Tracer transport in the Martian atmosphere

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Part I: Argon transport

Motivation

1. Argon (Ar) is an inert gas. Its mixing ration is only modified by CO_2 cycle, large-scale and eddy transport. Therefore It provides a measurement of quality of tracer transport in the GCM models.
2. Current Mars GCMs generally under predict the observed Ar enhancement by factor of two during southern winter over the winter pole.
3. Dynamical cores and advection schemes may affect the tracer transport.
4. Physics parameterization of radiative transfer influences the dynamics and consequently the tracer advection.
5. Improving the GCM representation of the spatial and temporal argon distribution will benefit other transport problems, such as water, dust and methane.

Method

1. Develop AR/MIT Mars GCM using the MITgcm finite volume dynamical core and MarsWRF physics. The AR/MIT GCM is also capable of simulating dynamics on Titan and gas giant planets.
2. Use cube-sphere grid to better resolve the polar dynamics without introducing excessive numerical diffusion normally associated with the polar filter in traditional longitude-latitude grids.
3. Compare tracer transport using variety of multi-dimensional temperature and tracer advection schemes.
4. Compare the impact of radiative transfer schemes, including a speedy wide-band model and a slow but more realistic k-distribution method.

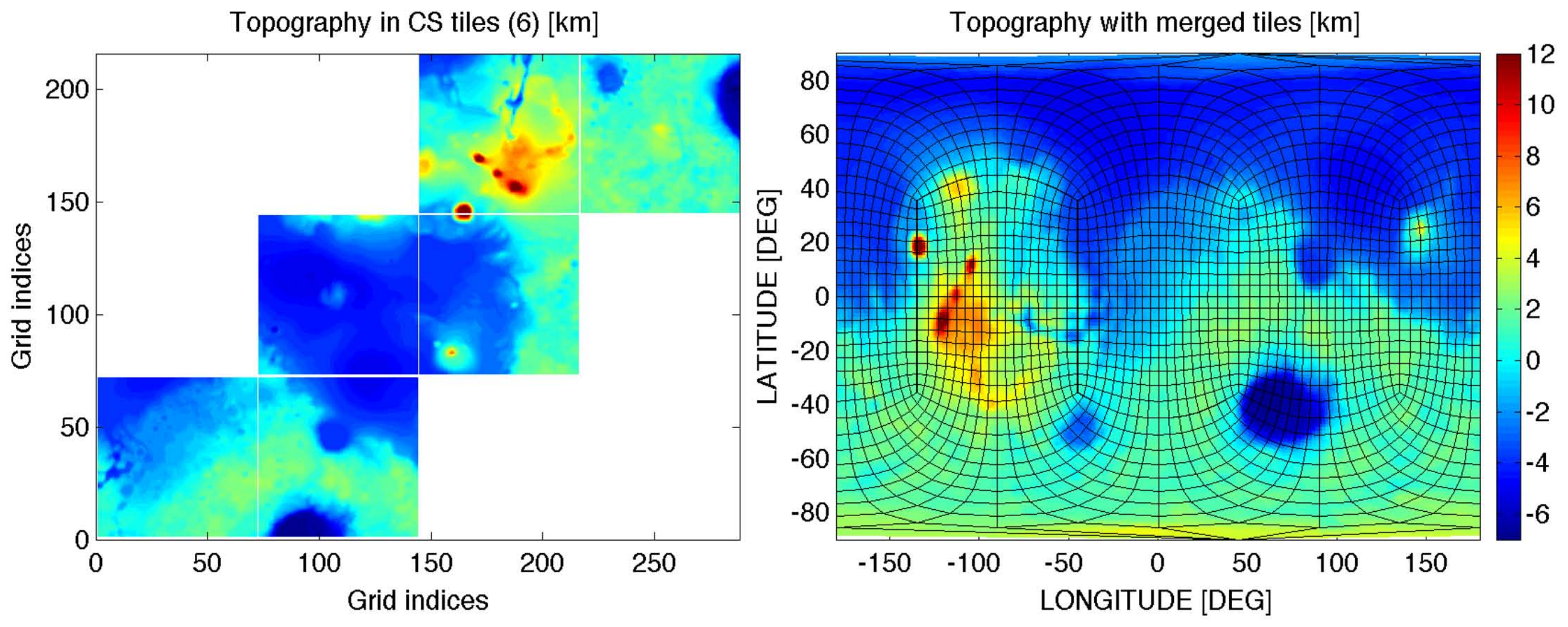

Figure 1. Mars MOLA topography in cube-sphere grid. The nominal horizontal resolution is C18, equivalent to 5° in longitude-latitude grid.

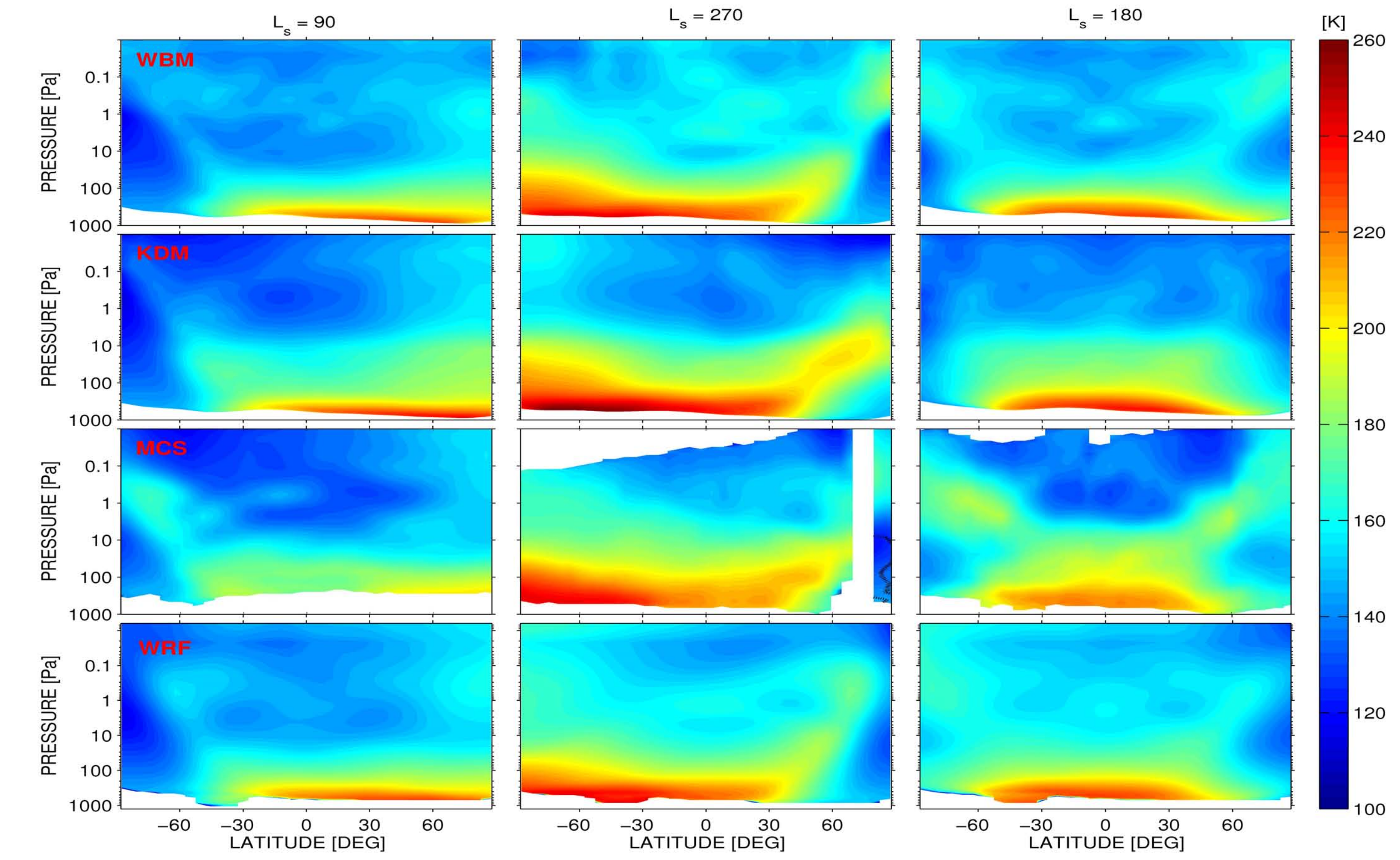

Figure 2. Comparison of zonal mean temperature between AR/MIT Mars GCM and MCS observations. The MarsWRF model result is also shown (the bottom row).

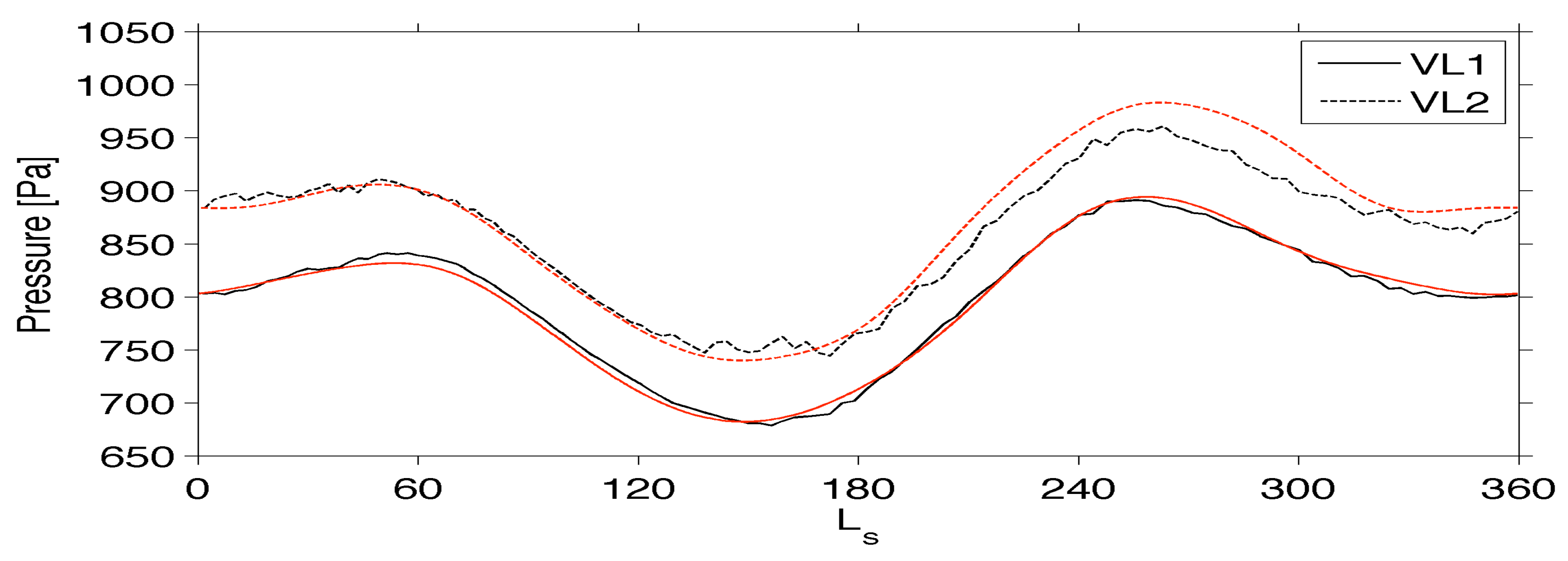

Figure 3. Annual CO_2 cycle at the Viking Lander 1 and 2 sites. Red lines are modeled CO_2 cycle.

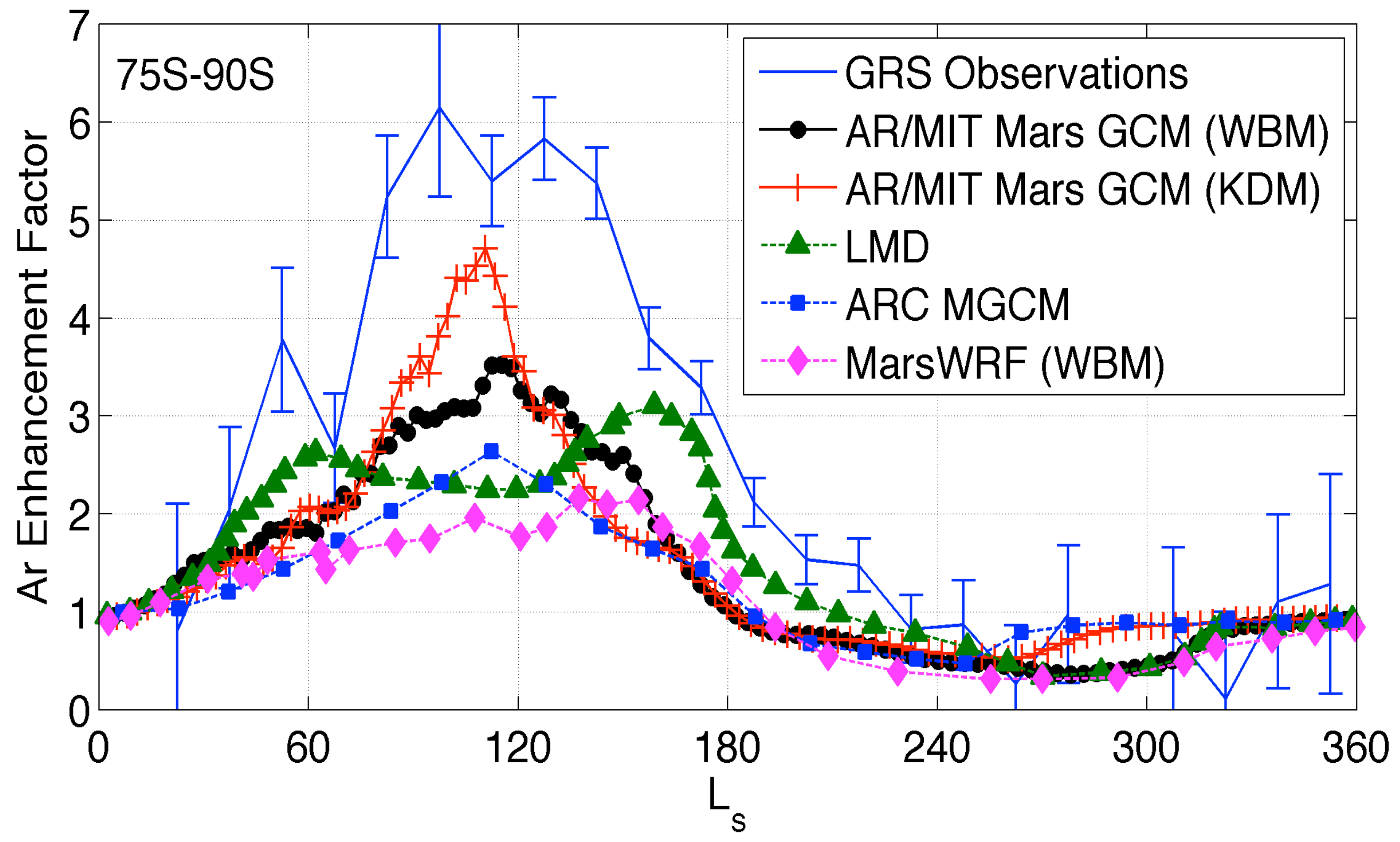

Figure 4. Inter-model comparison of polar Ar enhancement factor over the southern winter pole. "WBM" and "KDM" mean wide-band and k-distribution radiative transfer models respectively. All GCM results are scaled to the modeled Ar mixing ratio at VL2 site following the definition of Ar enhancement factor given by Sprague et al. (2007).

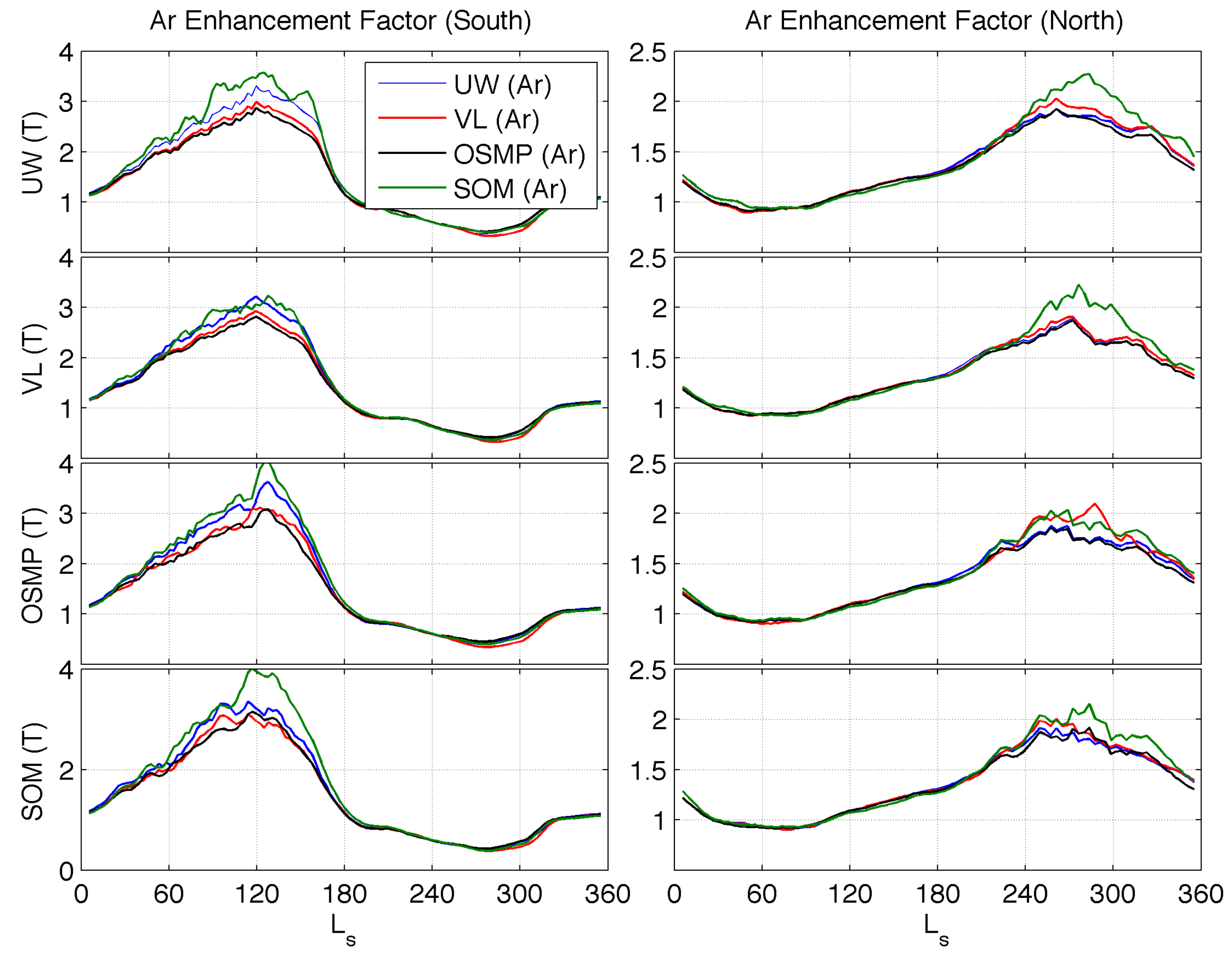

Figure 5. Comparison of polar Ar enhancement among all the temperature and tracer advection schemes used in the WBM simulations. The rows from top down are simulations using different temperature advection schemes. The colors are simulations with different tracer advection schemes. UW is 3rd order upwind scheme, VL is 2nd order Van Leer scheme, OSMP is 7th order one-step monotonicity preserving scheme, SOM is second-order-moment scheme. We find the combination of SOM temperature and tracer advection schemes produces the most satisfactory results.

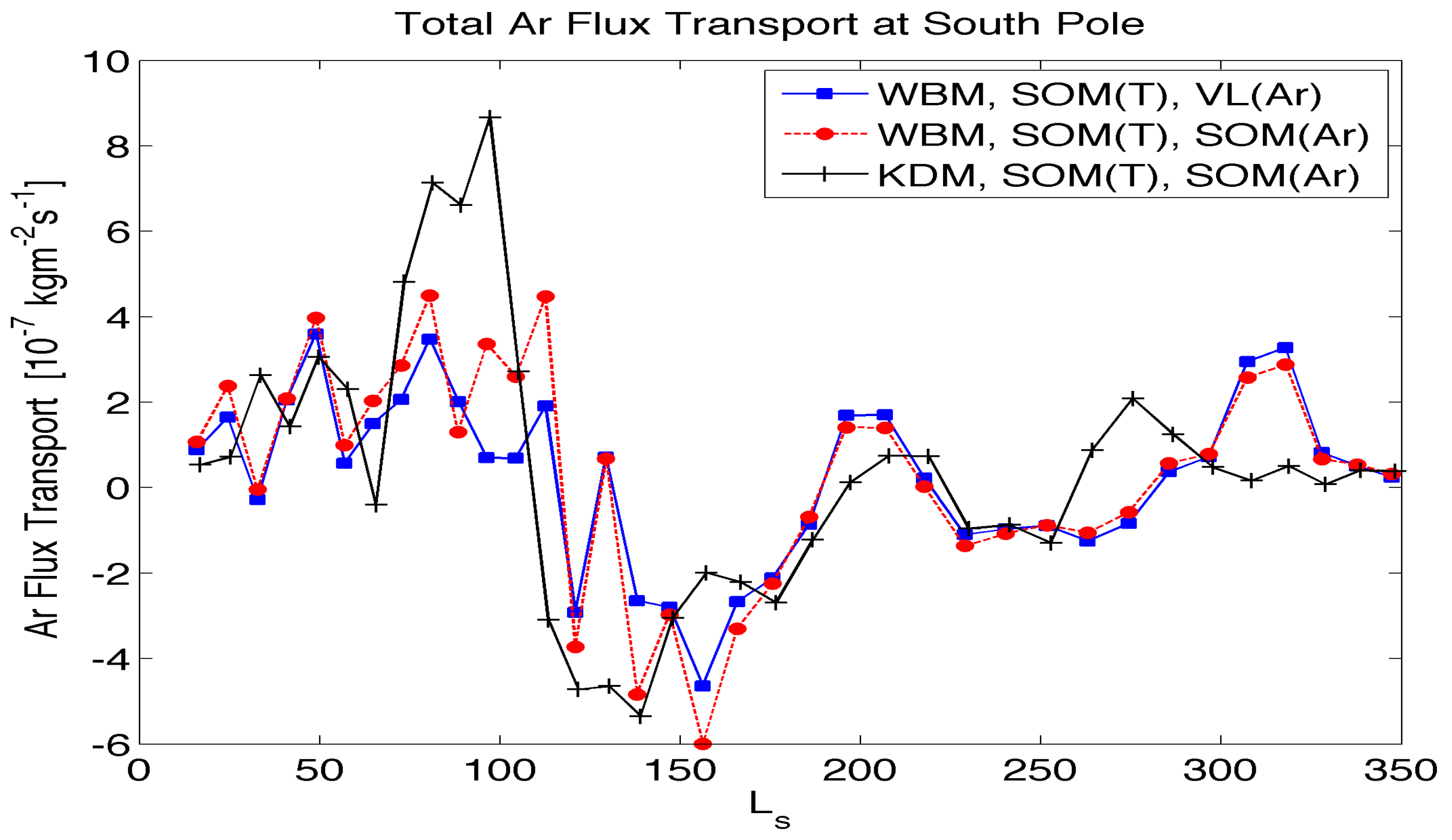

Figure 6. Total Ar mass flux at 75°S-90°S. Similar to Nelli et al. (2007)'s results, the mean meridional transport is responsible for the inflow and eddy transport is responsible for the outflow of Ar respectively. The eddy mixing of Ar reaches its peak during late southern winter.

Conclusion

1. The AR/MIT Mars GCM reproduces the observed zonal mean temperature and CO_2 cycle closely. Its finite volume dynamical core performs better than other grid-point models (i.e., MarsWRF) in tracer transport related problems.
2. Temperature and tracer advection schemes and radiative transfer schemes have significant impact on tracer transport.
3. Using the KDM radiative transfer, SOM temperature and tracer advection schemes, we are able to produce Ar enhancement factor larger than those from the existing Mars GCMs, but still under predict the observed value significantly.
4. Better polar confinement of Ar may be achieved by improving the physics parameterization, i.e., a detailed CO_2 microphysics and a better dust distribution. We will also explore the impact of grid resolution.

Part II: Water cycle

Motivation

1. Viking Orbiter MAWD, MGS TES and MRO CRISM have all observed water vapor in the Martian atmosphere. However, the relative importance of the northern polar cap, seasonal ice caps in both hemispheres, and the regolith as sources and/or sinks has not been determined and likely cannot be directly from the data alone.
2. Recent MCS observations provide quantified spatial and temporal distribution of water clouds. Reproducing the observed clouds helps to understand the pole-to-pole water transport and their radiative feedback.

Method

1. Introduce a simple water cycle to reproduce the temporal and spatial water vapor and ice distribution. This water cycle includes condensation, sublimation and sedimentation.
2. Use a simple regolith scheme to investigate how the exchange of water content between the atmosphere and the soil affects the spatial distribution of water vapor.

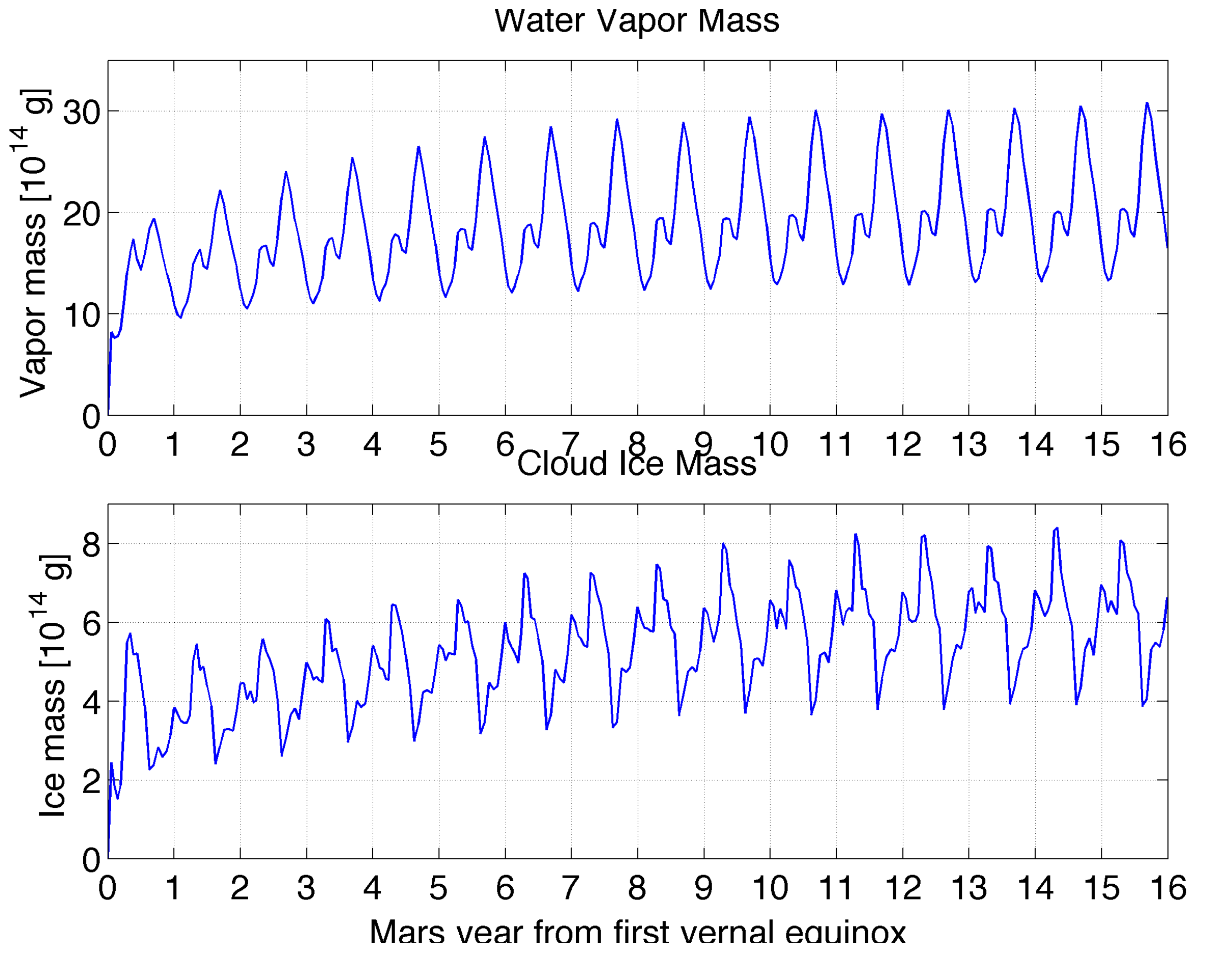

Figure 7. Water vapor mass and cloud ice mass in the Martian atmosphere without regolith exchange. The vapor and ice masses become equilibrated after 8 Martian years.

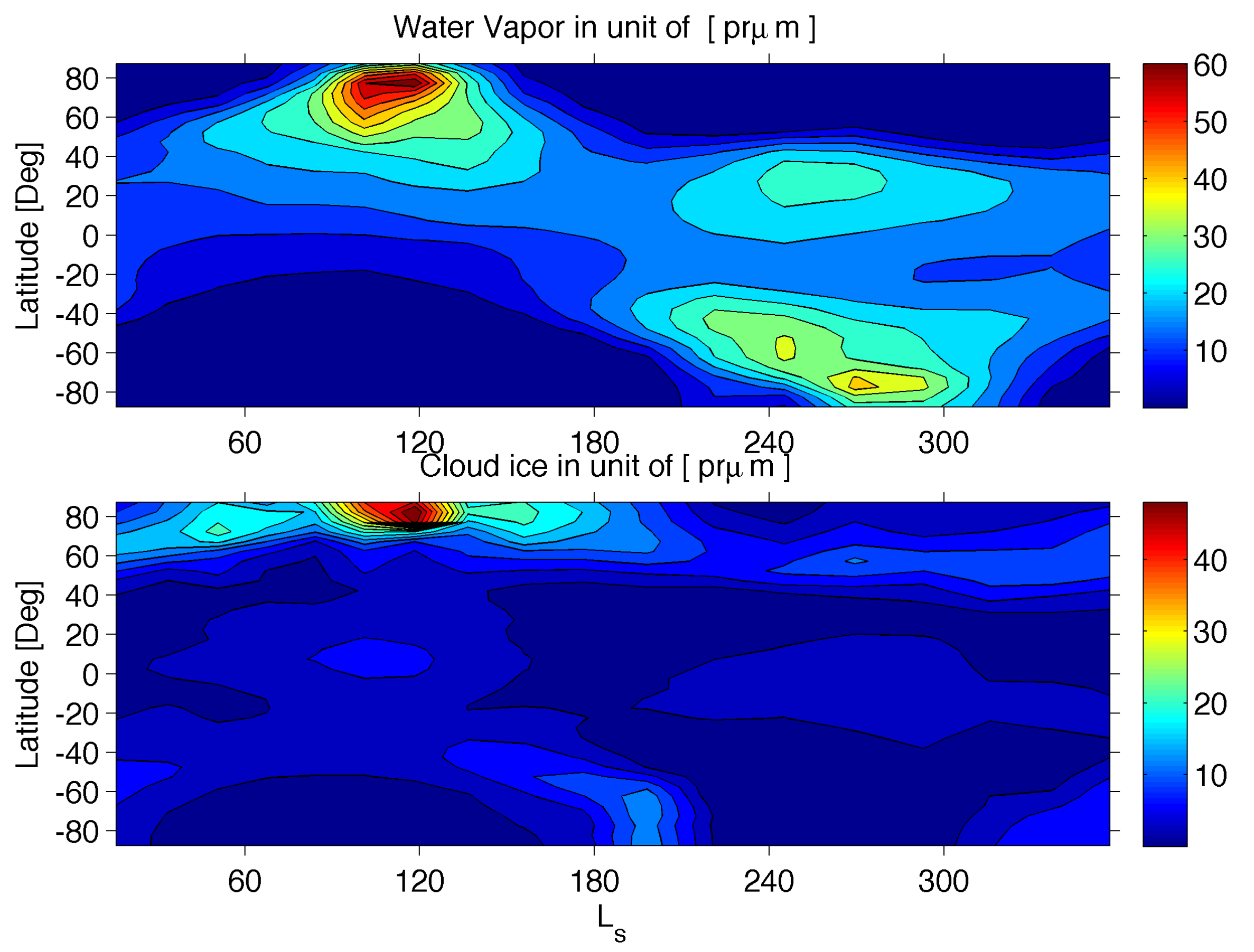

Figure 8. Temporal and spatial distribution of water vapor and cloud ice during a Martian year. The water vapor abundance at southern high latitudes during southern summer is higher than the observed.

Conclusion

1. We are able to reproduce the observed patterns of annual water cycle. Note we used a speedy 2nd order center advection scheme for these initial tests.
2. The temporal and spatial distribution of water vapor are similar to those of Richardson and Wilson (2002). Both GCMs produce water vapor mass higher than the observed, suggesting a surface sink of water content.
3. Besides adding the regolith-atmosphere exchange of water vapor, we will repeat the sensitivity studies of temperature and tracer advection schemes as we did for the Ar transport.