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Seasonal radiative modeling of Titan’s stratospheric temperatures at low latitudes

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Abstract

We have developed a seasonal radiative model of Titan’s stratosphere to investigate the time variation of temperatures in the 0.2-4 mbar range as observed by the Cassini/CIRS spectrometer. The model incorporates gas and aerosol vertical profiles derived from Cassini/CIRS and Huygens/DISR data to calculate the heating and cooling rate profiles as a function of time and latitude. At 6°N around Spring equinox, the radiative equilibrium profile is warmer than the observed one at all altitudes. Adding adiabatic cooling in the energy equation, with a vertical upward velocity profile quasi-constant in pressure coordinates below the 0.03-mbar level (corresponding to ~0.3 mm s^{-1} at 1 mbar) allows us to reproduce the observed profile. The model shows that the change in insolation due to the orbit eccentricity can explain the observed 4-K decrease in equatorial temperatures around 1 mbar since 2009. At 30°N and S, the radiative model predicts seasonal variations of temperature larger than observed, pointing to latitudinal redistribution of heat by dynamics. We show that a seasonal modulation of adiabatic cooling/heating is needed to reproduce the temperature variations observed from 2004 to 2016 between 0.2 and 4 mbar.

1. Introduction

Due to Saturn’s obliquity of 26.7°, Titan experiences large seasonal variations of insolation. The 0.056 eccentricity of Saturn’s orbit adds a significant modulation to this insolation. The Cassini Composite Infrared Spectrometer (CIRS) aboard Cassini allows us to monitor the thermal structure of Titan’s stratosphere since July 2004. The goal of this work is to investigate the heat balance of Titan’s stratosphere at mid-latitudes (30°S-30°N) using a seasonal radiative model based on measurements by Cassini/CIRS and Huygens/DISR of the distributions of the radiative agents.

2. Observations

Titan’s temperature field is retrieved using nadir and limb observations of the ν_4 band of methane through Focal Plane FP4 of Cassini/CIRS covering the interval 1050-1495 cm^{-1}. (e.g. [1]). In our analysis, we used temperatures retrieved at 0.2, 0.5, 1, 2 and 4 mbar, which cover the range of maximum temperature information and we restrained our analysis to equatorial and mid-latitudes between 2004 and 2016. We also compared our model to a “reference” profile retrieved from Cassini/CIRS at 6°N around equinox [6] above the ~5-mbar region and based on Huygens/HASI measurements [4] below that level.

3. Seasonal radiative model

We solve for the energy equation:

$$\frac{\partial T(z)}{\partial t} = h(z) - c(z) - w(z)\left(\frac{g(z)}{C_p} + \frac{\partial T(z)}{\partial t}\right) \qquad (1)$$

$h(z)$ is the solar heating rate equal to $-\frac{g}{C_p}\frac{dF_*(p)}{dp}$, where F_* is the downward solar flux, $c(z)$ is the cooling rate equal to $-\frac{g}{C_p}\frac{dF_{IR}(p)}{dp}$ with F_{IR} being the upward thermal emission flux, w the downward vertical velocity, C_p the specific heat capacity, and g the acceleration of gravity.

To model the radiative cooling and heating rates, we used vertical profiles of haze extinction from Huygens/ DISR in situ measurements [3] for the visible and near-IR regions, and Cassini/CIRS limb spectra near 20°S in 2007 [6] in the thermal infrared range. The methane profile is that derived from Huygens/GCMS data [5] and vertical profiles of hydrocarbon and nitriles were taken from the above-mentioned analysis of Cassini/CIRS measurements [6].

4. Results

Figure 1 shows our model prediction for 6°N in mid 2009, assuming no adiabatic heating/cooling (i.e. $w = 0$ in Eq. 1), compared with the observed "reference" profile. This purely radiative solution is warmer than observed at all levels, pointing to the presence of adiabatic cooling. Adding a vertical velocity profile roughly constant in pressure coordinates below the ~0.03-mbar level allows us to reproduce fairly well the observed profile below 0.1 mbar. The corresponding upward velocity at 1 mbar is ~0.3 mm s^{-1}.

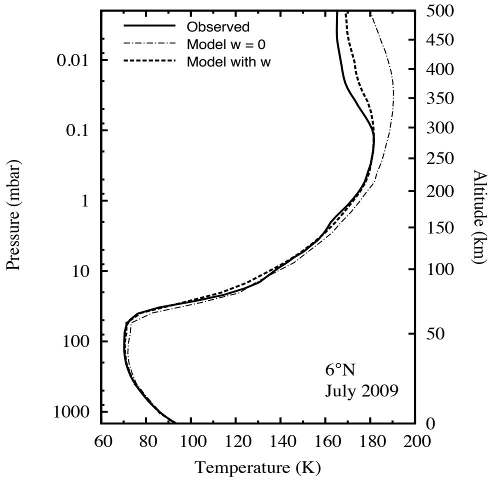

Figure 1: A temperature profile retrieved from Cassini/CIRS measurements near 6°N complemented by Huygens/HASI data (solid line) is compared with our model predictions with no adiabatic cooling (dash-dotted line) and with adiabatic cooling (dashed line).

This adiabatic cooling at low latitudes is associated with the general circulation that allows redistribution of heat to higher latitudes.

Running our model at 0°, 30°N and 30°S with this vertical velocity profile, constant with time, produces seasonal variations of temperatures much larger than observed between 0.2 and 4 mbar. At the equator, the predicted drop in temperature at 1 mbar, 7 K between 2007 and 2016, is due to the eccentricity of the orbit. The model outputs can be brought in agreement with the 4-K observed decrease, by adding a season-modulated term in the vertical velocity profile, such as a sinusoidal function of solar longitude with an amplitude of 1/3 of the constant term [2].

Similarly, at 30°N and 30°S, a good agreement with the observed time variation of temperatures since 2004, can be obtained by adding a sinusoidal modulation of the vertical velocity profile. Their amplitudes are larger than that at the equator, implying subsidence in winter and uplift in summer [2].

In the future, the model will be extended to high latitudes and will include the observed variations of gases and aerosols, to investigate the complex changes in the temperature field around equinox.

References

[1] Achterberg, R. K., Gierasch, P. J., Conrath, B. J., Flasar, F. M., and Nixon, C. A.: Temporal variations of Titan's middle-atmospheric temperatures from 2004 to 2009 observed by Cassini/CIRS, Icarus, Vol. 211, pp. 686-698, 2011.

[2] Bézard, B., Vinatier, S., and Achterberg, R. K.: Seasonal radiative modeling of Titan's stratosphere, American Astronomical Society, DPS meeting #48, id.509.06, 2016.

[3] Doose, L. R., Karkoschka, E., Tomasko, M. G., and Anderson, C. M.: Vertical structure and optical properties of Titan's aerosols from radiance measurements made inside and outside the atmosphere, Icarus, Vol. 270, pp. 355-375, 2016.

[4] Fulchignoni, M., et al.: In situ measurements of the physical characteristics of Titan's environment, Nature, Vol. 438, pp. 785-791, 2005.

[5] Niemann, H. B., et al.: Composition of Titan's lower atmosphere and simple surface volatiles as measured by the Cassini-Huygens probe gas chromatograph mass spectrometer experiment, J. Geophys. Res., Vol. 115, E12006, 2010.

[6] Vinatier, S., et al.: Seasonal variations in Titan's middle atmosphere during the northern spring derived from Cassini/CIRS observations, Icarus, Vol. 250, pp. 95-115, 2015.