# A 1-D Energy Balance Model

This one-dimensional numerical climate model predicts the zonally-averaged equilibrium temperature of the Earth-Atmosphere system represented by a number of latitude bands set from the Equator to the North Pole. The resulting zonal climate is governed by the equilibrium reached between absorption of solar radiation, the infrared radiation loss to space, and by the latitudinal transport of heat energy. This equilibrium climate is embodied by the zonal average temperature at nine 10° latitude bands i, $T_i$. The absorbed solar energy absorbed in a latitude zone depends on the albedo where small values result in higher amounts of absorbed solar energy and large values to more reflected solar energy. The zonal albedo is a combination of the atmospheric and of the surface albedos: the atmospheric albedo depends to a large extent to the reflectivity ($\alpha_{clouds}$) and amount ($C_i$) of clouds whereas the values at the ground depend on the surface type where snow and ice ($\alpha_{ice}$) produce high values and where most soil ($\alpha_i$) produces low values. The surface albedo is a function of $T_{crit}$, the surface temperature at the snowline. The outgoing thermal infrared energy at each latitudinal band depends on its temperature and on the greenhouse effect of atmospheric clouds, water vapour and carbon dioxide whose influence is taken into account through parameters $A$ and $B$. The latitudinal transport of energy is taking place where heat is in excess to latitudes where heat is in deficit and its rate is represented by parameter $K$. The overall temperature is also determined 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.

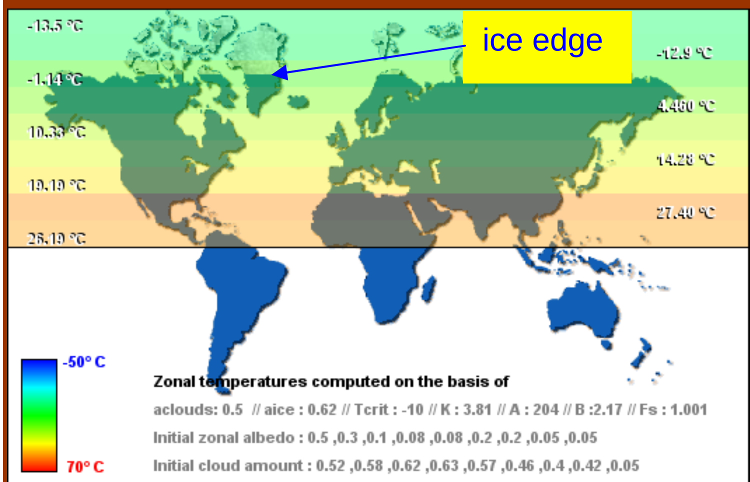
The values of $\alpha_{clouds}$, $\alpha_{ice}$, $\alpha_i$, $T_{crit}$, $K$, $A$, $B$, $F_s$ and $C_i$ can be modified within a range of reasonable values. One or more parameters may be changed simultaneously in order to understand the respective roles played by radiation and thermal characteristics of the climate system in order to produce the "zonality" of Earth's climate.

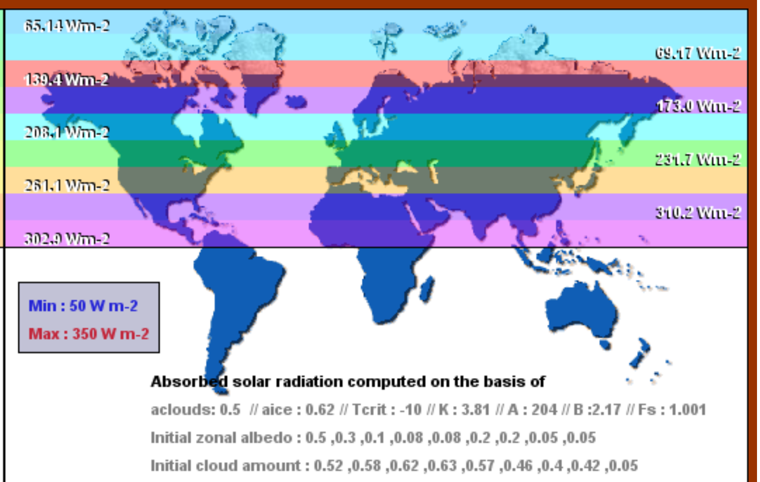
## Experiments

**No. 1** **Simulating the current Earth's climate**

| Parameters | Values | Comments |
|---|---|---|
| $\alpha_{clouds}$ | 0.50 | 50% of the solar energy is reflected back to space |
| $\alpha_{ice}$ | 0.62 | 62% of the solar energy is reflected by the surface ice |
| $\alpha_i$ | .5, .3, .1, .08, .08, .2, .2, .05, .05 | Latitudinal albedos derived from observations |
| $T_{crit}$ | -10.0 ºC | The surface zonal albedo usually become totally snow-ice covered at less than 0ºC |
| $K$ | 3.81 W $m^{-2}$ $C^{-1}$ | The rate of heat transfer suggested by Budyko (1969) |
| $A$, $B$ | 204.0 W $m^{-2}$, 2.17 W $m^{-2}$ $C^{-1}$ | Governing the infrared radiation loss (linear parameterization) |
| $F_s$ | 1.0 | The current solar input of 1370 W $m^{-2}$ is used and agrees with satellite measures |
| $C_i$ | .52, .58, .62, .63, .57, .46, .4, .42, .5 | Observed zonally-averaged cloud amounts |

**Results**: Temperatures / Absorbed solar radiation



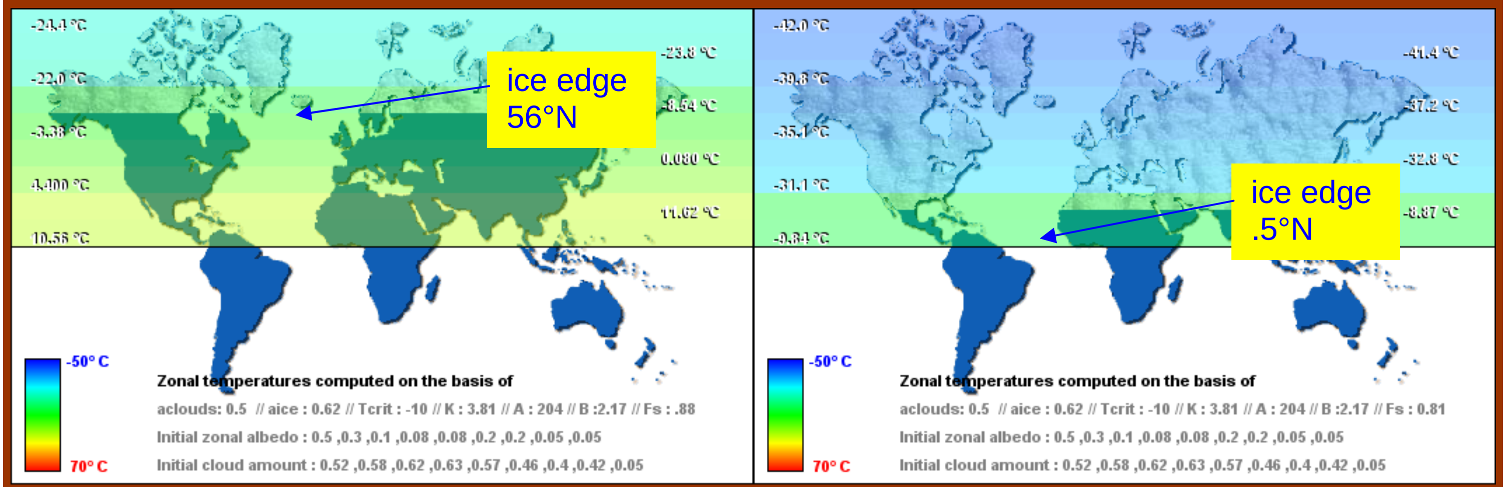



A temperature of approximately +15ºC (288 K) is simulated. The tropics absorb more solar energy than the Poles because of the relatively high solar input and of the low albedo. The ice margin is diagnosed at 71.3°N. These simulated quantities are in very good agreement with the observational features.

**No. 2 Simulating the ice age**

Keeping all the parameter values the same, except that of $F_s$, enable the analysis of the sensitivity of the model climate to the value of solar constant. For $F_s$ =1, the simulated global average temperature is about 15°C and the ice edge is located at 71°N, as shown in the above figures. If $F_s$ is reduced to 95% of its current value, the global average temperature is 9.5°C and the ice edge step southward to 68.7°N. The following figures show the temperature profiles and the ice edges when $F_s$ is further reduced to 88% and 81% of its current value:

Temperatures ($F_s$ = 0.88) Temperatures ($F_s$ = 0.81)




The global average temperature for $F_s$ = .88 is 0.1°C and the ice edge is located at 56°N. The globally averaged temperature for $F_s$ = .81 is -26°C and the ice edge is located at 0.5°N. Consequently the Earth is completely ice covered when the solar constant is decreased to 81% of its actual value, *i.e.*, to roughly 277 W $m^{-2}$ globally averaged. The relationship existing between the globally averaged temperature and the ice edge position is not linear. A decrease of the solar input through the parameter $F_s$ from the present day ($F_s$=1) means a gradual decrease of the temperatures where a runaway feedback loop causes a rapid drop in temperature and a total glaciation ($F_s$ = 0.81).

**Discussion**: EBMs are developed on relatively simple basis: the energy fluxes into and out of the Earth as a whole must balance out in order to preserve thermal equilibrium. This concept is fundamental to climate modelling: the basis of the EBMs is simple mathematical formulations and parameterisations represented in and executed easily on today's computer. Thus, many experiments can be carried out to test the sensitivity of the simulated climate to the various model's radiative and thermal parameters. In particular, this model allows analysing the rate of cooling of the globally averaged temperature in response to the decrease of the solar constant and the moment at which the Earth is ice covered. An "Ice Age" simulated when the solar constant is diminished to 81% of is current value.