Long Term Planetary Habitability and the Carbonate-Silicate Cycle.
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Introduction: The potential habitability of exoplanets is traditionally assessed by determining whether or not its orbit falls within the circumstellar 'habitable zone' of its star (Kopparapu *et al.*, 2013). However, this metric does not readily account readily for changes in the abundance of greenhouse gases and their associated radiative forcing as a result of the action of the carbonate-silicate cycle.

Methods: We develop a model of the carbon cycle on Earth, coupled with a a 1-D radiative-convective climate model with an Earth-like atmospheric water vapour profile [1], to explore the potential changes in the CO_2 greenhouse under conditions of varying planet size (0.5 – 2 $R_\oplus$) and stellar flux (0.75 to 1.25 $S_\oplus$).

Results: We find that likely changes in global topography, tectonic outgassing and uplift, and the hydrological cycle on larger planets results in proportionally greater surface temperatures and pCO_2 for a given incident flux. For planets between 0.5 and 2 $R_\oplus$ the effect of these changes results in average global surface temperature deviations of up to 15 K, which suggests that these relationships be considered in future studies of planetary habitability.

Furthermore, by coupling this model with the stellar evolution scheme presented in [2] and setting an upper temperature limit of 343 K, the habitable period of the Earth-sized world around the Sun can be quantified. For a 1 $R_\oplus$ planet, this limit is approximately 6.35 Gyr after planet formation, or 1.81 Gyr from present day.

Additionally, atmospheric CO_2 falls below the limit at which C3 and C4 plants can effectively photosynthesize after ~5.38 Gyr and ~6.1 Gyr respectively, which may initiatiate a significant reorganization of the biosphere of the planet well before average surface temperatures render it uninhabitable.

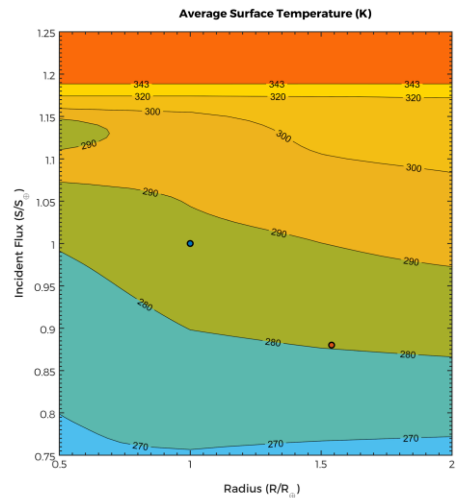

Fig. 1: Surface temperature as a function of planet radius and incident flux, both normalized to present Earth values. Also shown are the present day Earth (blue-filled marker) and GJ 667 Cc (red-filled marker).

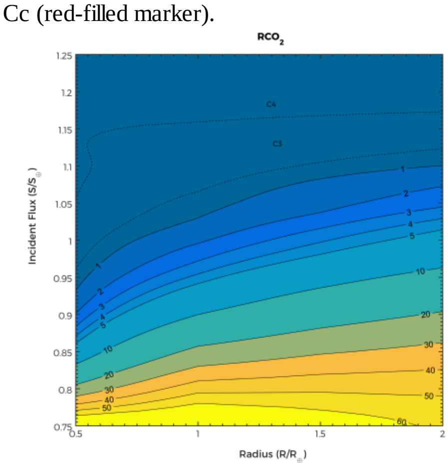

Fig. 2: pCO_2 as a function of planet radius and incident flux, both normalized to pre-industrial levels (280 ppm). Also shown are contours showing the photosynthesis limit for C3 and C4 plants.

References: [1] Kopparapu *et al.*, 2013 *The Astrophysical Journal* 765(2) [2] Rushby *et al.*, (2013) *Astrobiology*, 13(9), 833-849.