Are there multiple steady states in the long-term carbon cycle?

D. W. SCHWARTZMAN[1] AND A. KLEIDON[2]

[1]Department of Biology, Howard University; dschwartzman@gmail.com
[2]Max-Planck-Institut für Biogeochemie; akleidon@bgc-jena.mpg.de

Previous models of the long-term carbon cycle have implicitly assumed that there is only one climatic steady state, characterized by its global mean surface temperature (T_S) and associated level of atmospheric carbon dioxide (pCO_2) for a given source flux of carbon dioxide and land area. Here we investigate the possibility of multiple steady states in the long-term cycle through its coupling with the climate system, particularly its planetary albedo (a_p).

We first consider an "Abiotic World", i.e. exclude biotic effects on carbon cycling and climate. Multiple steady-states are possible, since the same weathering forcing can result from different pairs of (T_S, pCO_2, a_p): (1) high T_S, low pCO_2 with a low a_p, and (2) low T_S, high pCO_2 and high a_p. The critical factors largely determining a_p are cloud and possibly ice/snow cover characteristics and behavior, which are functions of T_S and pCO_2.

Adding life in a "Plant World" introduces a new level of complexity and degrees of freedom to the long-term carbon cycle by a multitude of effects, processes and feedbacks [1-3], including: (1) Biotic enhancement of weathering (BEW) on land; (2) Organic carbon burial, both terrestrial and marine; (3) Oxidation of reduced organic carbon, sulfides, ferrous iron in terrestrial sediments; (4) Biotic productivity; (5) Even the volcanic source flux can be influenced by biota, e.g., where on the ocean floor calcium carbonate is deposited can potentially affect the decarbonation flux; (6) surface albedo as a function of vegetation cover.

Therefore, multiple steady-states may exist in the "Plant World", arguably an even greater number than in the "Abiotic World", given the greater number of degrees of freedom. We propose that the climatic steady state that results in Maximum Entropy Production [4] will be the most likely attractor in the landscape of possible steady-states for the "abiotic" and "Plant" Worlds.

References

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