

Stratosphere and Troposphere Exchange using Chemical Tracers: A Comparative Study between Earth and Jupiter

Yuk L. Yung¹, Xun Jiang¹, Yuan-Tie Lee¹, Run-Li Shia¹, and Timothy E. Dowling²

¹ Department of Geology and Planetary Sciences, California Institute of Technology

² Department of Mechanical Engineering, University of Louisville

Abstract

We apply a novel technique for extracting the 2-D mass streamfunction from 3-D winds computed by a general circulation model (GCM). The advantages of the GCM-derived advection over that derived from diabatic heating rates are twofold (Jiang *et al.*, 2004). First, it unifies the tropospheric transport (the Hadley circulation) and the stratospheric transport (the Brewer-Dobson circulation). Second, it has the realism of a full GCM. For the Earth's atmosphere, we use winds from the National Center for Climate Prediction (NCEP). The Jupiter winds are taken from simulations obtained by the Comparative Planetology Laboratory at the University of Louisville. The chemical tracers used were N₂O and C₂H₆ for the terrestrial and Jovian atmospheres, respectively.

1. Stream Function

Stream Function on the Earth

NCEP/DOE Reanalysis II 4-times daily spectral coefficients are used to calculate the monthly mean meridional circulations, using the method of Johnson (1989). On the pressure surface, the 3-D meridional mass flux is calculated by the vertical integral of the 3-D meridional wind. Then we interpolate the 3-D meridional mass flux to isentropic surfaces, using a mass-conserving linear interpolation scheme. The 2-D isentropic mass stream function is derived by zonal averaging of the 3-D isentropic meridional mass flux along isentropes. Finally, we interpolate the 2-D isentropic mass stream function to the pressure coordinates to produce the pressure surface stream function so that it can be used to drive the 2-D chemistry and transport model.

Figure 1 shows the 2-D pressure stream function in the stratosphere in January, April, July and October of 1985. The seasonal variation is captured well by this stream function. The hemispheric asymmetry of the circulation verifies that the wave activity in the NH stratosphere is stronger than that in the SH.

Stream Function on the Jupiter

West *et al.* (1992) included the radiative heating by polar aerosols in their circulation model. They adopted the atmospheric aerosol distribution from the International Ultraviolet Explorer (IUE) observations.

An isentropic mass stream function was calculated using the meridional wind on the Jupiter. The Jupiter winds were taken from simulations obtained by an isentropic atmospheric model (Dowling *et al.*, 1998). Then the isentropic mass stream function was interpolated back to pressure surfaces. We merged the 2-D stream function in the lower atmosphere derived from the isentropic model (Dowling *et al.*, 1998) with that in the upper atmosphere (West *et al.*, 1992). The merged stream function, shown in figure 2 and figure 3, was used to drive the 2-D Caltech/JPL chemistry and transport model.

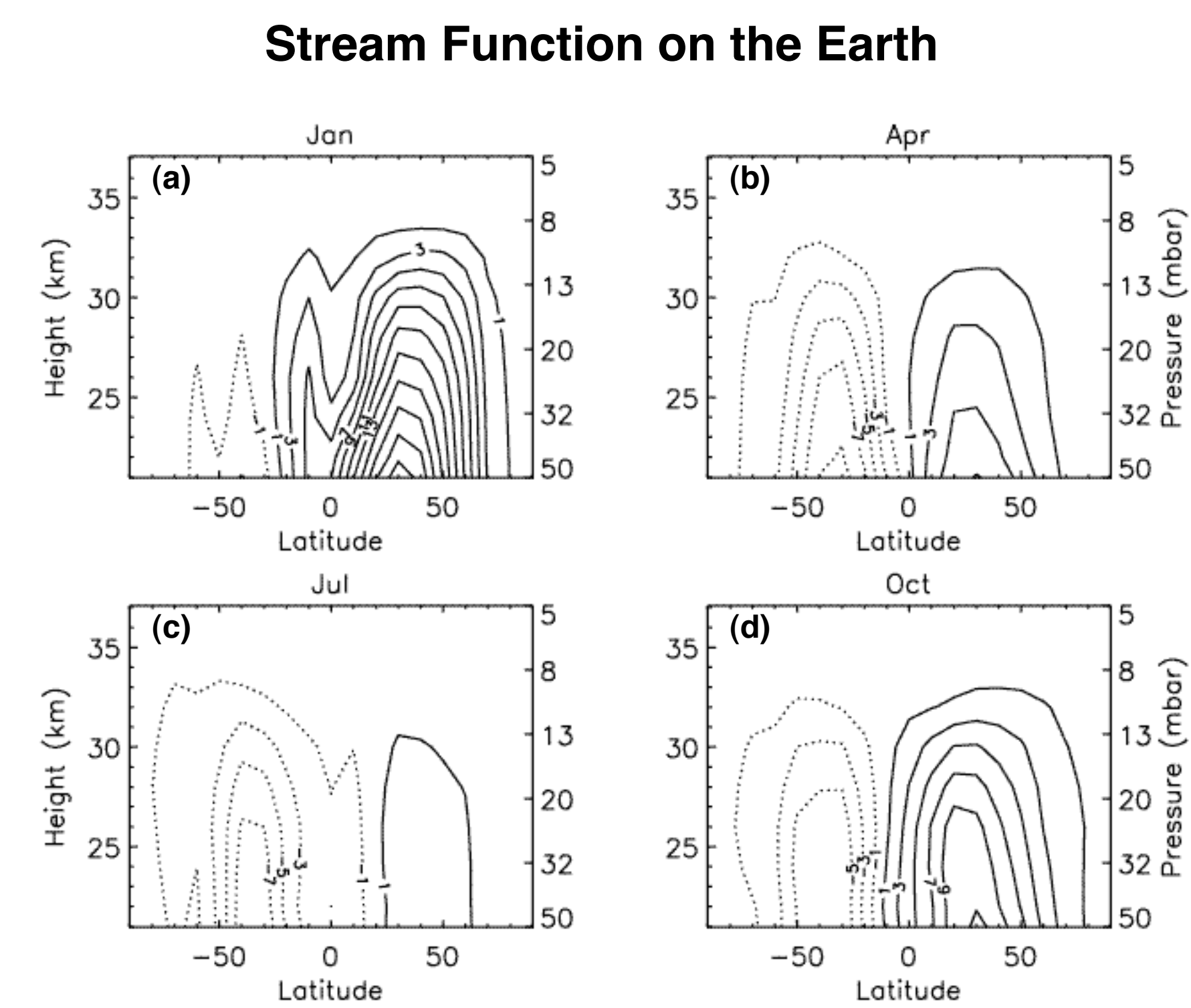


Figure 1: Stratospheric stream function on the pressure surfaces in 1985. (a) January, (b) April, (c) July, and (d) October. Units are $10^6 \text{ cm}^2/\text{s}$.

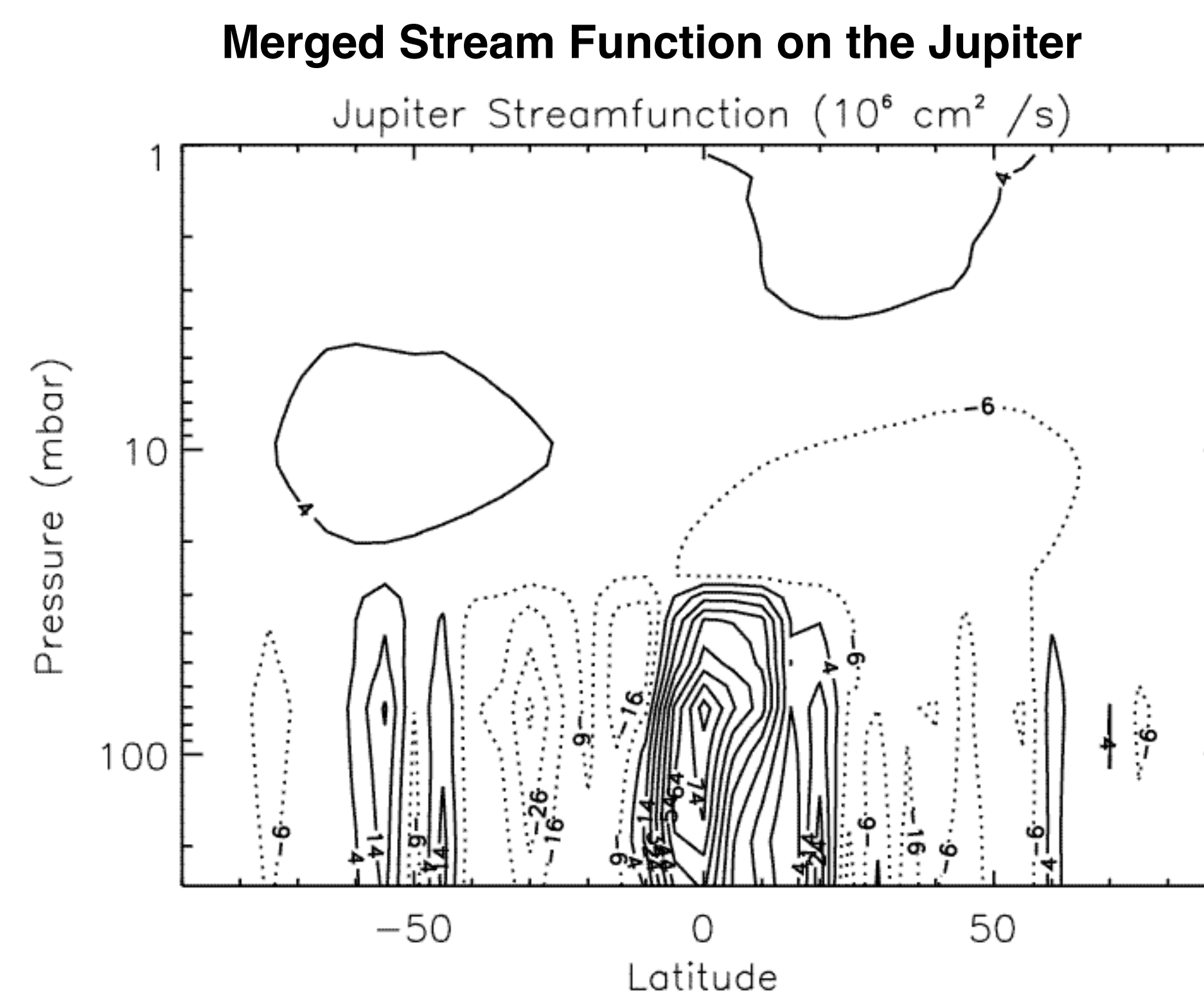


Figure 2: Merged stream function using the stream function from West *et al.* (1992) in the upper atmosphere and the stream function derived from Dowling *et al.* (1998) in the lower atmosphere.

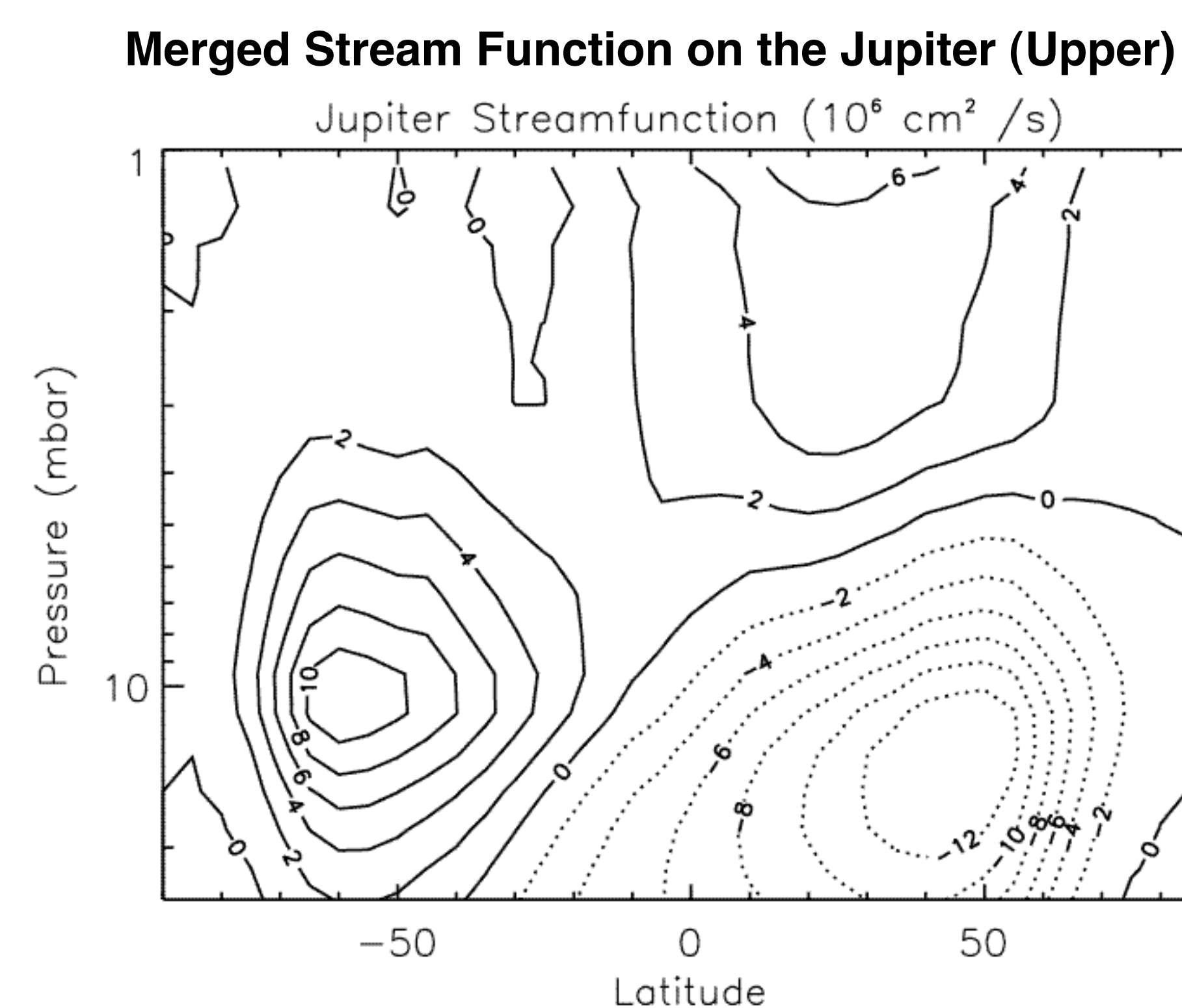


Figure 3: Merged stream function in the upper atmosphere.

2. C₂H₆ Model Results (Jupiter)

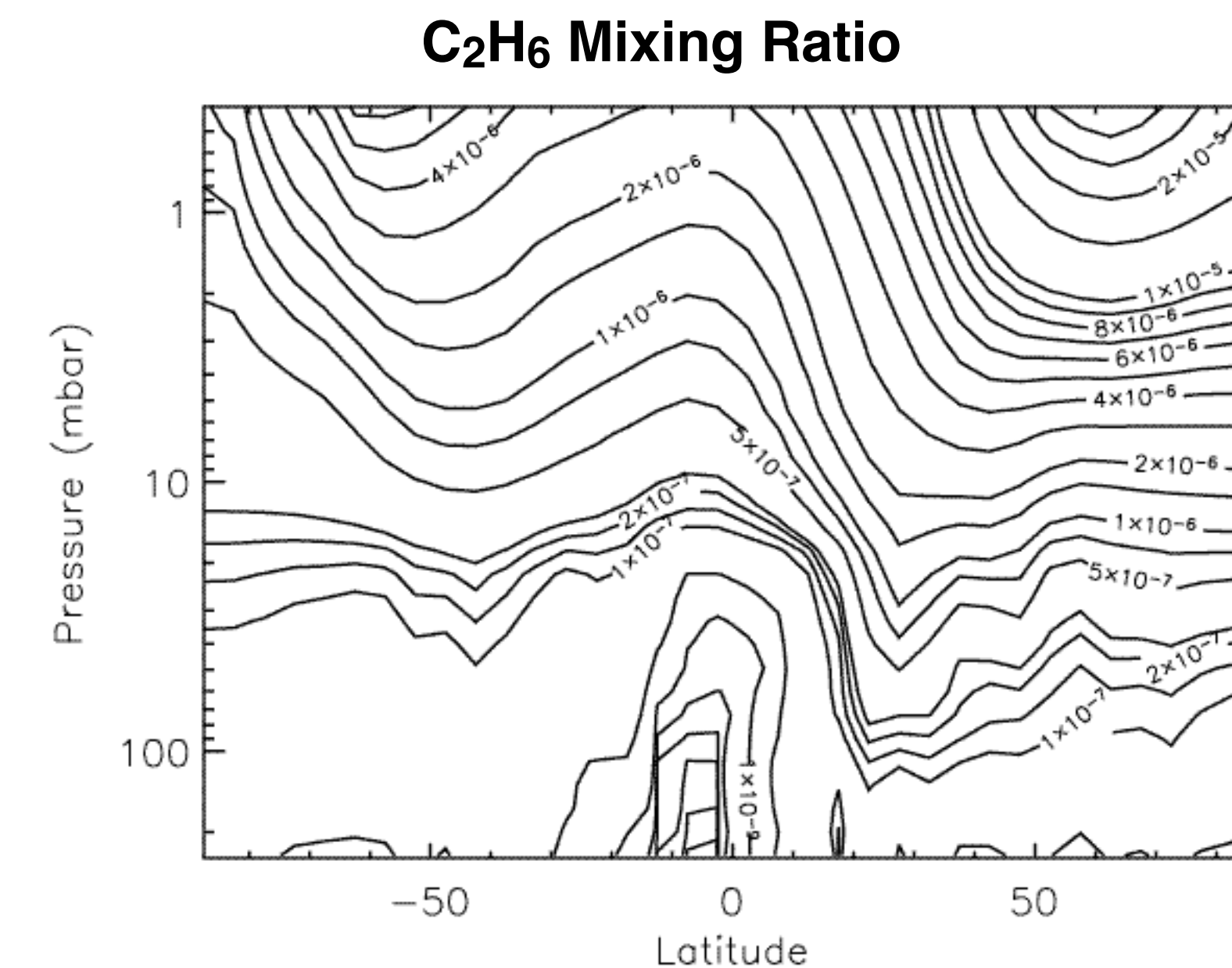


Figure 4: Mixing ratio of C₂H₆ as a function of altitude and latitude in January computed by the 2-D chemistry and transport model of Jupiter.

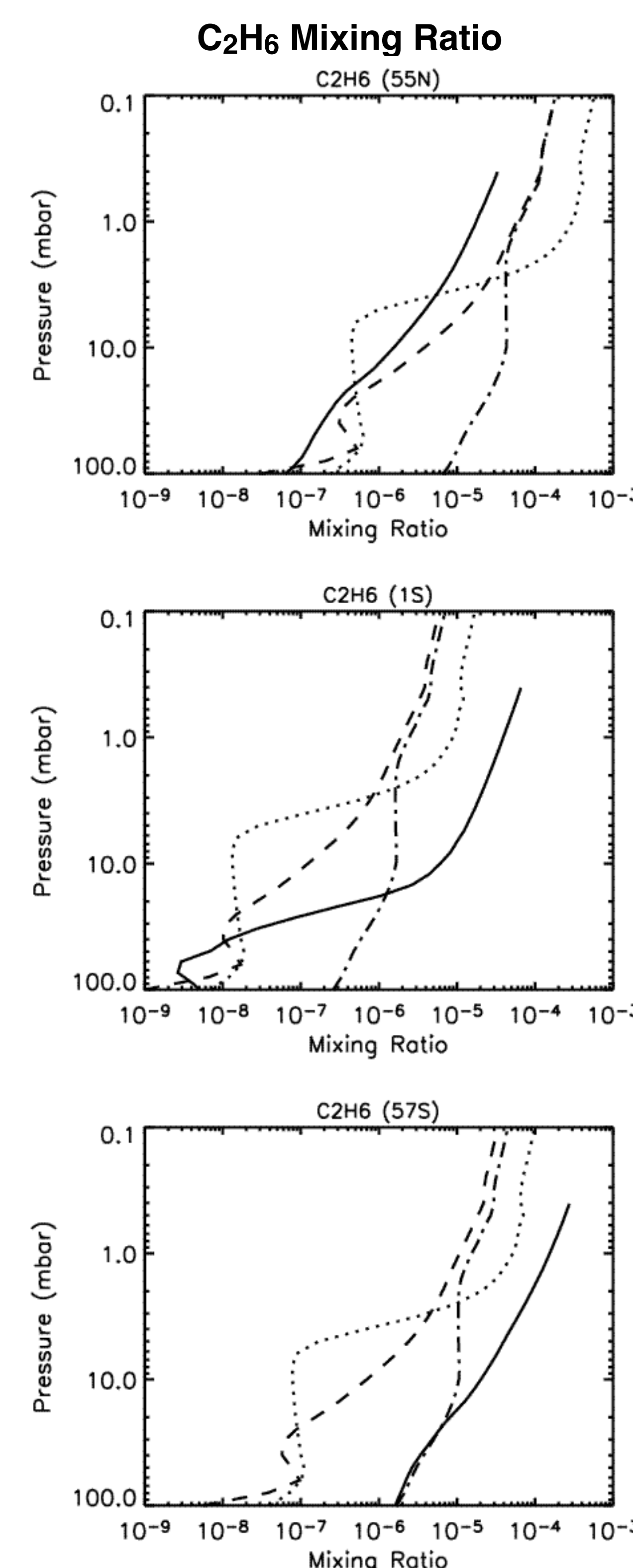


Figure 5: C₂H₆ vertical mixing ratio profiles at 55° N, 1° S, and 57° S. The dashed line, dotted line, and dash-dot lines in the panels agree with the infrared observation at the specific latitude (Orton *et al.*, 1989). The thick line in each panel represents our model results at the specific location.

3. N₂O Model Results (Earth)

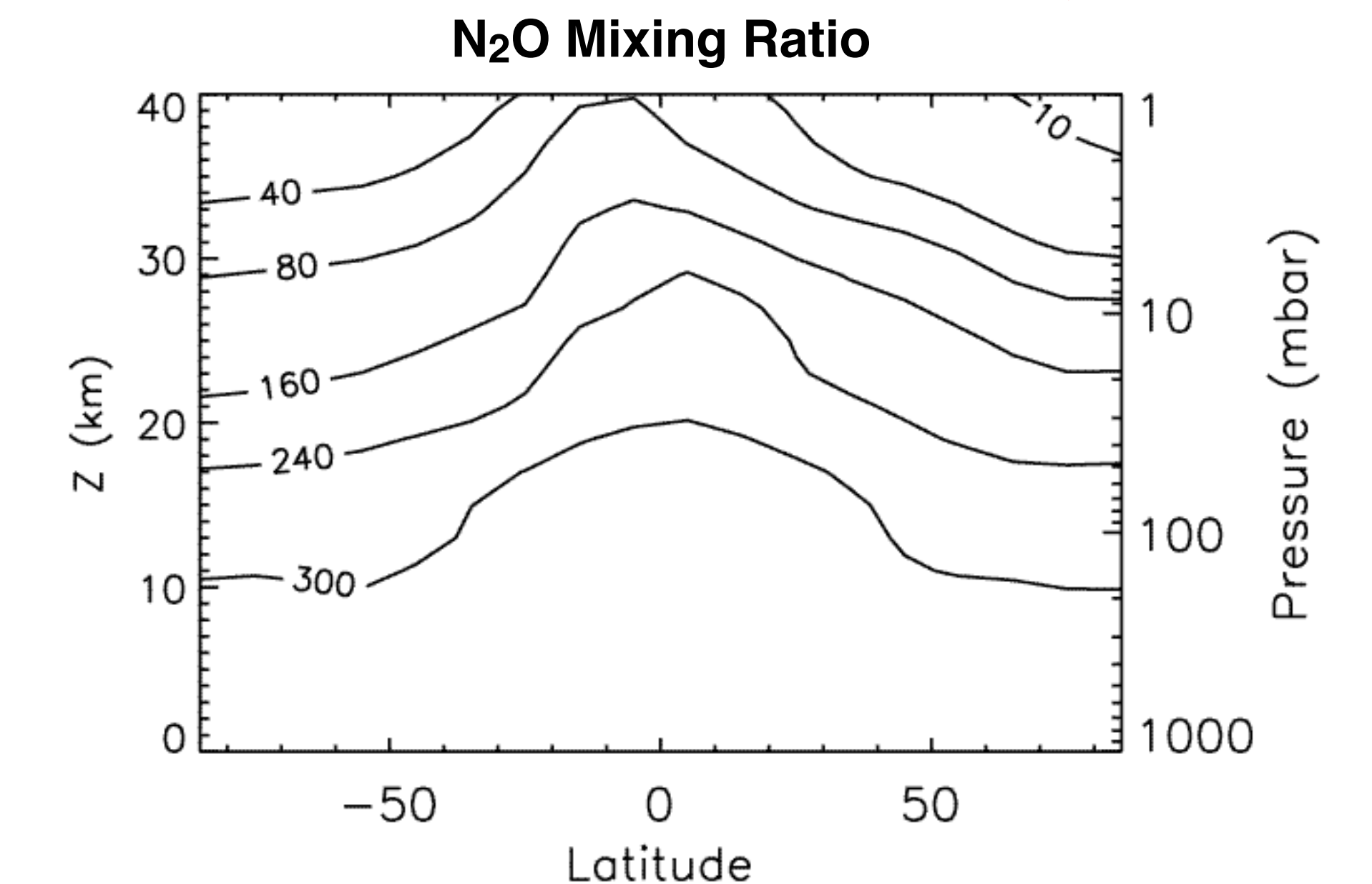


Figure 6: Mixing ratio of N₂O in ppbv as a function of altitude and latitude in January computed by the standard model of Morgan *et al.* (2004).

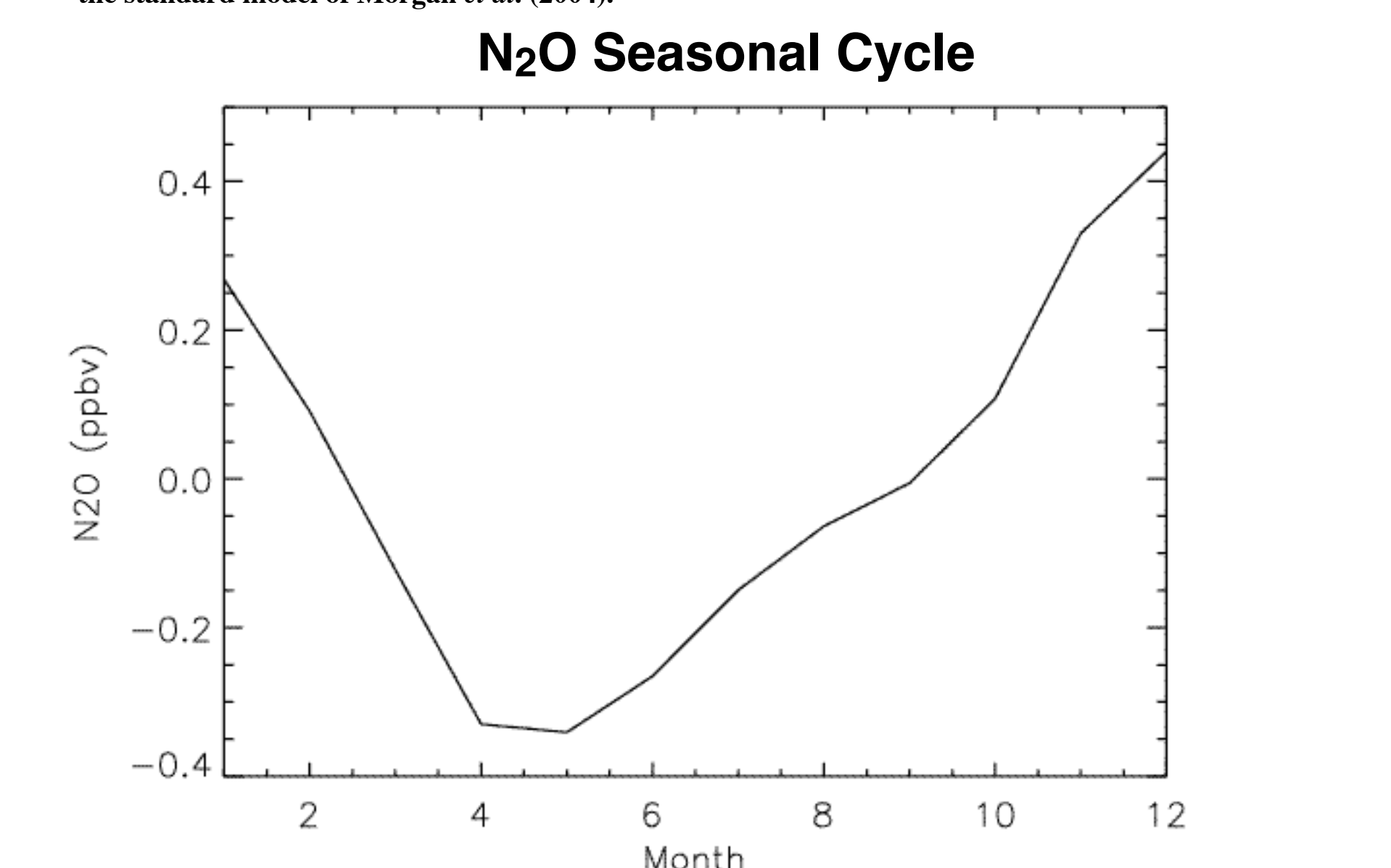


Figure 7: Model simulation of the seasonal variation of N₂O at the surface in the Northern Hemisphere caused by the exchange of air between the stratosphere and the troposphere. The model used is the standard model of Morgan *et al.* (2004).

Conclusions

1. The stratospheres of Jupiter and the Earth are similar in having a strong thermal inversion, caused by the presence of hydrocarbon aerosols and ozone, respectively. The study of chemical tracers provides insight into the transport processes in the middle atmospheres of these planets.
2. For Jupiter, we have successfully merged the 2-D stream function in the lower atmosphere derived from a GCM (Dowling *et al.*, 1998) with that in the upper atmosphere (West *et al.*, 1992).
3. The concentration of C₂H₆ in the atmosphere of Jupiter is sensitive to transport. Measurements of trace species may be used to validate the transport used in the model.
4. Similar type of 2-D modeling has been applied to N₂O in the terrestrial atmosphere (Morgan *et al.*, 2004). Downwelling of N₂O-poor air in the boreal spring produces a minimum in N₂O concentration that may be detectable.

References

1. Dowling, T. E., *et al.*, The Explicit Planetary Isentropic-Coordinate (EPIC) Atmospheric Model, *ICARUS*, 132, 221-238, 1998.
2. Jiang, X., *et al.*, QBO and QBO-annual Beat in the Tropical Total Column Ozone: A Two-dimensional Model Simulation, *J Geophys. Res.*, submitted, 2003. Paper available from website [http://lyly-mac.gps.caltech.edu/Ozone Paper/Jiang_QBO_03.doc](http://lyly-mac.gps.caltech.edu/Ozone%20Paper/Jiang_QBO_03.doc).
3. Johnson, D. R., The forcing and maintenance of global monsoonal circulations - An isentropic analysis, *Adv. Geophys.*, 31, 43-316 1989.
4. Morgan, C. G., *et al.*, Isotopic fractionation of nitrous oxide in the stratosphere: Comparison between model and observations, *J Geophys. Res.*, in press, 2004. Preprint available from website [http://lyly-mac.gps.caltech.edu/under "N₂O_JGR"](http://lyly-mac.gps.caltech.edu/under%20N2O_JGR).
5. Orton, G. S., *et al.*, An exploratory 5-MUM spectrum of URANUS, *ICARUS*, 77, 109-117, 1989.
6. West, R. A., *et al.*, Jovian large-scale stratospheric circulation, *ICARUS*, 100, 245-259, 1992.