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Simulations of Seasonal Haze Transport on Titan Using the FMS Core GCM

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Abstract

We have developed a new Titan General Circulation Model (GCM) using the Flexible Modeling System (FMS) dynamical core from the Geophysical Fluid Dynamics Laboratory (GFDL). The FMS core is state-of-the-art and actively maintained by GFDL; it conserves angular momentum better than other existing dynamical cores which is especially important for modeling Titan's thick atmosphere. Furthermore, a basic aerosol microphysics package has been developed and linked to the core model. This microphysics is based on the modified version of the Community and Radiation Model for Atmospheres (CARMA) used to study haze and cloud physical processes in Titan's atmosphere ([1], [2]). The model also uses a radiative transfer package that is based on the correlated-k two-stream model of [3]).

1. Introduction

A general circulation model (GCM; a global scale model that simulates the large scale behavior of an atmosphere) is the most complete tool available to comprehensively model planetary atmospheres. Adapting terrestrial GCMs to study Titan's extensive atmosphere has met with a number of complications from factors such as the long radiative time constant in Titan's lower atmosphere and the extensive haze layer which is the primary visible feature of Titan's atmosphere. Despite this, a number of platforms exist, such as [4],[5],[6]. We present a further attempt at understanding Titan's atmospheric circultion using the Flexible Modeling System (FMS) dynamical core which we have coupled to the key physics packages described below.

2. GCM key physics packages

The core of the radiative transfer code uses a generalized two-stream approximation for radiative transfer in inhomogeneous multiple scattering atmosphere [7]. The two stream approximation is reasonably accurate for most uses; for solar wavelengths it reduces to an exact result in the limit of no scattering and no reflecting surface; for ir wavelengths the results are not exact in the limit of no scattering except for a semi-infinite atmosphere. The two-stream source function technique is exact in the limit of pure absorption but retains the accuracy of the two stream approach when scattering occurs. Fluxes are recalculated for infra-red wavelengths for a more accurate solution to the two-stream equation. Gas opacities are calculated using a correlated-k approach. A number of databases are included for various atmospheric gases over a range of temperatures and pressures. A Mie code calculates the scattering and extinction efficiency values for atmospheric particles.

The microphysics package was adapted from the Community Aerosol and Radiation Model for Atmospheres (CARMA), described by [2]). The model solves the continuity equation for a particle n of volume v, with the form

$$\frac{\partial n}{\partial t} = -\frac{\partial}{\partial z}(nv_{fall}) - n_{gas}K_{diff}\frac{\partial[n(v)/n_{gas}]}{\partial z} + \frac{1}{2}\int_0^v K_{coag}(v', v-v')n(v')n(v-v')dv' - \int_0^\infty K_{coag}(v', v)n(v)n(v')dv' + P(v) - L(v) \quad (1)$$

For cloud particles, the production and loss terms are

$$P(v) - L(v) = J(v) - \frac{\partial}{\partial v}\big(G(v)n(v)\big) \quad (2)$$

Particles are transported vertically through sedimentation (regulated by fall velocity, $vfall$) and eddy diffusion (with coefficient, K_{diff}); though due to their sizes, aerosol particles generally move through diffusion and cloud particles generally fall. All particles are also subject to coagulation (with coagulation kernel K_{coag}). Collisions between involatile particle groups are generally handled by the equations for Brownian coagulation. Coalescence kernels are calculated for cloud-cloud collisions. The production term, $P(v)$ in Eqn. 1 describes the creation of involatile particles, such as by photochemistry. Aerosol particles are lost, $L(v)$, through nucleation to produce cloud particles, $J(v)$. Nucleation follows the classical theory as described in [8]. Cloud particles then interact with the volatiles through condensational growth and evaporation (regulated by the growth kernel, $G(v)$). The particles are represented by a number of radius bins, defined by a user specified minimum value and a mass ratio between bins.

3. Summary

Now that we have coupled these core physics packages to the FMS core we are in a position to demonstrate the applicability of the FMS core to Titan studies (Fig. 1) by showing simulations of the haze seasonal cycle.

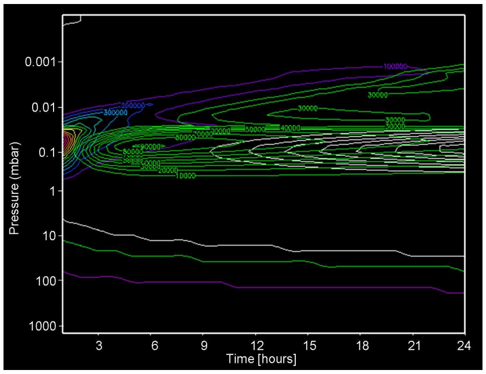

Figure 1: Titan haze particles in the GCM. The microphysics module simulates photo-chemical production of 10 Angstrom-sized haze particles between 200-300 km (1-0.1 mbar) which are shown with the colored contours (indicating cm^{-3}). The green contours indicate haze particles that have doubled in radius. These particles are created by the coagulation of smaller particles and so begin to show up about an hour after the 10 A particles. The white contours show haze particles with radii about a factor of 10 greater than the smallest size bin. Evidence of a vertical wind near the top of the production region can also be seen as the small particle population moves to higher altitudes with time.

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References

[1] Toon, O.B., McKay, C.P., Griffith, C.A., and Turco, R.P.: A physical model of Titan's aerosols Icarus Vol. 95, pp. 24-53, 1992.

[2] Barth, E. L. and Toon O.B.: Methane, ethane, and mixed clouds in Titan's atmosphere: Properties derived from microphysical modeling, Icarus, Vol. 182, pp. 230-250, 2006.

[3] McKay, C.P., Pollack, J.B., and Courtin, R.: The thermal structure of Titan's atmosphere, Icarus, Vol. 80, pp. 23-53, 1989.

[4] Hourdin, F., Talagrand, O., Sadourny, R., Courtin, R., Gautier, D., and McKay, C.P.: Numerical simulation of the general circulation of the atmosphere of Titan, Icarus, Vol 117, pp. 358-374, 1995.

[5] Richardson, M.I., Toigo, A.D. and Newman, C.E.: PlanetWRF: A general purpose, local to global numerical model for planetary atmospheric and climate dynamics, J. Geophys. Res., Vol. 112, pp. E09001, 2007.

[6] Friedson, J.A., West, R.A., Wilson, E.H., Oyafuso, F. and Orton, G.S.: A global climate model of Titan's atmosphere and surface, Planet. Space Sci., Vol. 57, pp. 1931-1949, 2009.

[7] Toon, O.B., McKay, C.P., Ackerman, T.P., and Santhanam K.: Rapid calculation of radiative heating rates and photodissociation rates in inhomogeneous multiple scattering atmospheres. J. Geophys. Res., Vol. 94, pp. 16287-16301, 1989.

[8] Pruppacher, H.R. and Klett, J.D.: Microphysics of Clouds and Precipitation, Norwell: Kluwer Academic Publishers, 1997.