CONSTRAINING THE ROLE OF SEAS AND LAKES IN TITAN'S CLIMATE: THE TITAN MARE EXPLORER MISSION.
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Introduction: The lakes and seas on Saturn's moon Titan provide the first evidence for an active condensable-liquid cycle on another planetary body, and play a key role, like on Earth, in its climate. The methane cycle on Titan (Fig. 1) is dominated by precipitation in polar regions and evaporation in equatorial regions, allowing the surface bodies of liquid to persist near the North and South Poles [1, 2]. More than 400 lakes and seas have been seen in Cassini radar data [3, 4] ranging in size up to 100,000 km^2 [4]. Constraints on Titan's methane cycle, analogous to Earth's hydrologic cycle, can be made through measurement of the chemistry of the seas, the conditions at the sea surface, and the sea volume. The Titan Mare Explorer (TiME) is a Discovery-class mission that has just completed a Phase A study, that would constrain Titan's active methane cycle as well as its potentially interesting prebiotic organic chemistry by providing in situ measurements from the surface of a Titan sea.

Sea Composition: The stability of lakes and seas on Titan is dependent upon the abundance of methane in the atmosphere-surface system, as well as liquid methane in the subsurface. Therefore it is critical to constrain the amount of liquid methane in the lakes and seas, which are thought to primarily contain methane and ethane [1, 5]. Ethane is a dominant product of methane stratospheric photochemistry at Titan, and its presence in the seas would increase their stability against evaporation [6]. Ethane has been identified in Ontario Lacus by the Cassini VIMS instrument [7], late winter tropospheric clouds (which must be largely methane) have been identified above the lakes region [8], and methane and ethane were detected by the Huygens probe after landing [9].

The ratio of methane to ethane in the sea is important in constraining the rate at which methane is transfered to the atmosphere by evaporation, and thus the rate of mass and latent heat transfer from sea to atmosphere. The ratio also provides a constraint on how chemically "evolved" the system on Titan is. Methane is depleted in the upper atmosphere while ethane is produced. The ethane produced over Titan's history was most likely sequestered in the interior through clathrate formation when fresh ice was exposed by cryovolcanic eruptions [10], or simply by impact breach of the icy crust [11]. What ethane remains as lakes and seas could have been produced in the last ~10^8 years [12]. Knowledge of the methane/ethane ratio in the surface–atmosphere system would allow the timing of ethane production to be deduced. In the atmosphere, the vapor pressure of ethane is so low that the air can hold only a small fraction of the total ethane in the system. Therefore to determine the ratio in the system, the methane/ethane ratio in the sea, along with knowledge of the liquid volume, can be combined with the known atmospheric methane abundance. These data, along with more detailed sea chemistry and Cassini measurements of the photo-dissociation rate of methane, may provide an estimate of the time since the last major methane outgassing event (or the rate of outgassing, if this occurs continuously).

In addition to likely seasonal changes in lake composition and depth [8, 13], Titan's lakes and seas may take part in longer-term pole-pole transport forced by the changing astronomical configuration of the seasons, similar to the manner in which the glacial cycles of Earth and Mars are forced by Croll-Milankovich [14]. Evidence for this long-term transport on Titan may be the much higher number of lakes and seas in the north polar region in comparison to the south polar region.

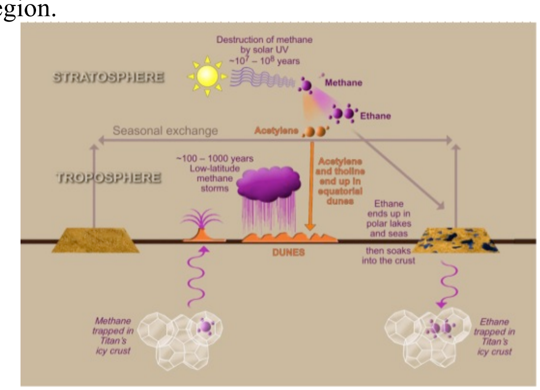

Figure 1. *Titan's methane cycle (after Lunine and Atreya [2]).*

Conditions at the Sea Surface: The Huygens probe has provided the only in situ data on Titan meteorology: an equatorial point-profile of wind speed and direction. However, models (e.g., [15]) indicate that the polar climate is distinctive. Conditions at the sea surface are likely to change over the course of a Titan day, driven by the diurnal variation in solar heating and the gravitational tide in the atmosphere forced by Saturn [16]. Measurement of windspeed, methane fraction in air and sea, and liquid temperature could be used to constrain evaporation in the Titan environment, using empirical terrestrial relations (e.g., [17]). In addition, observations from the sea surface would constrain atmospheric phenomena such as clouds, hazes, rain, and virga. Lorenz and Turtle [18] estimate that a 2500 hour mission may image rainfall as many as five times.

Sea Volume: To help to constrain the inventory of methane on Titan, it is necessary to determine the depth of the seas. The three seas, Ligeia, Kraken, and Punga, make up about 80% of the areal extent of all observed lacustrine features, with Ligeia accounting for about 30%. Depths of the smaller lakes can be constrained using empty lake basins [4]; if the three seas are of similar depth, measuring the liquid volume at Ligeia Mare will constrain at least one-third of the total lacustrine/sea contribution to Titan's organic inventory. The lack of a bottom return from large regions in the lakes and seas suggests that depths exceed the radar penetration depth of ~10 m (from the radar-absorptive properties of methane and ethane [19]). Based on comparisons to terrestrial lakes and seas, Lorenz et al. [12] estimated a central depth for Ligeia of 50–5000 m.

Estimates from Cassini radar data of the solid (dunes) and liquid organic inventory, while more than an order of magnitude larger than the carbon inventory in Earth's fossil fuel reservoirs [12] are far less than predictions for the potential cumulative organic inventory on Titan produced by photolysis of methane in the atmosphere over geologic time [20]. Initial estimates do that suggest that the seas buffer atmospheric methane against photolysis in the short-term [12], but resupply of methane from crustal or deeper sources must be occurring over the longer term. Constraining the surface liquid volume of methane to improve the estimate of the overall organic inventory is needed to better determine the rate of resupply of methane.

Titan Mare Explorer (TiME): The Titan Mare Explorer mission would operate for 6 Titan days (96 Earth days) at the surface of one of the large seas on Titan. The capsule would float with the winds and currents, possibly imaging a shoreline before the end of mission. The target for TiME is Ligeia Mare (78°N, 250°W), one of the largest seas on Titan with a surface area of ~100,000 km^2. TiME science objectives are: 1) measure the sea chemistry to determine their role as a source and sink of methane and its chemical products, 2) measure the sea depth to help constrain organic inventory, 3) constrain marine processes including sea circulation and the nature of the sea surface, 4) determine sea surface meteorology, and 5) constrain prebiotic chemistry in the sea. TiME instruments include a mass spectrometer, a physical properties and meteorology package, and an imaging system. The science objectives of TiME are directly responsive to goals from the 2003 and 2010 Solar System Decadal Surveys [21, 22], including understanding volatiles and organics in the solar system, through TiME measurements of organics on another planetary object, and understanding planetary processes, through TiME's first in situ measurements of a liquid cycle beyond Earth.

TiME would launch early in 2016, with an arrival in 2023. Earth spends much of each Titan day at elevations well above the horizon to permit direct transmission of data from the sea surface direct to the Deep Space Network throughout TiME's three-month nominal mission. A launch date for TiME before 2020 is enabling; launching after that date would result in an arrival during northern winter on Titan, after the sun and Earth have set, making direct to Earth transmission infeasible, and minimizing science observations of the sea surface, atmospheric phenomena, and shorelines.

TiME's high heritage instruments, simple surface operations, government-furnished launch and power systems, and relatively benign entry, descent and splashdown conditions make a lake lander mission to Titan achievable as a Discovery-class mission.

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