Tidal Coupling in the Earth's Atmosphere

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OUTLINE

- Motivation - Observations
- Tidal Nomenclature/Characteristics/Sources
- Results from the Global-Scale Wave Model (GSWM)
- Results from the Thermosphere-Ionosphere-Mesosphere-Electrodynamics General Circulation Model (TIME-GCM)
- Cautionary Words on the Interpretation of Measurements

Temperatures over Fort Collins, CO (41°, -105°)

Na lidar measurements (after *She et al., 2002*)

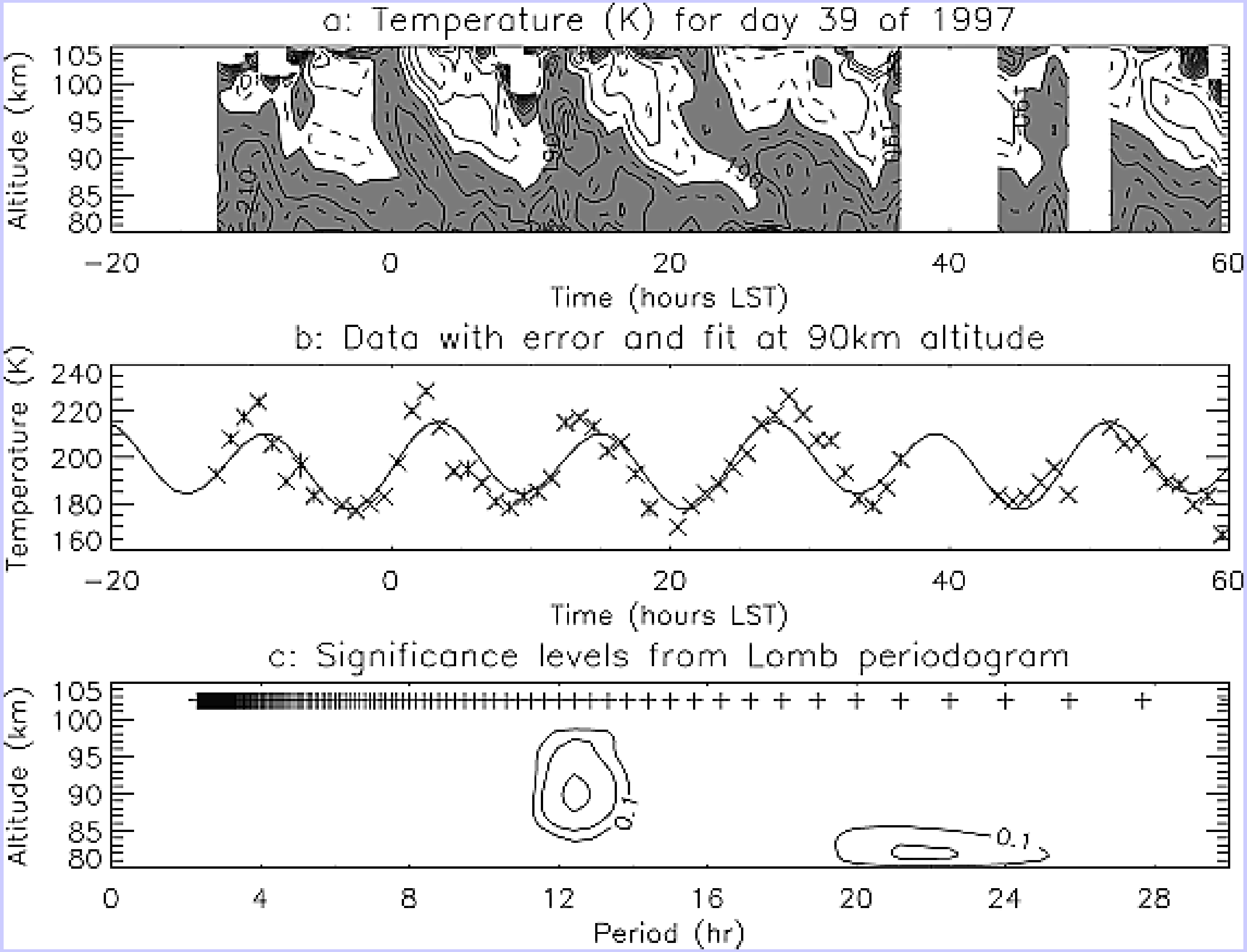
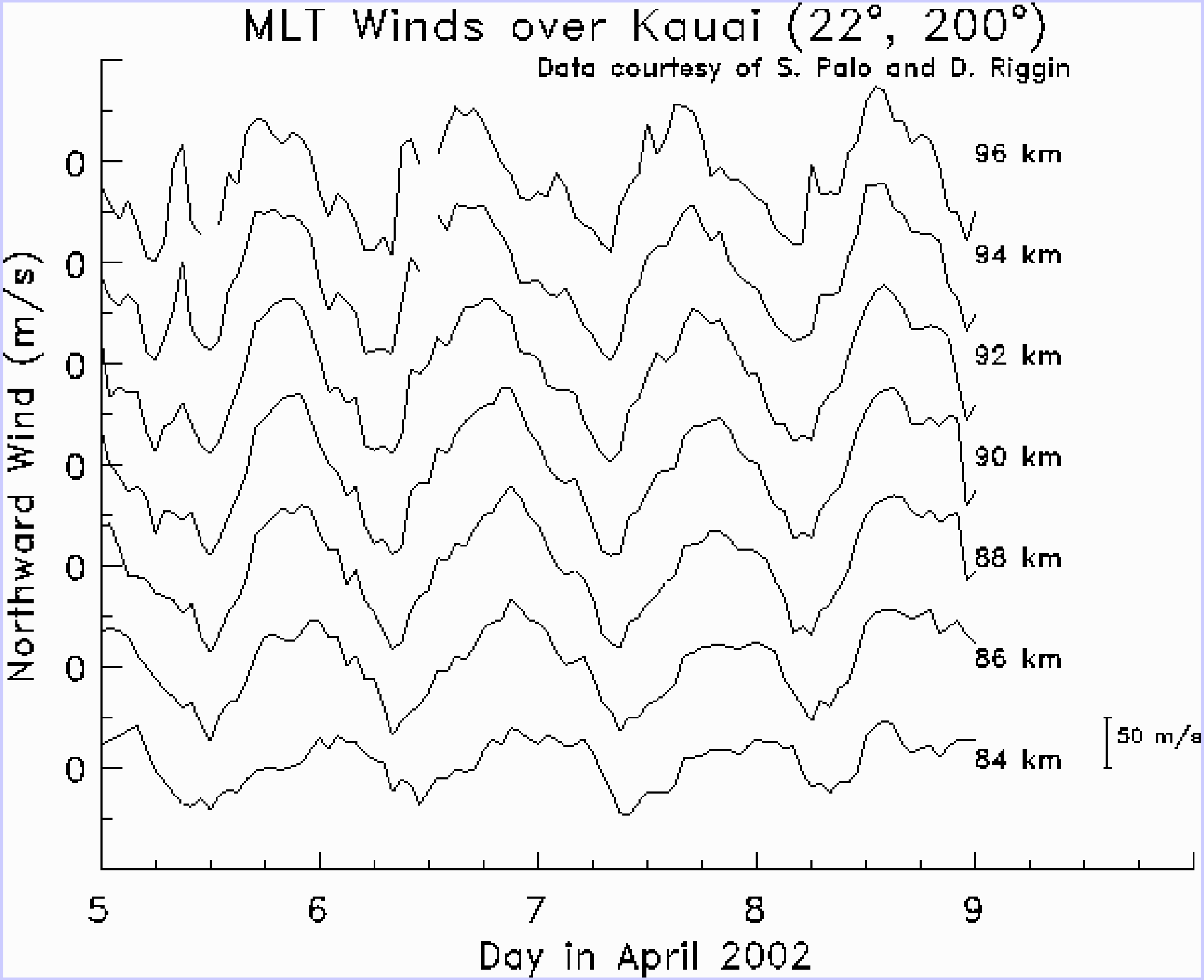
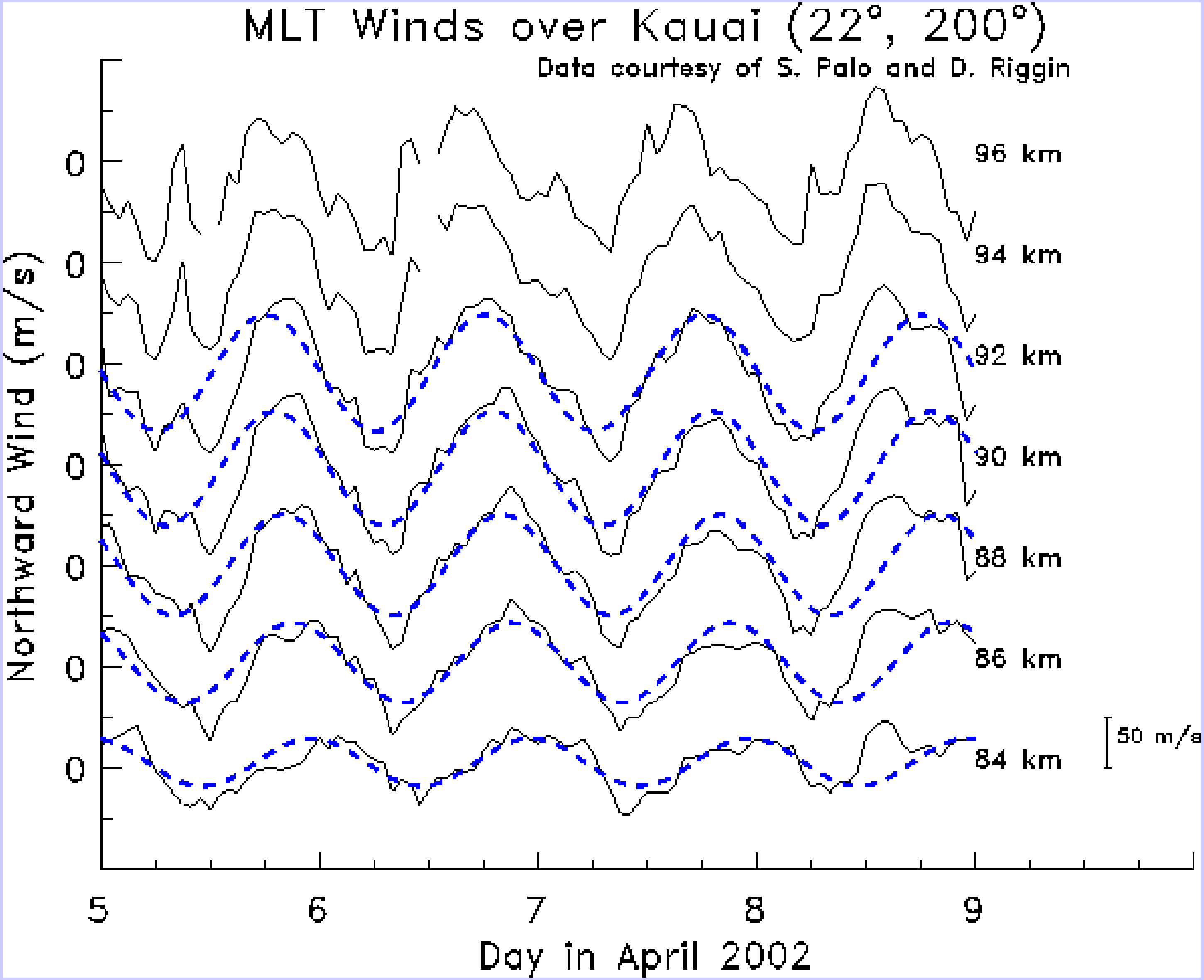


Exhibit 12-hour (semidiurnal) variations ➔ 30-50^{o}K peak-to-peak



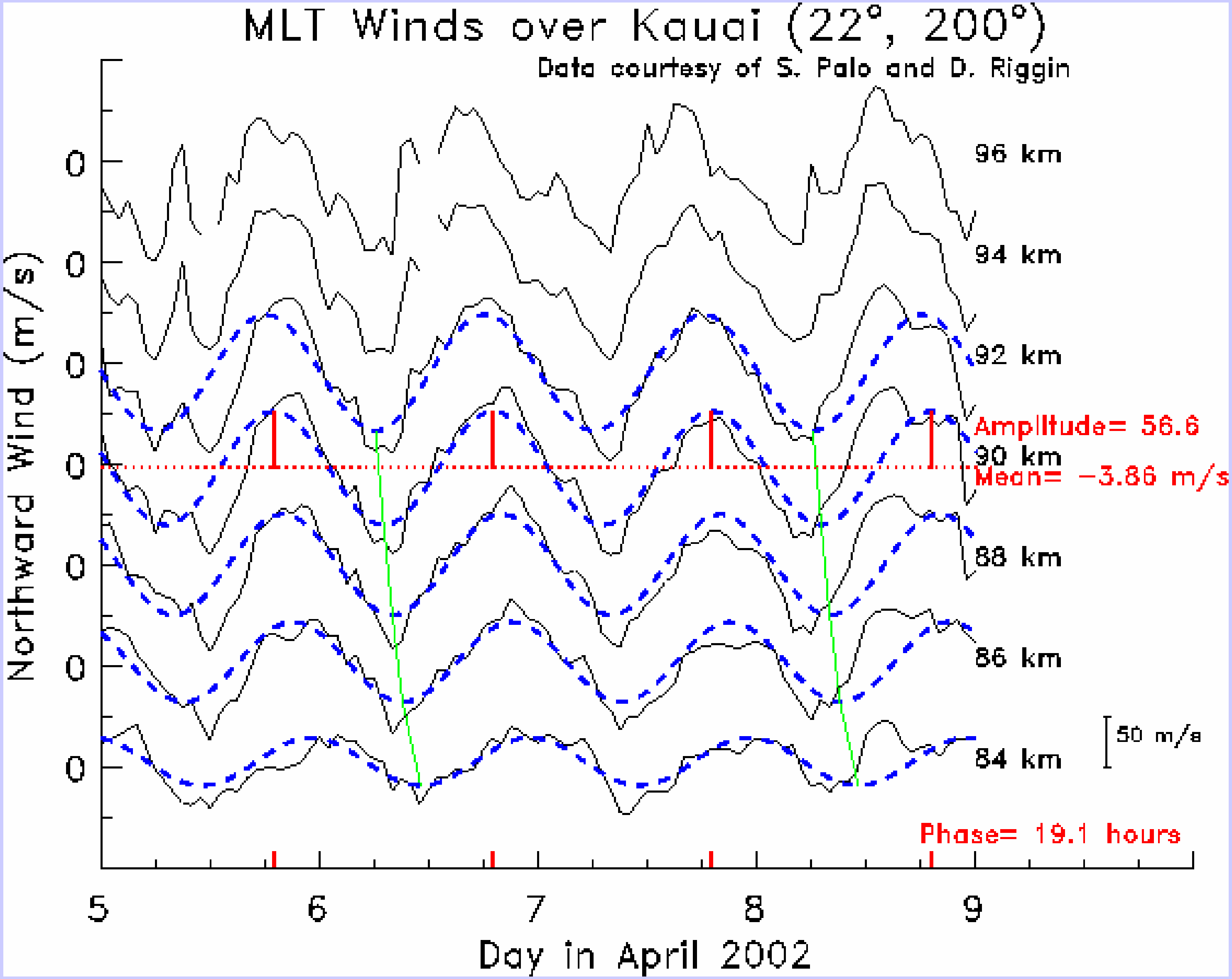
Medium Frequency (MF) Radar Measurements



24-hour (diurnal) variations ➔ 50 to > 100 m/s peak-to-peak

Amplitude increases with increasing altitude

Phase progresses downward with time



The characteristics of an upward propagating wave

Solar Atmospheric Tides

Ubiquitous - Persistent - Measurable

Global-Scale Waves

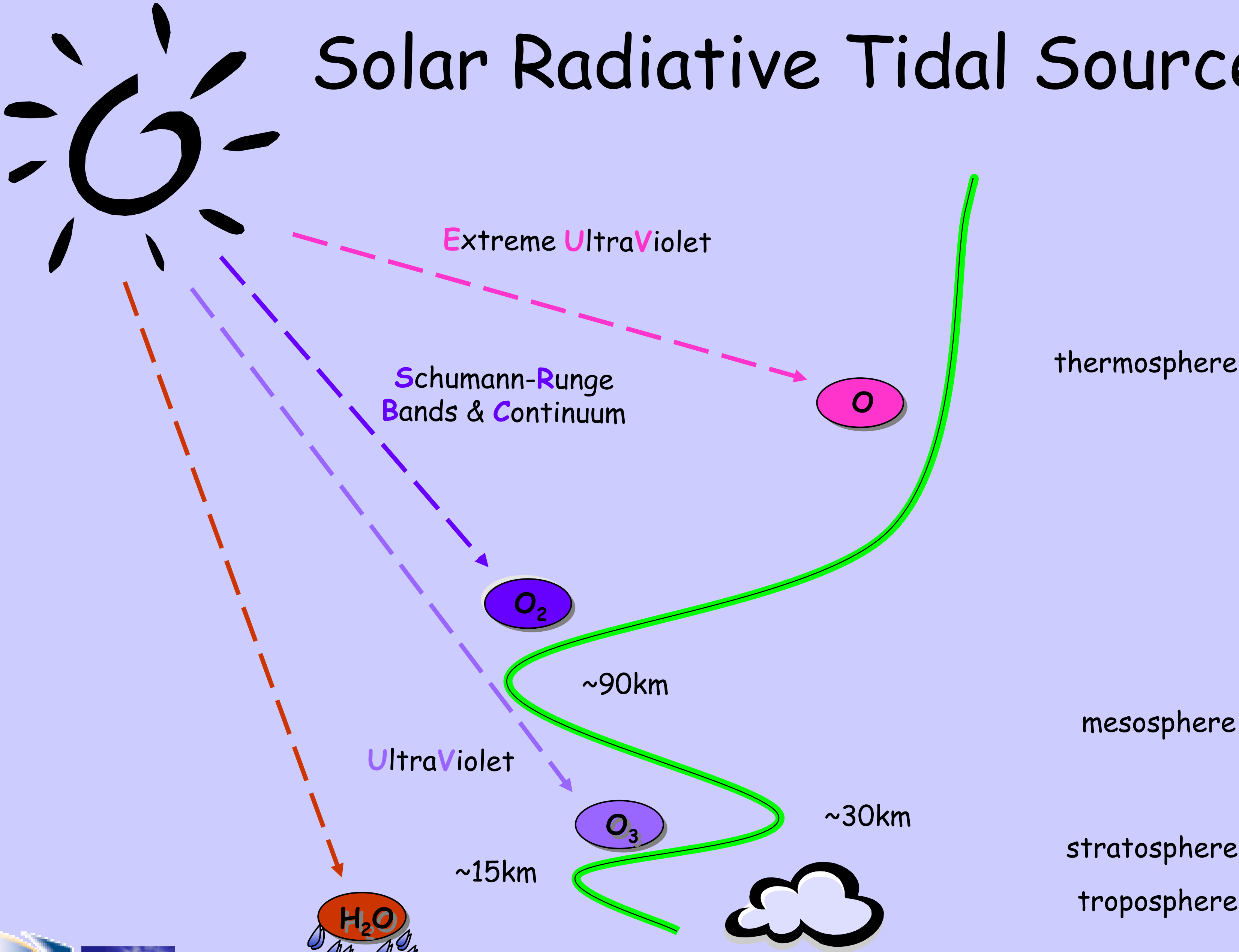
periods - harmonics of a solar day

migrating - propagate westward with the Sun

nonmigrating - propagate { eastward / westward* / stands }

- produce variations with longitude

Solar Radiative Tidal Sources



The Global-Scale Wave Model Results

- Solutions to the 2-D linearized steady-state tidal equations
- A priori:
  frequency
  wave number
  background atmosphere
- Non-classical response:
  background **U**
  background $\delta T/\delta\theta$
  dissipation
- Tidal forcing parameterizations:
  absorption of solar radiation*
  latent heat release
- Monthly tidal climatologies**

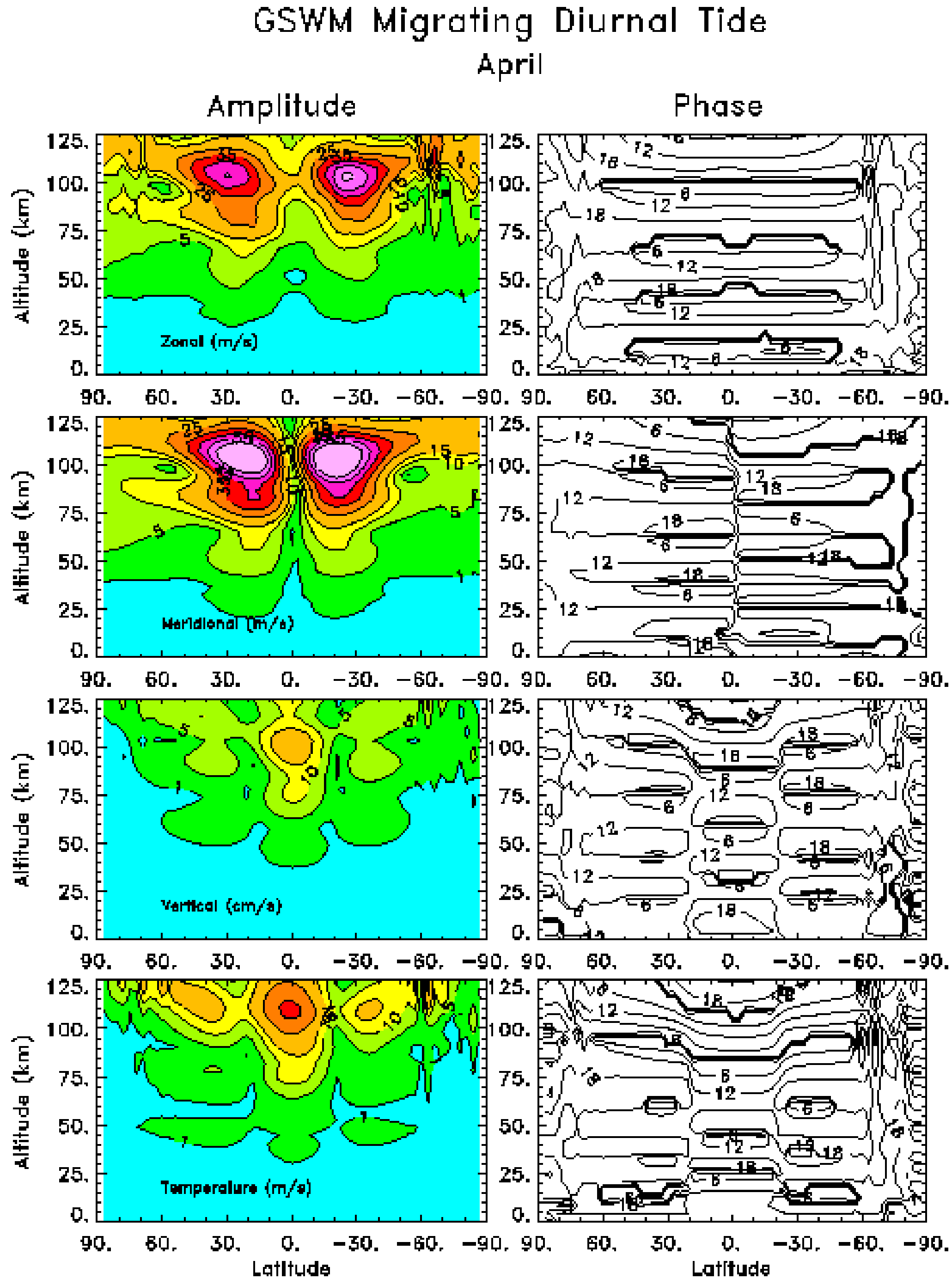
*GSWM-95; GSWM-98; GSWM-00
**GSWM-00

U

V

W

T



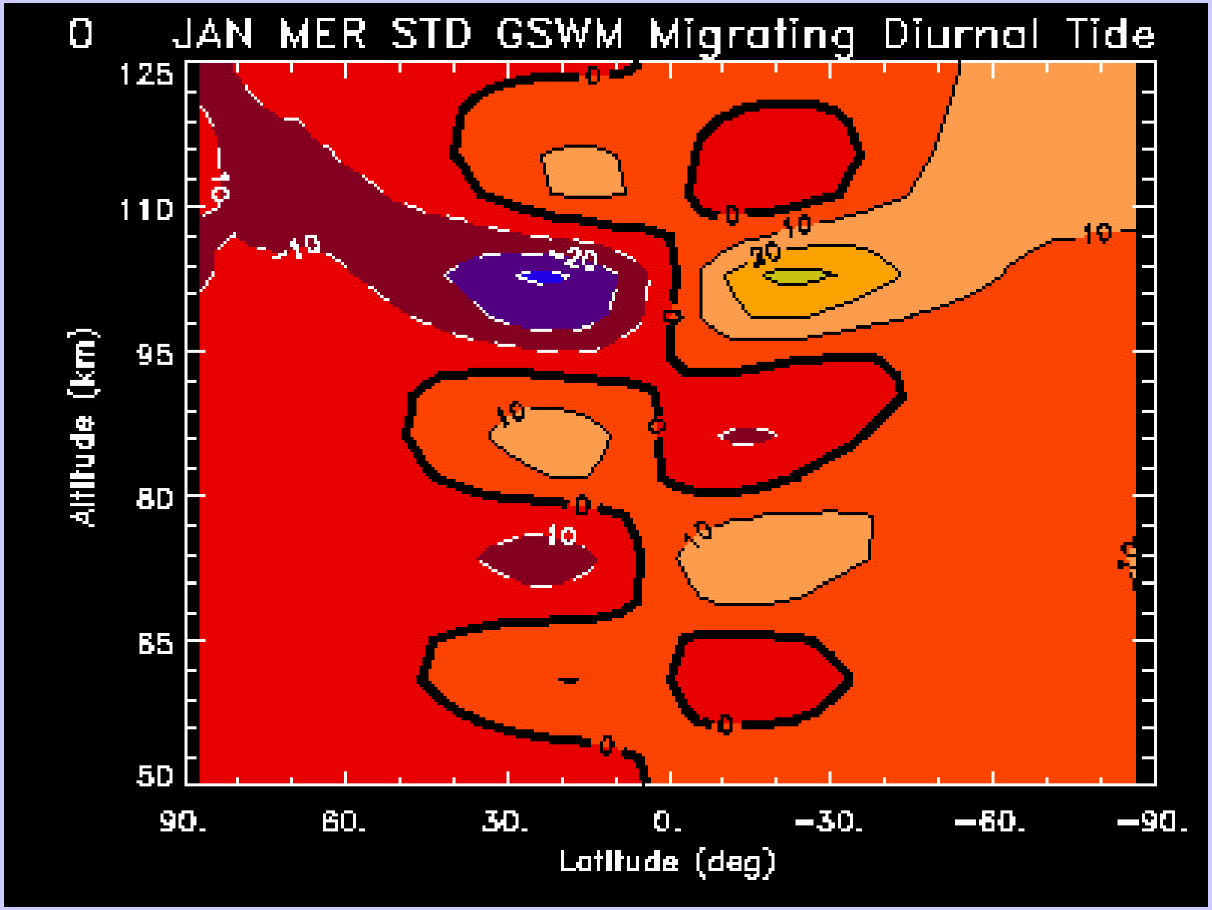
- ~60 m/s peak near +/-30° & 105 km
- Symmetric phase

- > 75 m/s peak near +/-20° & 105 km
- Asymmetric phase

- > 15 cm/s peak near 0° & 100 km
- Symmetric phase

- > 25°K peak near 0° & 115 km
- Symmetric phase

GSWM-00 Results
January Diurnal Meridional Winds



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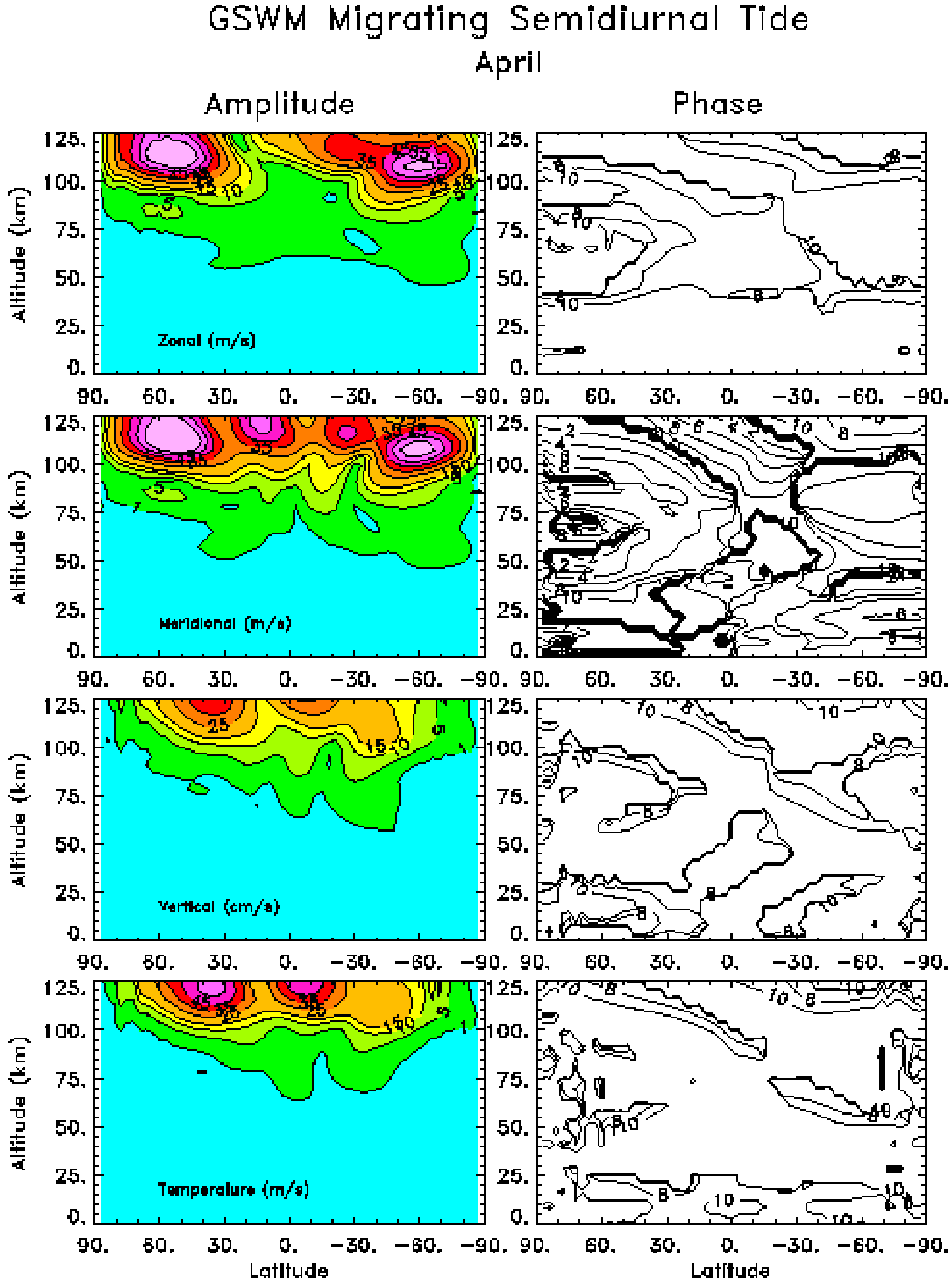


Peaks comparatively higher than the diurnal tide

Comparatively stronger responses at mid-high latitudes

Comparatively weaker responses in the mesosphere

Comparatively longer vertical wavelength

No pronounced hemispheric phase asymmetry

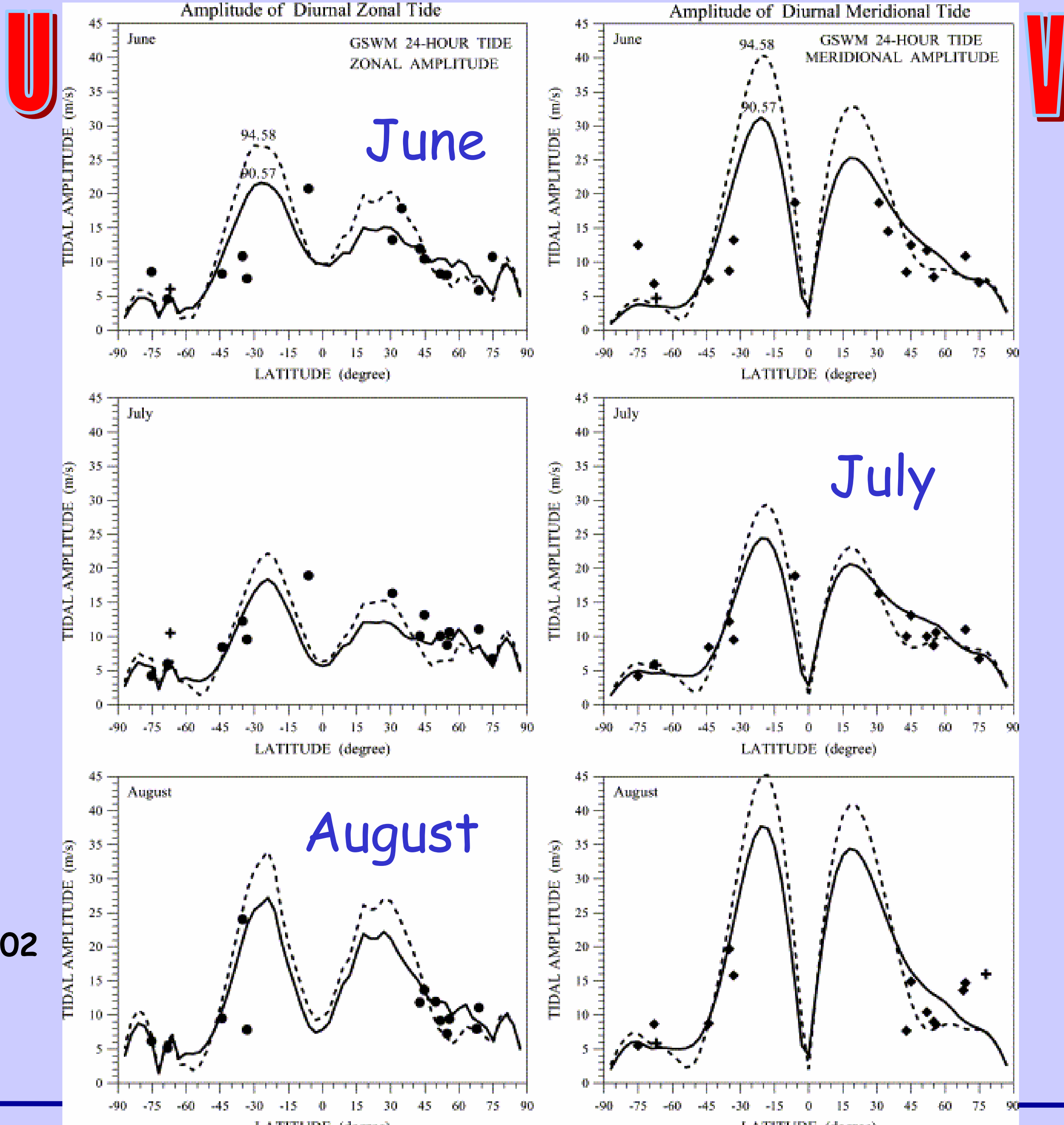
GSWM-00 Diurnal Wind Amplitudes

and

MLT Radar Wind Analysis Results

near 92 km

after *Pancheva et al.*, 2002

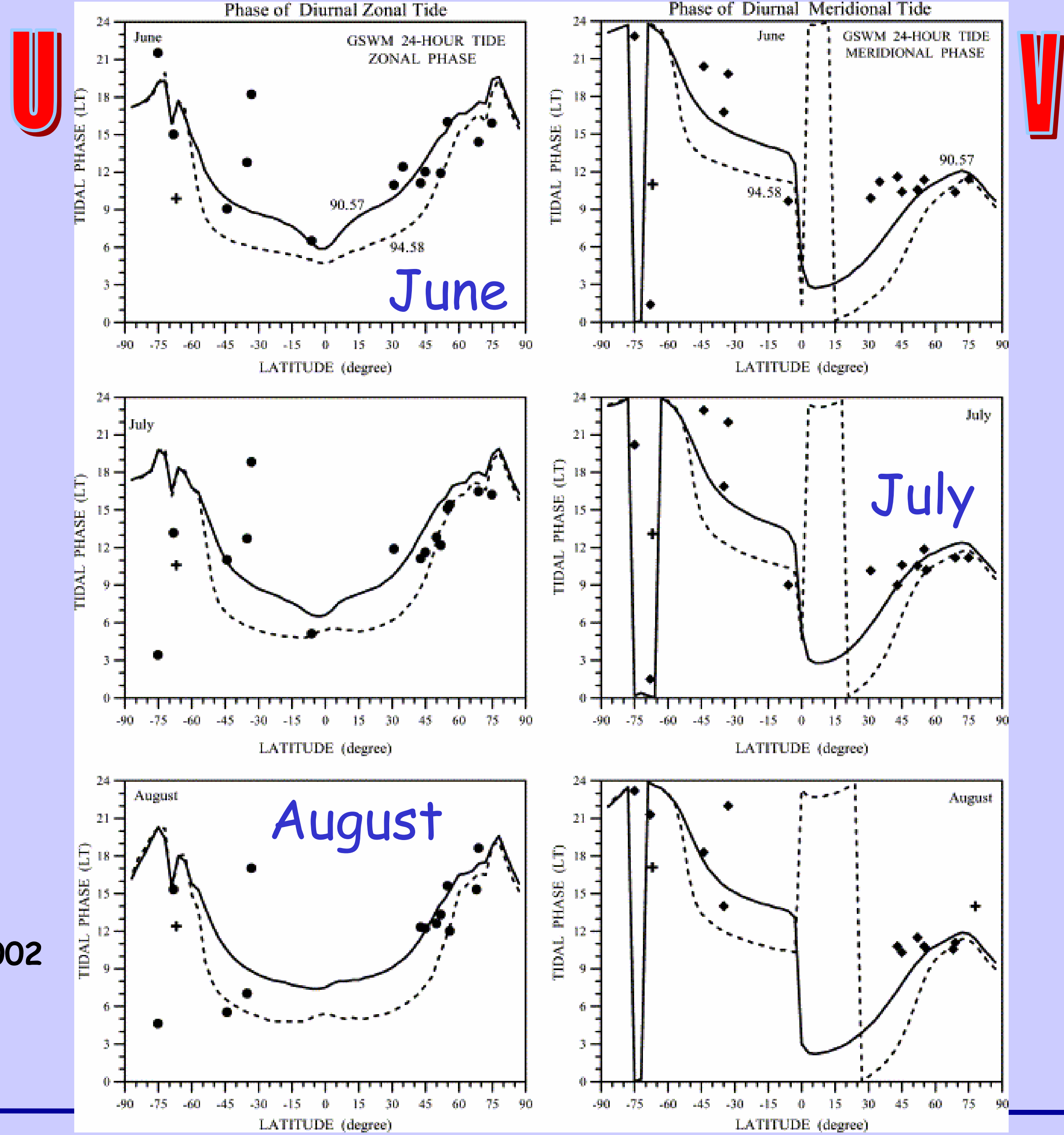


GSWM-00 Diurnal Wind Phases

and

MLT Radar Wind Analysis Results

near 92 km



after *Pancheva et al.*, 2002

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GSWM-00 Semidiurnal Wind Amplitudes

and

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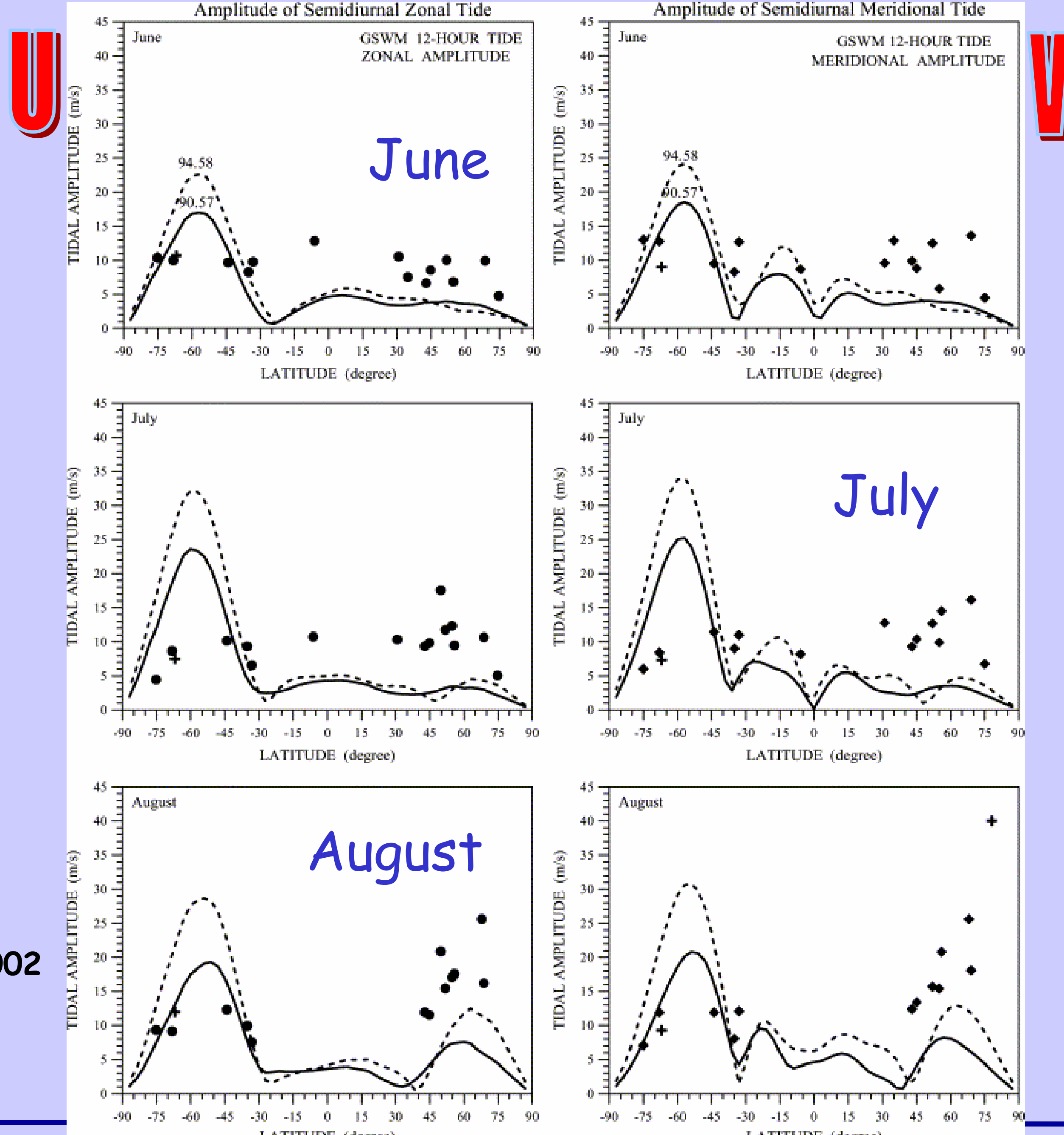

GSWM-00 Semidiurnal Wind Phases

and

MLT Radar Wind Analysis Results

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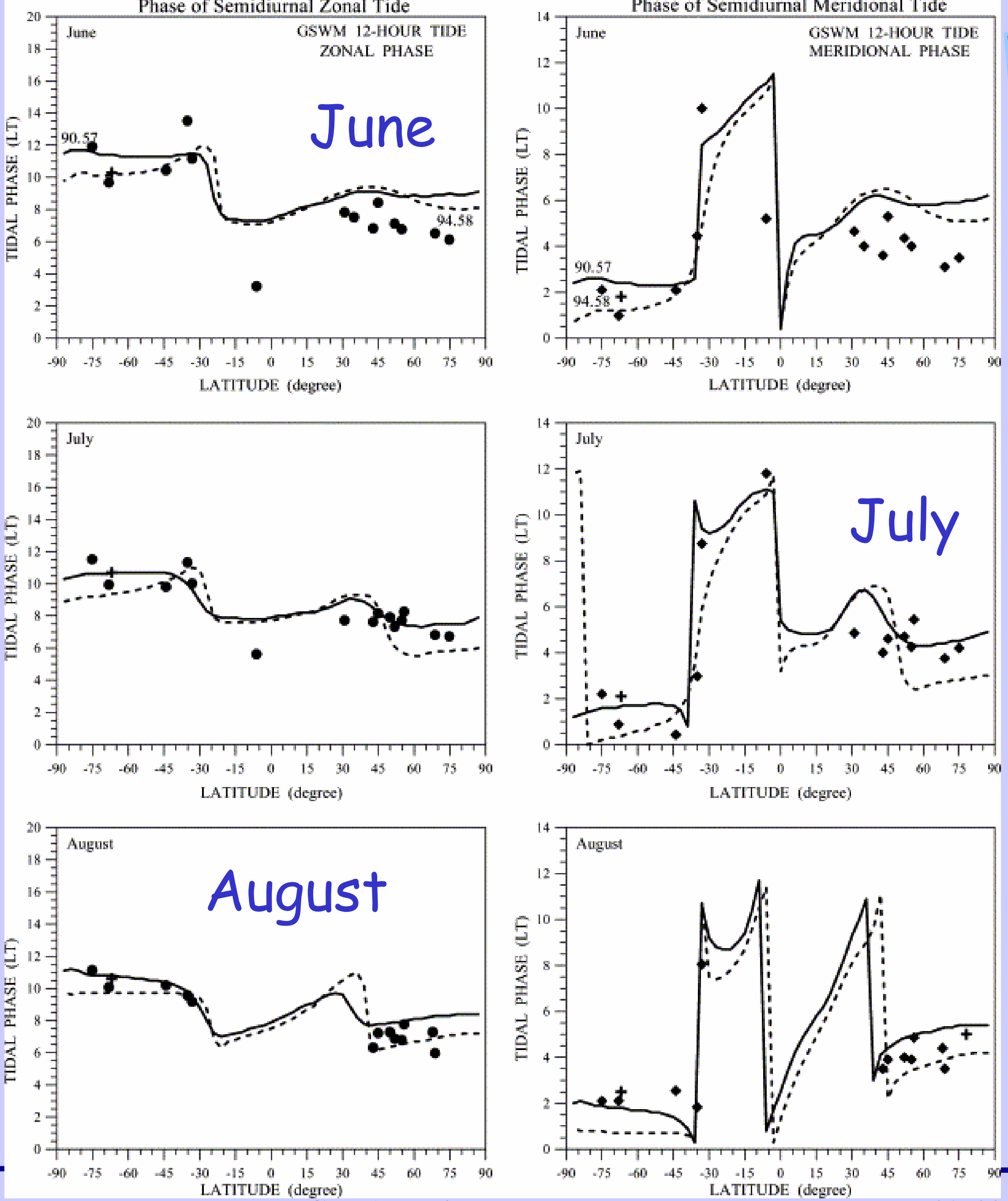


after Pancheva et al., 2002

Solar Atmospheric Tides

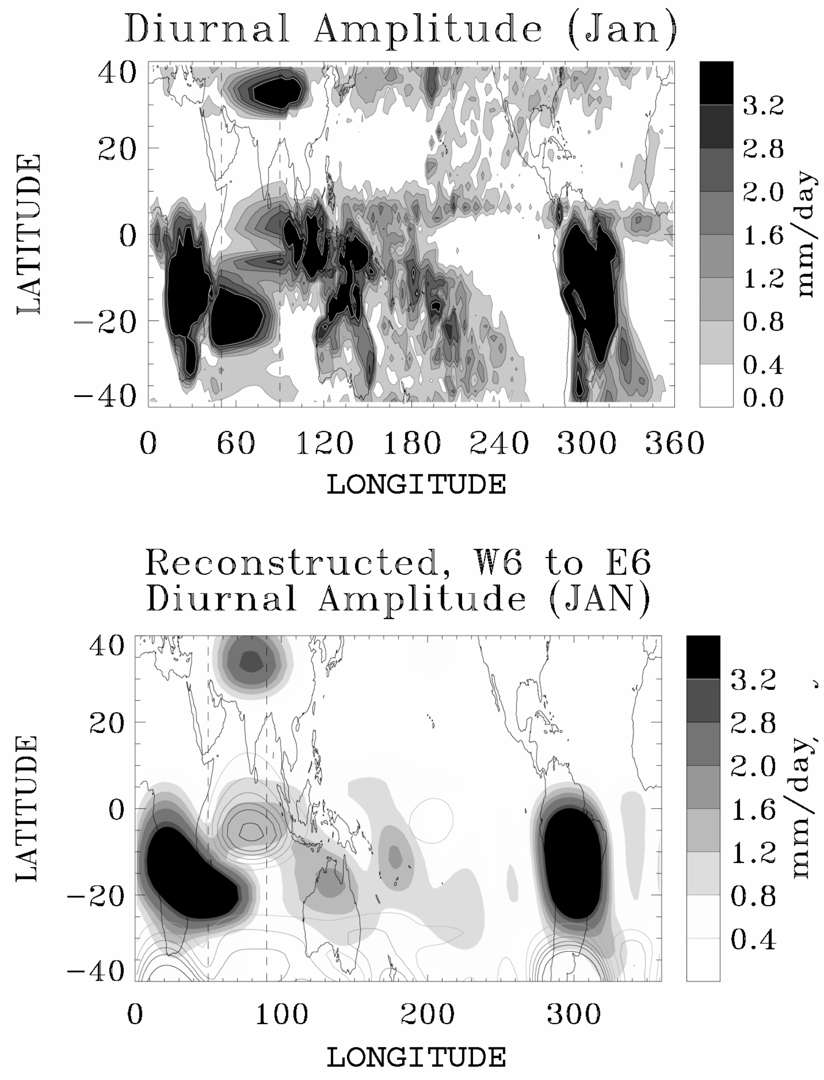
Excitation:

Absorption of Solar Radiation:
- IR: troposphere
- UV: strato-mesosphere
- EUV: thermosphere

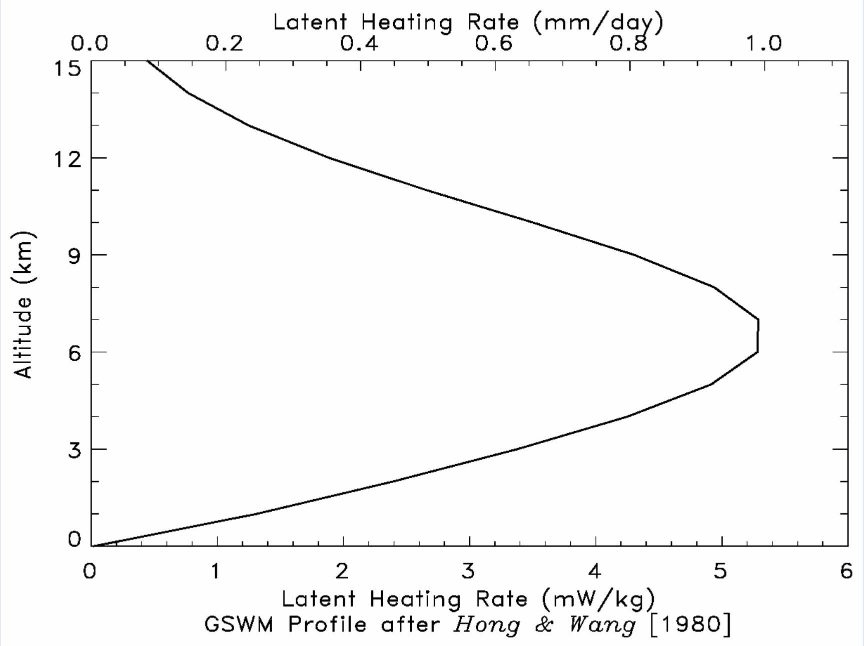
Latent Heat Release → Raindrop formation in deep clouds: tropical troposphere

Wave - Tide Interactions

GSWM Tidal Forcing due to Latent Heat Release



← Diurnal amplitude January



↑ Vertical structure

In collaboration with Jeff Forbes & Xiaoli Zhang

The Global-Scale Wave Model Results

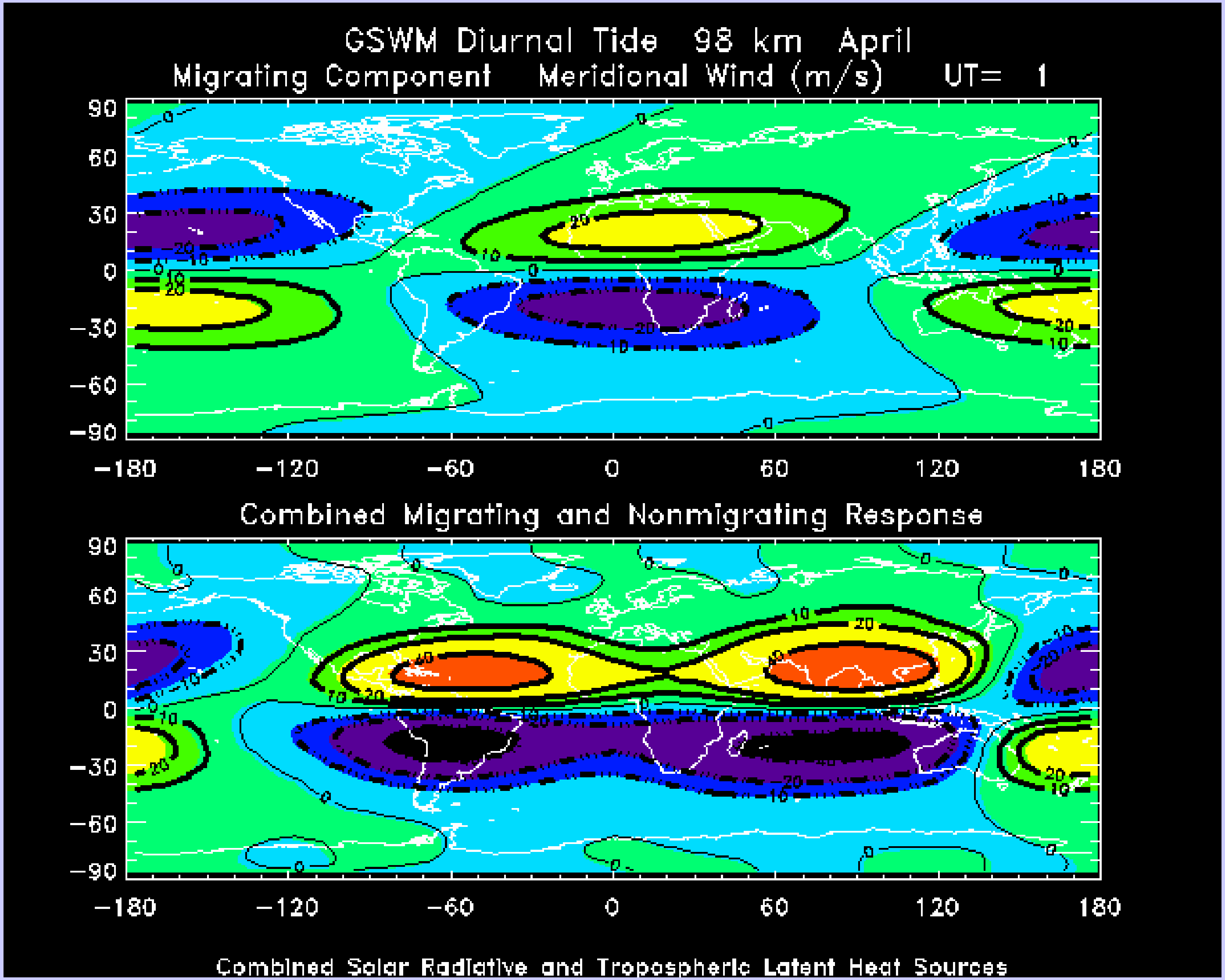
MLT Response to Diurnal Tropospheric Latent Heat Release

5 Major Component Solutions:

ΔU > 10 m/s
ΔV > 10 m/s
ΔT > 10 °K

Westward 1 (W1) - migrating
Westward 2 (W2)
Standing (S0)
Eastward 2 (E2)
Eastward 3 (E3)

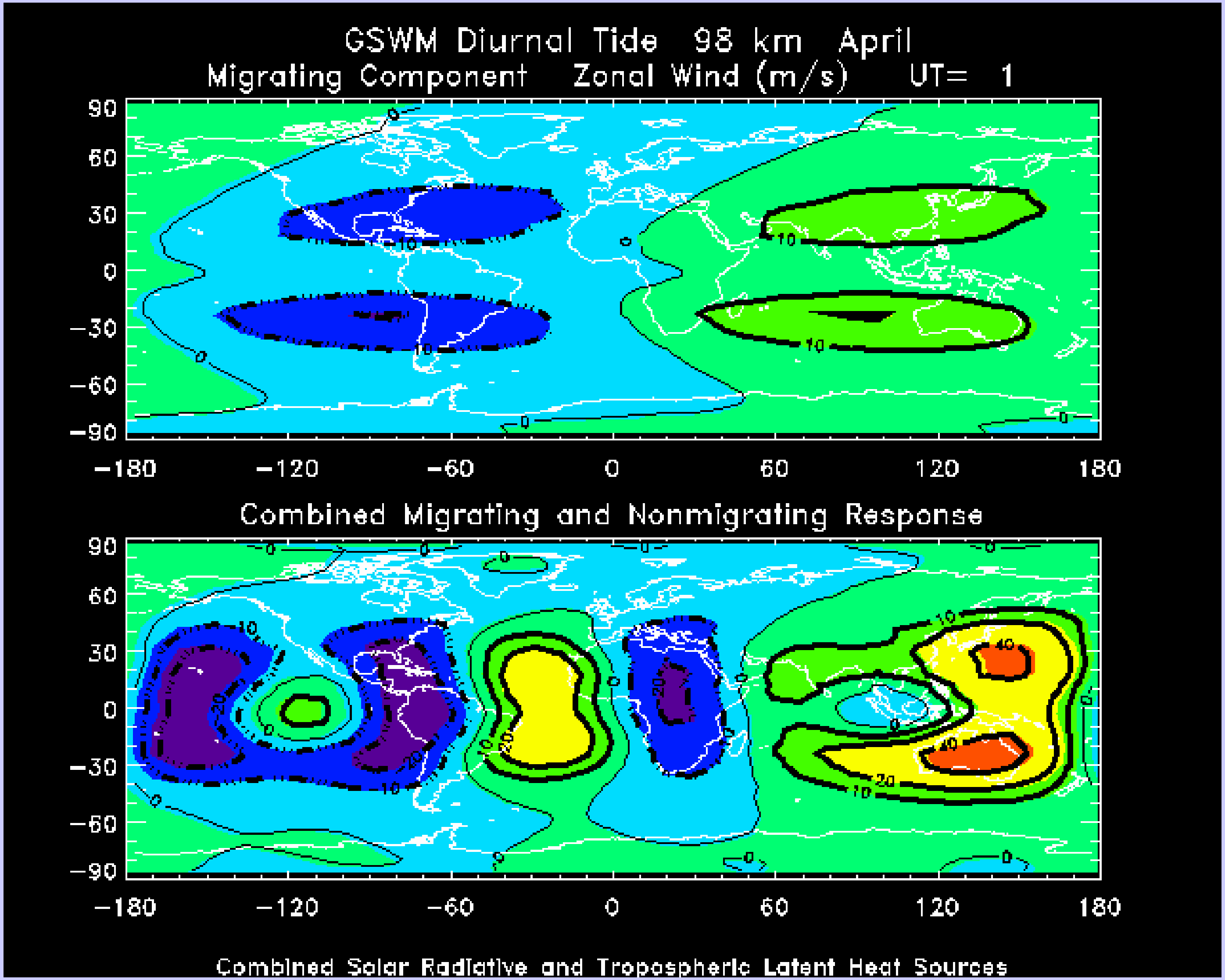
GSWM Diurnal Meridional Wind - 98 km



GSWM-00
migrating
tide

GSWM-02
=
GSWM-00
+
latent heat
response

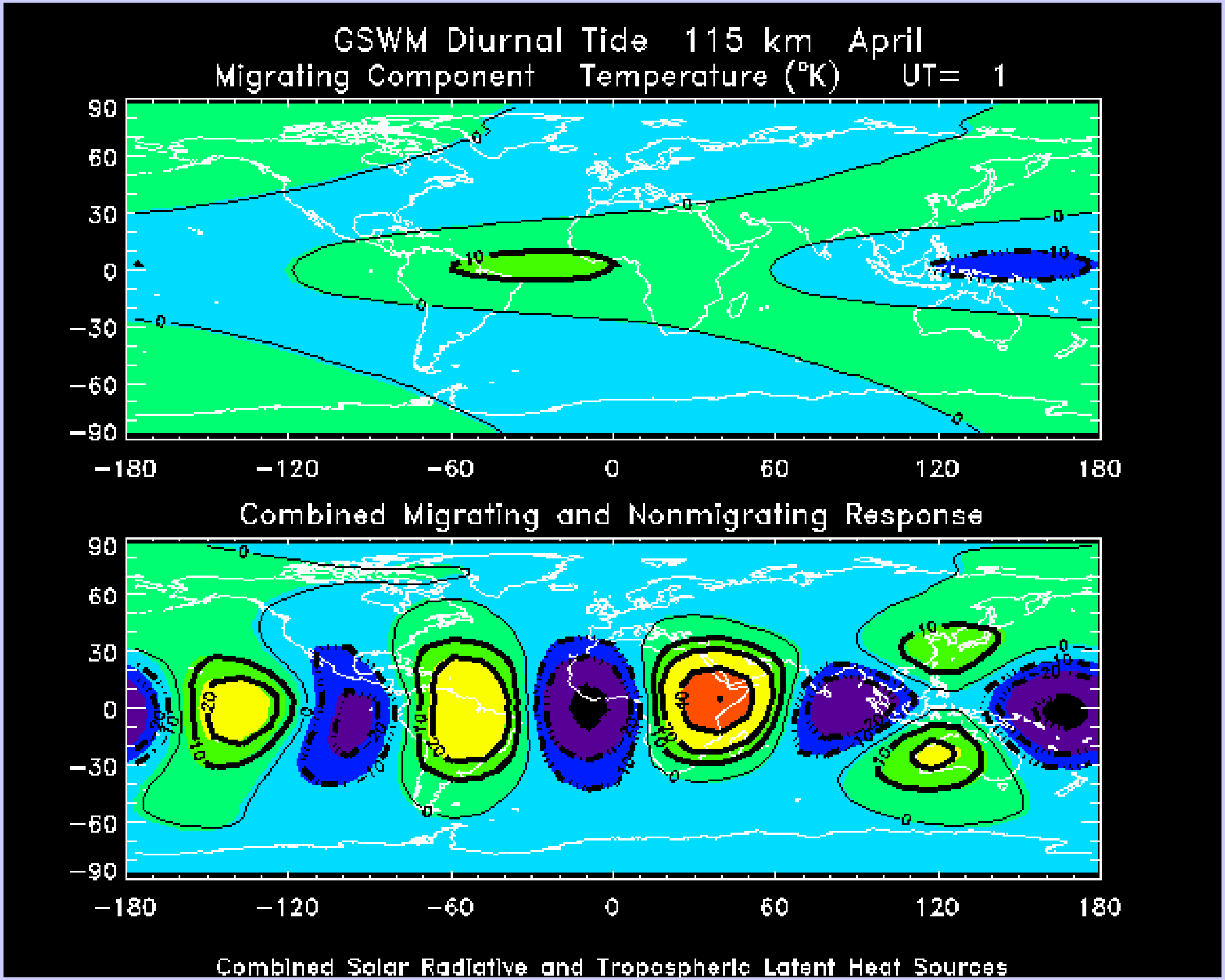
GSWM Diurnal Zonal Wind - 98 km



GSWM-00
migrating
tide

GSWM-00
+
latent heat
response

GSWM Diurnal Temperature - 115 km



GSWM-00 migrating tide

GSWM-02 = GSWM-00 + latent heat response

The GSWM does:

Produce robust monthly climatologies of both diurnal & semidiurnal tides

Account for two plausible tidal sources; absorption of solar radiation throughout the atmosphere, and tropospheric latent heat release

Capture many/most of the dynamical tidal features that are observed in the MLT

Provide tidal boundary conditions for models that don't have realistic lower or middle atmospheres

The GSWM does not:

Quantify day-to-day tidal variability

Include chemical dynamical tidal effects

- also observed in the MLT

Account for nonlinear effects:

- acceleration of the mean flow by dissipating tides
- wave-tide or tide-tide interactions*

*important tidal sources

BUT, the…

Thermosphere-Ionospere-Mesopere-Electrodynamics General Circulation Model (TIME-GCM)

…does!

The
Thermosphere
Ionosphere
Mesosphere
Electrodynamics
–
General
Circulation
Model
Simulations

- 3-D 1st Principles Calculation
  pressure coordinates;
  ~30-500 km
- Resolution:
  horizontal - 5º x 5º
  vertical - 2 grid points /scale height
- 5-minute time step
- 1-year simulation
  focus on April 9, 1993
- **L**ower **B**oundary **C**onditions:
  a) GSWM Migrating Tides
  b) GSWM + NCAR/NCEP daily data → PWs

Planetary Wave-Tide & Tide-Tide Interactions

$\cos(\sigma_1 t + s_1\lambda)\ \cos(\sigma_2 t + s_2\lambda) \rightarrow (\sigma_1 + \sigma_2,\ s_1 + s_2);$
$(\sigma_1 - \sigma_2,\ s_1 - s_2);$
$(2\sigma_1,\ 2s_1);\ (2\sigma_2,\ 2s_2)$

-for example-

Migrating Diurnal (westward wavenumber 1; **W1**) **Tide:**

$s_1 = -1$ (positive eastward); $\sigma_1 = 1/24$

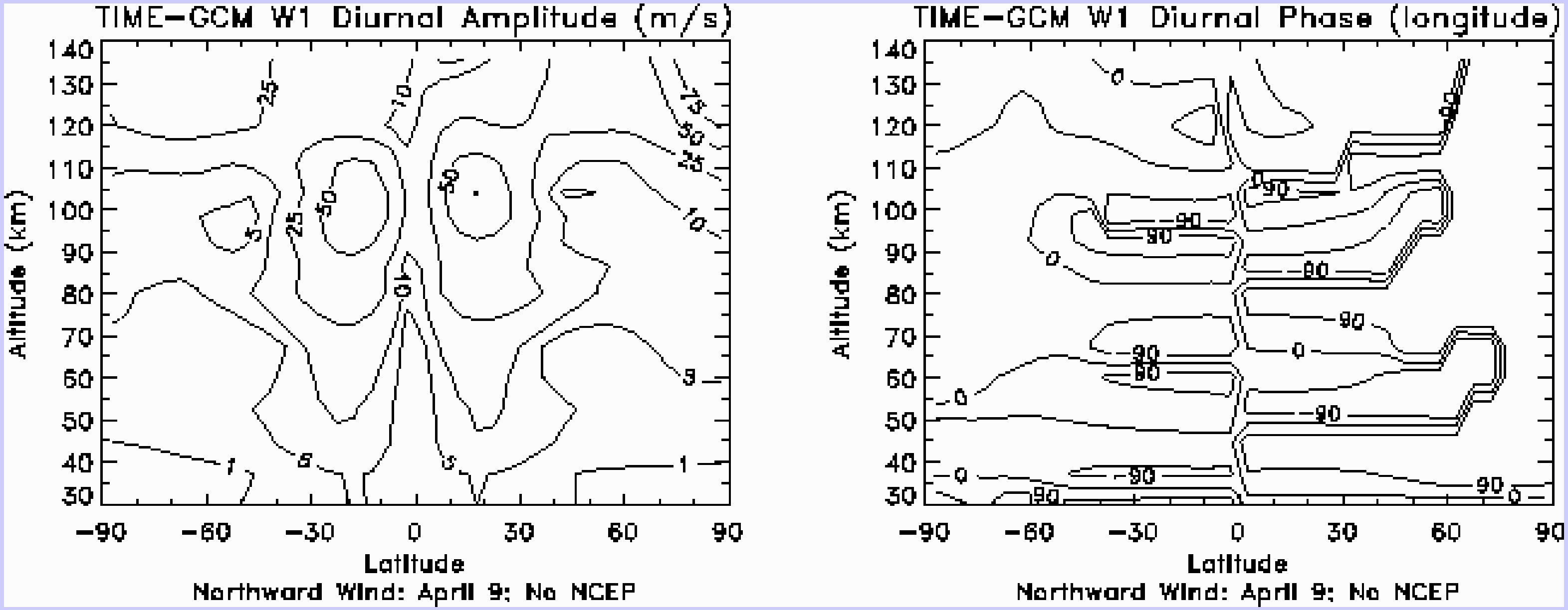
Stationary Planetary Wave 1 (PW1):

$s_2 = 1$; $\sigma_2 = 0$

(0, 1/24) Standing **(S0)** Diurnal Tide
(-2, 1/24) Westward 2 **(W2)** Diurnal Tide
(-2, 1/12) Migrating Semidiurnal Tide
(2, 0) Stationary PW2

TIME-GCM Control Case Results

Diurnal Meridional Wind on April 9



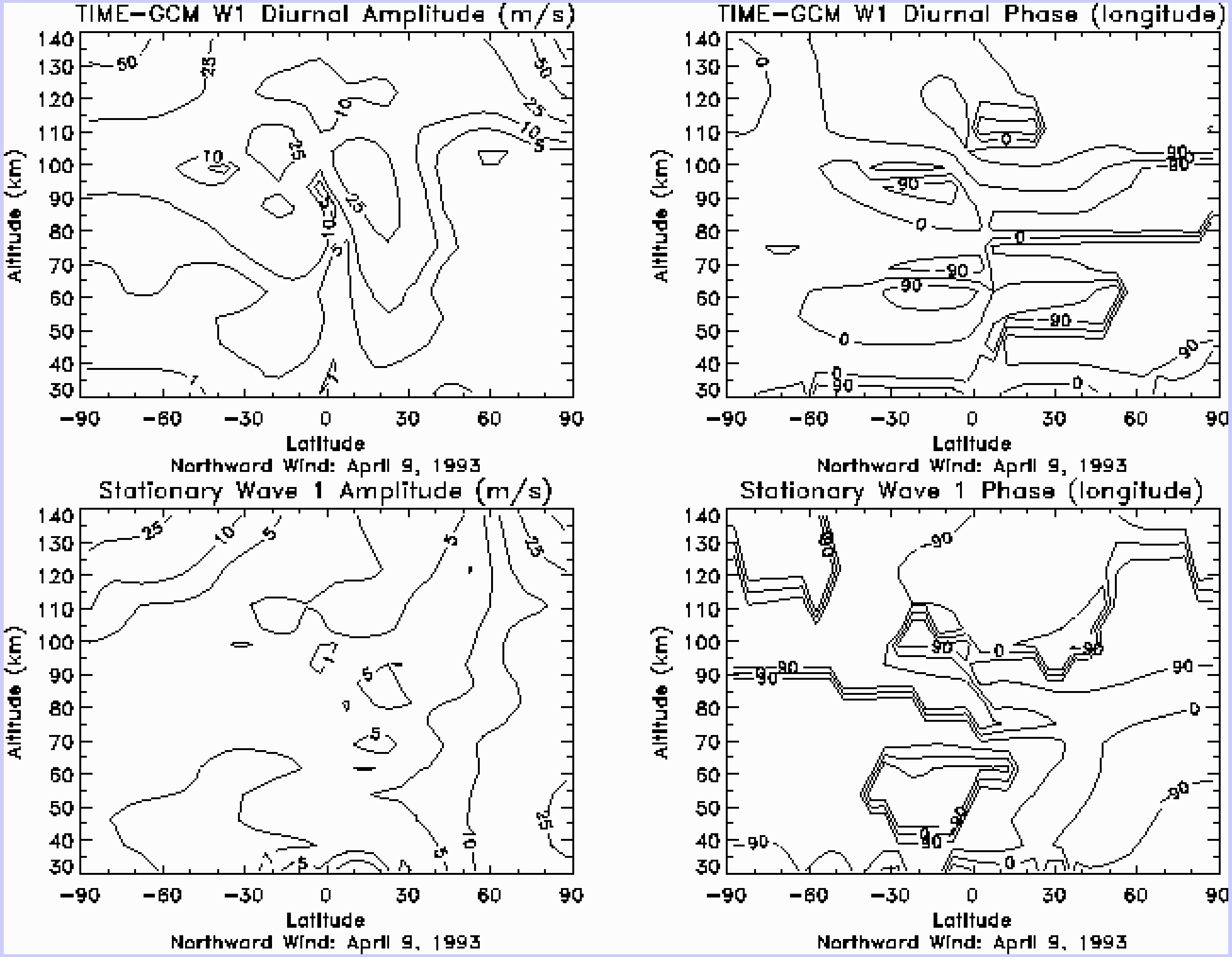
after *Hagan and Roble,* 2001

TIME-GCM "Realistic" Results

Meridional Wind Components on April 9

- Migrating diurnal tide
- Up to 50% smaller than control case

- Stationary planetary wave 1
- Propagates upward into the NH MLT



after *Hagan and Roble,* 2001

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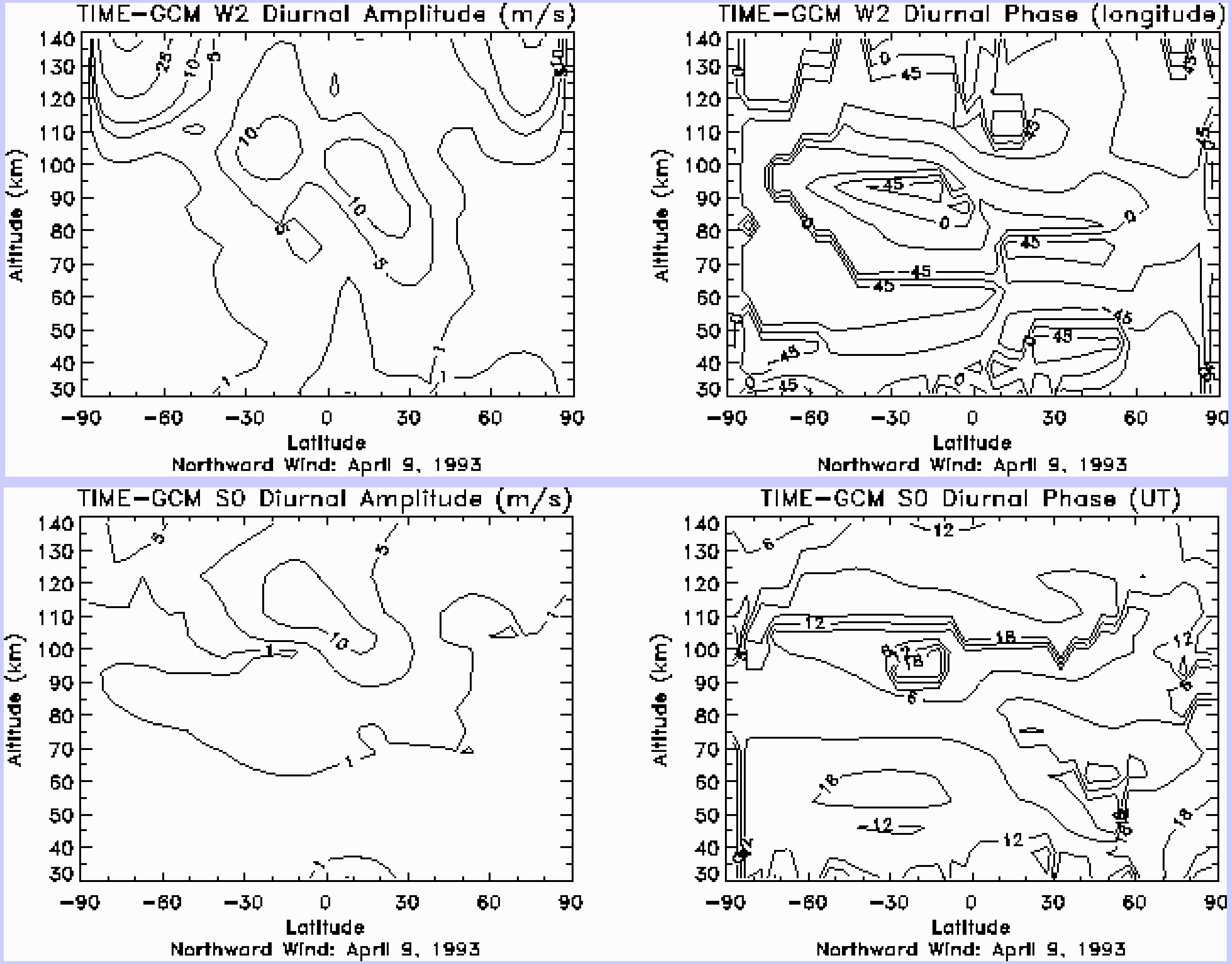
TIME-GCM "Realistic" Results

Meridional Wind Components on April 9

- W2 diurnal tide
- Structure similar to the W1 component

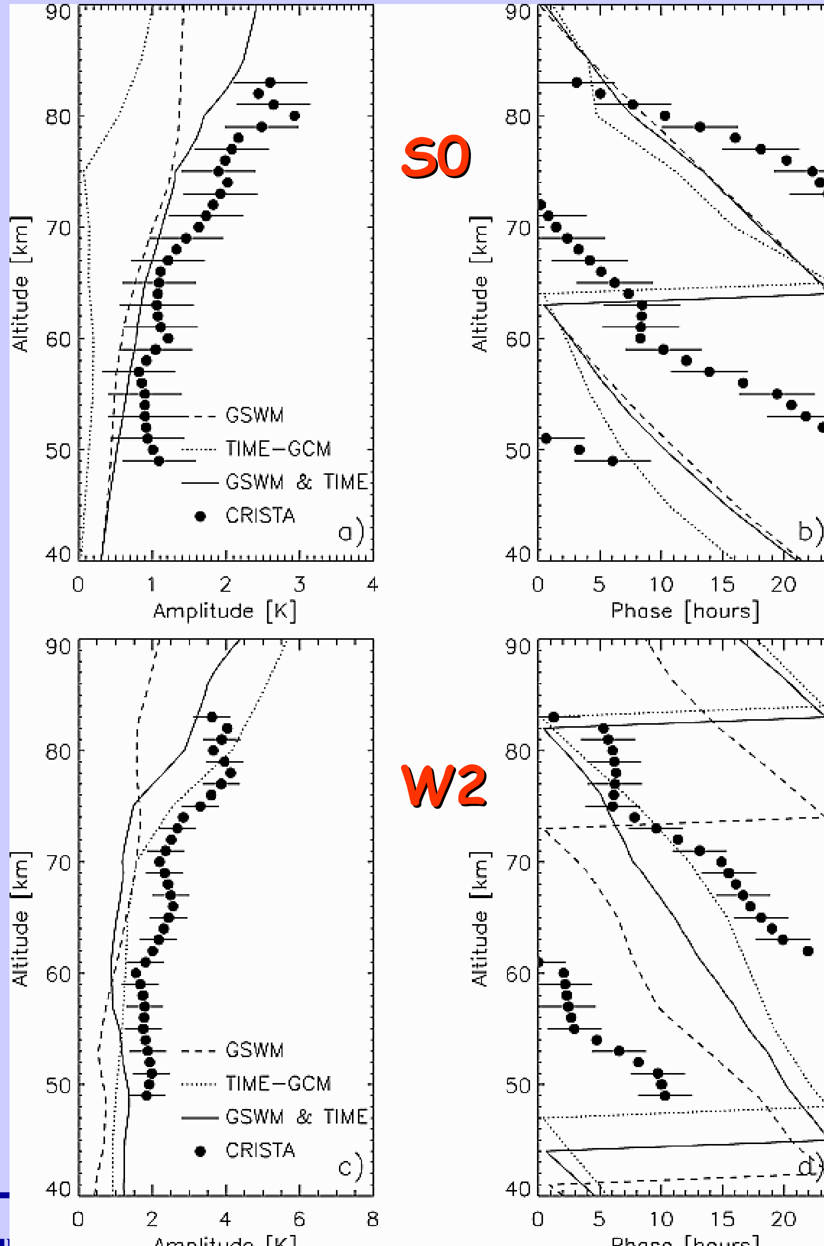
- S0 diurnal tide
- Peaks higher than W1 and W2 near 0°



after *Hagan and Roble,* 2001

Equatorial Nonmigrating Diurnal Tidal Temperatures

CRISTA S0 tide is largely attributable to the tropospheric latent heat source.



CRISTA W2 response is dominated by the nonlinear interaction source.

points: CRISTA measurements made on November 9, 1994

dashes: GSWM predictions for November

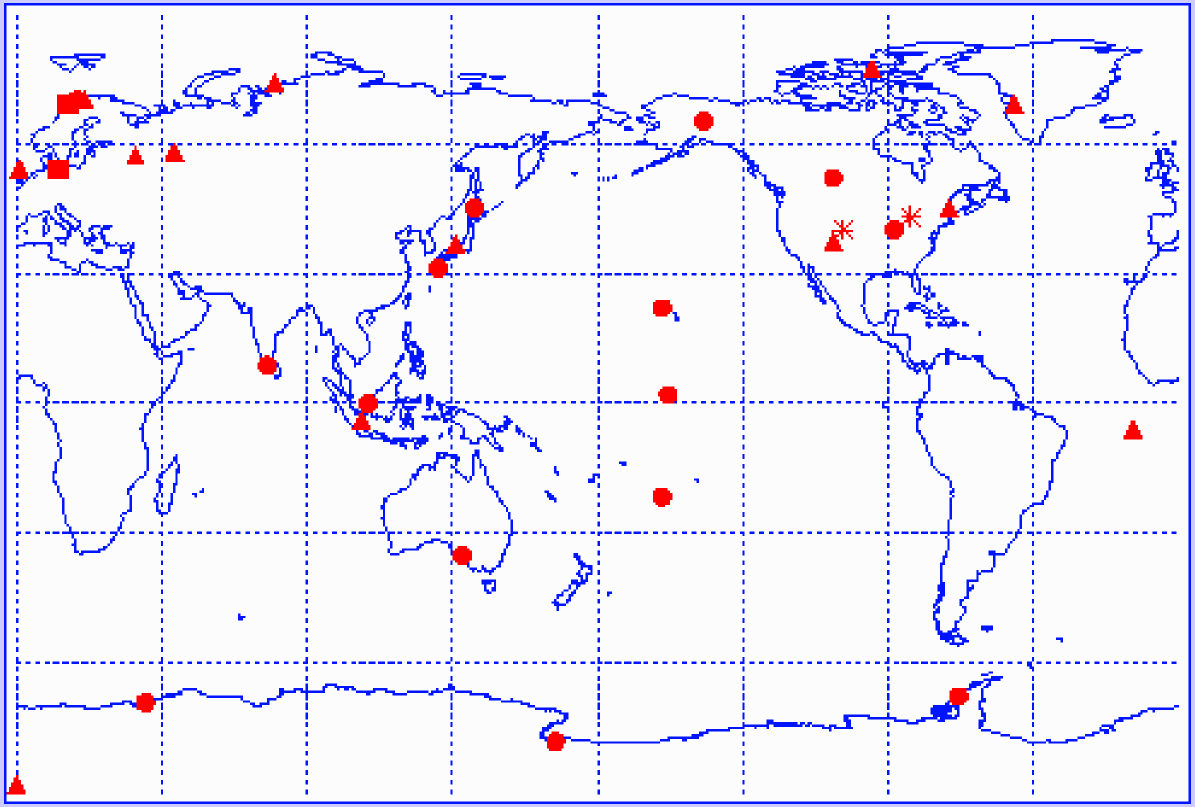
dots: TIME-GCM predictions for November 9

solid: combined GSWM & TIME-GCM

after *Oberheide et al.*, 2002

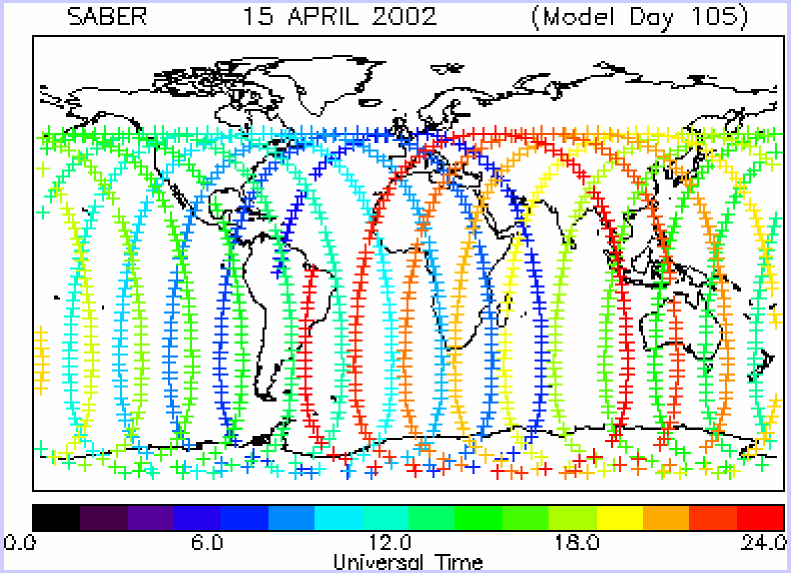
Ground-Based Radar Locations

for TIMED-CEDAR Studies



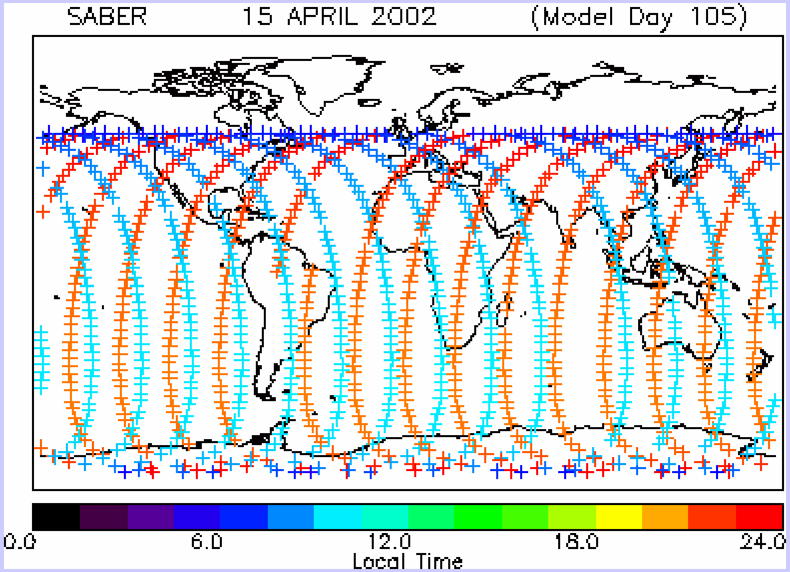
Courtesy of Scott Palo & Xioali Zhang

TIMED SABER Temporal Sampling



← SABER Footprints as a function of Universal Time

SABER Footprints → as a function of Local Solar Time



TIDAL ALIASING: LST is constant at a given latitude along ascending/descending orbit tracks

Outlook

- **TIMED-CEDAR** observations promise new insights into tidal structure and variability, for the **semidiurnal tide** in particular.
- Studies of **tidal effects on lower thermospheric electrodynamics** provide exciting opportunities to investigate coupling into the ionosphere and upper thermosphere.
- The developing **Whole Atmosphere Community Climate Model** (WACCM) allows for self-consistent studies of (almost) **all tidal sources**.
- The **TIME-GCM and GSWM remain valuable**; both as "independent" research models and as diagnostic tools for WACCM studies.

Thank You

Jeff Forbes (CU/AeroEngSci)
Ray Roble (NCAR/HAO)

The
CEDAR, SCOSTEP, UARS, & TIMED
Communities

Scott Palo & Xiaoli Zhang
CU/AeroEngSci
Dora Pancheva, Dennis Riggin, Joe She
U Bath CoRA CSU