A Planetary Energy Balance Model

This simple numerical climate model predicts evolution of temperature of the global Earth-Atmosphere system represented by a single point in space under the influence of solar and infrared radiation. The temperature, T, evolves from an arbitrary initial value, T_o, to a constant value until the equilibrium between the absorbed solar energy and the outgoing thermal infrared energy is reached. The absorbed solar energy depends on the planetary albedo, α_p, where small values result in higher amounts of absorbed solar energy and large values to more reflected solar energy. The outgoing thermal infrared energy depends on the system temperature as well as on the infrared transmissivity, τ_a, where small values imply an opaque atmosphere and large values correspond to a more transparent atmosphere. The value of T is also controlled by the fraction of the solar constant, F_s, where values <1 represent a weaker sun and consequently less solar energy reaching the Earth and values >1 a stronger sun with more solar energy reaching the Earth. Finally, the heat capacity of the Earth-Atmosphere system is controlled to a large extent by the ocean mixed-layer depth, D_m, where a shallow ocean produces a rapidly responding system whereas a deep ocean produces a slowly responding system, in terms of its global average temperature.

The values of T_o, α_p, τ_a, F_s and D_m can be modified within a range of reasonable values. One or more parameters may be changed simultaneously in order to understand the respective roles played by radiation and thermal characteristics of the climate system with respect to global average temperature.

Experiments

No. 1 **Simulating the global temperature of an earth without any atmosphere**

Parameters	Values	Comments
α_p	0.30	30% of the solar energy is reflected back to space
τ_a	1.0	The system behaves as a black body. All the infrared radiation emitted at the surface escape directly to space
F_s	1.0	The current solar input of 1370 W m^{-2} is used and agrees with satellite measures
D_m	50 m	Represents the ocean depth that responds the most quickly and directly to atmospheric forcing
T_o	250 K	Equals to -23ºC; this represents a cold start of this model

Results: a constant temperature of 255 K (-18ºC) is reached after 10 years of simulation. Thus, an Earth devoid of any atmosphere is a very cold system !

No. 2 **Simulating the current global climate temperature**

Parameters	Values	Comments
α_p	0.30	This value is corroborated by satellite observations
τ_a	0.62	38% of the infrared energy is prevented to escape to space; this is the natural greenhouse effect generated by the natural atmospheric components!
F_s	1	Same as in Exp. 1
D_m	50 m	Same as in Exp. 1
T_o	250 K	Same as in Exp. 1

Results: a stable temperature of 288 K (15ºC) is reached after 10 years of simulation. The natural greenhouse effect maintains the Earth's temperature within reasonable limits for living organisms to flourish.

No. 3 **Simulating the change in global temperature following a doubling of CO_2 concentration in the atmosphere**

Parameters	Values	Comments
α_p	0.30	kept the same as in Exp. 1; therefore feedbacks are neglected
τ_a	0.60	A doubling of atmospheric CO_2 is producing an enhanced greenhouse effect caused by a 2.5% increase of atmospheric infrared radiation trapping
F_s	1	Same as in Exp. 1
D_m	50 m	kept the same as in Exp. 1; therefore feedbacks are neglected
T_o	250 K	same as in Exp. 1

Results: after 10 years of simulation, a steady temperature of 289.75 K (15ºC) is reached corresponding to a +1.8ºC change in global temperature with respect to current climate. This result is in line with other results obtained with complex Global Climate Models which also predict a positive change in the range of 1.5ºC to 4. ºC. This range is mainly due to model complexity and numerical approaches to represent various components of the climate system.

Concluding remarks: these examples obtained with a simple Energy Balance Model emphasize the role of the atmosphere and of the anthropogenic influence on climate warming; enhanced concentrations of greenhouse gas such as CO_2 can increase the global mean temperature significantly which in turn will have an impact on other natural and socio-economic systems on Earth.