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Terraforming planet Dune: Climate-vegetation interactions on a sandy planet

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The climate and the biosphere of planet Earth interact in multiple, complicated ways and on many spatial and temporal scales. Some of these processes can be studied with the help of simple mathematical models, as done for the effects of vegetation on albedo in desert areas and for the mechanisms by which terrestrial vegetation affects water fluxes in arid environments. Conceptual models of this kind do not attempt at providing quantitative descriptions of the climate-biosphere interaction, but rather to explore avenues and mechanisms which can play a role in the real system, providing inspiration for further research. In this work, we develop a simple conceptual box model in the spirit illustrated above, to explore whether and how vegetation affects the planetary hydrologic cycle. We imagine a planet with no oceans and whose surface is entirely covered with sand, quite similar to planet Dune of the science-fiction series by Frank Herbert (1965). We suppose that water is entirely in the sand, below the surface. Without vegetation, only evaporation takes place, affecting the upper sand layer for a maximum depth of a few cm. The amount of water that is evaporated in the atmosphere is relatively small, and not sufficient to trigger a full hydrologic cycle. The question is what happens to this planet when vegetation is introduced: the root depth can reach a meter or more, and plant transpiration can then transfer a much larger amount of water to the atmosphere. One may wonder whether the presence of vegetation is sufficient to trigger a hydrologic cycle with enough precipitation to sustain the vegetation itself and, if the answer is positive, what is the minimum vegetation cover that is required to maintain the cycle active. In more precise terms, we want to know whether the introduction of vegetation and of the evapotranspiration feedback allows for the existence of multiple equilibria (or solutions) in the soil-vegetation-atmosphere system. Although the box model introduced here is best formulated in terms of a hypothetical sandy planet, the results can be used to study the hydrologic cycle on wide continental regions of the Earth. On the other hand, our findings show how the definition of a habitable climate may also depend on surface characteristics, and in particular on biosphere and climate interactions.