EPSC Abstracts
Vol. 6, EPSC-DPS2011-166, 2011
EPSC-DPS Joint Meeting 2011

Non-local deep transport in terrestrial planetary atmospheres: Earth, Mars, Venus, and Titan

S. Rafkin
Southwest Research Institute, Colorado, USA (Rafkin@boulder.swri.edu

Abstract

Non-local deep transport (NLDT) is accomplished through coherent and vertically extensive circulations, and provides for both up- and down-gradient transport that, unlike diffusion, does not fundamentally depend on the local gradient. One of the most important aspects of NLDT is its ability to produce local maxima of various quantities in the absence of a local source, and it is this characteristic that makes it "non-local". NLDT likely plays an important role in the dynamics, energetics, and chemistry of the atmosphere of Mars, much as it does for Earth. It may also be of importance in the energy and hydrological cycle on Titan and in the energy, momentum, and chemical cycles on Venus. Below, the known impact of NLDT on Earth is discussed, followed by a discussion of how NLDT may operate in the atmospheres of Mars, Venus, and Titan.

1. Earth

The best known example of NLDT on Earth is that of "hot towers" first described by [1] to explain the upper tropospheric maximum of moisture and enthalpy (a.k.a. moist static energy) in the Earth's tropical atmosphere and a corresponding moist static energy minimum in the mid-troposphere. It is the rapid and deep transport through updraft cores of tropical thunderstorms that provide the mechanism by which the upper tropospheric maximum is produced and maintained. Clouds in the tropical atmosphere do the work of vertical transporting energy, moisture, momentum, and chemical species before it is transported in the poleward branch of the Hadley Cell.

These storms occupy only a small fraction of the total area of the tropics. The non-cloud environment occupies most of the tropics and it is within this broad area where compensating subsidence produces adiabatic warming, which is primarily how the sensible heat within the small fractional area of clouds is communicated to the rest of the tropical atmosphere. It is the net difference between the narrow but strong updrafts of convection and the weaker convective downdrafts and compensating subsidence that results in the rising branch of the Hadley Cell. The rising branch of the Hadley Cell, therefore, is a mathematical construct and not a physical circulation. It follows then, that vertical advection is performed by actual physical circulations: either within clouds or in the surrounding subsidence.

The mechanism of transport is more than academic. There are important and pronounced effects of NLDT through clouds. GCM simulations without deep convective clouds display a weaker Hadley Cell, weaker trade winds, and eddy kinetic energy of the circulation in discord with observations [2]. Additional studies have shown that neglecting the rapid and deep transport of mass, momentum, and energy by tropical thunderstorms leads to a grossly inaccurate representation of the hydrologic cycle [3].

2. Mars

Elevated and detached haze layers have been observed on Mars for decades [4][5]. Thermal Emission Spectrometer limb dust retrievals also show elevated dust layers, and elevated dust layers have now been observed by the Mars Climate Sounder [6]. Despite the elevated layers of dust and water on Mars, the transport of these quantities has, with few exceptions, been credited to the Hadley Cell. As noted for Earth, the mean meridional circulation (or diffusion) cannot produce elevated layers of water and dust, leading [6] to state "the existence of this maximum suggests that current understanding of the mechanisms by which dust enters and leaves the atmosphere is incomplete."

[7] specifically identified NLDT as a likely mechanism by which elevated dust layers could be created, and the potential importance of NLDT for Mars was further emphasized in [8] with specific reference to the hot towers of [1]. The proposed NLDT circulations are not just those of the massive Tharsis volcanoes, but to thermal circulations associated with lesser topography such as crater rims and hills (Figure 1). Strong, narrow and coherent updrafts of several m/s in strength are not unlike terrestrial thunderstorms. These are penetrative circulations that "punch" into the stable

atmosphere above to heights substantially above the top of the convective planetary boundary layer.

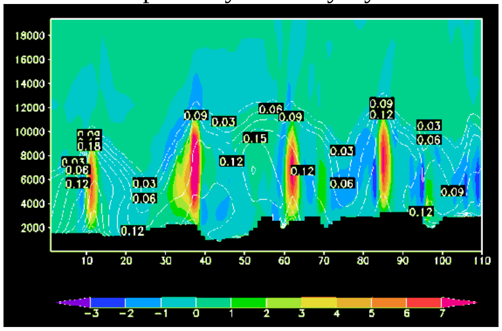

Figure 1: A typical example of NLDT associated with small scale topography as simulated by the MRAMS (Rafkin et al 2001). Vertical velocity (m/s) is shaded, dust mixing ratio (g/kg) is contoured. Grid spacing is ~9 km. Dust is injected above the convective boundary layer by circulations.

NLDT on Mars should not be limited to dust. The transport of water was specifically targeted in [9]. Quantitative analysis of model output showed that the vertical mass flux was roughly one third of the total mass flux that would be provided by the Hadley Cell. Thermal circulations may be the dominant NLDT mechanism on Mars, but the observational and modelling evidence for NLDT in dust storms cannot be ignored [10] [11]. The impact of NLDT on the general circulation has not been studied.

3. Titan

Titan has deep convective clouds that behave dynamically similar to those of Earth [12]. It is reasonable to suspect that transport within the clouds plays an important and significant role in global dynamics and atmospheric structure. In particular, when deep convective activity is active (e.g., polar regions at solstice), the rising branch of the Hadley Cell may be a statistical artifact rather than a physically real circulation. This would have important consequences on the volatile cycle budget, since the clouds would provide a mechanism by which methane could be rapidly injected at and above the tropopause.

4. Venus

Venus is known to have a deep layer of convective clouds from ~45-65 km. The circulation in this cloud layer were measured directly by the Vega balloons, which indicated updrafts of at least several m/s. Therefore, there is little doubt that NLDT is occurring within the cloud layer. Unlike terrestrial convective clouds, it is possible that Venus' clouds are effective at venting cloud top air into the subcloud layer via downward penetrative convection [13]. This rapid transport should have important implications in the global chemical cycle. Mixing within the cloud cores is likely to be minimal and the short timescale of transport means that all but the fastest chemical cycles will be of importance.

Additionally, cloud transport can effectively transport momentum and this transport may be an important forcing term in the angular momentum budget; the supperotation of Venus' atmosphere is a long standing problem.

References

[1] Riehl, H. and J. S. Malkus, *Geophysica* Vol. 6: pp. 503-537, 1958.

[2] Manabe, S., J. L. Holloway, et al. *J. Atmos. Sci.* Vol 27, pp. 580-613, 1970.

[3] Donner, L. J., H.-L. Kuo, et al. *J. Atmos. Sci.*, Vol 39, pp. 2159-2181, 1982.

[4] Anderson, E. and C. Leovy (1978). *J. Atmos. Sci.*, **35**(4): 723-734;

[5]. Jaquin, F., P. Gierasch, et al. (1986). *Icarus* **68**(3): pp. 442-461, 1986.

[6] McCleese, D. J., N. G. Heavens, et al., *J. Geophys Res.* Vol. 115, pp. E120126, 2010

[7] Rafkin, S. C. R., M. R. V. Sta. Maria, et al., *Nature* Vol. 419, pp. 697-699, 2002.

[8] Rafkin, S. C. R., International Workshop: Mars Atmsophere Modeling and Observations. Granada, Spain, 2003;

[9] Michaels, T. I., et al., *Geophys. Res. Lett.*, Vol. 33, 2006.

[10] Rafkin, S.C.R., *Mars J.*, submitted, 2011.

[11] Rafkin, S.C.R., *Adv. Space. Res.*, submitted, 2011.

[12] Barth, E., and S. C. R. Rafkin, *Icarus*, Vol. 34, 2007.

[13] Baker, R. D. et al., *J. Atmos. Sci.*, Vol. 55, pp. 3-18. 1998.