COMPARATIVE HYDROLOGY OF THE NORTH AND SOUTH POLAR REGIONS OF TITAN

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The north and south polar distribution of lakes on the hydrologically active (liquid methane-based) moon Titan has been attributed to the orbital behavior of the Saturn system [1]. However, the hypothesis that Saturn's orbital evolution exerts a dominant effect on the lake distribution has not been tested with detailed hydrological and climatic modeling. Furthermore, climate modeling work cannot explain the observed lake area asymmetry between the north and south polar regions. The predicted ratio between the lake area in the south and north polar regions predicted by past climate modeling work is 0.59 [2] and 0.56 [3], compared to 0.04 observed [1]. This suggests that other factors must also play a role, such as the surface and subsurface hydrology [4, 5] and differences in the topography between the north and south polar regions.

The lake area distribution at the north polar region has been reproduced by modeling the large-scale subsurface and surface hydrology of Titan coupled with a general circulation model of the present-day climate [6]. That work showed that subsurface flow contributes substantially to the fluid budget of lakes, but that a locally lower permeability around the pole and suppression of evaporation over the seas, due to either lake cooling effects or less volatile hydrocarbons in the large north polar seas, is required to explain the distribution of north polar lakes. In this study, we use results from a Titan general circulation model [3] and a hydrological model [6] to investigate the formation of lakes at Titan's north and south polar regions, explore the effects of topography, climate, and hydrological properties on the resulting lake distribution, and compare the predicted lake distributions with the distributions observed.

Methodology: The hydrological modeling was performed with a well benchmarked finite-difference model of unconfined saturated flow that incorporates an analytical solution to the overland flow equation [6]. Recharge and surface runoff are determined using an Earth-based empirical relationship dependent on the annual potential evaporation and precipitation rates at the south polar region based on a Titan general circulation model (TitanWRF [3]). Similar to previous work [4], the lake area distribution as a function of latitude was compared to the observed lake distribution at the south polar region [7].

Though long-wavelength topographic models have been generated for Titan [8], we generate synthetic topography is generated based on the statistical properties of the Synthetic Aperture Radar (SAR) topography [6]. This produces a fractal model of the topography at Titan's poles and includes SAR topography data where present. Additionally, we impose the large sea basins assuming that the elevation must be below the shoreline elevation at the 4 largest seas in the north polar region. A similar method is utilized to generate the topography of the south polar region. However, instead of using the present-day lake distribution to guide the topographic generation, we used previously mapped paleo-basins [9]. This provides an accurate representation of both the actual long wavelength topography and the fractal nature of the short-wavelength topography of both poles, allowing us to test the influence of topography on the distribution of lakes.

For this work, we first test the relative importance of climate, running models using the south polar climate with the north polar topography, which can be compared to models using north polar topography and the north polar climate. Next, to test the relative importance of topography, we run models using the south polar topography and the south polar climate to compare with the north polar topography and south polar climate. Finally, we test the importance of permeability, running models using the south polar topography, the south polar climate, and a higher aquifer permeability. This setup allows us to explore the climatic, hydrologic, and topographic influence on the north and south polar lake distribution.

Results: We first investigate the difference between north and south lake area from a purely climate perspective. Comparing the fractional lake area as a function of latitude at intermediate permeability (10^{-12} m^2) for the same north polar topography forced by the south and north polar climates, we find a modest difference between the two with a total lake area ratio of 0.64 (Fig. 1a-b, d). The more arid south polar climate results in a smaller total lake area at lower latitudes and a slight increase in lake area near the pole (Fig. 1d). The differences in climate results in an average fractional lake area decrease of 11% above 75°N (above which the majority of the lake area is concentrated) compared with the model using a north polar climate. The south polar climate model loses almost all lakes south of 75°N.

A model using the south polar topography and south polar climate shows that the distribution of basins and topographic lows has a minor influence on the distribution of lakes with a total lake area ratio of 0.87. (Fig. 1b-d). The differences in the topography result in an average fractional lake area decrease of 5% above 75°N compared with the model using north polar

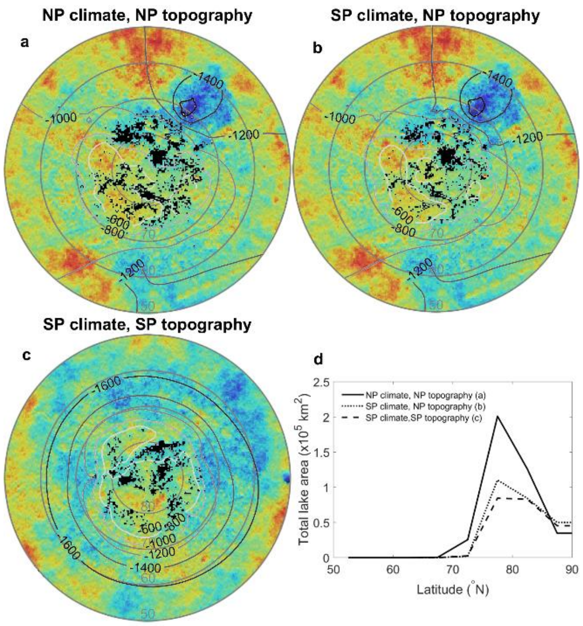

*Fig. 1. Modeled lake distribution (black) overlain on synthetic topography under the current **(a)** north polar climate and topography, **(b)** south polar climate and north polar topography, and **(c)** south polar climate and topography. **(d)** The influence of the topography and climate on the latitudinal distribution of lake area shown as the fractional difference in lake area for each model pair.*

topography. A larger number of deep depressions are found at lower latitudes in the south polar region, whereas a larger number of deep basins are concentrated at higher latitudes in the north polar region where methane is more stable. This facilitates the transport of methane away from the south polar lakes and toward the arid low latitudes.

However, the predicted lake area for the south polar region substantially exceeds the observed lake area in the models above. Large seas in the wetter polar regions are predicted at permeability values of 10^{-12} m^2 as large basins at high polar latitudes allow methane to accumulate and the intermediate permeability prevents this methane from draining to the more arid lower latitude regions (Fig. 1c). As the permeability is increased, lake area decreases because methane is transported to the arid low latitudes, and only small scattered lakes are predicted at high latitudes (Fig. 2b). Thus, another factor besides climate and topography must also play a role in the lake asymmetry.

Comparison of these results to the observed distribution of lakes at the south polar region suggests that increased permeability may be responsible for the observed lake distribution (Fig. 2c). In contrast, the north polar lake distribution requires a less permeable aquifer and significant evaporation suppression over the

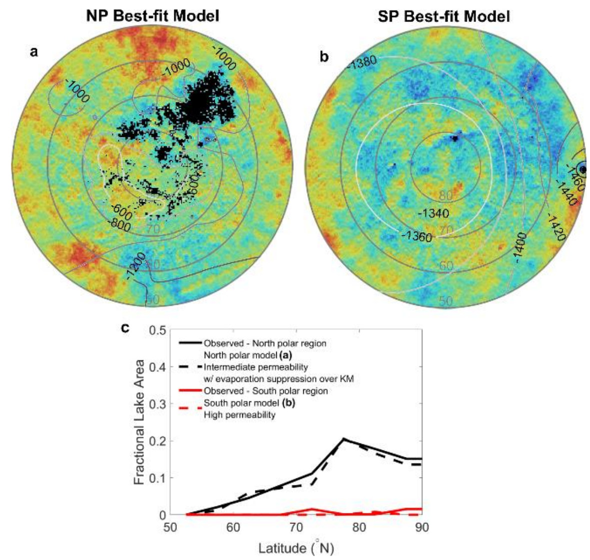

*Fig. 2. Modeled lake distribution (black) overlain on synthetic topography for **(a)** a north polar climate and topography with an intermediate permeability and evaporation suppression over Kraken Mare (KM), and **(b)** a south polar climate and topography with a high permeability aquifer. **(c)** The fractional lake area distribution as a function of latitude is shown for the observed distribution (solid lines) and for the two models shown in **(a)** and **(b)** (dashed lines).*

largest seas, Kraken Mare (Fig. 2a) [6]. A permeability difference between the north and south polar regions is possible given evidence for a possible polar deposit [10] and karstic features [11] suggesting that the permeability structure at both poles may be complex.

Conclusions: Though the south polar region is expected to be more arid than the north, we show that permeability, and to a lesser extent climate and topography can influence the distribution of lakes and total lake area. While the climate and topography of the south polar region exerts a modest control on the total lake area and lake distribution, this cannot explain the large lake area asymmetry [1]. However, difference in hydrologic conditions (i.e., permeability) between the north and south polar region can result in lake area distributions predicted by the model in good agreement with the observed lake distribution at both poles.

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