THE CHEMICAL CHARACTERISTICS OF A TERRESTRIAL-LIKE PLANET AT TITAN'S DISTANCE.

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Introduction: Despite Titan's distance from the Sun, it is characterized as Earth-like. Titan has a moderate atmosphere that is ten times more massive than Earth's, albeit Titan is less than half the size of Earth. It also has weather patterns with rain, clouds, and wind [1], and even rivers, lakes, and seas [2]. However, there are two important differences between Titan and Earth — Titan is much colder with more atmospheric methane. A warmer Titan would have driven off volatiles like methane during its formation so the lower temperature and the larger methane abundance helps to explain the important role of Titan's organic inventory.

The story of Titan's organic inventory begins with methane vapor. Its source is Titan's surface, where ~5% is recycled into an otherwise mostly pure N_2 atmosphere. ~2% of the methane is then transported into the upper thermosphere where CH_4 and N_2 are dissociated from solar UV photons and energetic particles from Saturn's magnetosphere [3]. The many by-products resulting from the photodissociation of methane and the nitrogen atoms and ions are observed by the Cassini Composite Infrared Spectrometer (CIRS) [4]. These photofragments, atoms, and ions then recombine into more exotic trace organics, and these trace compounds in turn combine, polymerize, and form Titan's ubiquitous photochemical aerosol [5]. The aerosol drifts downward and becomes ice-coated in the stratosphere as a result of vapor condensation from the trace organic vapors that are also created at these high altitudes from the same photochemical processes as the aerosol [6].

The formation of Titan's organic stratospheric clouds is a direct result of the general circulation pattern. The winter and summer seasons in the stratosphere are marked by a cross-equatorial circulation, with subsidence over the winter pole, similar to Earth. At high altitudes the associated adiabatic heating dominates, producing high temperatures over the winter pole. Lower down, radiative cooling dominates, and yields a cold polar stratosphere. Here the trace organic vapors condense and precipitate to form successive pure and mixed ice cloud layers; these clouds are also observed by CIRS [6, 7]. Titan's stratospheric cloud structure is therefore the most complex of any observed in the solar system, forming over a dozen organic ice compounds by way of vapor condensation processes. Ice thin film transmission spectra are then obtained from the NASA-GSFC SPECtroscopy of Titan-Related ice AnaLogs (SPECTRAL) chamber, in order to determine the relative abundances and identify the observed ices.

In addition to vapor condensation processes, evidence is steadily mounting for solid-state chemistry as an alternate formation mechanism for the production of some stratospheric ice clouds [8]. Such processes are similar to the heterogeneous surface chemistry that occurs in Earth's polar stratosphere, which is known to produce nitric acid coatings on terrestrial water ice particles — this process is ultimately responsible for the ozone holes in Earth's stratosphere [9]. The cold temperatures in Titan's lower stratosphere and the associated strong circumpolar winds that isolate polar air act in much the same way as on Earth. This gives rise to compositional anomalies and stratospheric condensate clouds that are the sites of heterogeneous chemistry [8]. While there are differences in detail — the terrestrial case entails oxygen and halogen compounds, whereas Titan's chemistry involves organics — the overall picture is remarkably similar on the two worlds.

Titan's organic aerosol and most of the stratospheric organic icy material will deposit onto its surface. If Titan were a large enough planet, and it had processes (*e.g.*, plate tectonics on Earth) that could drive or transport the surface organic material containing hydrogen, nitrogen, and carbon deeper down into the lithosphere, then this would be the means of bringing this organic material down to where it is warm enough to reach liquid water. The opportunity may then arise to create biotic precursors such as amino acids on such a terrestrial-like planet. We are using Titan as an observed example of a terrestrial-like exoplanet in order to show that the organic chemistry in such a planet's atmosphere is inevitable at a Titan-Sun distance. Such a distance from the host star is necessary so the volatiles are retained and not driven off during the planet's formation.

References: [1] Porco *et al*. (2005), *Nature* 434, 159-168. [2] Turtle *et al*. (2009), *GRL 36,* L02204. [3] Yung *et al*. (1984), *ApJ Supplement Series* 55, 465-506. [4] Coustenis *et al*. (2007), *Icarus* 189, 35-62. [5] Waite *et al*. (2005), *Science* 308, 982-986. [6] Anderson *et al*. (2010), *Icarus* 207, 914-922. [7] Anderson C. M. and Samuelson R. E. (2011), *Icarus* 212, 762-778. [8] Anderson *et al.* (2016), *GRL* 43, 3088–3094. [9] Molina *et al.* (1987), *Science* 238, 1253-1257.