Long-term Co-evolutionary Biosphere and Geosphere Models COEM

POEM

Project goals

COEM will focus on specific dynamic processes within and between ecosphere subsystems. The main point of the investigations, e.g., concerns the balance and interactions between geosphere and biosphere with respect to the limits of self-stabilisation against perturbations. Dynamic system theory is well suited for uncovering qualitative phenomena and for exploring the fundamental ecosphere system properties, like the total life span or the overall limits of the habitable zone (HZ) in our solar system and extrasolar planetary systems. The main tasks are to analyse the critical dynamical boundaries of the ecosphere, its structural stability and, especially, its potential regulation capacity under stress.

Habitable zones in extrasolar planetary systems

The long-term co-evolution of the geosphere-biosphere complex is investigated using a conceptual Earth-system model.

The model focusses on the global carbon cycle as mediated by life and driven by increasing central star luminosity and plate tectonics. The main CO_2 sink and source are determined.

As a major result we determine the HZ for an Earth-like extrasolar planet at a given (but arbitrary) distance *R* in the stellar mass-time plane (Fig. 1).

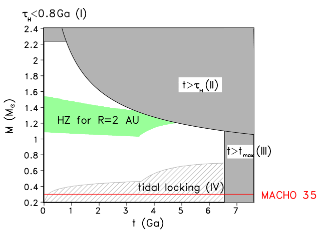

Fig. 1: HZ for an Earth -like extrasolar planet at R=2 AU.

The Hz is limited by the following effects that are independent of *R*:

(I) Minimum time for the biosphere development ($\tau_H < 0.8$ Ga)
(II) Central-star life time on the main sequence ($t > \tau_H$)
(III) Geodynamics of the Earth-like planet ($t > t_{max}$)
(IV) Tidal locking of the planet.

The excluded realms are marked by grey shading in case of the first three factors, and by grey hatching for the tidal-locking effect. The horizontal red line represents the probable "life time" of the hypothetical MACHO-98-BLG-35 planet.

The role of herbivores in a fragmented Daisyworld

A two-dimensional version of the simple Lovelock-Watson model for geosphere-biosphere feedback is used. In order to reflect fundamental ecosystems dynamics based on trophic interactions, the 2D model is extended even further and herbivores are added to this toy planet.

These vegetarion "lattice animals" move on the grid as random walkers. As in reality the herbivores are capable of reproduction depending heavily on their nutritial state.

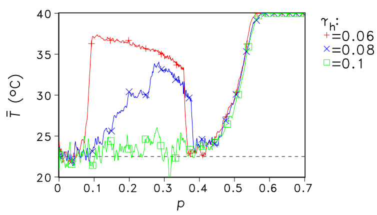

Fig. 2: Global temperature T as a function of fragmentation p for different values of herbivore mortality γ_h.

The interaction between plants and animals is realized by two processes, namely (i) temperature dependent reproduction of herbivores and (ii) ingestion of daisies.

The co-dynamics of plants and animals are studied in a landscape with increasing fragmentation. The introduction of herbivores to fragmented Daisyworld generates an extremely rich ecodynamics. Intensive numerical calculations have shown that a crucial parameter for the system behaviour is the herbivores' mortality (see Fig. 2): Below a critical threshold for mortality several phase transitions occure at increasing fragmentation.

Pascal "forest-grass" model of the global vegetation pattern

These set of models of the global vegetation pattern (GVP) are based on some simple probabilistic "urn" schemes. Nevertheless sufficiently complicated dynamics is described by the system of integro-differential equations with partial derivatives. The reduction to two age cohorts - juvenile (young) trees and mature ones gives us two ordinary differential equations

$$\frac{dp_2}{dt} = \frac{1}{2\tau_m}(p - \alpha p_2 - \mu p_2^2)$$
$$\frac{dp}{dt} = \gamma_1(1-p)(lp_2 - p) \qquad (1)$$

for two state variables: the fraction of area covered by forest, *p(t)*, and the fraction of area covered by mature trees, $p_2(t)$, $0 \le p_2(t) \le p(t) \le 1$. The system depends on the parameters α, τ_m, μ, γ_l, and l changing with mean annual temperature and precipitation.

We start from the planet covered by grass under the contemporary climate. The final GVP is shown in Fig. 3.

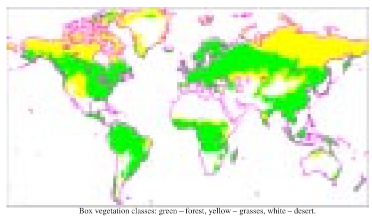

Fig. 3: Global vegetation pattern

The critical region on the map is Eastern Sibiria where the large area is occupied by tundra, when in reality it is a taiga region. It could be explained by the insufficient accuracy of the model calculations in areas with low temperatures.

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