THE INFLUENCE OF ORBITAL FORCING ON THE DISTRIBUTION OF TITAN'S SURFACE LIQUIDS.

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Introduction: Titan supports an active hydrologic cycle, which includes observed features such as rivers, lakes and seas comprising liquids of mostly methane [1–2]. Most of these such extant surface reservoirs reside in the northern polar regions, with only one prominent lake in the south [1]. However, geomorphologic mapping of Titan's poles suggests that approximately equal areas of the surface in the two hemispheres are made up of low-lying basins; these are largely empty in the south, and have therefore been interpreted as now-dry paleo-seas.

Relatedly, general circulation models (GCMs) of Titan's climate have previously shown that the atmosphere tends to transport methane vapor to the polar regions when methane liquid is available nearly globally, and the resulting build-up at the poles is preferentially cold-trapped [3–5]. However, when lower latitudes are entirely dry, the atmosphere mixes methane vapor equatorward, and coupled atmosphere-land-hydrology simulations suggest that runoff and subsurface flow are important for maintaining a surface liquid distribution that resembles observations [6].

A key hypothesis to explain the hemispherically asymmetric distribution of lakes and seas on Titan invokes the variations of Saturn's orbit and their resulting influence on Titan's top-of-atmosphere insolation distribution [7]. Currently, Titan's southern summer is shorter but more intense than its northern counterpart, and indeed this has been shown to produce a preferential build-up of methane in the north in idealized simulations [8]. This preferential accumulation was further associated with net cross-equatorial atmospheric vapor transport [9]. Yet the resulting asymmetry was much smaller than observed, coupled land-atmosphere feedbacks were ignored, and more recently alternative mechanisms have been suggested to account for the asymmetry. Thus, whether the observed distribution of Titan's liquids is a signature of its recent paleoclimate, a consequence of longer-term climate variations, or due to something else entirely remains unresolved.

Methods: We address the above questions, testing the importance of orbitally-forced seasonal insolation asymmetries in the global transport of methane, with a coupled GCM and hydrology model that additionally includes topography [10]. The model is a configuration of the Titan Atmospheric Model (TAM) [5], which has been validated previously against a range of observations and satisfactorily reproduces many aspects of Titan's hydroclimate [2, 5, 6, 11]. The hydrology model [6] calculates infiltration, runoff, and a subsurface methane table with lateral flow, and is coupled to the atmospheric model via precipitation and evaporation. Run with current orbital conditions, the coupled model produces a distribution of surface liquids that resembles Titan's modern distribution, albeit with more liquids in the south than observed (**Fig. 1**).

We run various simulations that are otherwise identical but vary i) the effects of topography on the atmospheric circulation (with/without topography) ii) the hydraulic conductivity of the surface (from 5×10^{-5} to 10^{-4} m s^{-1}) and iii) the longitude of perihelion (modern/180° from modern). In all cases we run simulations for 100 Titan years.

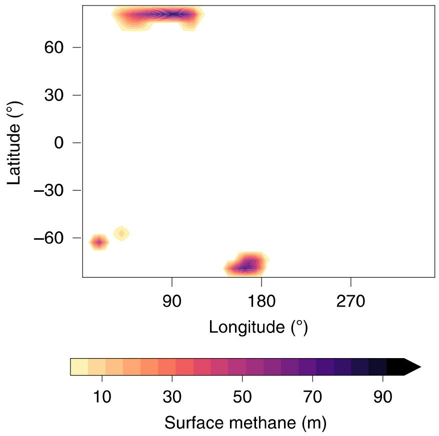

Figure 1: Surface distribution of liquid methane from simulations from [6].

Results and discussion: The inclusion of the effects of topography on the atmosphere, relative to a case with a flat surface, causes the lower-elevation polar regions to be warmer as a result of the lapse rate. This in turn promotes stronger evaporation, which means that an equilibrium with extant polar surface liquids requires more replenishment from the subsurface (a higher hydraulic conductivity). Other impacts of topography include minor changes to the distribution of precipitation, but no meaningful differences in its north to south contrasts.

The orbital forcing produces a clear response in the net atmospheric transport of methane moisture (**Fig. 2**), in agreement with previous results [9]. Specifically, the modern longitude of perihelion leads to net northward atmospheric moisture transport. The reversed perihelion case, wherein the northern summer is the shorter but more intense one, leads to net southward atmospheric moisture transport. This occurs irrespective of the presence of topography.

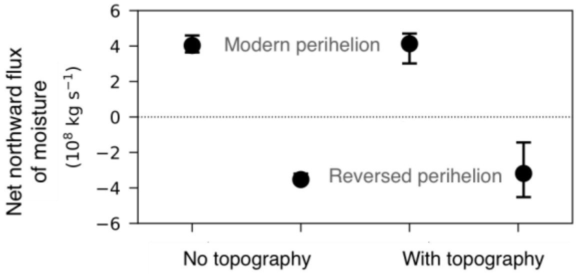

Figure 2: Net northward moisture transport by the atmosphere in simulations with and without topography, and with modern or reversed perihelion. The average of the final three decades of each simulation is shown, and error bars indicate the range of decadal averages of the final three decades. Adapted from [10].

However, these small net transports do not cause a strong response of surface liquid distribution to the orbital forcing. In both cases, the northern basins contain larger volumes of liquid, and near-surface liquids comprising polar "wetlands" are of similar area (**Fig. 3**). These findings contradict the hypothesis that the distribution of Titan's liquids is a record of orbitally-forced paleoclimate, despite the fact that the atmosphere does respond robustly to seasonality changes. However, it bears noting that many uncertainties remain, including in the true values of key parameters, such as the hydraulic conductivity and even the validity of the global topography reconstruction used. Work further addressing some of these key uncertainties is ongoing, but ultimately future missions to provide better and more complete data of Titan will be required to determine whether Titan's surface provides a history of its climate, as on Earth and Mars.

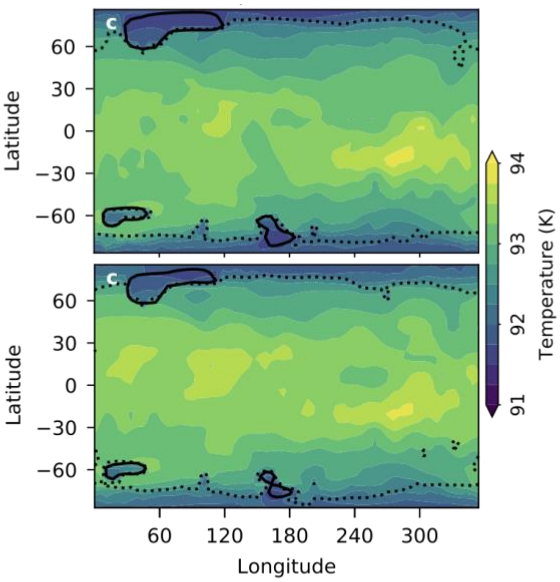

Figure 3: Time-averaged surface temperatures (colors), surface liquids exceeding a minimum threshold (solid contours), and polar "wetlands" from which evaporation exceeds 0.1 mm day-1 (poleward of dotted contours) for simulations with modern (top) and reversed (bottom) perihelion. Adapted from [10].

Acknowledgments: This abstract is largely based on recently published work [10]. The simulations used were run on the Grace cluster maintained by the Yale Center for Research Computing.

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