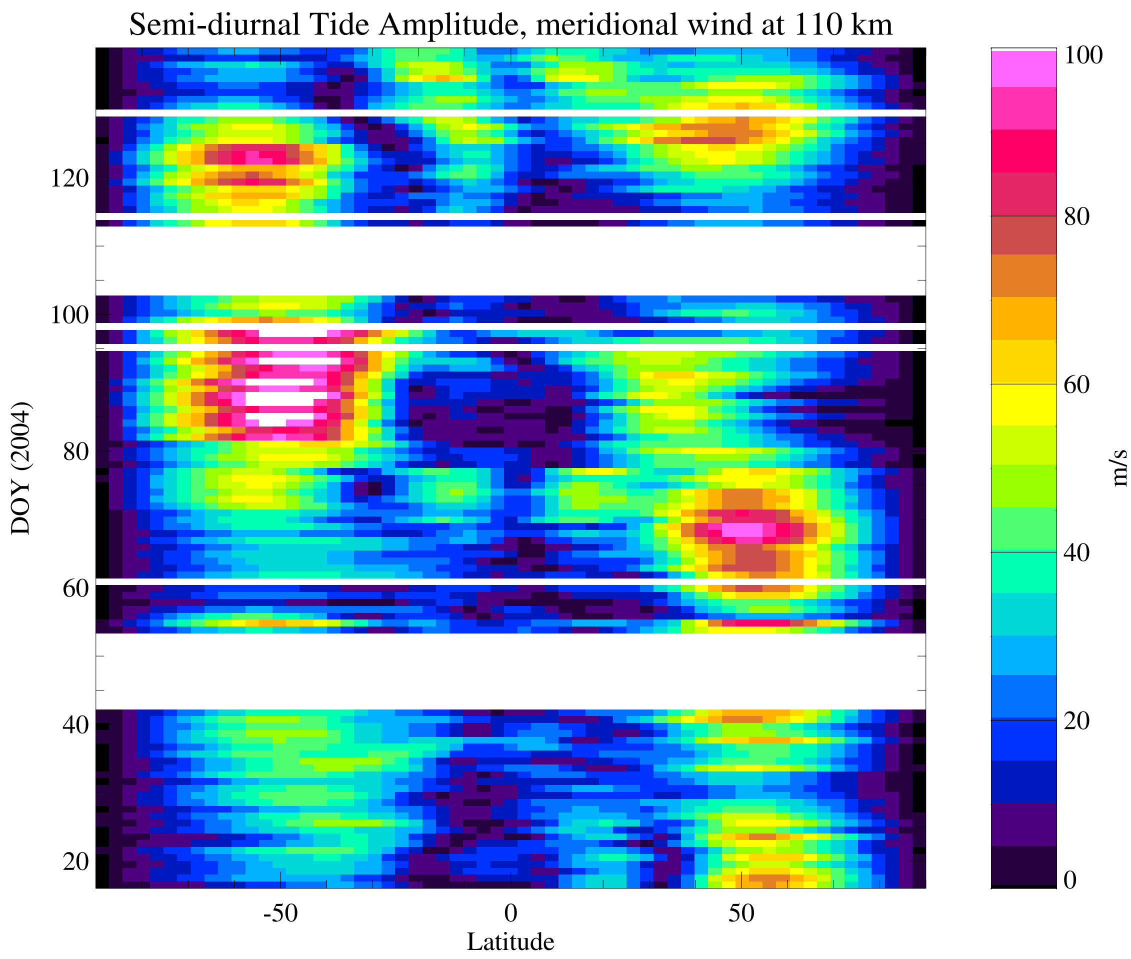
Zonal mean wind and temperature; tidal amplitudes



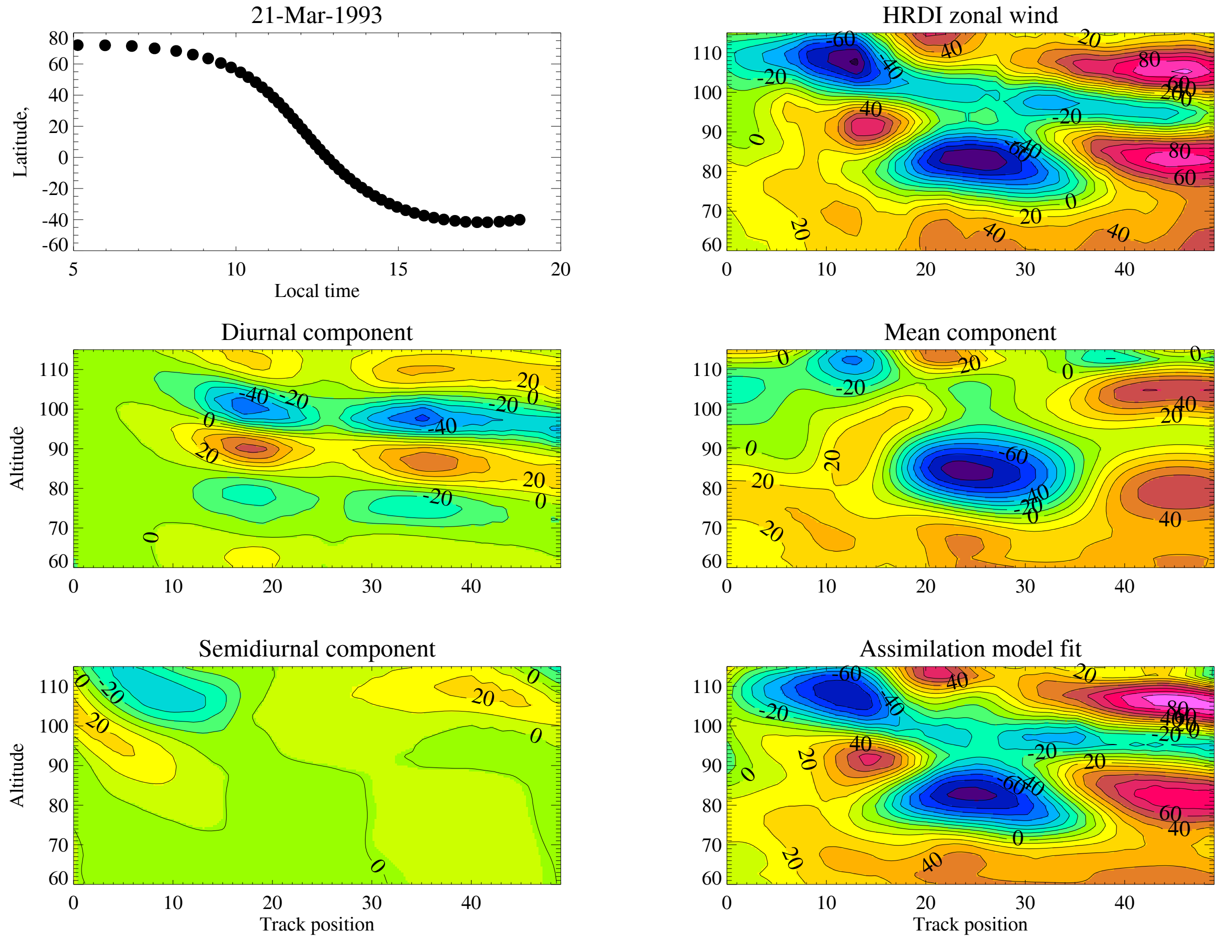
Amplitude of the diurnal tide
TIMED measurements, Jan-May 2004



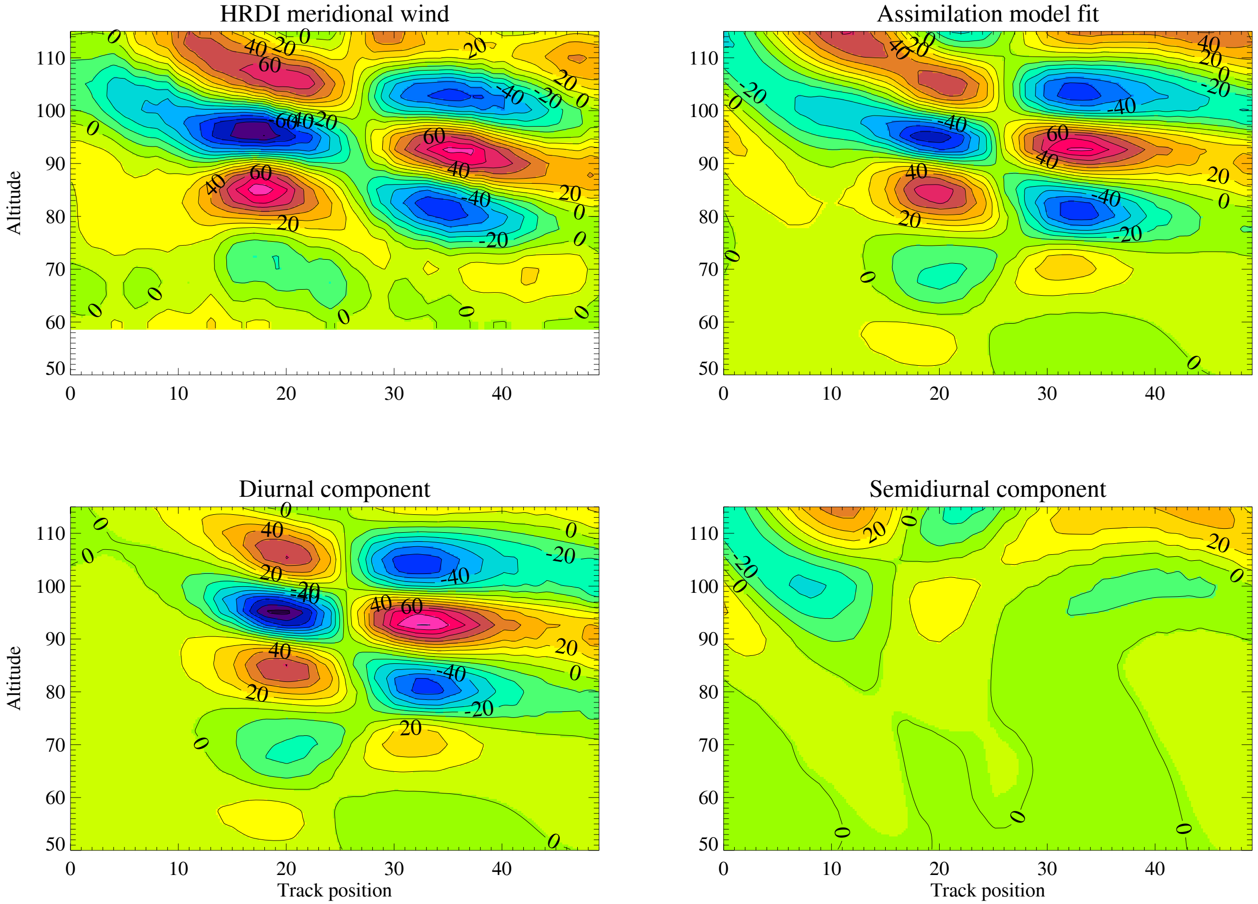
Semi-diurnal v amplitude at 110 km



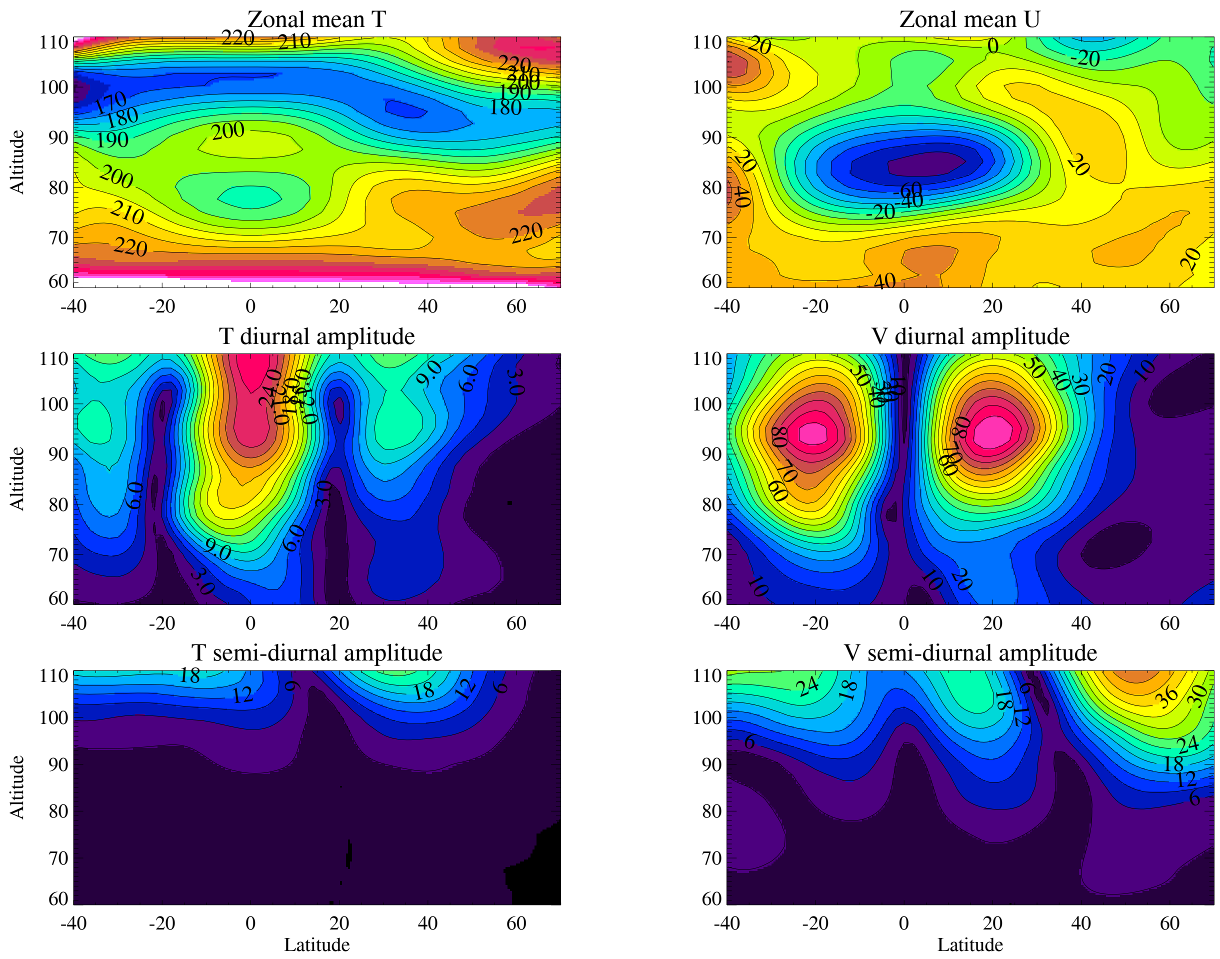
Results for HRDI data
Zonal wind



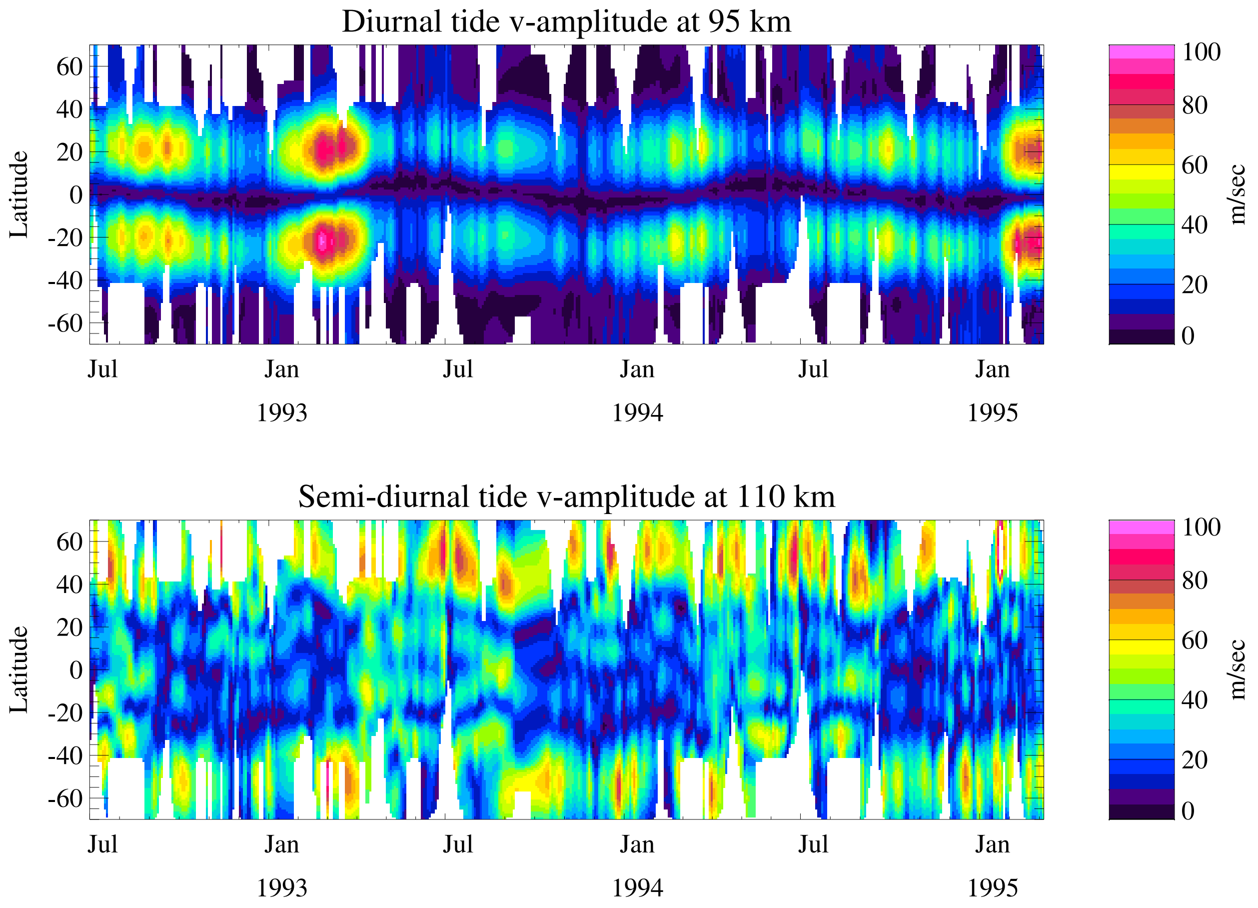
Results for HRDI data meridional wind



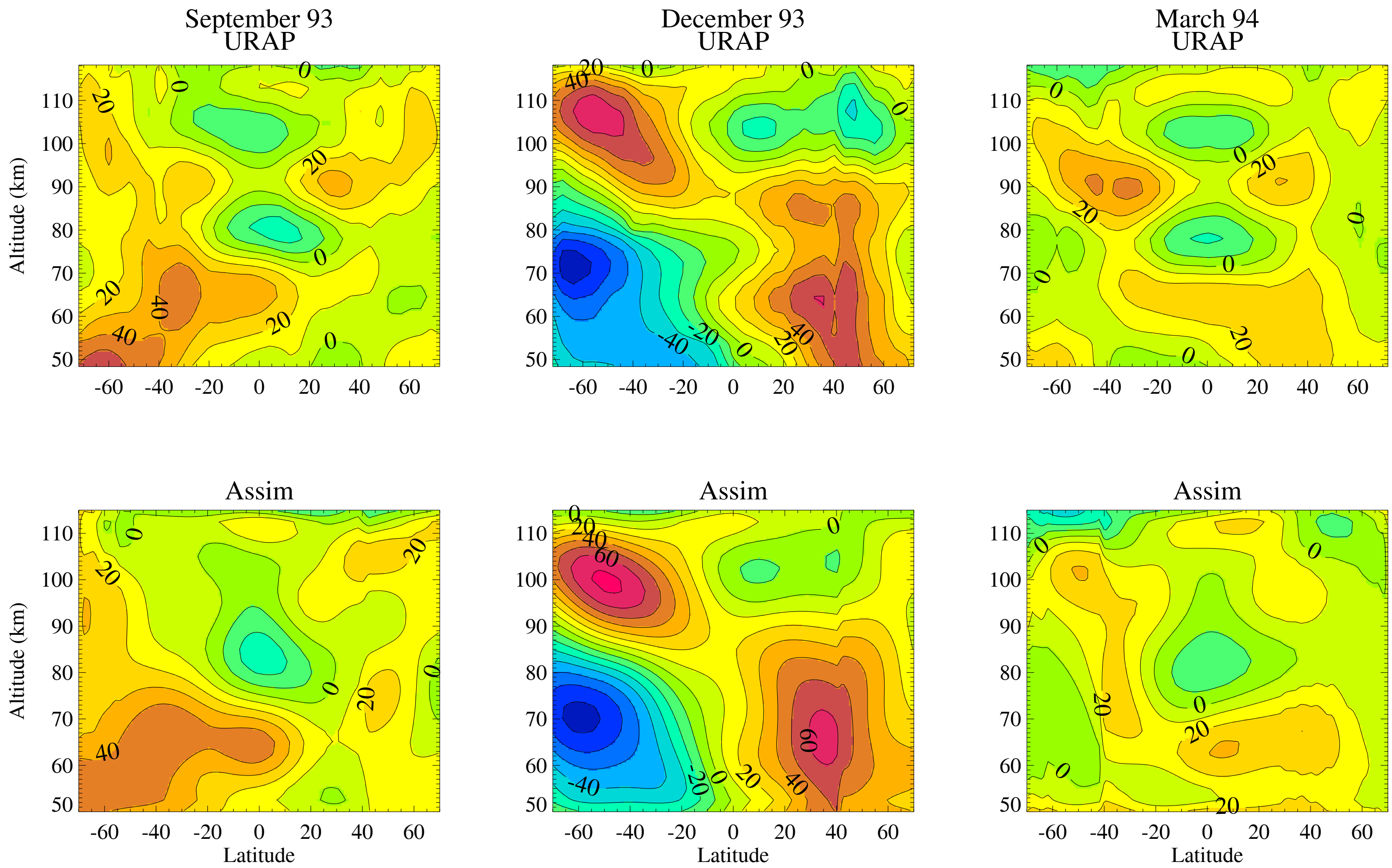
HRDI assimilation mean flow and tide amplitudes



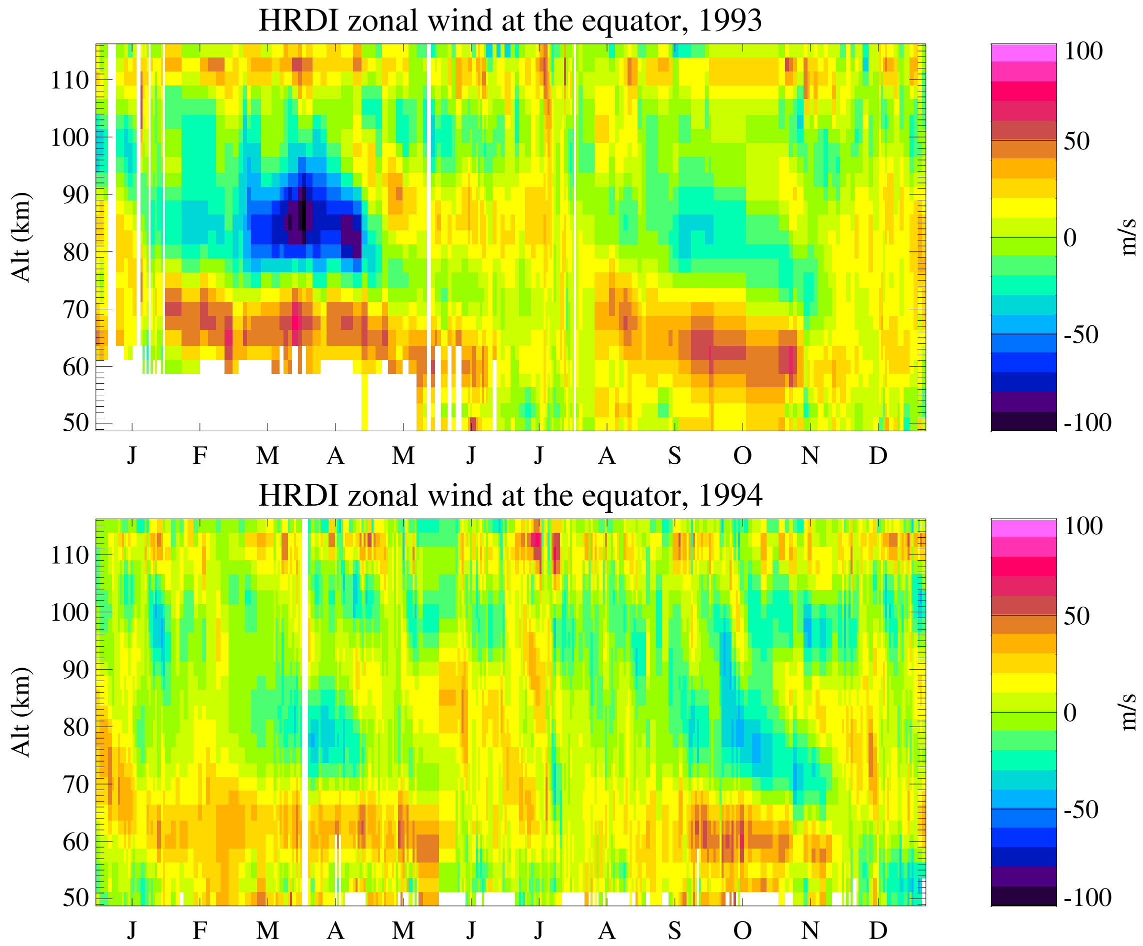
HRDI tide amplitudes meridional wind at 96 km 1992-1995



Assimilation monthly and zonal mean zonal wind compare to URAP wind climatology: tides removed

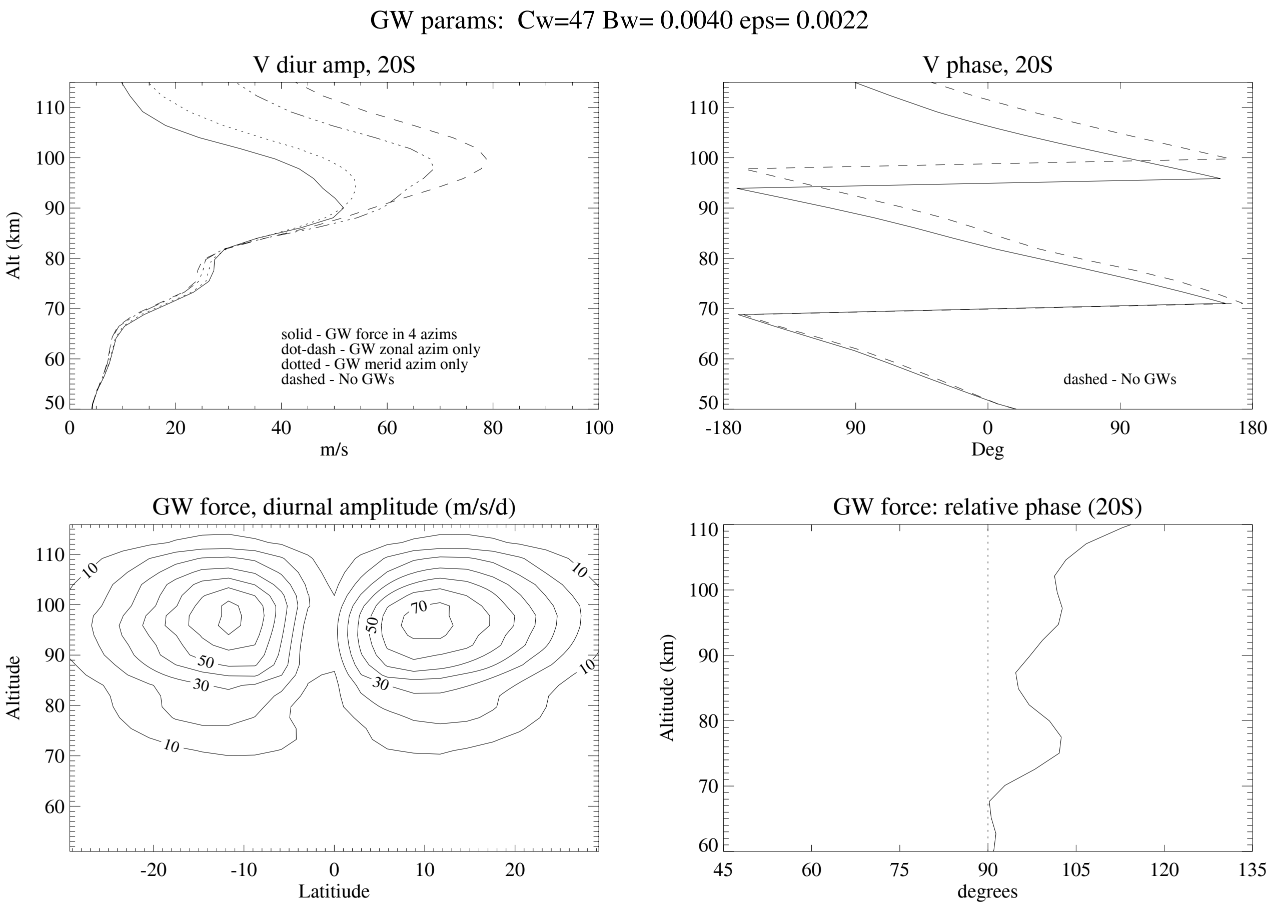


Mean zonal wind at the equator
Evolution of the SAO

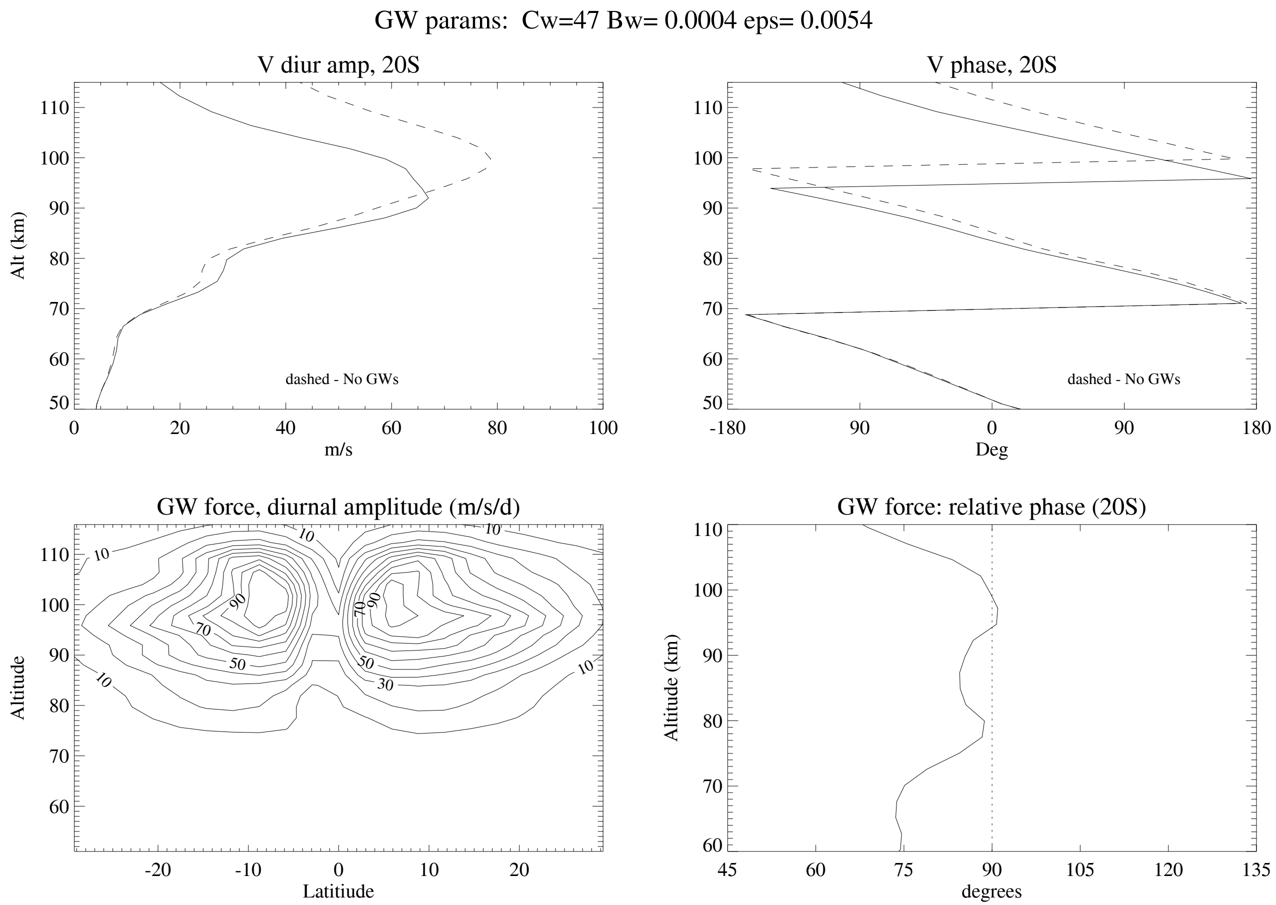


GW effects on the tide

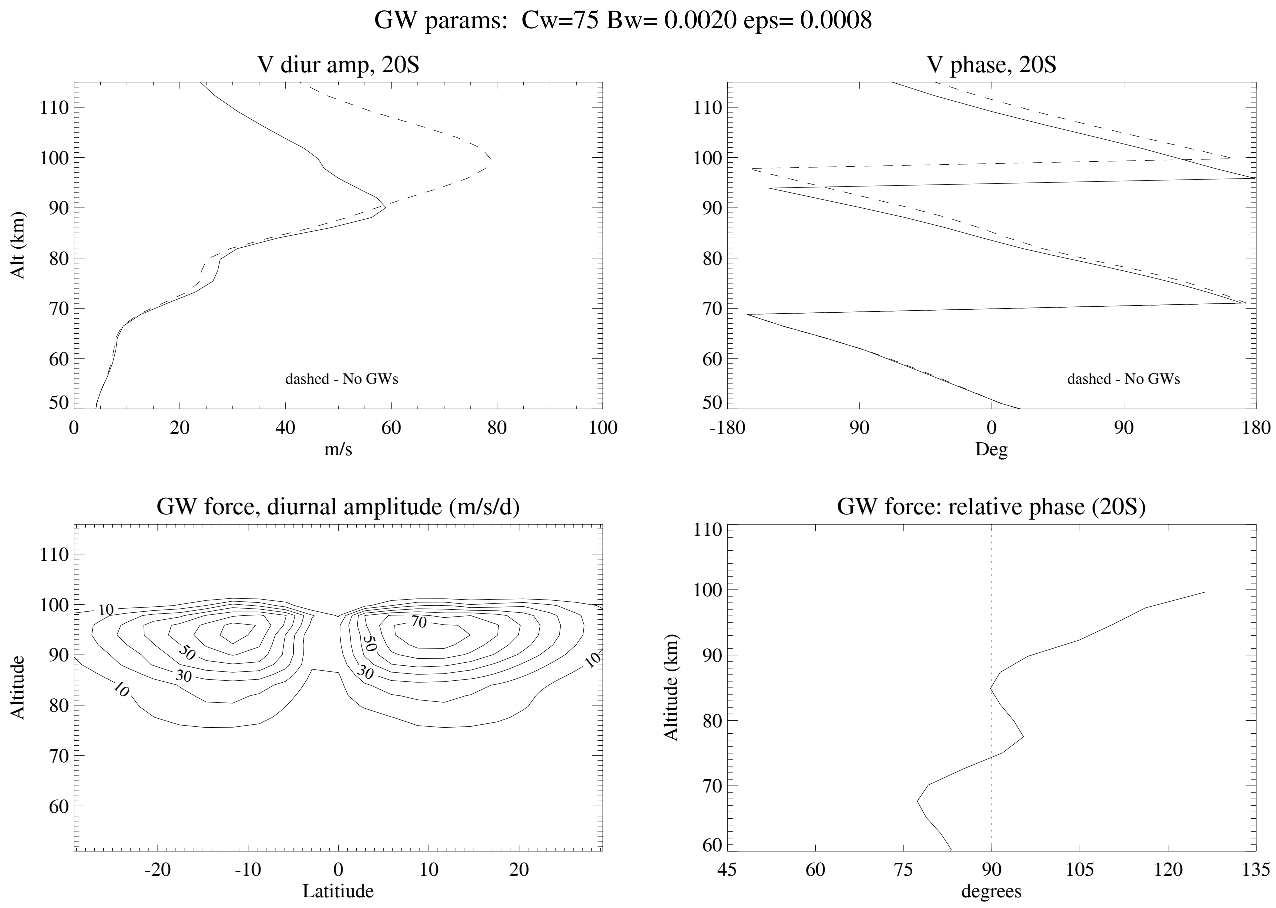
Best fit to HRDI



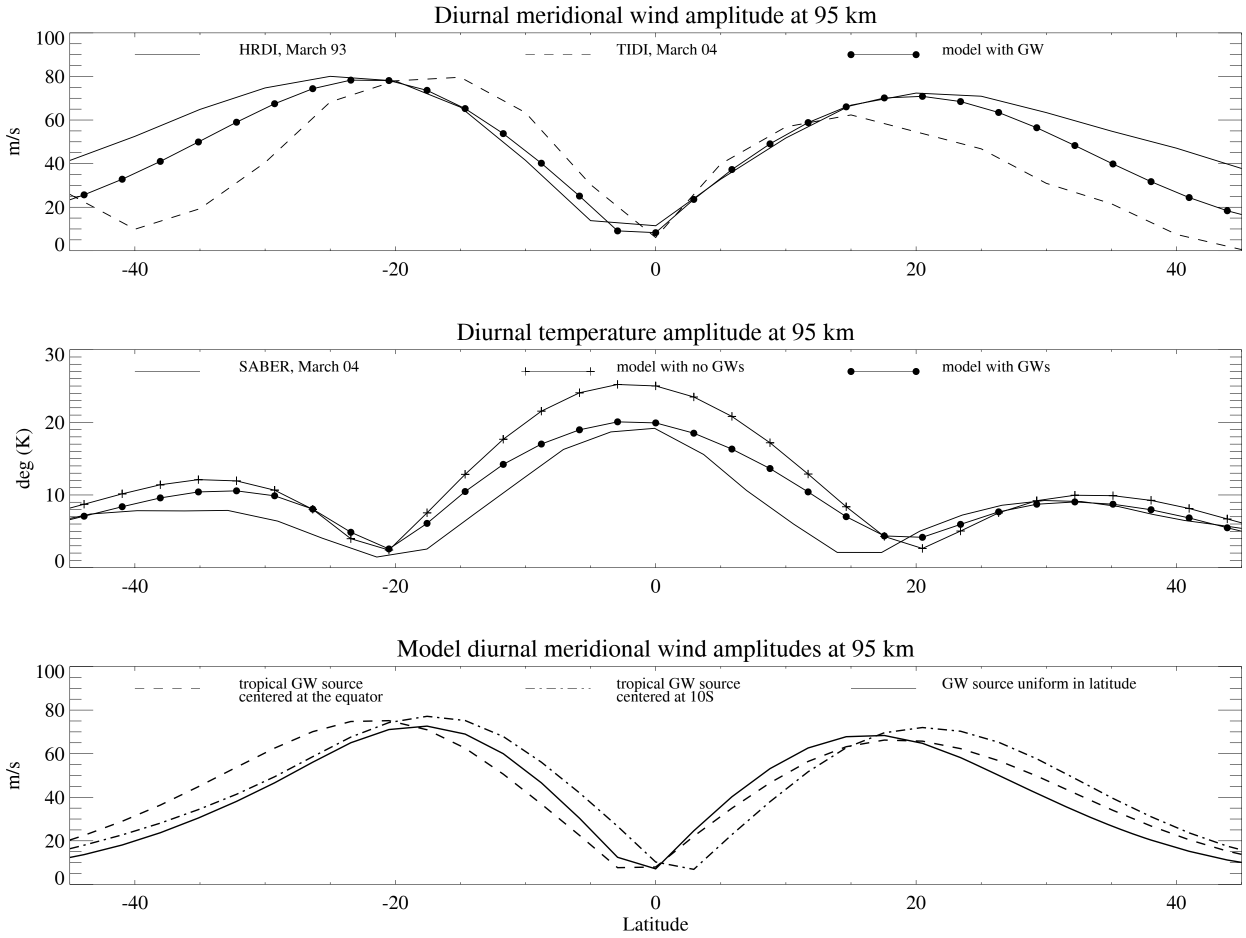
Example: decrease momentum flux of the GW source, increase intermittency



Example: change width of the GW source



GW forcing also affects:
Horizontal structure
relative amplitude of wind and temperature



Summary and future work

- Assimilation of MLT data should involve adjustment of wave sources and parameterization schemes as part of an initialization step
- Improve mean flow representation: more accurate balance, include MMC
- Include internal tide source and nonlinear interactions in the model
- Expand to 3D to include other waves: nonmigrating tides, 2-day wave, stationary waves