A POWER DRIVEN MODEL FOR PREDICTING MICROBIAL GROWTH IN POORLY CHARACTERISED ENVIRONMENTS. P. M. Higgins[1] and C. S. Cockell[1], [1] UK Centre for Astrobiology, School of Physics and Astronomy, University of Edinburgh, EH9 3FD, UK. Correspondence: p.m.higgins@ed.ac.uk

Introduction: An appropriate energy supply, whether perpetual or fleeting, is tantamount to the success of life in the Universe as we know it. Using the energetic approach to habitability [1], a new general astrobiological model concept has been developed which aims to estimate how much biomass an environment could provide were it to support life, and how that microbial community might affect the local chemistry.

The current understanding of the environmental parameters and potential habitability of locations throughout the Solar System varies substantially from Earth [e.g. 2] to Mars [e.g. 3, 4] and icy moons [e.g. 5, 6]. Data from space missions in the outer Solar System is limited and thus models are an important way to assess these extraterrestrial environments.

The Model: A new model concept for assessing the potential biological productivity of poorly characterised environments is proposed, in which a collection of organisms and their local environment are considered as self-contained objects communicating only via energy and nutrient exchange. By examining local energetic, thermodynamic, and chemical properties, the growth of a given population of organisms can be predicted yielding a first approximation of the levels of biomass which could be observed.

In qualitative terms the model proceeds as follows. Only a certain amount of energy from some environment can be recovered and stored. A portion of this is then periodically removed to quench some 'maintenance power', which encapsulates the energetic cost of biochemical processes required for proper cellular function [7]. The remainder of the energy can be used for growth. However, this can only occur if there is sufficient nutrient uptake from the proposed habitat to build the relevant structures (e.g. proteins and other biomacromolecules). More generally, the model estimates the habitability of environments by not only assessing energetic availability, but also whether there is enough to actually facilitate survival or even growth against local stresses.

An Example – Enceladus: To demonstrate the concept, several simulations of methanogens in an Enceladus' ocean 'sample' have been performed using the limited data available in the literature for this environment. Cassini measurements point to the existence of CH_4, CO_2, and H_2 in the subsurface ocean [e.g. 5] – the ingredients of the methanogenesis metabolism. However, predicting the actual oceanic composition of these species has proven difficult, limiting estimates to many orders of magnitude with strong dependencies on pH [5], which is poorly constrained itself, as somewhere between 8.5–13.5 [6, 8]. By iterating through microbial parameters such as maintenance, metabolic efficiency and P uptake, one can predict the final biomass amounts which a potential environment could sustain (e.g. Figure 1 overleaf). This picture changes considerably for different local pHs, temperatures and compositions.

Results and Conclusions: In the most thermodynamically favourable scenario, pH 8.5, the toy model predicts a maximum possible cell density of approx. 10^4–10^5 cells cm^{-3} and minimum of 0 (e.g. death of all cells injected). Assuming the former scenario, and a global temperature of about 273 K, the total biomass in the ocean could reach approx. 10^{10} kg. This represents a very slim slice of the potential environment, however, and in the majority of cases there is simply not enough energy available for methanogens to grow. The pH in particular is an important factor in this, adding a significant throttle to the energetic availability of methanogenesis at highly alkaline levels due to its effect on predicted temperature and composition by current models.

Unless better constrained, at the current level of understanding there is no definitive answer as to whether Enceladus' subsurface ocean could be habitable by taking an energetic approach, simply a small range of parameters which may be favourable for life. This provides an interval to keep in mind in future characterisations of the ocean and identifies pH as a critical parameter to estimate with greater confidence, less an entirely new compositional model is proposed.

References: [1] Hoehler T. M. (2007) *Astrobiology, 7.6*, 824–838. [2] Harrison J. P. et al. (2013) *Trends Microbiol, 21.4*, 204–212. [3] Ehlmann B. L. and Edwards C. S. (2014) *Annu. Rev. Earth Planet Sci, 42.1*, 291–315. [4] Fisk M. R. and Giovannoni S. J. (1999) *J. Geophys. Res., 104 E5*, 11805–11815. [5] Waite J. H. et al. (2017) *Science, 356.6334*, 155–159. [6] Hsu H-W. et al. (2015) *Nature, 519.7542*, 207–210. [7] LaRowe D. E. and Amend J. P. (2016) *ISME J., 10.6*, 1285–1295. [8] Glein C. R. et al. (2015) *Geochim. Cosmochim. Acta, 162*, 202–219.

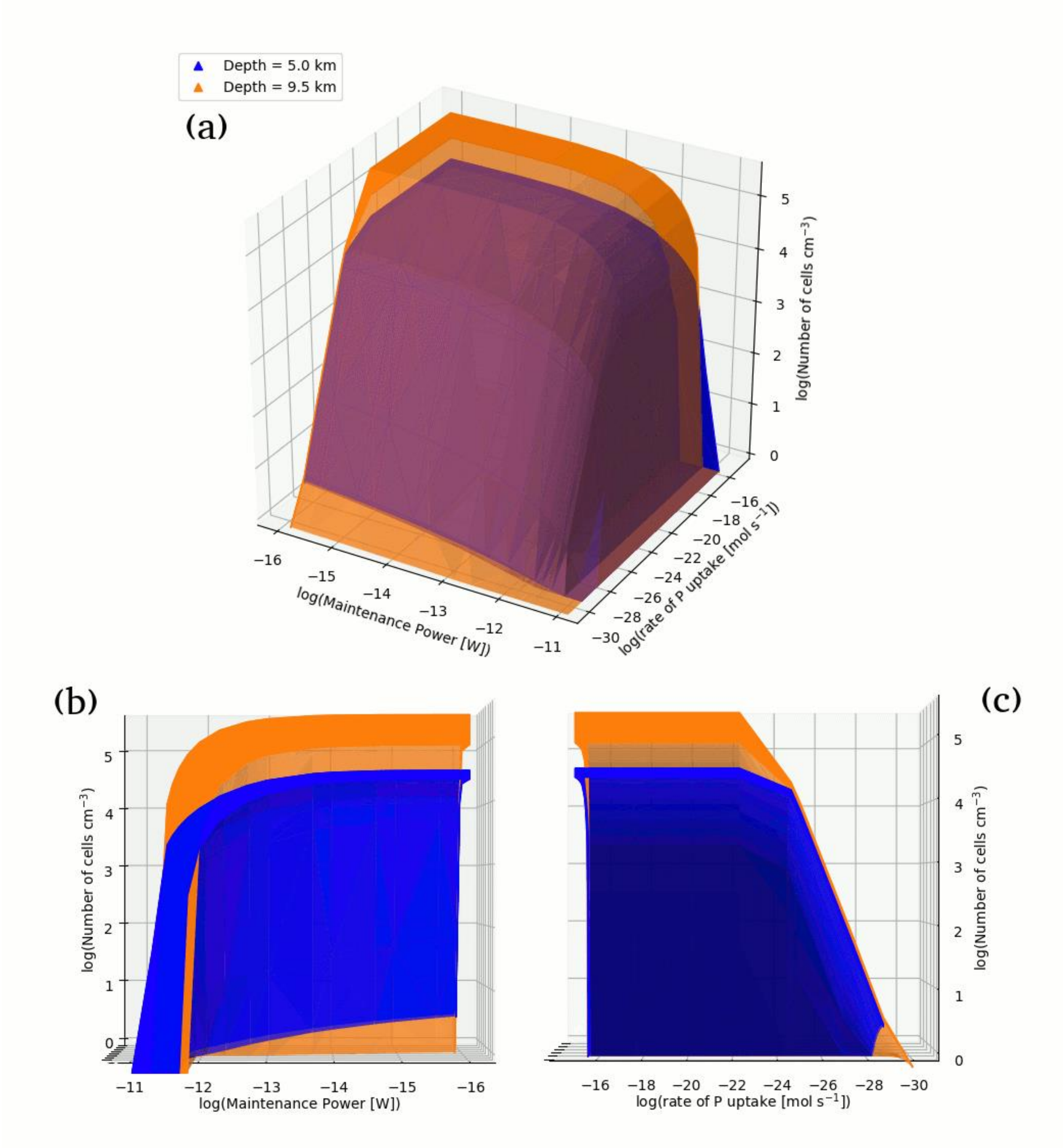

Figure 1. Three viewpoints of a map of the final predicted biomass for a pH 8.5 Enceladean subsurface ocean, at two depths (corresponding to 273 K and 383 K for blue and orange, respectively), varying the rate of Phosphorus uptake, maintenance power, and ATP yield (denoted by thickness).