Surface–Atmosphere Coupling in Titan's Hydrologic Cycle

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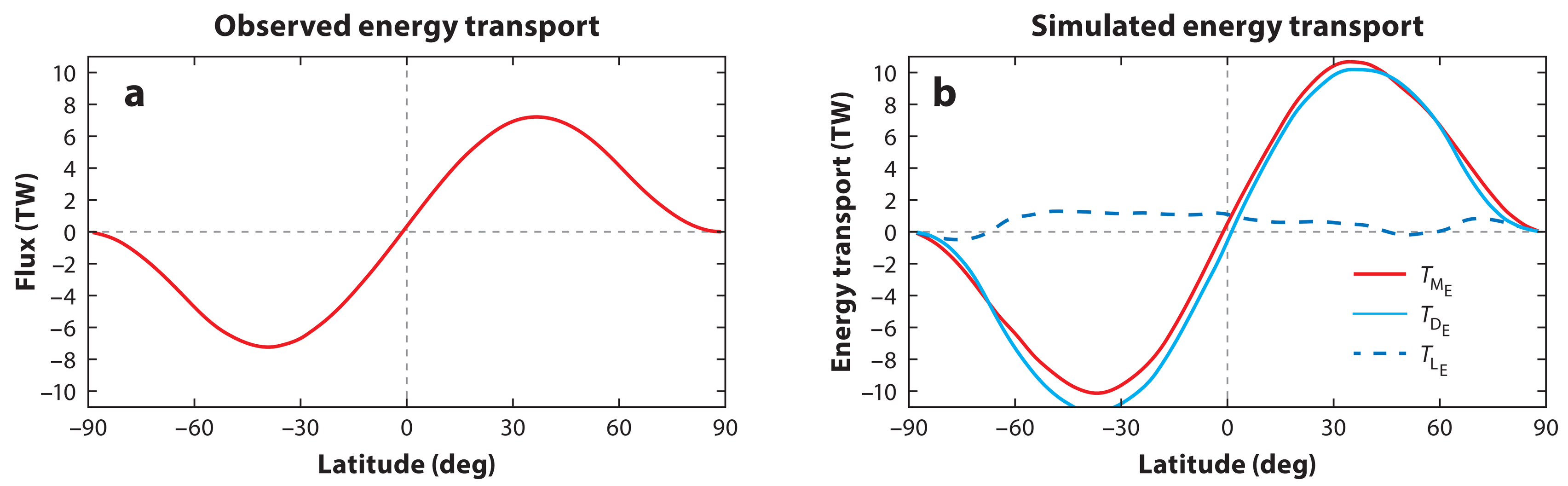
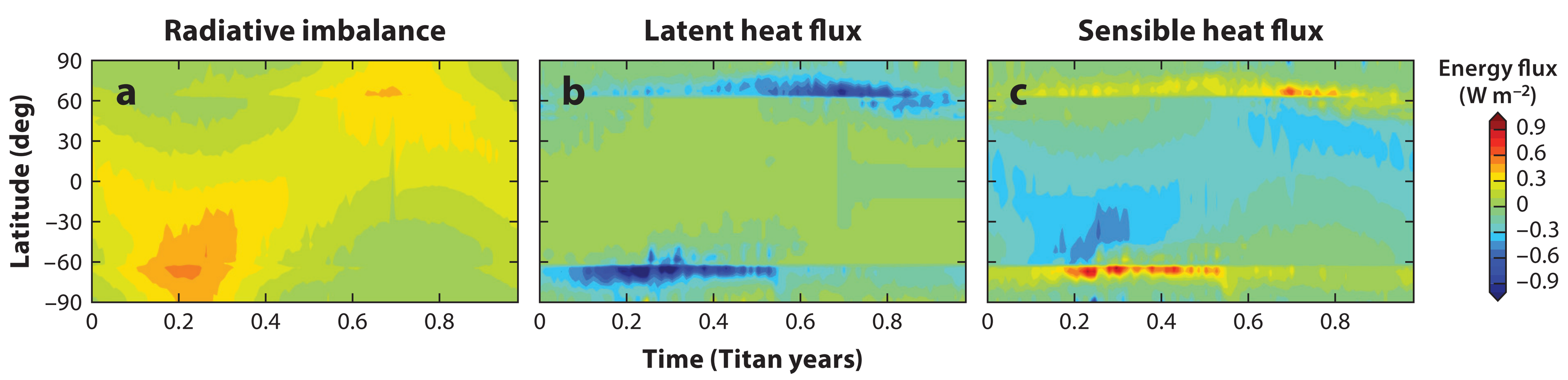
Motivation: Titan is the only satellite in the Solar System—and the only Ocean World—with a substantial atmosphere, and the only known object other than Earth to sustain stable surface liquids. Because methane close to Titan's surface is near its triple point, an active methane cycle akin to Earth's water cycle operates in Titan's atmosphere-surface system. Titan's lakes and seas are impressive in size, but small compared to the total methane inventory of the atmosphere. This raises the questions of whether there is more liquid methane in the surface layers than is apparent, and how the atmosphere redistributes this methane globally.

Energy transport in Titan's atmosphere inferred from observations of the radiation imbalance (a) and as simulated by TAM (b). Transport of latent energy is small, but non-negligible, and implies considerable advection of atmospheric methane.

Mitchell, J.L., J.M. Lora (2016). The climate of Titan. *AREPS* 44, 353–380

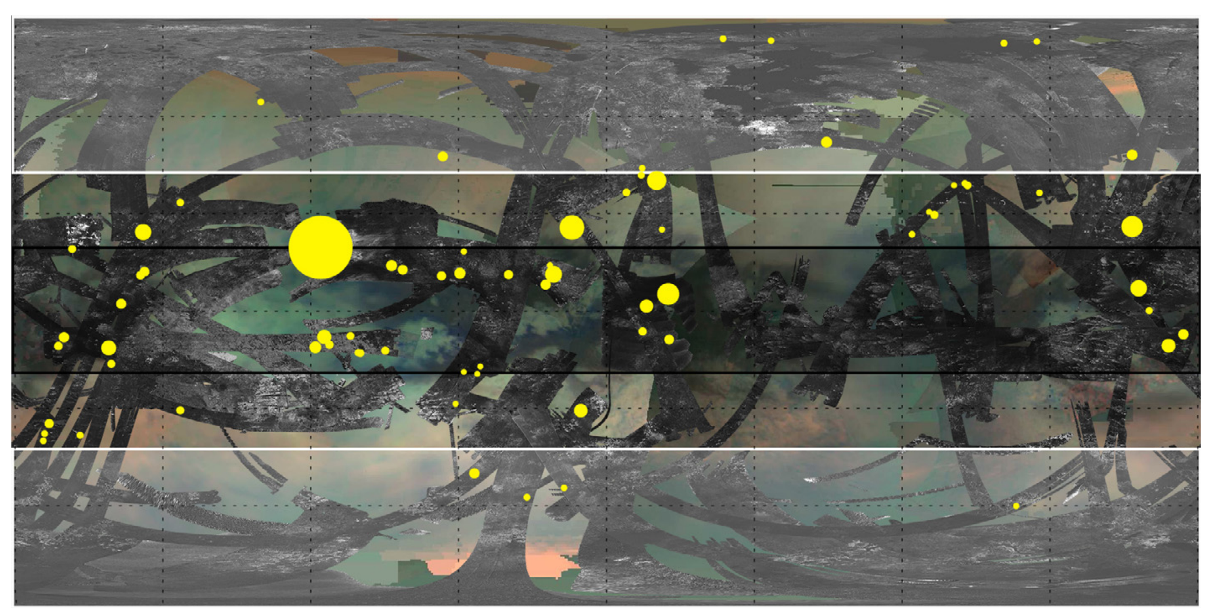


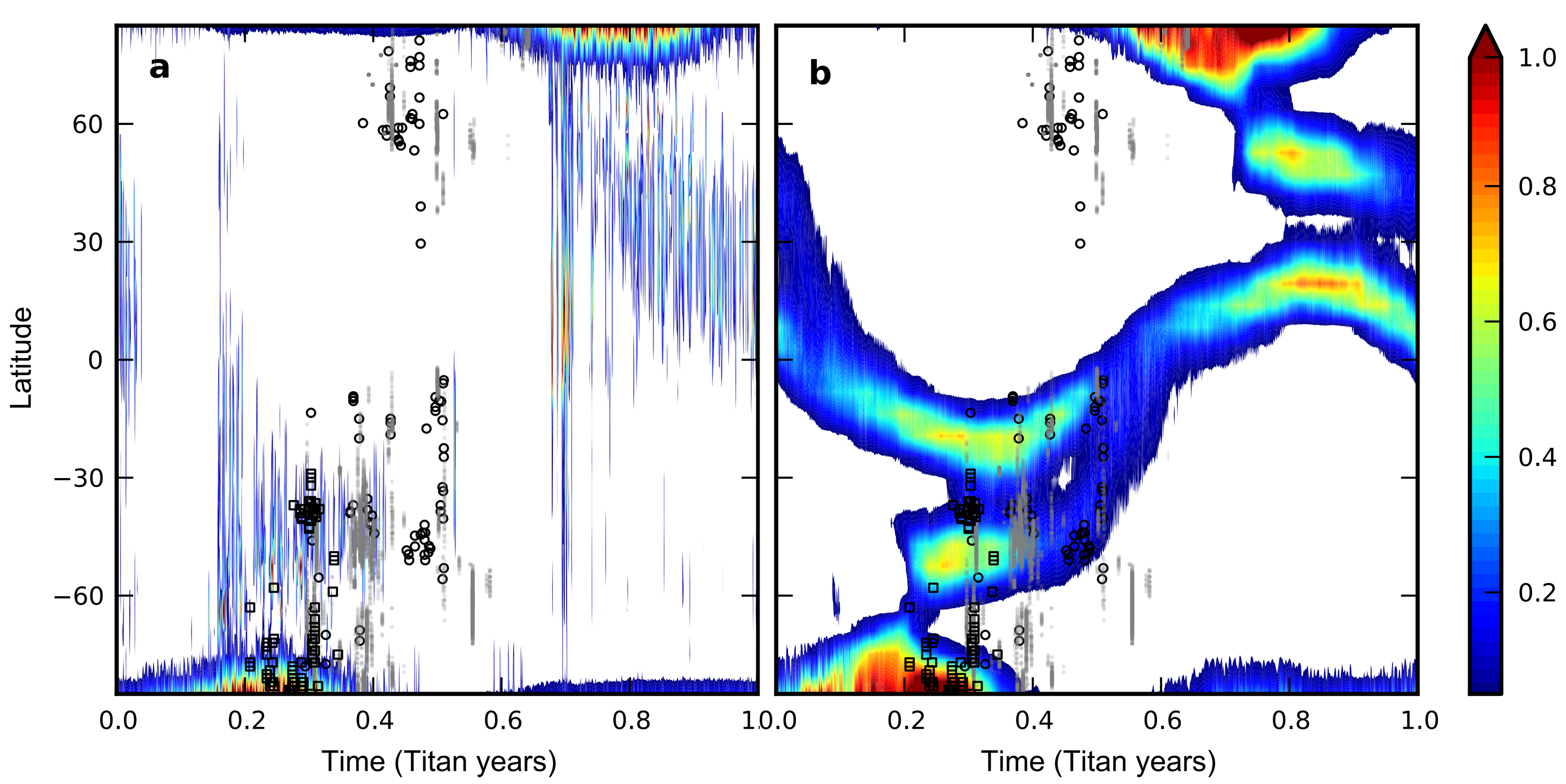


Simulated surface energy fluxes through one Titan year (positive down), which demonstrate local and seasonal variations driving the exchange of heat and moisture between atmosphere and surface.

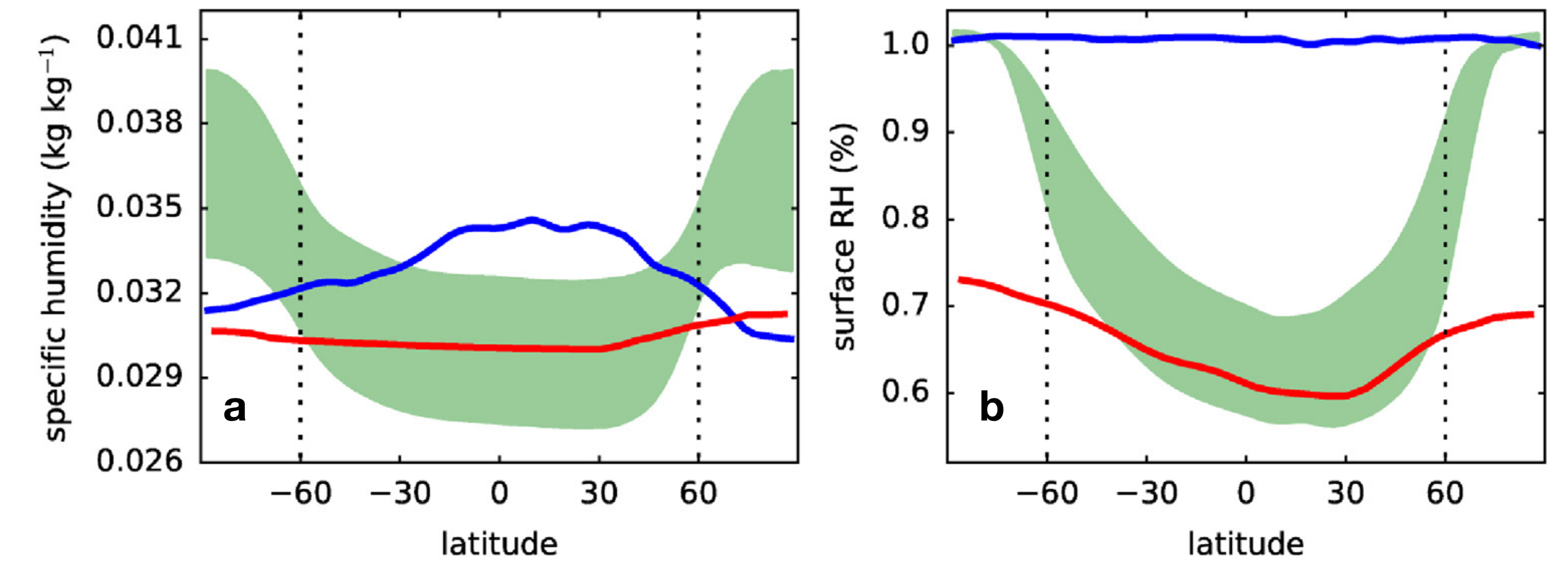
Where are Titan's surface liquids? The observed crater distribution shows substantially more craters at low-latitude highlands, suggesting the possibility of "wetlands" at Titan's low-lying high latitudes. The polar regions already sustain lakes and seas, so polar "wetlands" just extend the surface area of contact between surface liquids and the atmosphere.

Neish, C.D., et al. (2016). Fluvial erosion as a mechanism for crater modification on Titan. *Icarus* 270, 114–129

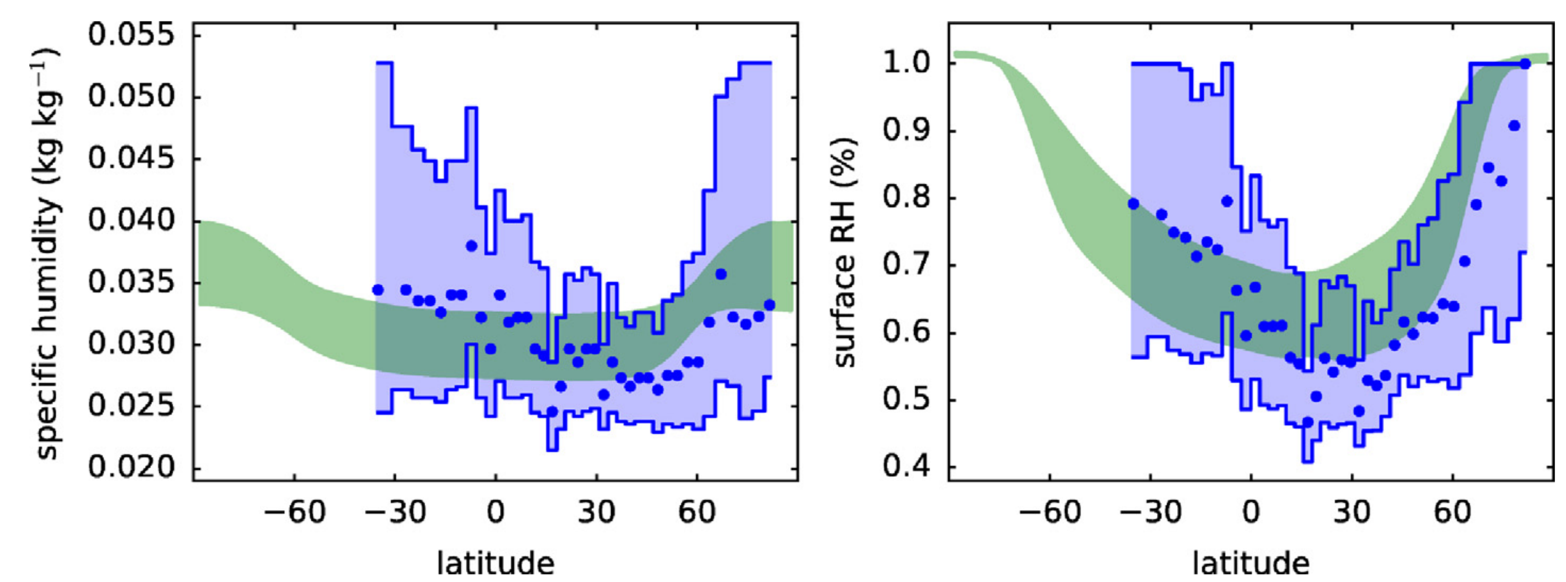




Zonal-mean precipitation distribution from two TAM simulations, one with polar "wetlands" (a), and the other with global surface methane (b). A comparison between the predicted precipitation and observed cloud locations (grayscale symbols) shows that wetlands produce a better match to observations. Most prior modeling has assumed ample surface liquids, producing rain distributions similar to (b).



Simulated boundary layer specific humidity (a) and surface-level relative humidity (b) in an ensemble of "wetlands" runs (green), a lakes-only run (red), and a methane-ocean run (blue), indicating the importance of the surface liquid distribution to the atmospheric humidity. All curves correspond to the season of ground-based observations (2014).



Comparison of the "wetlands" simulations (green) to retrieved boundary layer specific humidity and surface-level relative humidity from recent high-resolution ground-based observations with Keck/NIRSPAO (blue points with uncertainty envelopes).

Lora, J.M., M. Ádámkovics (2017). The near-surface methane humidity on Titan. *Icarus* 286, 270–279

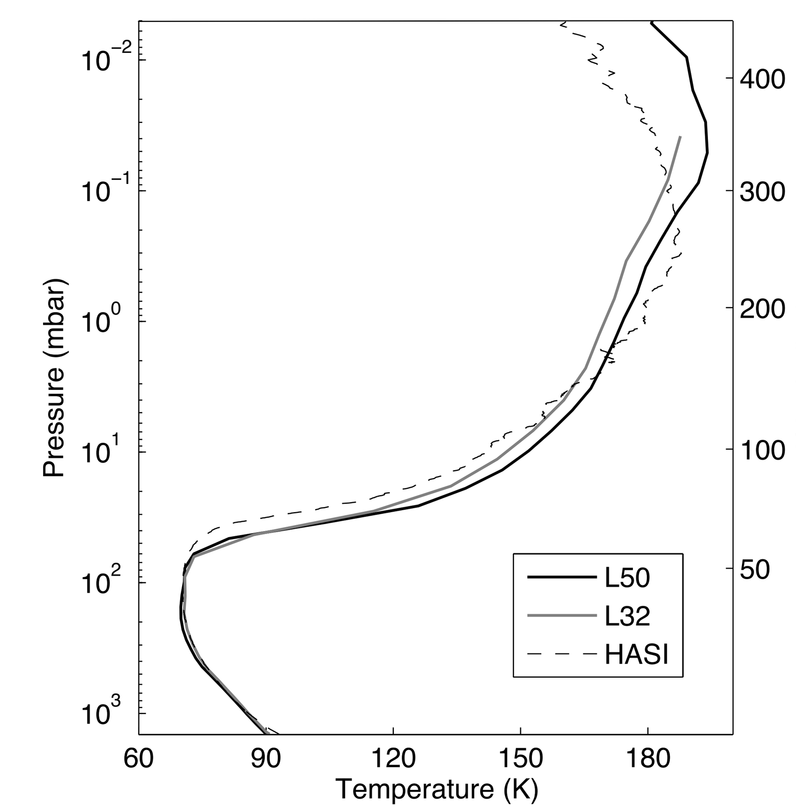
Titan Atmospheric Model

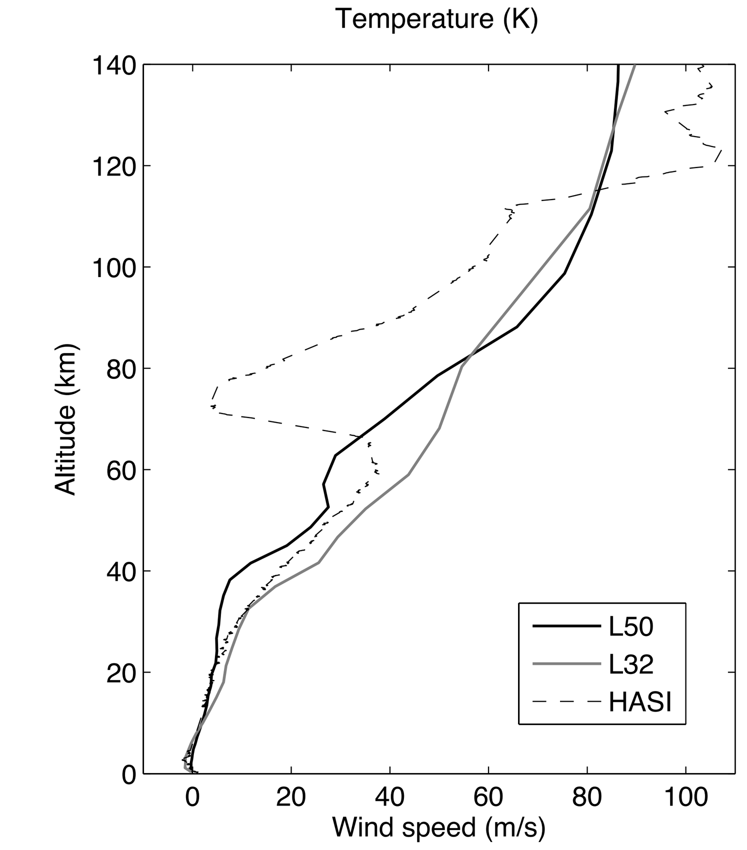
The general circulation model (GCM) used in this work is a fully three-dimensional model that couples the GFDL FMS spectral dynamical core to a suite of parameterizations for Titan:

1. Fully non-gray, scattering two-stream radiative transfer that includes opacity from haze, CH_4, C_2H_2, C_2H_4, C_2H_6, HCN, and pairs of H_2, N_2, and CH_4
2. Moist processes including large-scale condensation and a quasi-equilibrium moist convection scheme
3. Boundary layer diffusion, and atmosphere-surface exchange of momentum, heat, and vapor
4. Multi-layer land model for calculating surface temperatures, and a "bucket" scheme for self-consistently tracking surface liquid

TAM simulations straightforwardly reproduce Titan's atmospheric temperatures, zonal winds, and low-latitude humidity compared to Cassini/Huygens measurements. Shown at right are equatorial profiles of temperatures and zonal winds, and Huygens/HASI measurements (dashed lines) for comparison. The temperature structure is accurate through the stratopause, and atmospheric superrotation is well reproduced. These features make TAM ideal for studying Titan's atmosphere and for diagnosing its circulation.

Lora, J.M., J.I. Lunine and J.L. Russell (2015). GCM simulations of Titan's middle and lower atmosphere and comparison to observations. *Icarus* 250, 516–528





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