Numerical Calculations of the Longevity of Impact Oases on Titan

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Impacts onto Titan's surface can provide sufficient energy to create significant melt within the craters they form (Artemieva and Lunine 2002). We numerically model the cooling and freezing of liquid water and water-ammonia melt pools in impact craters on Titan to determine how long these liquid environments may remain stable on the surface of Titan. These 'impact oases', and the duration of their existence, have significant astrobiological implications.

Many photochemical products result from the interaction of Titan's atmosphere (mostly methane and nitrogen) with solar UV, such as hydrocarbons and nitriles including HCN, CH_3CN, and C_2N_2 (Lorenz and Mitton 2002). These products condense as liquids or solids in Titan's lower atmosphere and are eventually deposited on the surface. While these molecules may be significant precursors to those associated with life (such as amino acids and nucleic acids), they cannot make that evolutionary leap without exposure to a polar solvent such as liquid water, which cannot exist in equilibrium with the present surface temperature of 95 K. Additionally, to make biologically significant molecules, oxygen is required, but oxygen containing molecules are extremely rare in Titan's atmosphere (Lorenz and Mitton 2002), and while water ice probably makes up a significant fraction of Titan's surface, water is not expected to be present in liquid form given the low surface temperature.

If a liquid water medium were to be present on Titan's surface for a period of time, it could serve as both a medium in which chemical synthesis could occur, and as a source of oxygen which is necessary for the conversion of basic nitriles to biologically significant molecules (Khare et al. 1986). Thompson and Sagan (1992) suggested that the temporary liquid environment created during an impact could provide such a medium, and made preliminary analytical calculations to determine how long such environments may persist.

Using a finite-difference thermal code (which explicitly includes the latent heat due to phase changes), we have simulated the cooling of impact-generated melt in craters on Titan for a wide variety of crater diameters, depth/diameter ratio, volume fraction of melt, post-impact temperature profiles, and compositions (pure water or ammonia dihydrate). For example, we find that a 15 km diameter crater in water ice with a depth/diameter (d/D) ratio of 0.1 and a volume fraction 0.05 of liquid can sustain the liquid for about 1,000 years. For the same crater in ammonia dihydrate, the liquid can persist for about 2,000 years. A 150 km crater in water ice with d/D of 0.05 and a volume fraction 0.1 of liquid can sustain the liquid for about 50,000 yr, and for the same crater in ammonia dihydrate, liquid can persist for about 100,000 yr. Compared to Thomson and Sagan's (1992) estimates of cooling times, our estimates are 1-2 orders of magnitude lower. We believe that this is the result of our use of a more advanced thermal model with a more realistic crater and melt sheet geometry.

Our calculations confirm the longevity of transient aqueous environments on Titan, and the timescales we obtain for their existence might be long enough for low temperature synthesis of carboxylic acids, including amino acids, and more speculatively, peptides. Whether self-organizing chemistry could occur will have to await surface exploration in the form of post-Cassini missions to Titan's surface. Our results indicate the burial depth and spatial extent of the most processed material, where sampling by future missions to Titan should most profitably be directed.

References:

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