Exploration of the Mars Polar Atmosphere Using the Mars Climate Sounder (MCS) and the Ensemble Mars Atmosphere Reanalysis System (EMARS)

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Why study the polar region with MCS and EMARS?

- Building on prior study of transient eddies, we are interested in further characterizing the spatiotemporal variability of the Martian atmosphere.
- Some phenomena in the polar region of Mars remain relatively unexplored, but are well-observed by MCS.
- EMARS provides full spatiotemporal coverage of many meteorological quantities, including ones not observed by MCS, but EMARS has difficulty representing some features observed by MCS. How can we improve?

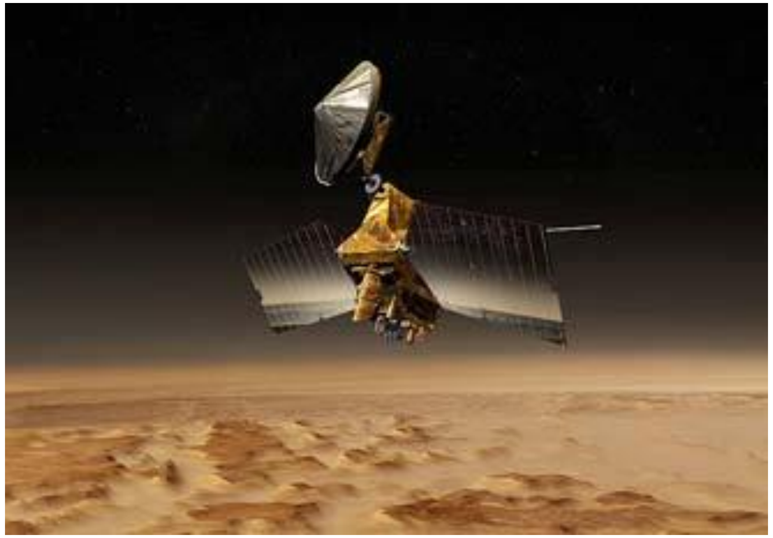
Outline

- MCS and EMARS background
- Climatological polar structure
- CO_2 latent heating
- Thermal tides
- H_2O transport

Mars Climate Sounder (MCS)

- Limb-observing infrared radiometer
- 105 vertical levels of data retrieved, from the surface to 100 km
- Along-track and cross-track observations
- Temperature from MCS assimilated into EMARS
- Column dust in EMARS constrained by MCS

  (Montabone et al., 2015)



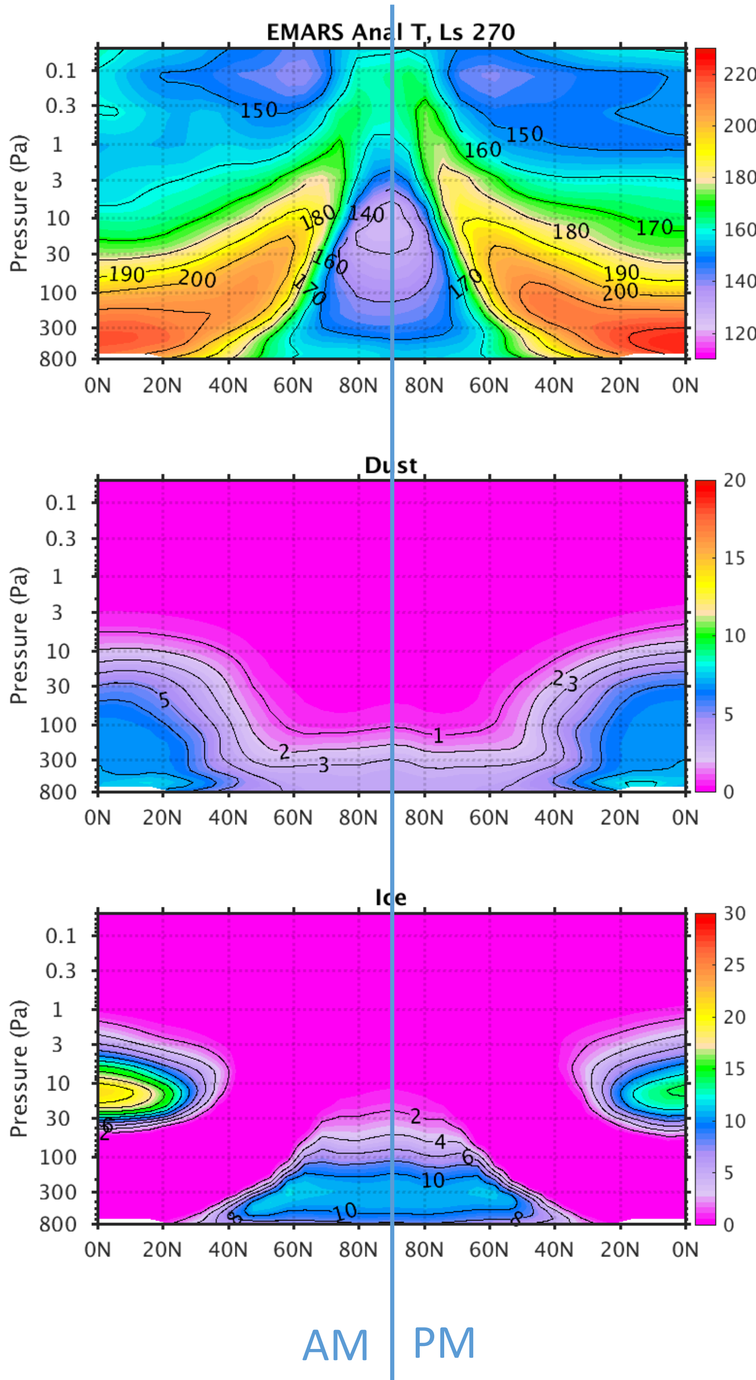
Concept art courtesy of NASA/JPL

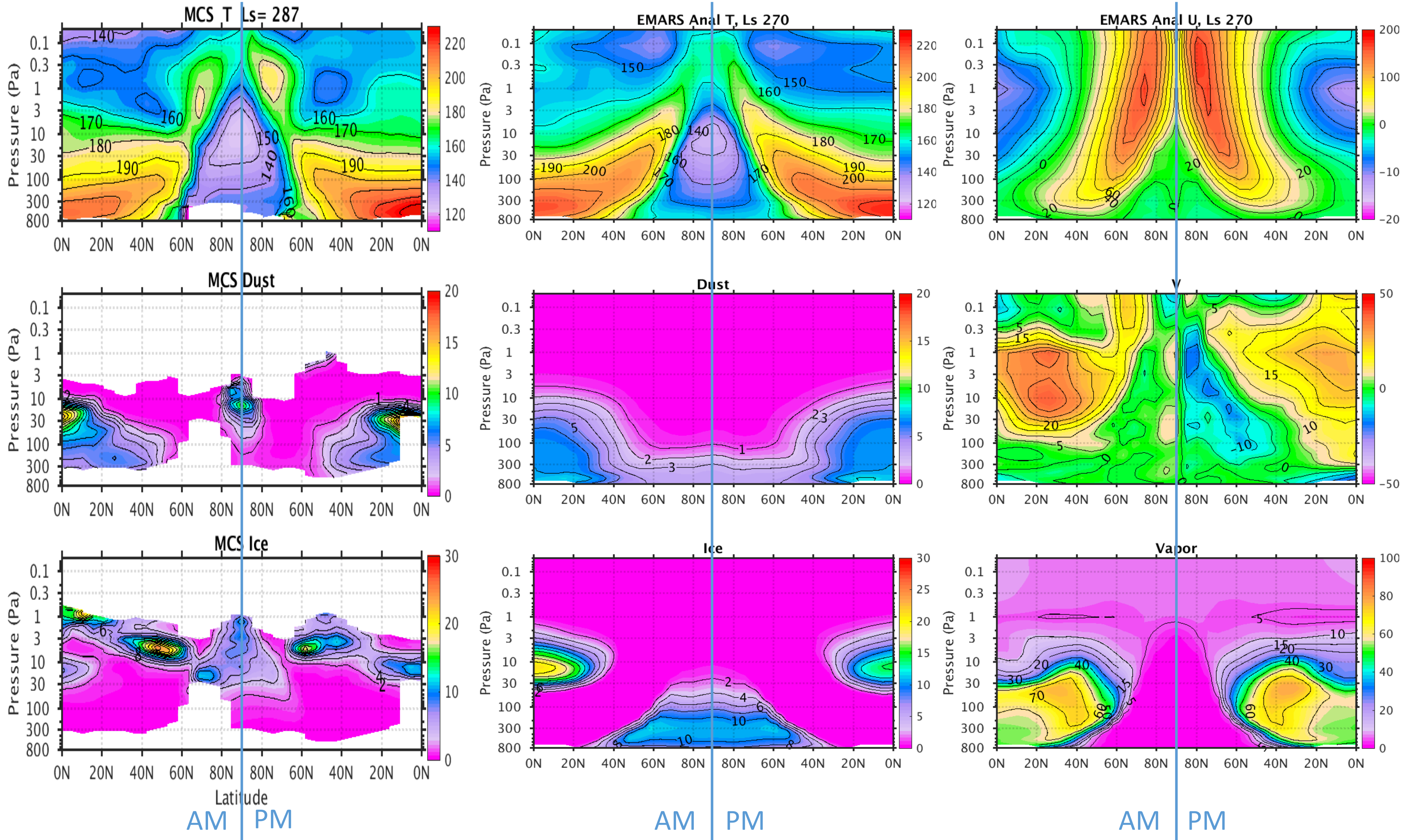
Ensemble Mars Atmosphere Reanalysis System (EMARS)

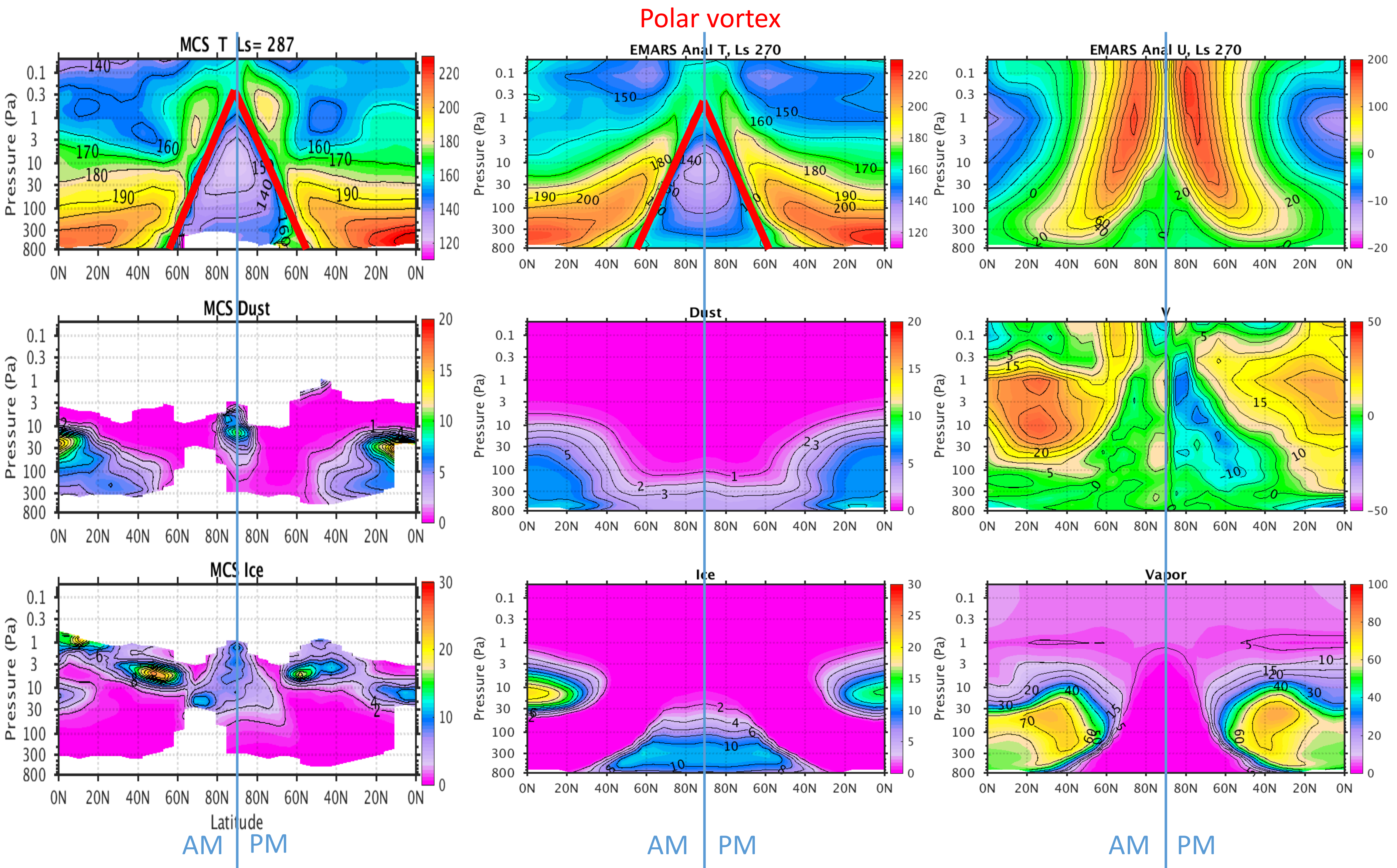
- Geophysical Fluid Dynamics Laboratory (GFDL) Mars Global Circulation Model (MGCM) (Wilson et al., 2002)
  - Grid spacing 5° by 6° (~150 km), with 28 vertical levels
  - Aerosols advected by model in both horizontal and vertical
- Local Ensemble Transform Kalman Filter (Hunt et al., 2007)
  - 16 ensemble members, water ice and dust varied among members

Climatological polar structure

- Data from 3 AM and 3 PM local time in EMARS are retained
- Zonal mean over 20 sols of EMARS, centered on Ls 270 (northern winter solstice)
- 3 AM is on the left, and 3 PM is on the right
- MCS plots are similar, but are averaged over 5 Ls (about 10 sols)

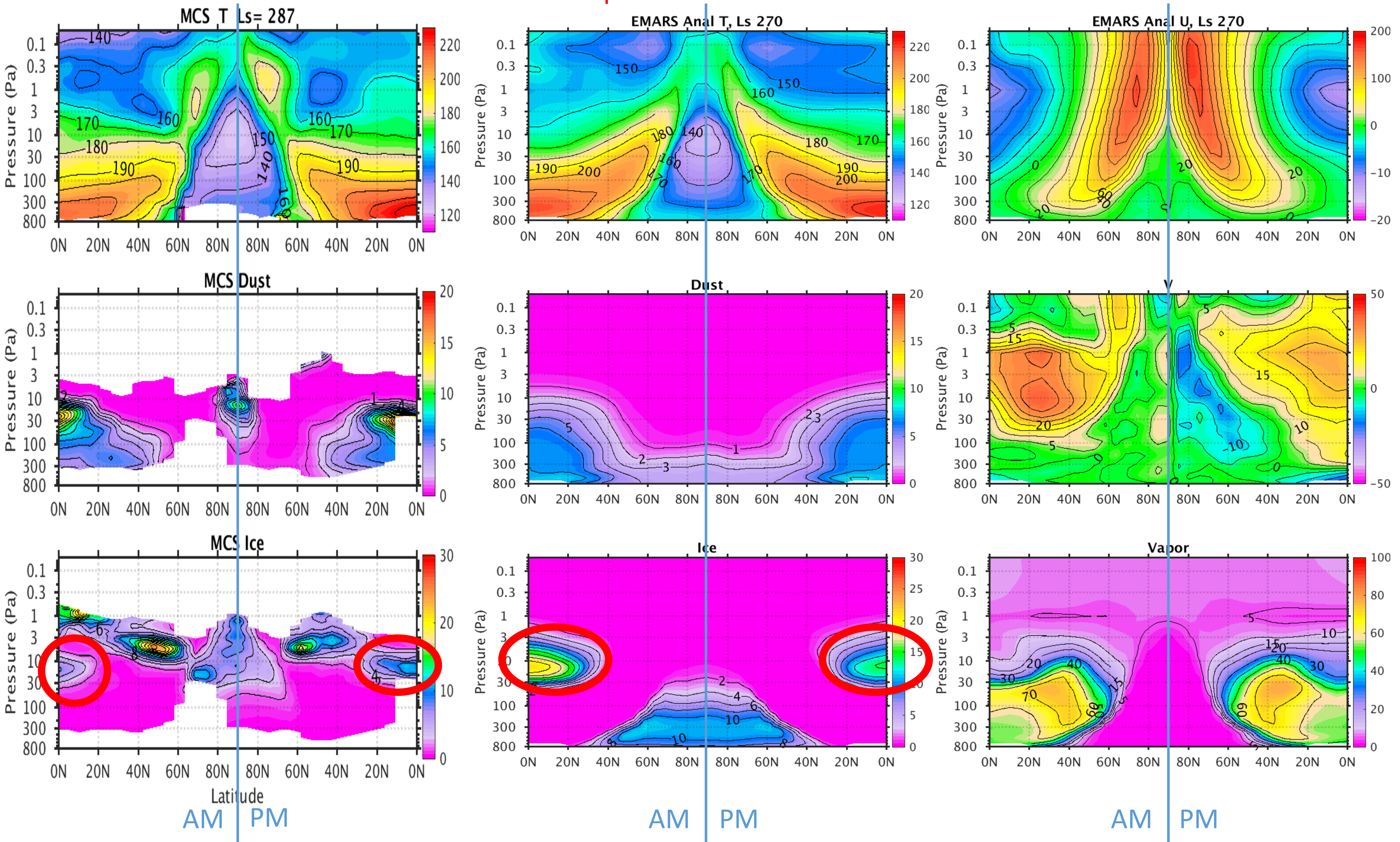


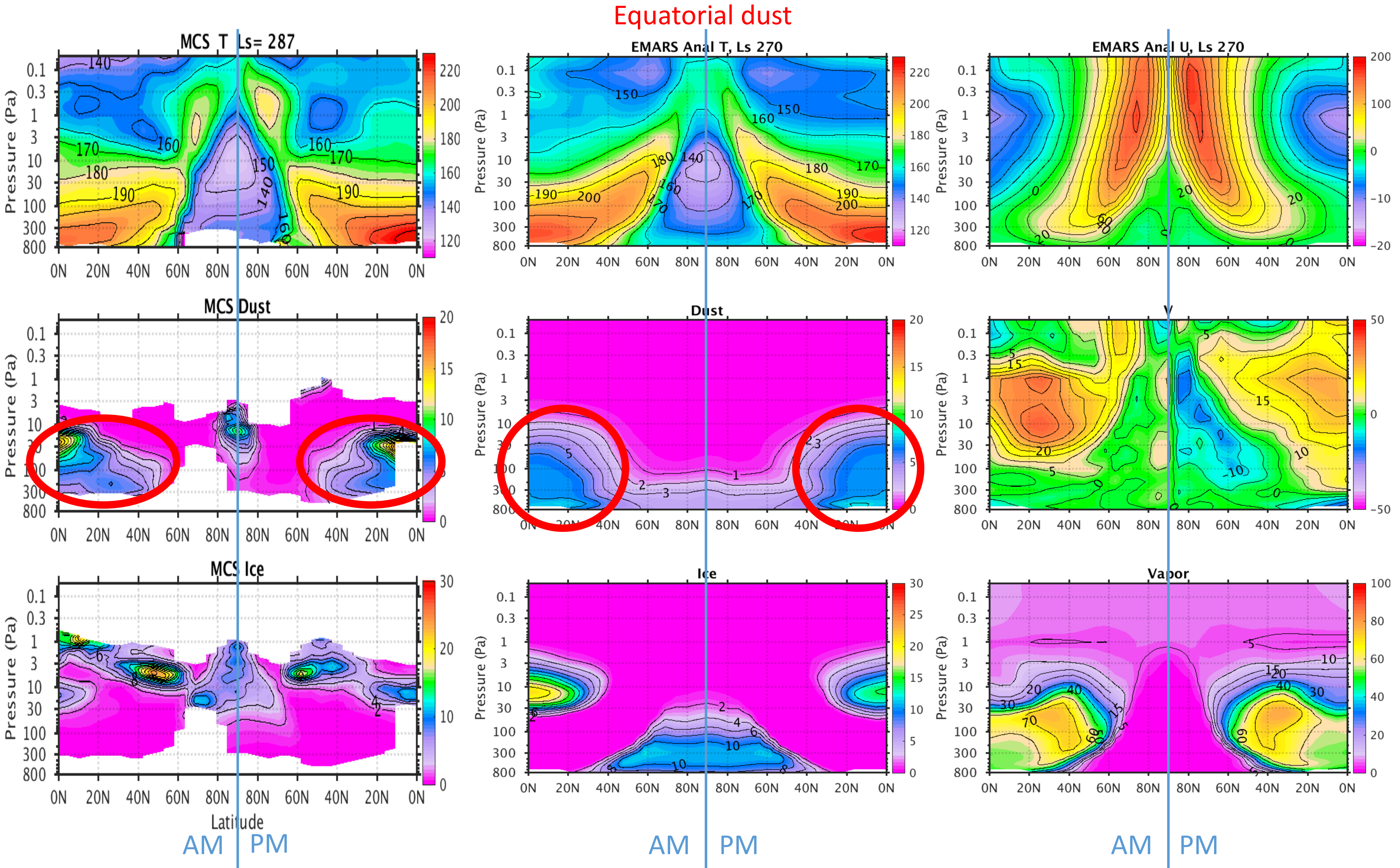

MCS T Ls= 287
EMARS Anal T, Ls 270
EMARS Anal U, Ls 270
MCS Dust
Dust
V
MCS Ice
Ice
Vapor
Pressure (Pa)
Latitude
AM
PM
AM
PM
AM
PM



Polar vortex
MCS T Ls= 287
EMARS Anal T, Ls 270
EMARS Anal U, Ls 270
MCS Dust
Dust
V
MCS Ice
Ice
Vapor
Pressure (Pa)
Latitude
AM
PM
AM
PM
AM
PM

Equatorial ice clouds





Equatorial dust
MCS T Ls= 287
EMARS Anal T, Ls 270
EMARS Anal U, Ls 270
MCS Dust
Dust
V
MCS Ice
Ice
Vapor
Pressure (Pa)
Latitude
AM
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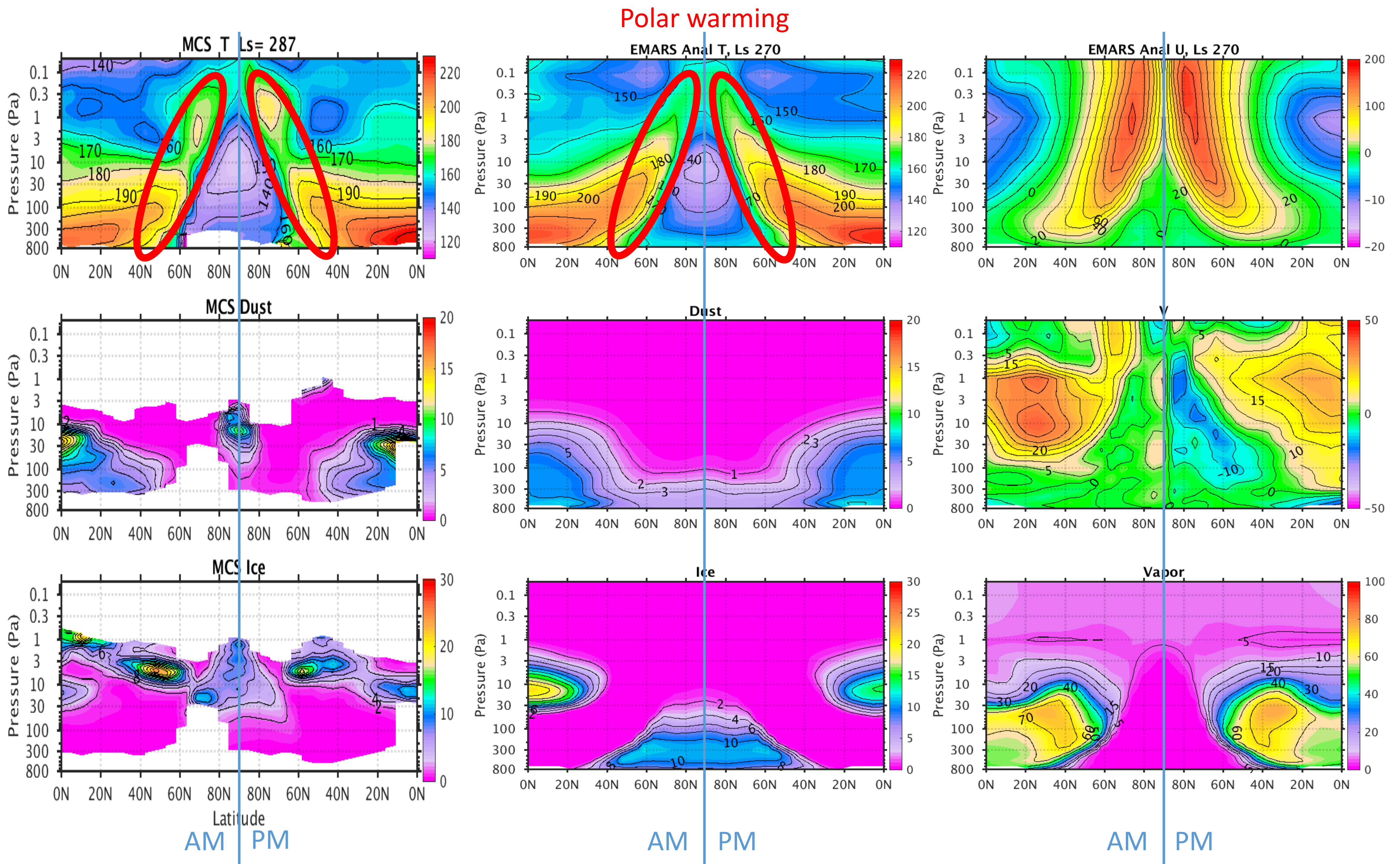
PM



Polar warming
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EMARS Anal U, Ls 270
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Dust
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MCS Ice
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Vapor
Pressure (Pa)
Latitude
AM
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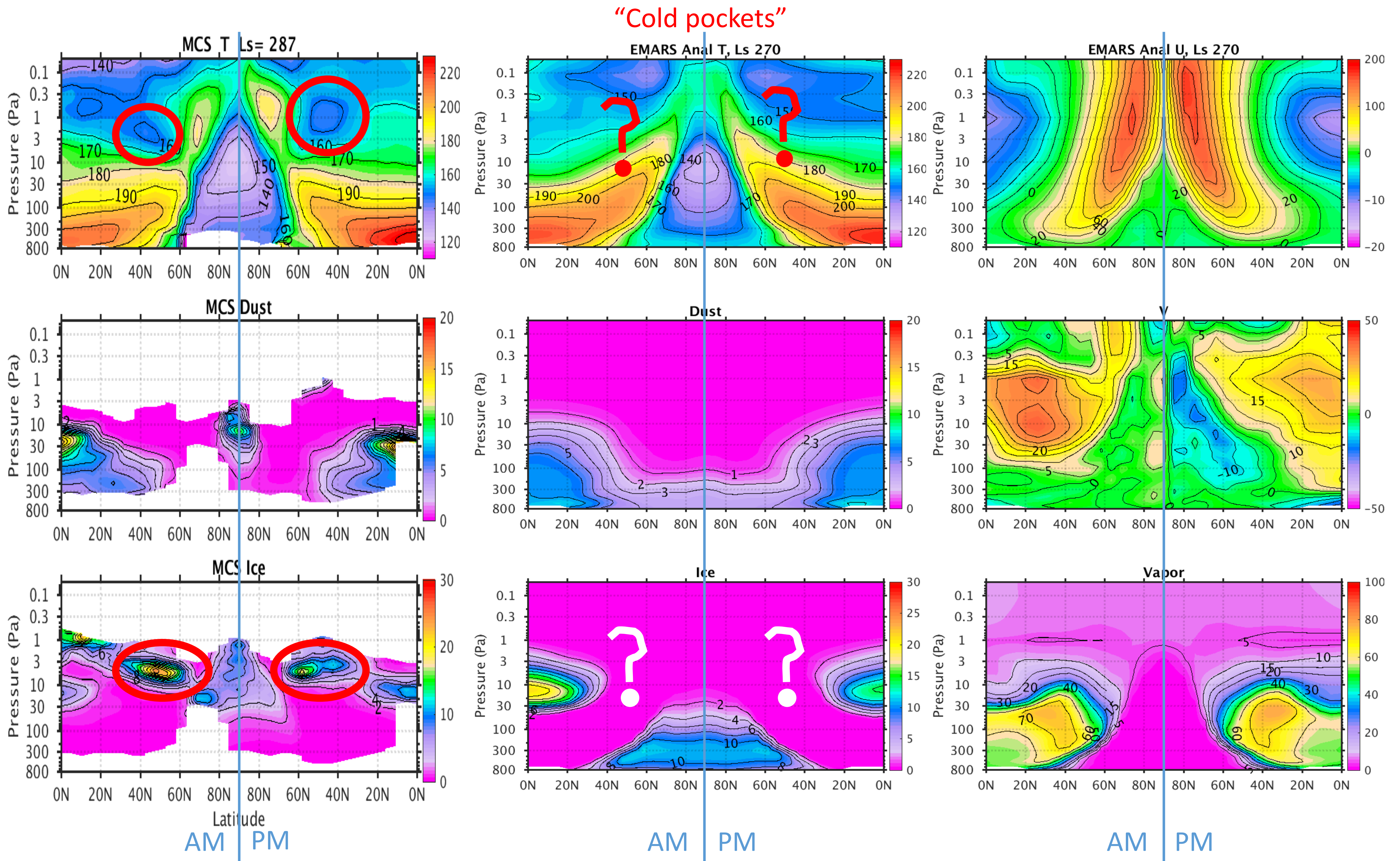
"Cold pockets"
MCS T Ls= 287
EMARS Anal T, Ls 270
EMARS Anal U, Ls 270
MCS Dust
Dust
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MCS Ice
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Pressure (Pa)
Latitude
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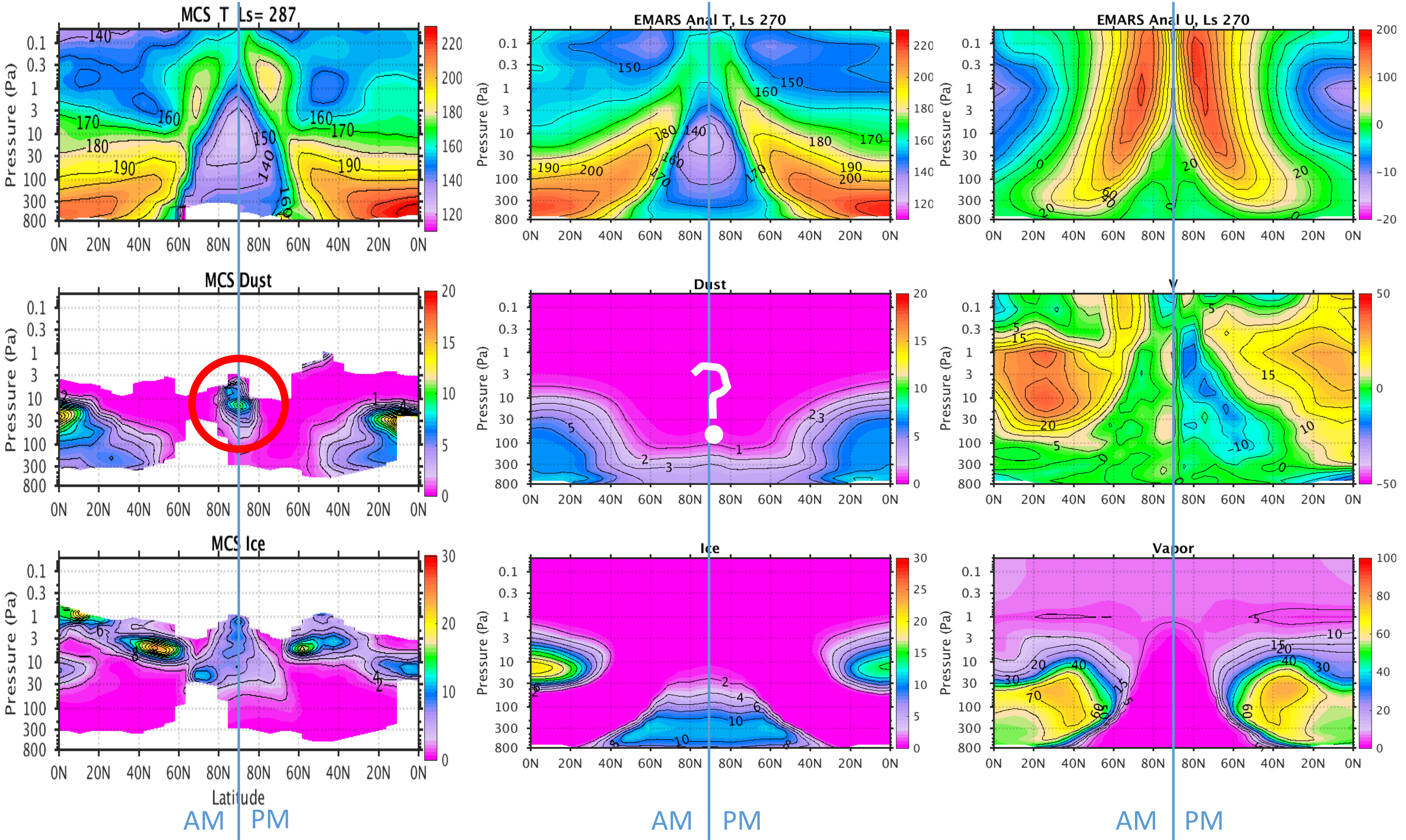
MCS T Ls= 287
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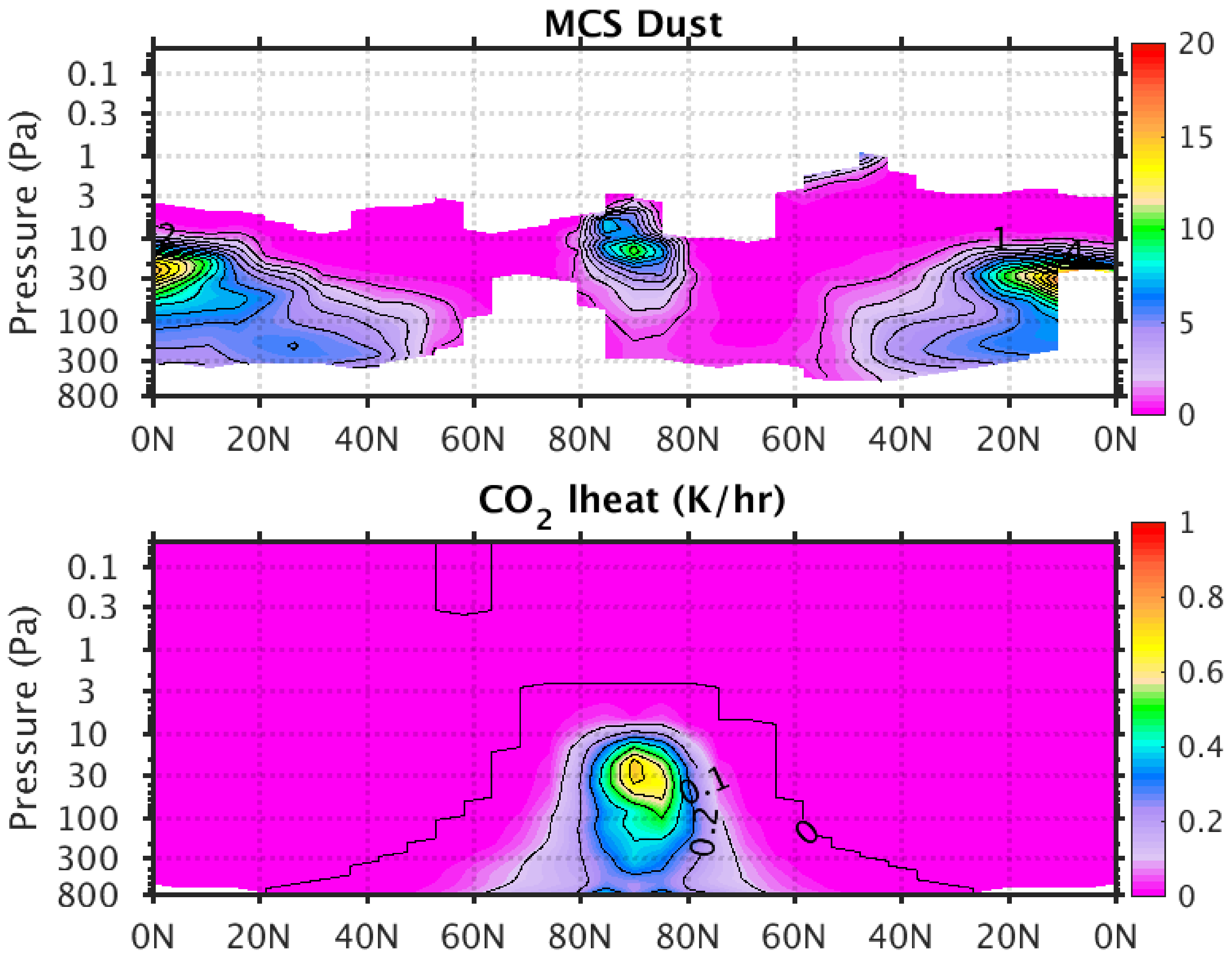
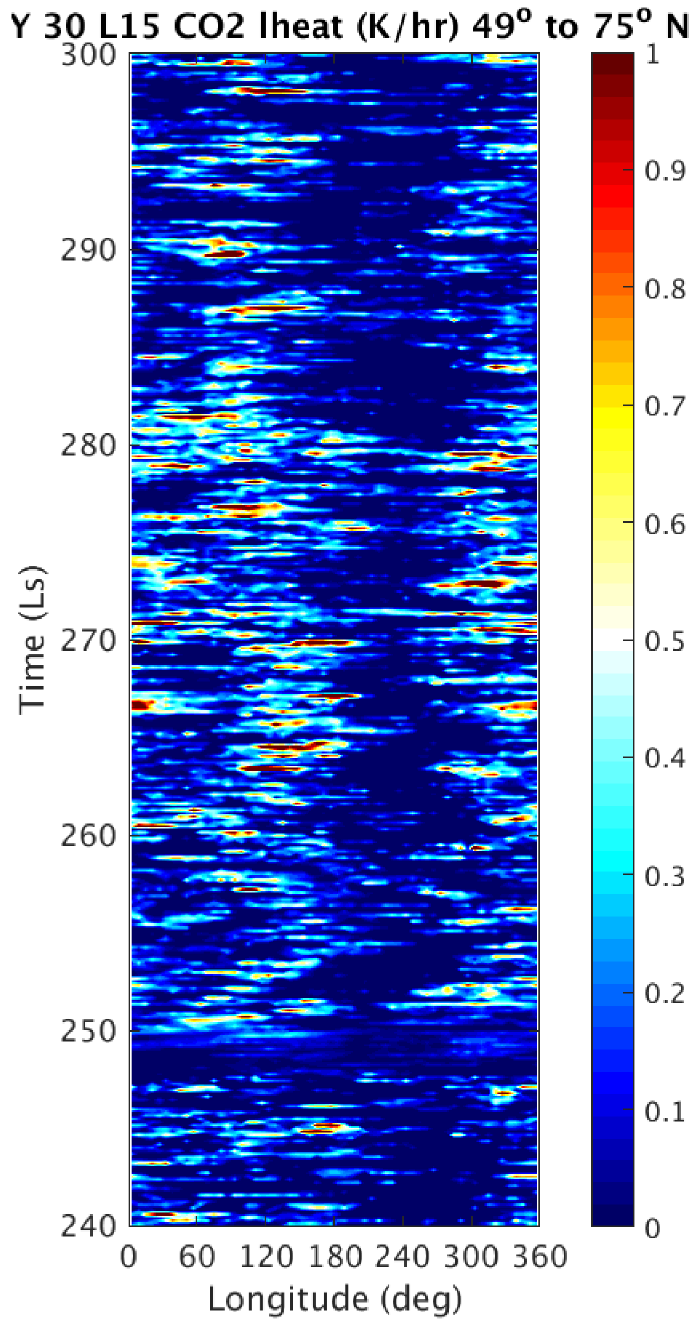
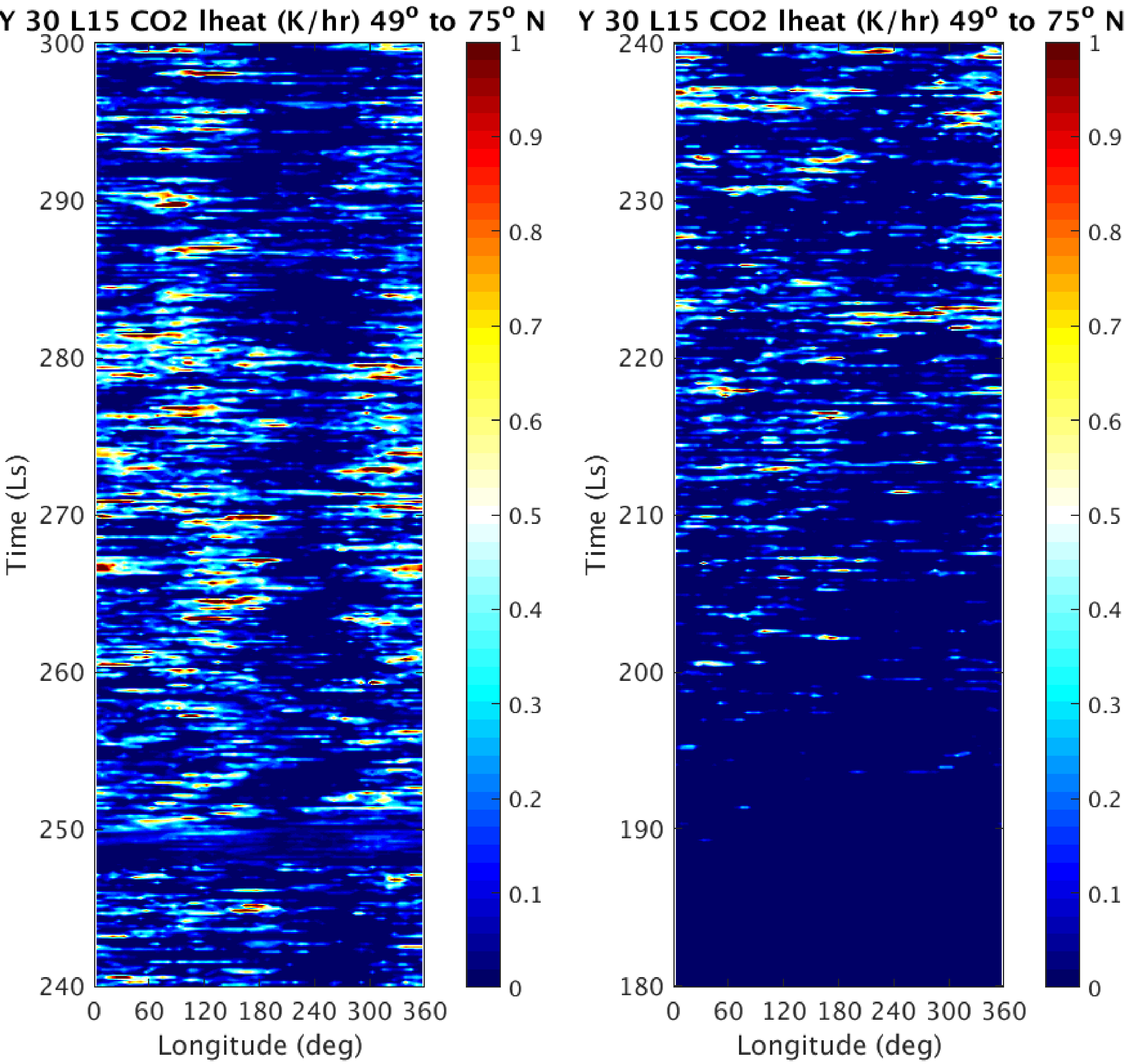


The polar MCS "dust" observation is an observation of solid CO_2. EMARS also suggests that CO_2 deposition occurs within the core of the polar vortex. We'd expect various atmospheric waves to have an effect on CO_2 deposition. Are these waves present in MCS or EMARS data?

CO_2 latent heating

- Hovmöller diagrams, with increasing time ascending instead of descending
- EMARS and EMARS control data from one model level and a range of latitudes specified on the plot are plotted
- Here, the largest value of CO_2 latent heating between 49 and 75 N is plotted at each longitude
- 1° Ls ≈ 2 sols (Martian days)

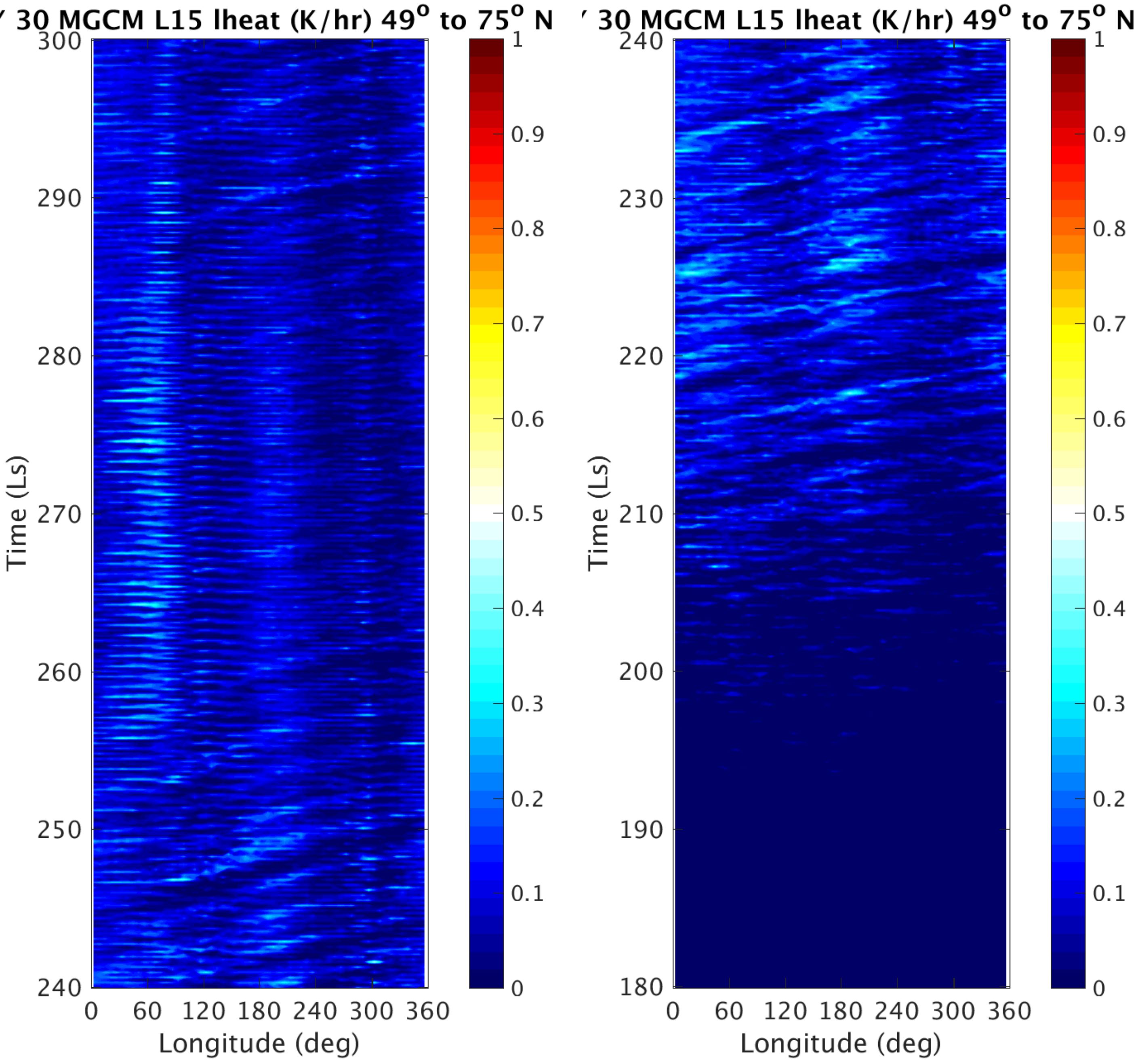




EMARS CO_2

Vertical coordinate: σ ~ 0.3 (200 Pa, or 12 km)

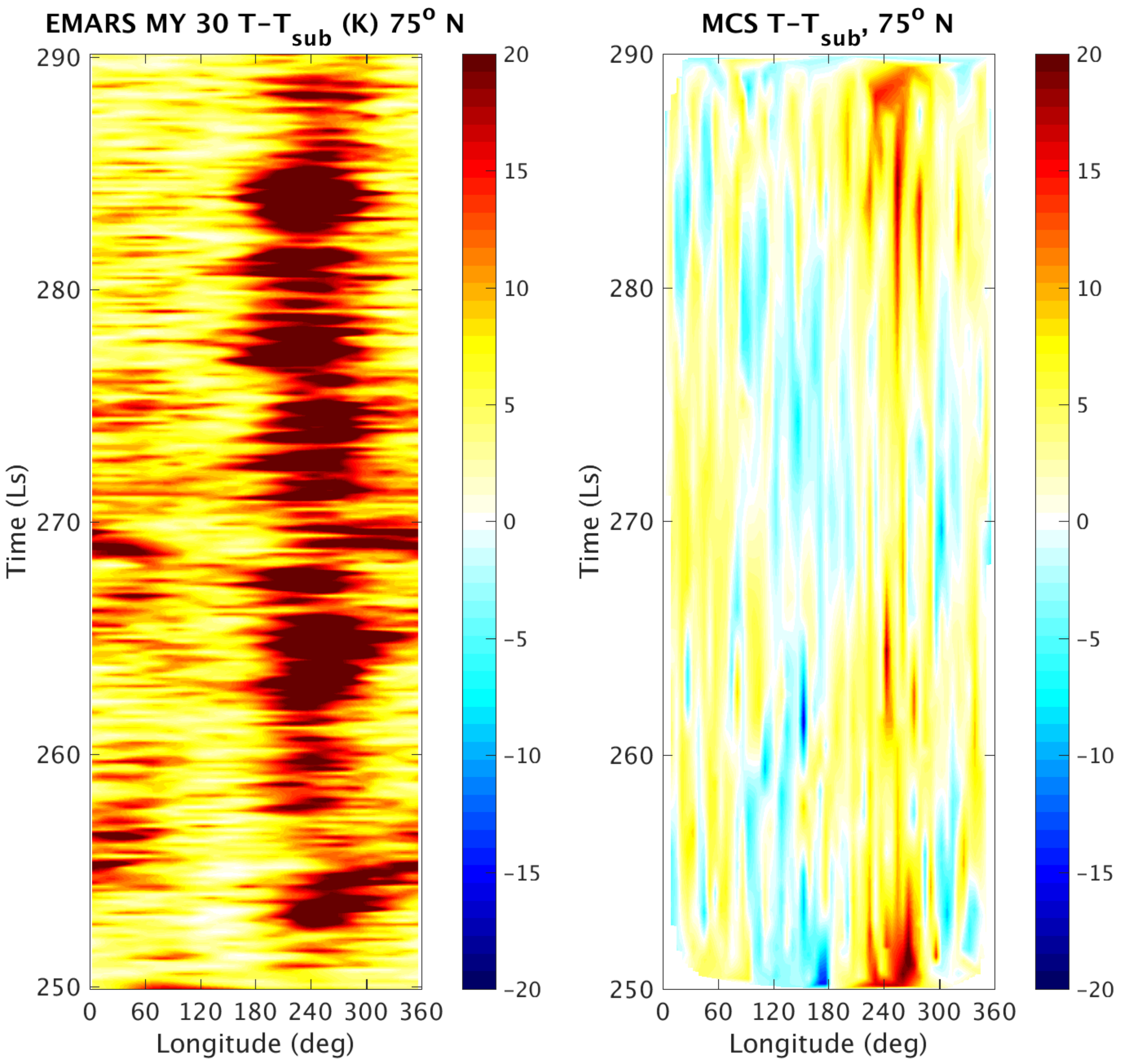
The amount of time between each burst of CO_2 seems to be close to 1 sol. A stationary wave of wavenumber 2 is apparent, but it's hard to discern any horizontal motion of a CO_2 anomaly.



EMARS Control CO_2

Vertical coordinate: σ ~ 0.3 (200 Pa, or 12 km)

In the model, the CO_2 is a superposition of a tidal influence, a stationary wave, and transient eddies. CO_2 occurs primarily near 60 E and 200 E here, while in EMARS, 120 E and 330 E were the maxima.

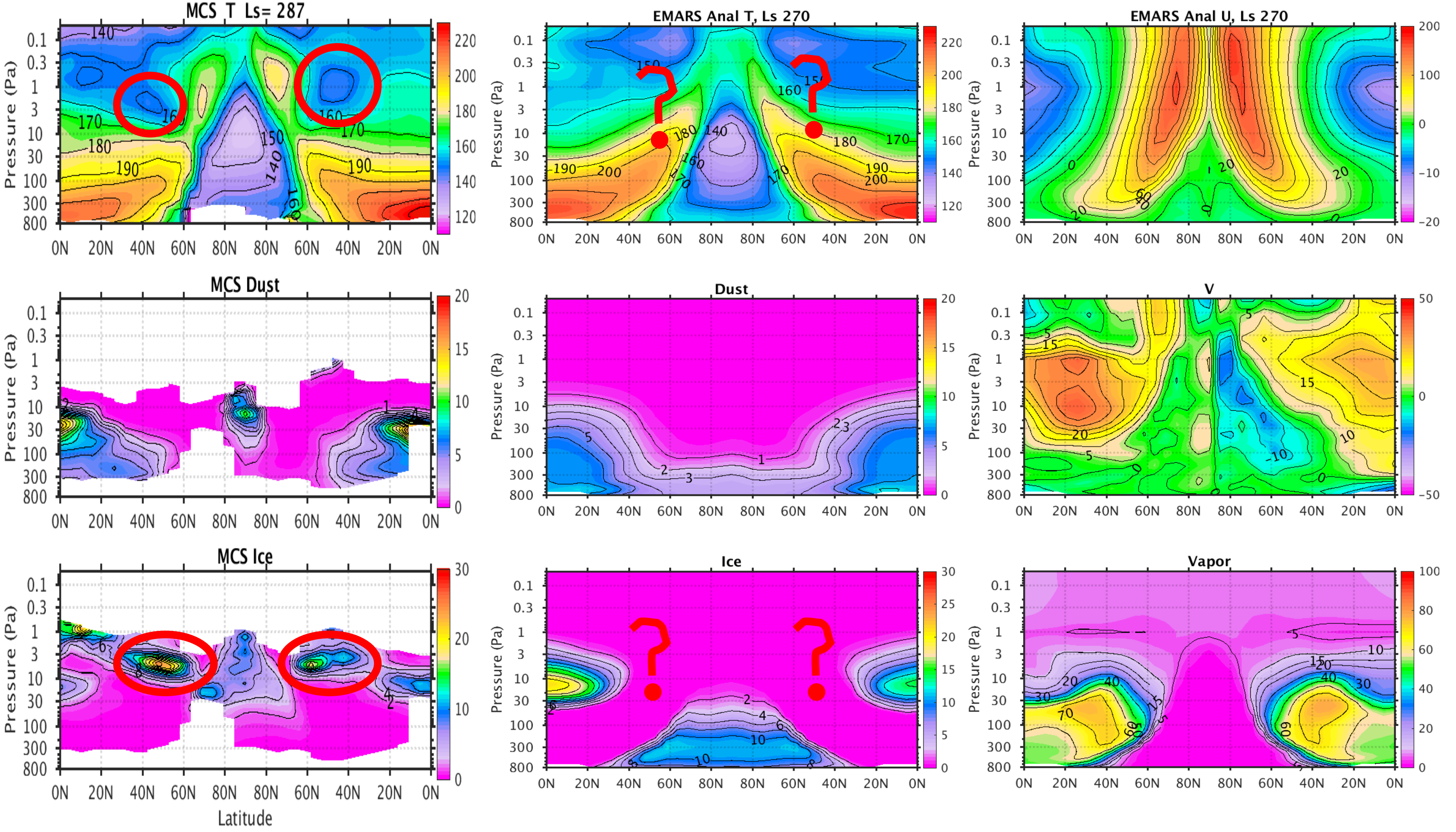


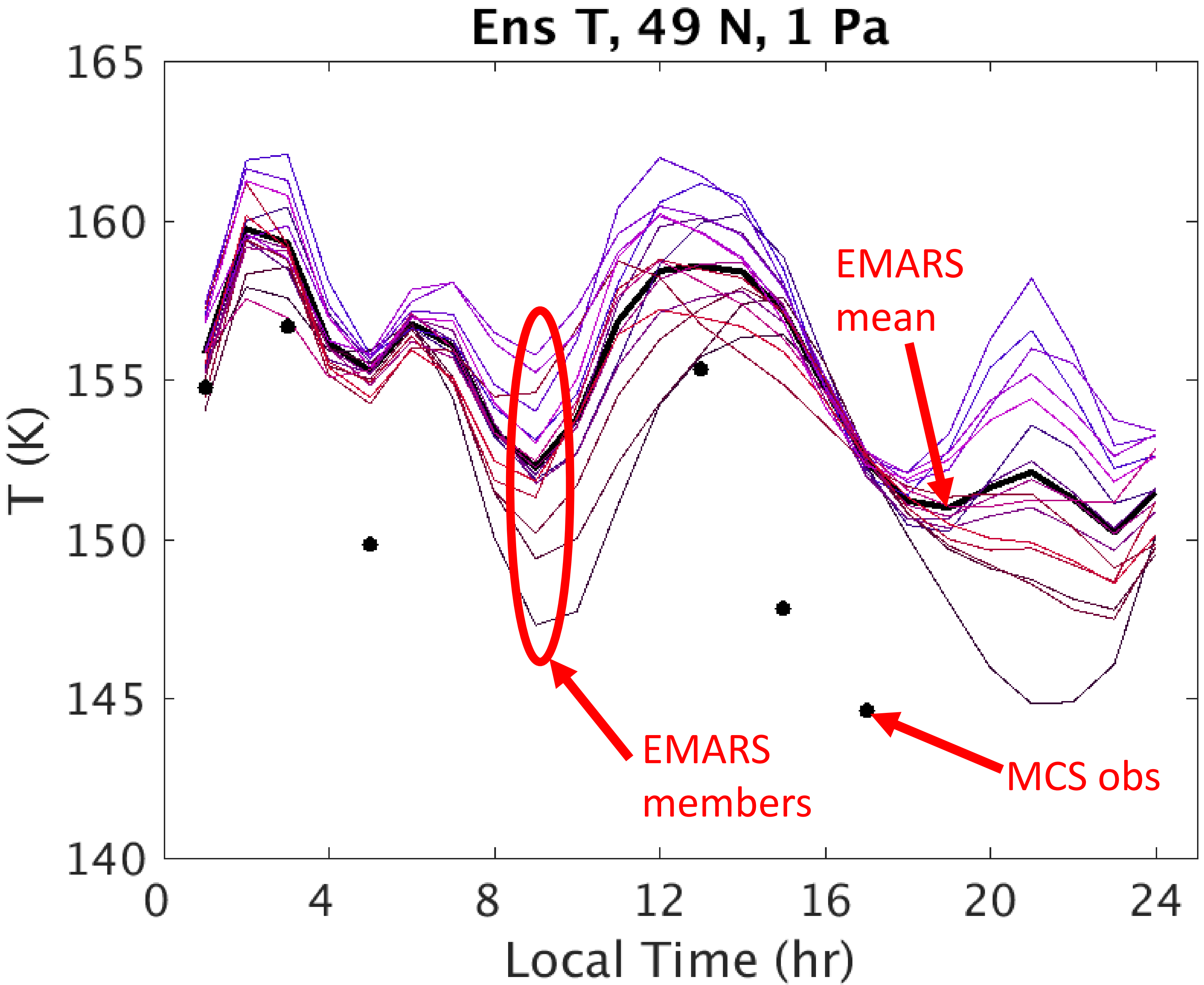
Difference between EMARS and MCS temperature and sublimation temperature of carbon dioxide at 80 Pa (22 km)

A stationary wave that appears to be a combination of wavenumbers 1 and 2 are present. Transient eddy activity is more difficult to discern, if it is present.

Notice that the EMARS and MCS stationary wave extrema are at similar longitudes. The EMARS control run places the extrema at different longitudes.

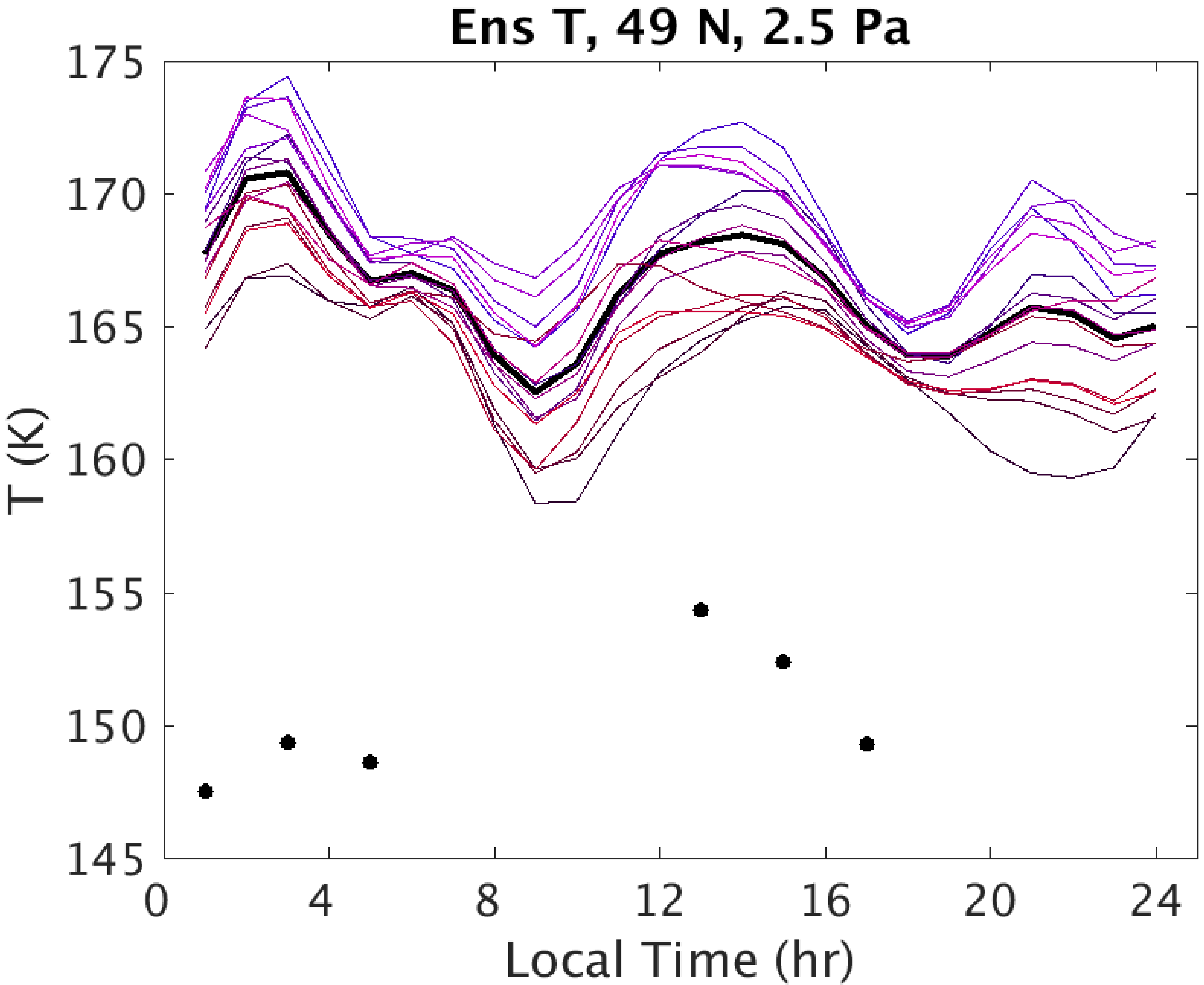
Thermal tides





10 sol mean
Ensemble members are colored according to their dust and ice radiative factors.
Black → red: more dust
Black → blue: more ice

Warmer members have more ice, and to a lesser extent, more dust.



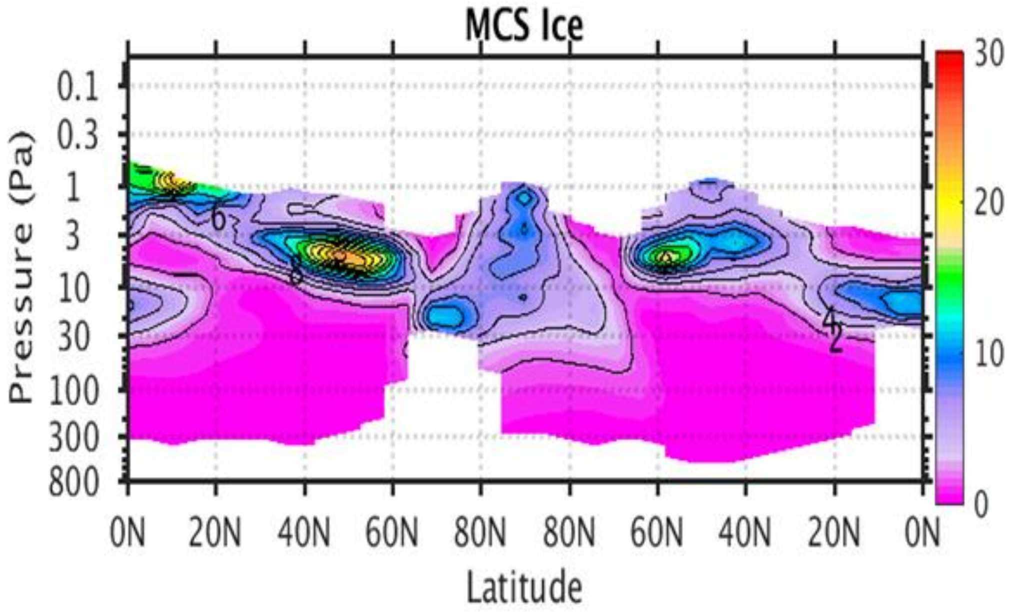
EMARS represents the tidal signal measured by MCS well in the cold pockets, despite the temperature difference.

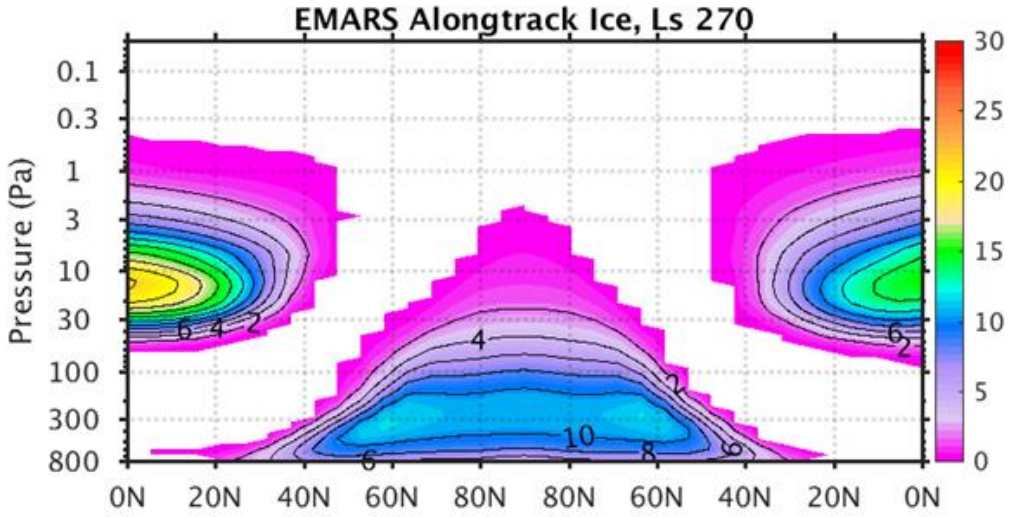
There are differences in the amplitudes of the various tidal modes among the ensemble members, which may aid in assimilating tidal information.

H_2O transport

Evidently, there is water within the polar vortex in both MCS and EMARS, though the distribution is different.

Is water in the polar vortex isolated from the rest of the atmosphere?
How does H_2O enter the polar regions?

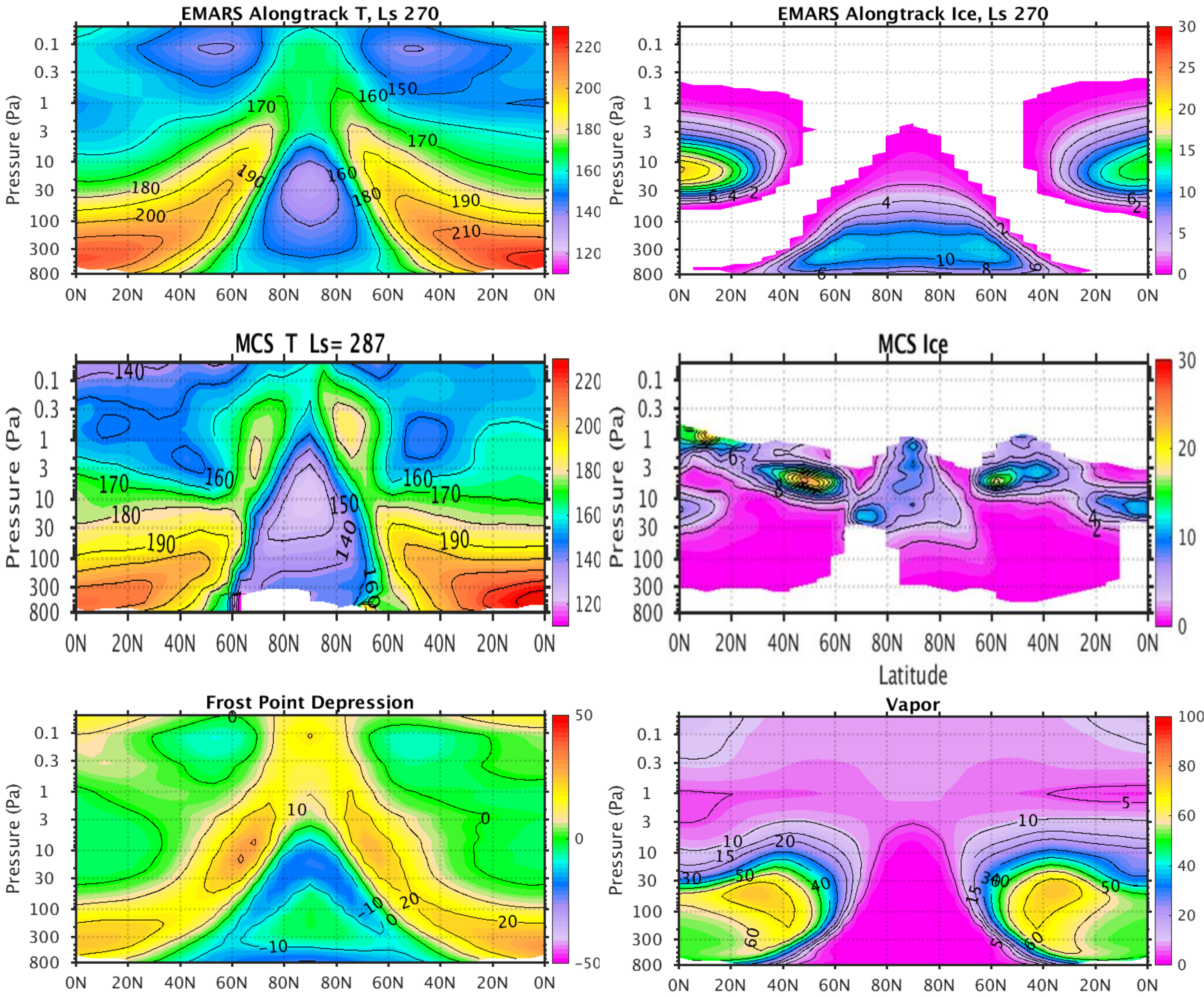


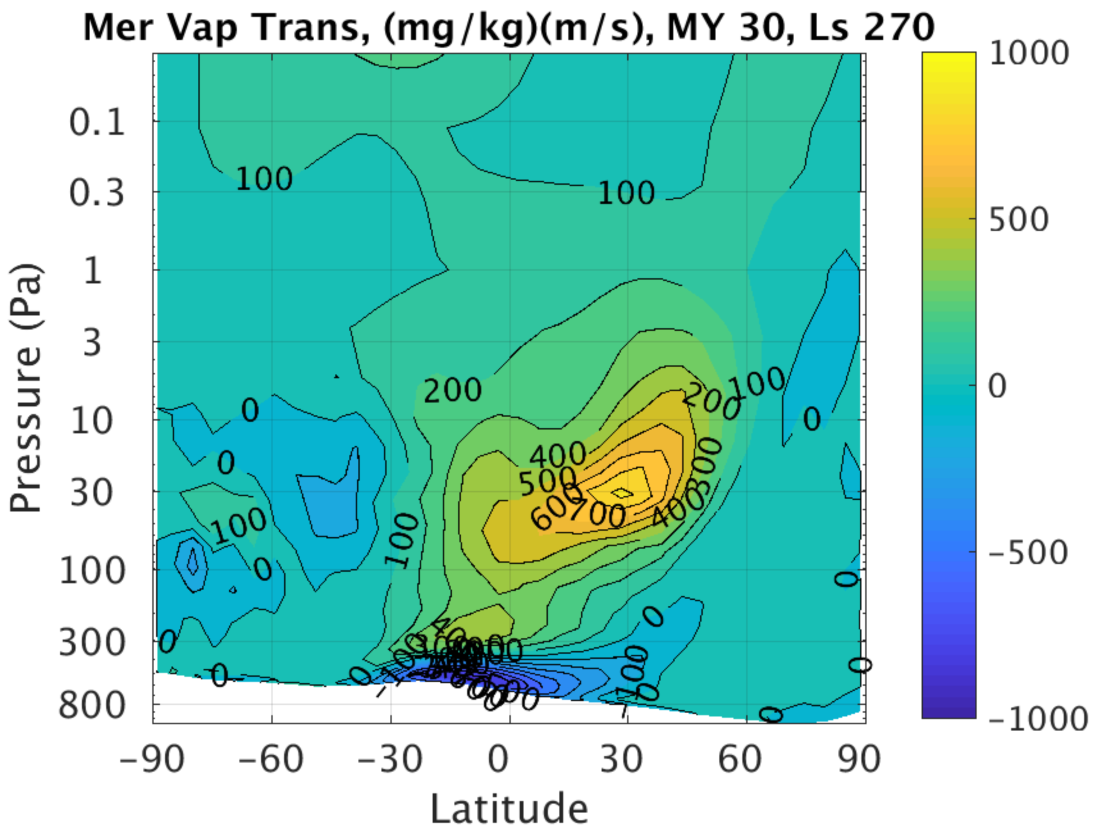


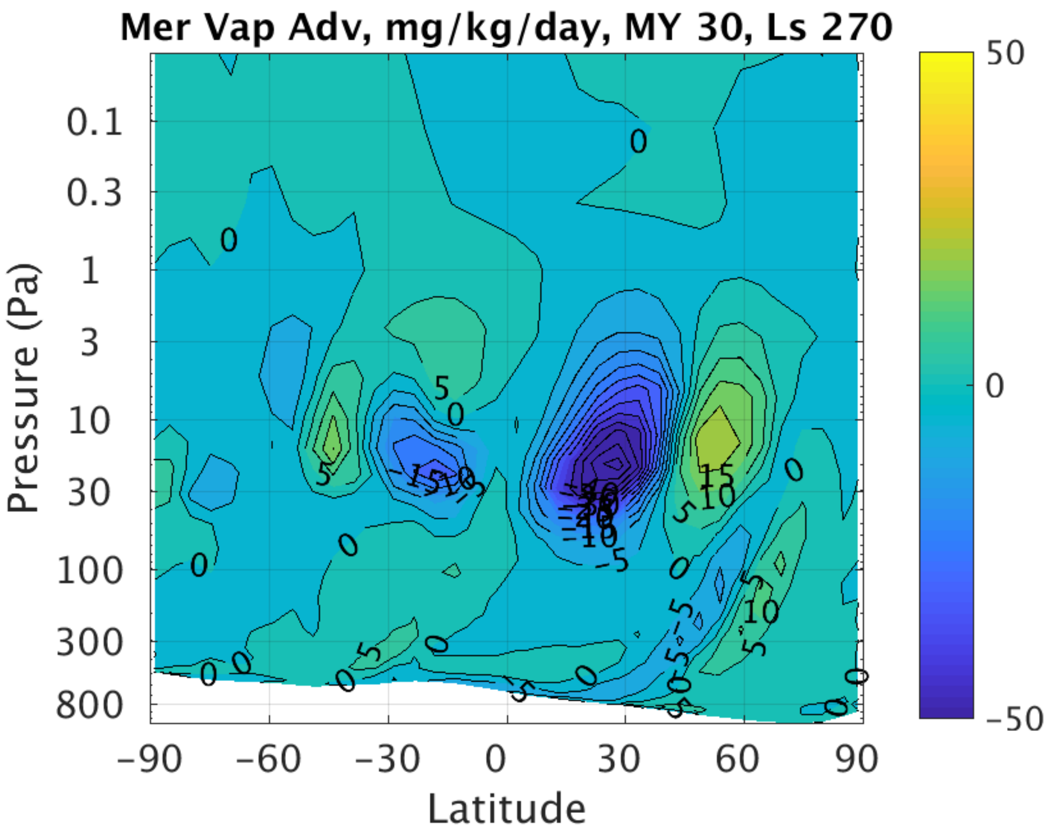
Ice values below 0.1 mg/kg not shown

The polar vortex is saturated in EMARS.

There is water vapor in the cold pockets, but it's not cold enough in EMARS for clouds to form there.

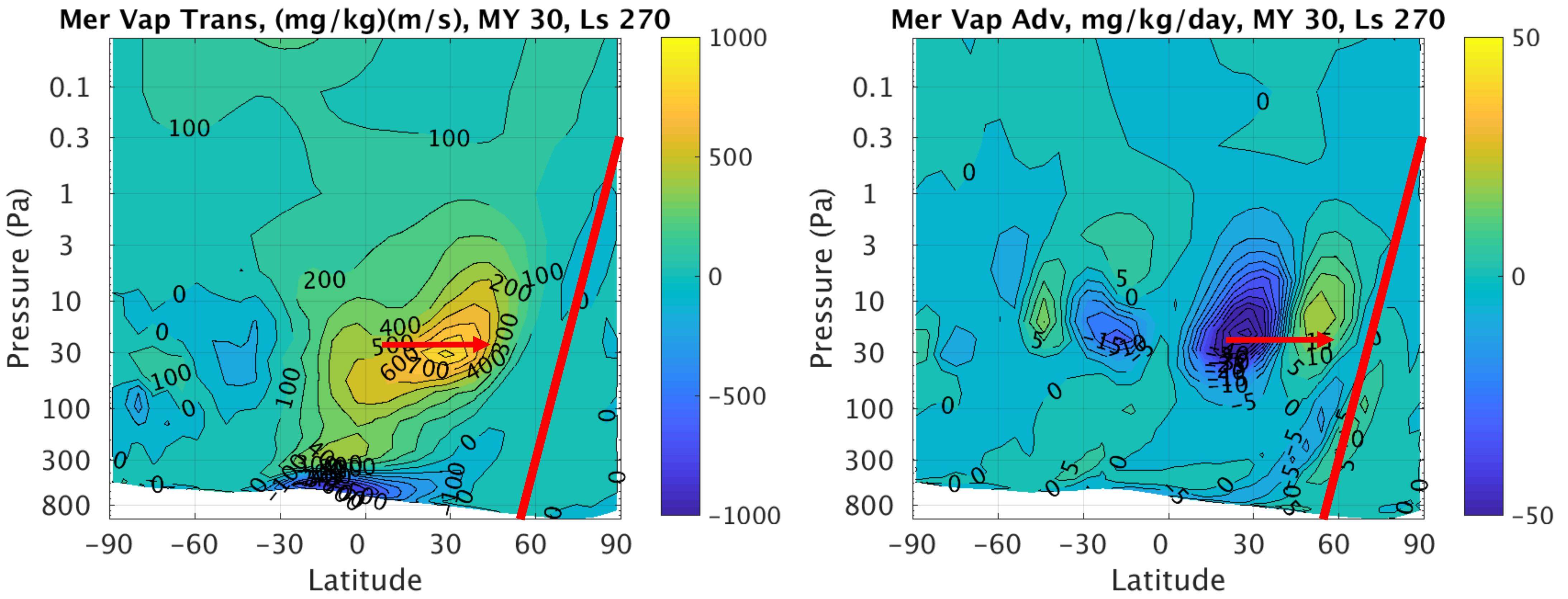






The left plot is vapor transport by meridional wind, while the right plot is vapor advection by meridional wind, as a 20-sol zonal mean.

The most notable effect suggested by the two plots together is the movement of water vapor from 25 N to 50 N, at 20 Pa, by the meridional wind.



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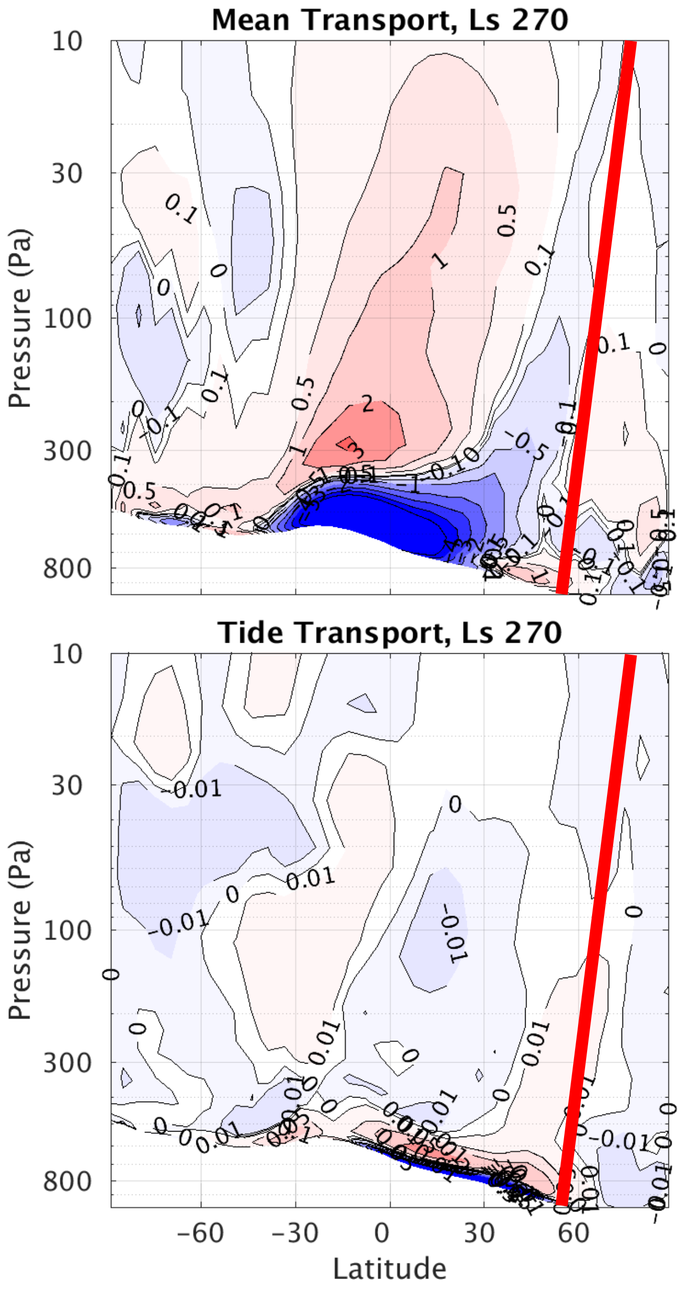

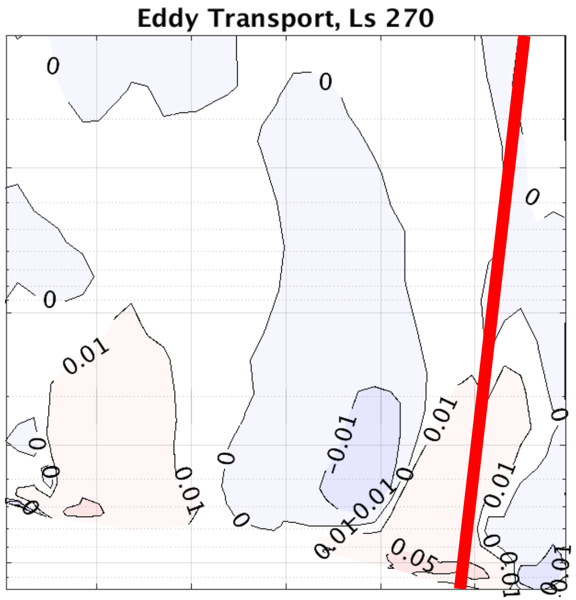

Plot of meridional transport of vapor + ice in EMARS

Units of meridional transport are mg m^-2 s^-1

20-sol time mean and zonal mean with hourly data

The color scales are different on each plot.

Most of the transport is mean transport.

Some transport into the vortex is evident below 800 Pa.

Above 800 Pa, at the outer edge of the polar vortex, water is transported equatorward. A band of equatorward transport is also present within the polar vortex near the surface. These features suggest that the water inside the polar vortex is isolated from the rest of the atmosphere.

Conclusions

- The zonal mean structure of MCS and EMARS are somewhat similar, but some differences remain challenging to resolve.
- EMARS and MCS identify stationary waves in CO_2 deposition in different locations than in the EMARS control run.
- The combination of dust and ice variation among the EMARS ensemble members and information about Martian tides from MCS may inform future Mars modeling decisions.
- Water in the polar vortex is relatively isolated from water outside. Water seems to enter the vortex primarily in the lowest quarter of the mass of the atmosphere.

Open Questions

- What are the causes of the “cold pockets” present in MCS?
- How can we model and assimilate the Martian polar warming better?
- Can we use cross-track observations to assimilate the Martian thermal tides in a better way than conventional DA?
- Can we design a parameter estimation experiment to refine our estimates of Martian dust and ice radiative parameters?
- How can we use aerosol observations most effectively in assimilation?

Acknowledgments

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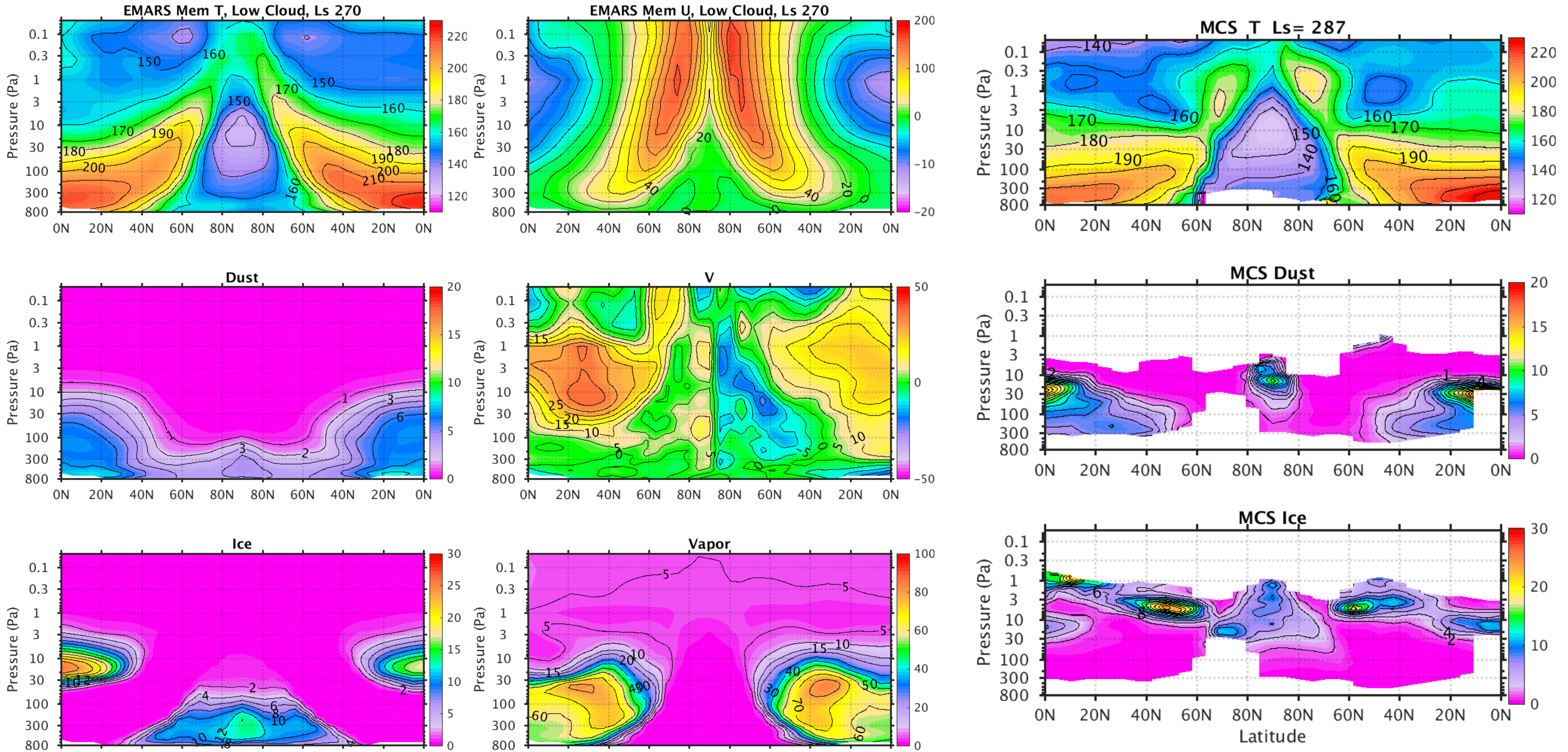
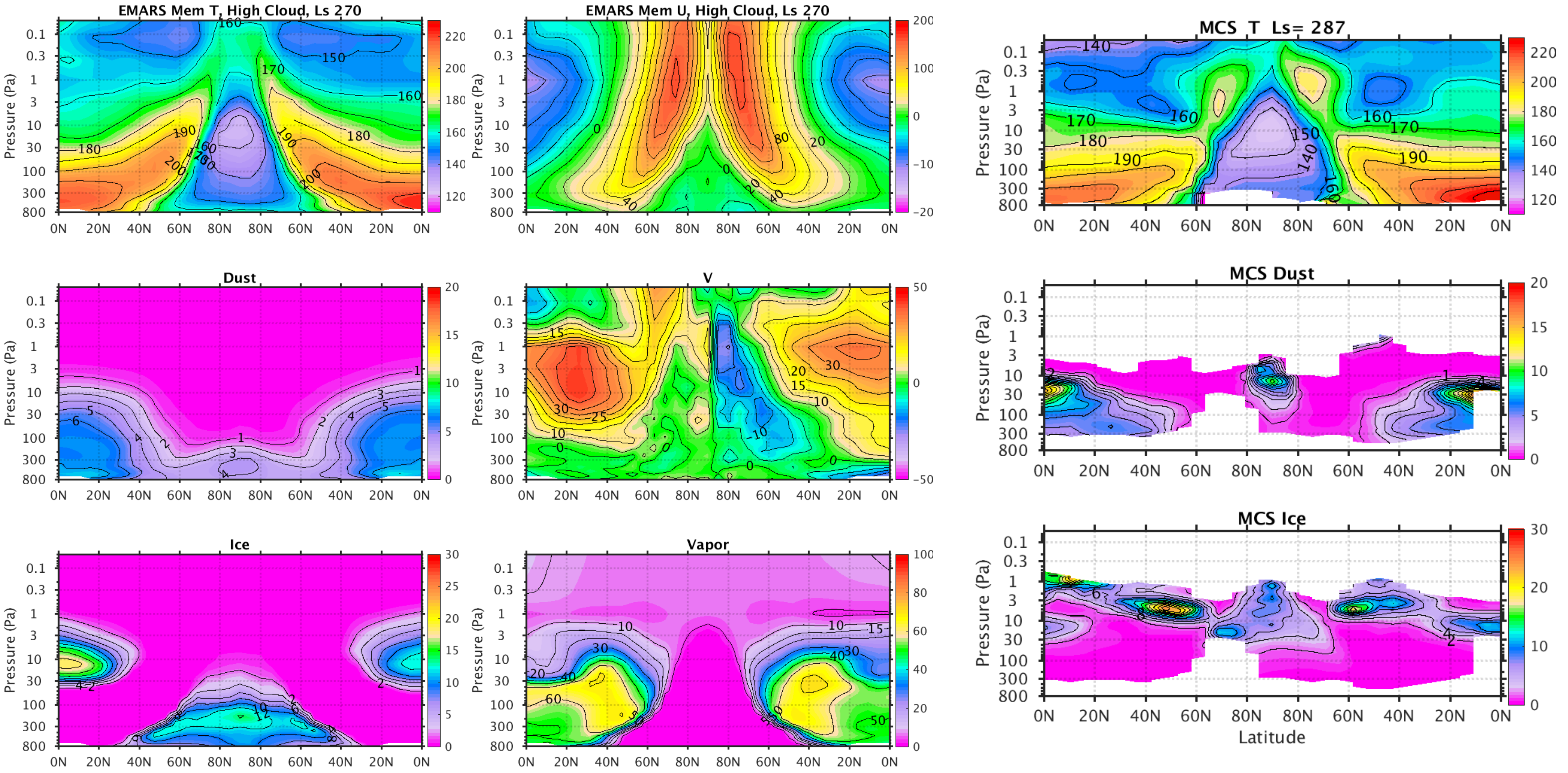
Spare slides

Some nomenclature for the experiments:

Exp Name	Meaning
EMARS All Obs	EMARS with along-track and cross-track MCS observations assimilated
EMARS	Alias for EMARS All Obs, unless specified otherwise
EMARS Alongtrack	EMARS with only along-track MCS observations assimilated
EMARS PoleXtrack	EMARS with along-track MCS observations assimilated as well as cross-track observations poleward of 45° assimilated
MGCM	No observations assimilated; freely running model


EMARS Mem T, Low Cloud, Ls 270
EMARS Mem U, Low Cloud, Ls 270
MCS T Ls= 287
Dust
V
MCS Dust
Ice
Vapor
MCS Ice
Pressure (Pa)
Latitude



EMARS Mem T, High Cloud, Ls 270
EMARS Mem U, High Cloud, Ls 270
MCS T Ls= 287
Dust
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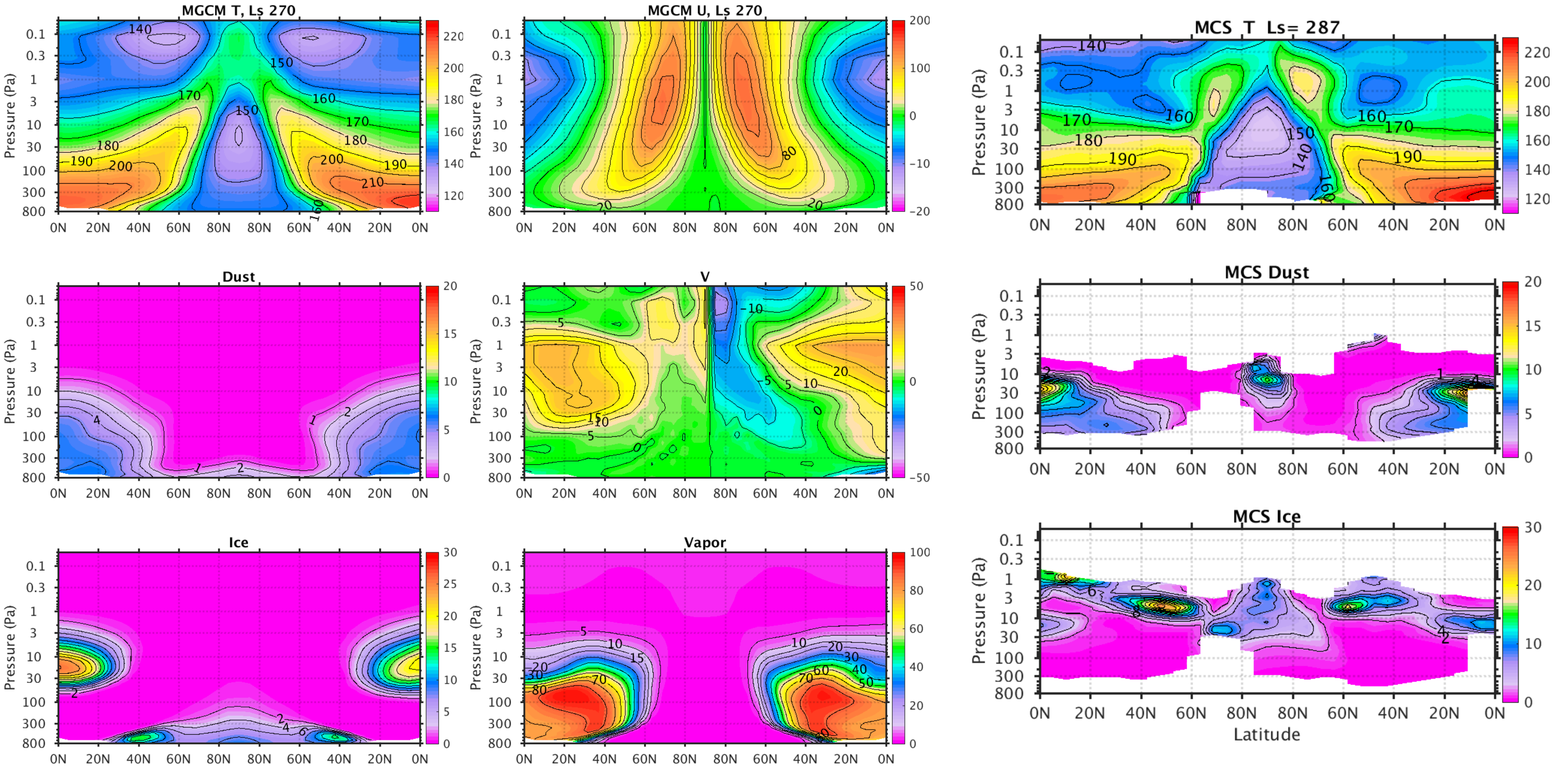
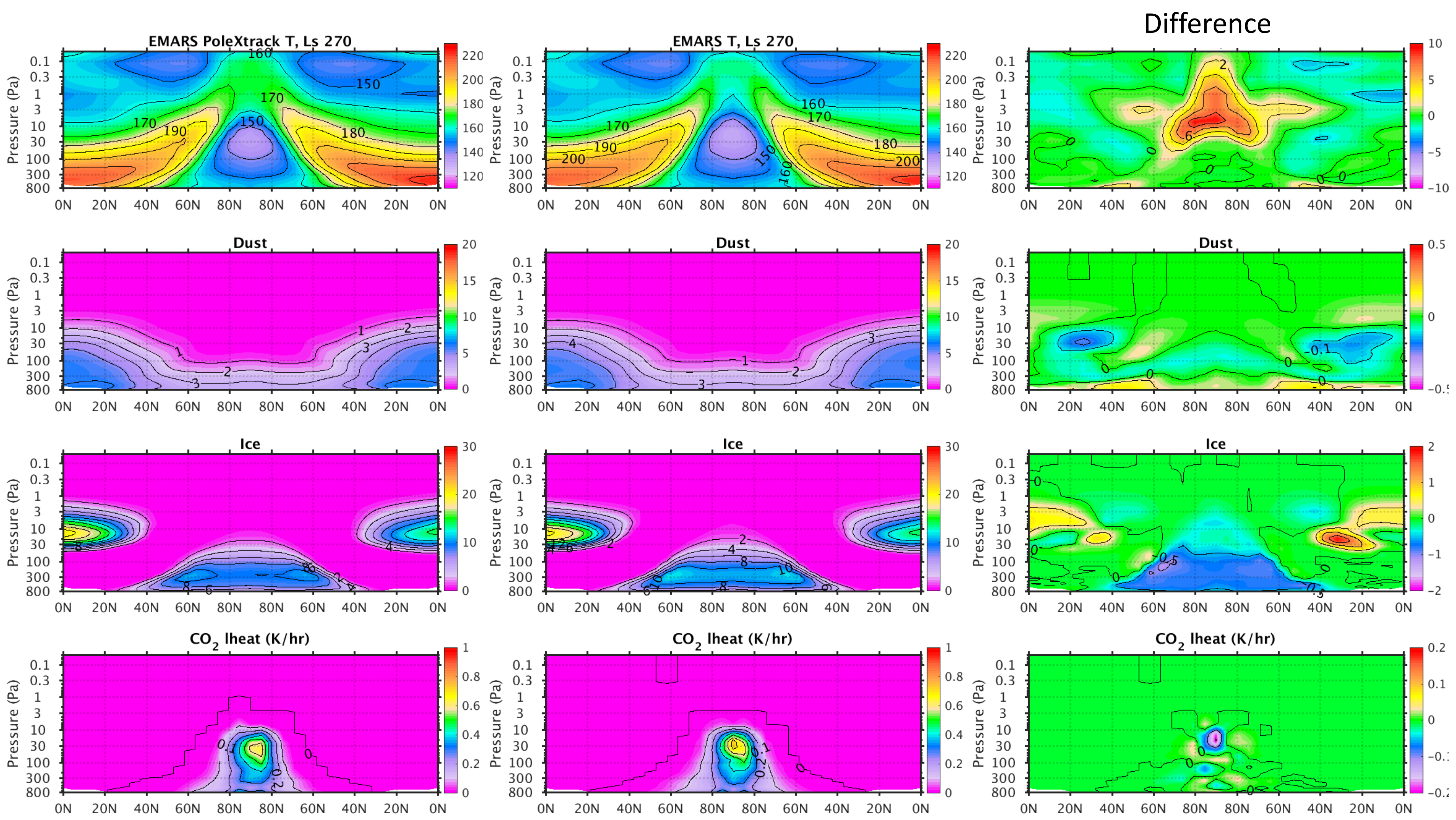
MCS Ice
Pressure (Pa)
Latitude

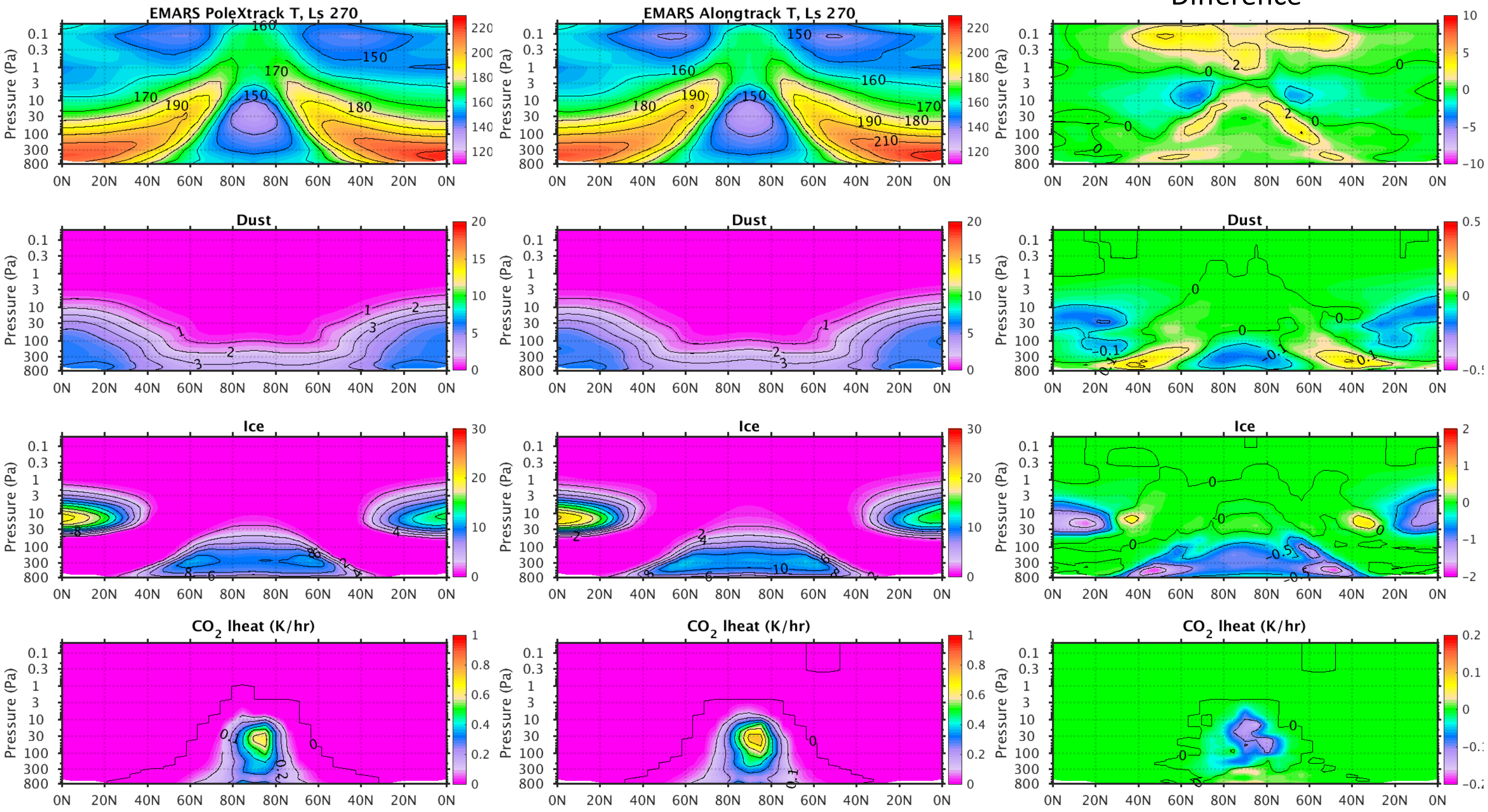

MGCM T, Ls 270
MGCM U, Ls 270
MCS T Ls= 287
Dust
V
MCS Dust
Ice
Vapor
MCS Ice
Pressure (Pa)
Latitude



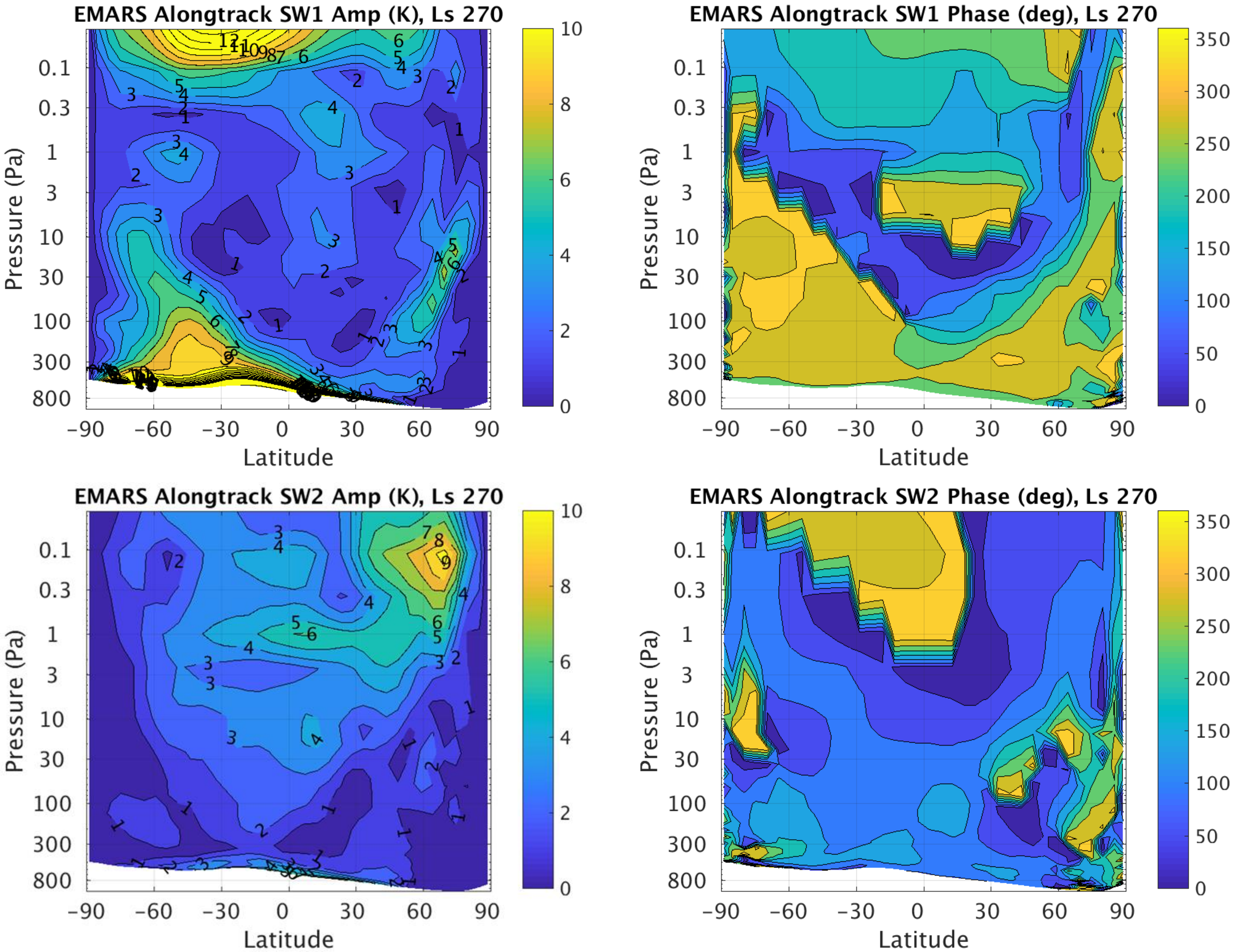
Difference is polar x-track minus default EMARS. That is, the difference comes from tropical cross-track data.

These unnecessary. However, move EMARS CO2 next to MCS dust ahead of CO2 slides.

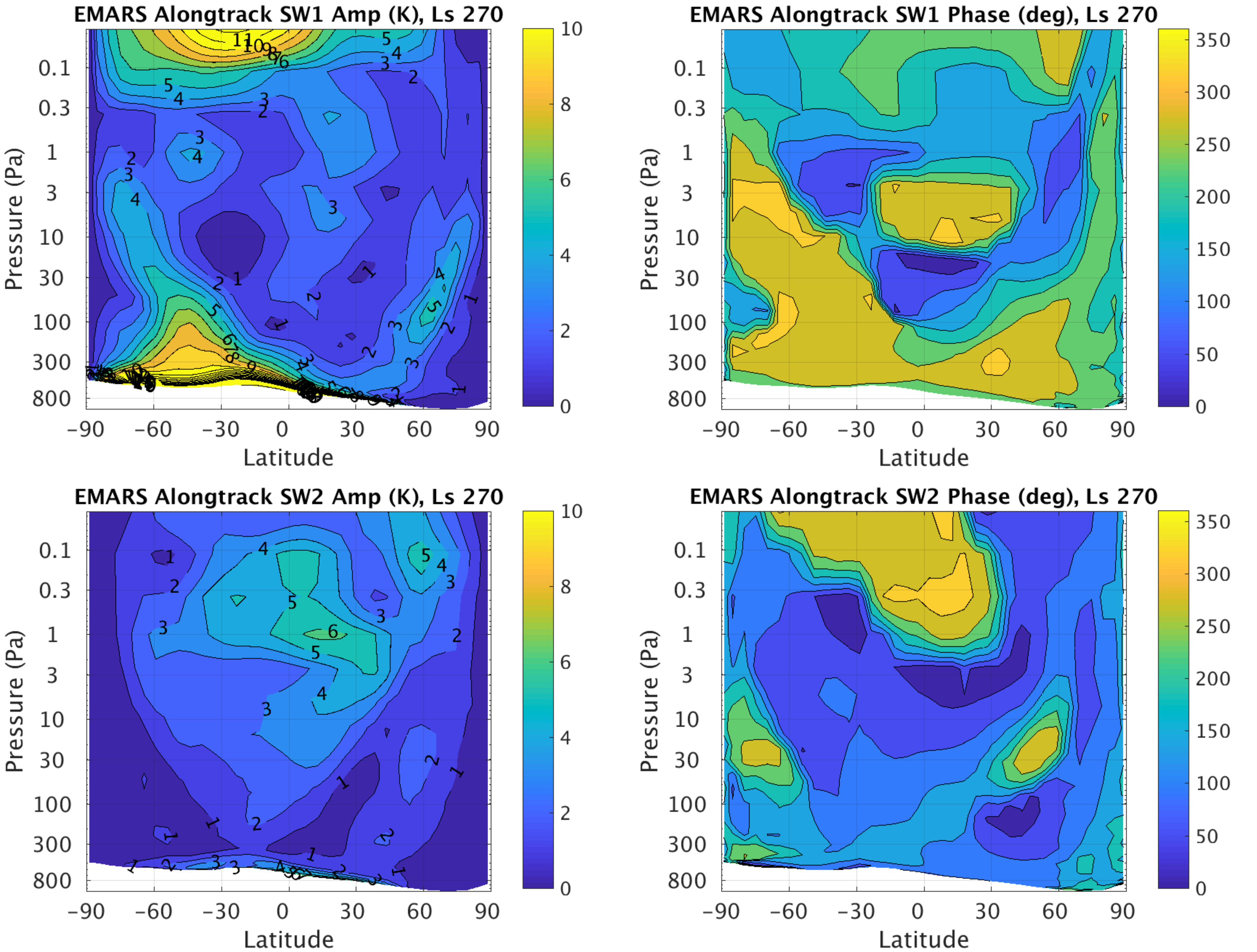
Difference



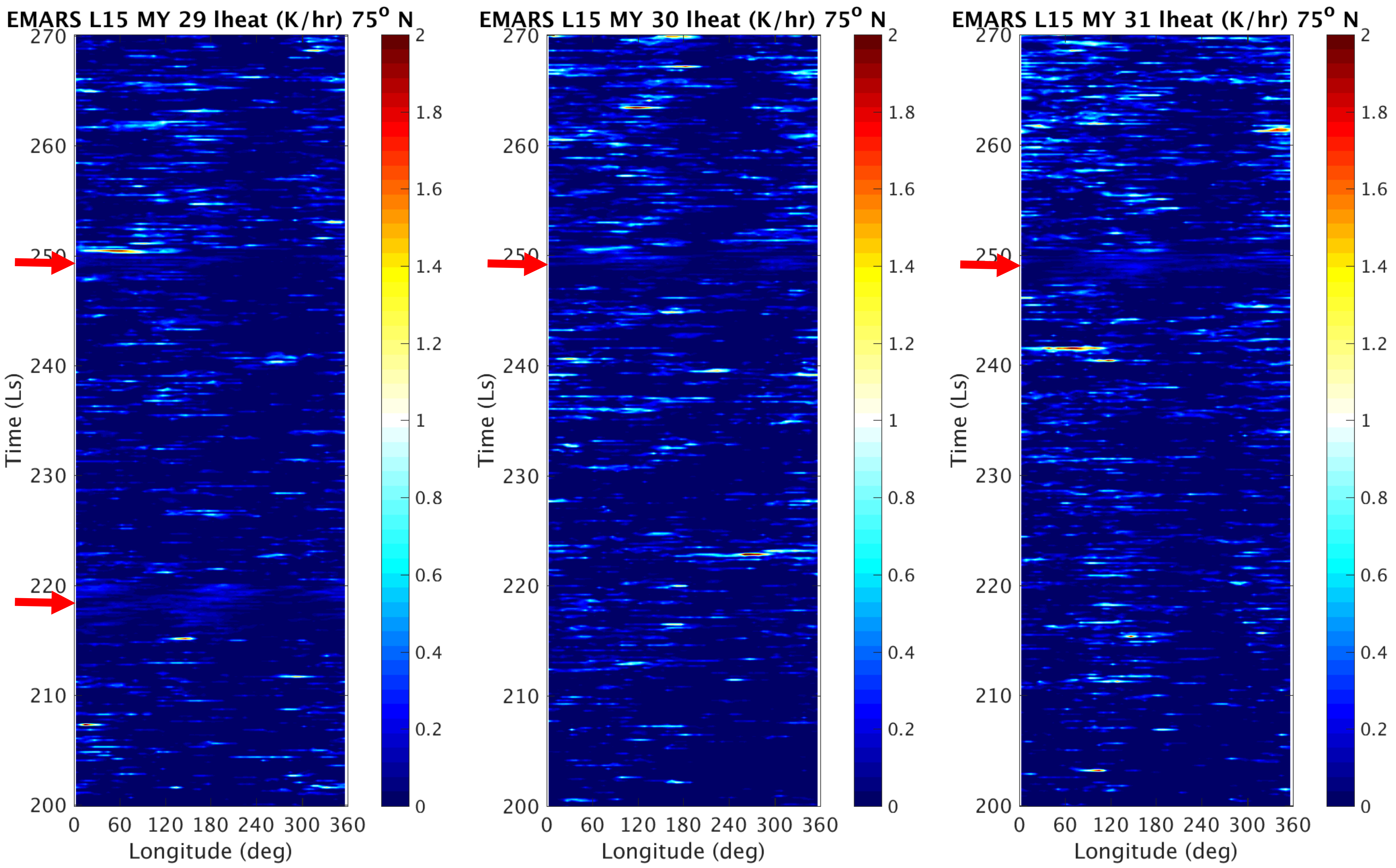
Difference is polar x-track minus alongtrack. That is, the difference comes from polar cross-track data.



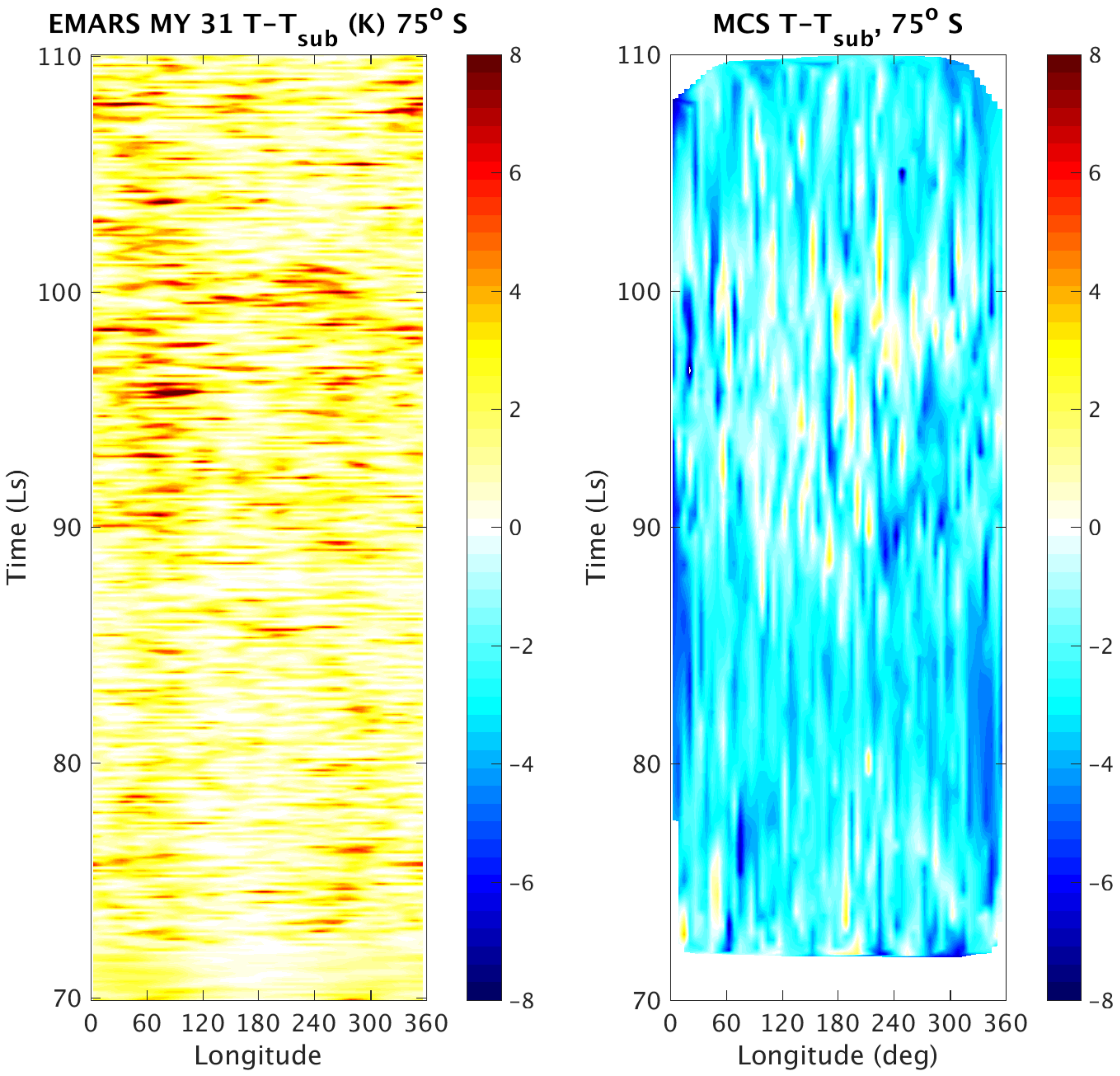
EMARS reproduces expected features of the diurnal tide amplitude, such as the large near-surface diurnal tide and greater amplitudes in the summer hemisphere than the winter hemisphere.



However, there is a difference between using 1-hour forecasts and 0-hour analyses. Most of the differences are in the highest part of the atmosphere or the phasing, which appears to largely be smoothed.



Red arrows indicate changes in the latent heating behavior of the type investigated by David Kass and presented during the last telecon. He suggested that these may have a dynamical origin, and these plots suggest a lack of diurnal tide influence on latent heating. It is especially notable that an event seems to occur at about Ls 248 in each year.

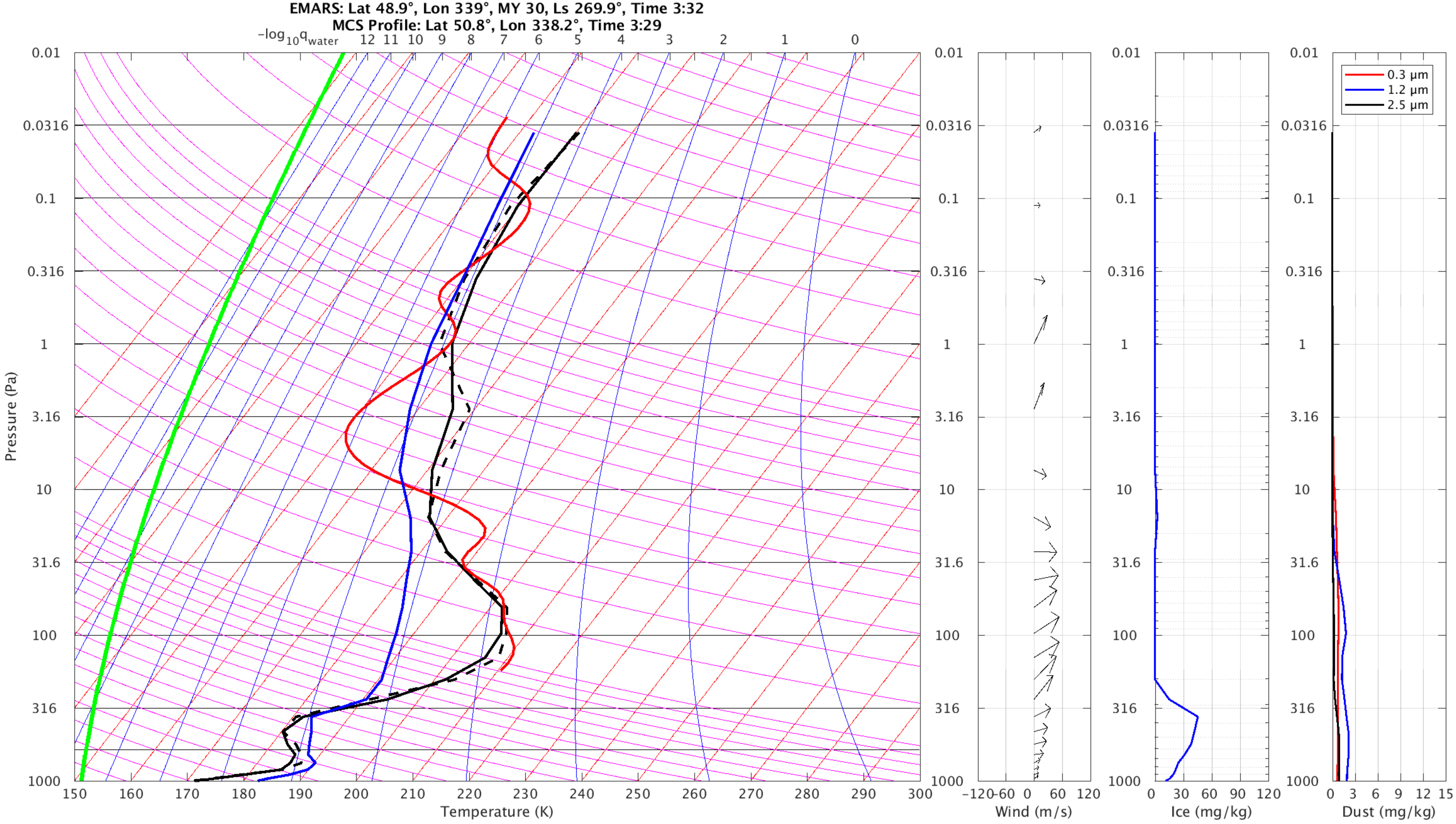


A stationary wave is also present in EMARS in the Southern Hemisphere, but with a substantially lower amplitude. MCS shows little evidence of a stationary wave, and most of the temperatures recorded at this pressure level are below the sublimation temperature of carbon dioxide, as approximated by James et al. (1992).

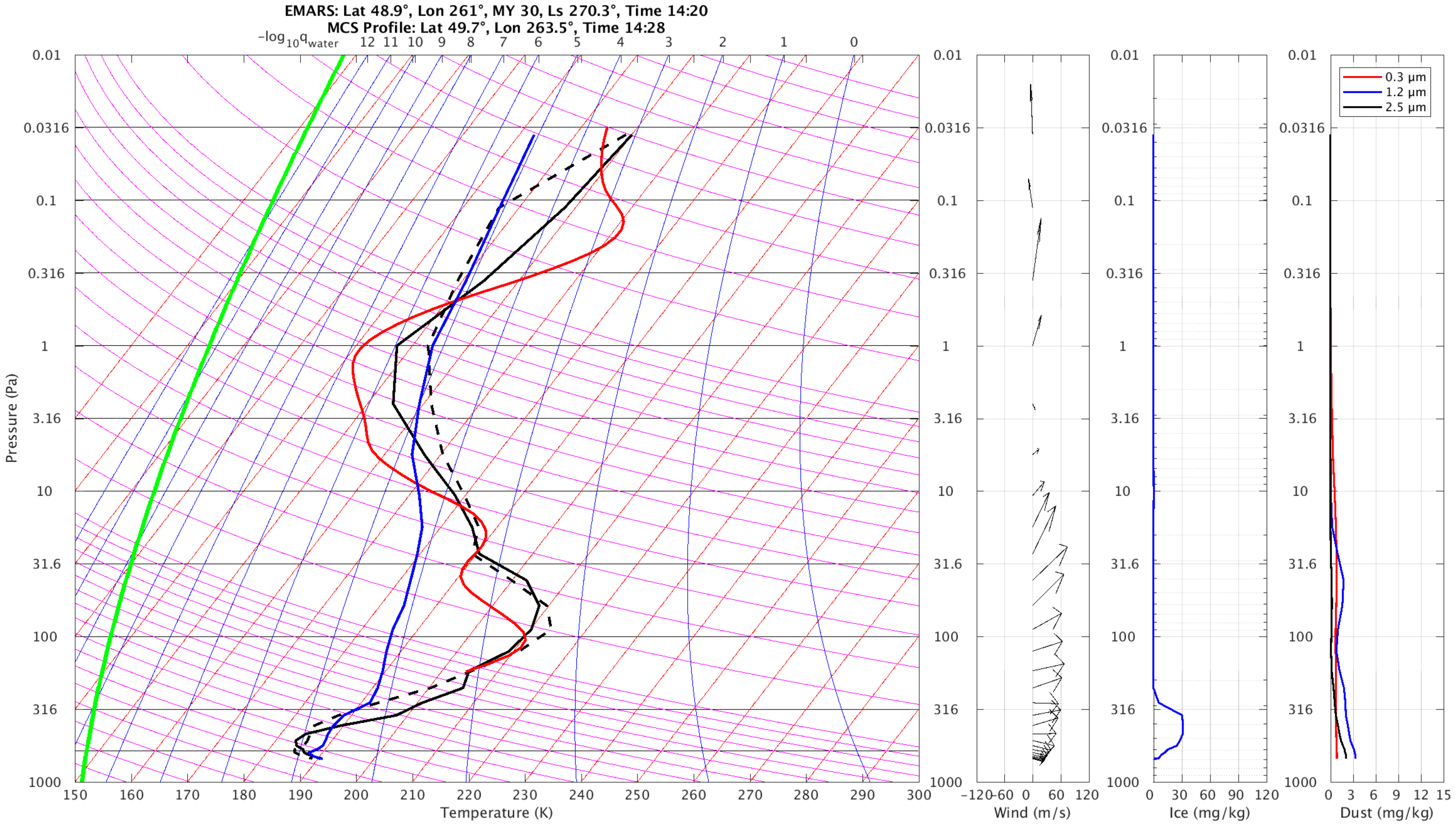
Skew-T plots

BOLD LINES:
Black, solid – EMARS analysis
Black, dashed – EMARS background
Blue – EMARS analysis frost point
Red – MCS observation
Green – CO_2 deposition point

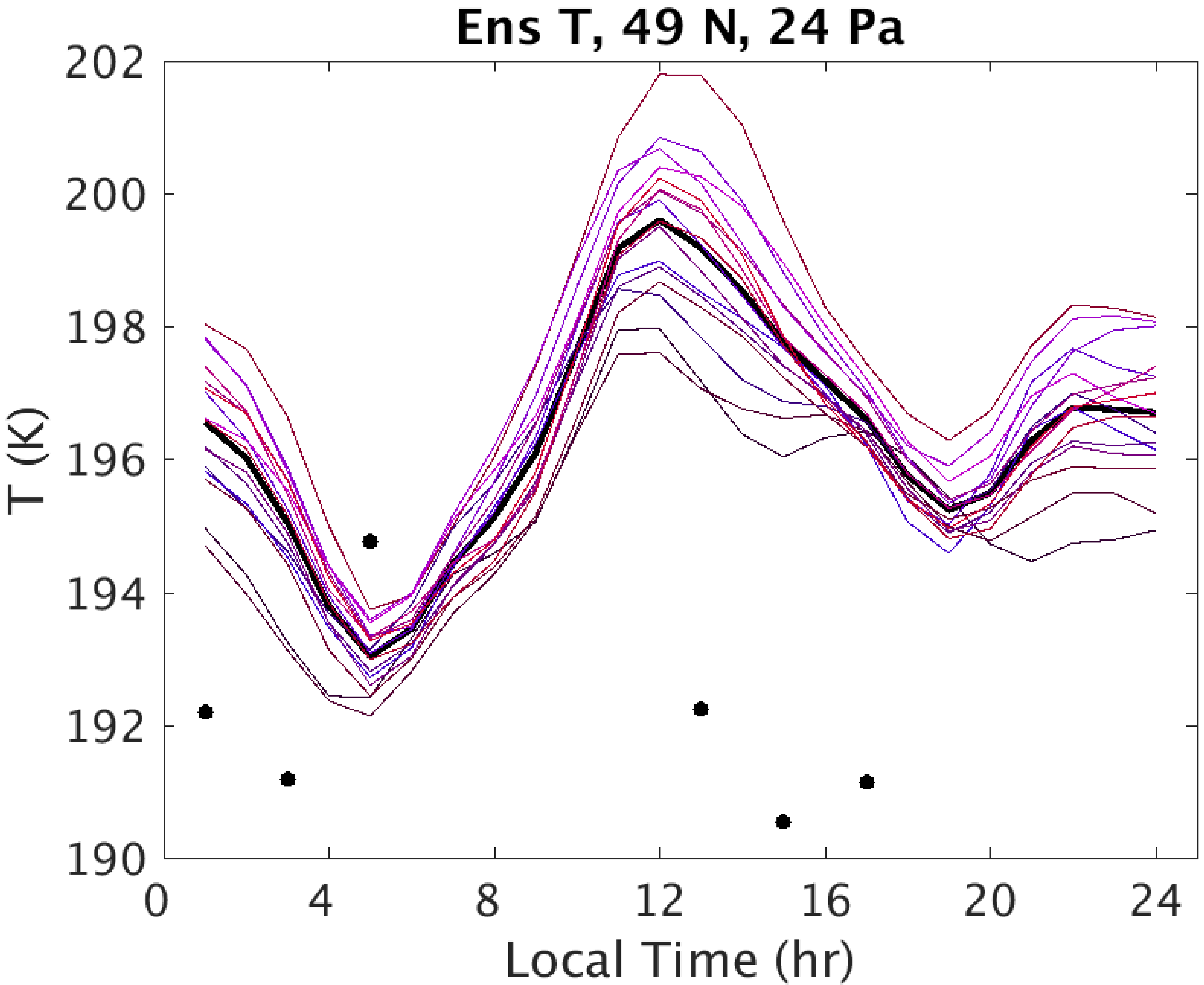
THIN LINES:
Black – pressure (values at left)
Red, straight, positive slope – temperature (values at bottom)
Magenta, curved, negative slope – adiabats (611 Pa reference pressure)
Blue – water vapor mixing ratio (values at top)



Notice in this instance that EMARS Alongtrack is close to MCS, except near 5 Pa, at the bottom of the MCS “cold pockets”.



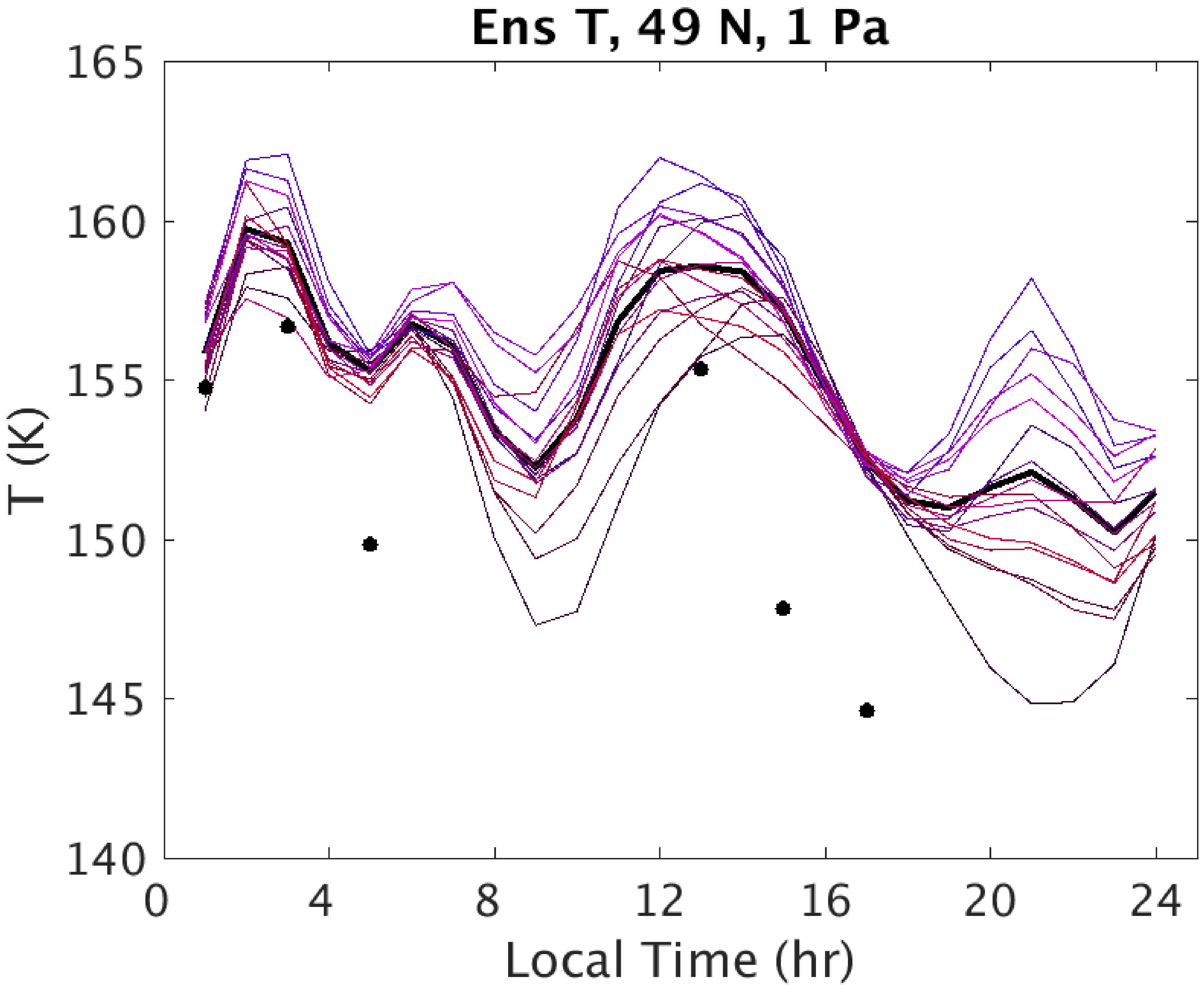
Sometimes, EMARS responds strongly to MCS observations.



The thick curve is the ensemble mean over 10 sols centered on Ls 270, the dots are the means of MCS observations, and the thin lines are ensemble members. Ensemble members are colored according to their dust and ice radiative factors.

Black → red: more dust

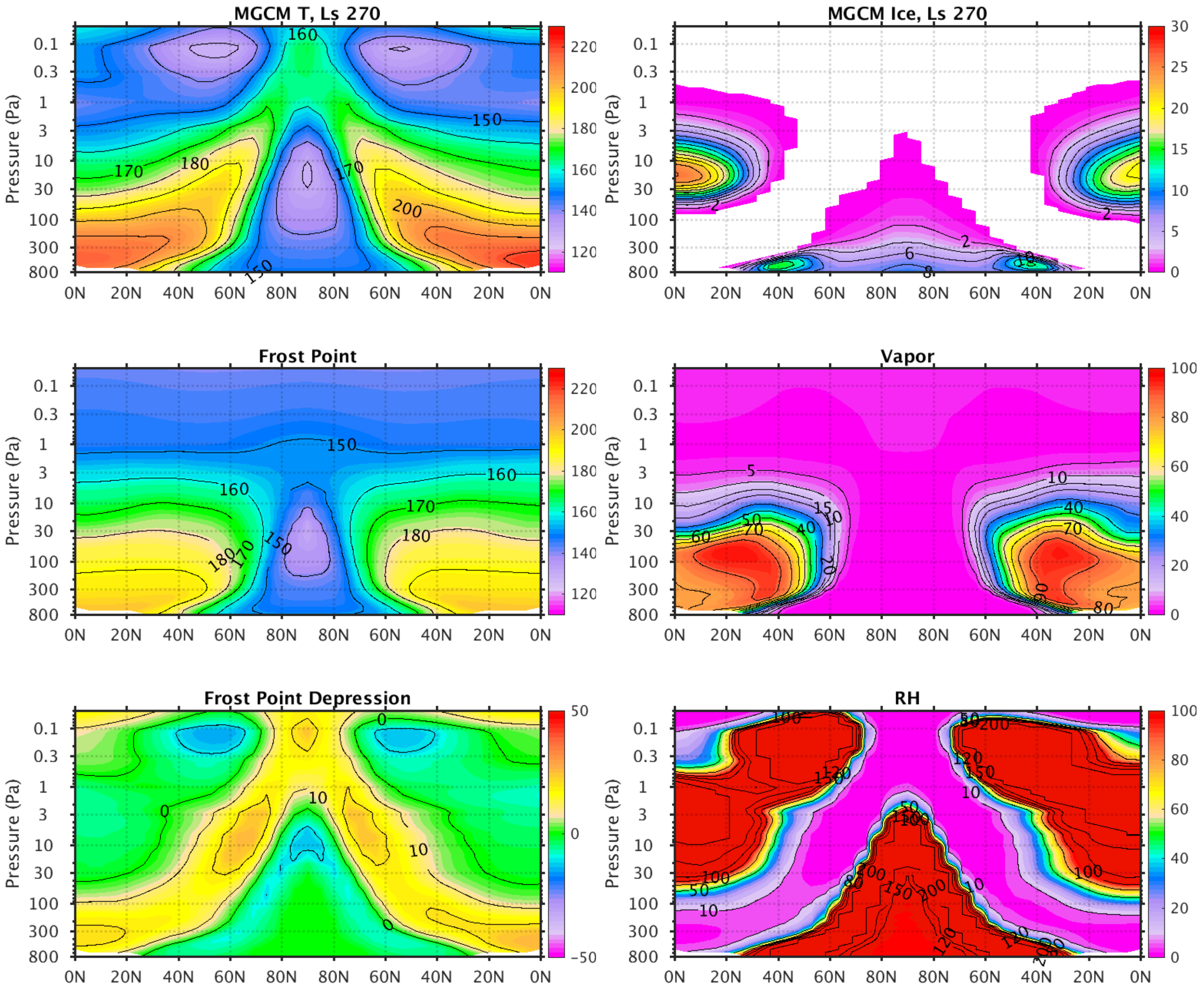
Black → blue: more ice



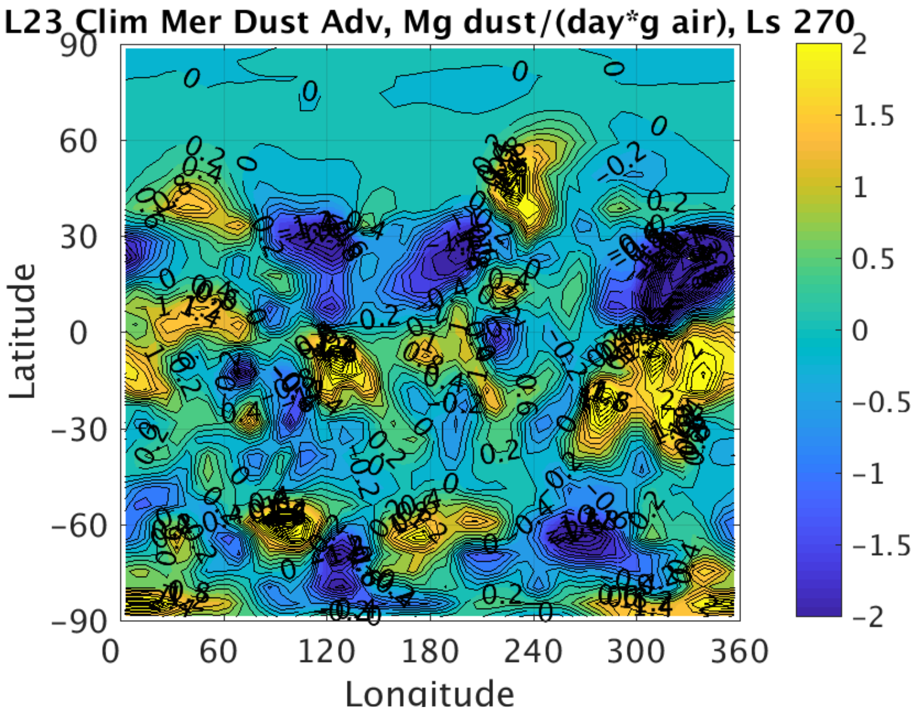
The thick black curve is the ensemble mean over 10 sols centered on Ls 270, the dots are the means of MCS observations, and the thin lines are ensemble members. Ensemble members are colored according to their dust and ice radiative factors.

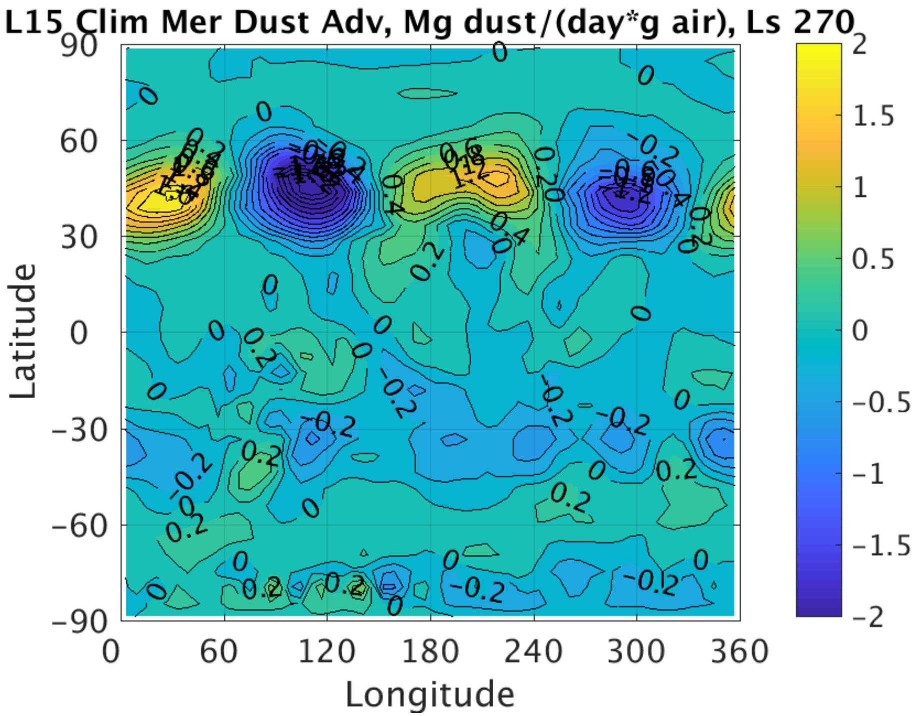
Black → red: more dust

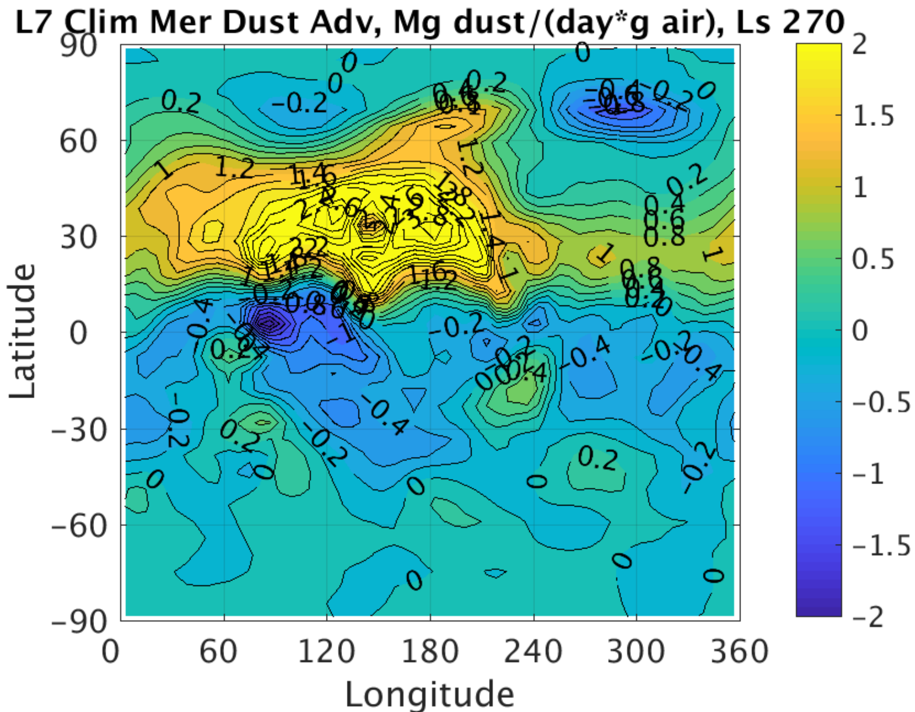
Black → blue: more ice



Notice, in particular, the differences in the frost point depression in the MGCM compared to EMARS. The near-surface negative frost point depressions are no longer present, which may contribute to the concentration of ice clouds at the edge of the polar vortex near the surface.







Probably remove