Climate bistability of rocky exoplanets

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Until about 600 million years ago, our planet experienced temporary snowball conditions, with continental and sea ices covering a large fraction of its surface. This points to a potential bistability of Earth's climate, that can have at least two different (statistical) equilibrium states for the same external forcing (i.e., solar radiation). Here we explore the probability of finding bistable climates in rocky exoplanets, and consider the properties of planetary climates obtained by varying the semi-major orbital axis (thus, received stellar radiation), eccentricity and obliquity, and atmospheric pressure. To this goal, we use the Earth-like planet surface temperature model (ESTM), an extension of 1D Energy Balance Models developed to provide a numerically efficient climate estimator for parameter sensitivity studies and long climatic simulations. After verifying that the ESTM is able to reproduce Earth climate bistability, we identify the range of parameter space where climate bistability is detected. An intriguing result of the present work is that the planetary conditions that support climate bistability are remarkably similar to those required for the sustainance of complex, multicellular life on the planetary surface. The exploration of potential climate bistability proceeds with the case of a Earth-like planet partially covered by vegetation that generates a positive vegetation-albedo feedback, in the spirit of the Charney conceptual model. In this case, it is shown that the presence of this vegetation feedback can induce relevant changes in climate dynamics and alter the range of habitable conditions for the planet.