

# Improved Understanding of Dust Distribution and Cap Edge Processes via Data Assimilation

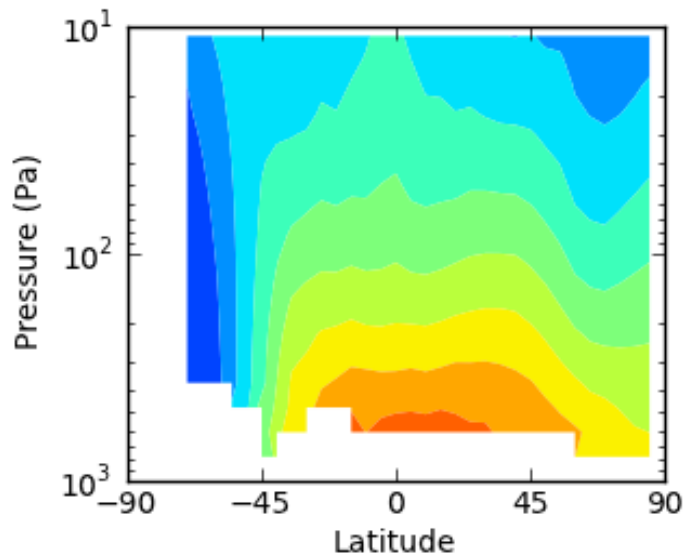
Mark Richardson (AR), Chris Lee (AR),  
Jeff Anderson (NCAR), Nancy Collins (NCAR),  
Tim Hoar (NCAR), Greg Lawson (Point Carbon)

# Overview

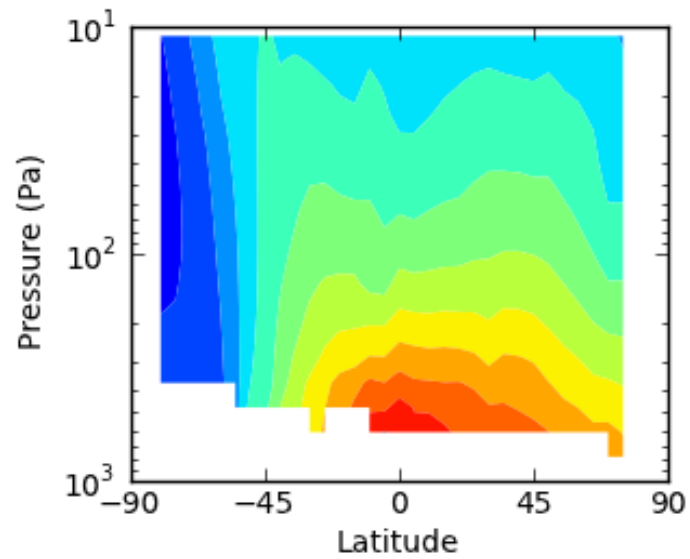
- Data assimilation (DA)
  - “reanalysis” (*models not ready yet*)
  - model testing (*really useful*)
- Initial DA study
  - dust vertical distribution crucial
  - cap edge resolution
- Open source DA system (MarsWRF and DART)
  - ensemble kalman filter approach
  - radiance assimilation (retrieval assimilation option)
  - *www.marsclimatecenter.com*

# Data Assimilation and Reanalysis

- For many dynamical problems we want to recover the full global state from limited observations (as best we can)
- Extrapolation options (a question of constraints):
  - linear (*e.g.* zonal average)
  - wave fitting (*e.g.* spherical harmonics)
  - dynamical model (physics, mechanics of rotating spherical shell)
- Reanalysis only as good as the dynamical model
  - error in model = error in extrapolation

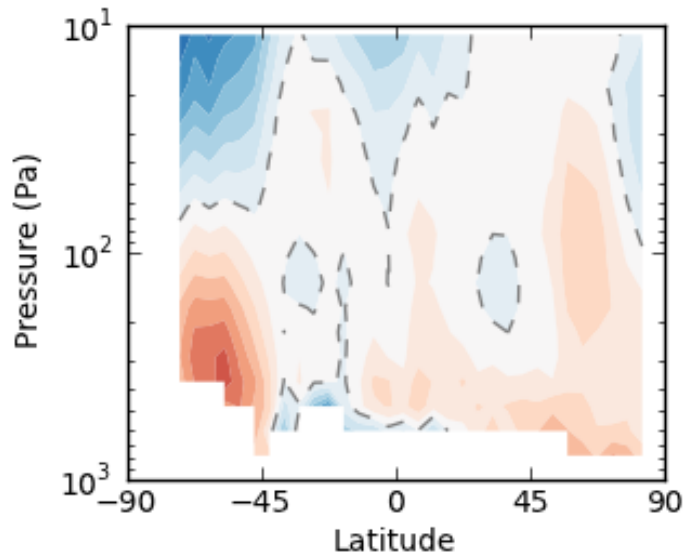


120 140 160 180 200 220 240  
TES AM Temperature (K)

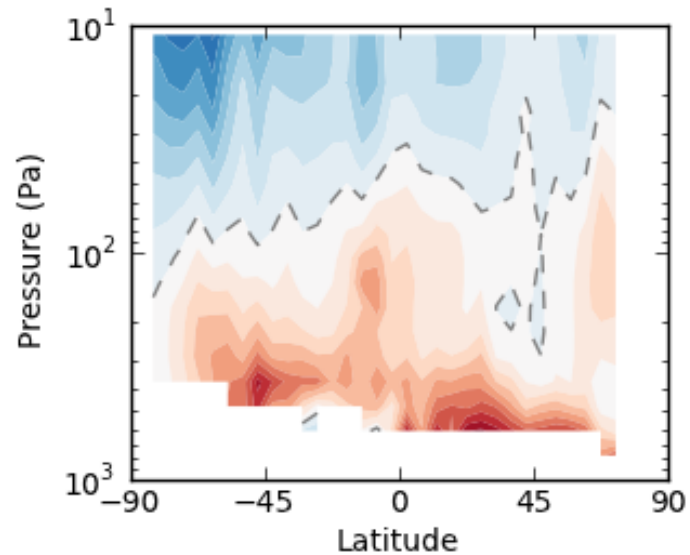


120 140 160 180 200 220 240  
TES PM Temperature (K)

TES  
Observations



-16 -12 -8 -4 0 4 8 12 16 20  
AM Prior - Ret. Temperature (K)



-16 -12 -8 -4 0 4 8 12 16 20  
PM Prior - Ret. Temperature (K)

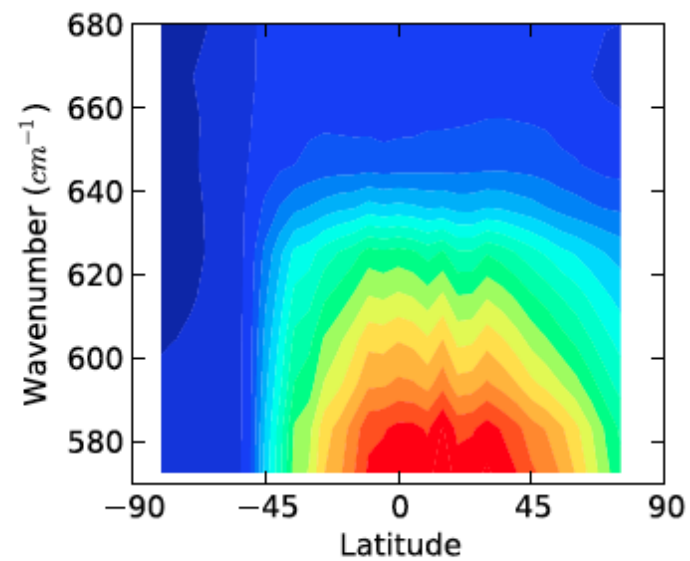
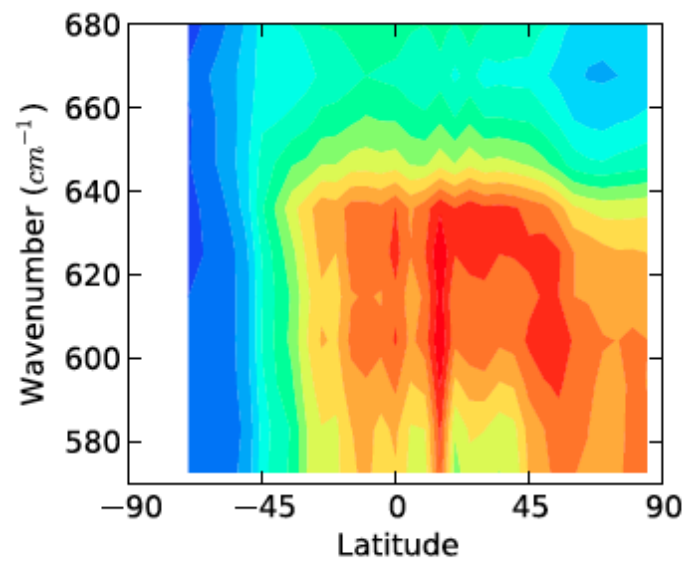
DA GCM  
Prior - TES  
Observations

Ls=150

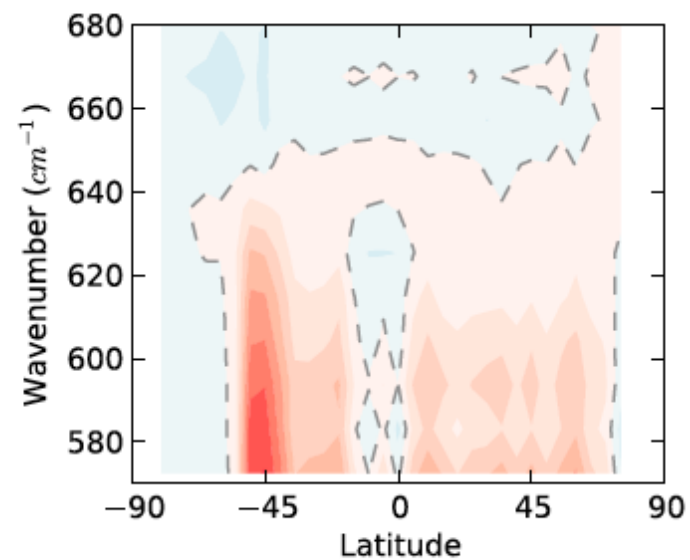
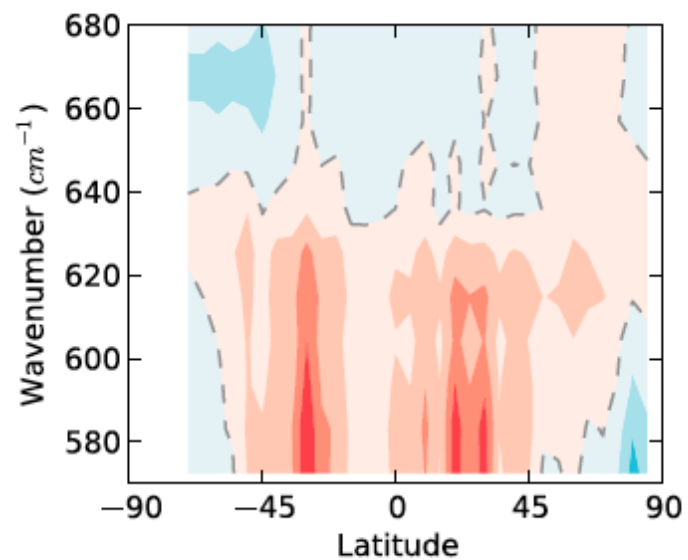
Lee *et al.*, 2011  
*JGR-Planets*

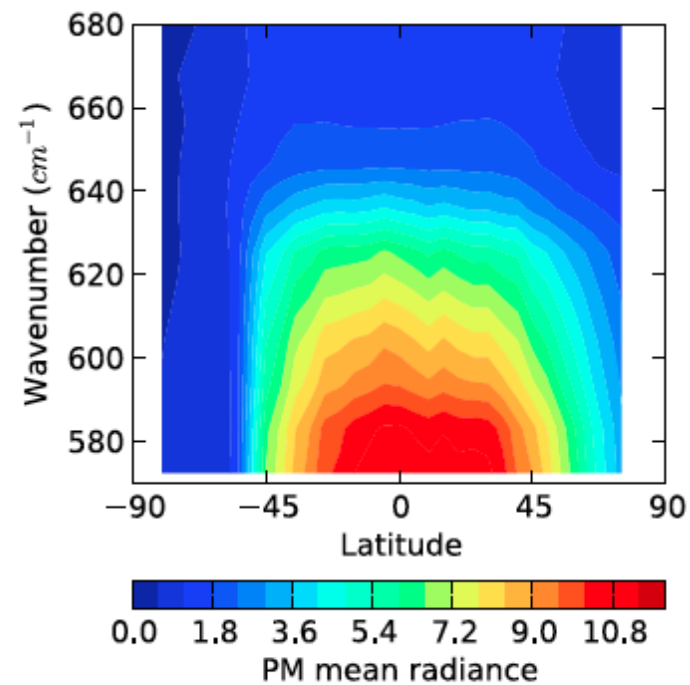
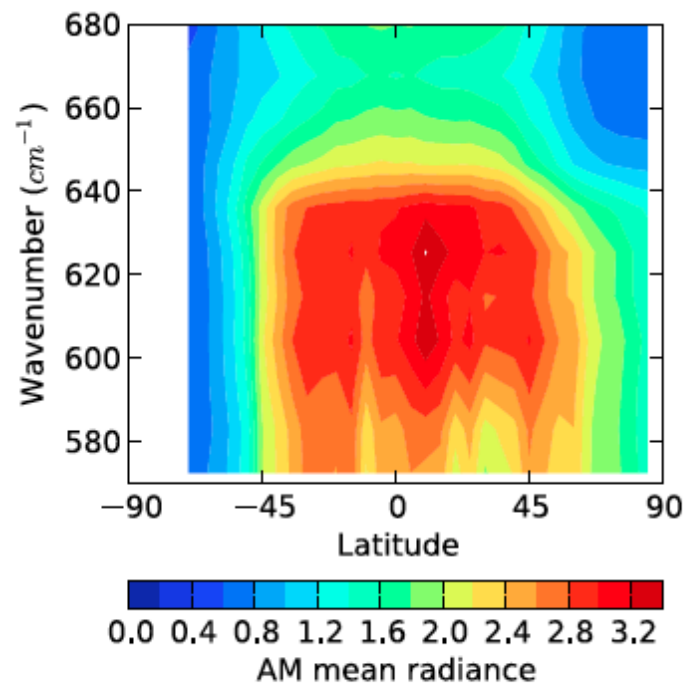
# Data Analysis with DA

- Modeling of data is essential for knowledge gain
- DA provides the most complete means of testing models with data:
  - rejection / acceptance statistics, distributions
  - prior vs. data biases
  - isolation of model errors from real transient phenomena (best possible)
  - can obviate need for intermediate retrieval step
- Frame work for iterative model improvement and testing

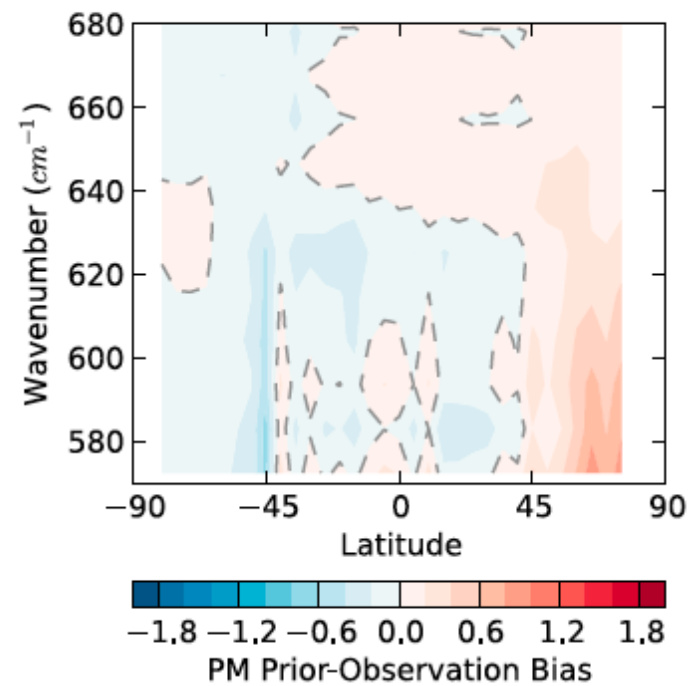
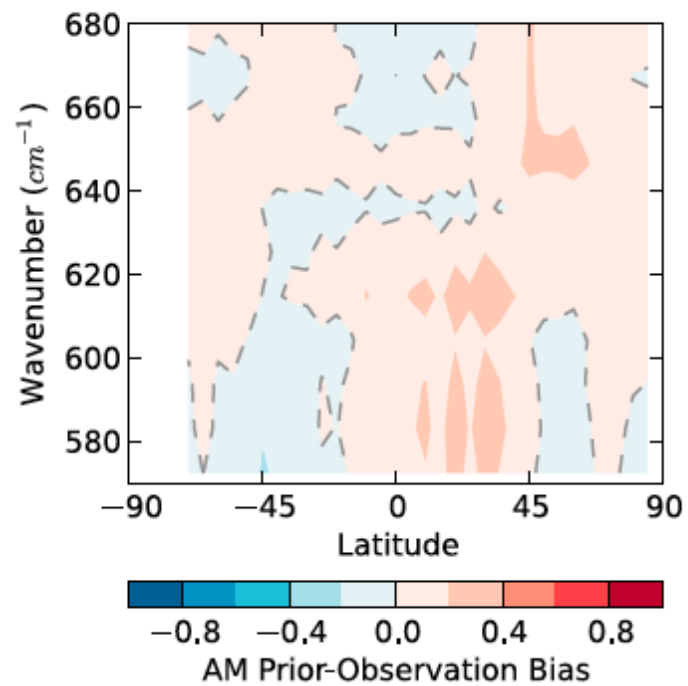


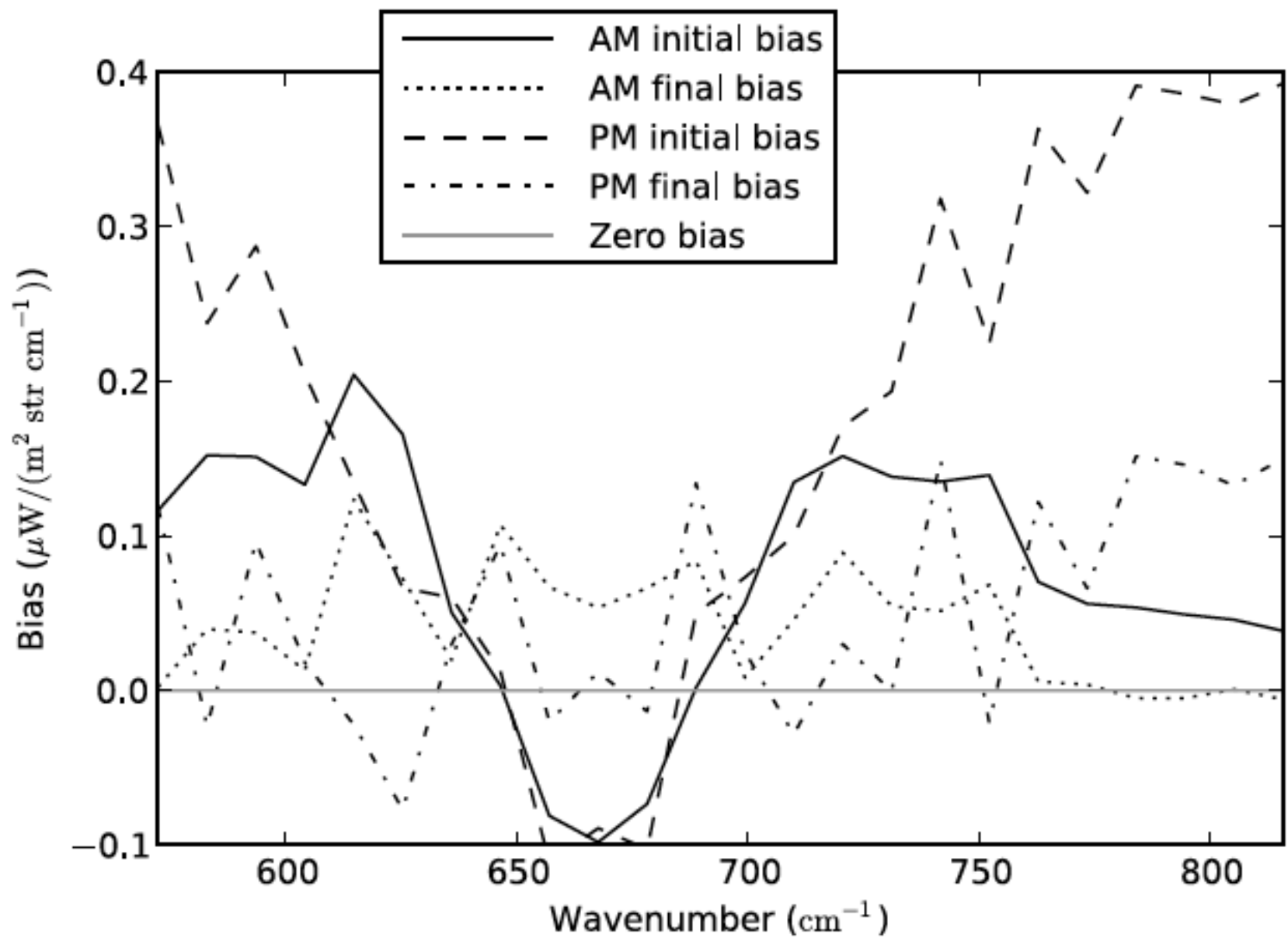
Ls=150





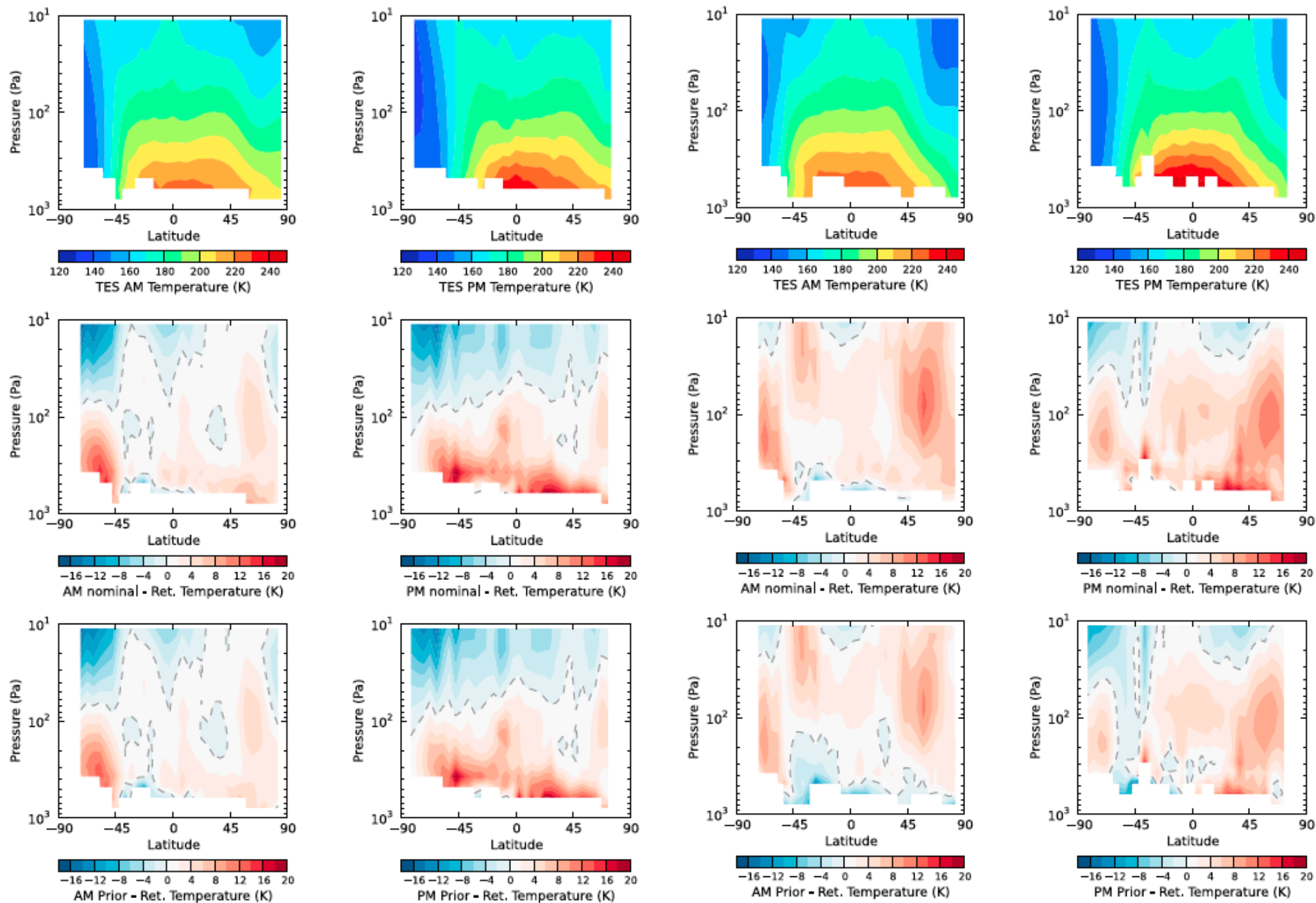
Ls=170



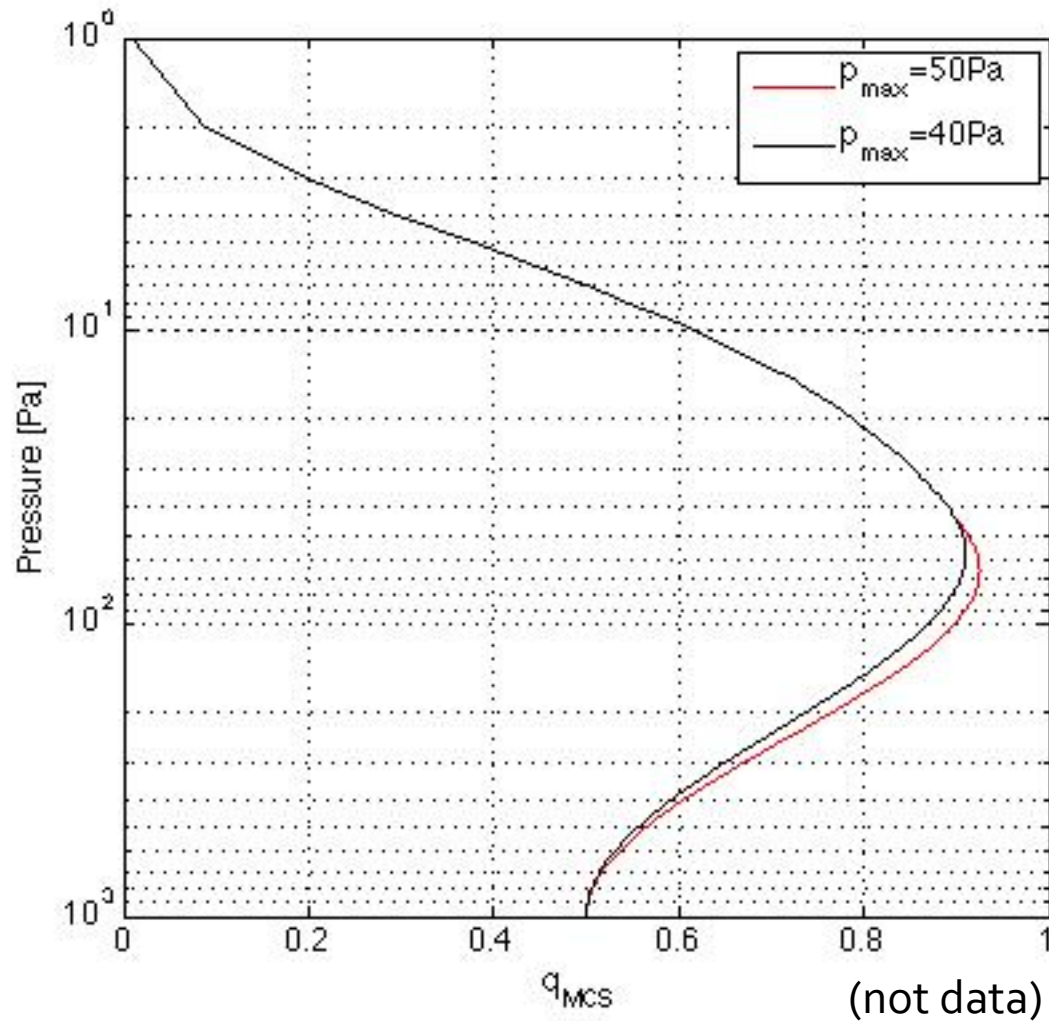


Ls=150

Ls=170

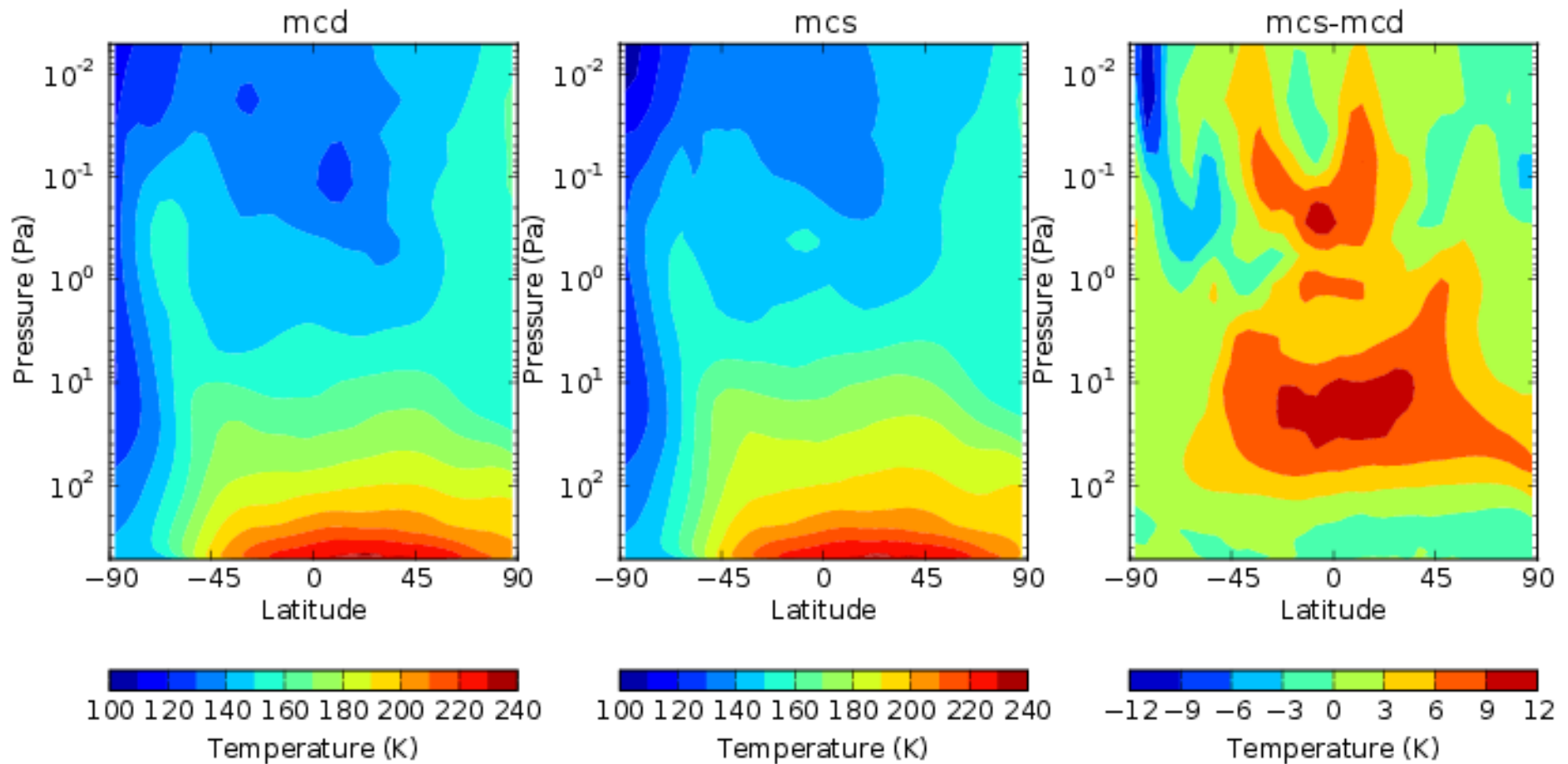


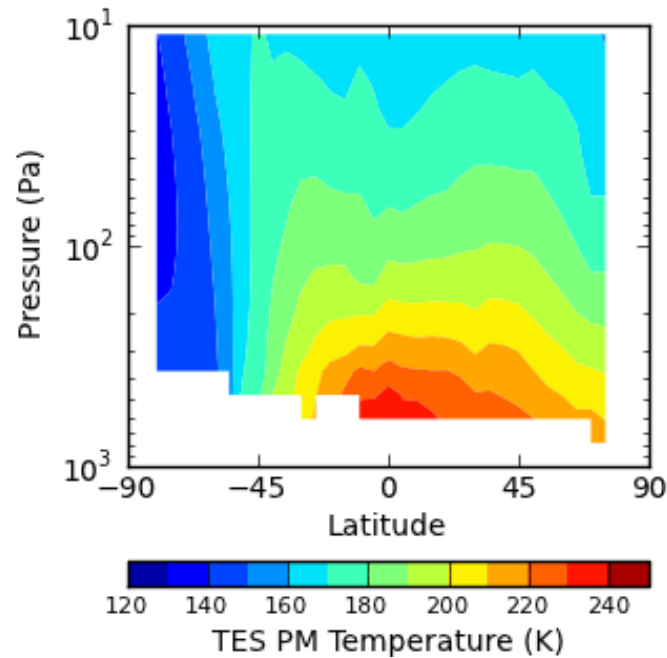
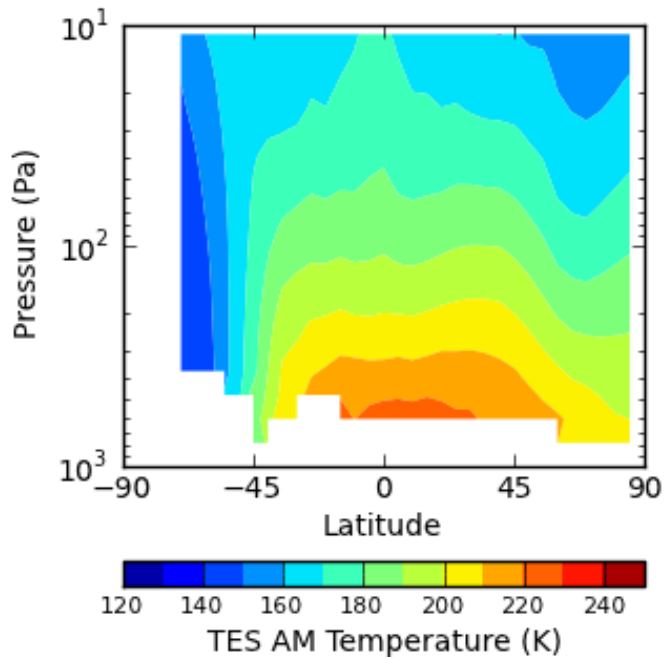
# Dust vertical distribution



Dust mass mixing ratio peak looks to be about 20-30 km based on MCS

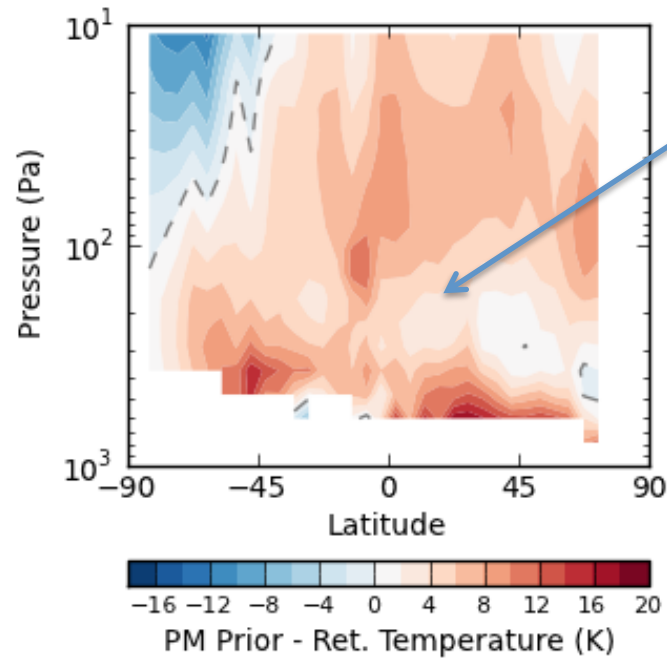
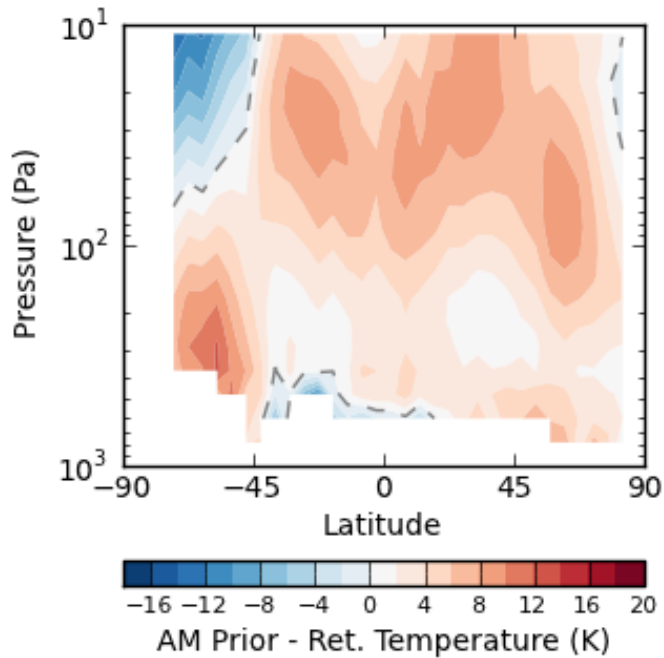
# Result of dust peak:





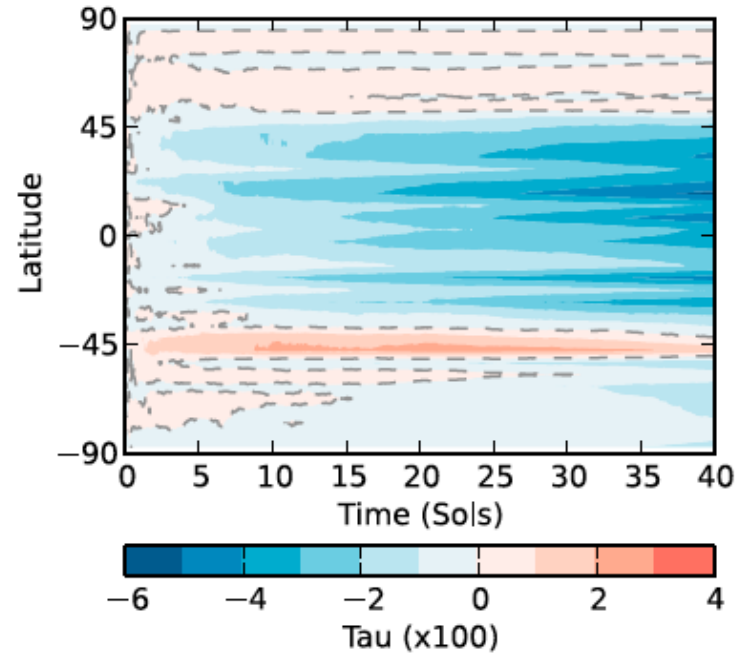
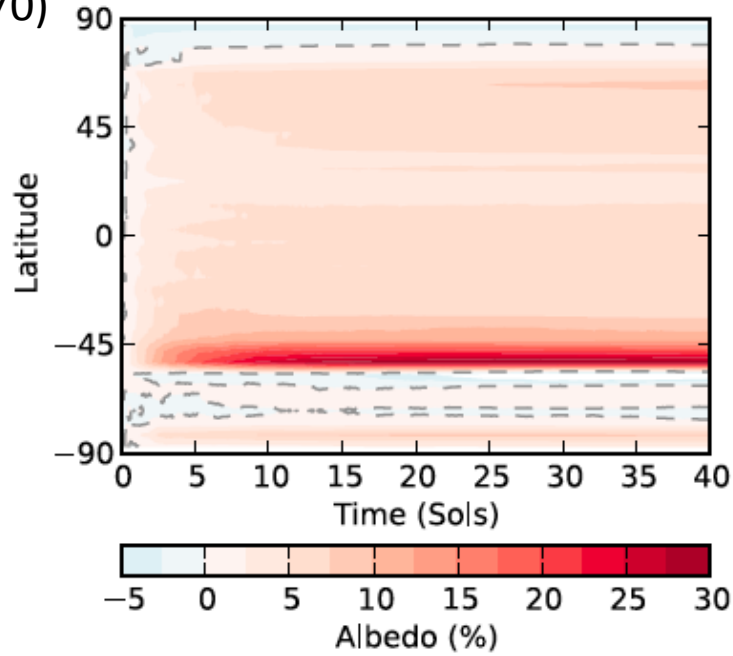
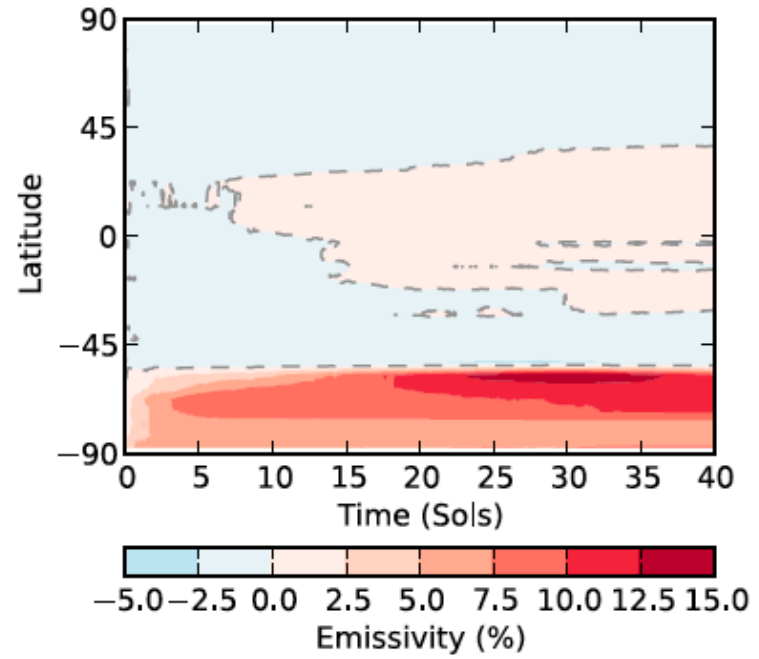
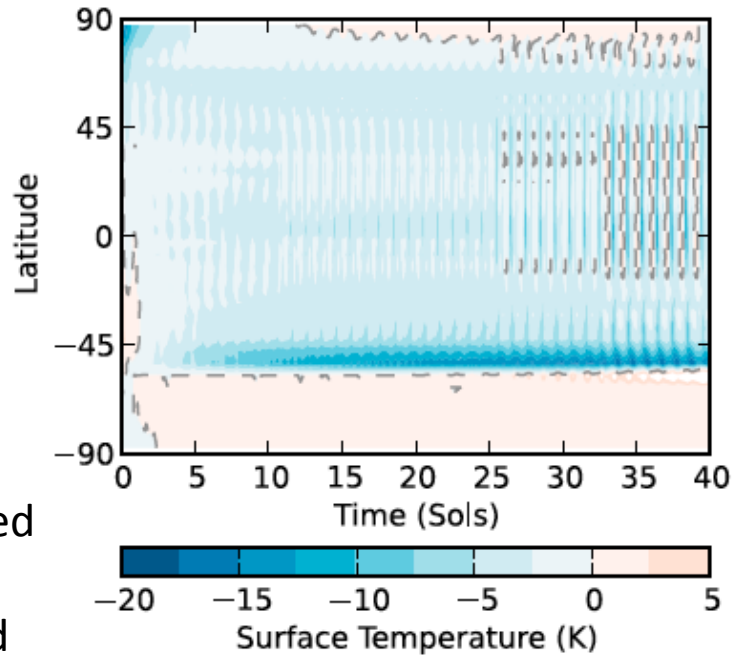
**Assimilation  
with MCS-like  
dust  
distribution**

Much better but  
still too warm  
(dust optical  
properties)

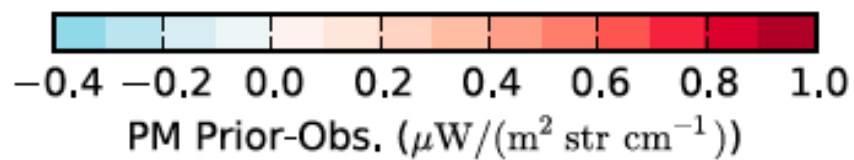
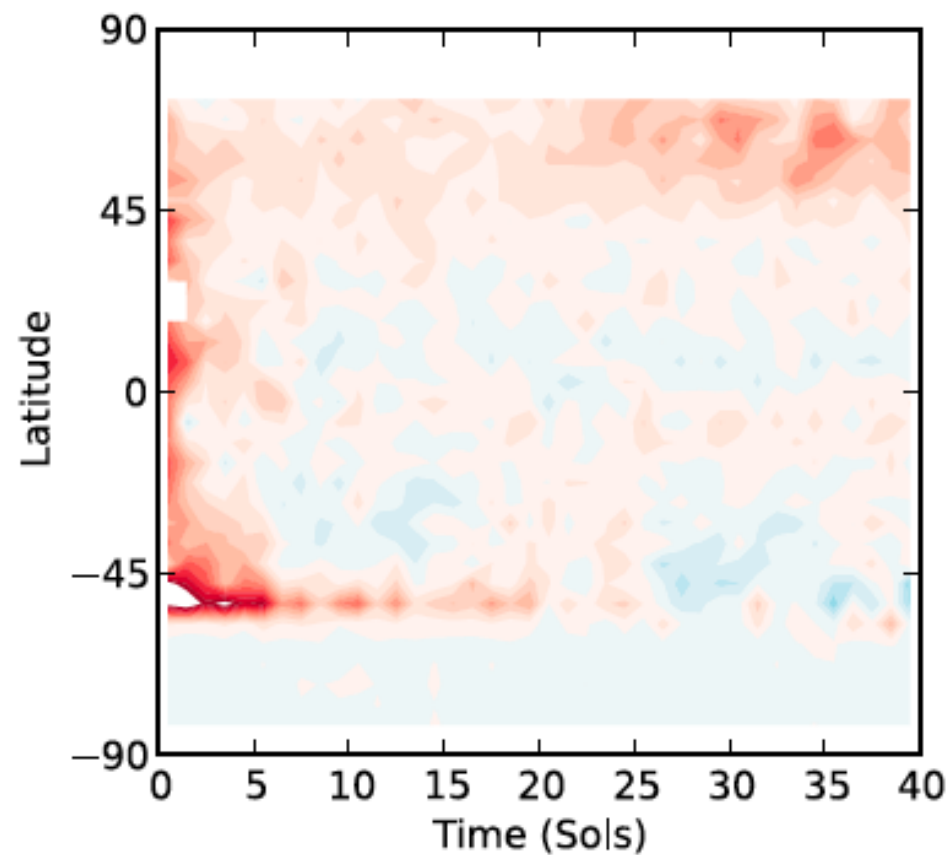
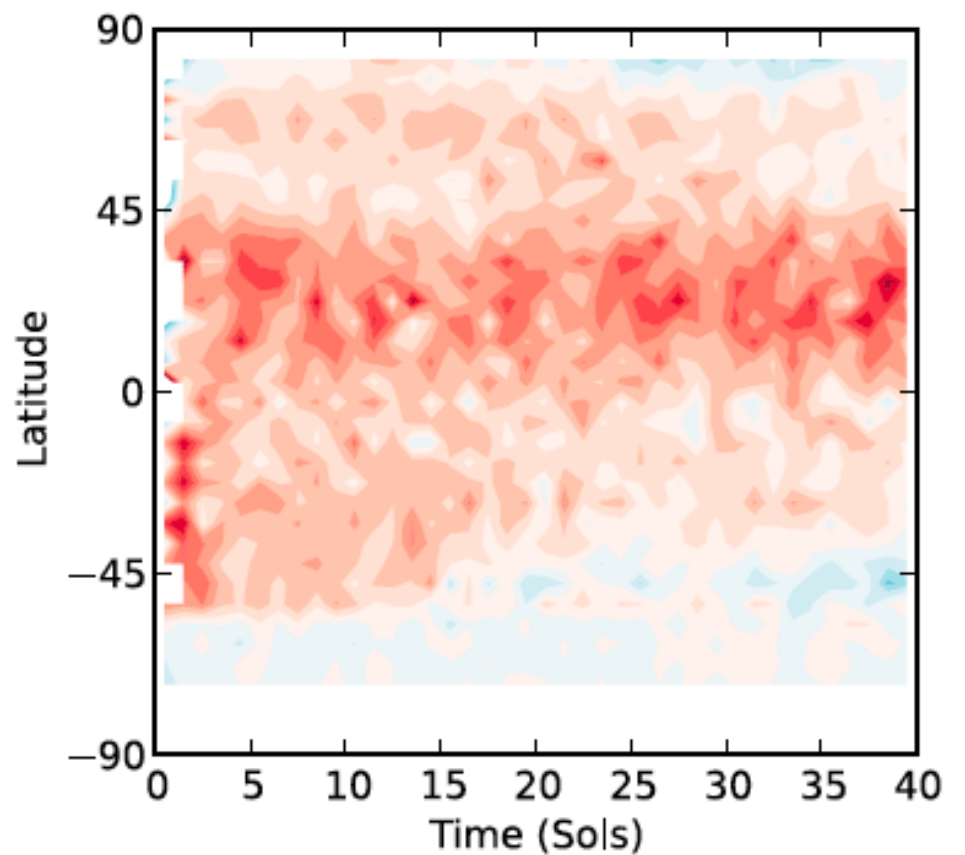


Ls=150

Assimilated  
minus  
standard  
model  
(Ls=150-170)



# Ground Temperature Errors



# Where We Stand with DA for Mars

- Several DA systems now working
  - Open University / Oxford; Maryland; as well as our (Ashima/NCAR) Mars DART system
- Model biases mean “reanalysis” creation not yet viable (not useful)
- DA provides a very powerful tool for isolating and correcting errors / omissions in “physics”
  - a crucial aspect of data analysis in itself
- With effort put into the instrument forward models, DA can provide a much more convenient way of using a whole range of spacecraft data to test dynamical models

# DART for Mars

- DART – ensemble DA framework
- Can drive (pretty much) any model
  - Needs access to ‘namelist’ and output/restart files
- Includes TES forward radiance model
- Can ingest “retrieved” data from any instrument
- Hope to include MCS and TES forward limb radiance models in the near future
- Completely open source

[www.marsclimatecenter.com](http://www.marsclimatecenter.com)

**Can download:**

- MarsWRF GCM,
- DART system including TES forward model,
- other random goodies (like full MGS MOC WA color daily global maps)

**Demonstration of ensemble data assimilation for Mars using DART, MarsWRF, and radiance observations from MGS TES**

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[1] We describe a global atmospheric data assimilation scheme that has been adapted for use with a Martian General Circulation Model (GCM), with the ultimate goal of creating globally and temporally interpolated “reanalysis” data sets from planetary atmospheric observations. The system uses the Data Assimilation Research Testbed (DART) software to apply an Ensemble Kalman Filter (EnKF) to the MarsWRF GCM. Specific application to Mars also required the development of a radiance forward model for near-nadir Thermal Emission Spectrometer (TES) observations. Preliminary results from an

radiance data, taken around  $L_s = 150^\circ$  (August 1999, Mars Global Surveyor TES observations are ingested and used to improve the model with bias and error reductions obtained throughout the assimilation suggest steepening of the latitudinal and vertical zonal wind profiles and strengthening of the mid-latitude zonal jets, and a more defined northern polar ice edge than predicted by the unaided GCM. The best model are highlighted by the presence of an atmospheric dust layer. These results suggest the prescribed dust vertical profile might not be in accordance with more recent observations of the vertical structure from the Mars Climate Sounder. The tools developed using this DA system are available at [www.marsclimatecenter.com](http://www.marsclimatecenter.com). A tutorial and example TES radiance data are provided.

Lee, C., I. Richardson, J. L. Anderson, N. Collins, T. Hoar, and M. Mischna (2011), Demonstration of ensemble data assimilation for Mars using DART, MarsWRF, and radiance observations from MGS TES, *J. Geophys. Res.*, 116, E11011, doi:10.1029/2011JE003815.

the context of climate modeling and weather forecasting, this work, Hoffman et al. [2010b], and Moulden et al. [2010].

[3] In order to ingest observations into a GCM, a method that allows us to objectively compare model predictions with observations while accounting for error in both processes. One such method is