National Aeronautics and Space Administration

Degradation of organics and microorganisms in Enceladus' plume deposits

Principal Investigator: Edith Fayolle (322); Co-Investigators: Tom Andre Nordheim (322), James Sinclair (322), Mathieu Choukroun (322), Robert Hodyss (322), Aaron Noell (389)

Program: FY21 R&TD Innovative Spontaneous Concepts

Background

Enceladus is a prime target in the search for life beyond Earth because its sub-surface ocean is in contact with a rocky core which may create hospitable conditions for life to develop. Plumes followed by redeposition likely bring some of the ocean content up to the surface where potential future missions may be able to measure it in situ.
But would organic molecules related to biological activity, or even living organisms, be able to survive the radiation environment and the low temperatures found at the surface?

Cassini sampled Enceladus' plume and revealed a composition dominated by water as well as relatively large amounts of organics, ~1% in mass (Postberg et al 2018). Modeling of the plume activity by Southworth et al (2019) estimated the redeposition rate on the surface to be as high as ~ 0.1 to 1 mm/year. The dose of energetic particles, such as electrons, appear to be low enough that degradation of organics at Enceladus' surface via radiolysis is not significant (Nordheim et al., in prep).
However, the flux of solar UV photons is not negligeable at Enceladus, and these particles are energetic enough to photolyze organics and inactivate potential microorganisms on Enceladus' surface.

Approach and results

Laboratory experiments measured the degradation rate of biomolecules and the inactivation of microorganisms by UV photons and at temperatures under 100K (e.g. Johnson et al 2012, Munakata et al 1991, Fayolle et al 2020). We used these wavelength-dependent photolysis rate as model inputs and extrapolated them over a wider wavelength range using their absorption profile.

The fraction of organic/microorganism survival is given as

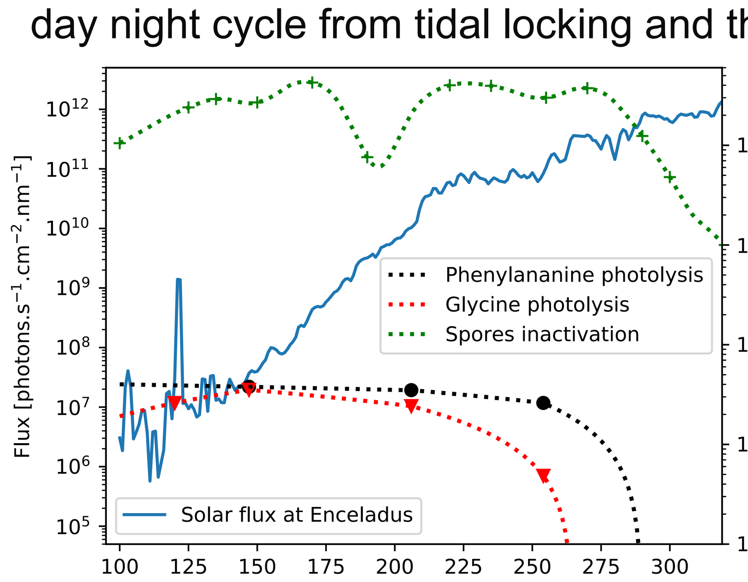
f=exp(-flux x photolysis rate x time between grain deposition)

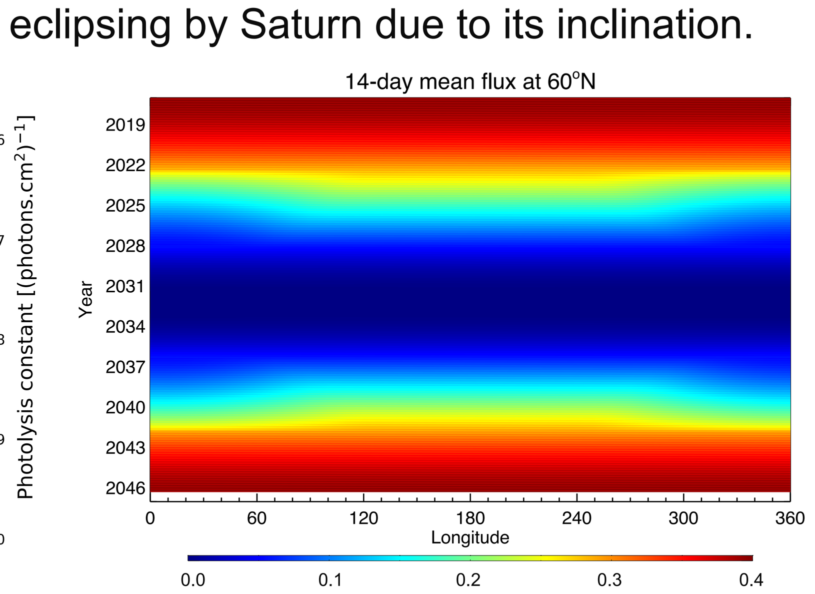
with the flux as a function of time and latitude, and being attenuated by the amount of darkening material in the grain and scattering versus ice depth.

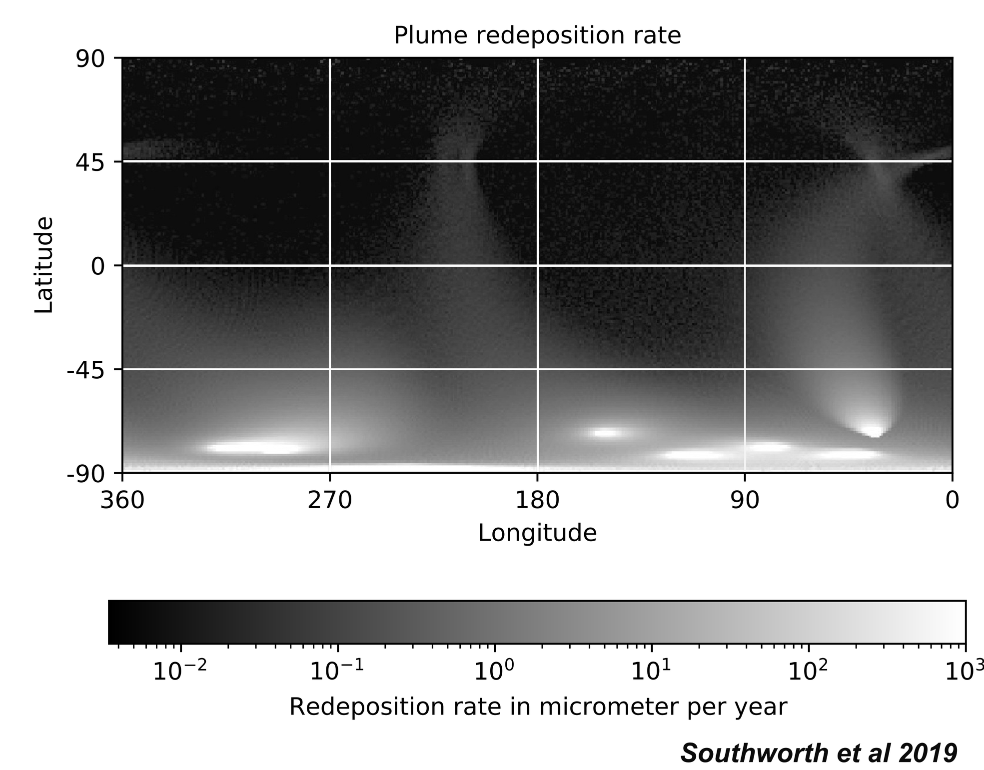
We adopted a mean ice grain diameter of 6 micrometers (Ingersoll & Ewald, 2011) and assumed bubble-free intimate mixtures. We explored the effect of the ice grain size in the micron range but it did not affect our results since scattering in the UV takes over quickly and only the grains at the top surface undergo photolysis. We also assume that sintering is not taking place given the timeframe and surface temperature (Molaro et al. 2019, Choukroun et al 2020).

We explored the effect of the amount of "darkening material" present in the water ice grains, which is determined to be around 1% and to be "tholin-like" according to surface albedo modeling by Hendrix et al 2012. We also assume that the amount of the organics studied here is extremely low compared to that of the "darkening material".

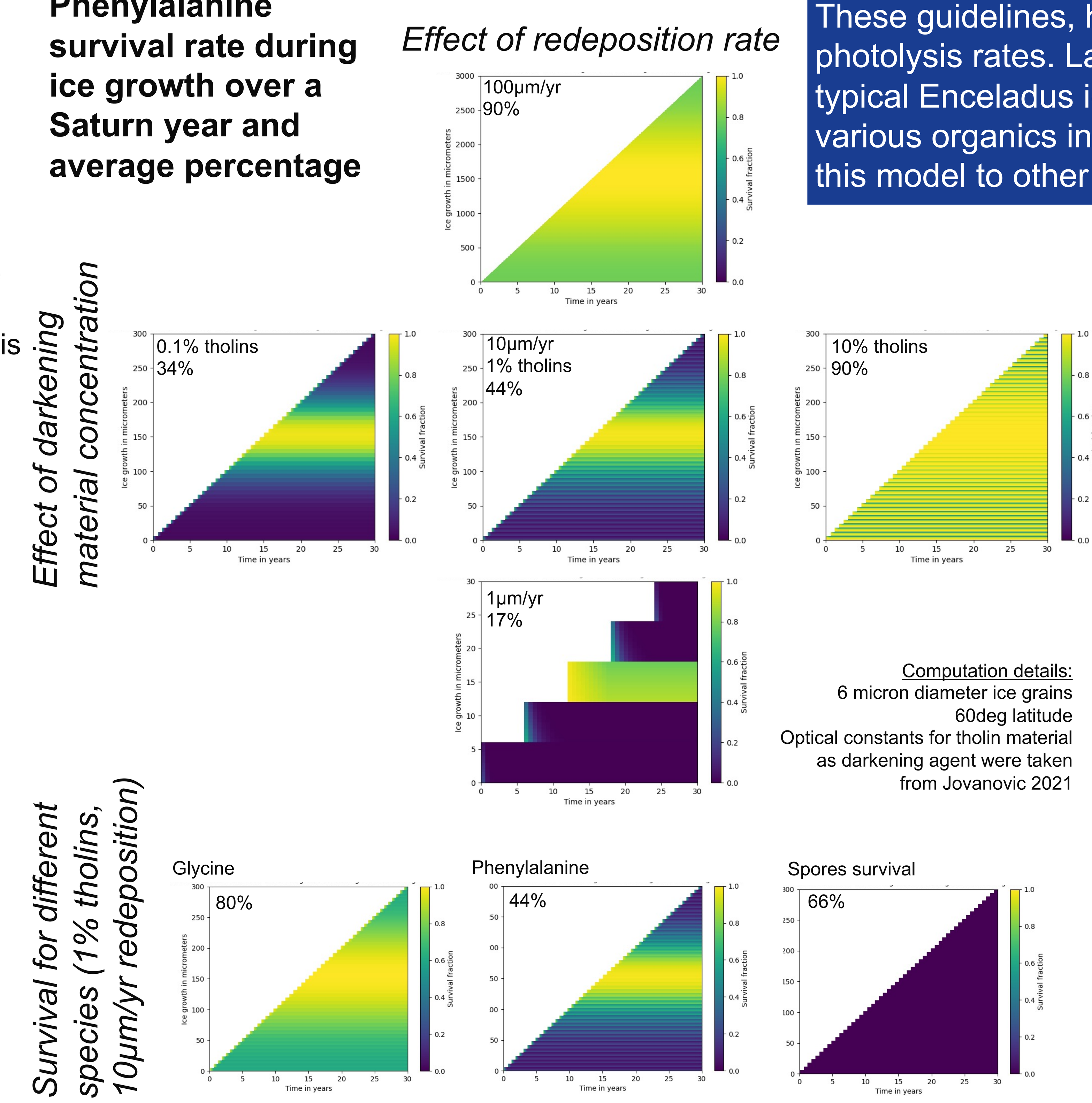
We calculate the 14-day mean flux versus longitude and latitude, taking into account the day night cycle from tidal locking and the eclipsing by Saturn due to its inclination.







Phenylalanine survival rate during ice growth over a Saturn year and average percentage



Objectives:

The overall goal of this ISC is to estimate the degradation of organics and the inactivation of potential microorganisms in plume deposits on Enceladus' surface to guide organic detection for potential future landed missions.
The objective is to build a model that computes survival fraction by combining
i) laboratory photolysis rate of organics and inactivation rate of spores,
ii) plume composition and redeposition rate estimates, and
iii) UV flux as a function of seasons and location.

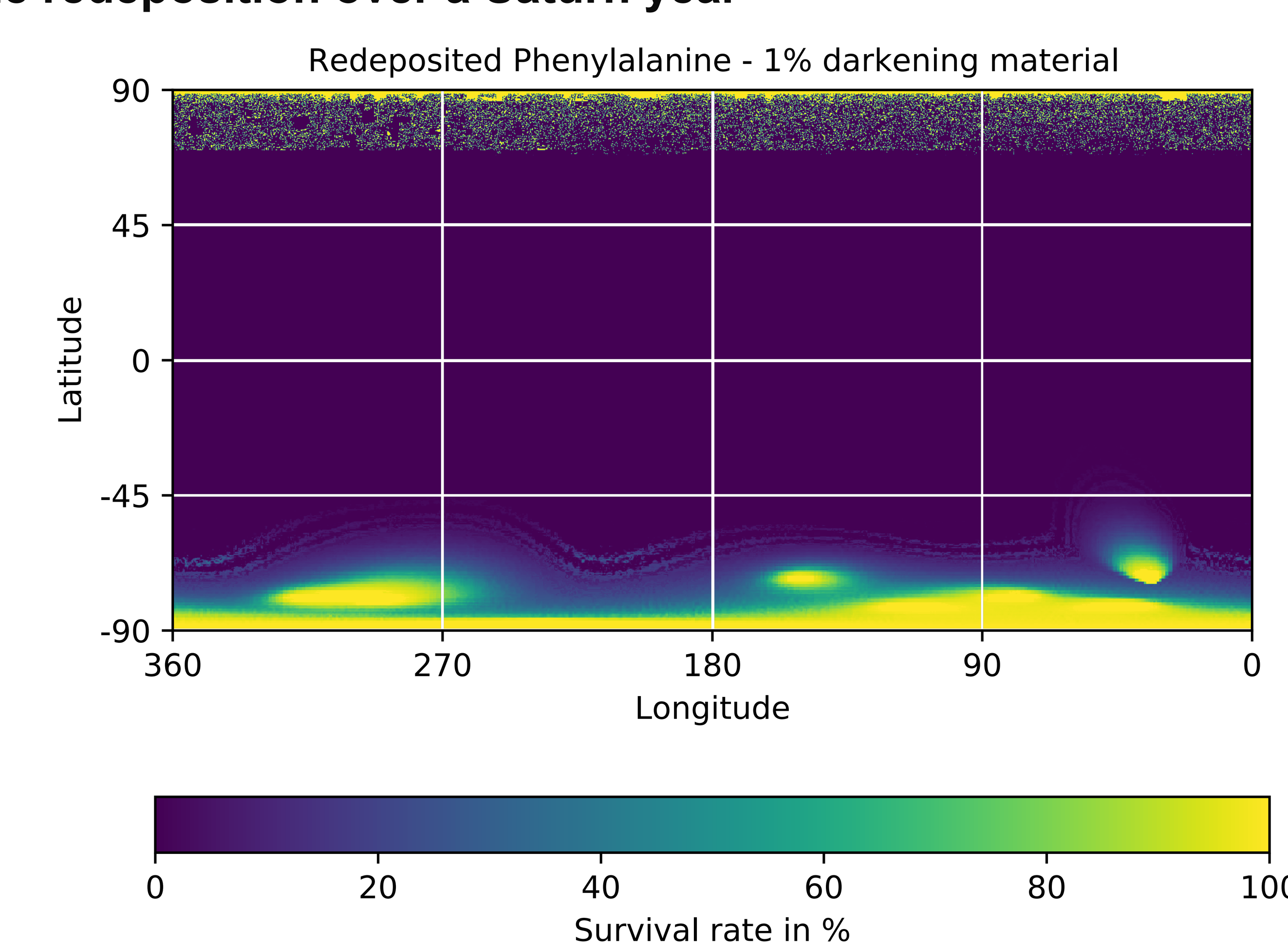
Conclusions/Significance/Benefits to JPL and NASA

The concentration of organics at the surface of Enceladus highly depends on the plume redeposition rate, the concentration of tholin-like material in water-rich grains, the latitude, and the photolysis spectrum of each specific organics.

Based on our current results, we provisionally advise potential future landed mission to consider sampling at locations where the redeposition rate is above 0.03 mm per year and at high latitude since more than 90% of most organics will likely be preserved in these regions.

These guidelines, however, rely heavily on calculated and extrapolated extinction coefficients and photolysis rates. Laboratory experiments are crucially needed to obtain refractive indices of typical Enceladus icy grain mixtures and measure wavelength-dependent photolysis rates for various organics in order to validate the numbers provided here and extend the applicability of this model to other chemical species.

Averaged phenylalanine survival rate from plume redeposition over a Saturn year



National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California
www.nasa.gov

PI/Task Mgr Contact
Email: edith.c.fayolle@jpl.nasa.gov

Clearance Number:
RPC/JPL Task Number: R21215