Synthesis of MGS Observations of the 2001 Global Dust Storm on Mars: Implications for Atmospheric Dynamics

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Objctives

- Combine and examine a synthesis of MGS observations of the 2001 global dust storm to better characterize the development of the storm and to investigate which components of the general circulation were involved in the onset and evolution of the storm.

- Conduct simulations of the storm using the NASA-Ames Mars GCM to better understand the atmospheric dynamics involved.

Datasets

- MOC daily global maps (Mike Malin and Bruce Cantor)
- TES measurements of atmospheric temperature and 9 μm dust opacity (Phil Christensen and Mike Smith)
- Mars Horizon Sensor Assembly (MHSA) measurements of middle atmosphere temperatures. (Terry Martin & Jim Murphy)

Approach

- Examine and compare various MGS datasets by superimposing binned TES and MHSA data on MOC daily global maps to see how the temperature and dust fields evolved together.

- Use the Ames GCM to conduct simulations and compare results with the above datasets in order to better understand the role of large-scale dynamics in the dust storm.

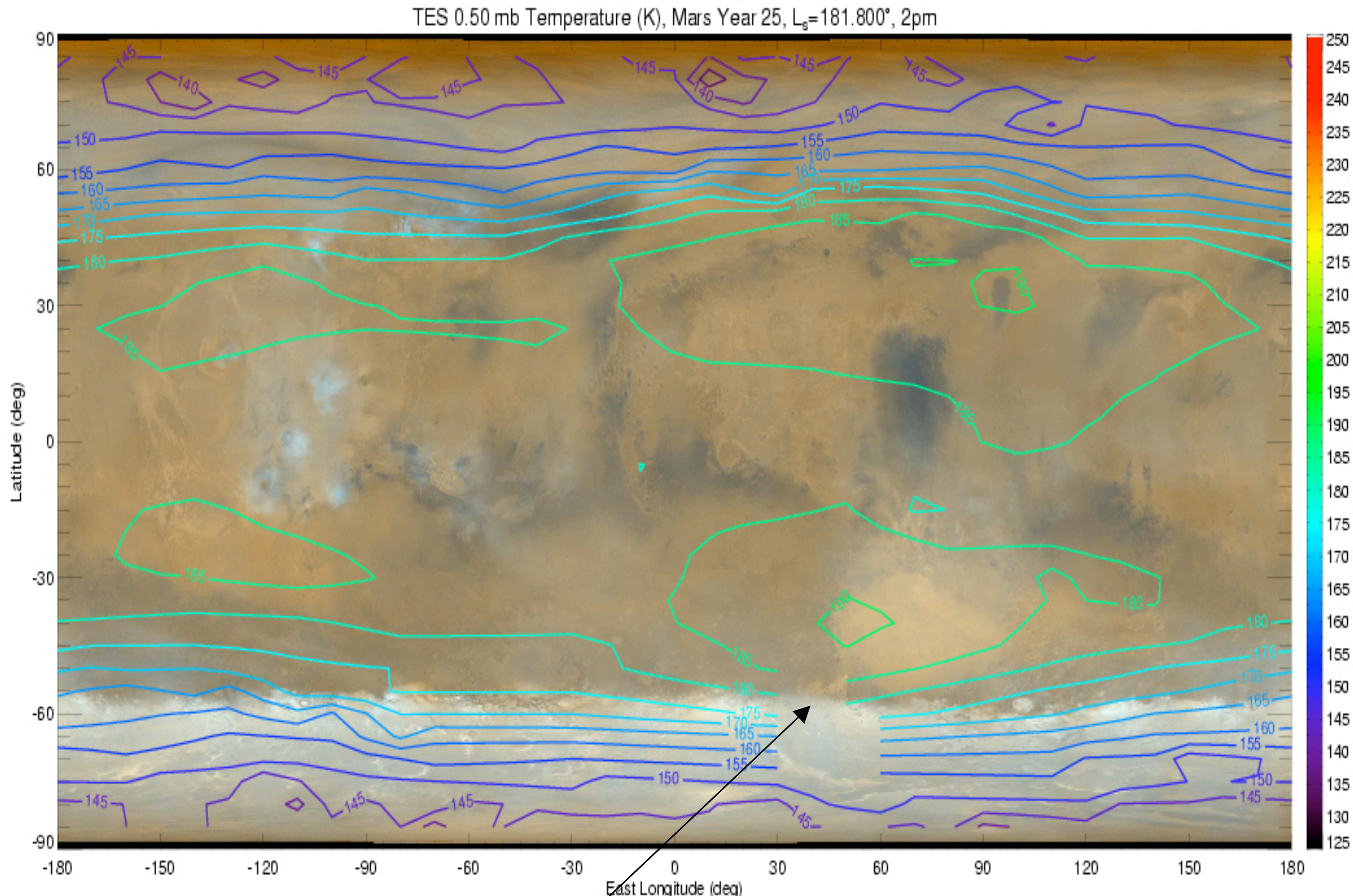
- Force the model with observed TES opacities - we were not doing any transport simulations with the model.

Precursor phase (L_s=176 –184.4) Observations and GCM simulations

- MOC observations indicate that the initial regional storm in Hellas developed following a series of pulses of dust lifting originating along the edge of the south polar cap which was in retreat at that point. These pulses occurred roughly 2 - 3 sols apart.

- Our simulations indicate that they can be identified as eastward-traveling baroclinic eddies.

Storm Onset in Hellas

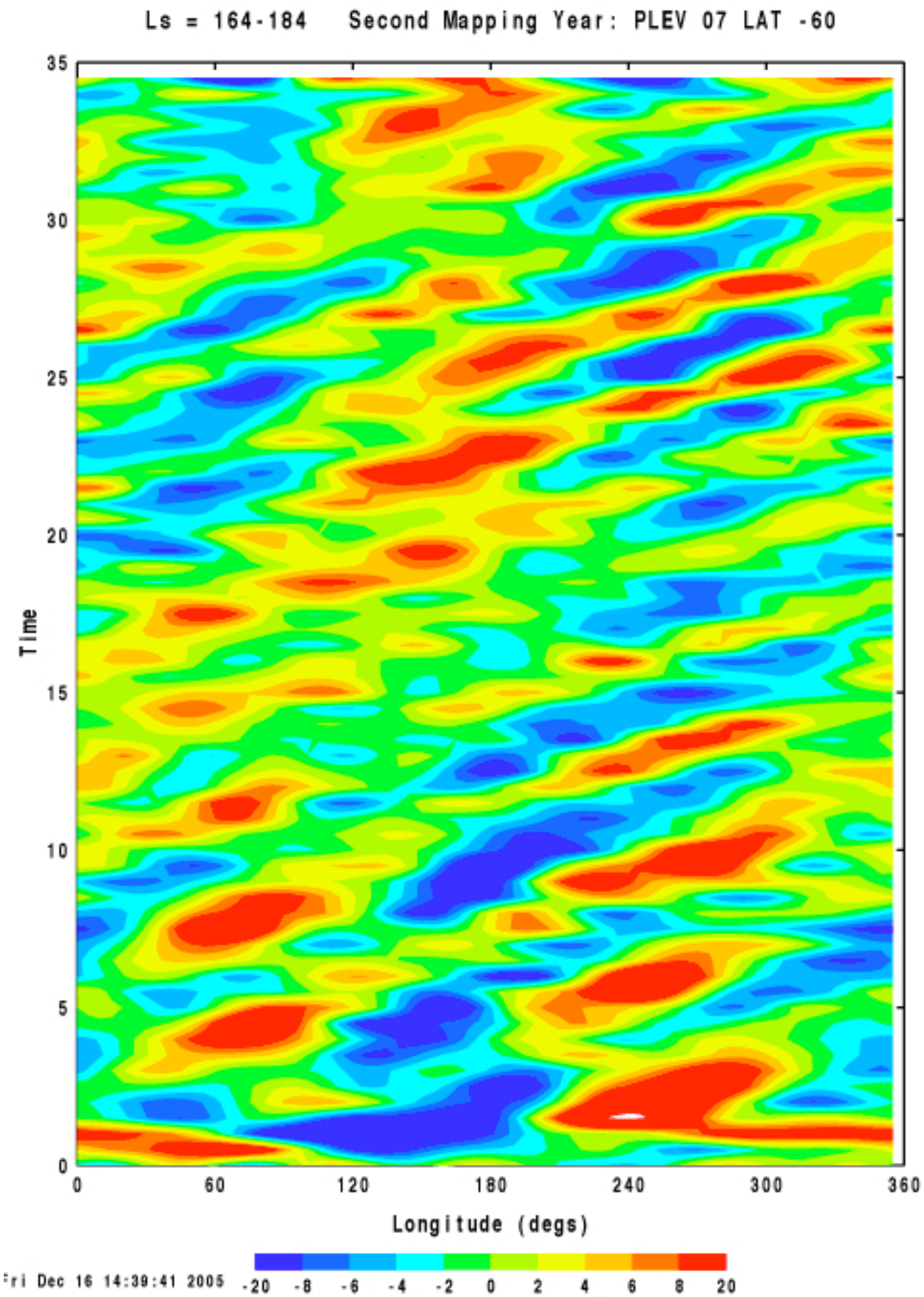


Pulse at L_s=181.8

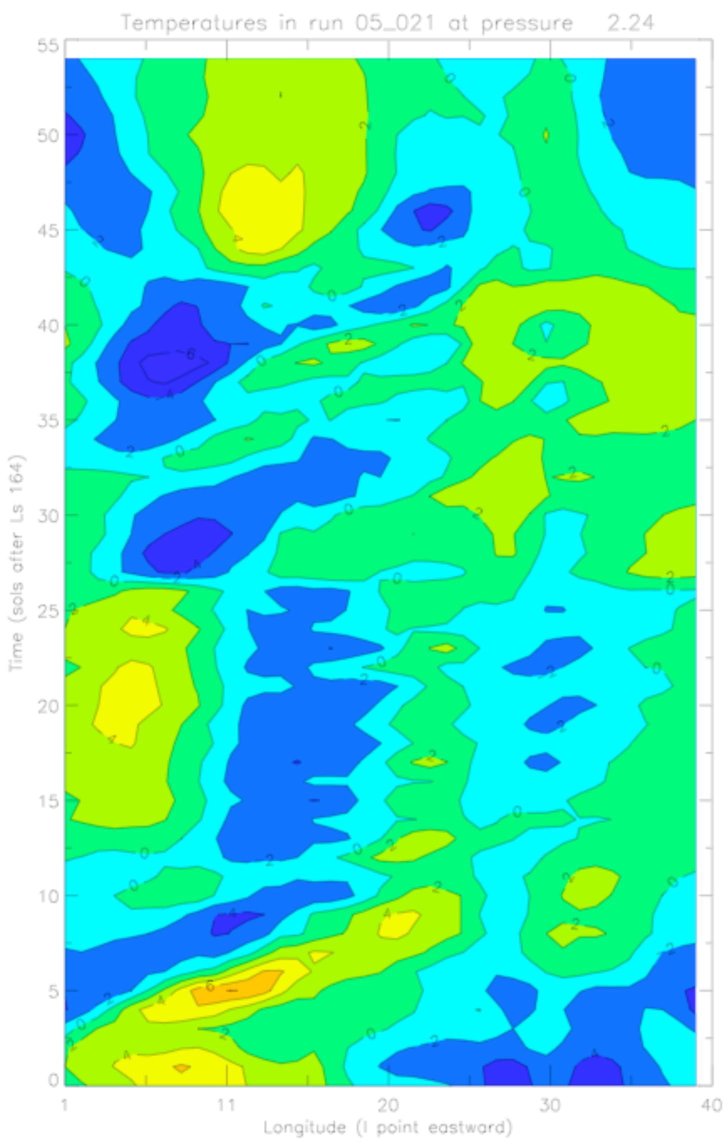
- TES data that has been filtered with Barnes' Fast Fourier Synoptic Map program show a sequence of cold centers from ~ L_s= 175 – 182 in the Hellas region with an approximate 2-sol periodicity, confirming the presence of these eddies in the thermal field.

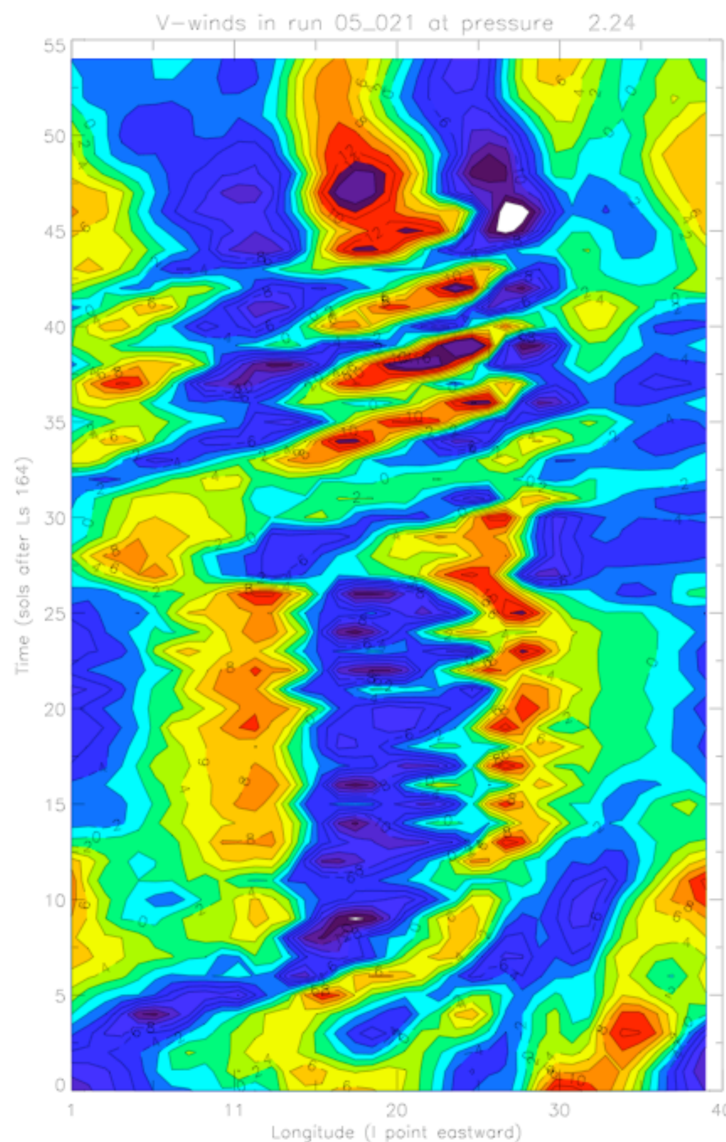
- This process removes the time-mean and the zonal mean along with the very low frequencies. The westward diurnal tide (wavenumber one) is also removed.

- We hypothesize that these eddies served to "prime the pump", leading to the regional-scale Hellas dust storm around L_s=184.

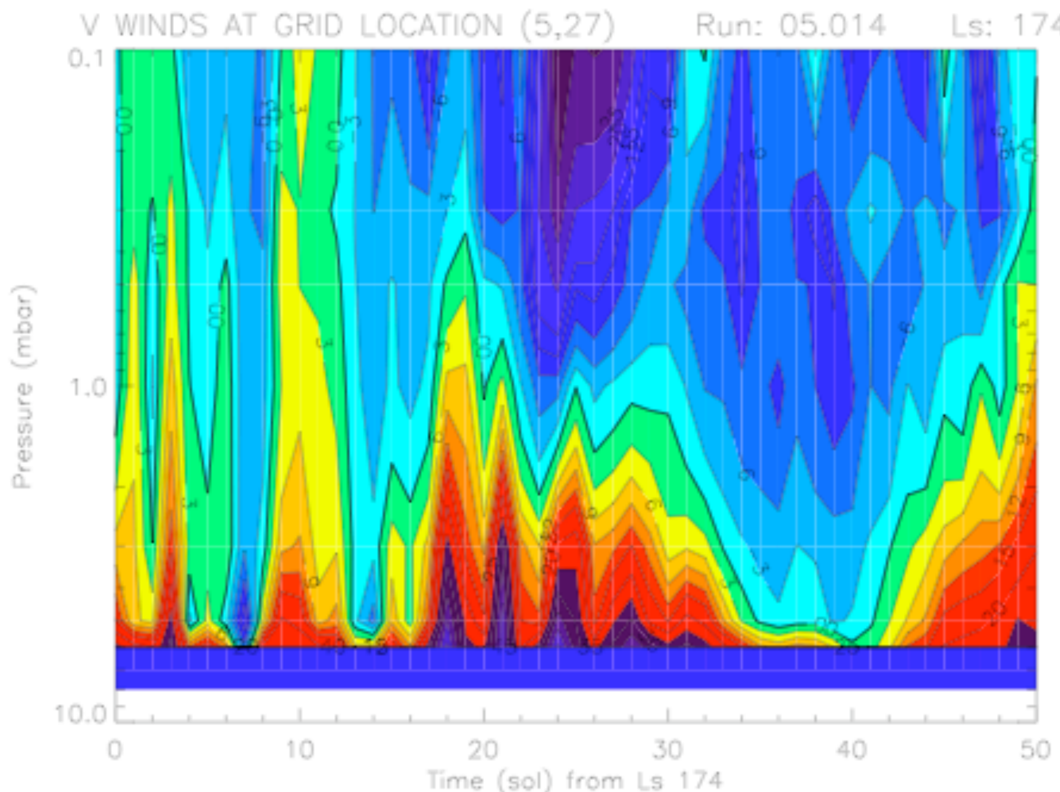


Hovmoller plots of GCM simulations of Mars Year 25 - 2.24 mb, temperature and meridional winds

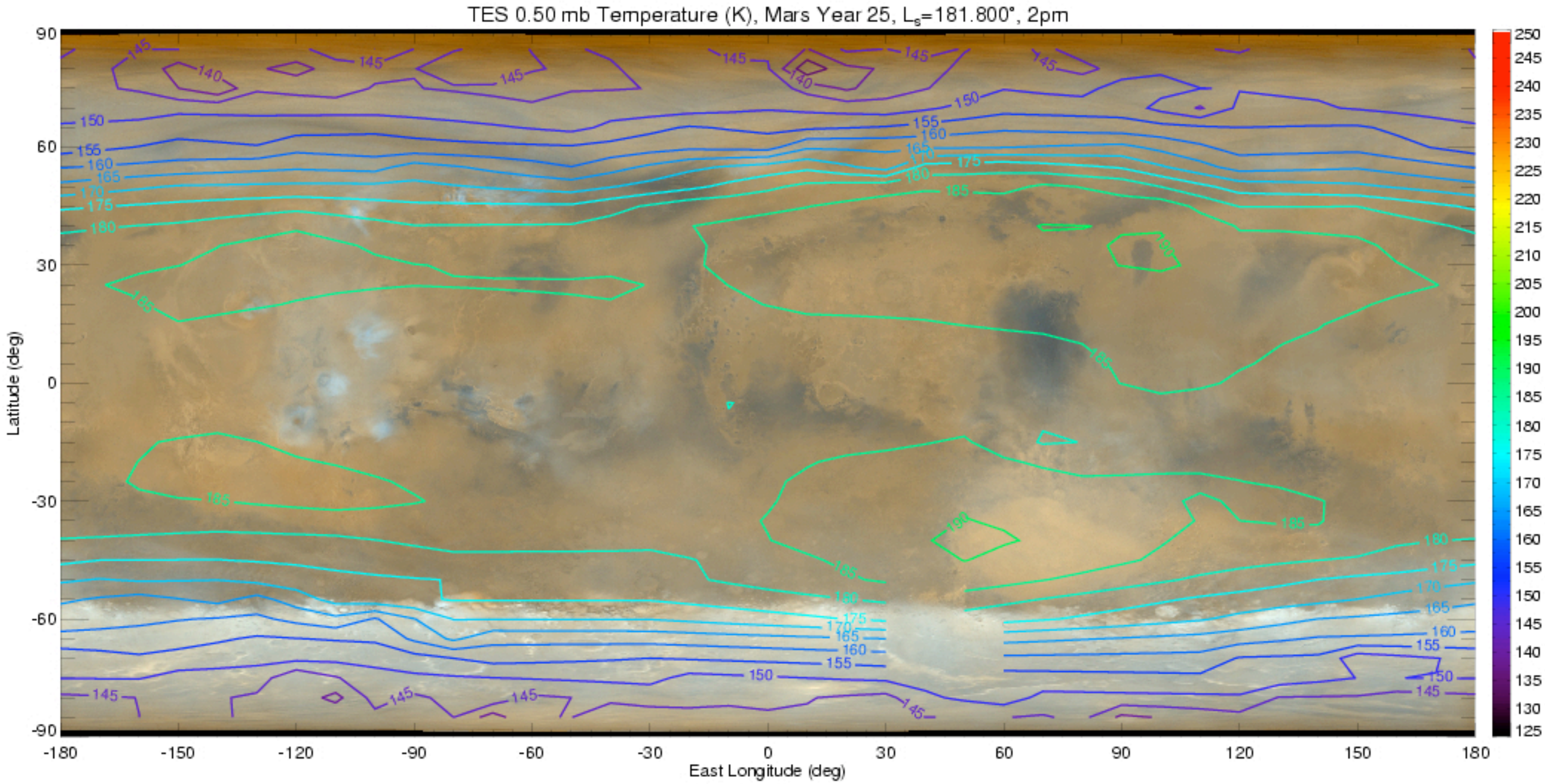




- GCM simulations of the daily average value of the meridional wind at a point near where these pulses originated oscillate with a period of ~2 sols, and thus appear to be capturing this behavior.
- Sol averaged meridional wind shows the the depth of the disturbance. Pattern changes significantly when the dust storm kicks in.

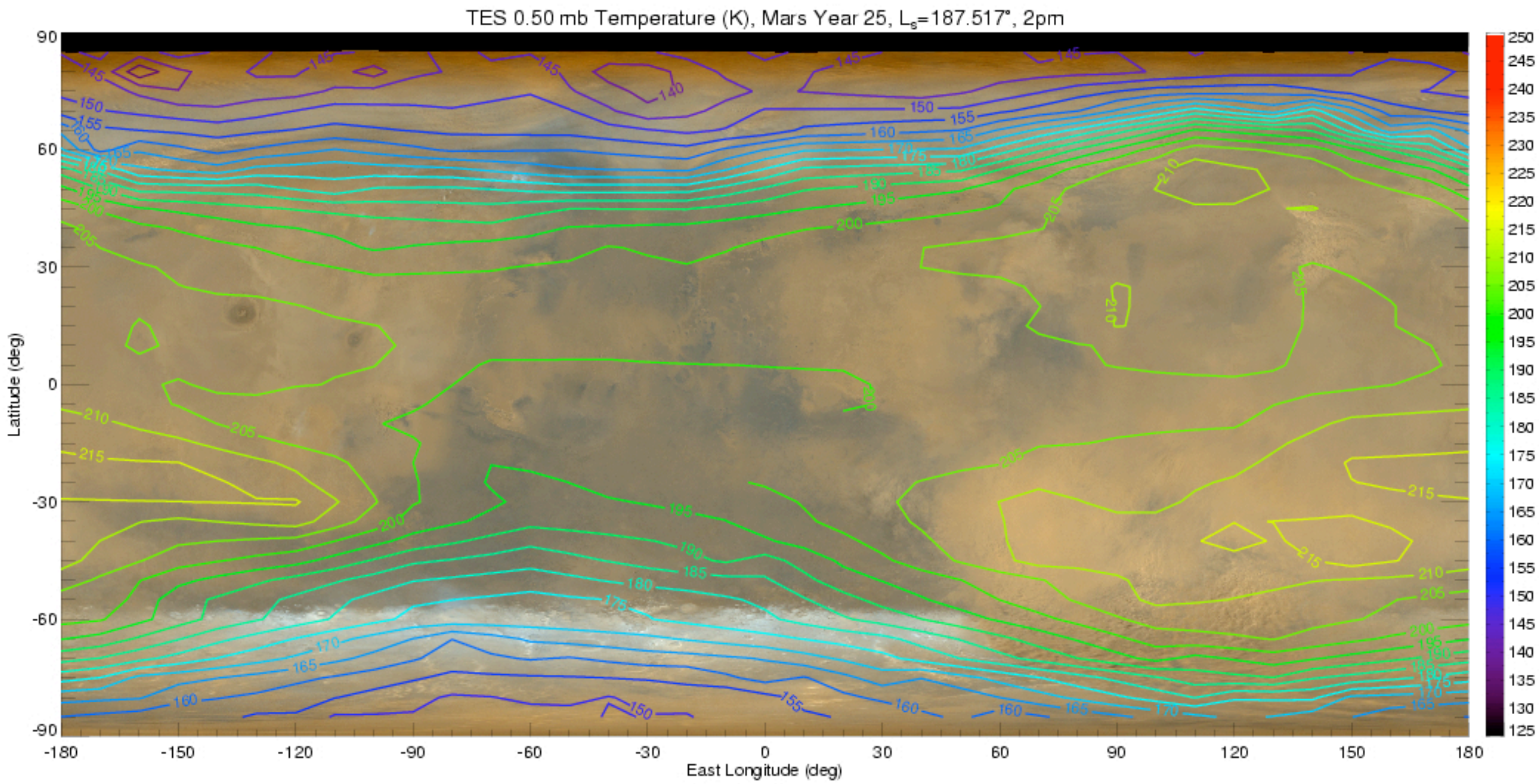


- Both TES and MHSA data show the development of a wave one pattern with ridge in eastern hemisphere and trough in western hemisphere by L_s=181, amplitude of ~ 5K – 10 K

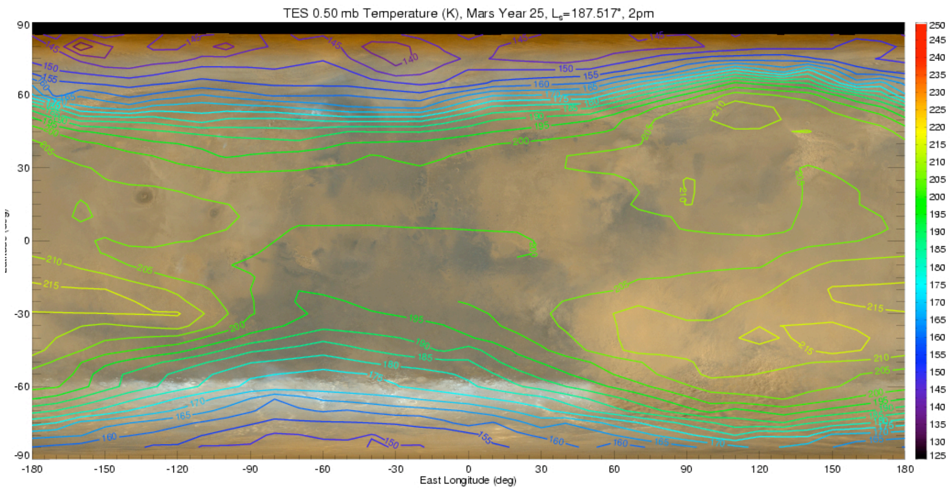


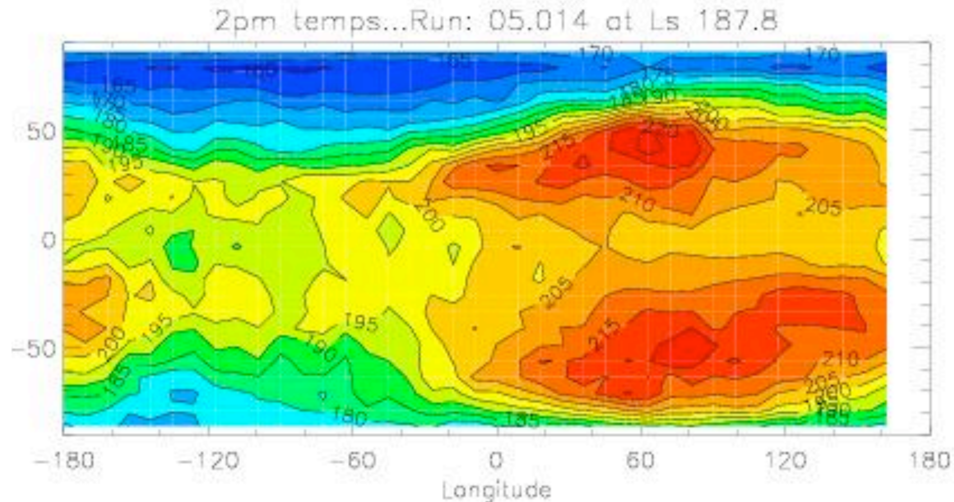
Expansion phase (L_s=184 –205)

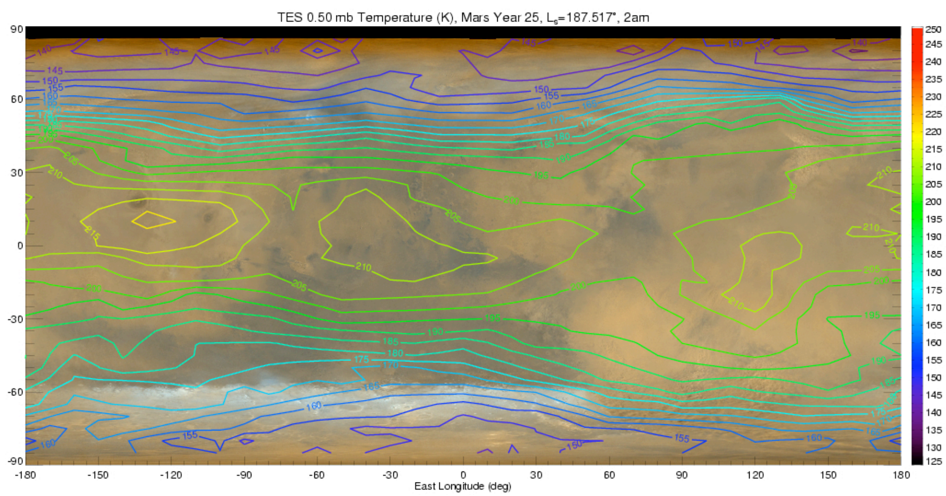
- MOC imagery with TES 2pm temperatures superimposed show that by *Ls*=187-188, the lifted dust in the Hellas sector had led to the development of a large-amplitude quasi-stationary wave one feature in the temperature field from .11 mb to .83 mb, with a peak-to-trough amplitude of ~30K (at 0.5mb).

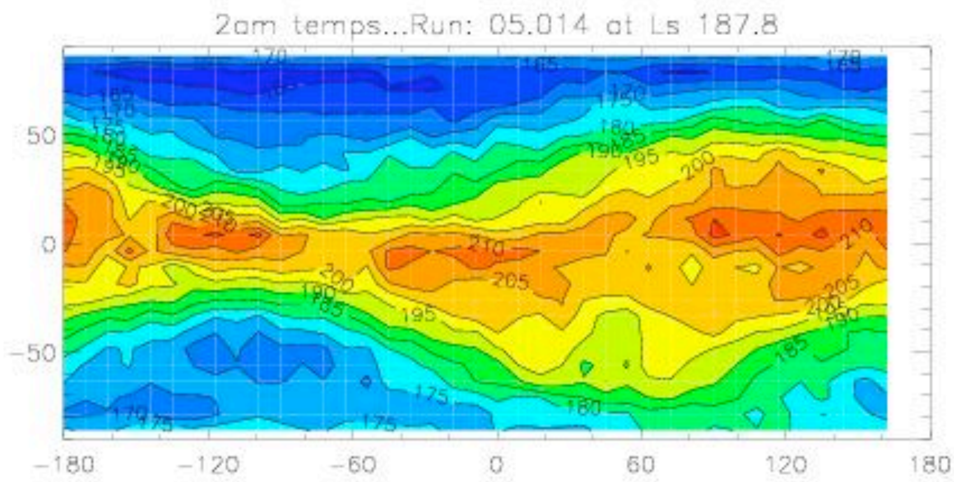


GCM simulations of the temperature field contain this same feature with both amplitude and phase well-reproduced.

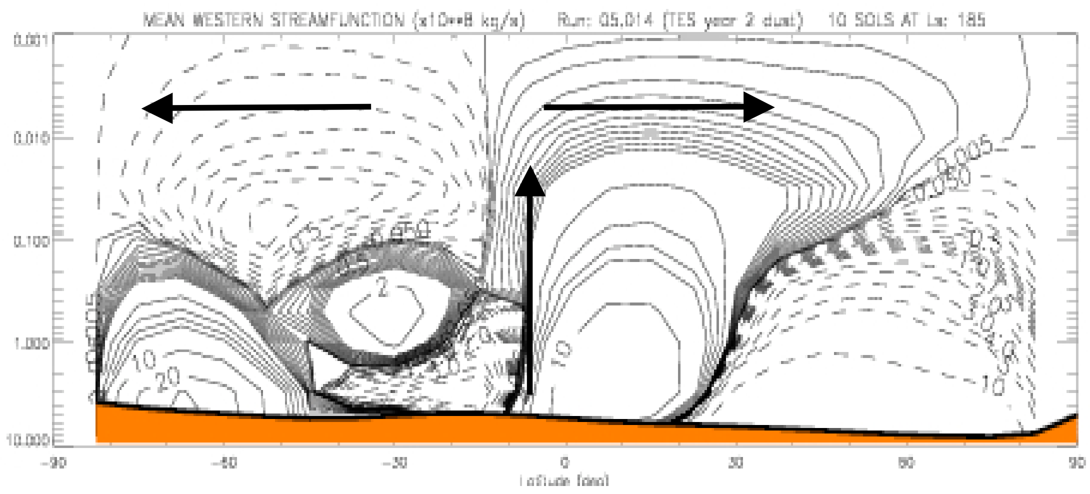




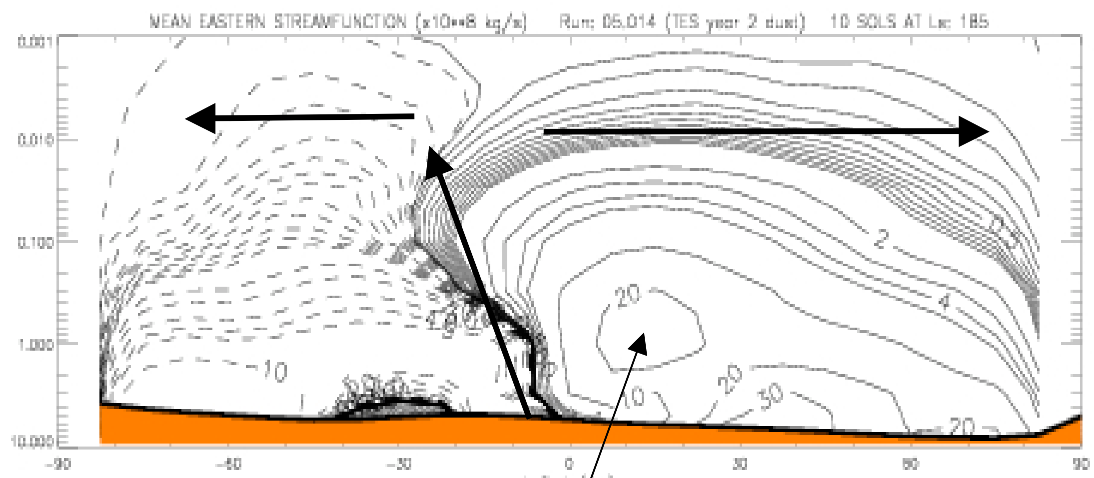




GCM simulations of the mass stream function based on 10 sols of data from L_s=185 show a significant difference in the structure of the Hadley circulation. Dust forcing in Hellas is perturbing the circulation - disturbance in the atmosphere is longitudinally dependent.



Western hemisphere

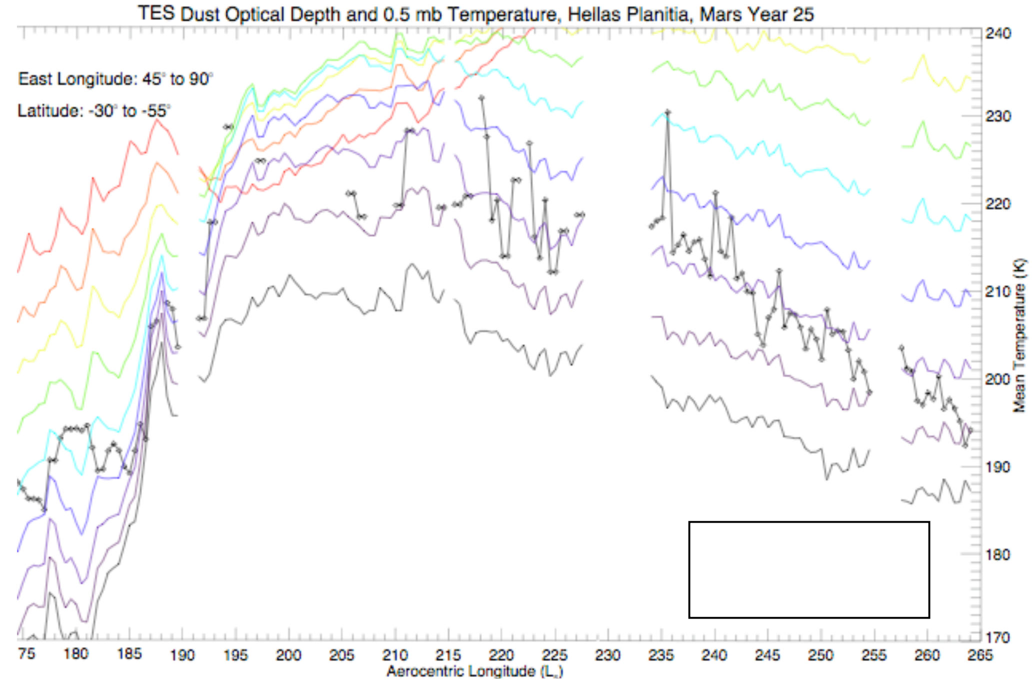


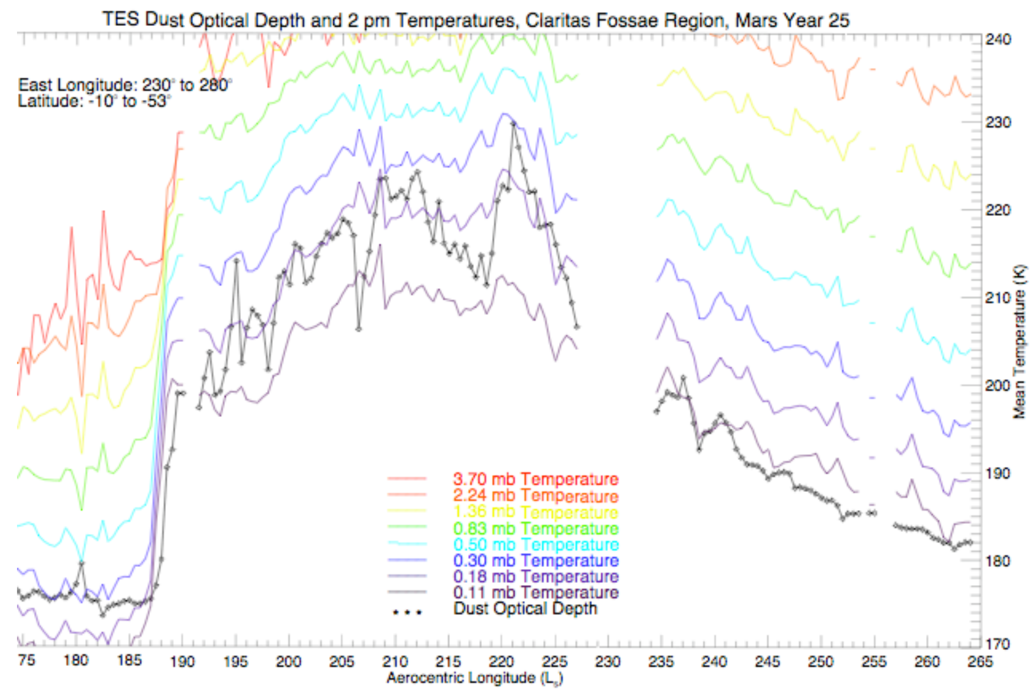
Stronger and Broader HC

Eastern Hemisphere:

- Symmetric Hadley cell that extends from the equator to each pole.

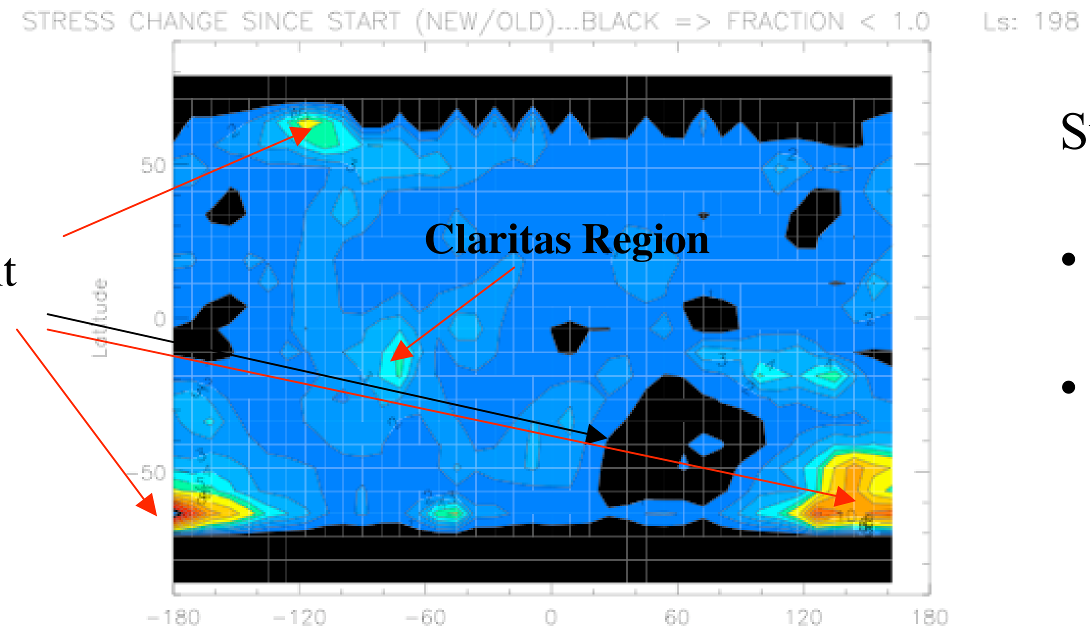
- Sinking motion associated with the descending branch that causes the warming of the temperatures in the NH.


TES Dust Optical Depth and 0.5 mb Temperature, Hellas Planitia, Mars Year 25
East Longitude: 45° to 90°
Latitude: -30° to -55°
Mean Temperature (K)
Aerocentric Longitude (Ls)


TES Dust Optical Depth and 2 pm Temperatures, Claritas Fossae Region, Mars Year 25
East Longitude: 230° to 280°
Latitude: -10° to -53°
3.70 mb Temperature
2.24 mb Temperature
1.36 mb Temperature
0.83 mb Temperature
0.50 mb Temperature
0.30 mb Temperature
0.18 mb Temperature
0.11 mb Temperature
Dust Optical Depth
Mean Temperature (K)
Aerocentric Longitude (Ls)

Change In Surface Stress Patterns from Ls=180° to 198°

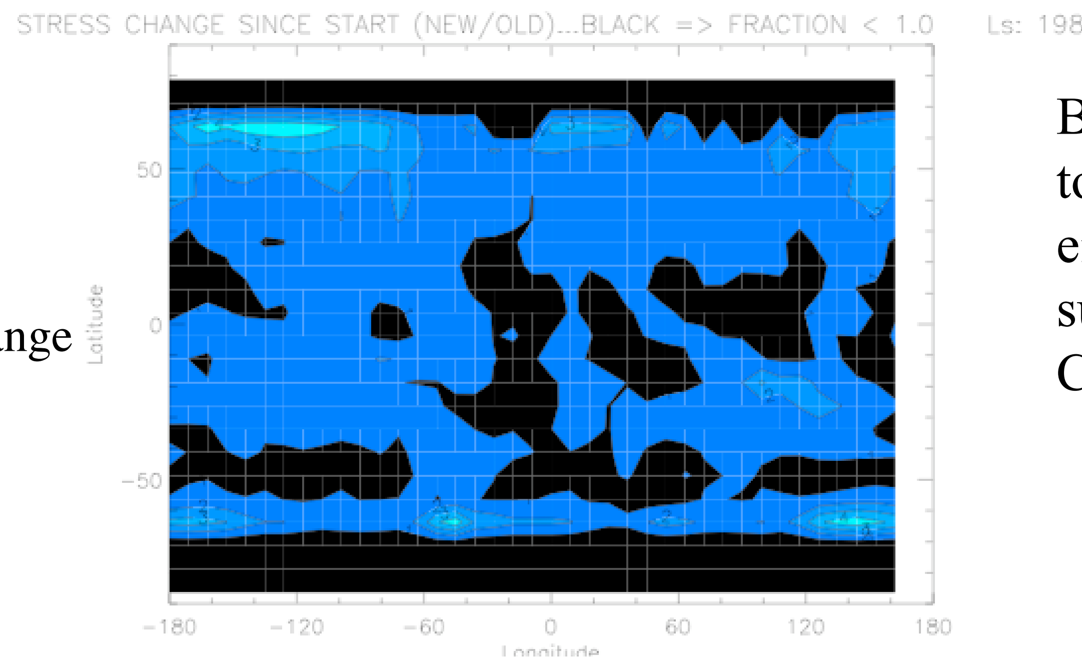
MY 25:
Significant
Changes



Surface stresses:

- decrease in Hellas
- increase in Claritas

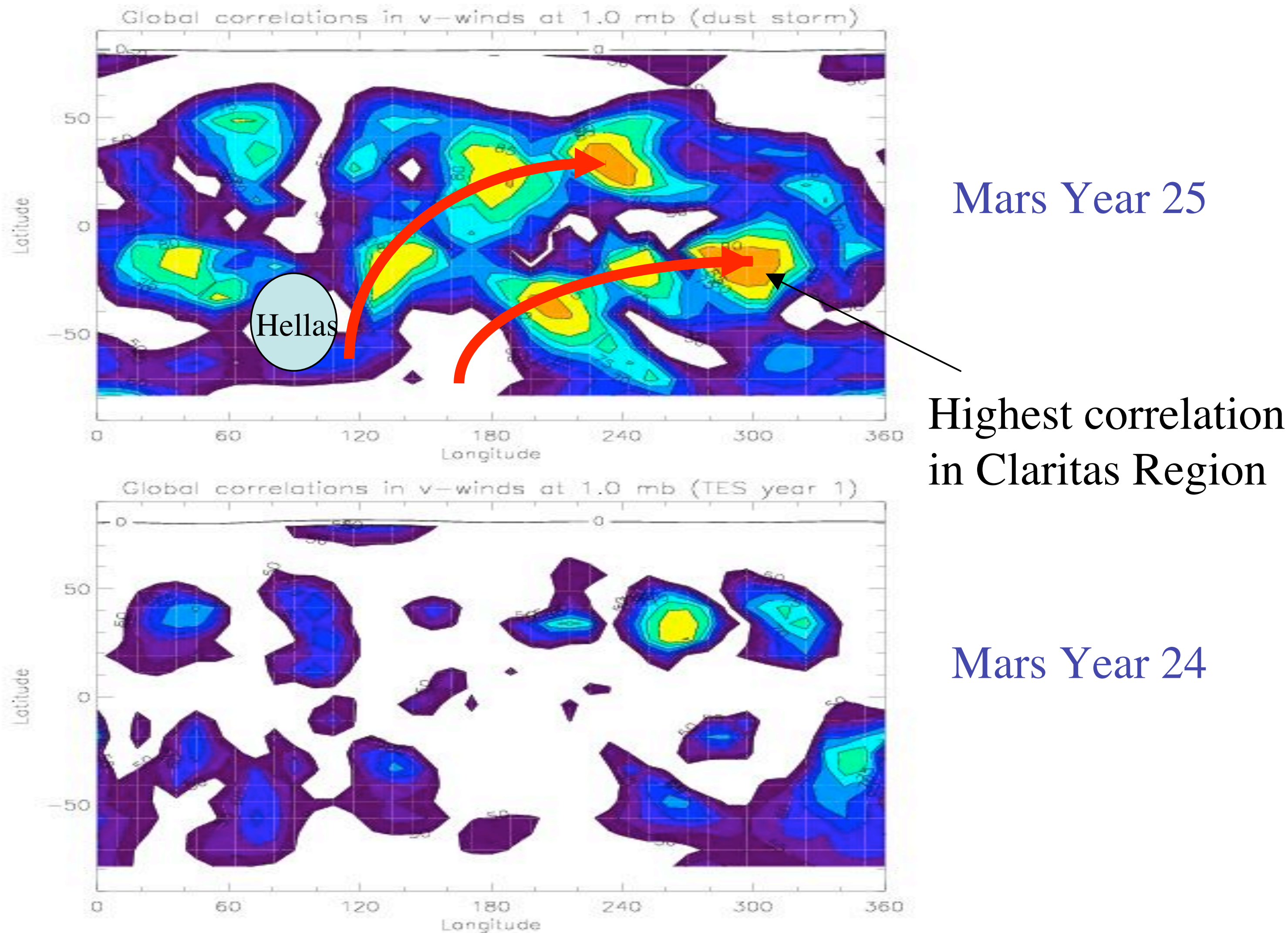
MY 24:
Little Change



Black shading corresponds to regions when there was either a decrease in the surface stress or there is CO_2 frost on the ground.

- We are looking at the possibility that the heating in Hellas lead to a Rossby wave train which triggered lifting in Claritas.

Global Correlations of V-winds



Working Hypothesis

- The storm was triggered by traveling baroclinic eddies in combination with a topographically enhanced cap edge circulation in the southwest region of the Hellas basin. Westerly winds carried the dust eastward into a longitude sector where a wave-one stationary wave pattern advected the dust southward over the polar cap. As the dust reached higher altitudes in this longitude sector, the subsequent heating over a deep part of the atmosphere amplified the wave-one stationary wave exciting a Rossby wave train that propagated into the opposite hemisphere.

- Shortly after the wave-one reached its maximum amplitude, dust lifting began in the Syria-Claritas region, a development possibly related to the propagating Rossby wave train. Lifting in this region, which was the major source of atmospheric dust, may have been sustained by enhanced thermal tides augmented by upslope/downslope flows. Zonal mean westerlies and the mean meridional circulation affected the largely eastward movement of dust during storm onset, and eventual northward and global dispersion.

Summary

- **Many components of the General Circulation appear to play a role**
  - Traveling baroclinic eddies
  - Quasi stationary waves
  - Hadley circulation
  - Thermal Tides
- **Understanding the cause of lifting in Claritas is the key**
  - Rossby wave trains may have emanated from Hellas and triggered lifting in Claritas.
  - GCM simulations suggest this.
  - But connection between them and surface stress needs to be understood
  - These ideas will be tested with general circulation model simulations.