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Twilight on Ligeia: Implications of communications geometry and seasonal winds for exploring Titan's seas 2020–2040

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Abstract

Titan's lakes and seas are targets of particular interest for future exploration. We review candidate splashdown areas in Ligeia and Kraken Mare, and Ontario Lacus. Titan's thick and dense atmosphere means that landing dispersions of spacecraft are dominated by uncertainties in wind drift, and thus the feasibility of landing safely in the sea with a simple Huygens-like descent system (i.e. without guidance or propulsion) is dependent upon these uncertainties being small enough that the landing point dispersion lies within the sea. Because Titan's winds vary with season, notably through the formation of a high-speed stratospheric jet in the winter hemisphere, landing point dispersions are seasonally-dependent as well as latitude-dependent. Ligeia Mare, at 78°N, sees relatively small dispersions but offers viable Direct-to-Earth (DTE) communication only until 2024. A wide part of Kraken Mare (450×90 km) at 70°N can be comfortably reached at all times, and is viable for assured Direct-to-Earth communication until 2026, or with a relay spacecraft thereafter. The seasonal geometry permits DTE from the northern seas again after 2040. Wind dispersions are always too large for Ontario, unless a steerable parachute or similar system is used to tighten the landing ellipse.

Keywords: Titan; Mission design; Direct-to-Earth communications; Wind dispersions; Navigation

1. Introduction

Among Titan's many interesting features such as dunes and river channels revealed by the Cassini–Huygens mission (e.g. Lorenz and Mitton, 2010; Coustenis and Taylor, 2008; Brown et al., 2009), perhaps the most striking aspect is Titan's geographical diversity and in particular that there are major and systematic variations with latitude of the character of the surface and the properties of the atmosphere. Of these variations, most remarkable is the presence of large and persistent bodies of hydrocarbon liquids at high latitudes and especially the north. These seas and lakes have attracted great interest as targets for future exploration, most recently as the Titan Mare Explorer (TiME) Discovery mission concept (Stofan et al., 2013, Fig. 1) but also the National Research Council/NASA Decadal Survey Titan Lake Lander circa 2010 (JPL, 2010 – see also Space Studies Board, 2012), and a landed element in the NASA–ESA TSSM (Titan Saturn System Mission) study of 2008 (ESA, 2009; Reh and Elliott, 2010), as well as more recent ideas (Mitri et al., 2014). In addition to the scientific appeal of in situ study of Earth-like air–sea interactions and a major volatile reservoir and chemical deposit of astrobiological interest, Titan's seas offer the practical convenience of safe landing by splashdown and thereby avoid the need to provide retropropulsion, impact attenuation by airbag or other systems that would be costly to develop and test for the Titan environment. However, to exploit splashdown obviously

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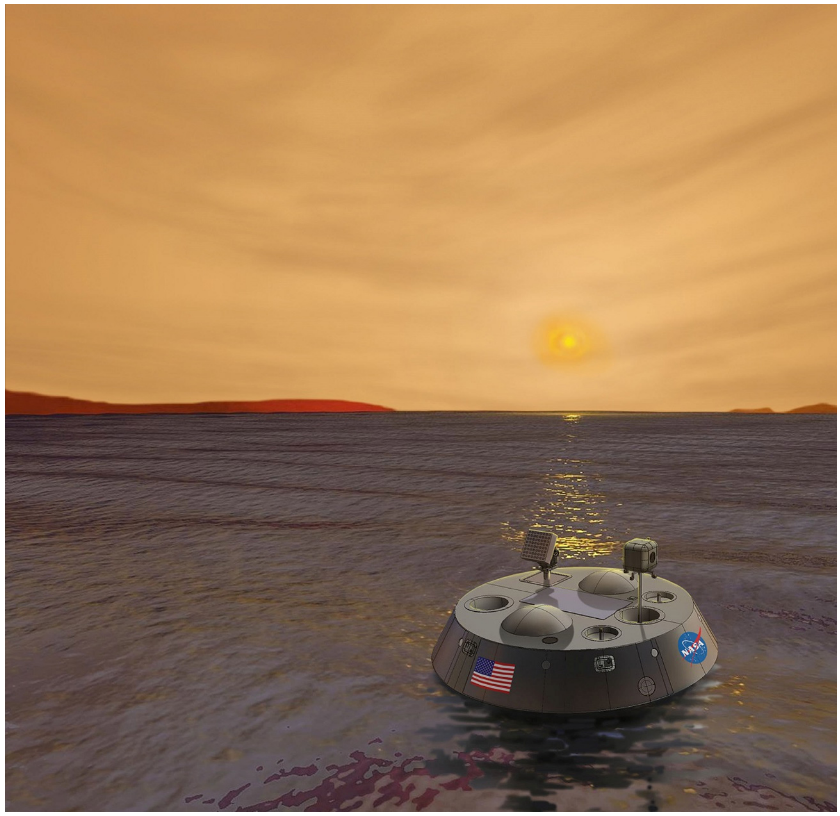

Fig. 1. Artist's concept of the Titan Mare Explorer (TiME) mission, as conceived at the beginning of the Phase A study (May 2011). An instrumented capsule, with a camera and planar communications antenna, is shown on Ligeia Mare, with the sun low in the sky. Image: Johns Hopkins Applied Physics Laboratory/Lockheed Martin.

requires that the vehicle land at sea, and doing so requires quantitative consideration of the target areas involved and the dispersion of the splashdown points by the wind profile.

Because of Titan's effective obliquity (actually, largely due to Saturn's obliquity of 26.7°), the polar regions see considerable seasonal variation of solar and earth elevation. This directly influences illumination, and the possibility of Direct-to-Earth communication, and indirectly influences winds, which (especially in the stratosphere) change significantly with season.

A previous paper (Lorenz et al., 2012a), informed by Cassini and groundbased observations and four independent Global Circulation Models (GCMs), summarized northern summer polar wind conditions (specifically, regions north of 70°N, during the 2023–2024 period, or solar longitude $L_s \sim 150^o–170^o$) and presented a simple analytical formulation of expected, minimum and maximum winds as a function of altitude, with specific reference to the Titan Mare Explorer (TiME) Discovery mission (Fig. 1). The present paper considers (and quantifies) a broader range of target locations and seasons to inform prospects for future missions to Titan's seas, in which considerable interest remains (e.g. Mitri et al. (2014)).

2. Geographic and astronomical context

Titan's seas, while anticipated before Cassini, were only revealed (in winter darkness) over two years after Cassini's arrival. Mapping (Fig. 2) by radar showed (Stofan et al., 2007; Lopes et al., 2007; Aharonson et al., 2009; Lorenz et al. 2014) many small lakes around Titan's north pole, and then three major seas (in order of increasing size, Punga Mare, Ligeia Mare and Kraken Mare). These are also now being mapped in the near-infrared (e.g. Sotin et al. (2012)) as we move towards northern summer. The southern hemisphere lacks such seas, having only one major lake (Ontario Lacus).

2.1. Target areas and tolerable footprints

We consider four target areas. The first is Ligeia Mare, the nominal target of the TiME mission. Being the northernmost, however, this becomes unusable for Direct-to-Earth communication earliest as the sub-Earth point migrates south in the 2020s. The next two are regions of Kraken Mare: this body – the largest sea on Titan – is somewhat irregular in shape (which may lead to interesting