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Investigating Titan's Surface-Atmosphere Interactions with a General Circulation Model

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Abstract

Titan's surface shows significant evidence for surface-atmosphere interactions in the form of dunes, lakes, and surface features attributed to past or recent rainfall [1,2,3]. We use the TitanWRF General Circulation Model (GCM) to predict the near-surface circulation and methane cycle, compare our resulting predictions of dunes and evaporation / precipitation with observations, and use this to better understand Titan's coupled atmosphere-surface system.

1. Motivation

While theory and simple analytical modeling provide valuable insight, and are extremely useful at an early stage for making predictions and forming hypotheses, most phenomena that are linked to the atmospheric circulation cannot be fully understood without fully modeling the latter, as non-linear interactions and feedbacks can produce unexpectedly complex results.

The most rigorous way to examine possible mechanisms and explore hypotheses is therefore by modeling the entire atmosphere-surface system using a three-dimensional GCM. This is not to say that GCMs are expected to be perfect representations of the atmospheric circulation (and hence its impact on the surface) *a priori*. On the contrary, owing to the large number of poorly known parameters and assumptions contained within such models, and the possibility that important processes may be missing entirely, we must *expect* a GCM to provide somewhat incorrect predictions until confronted with data. The use of GCMs here is thus highly synergistic: on the one hand, we can use surface observations to gain insight and constrain the GCMs' representation of physical processes; on the other hand, we can use GCMs to provide insight into surface phenomena and ultimately to provide predictive capabilities.

2. The TitanWRF GCM

TitanWRF is the Titan version of the planetWRF GCM, and is described in detail in [4]. It produces realistically large stratospheric superrotation, and currently includes a simple methane cycle [5]: condensation occurs when methane exceeds a prescribed relative humidity RH_C at a model grid point; this methane falls immediately to the surface as precipitation, unless a grid point with humidity < RH_C is encountered on the way down; methane evaporation is also parameterized at the surface based on wind stress and sub-saturation of the near-surface layer; and the surface methane abundance (affected by evaporation and precipitation) is tracked throughout. TitanWRF also includes global topography maps based on extrapolation of Cassini Radar SARTopo and altimetry data.

3. Dune results

Dunes represent the time-integrated result of a non-linear, threshold-dependent, wind-driven process (particle saltation). For this reason, while dune morphologies may be used to try to *infer* dominant wind direction(s), a far better approach is to predict the long-term time series of the near-surface wind field and use it to *predict* dune characteristics. We use the Gross Bedform-Normal Transport (GBNT, [6]) method to predict dune orientations for a range of saltation thresholds, using the quality of the match to observed dune orientations to provide insight into the realism of the near-surface wind field and the accuracy of relevant processes and parameters.

Figure 1 shows the predicted resultant (net) transport direction (related to the direction of likely dune migration) and dune orientations at low-latitudes for a TitanWRF simulation with topography and a high saltation threshold. For a 'flat Titan' simulation, or with topography but a low threshold value, TitanWRF predicts predominantly westward resultant transport and dunes nearly parallel to the equator at low latitudes, whereas in Figure 1 the dune orientations vary from parallel to perpendicular, and there is substantial eastward transport. Comparison to actual orientations, inferred migration directions, *etc.* should let us identify the most appropriate saltation threshold for Titan's dunes, and (based on whether a match can be found) judge how well TitanWRF captures the impact of topography on the circulation.

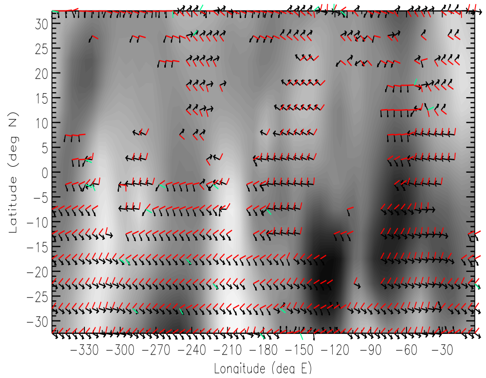

Figure 1: Predicted low-latitude resultant transport directions (black arrows) and primary (red lines) and secondary (green lines) dune orientations using the GBNT method, assuming a saltation threshold of 0.021N/m^2. Shading shows topography (black = lower, white = higher).

4. Methane cycle results

Figure 2 (top) shows the predicted zonal-mean precipitation for 3 Titan years from a TitanWRF simulation with infinite surface methane availability at the surface. The dominant features are substantial precipitation throughout much of the year at high latitudes (associated with strong upwelling in polar cells), and moderate precipitation predicted to move roughly from pole-to-pole and back again each year (associated with the seasonal passage of the Inter-Tropical Convergence Zone; the location of convergence and upwelling in Titan's Hadley cells). Figure 2 (bottom) shows the difference when a finite methane abundance is used (producing a steady state with methane confined polewards of ~70°), with latent heat effects activated and a higher surface thermal inertia used: precipitation is now more confined to high latitudes around summer solstice, with rare, concentrated precipitation at low latitudes.

5. Summary

GCMs provide insight into, and provide a means of proving (or refuting) hypotheses regarding, the physical mechanisms responsible for features on Titan's surface. In turn, surface observations provide valuable constraints on GCMs. We use this synergy to explore the full Titan system with TitanWRF.

Acknowledgements

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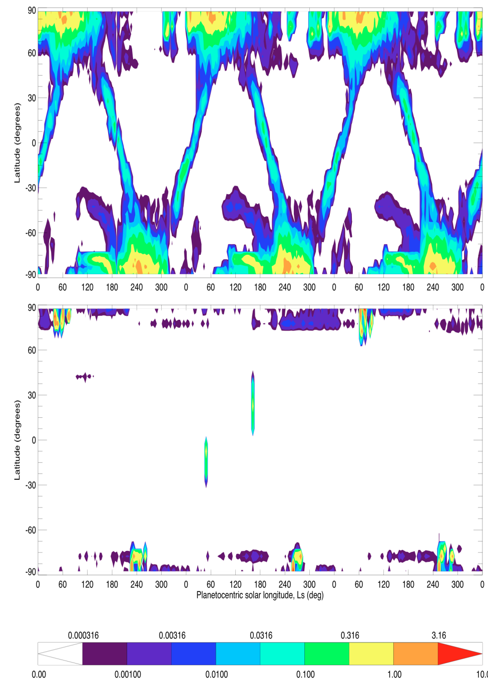

Figure 2: Predicted zonal-mean precipitation (in mm/Earth hour) as a function of latitude and season for 3 Titan years with (top) infinite surface methane and no latent heating, and (bottom) finite surface methane, latent heating effects at the surface and in the atmosphere, and a raised surface thermal inertia. Note the logarithmic contour intervals.

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