Simulation of the 2001 Planet-Encircling Dust Event with the NASA/NOAA Mars General Circulation Model

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Objective

Understand the role of large-scale dynamics in the onset and evolution of the 2001 planet encircling dust event (PEDE)

Key Data Sets

- MOC daily global maps (Mike Malin and Bruce Cantor)
- TES temperature/opacity data (Mike Smith)
- Mars Horizon Sensor Assembly (MHSA) (Terry Martin & Jim Murphy)

Smith et al. (2002); *Straussberg et al*. (2005); *Cantor* (2007)

Approach

- Interpret dynamics using a Mars Global Climate Model (MGCM) to explore the possible structure of the atmospheric circulation and the 3-D dust field.
  - Force the model with an evolving column opacity field derived from a synthesis of the TES observations and MOC imagery.
  - Understanding of the evolution of the 3-D dust field and the surface stresses that may be associated with storm growth via dust lifting
  - Compare simulated temperatures with available TES retrievals

MGCM Modeling

GFDL MGCM

- FV dynamical core with cubed-sphere geometry
- L28 with 2° x 2° resolution
- Ames radiation: 2 stream with correlated-k gaseous absorption

"Dust Assimilation"

Goal: A realistic vertical and meridional variation of dust in simulations with prescribed dust opacity

The MGCM predicts the evolution of a 3D dust distribution(s) subject to the constraints of the available MGS TES dust column opacity observations.

Dust is added/removed from the boundary layer as needed to fit the observed column dust opacity

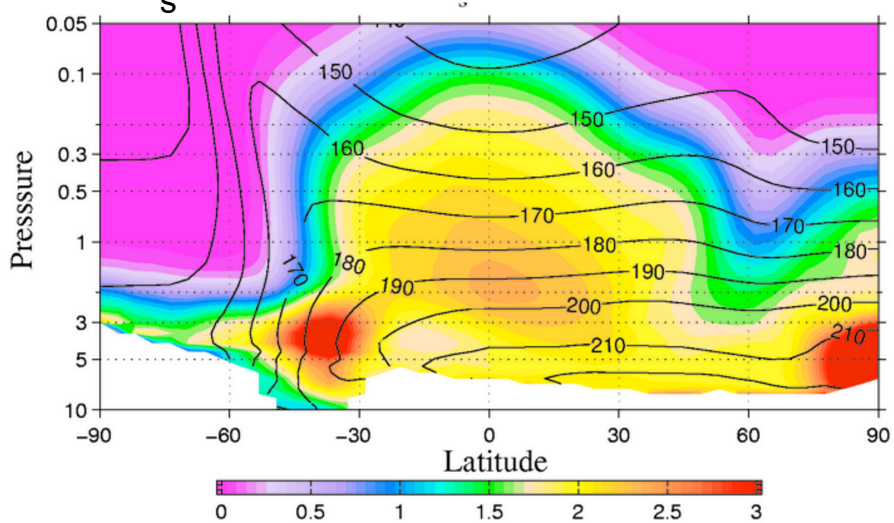
The dust particle size spectrum plays a significant role in the vertical and meridional extent of the resulting opacity field.

Currently using 3 dust tracer fields.

Annual Cycle Simulation with "Assimilated" Dust

L_s= 130°

Pressure



Latitude-Pressure Section: L_s= 130°

Zonal-Mean dust mixing ratio (shading)

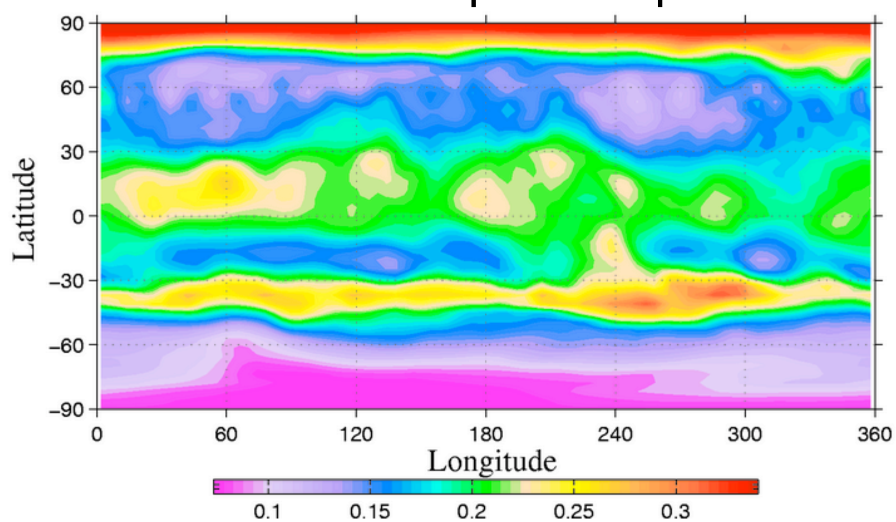
and Temperature: (contour @10 K)

Dust distribution is similar to that derived from MCS retrievals;

Temperature in good agreement with TES

Normalized Optical Depth

Latitude

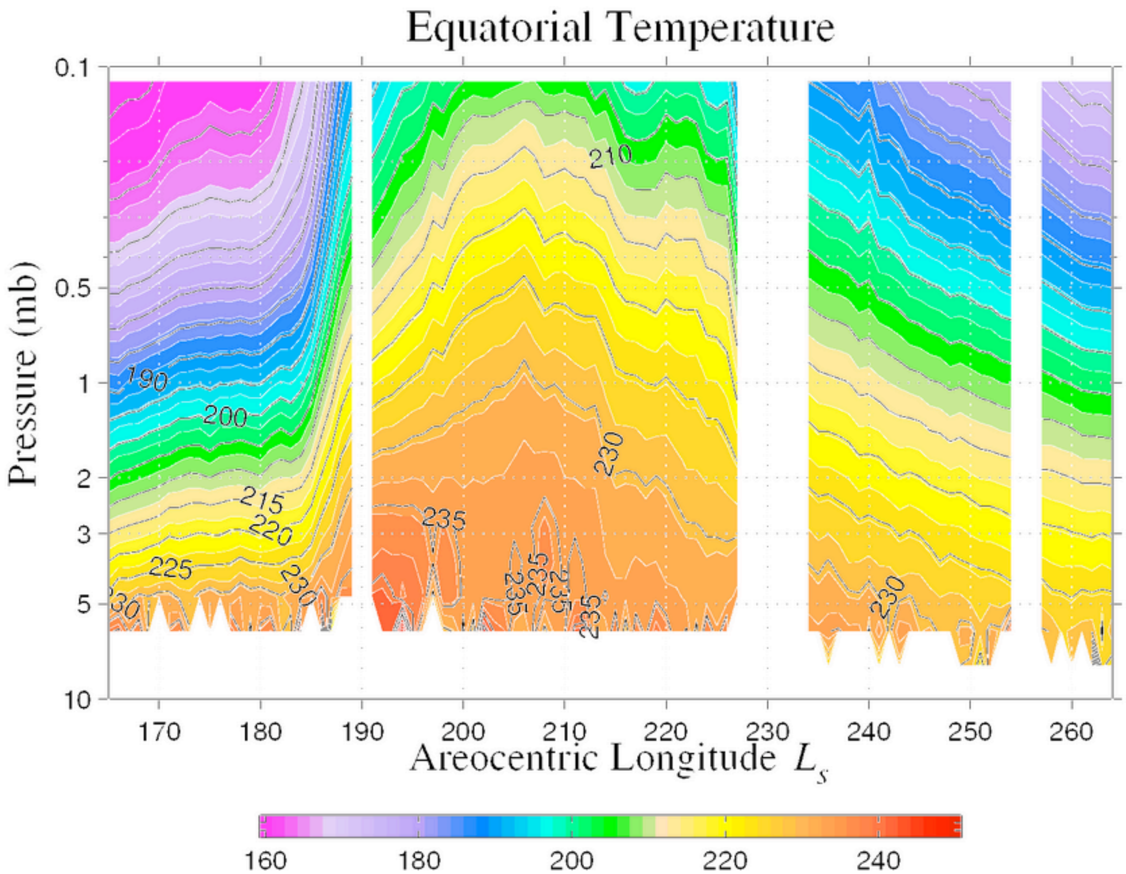


Longitude

Latitude-Longitude column dust opacity (normalized)

Evolution of Zonally-Averaged Equatorial Temperature

(daytime TES observations)



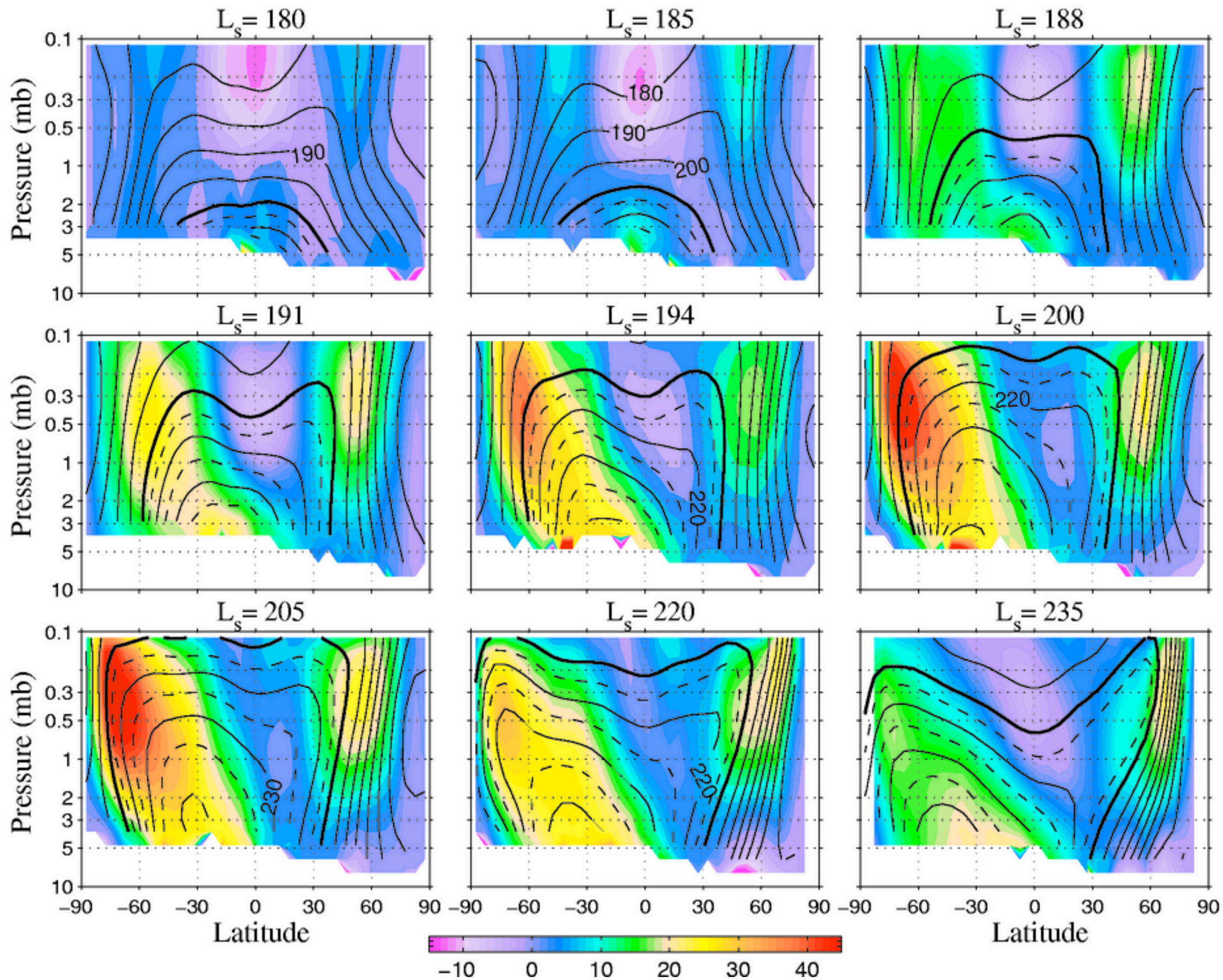
Precursor phase: Sequence of localized dust events in Hellas vicinity

Storm initiation in Hellas at L_s= 184.7°

Regional development in Syria/Claritas at L_s= 189.6°

Planet-encircling by L_s= 192°

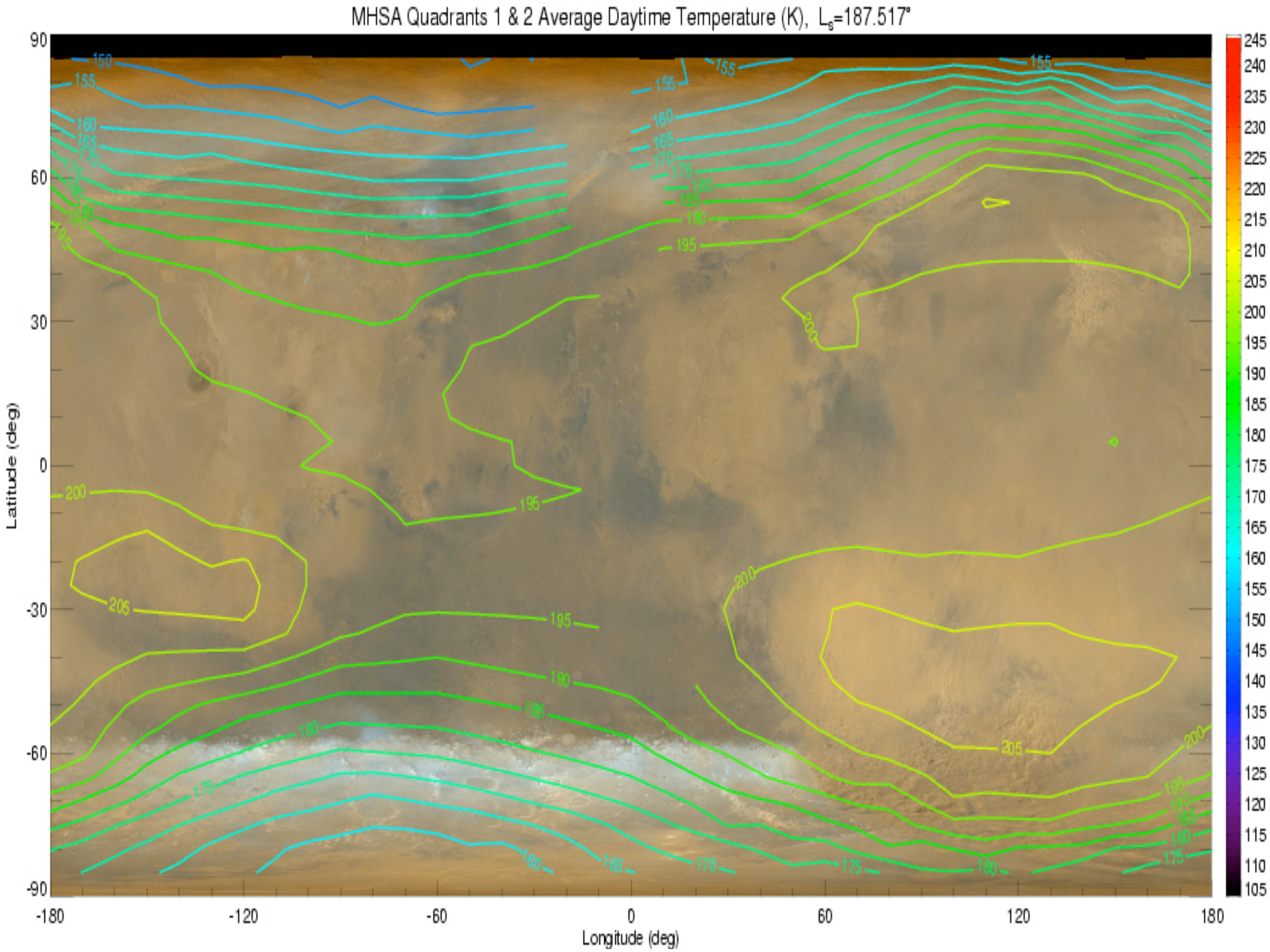
Evolution of “Diurnal Tide Amplitude” and Zonal Mean Temperature



Tide = (T_{2pm} – T_{2am}); (shading)

Temperature (contoured at 10 K intervals; 200 K contour heavy line)

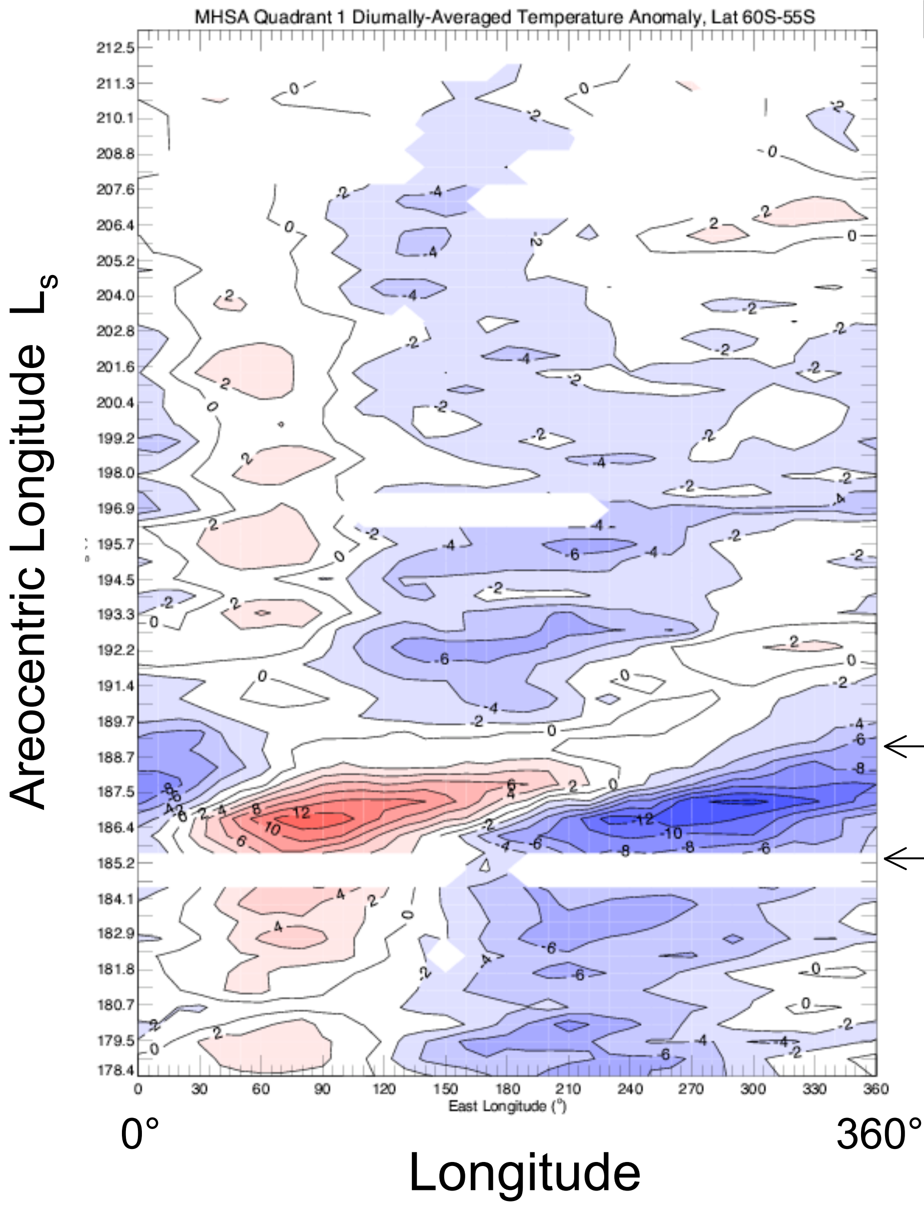
MOC Global Map L_s= 187.5°



Latitude (-90° to 90°)

Longitude (-180° to 180°)

Amplification of Zonal Wave 1: MHSA Temperatures



Depth Weighted temperature ~0.5 hPa

Latitude 60°S - 55°S

Unlike TES, no data gap at L_s= 190-191

L_s= 189°

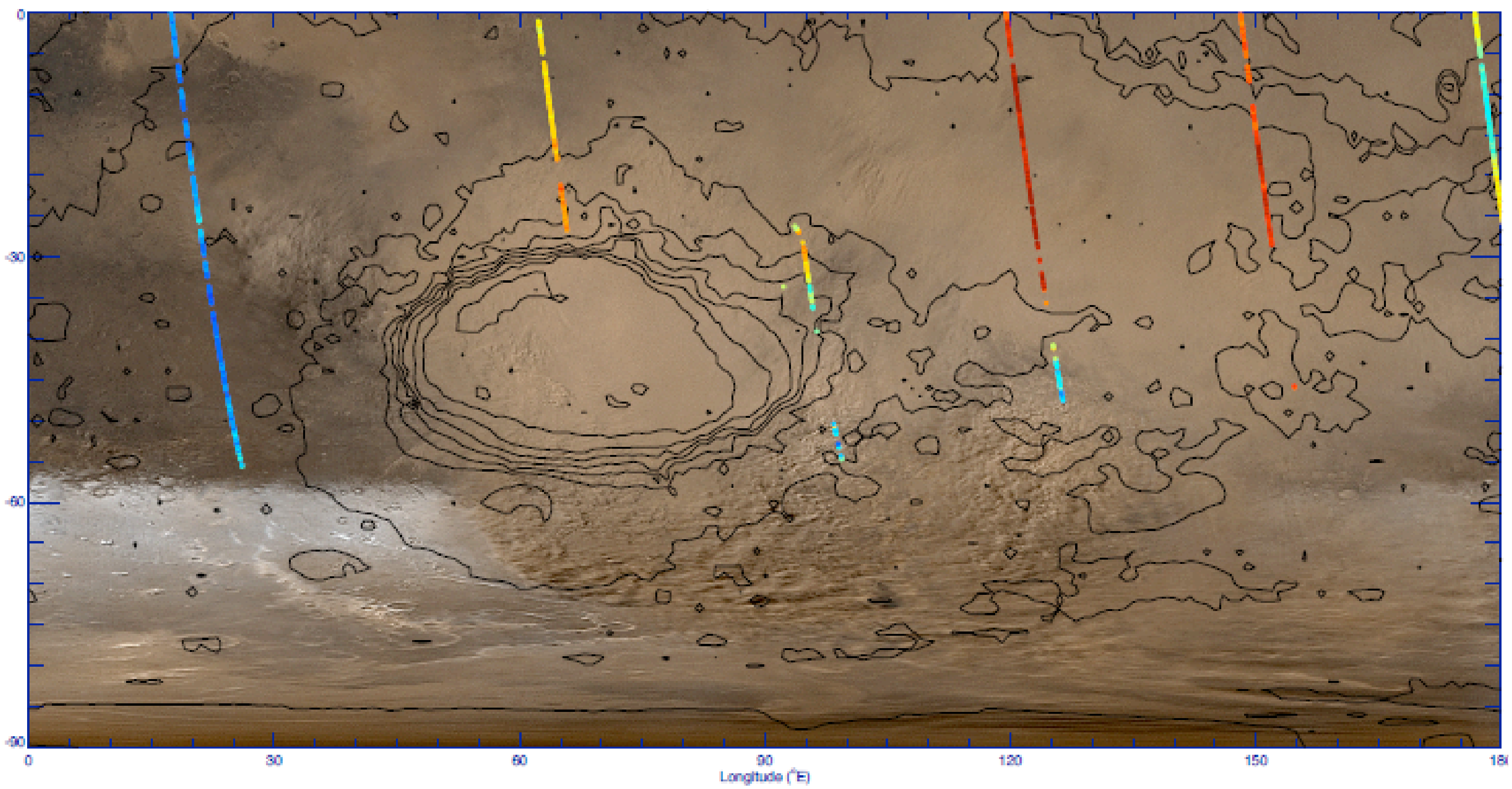
L_s= 185°

MOC Wide Angle Map

L_s= 187.51-188.09

Available TES opacity retrievals: low → high

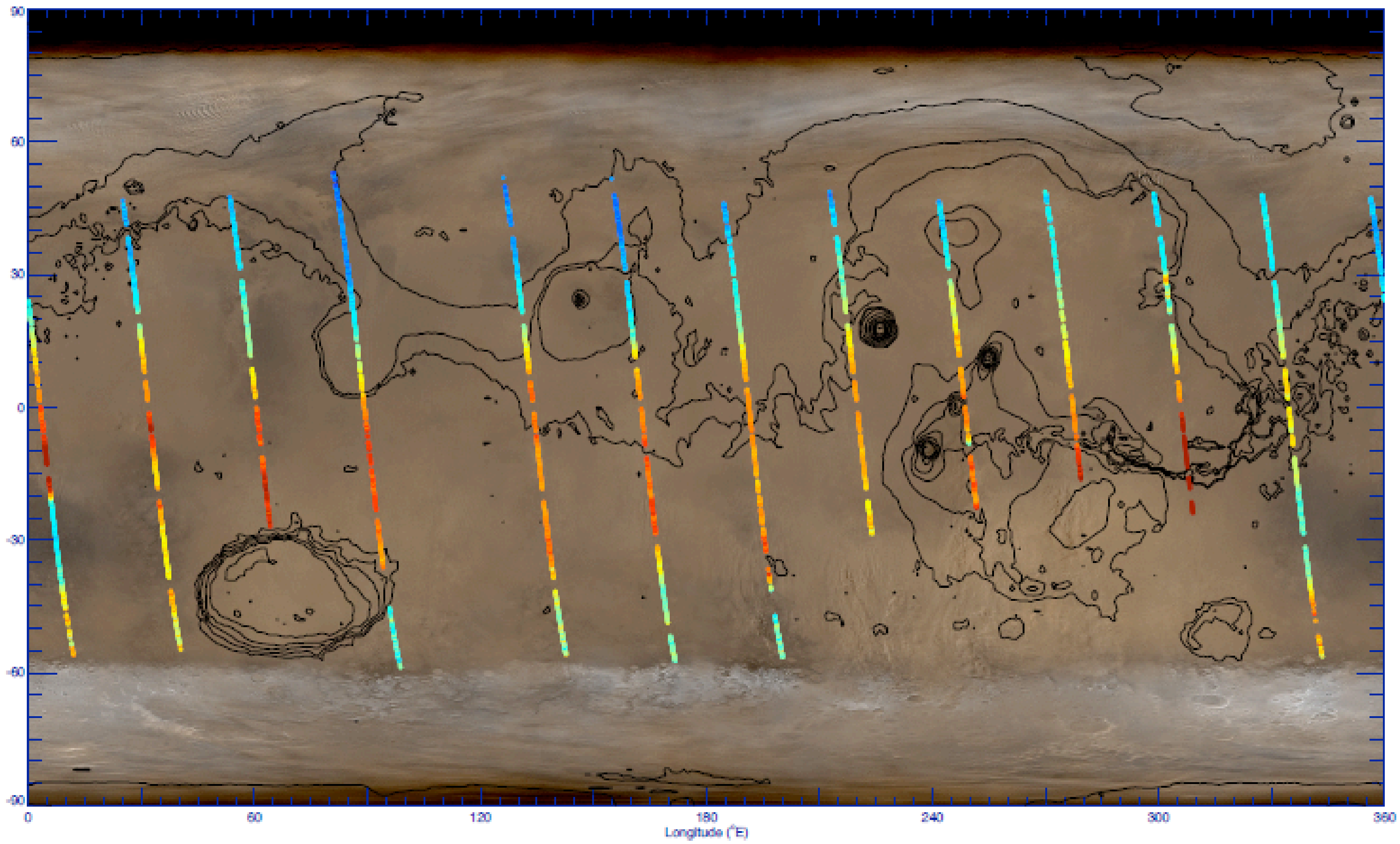
Latitude 90S to 0



Longitude 0-180 E

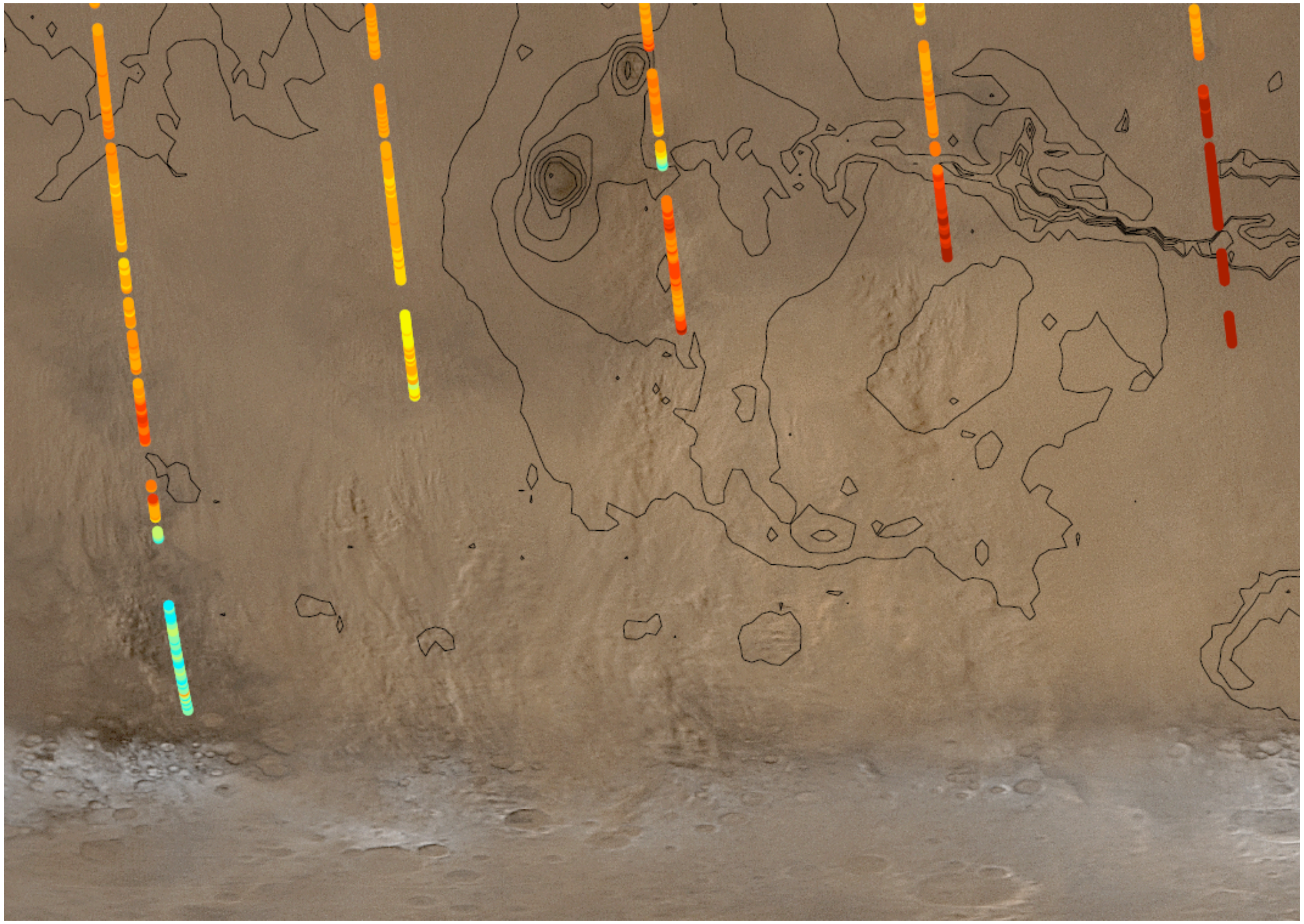
L_s= 187.51-188.09 Sol 385 1400 LT

MOC Wide Angle Map L_s= 192

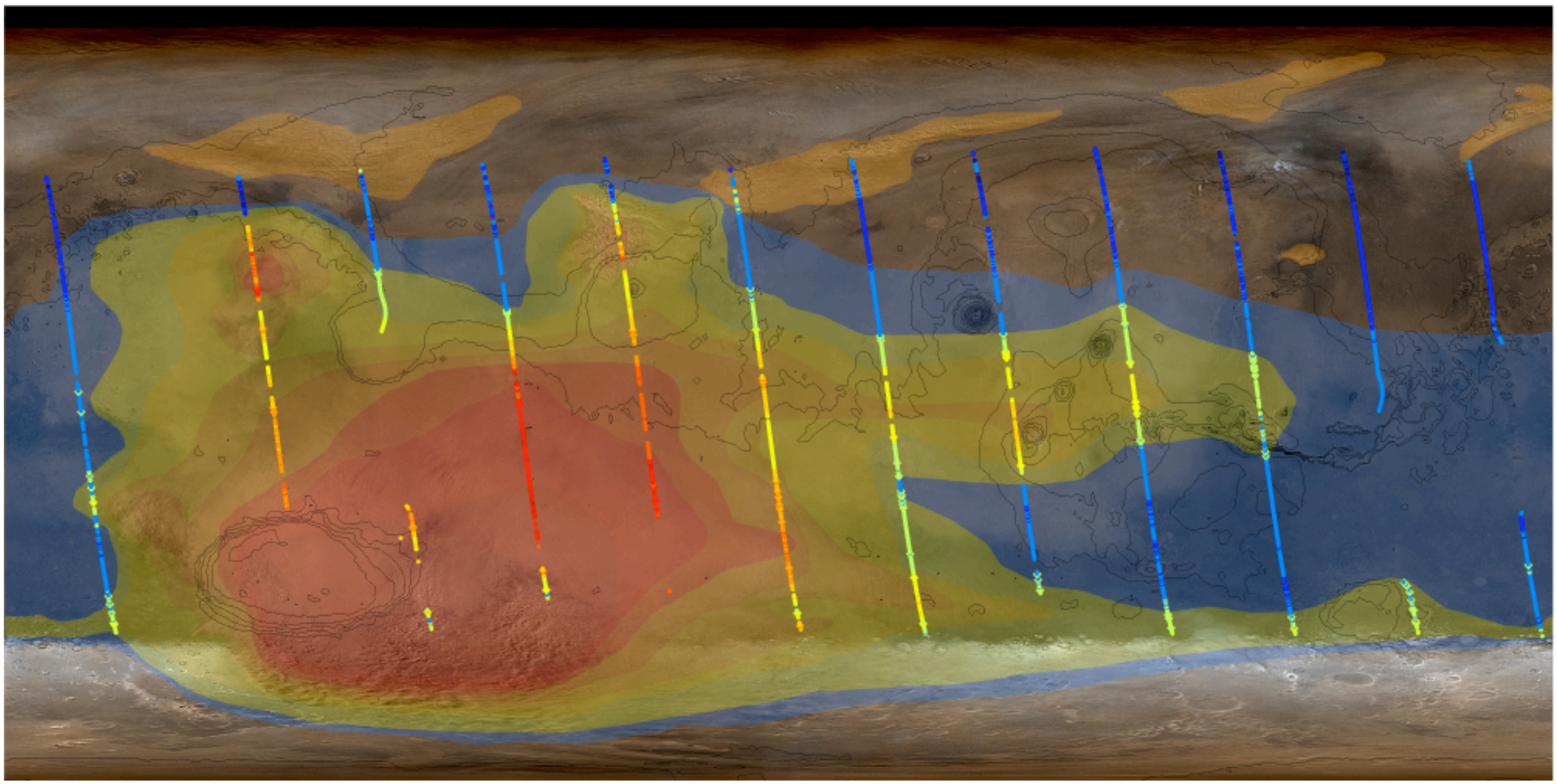


MOC Wide Angle Map L_s= 192

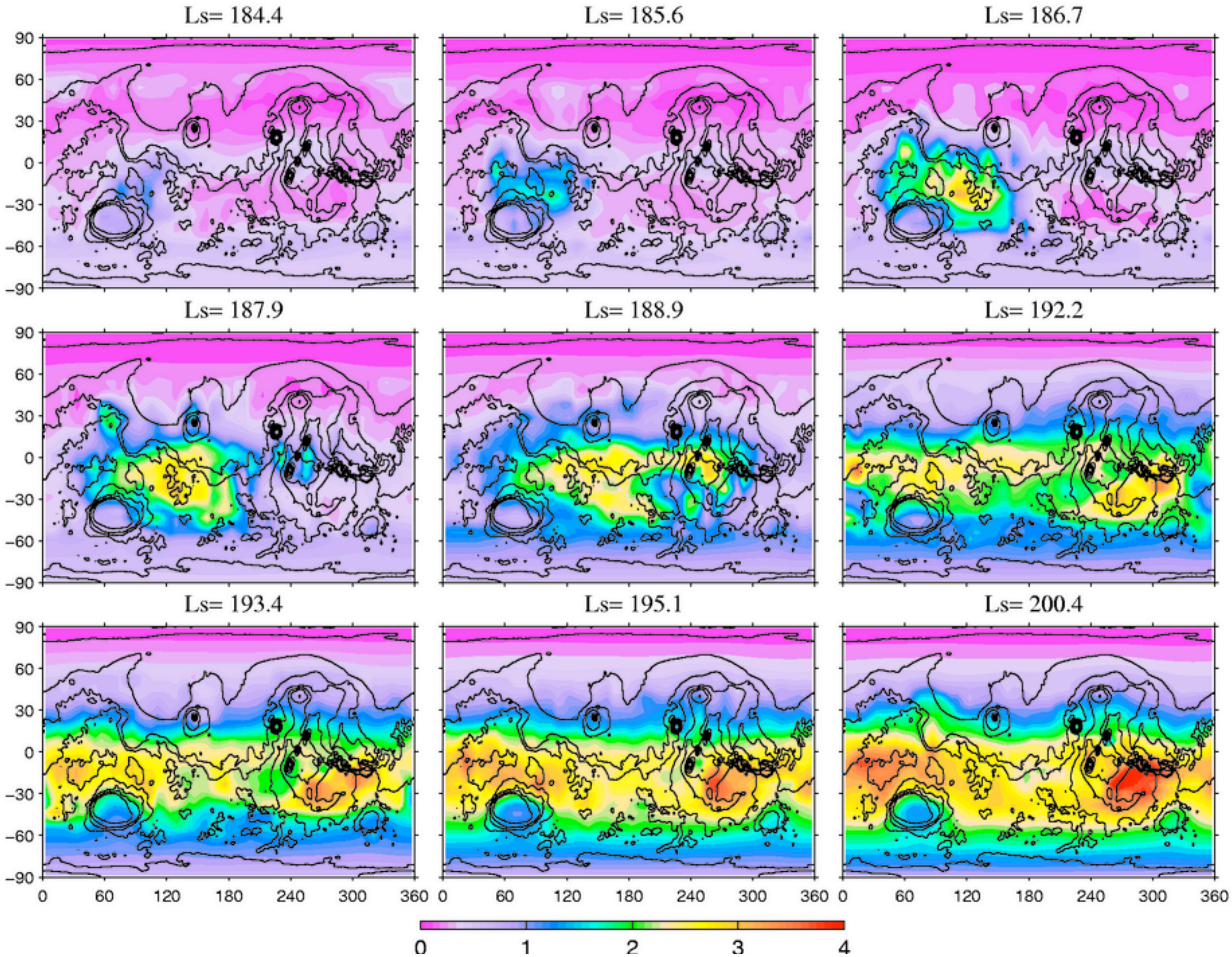
Zoom on Tharsis/Solis Planum/Syria/Thaumasia



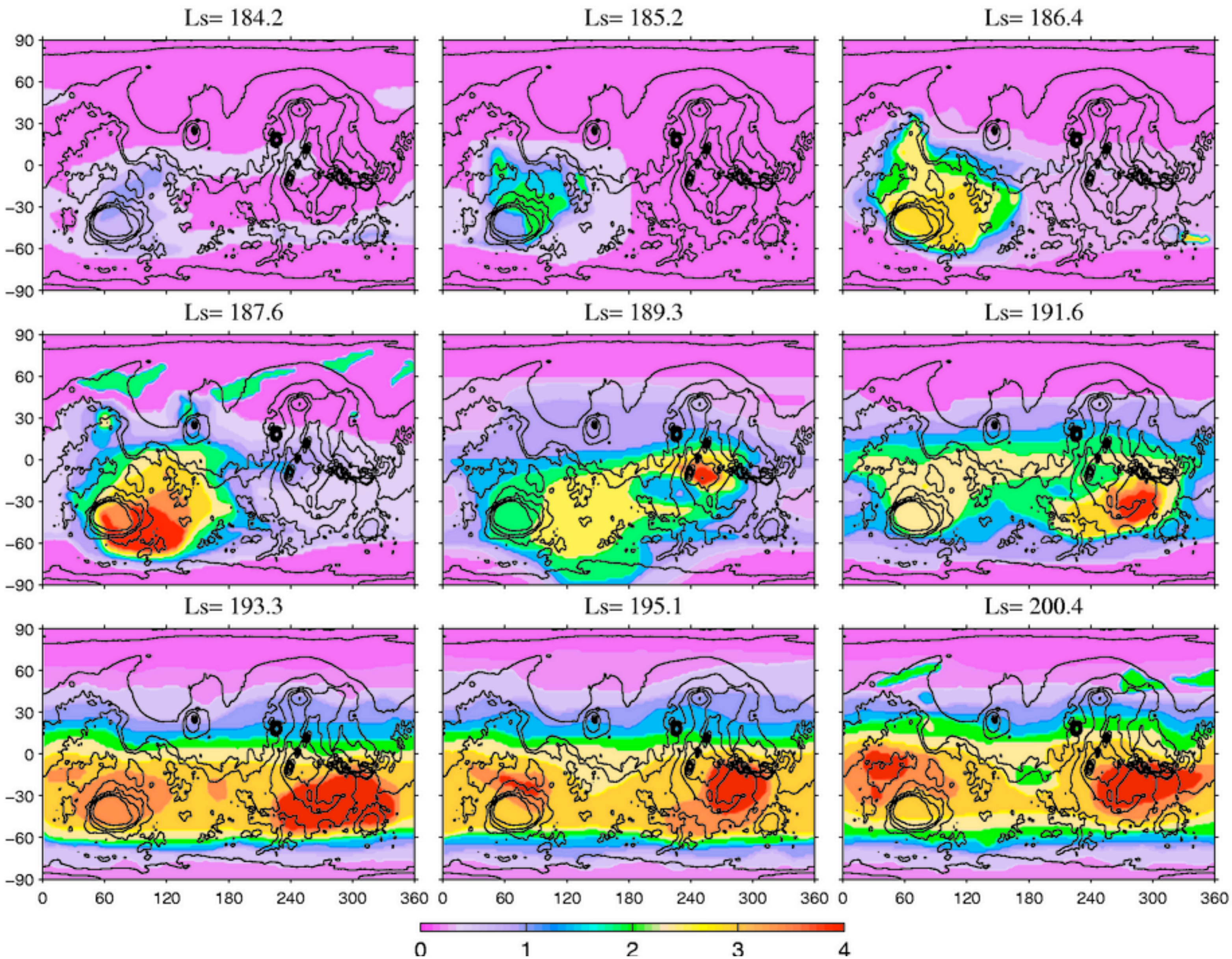
Synthetic Dust Column Opacity Map L_s= 187.5°



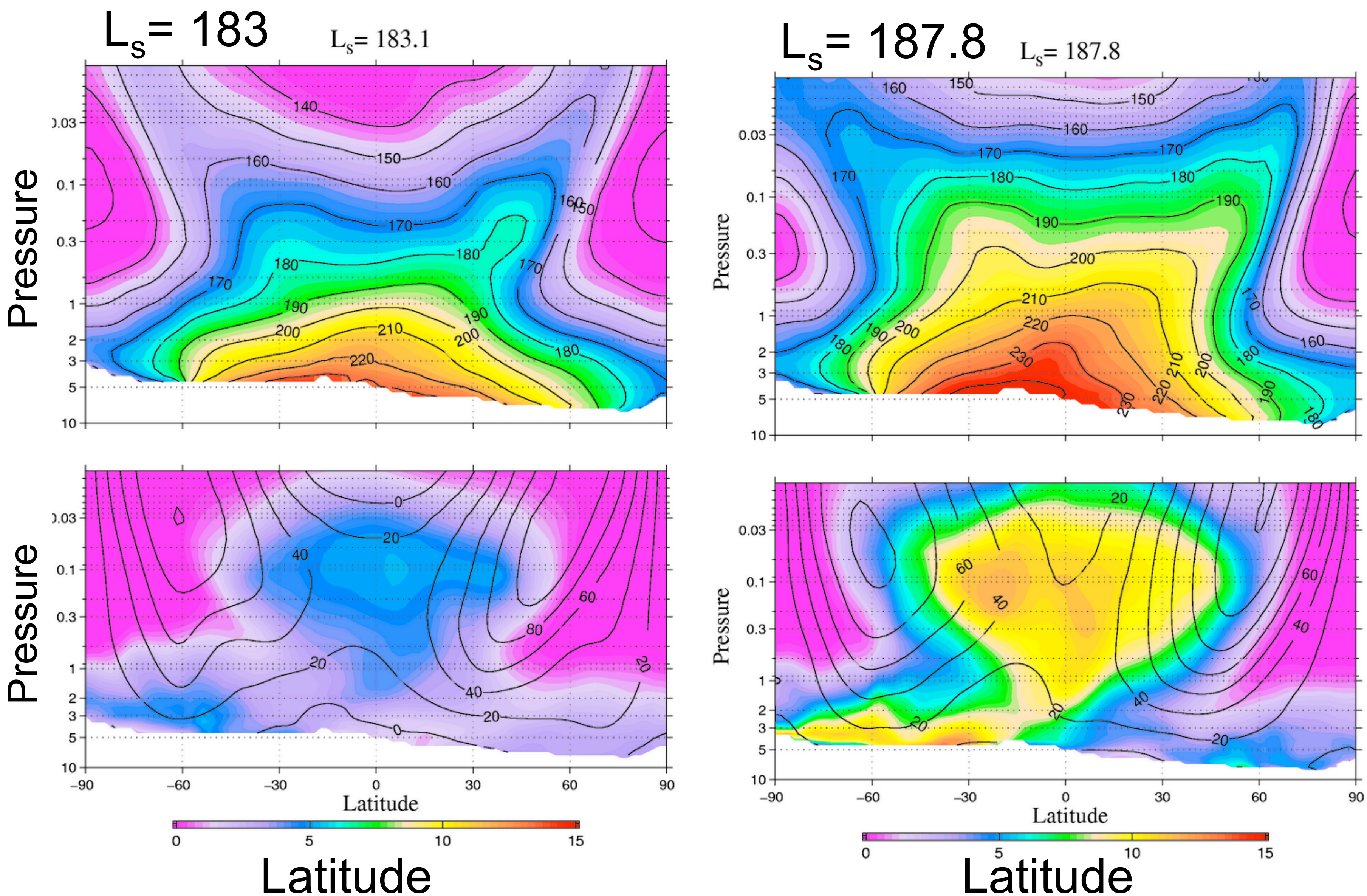
Gridded TES Column Opacity

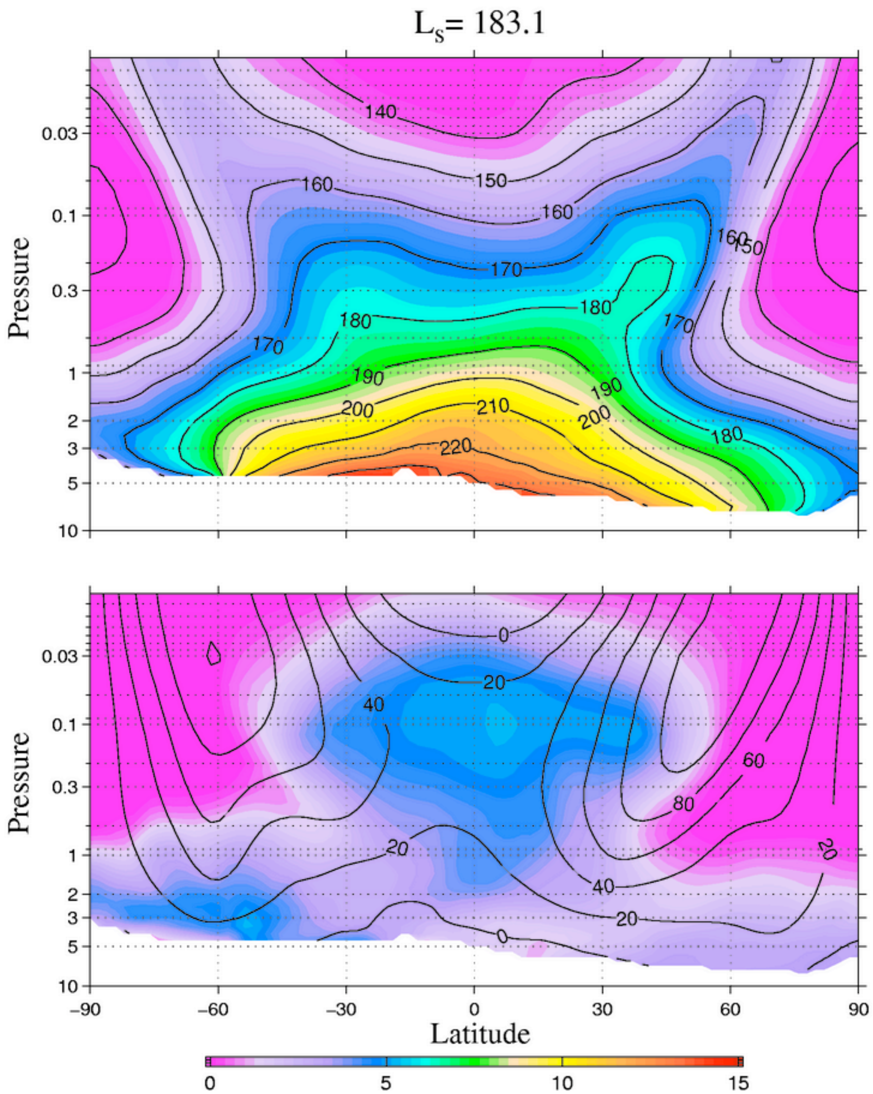


Revised TES Column Opacity

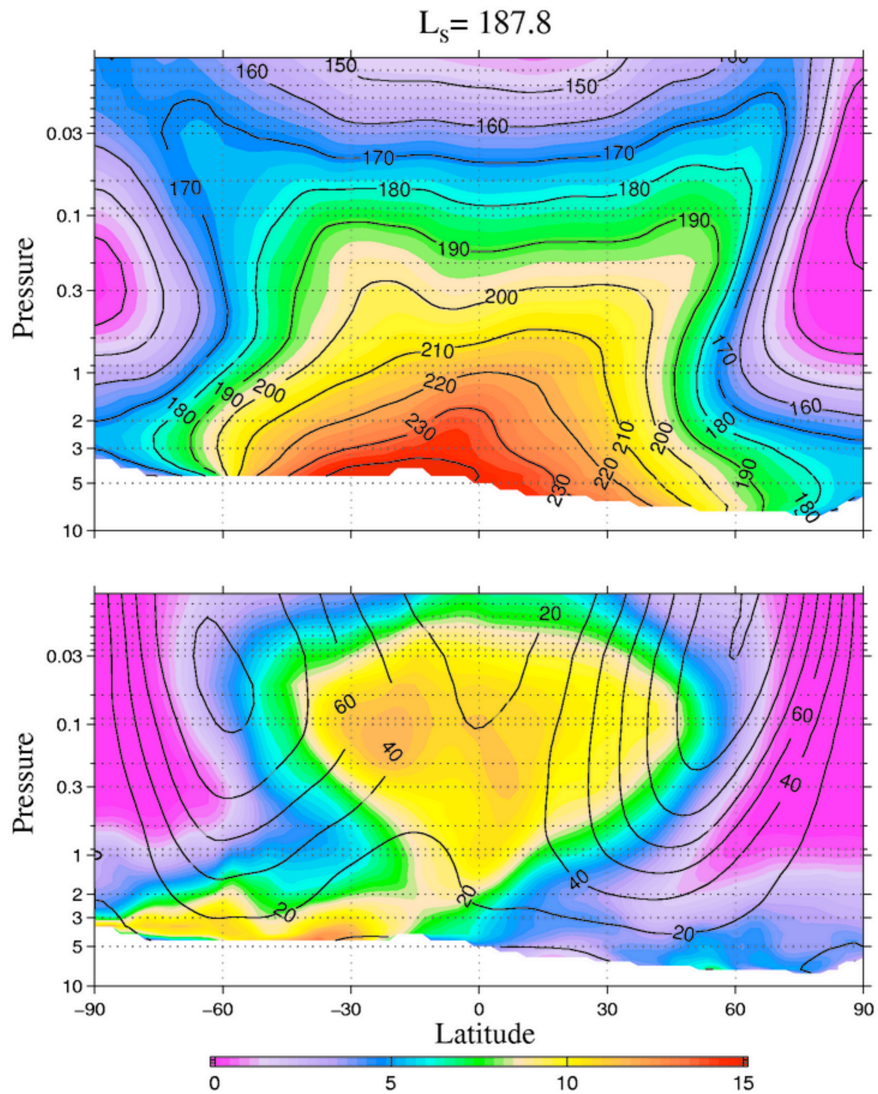


Simulated U, T, Opacity

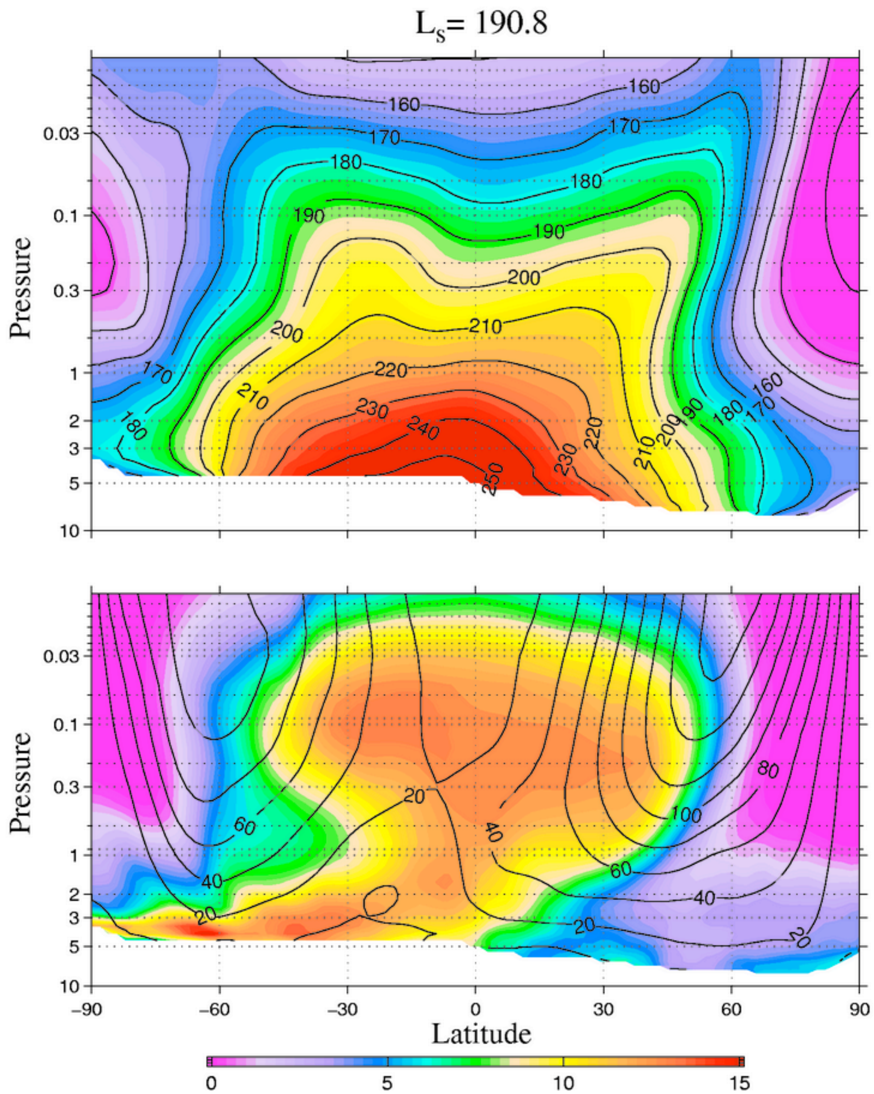




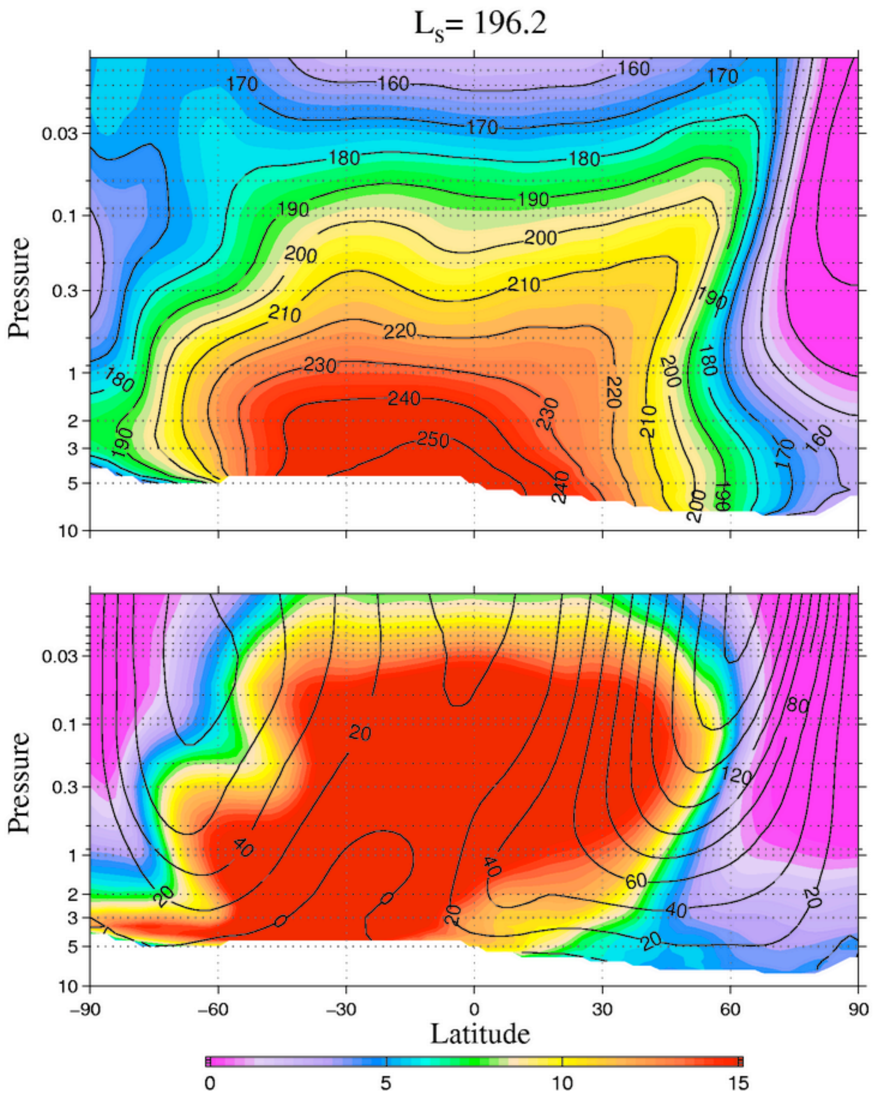
L_s= 183.1
Pressure
Latitude
140
150
160
170
180
190
200
210
220
0
20
40
60
80
0.03
0.1
0.3
1
2
3
5
10
−90
−60
−30
0
30
60
90
5
10
15



L_s= 187.8
Pressure
Latitude
0.03
0.1
0.3
1
2
3
5
10
−90
−60
−30
0
30
60
90
150
160
170
180
190
200
210
220
230
20
40
60
0
5
10
15



Ls= 190.8
Pressure
Latitude
160
170
180
190
200
210
220
230
240
250
20
40
60
80
100
0
5
10
15



L_s= 196.2
Pressure
Latitude
170
160
160
170
170
180
180
190
190
200
200
210
210
220
230
240
250
230
240
220
210
200
190
180
190
200
180
170
160
80
120
20
40
20
0
0
20
40
60
40
20
20
0.03
0.1
0.3
1
2
3
5
10
−90
−60
−30
0
30
60
90
0
5
10
15

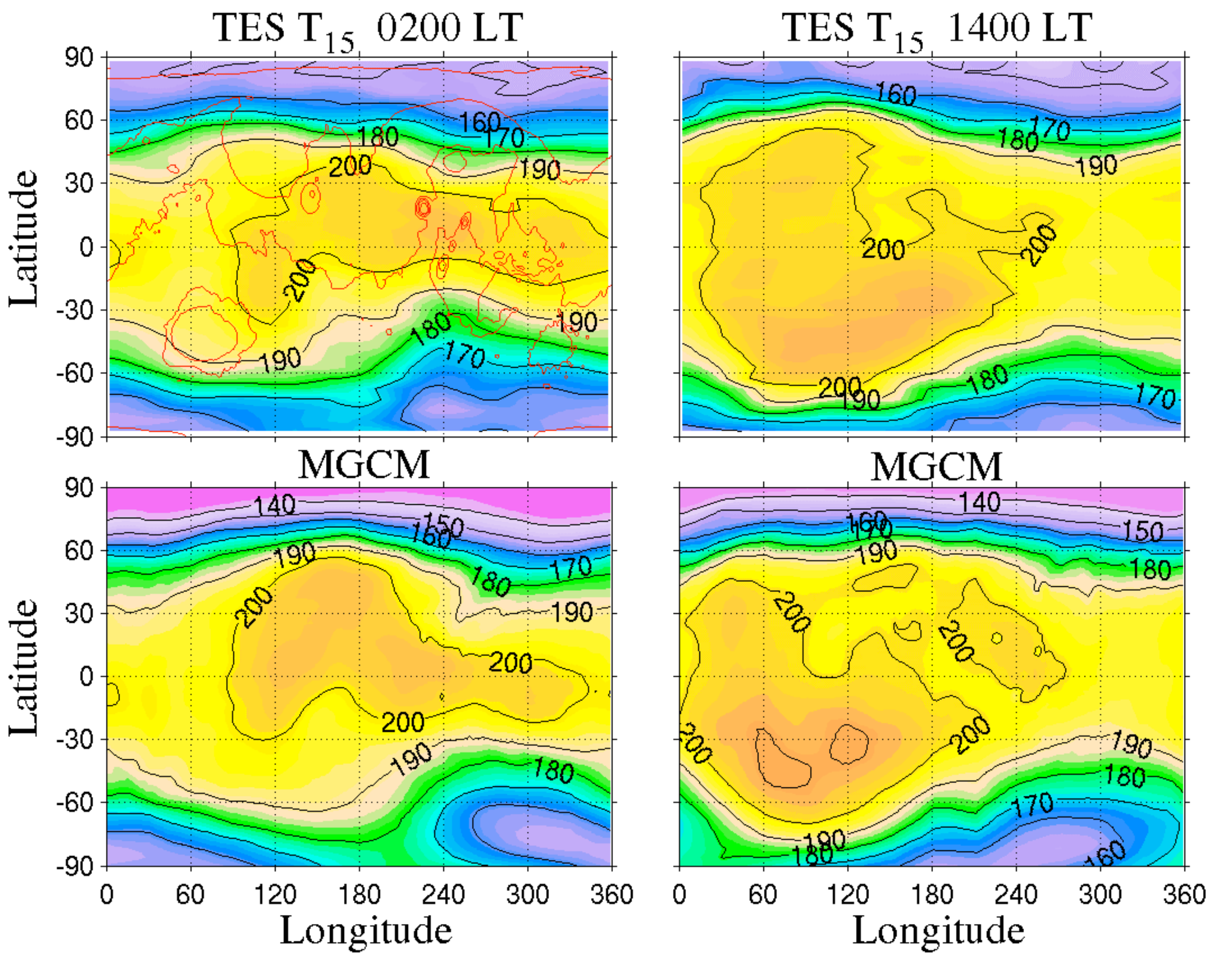
TES 2am and 2pm Temperature vs MGCM

L_s = 187.5°

T_{15} = depth weighted temperature centered at 0.5 mb

2 am

2 pm

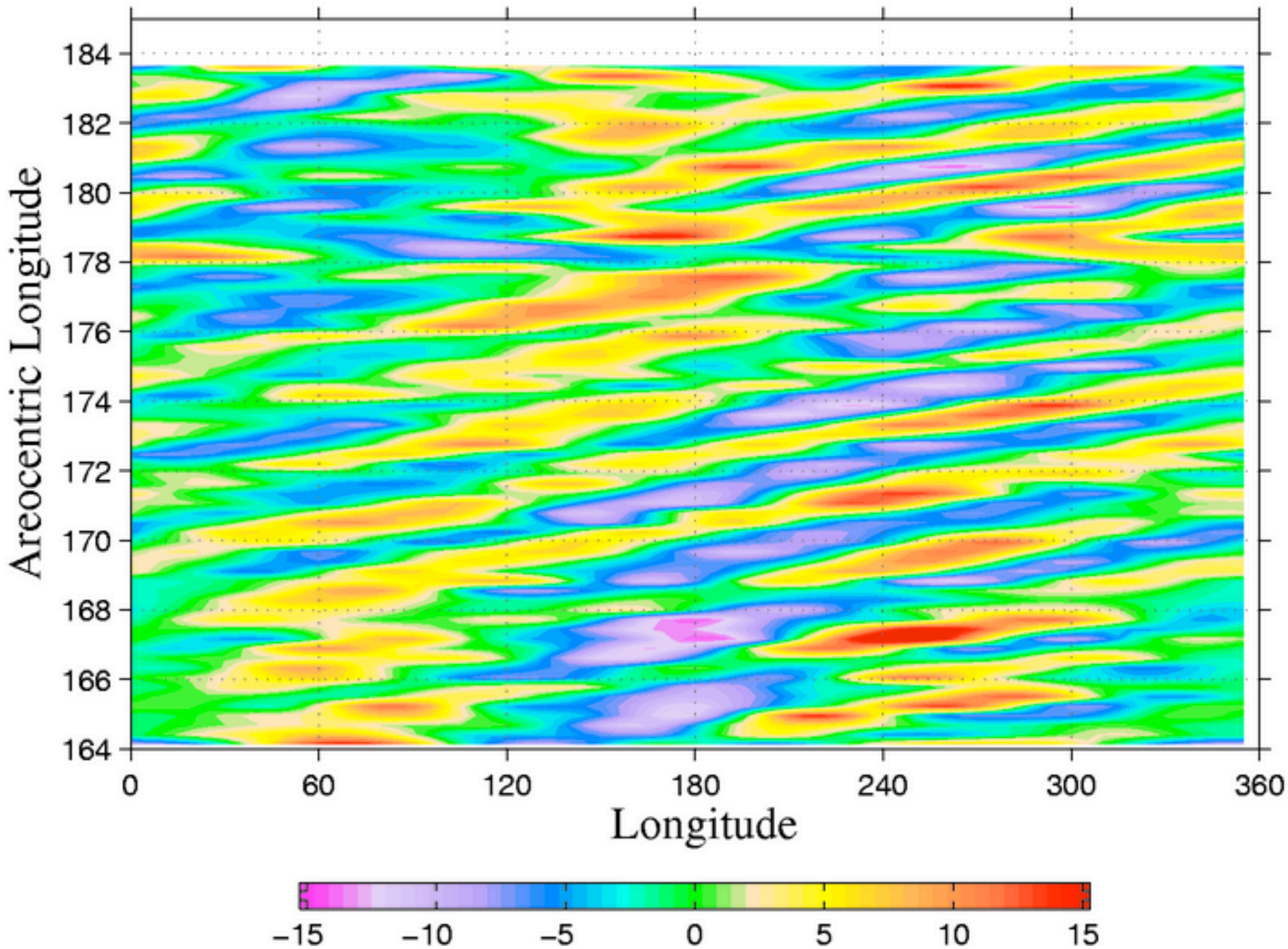


TES

MGCM

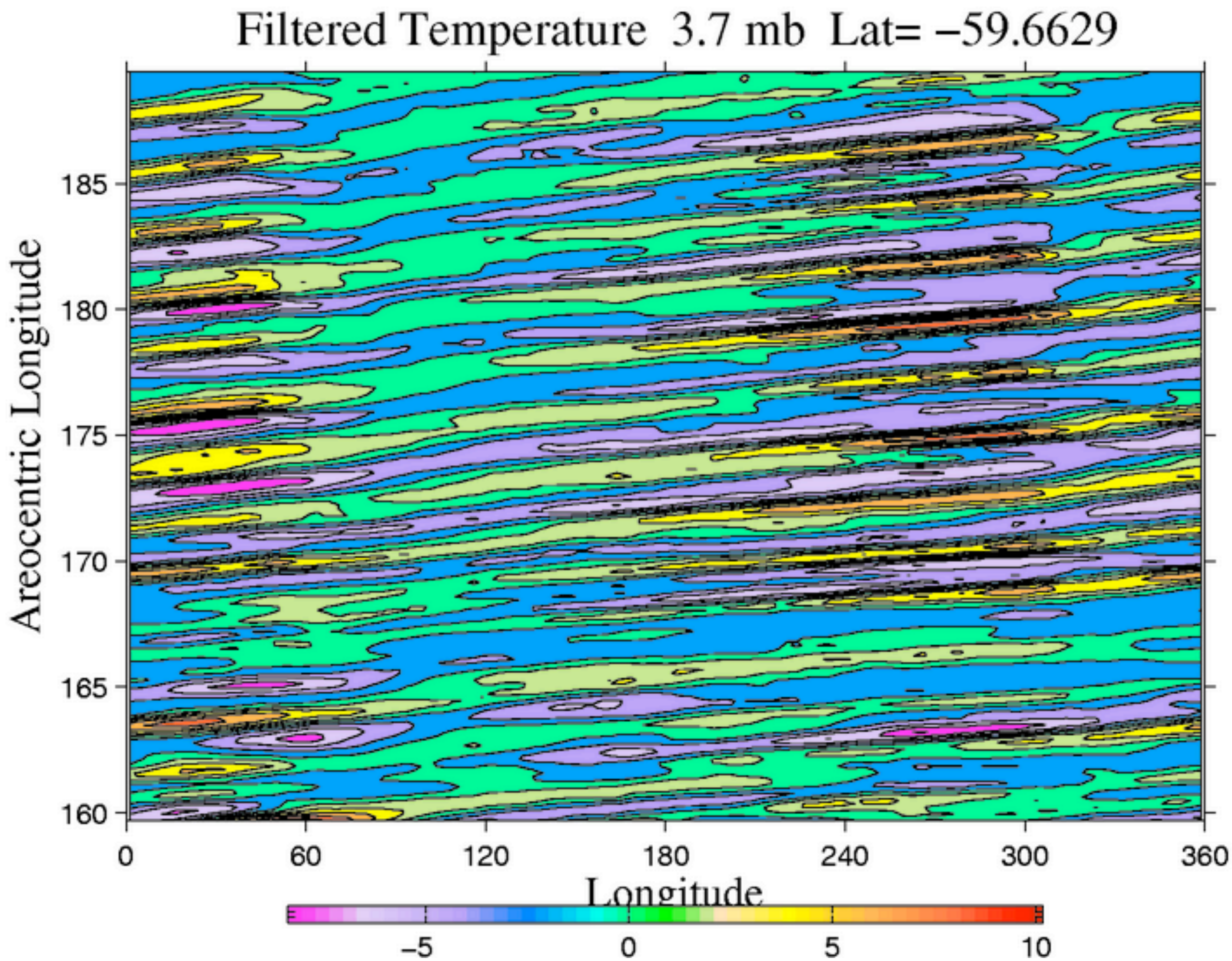
TES Eddy Temperature   60°S   3.7 mb

Evidence for traveling wave activity during the precursor phase

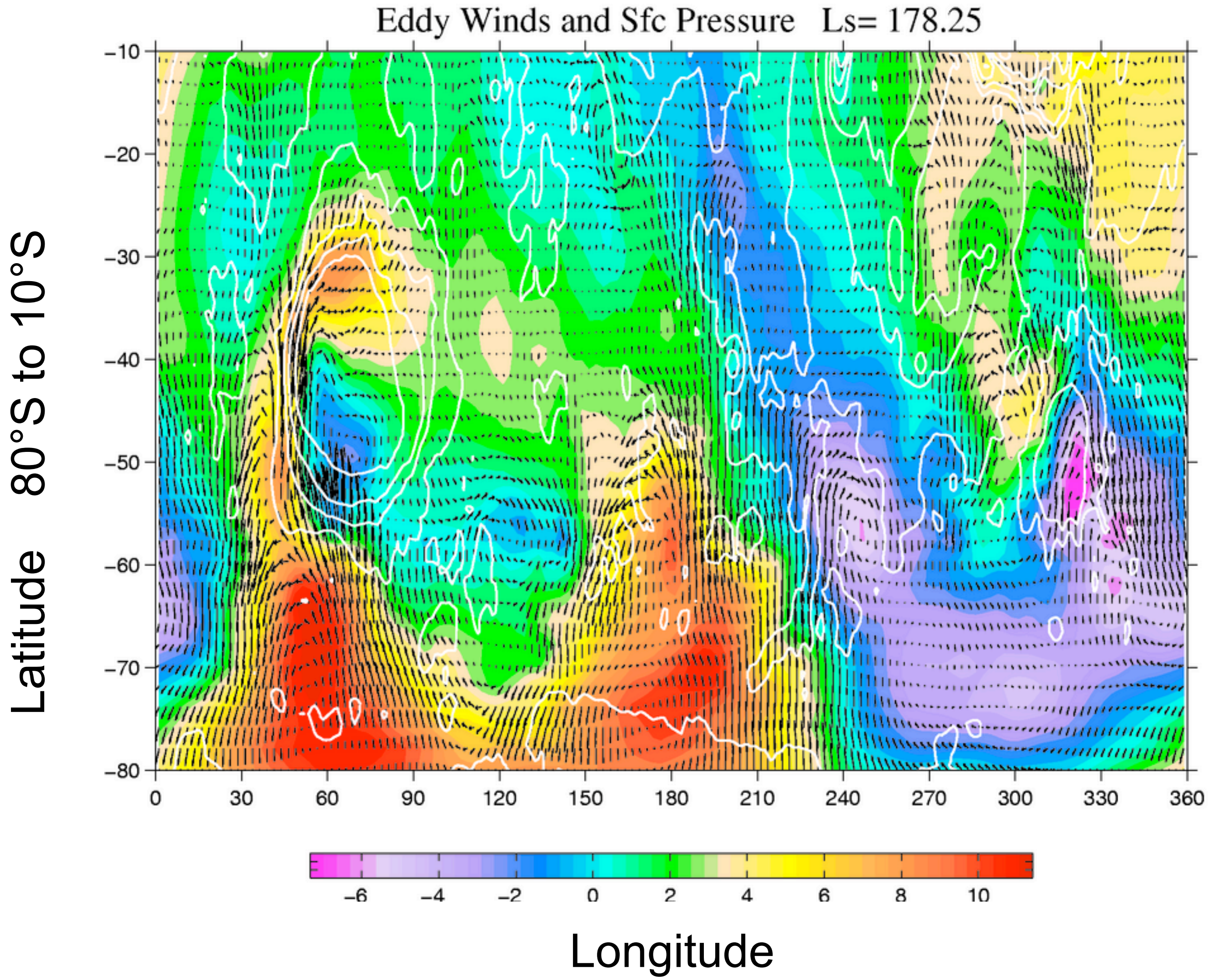


*Fast Fourier Spectral Mapping method: Jeff Barnes

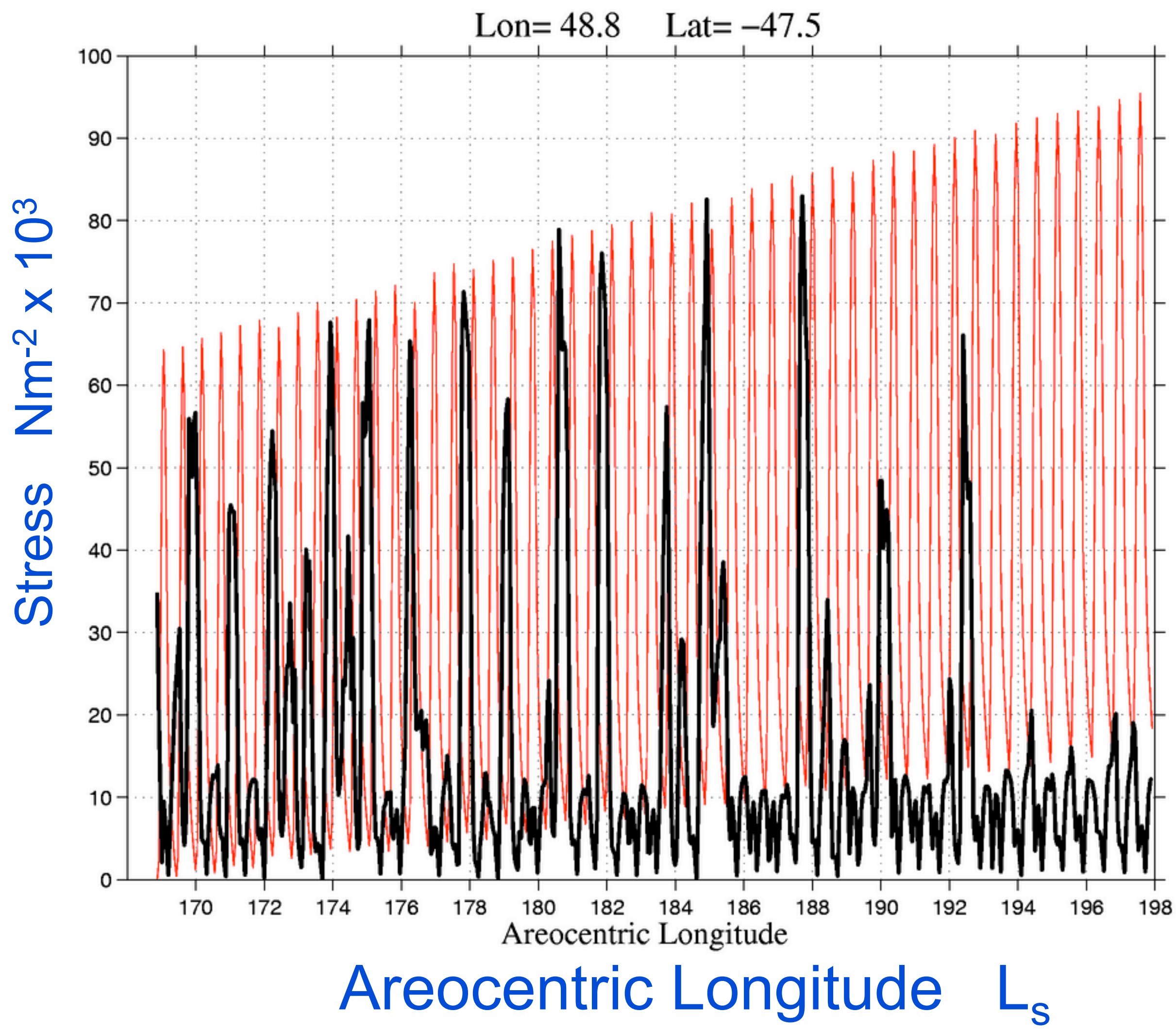
Similar wave activity is found in the MGCM simulation



Eddy winds significantly augment winds along southern and western rims of Hellas basin



Surface Stress in the SW Corner of Hellas

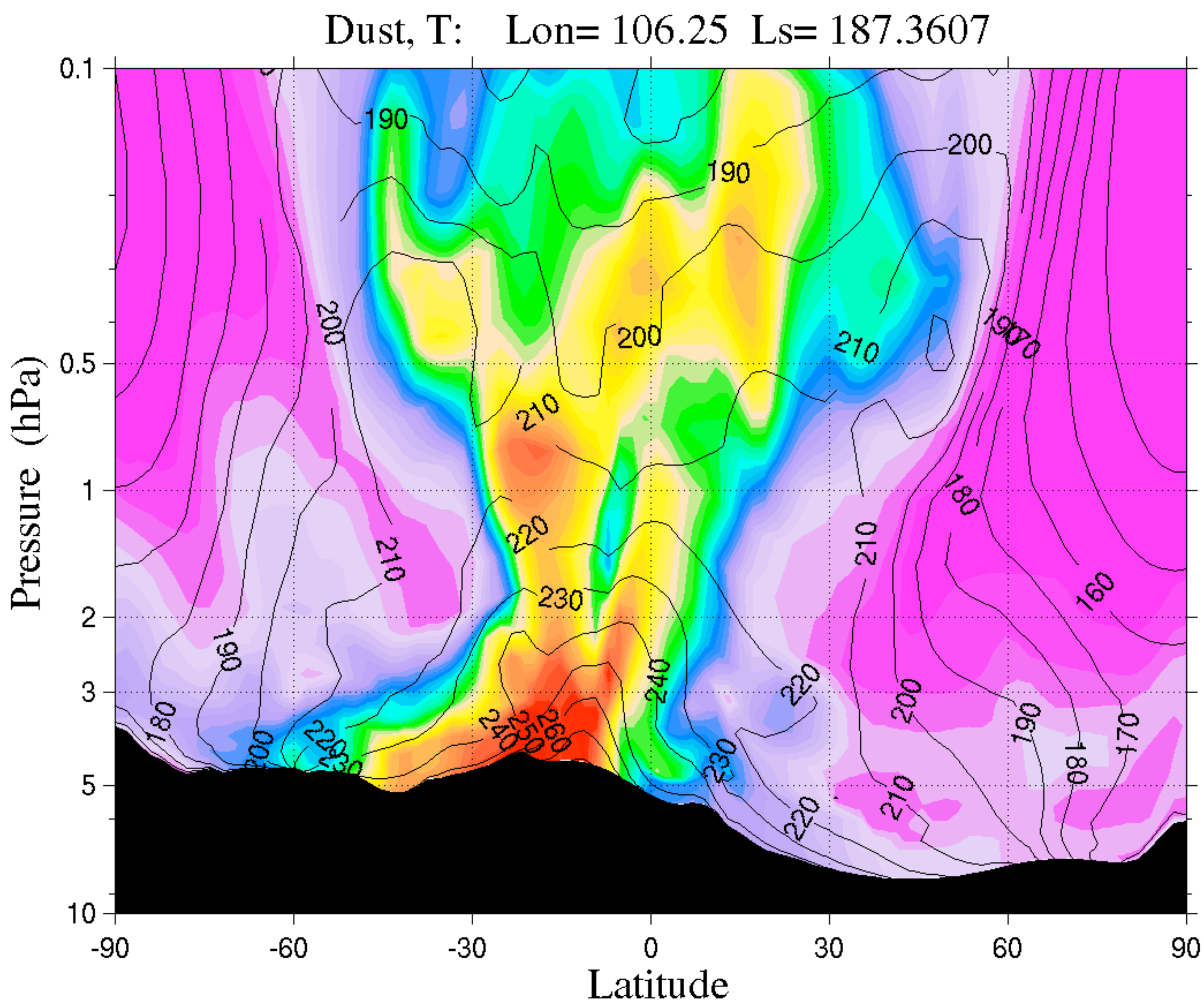


Pulses of high stress (black) at intervals of 2 to 4 sols.

Peak stresses when the traveling waves are in sync with the nighttime diurnal slope winds

Red curve shows scaled Tsfc to indicate the phase of the diurnal cycle

Afternoon (2 pm) Dust Mixing Ratio and Temperature



Temperature contoured at 10 K intervals

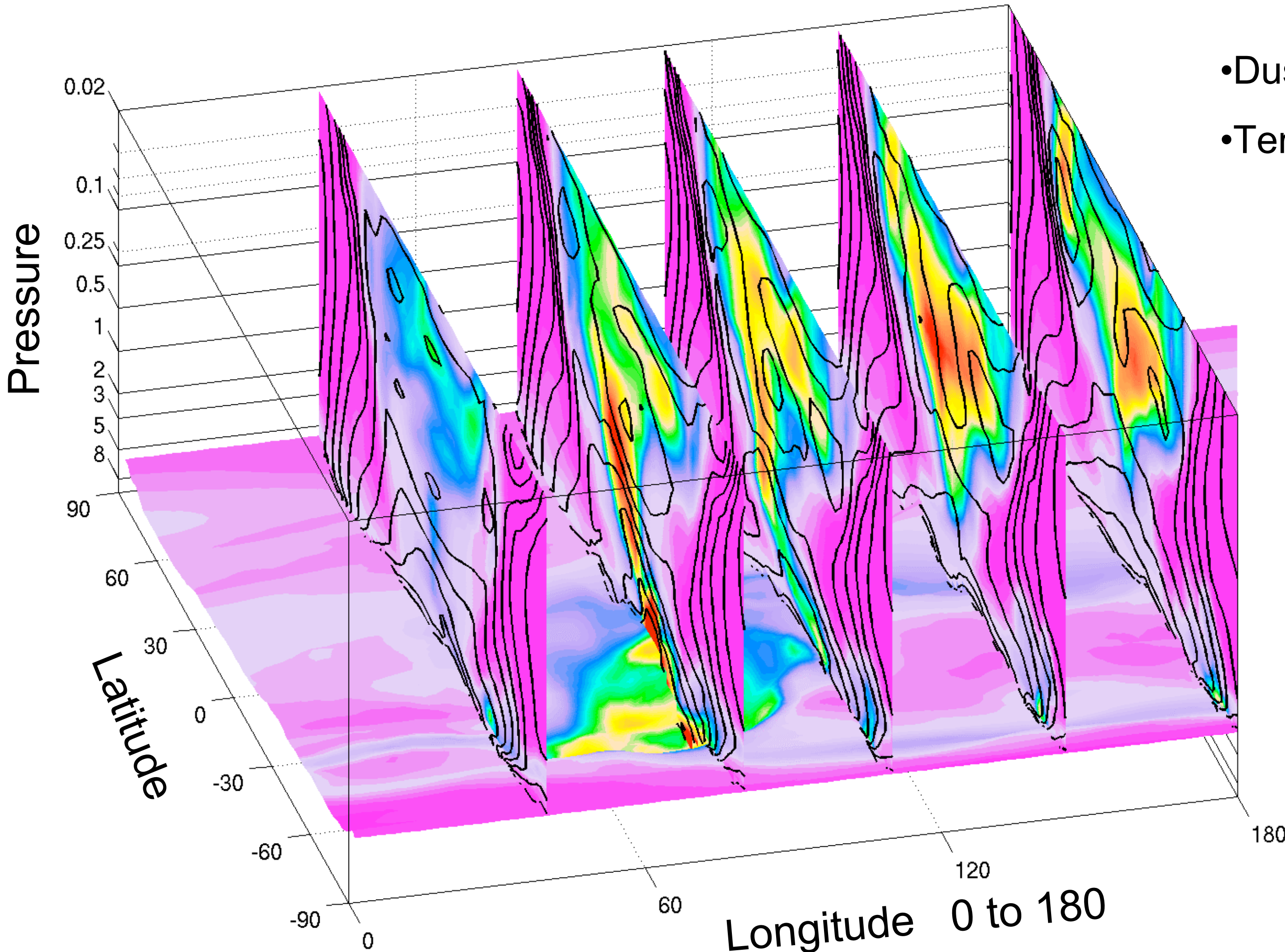
Diurnal Tide / Hadley Circulation ---> Strong convergence and upward motion in the tropics

Dust Distribution L_s= 187

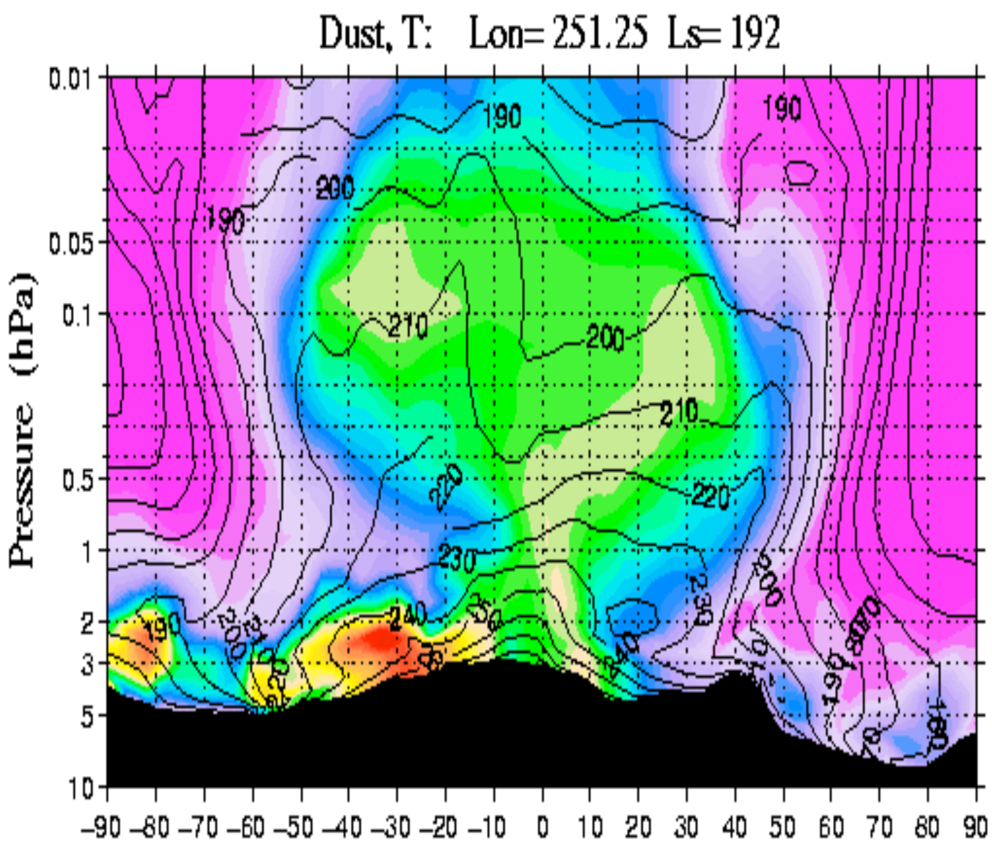
•Column dust opacity on bottom plane

•Dust mixing ratio (shaded)

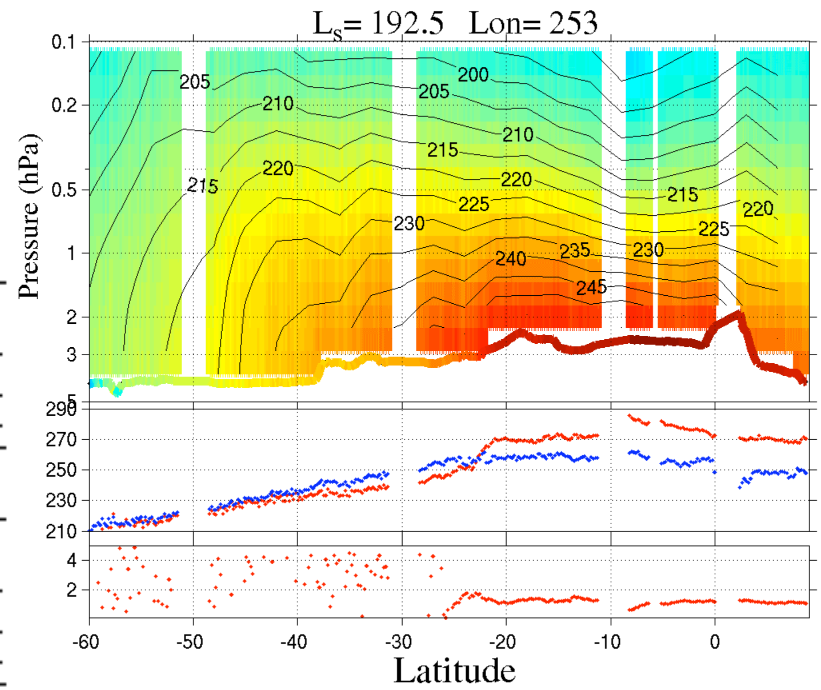
•Temperature (contoured)



Temperature contoured at 10 K intervals



Latitude



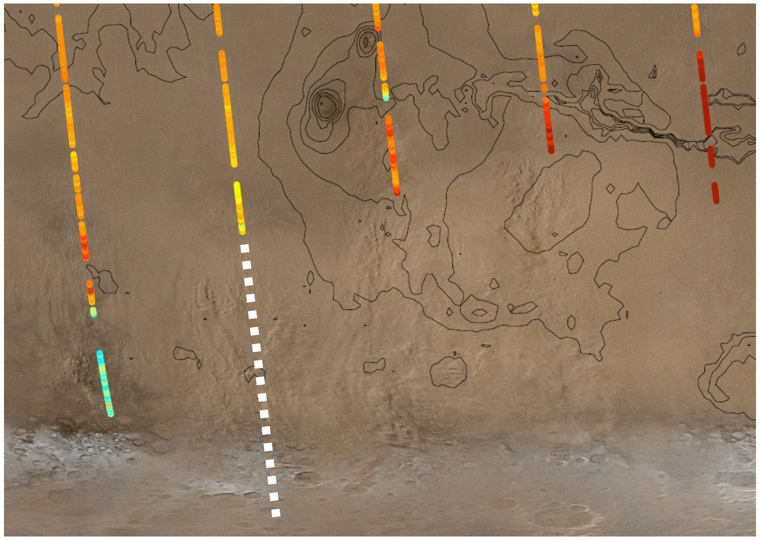
*1°

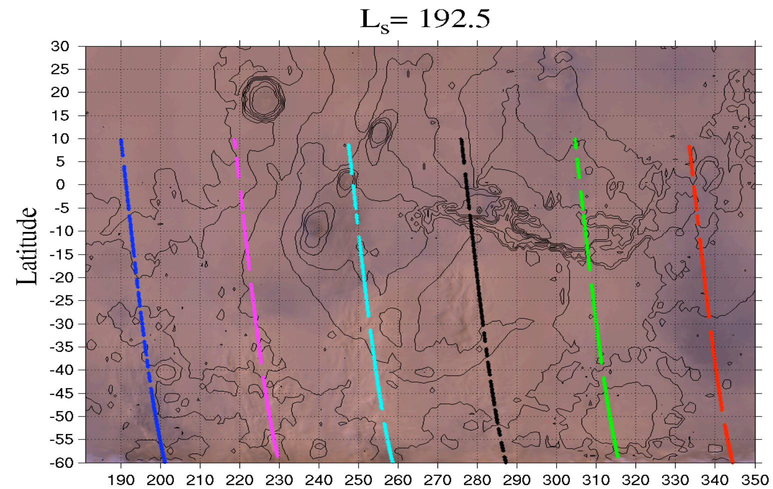
Zoomed View

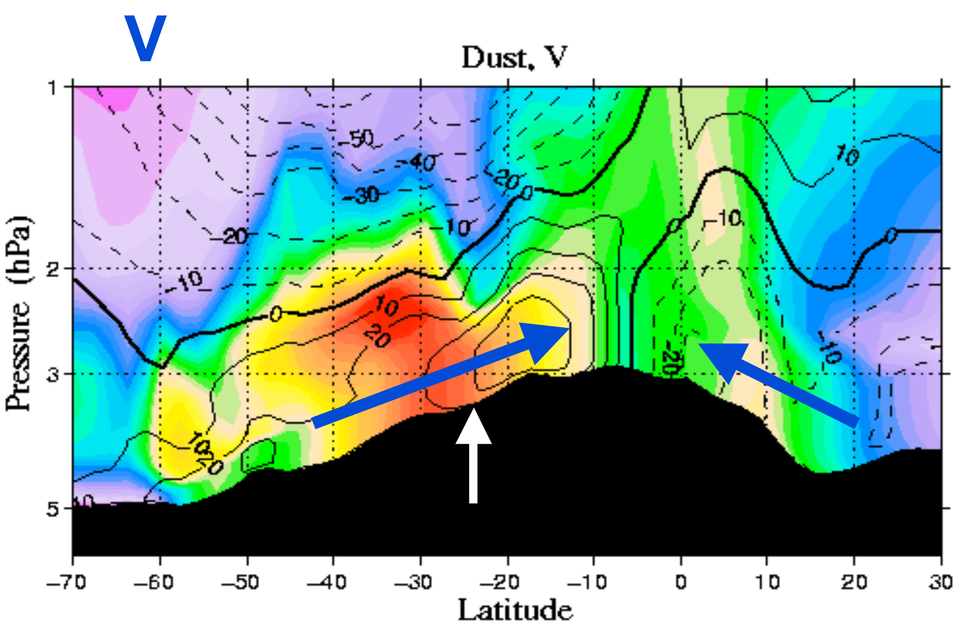
Dust mixing ratio: shading

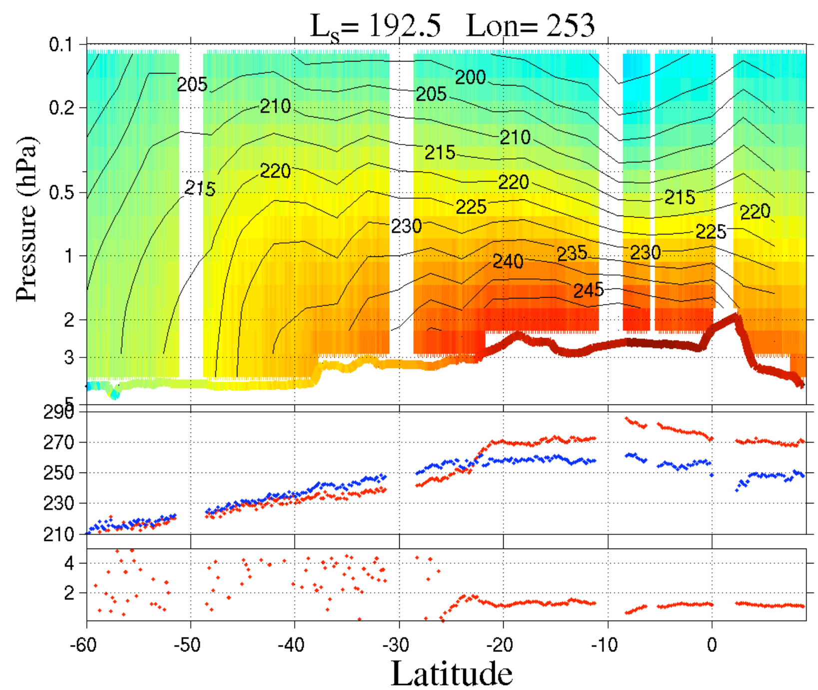
Meridional Wind: contour (10 ms^{-1})

C45L28 (2°x2°)



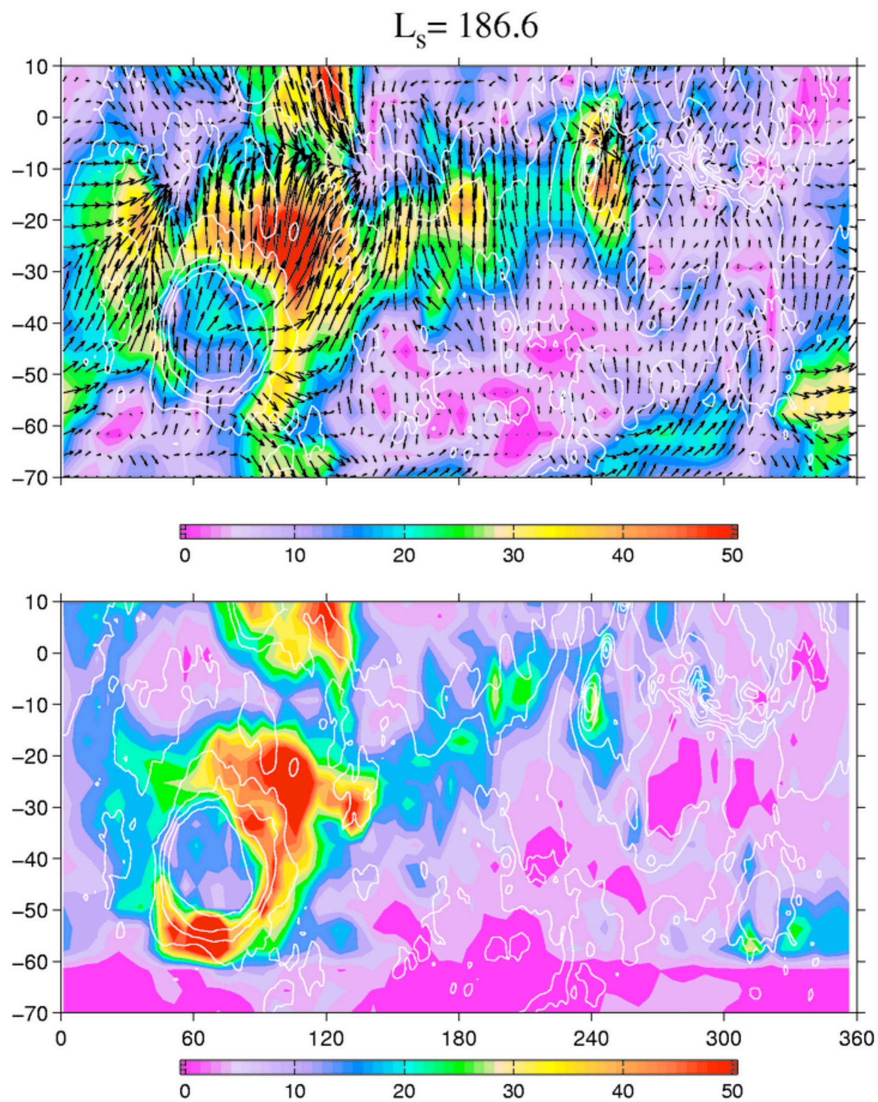






V 10 ms^{-1} intervals

2 pm Winds (top); Diurnal Maximum Surface Stress (bottom)



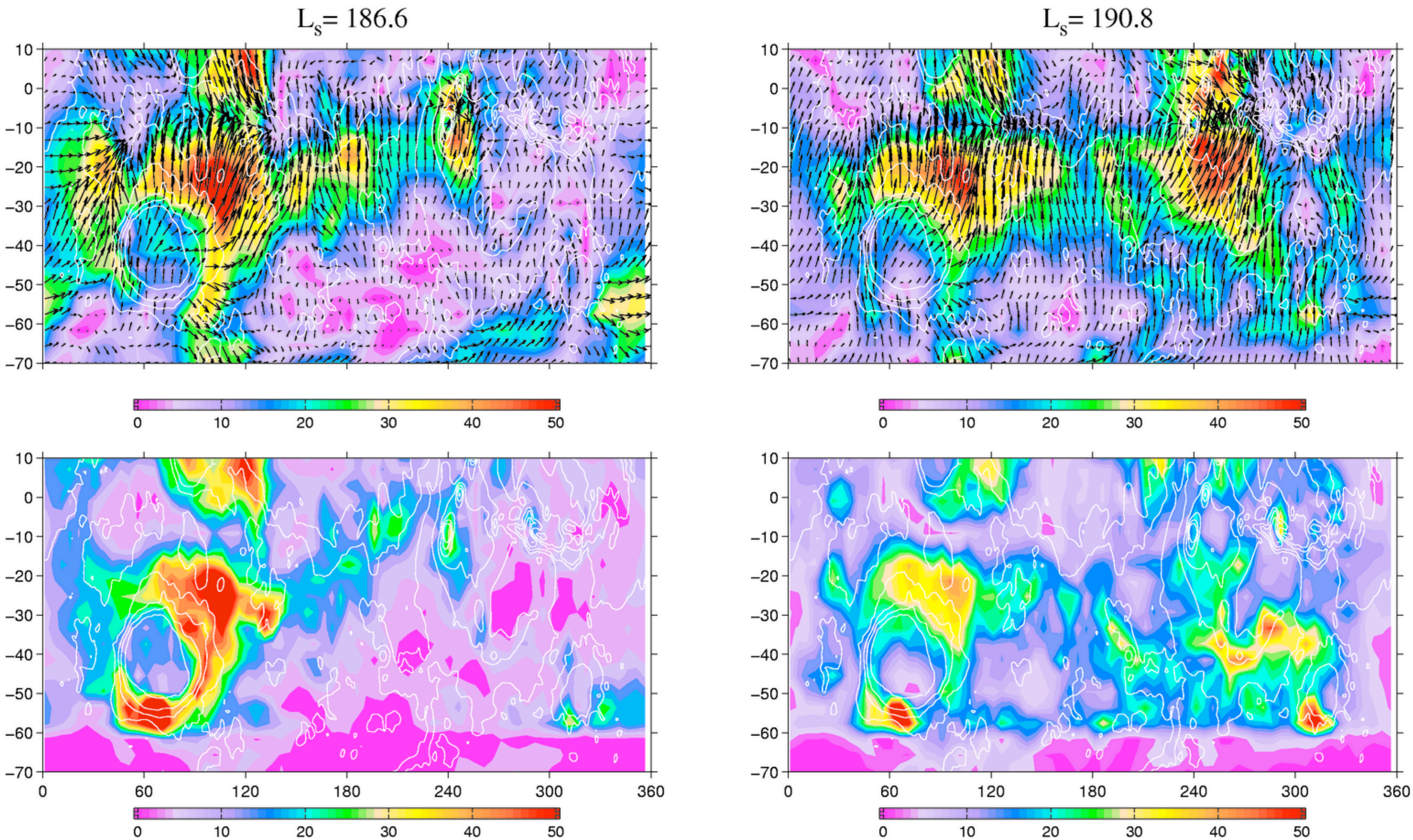
1400 Local Time Winds (1 km agl)

Wind magnitude (shaded)

Daily maximum stress

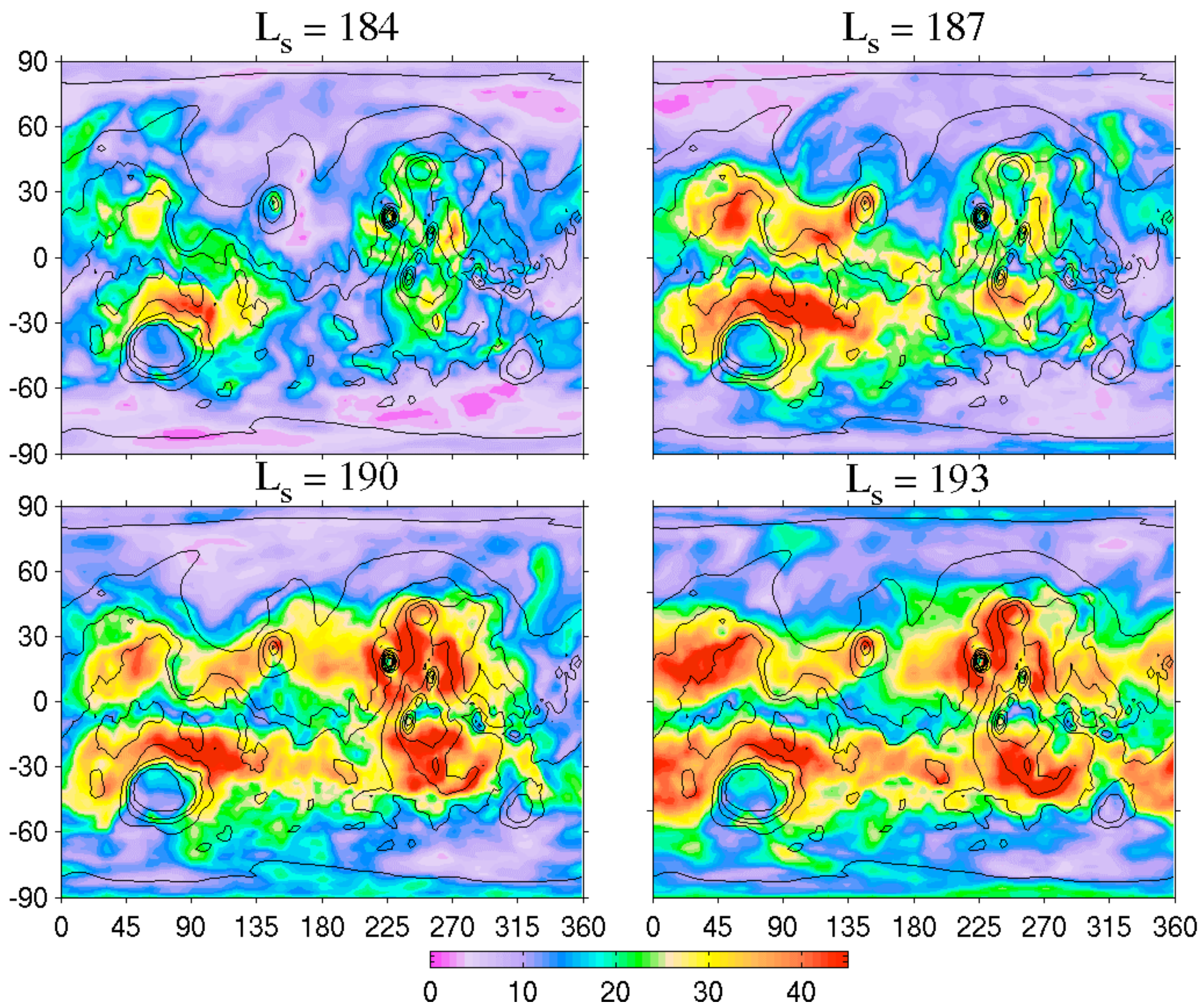
Nm^{-2} x 1.0^{3}

2 pm Winds (top); Diurnal Maximum Surface Stress (bottom)



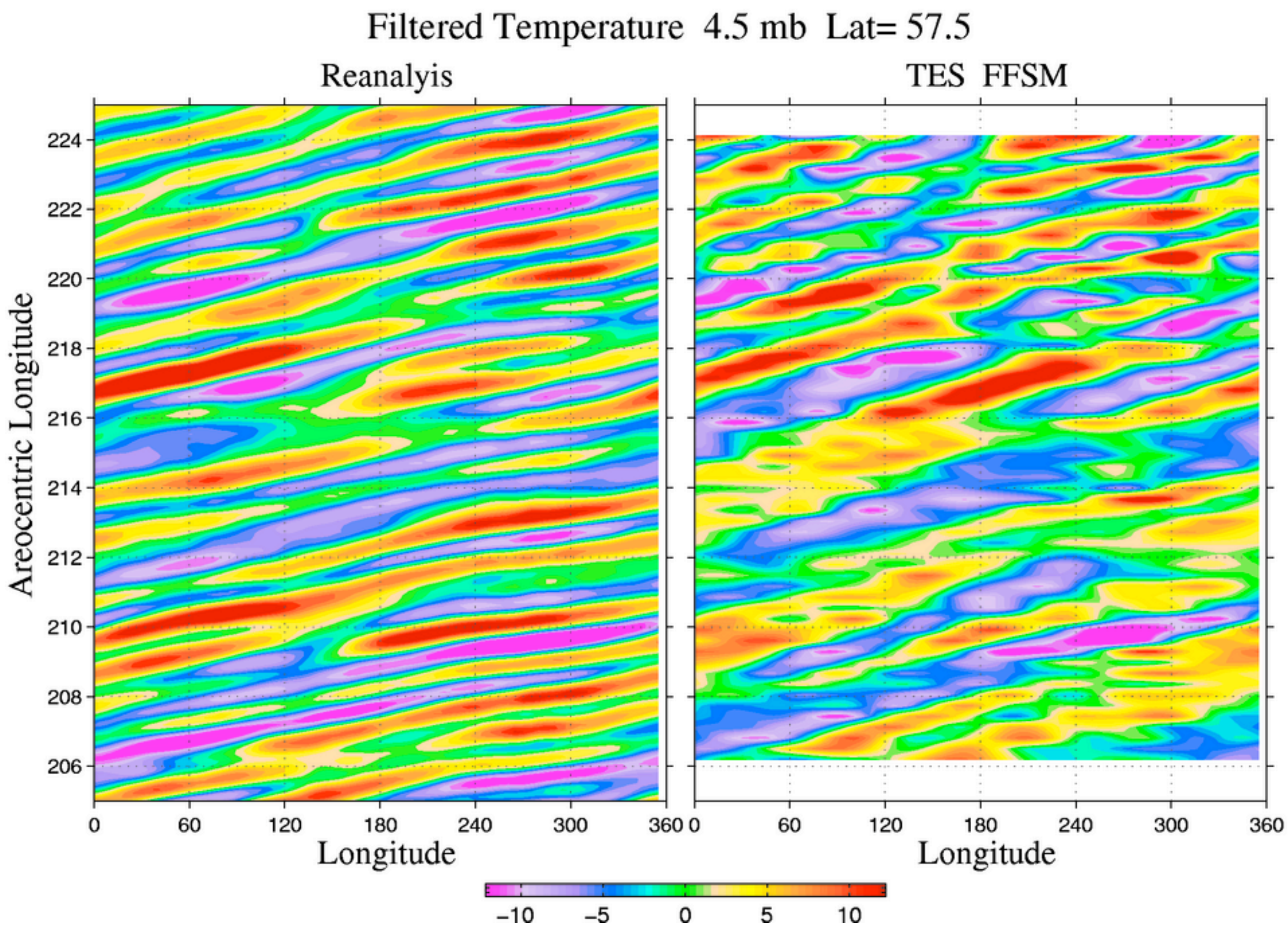
The evolution of tide wind amplitude

~300 m above ground level

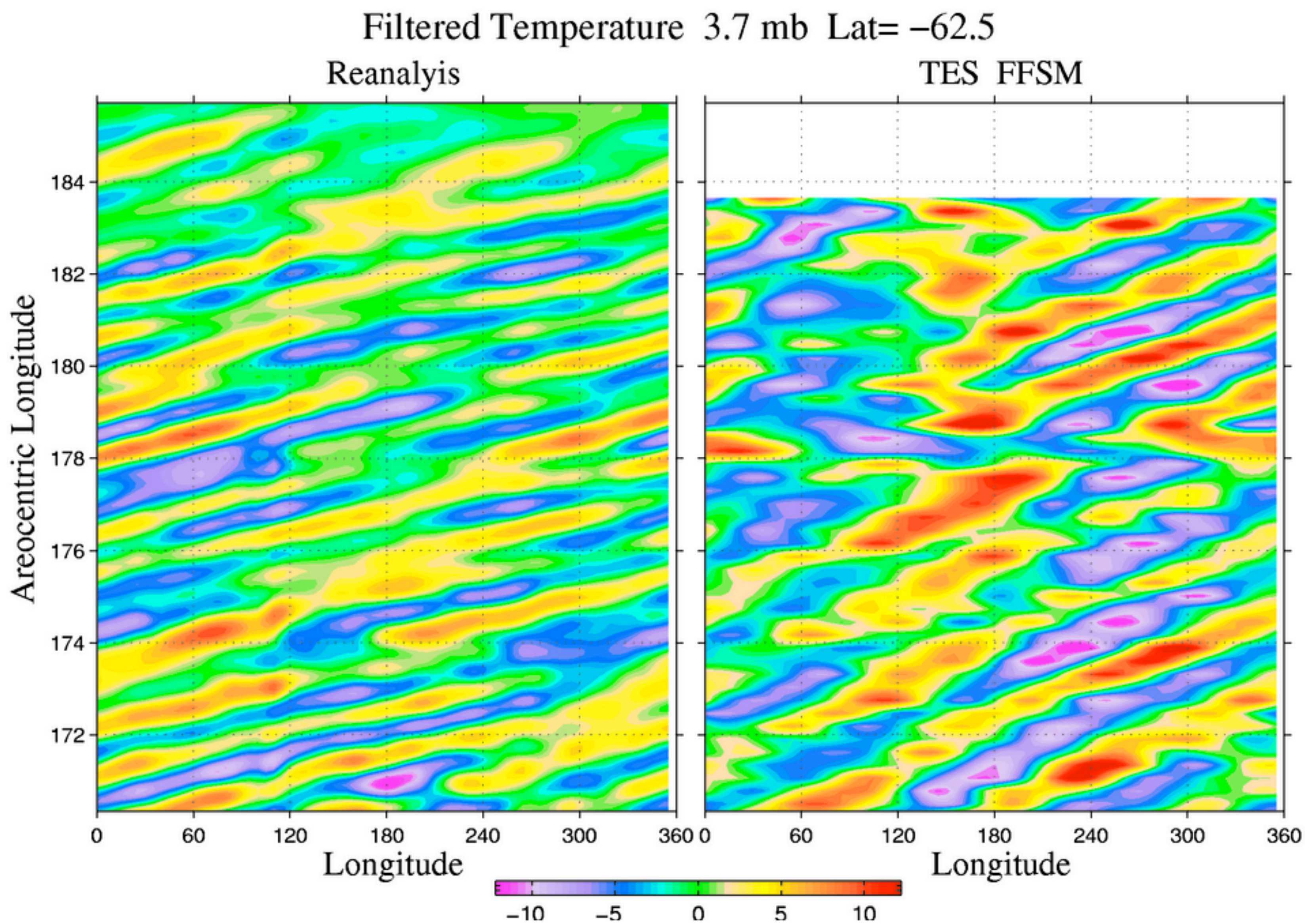


Summary

- **Many components of the general circulation appear to play a role:**
  - Eastward traveling baroclinic eddies
  - Quasi stationary waves
  - Hadley circulation
  - Thermal Tides
- **Understanding the cause of lifting in Claritas remains a key issue**
  - Tide amplification appears to be important.
- **More work remains in improving and analyzing the MGCM simulations:**
  - Further refinement of the dust opacity estimates.



Filtered Temperature 4.5 mb Lat= 57.5
Reanalyis
TES FFSM
Areocentric Longitude
224
222
220
218
216
214
212
210
208
206
0
60
120
180
240
300
360
Longitude
Longitude
−10
−5
0
5
10



Filtered Temperature 3.7 mb Lat= −62.5
Reanalyis
TES FFSM
Areocentric Longitude
184
182
180
178
176
174
172
Longitude
0
60
120
180
240
300
360
−10
−5
0
5
10