PROJECTING THE EVOLUTION OF TITAN'S ATMOSPHERE UNDER A REDDENING SUN

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WHAT'S SO SPECIAL ABOUT TITAN? Titan is of significant astrobiological interest, due in most part to its thick atmosphere, unique amongst the moons in our solar system. Its atmospheric mixture of nitrogen, methane and other organic molecules, with a surface temperature of <100K, makes Titan comparable to a frozen primordial Earth. An orange haze layer, consisting mostly of complex organic molecules, shrouds the moon's surface from view, indicating that complex reactions under photolysing Lyman α radiation from the Sun occur in Titan's atmosphere. This preliminary study presents an analysis of the evolution of Titan's atmosphere and conditions as the Sun becomes a red giant over the course of the next 7.6Gyr.

A CLOSER LOOK AT TITAN

CLICK HEADINGS FOR FURTHER DETAILS

METHANE PROFILE, PHOTOLYSIS & HAZE LAYER FORMATION

SOLAR IRRADIATION INTENSITY & SPECTRUM

TEMPERATURE PROFILE

METHANE CYCLE

PRELIMINARY CONCLUSIONS & FUTURE WORK: Titan is expected to experience an increase in temperature over the course of the next 7.6Gyr, as the Sun becomes a red giant, to reach surface temperatures >200K around 11.9Gyr. At this stage, Titan could possibly still maintain a reducing methane atmosphere, therefore bringing Titan closer to hypothesized primordial Earth conditions and in turn rendering the formation of more complex organic molecules on Titan feasible. Similar conditions to those in which life originated on Earth 3 billion years ago could thus be present on Titan at a solar age of around 12Gyr. Further work would analyse methane replenishment mechanisms and aim to determine if this would be maintained throughout the entire timeline studied. In addition, photolytic pathways for methane and consequent formation of complex organics could be further explored.

Solar Irradiation Intensity & Spectrum

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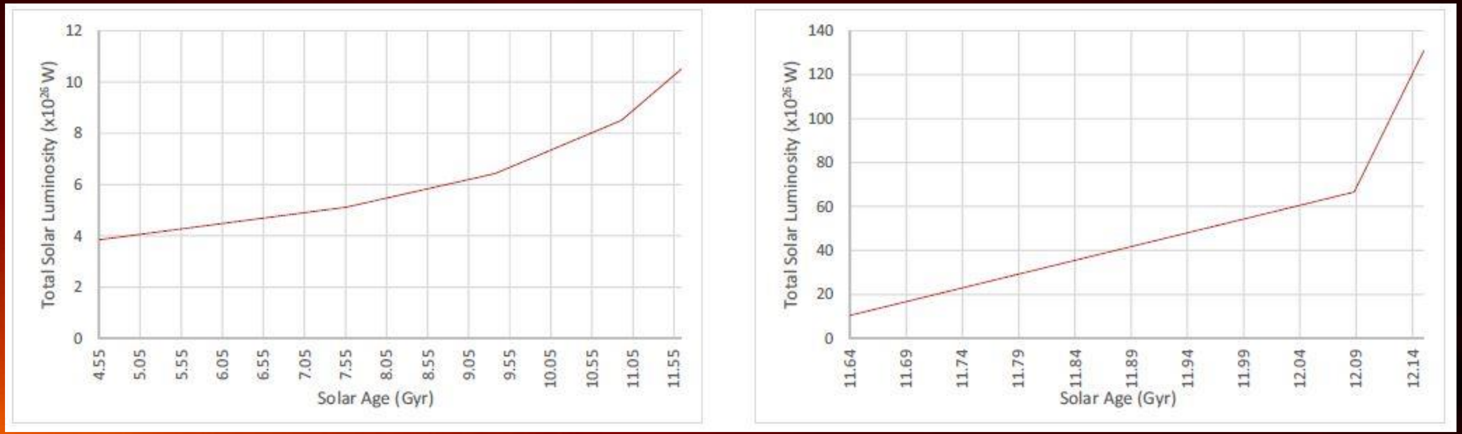
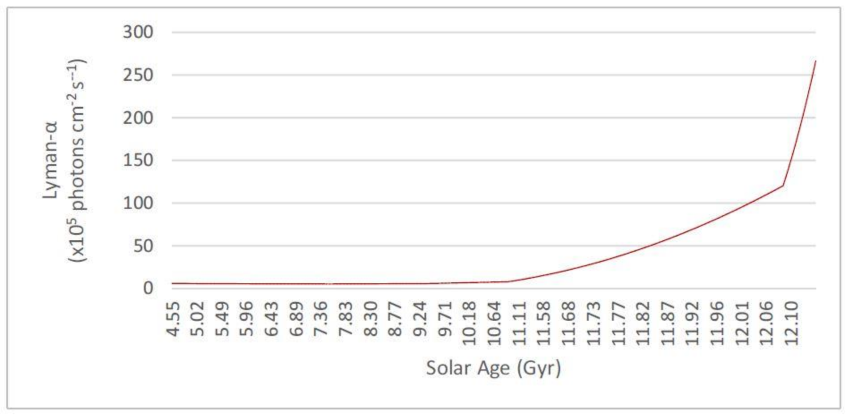
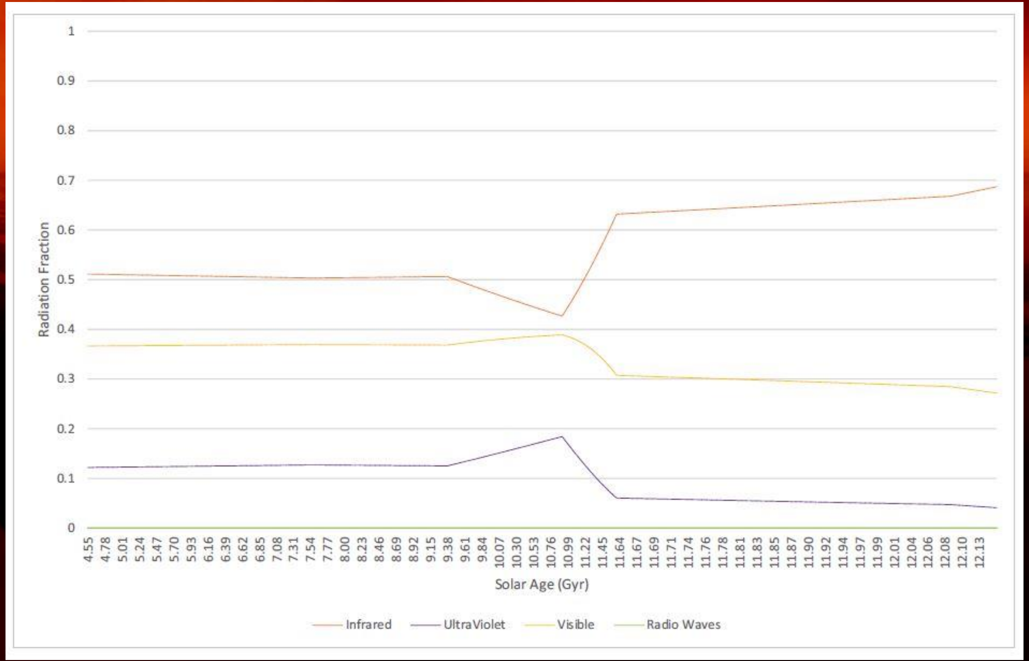
Incoming solar radiation varies in both intensity and spectrum as the Sun approaches its red giant phase. Based off a literature solar model, the varying solar irradiation was used as a model input for Titan. This was used to determine altitudinal temperature profiles, significantly due to variations in altitudinal concentrations of methane. This resulted in a varying greenhouse effect over time, which itself resulted in variation in methane evaporation rates over time. Variations in solar Lyman α radiation input were separately considered, and used to analyse photolytic rates of methane at different altitudes.



Variation in total solar luminosity with time, from present solar age (4.55Gyr) till 9.37Gyr (left) and solar ages 9.37Gyr till 12.15Gyr (right)



Variation in Lyman- α actinic flux with time, from 4.55Gyr to 12.15Gyr



Fractions of different solar radiation spectrum domains as varying with time, from 4.55Gyr to 12.15Gyr

Methane Cycle

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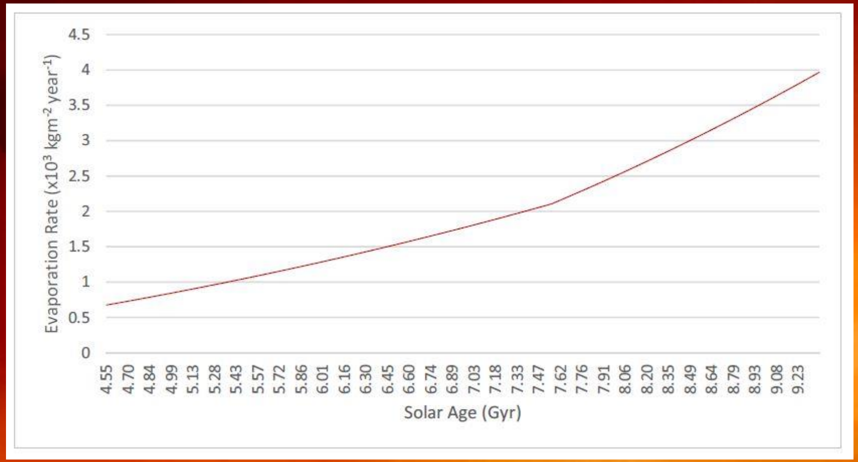
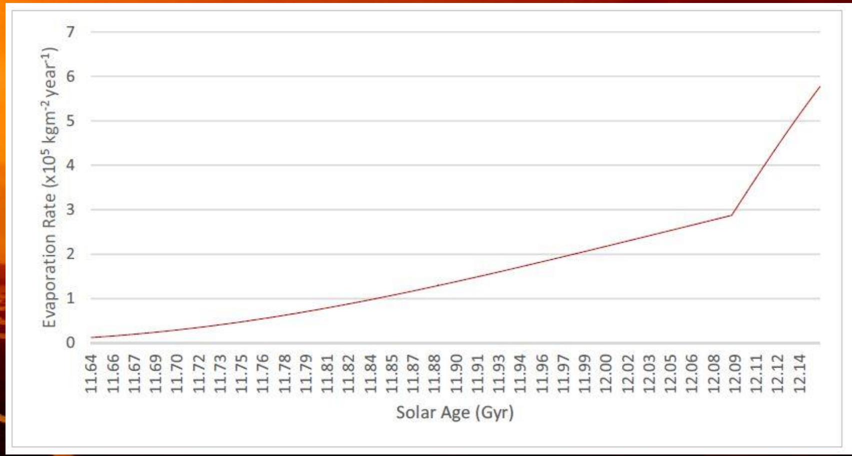
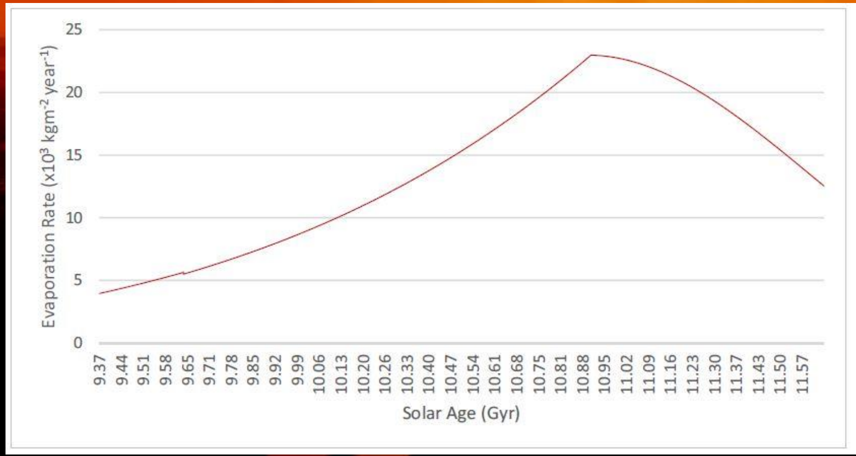
Due to a significant concentration of methane at Titan's surface and in Titan's troposphere, Titan has an ongoing methane cycle analogous to Earth's water cycle. Methane evaporates from Titan's surface lakes, forms methane clouds and precipitates back to Titan's surface. The changing rate of evaporation and precipitation was investigated.







Variation of evaporation rate from Titan's surface lakes over time, calculated using the Bulk Aerodynamic method. Evaporation rates were found to vary with changes to surface temperatures on Titan, as expected. A current (4.55Gyr) evaporation rate of ≈0.675x10^3 kg m^{-2} yr^{-1} was calculated, within range of quoted values (between 0.3 and 5.0x10^3 kg m^{-2} yr^{-1}) in literature.

Titan was only fairly recently confirmed to have large surface lakes, spanning over around 15% of the moon's surface area. Lakes of methane likely sustain a methane rich atmosphere, although the replenishment mechanism for these methane lakes themselves is unknown. For this study, the current lake reservoir on Titan was assumed to be maintained throughout the course of time covered.

Methane Profile, Photolysis & Haze Layer Formation

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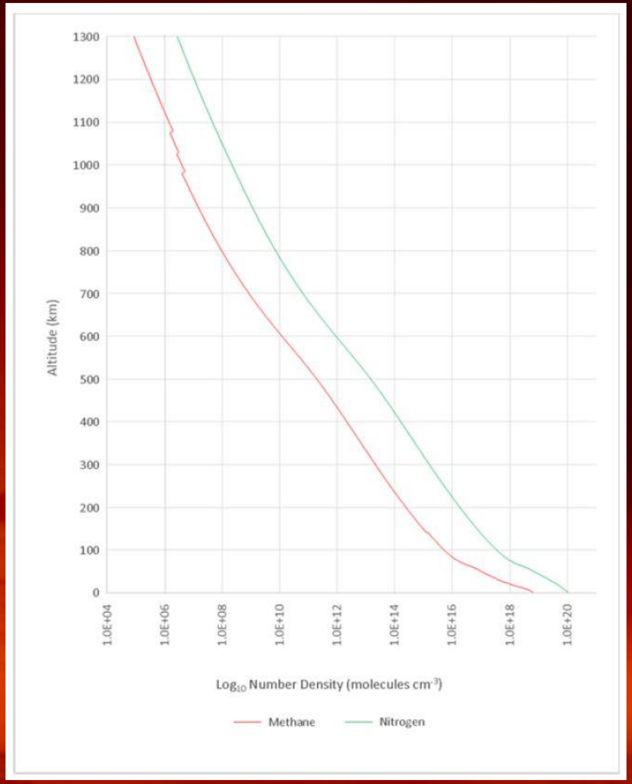
Variation in altitudinal levels of methane was investigated, and the change in altitudinal concentrations of methane over time was assessed. The photolytic breakdown of methane in Titan's atmosphere results in the pressure-dependent formation of complex organic molecules, termed aerosols, that form Titan's characteristic orange haze. Methane photolysis via Lyman-α radiation occurs via three main pathways, with specific quantum yields ϕ.

$CH_4 \rightarrow CH_3 + H$ ϕ=0.41

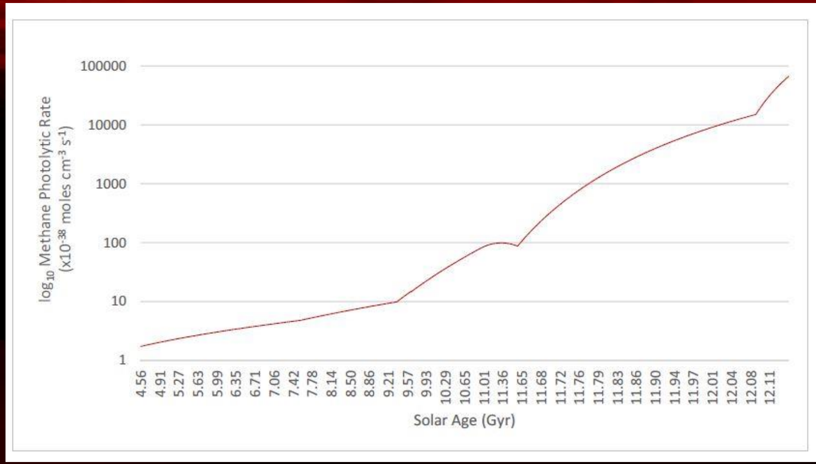
$CH_4 \rightarrow CH_2 + H_2$ ϕ=0.53

$CH_4 \rightarrow CH + H + H_2$ ϕ=0.06

Preliminary results indicate that a concentration of methane will persist at Titan's lower altitudes, notwithstanding methane photolysis from Lyman-α radiation, provided that current estimated surface lake area and volume is maintained. This allows for replenishment of photolysed methane via lake surface evaporation and atmospheric vertical transport. Further investigation into possible replenishment mechanisms for methane on Titan is required to validate such conclusions.



Altitudinal variation in the two major constituents in Titan's atmosphere, nitrogen and methane, at the model starting point (4.55Gyr). These values were in turn used to calculate altitudinal pressure profiles, methane photolysis rates, infrared radiation absorption at different altitudes resulting in a global warming effect and Rayleigh scattering of incoming radiation, as well as pressure-dependent haze layer formation rates. The altitudinal variation of methane with time, as a result of photolysis, the methane cycle and methane transport, in turn allowed for the computation of varying temperature and pressure profiles amongst others.



Variation in total photolytic rate of methane on Titan with time, resulting from increased total Lyman-α radiation actinic flux over time.

Temperature Profile

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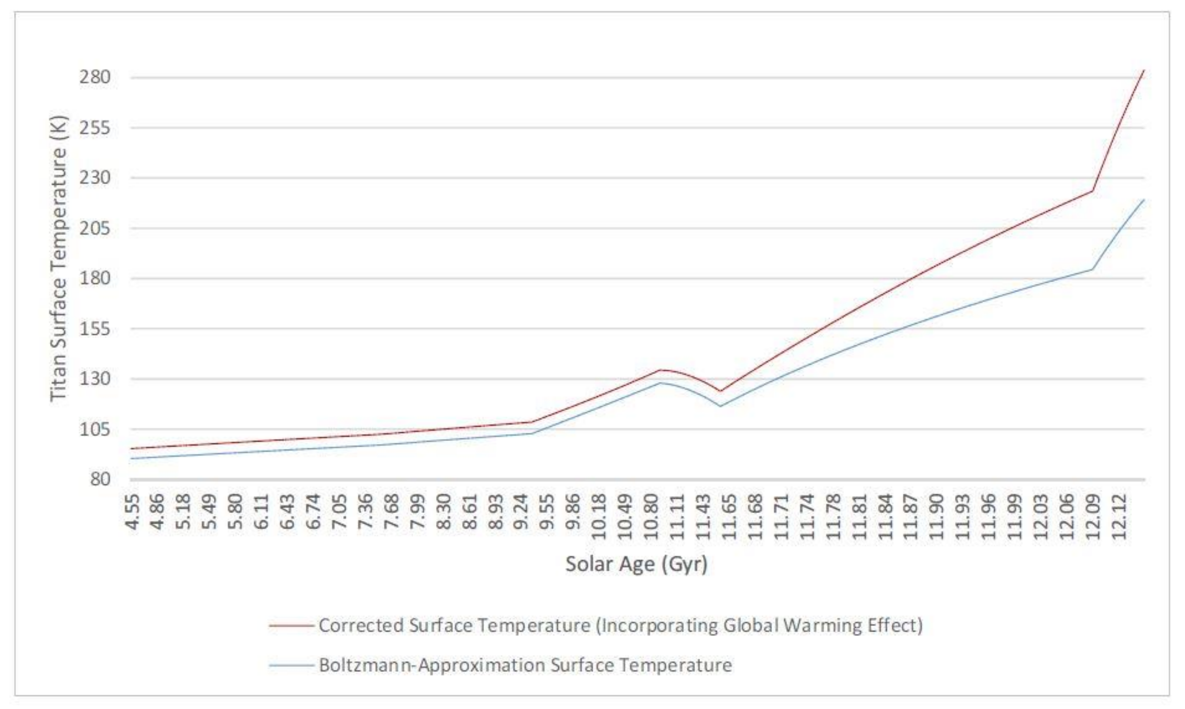
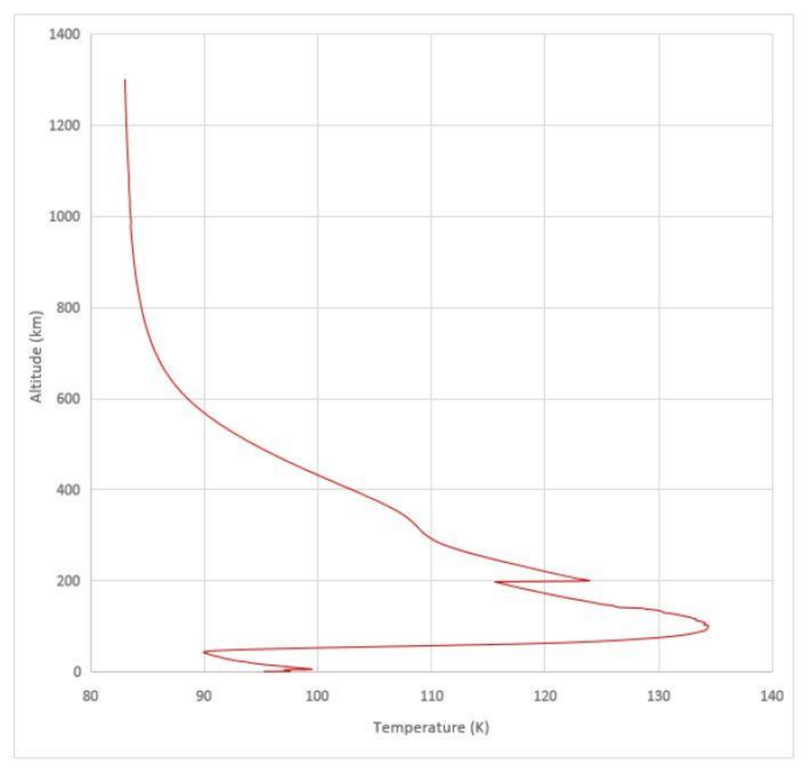
Temperature-altitude profiles were calculated for Titan across the entire studied timespan. Altitudinal variation of temperature was found to be strongly correlated with altitudinal variations in methane, which exhibits a considerable greenhouse effect. Feedback from altitudinal variations of methane with time resulted in subsequent variations in temperature-altitude profiles, coupled with the changing solar irradiation as the Sun becomes a red giant. It was found that surface temperatures will increase over time, with surface temperatures >200K projected at around solar age 11.9Gyr and after. Current surface temperature retrieved from the model was of approximately 95K, in concordance with surface temperature measurements from the Huygens probe.



Surface temperature variation over time, showing the Boltzmann approximation and the temperature corrected for global warming effects due to methane.



Temperature-altitude profile for Titan at current solar age, 4.55Gyr, using temperature values corrected for global warming effects.