GSA Data Repository

Figure DR1

Sensitivity of the model results to the oceanic overturning rate. Since the ocean becomes capped by a thick sea-ice, the ocean overturning is expected to be drastically reduced as a result of the collapse of the thermohaline circulation. An exploration of parameter space shows that reducing the vertical oceanic mixing up to a factor of 100 does not change significantly the resulting partial pressure of CO_2 after a simulation of 30 million of years. The transfer of carbon from the surface down to the deep ocean thus remain efficient. Since the snowball oceanic heat budget seems to be dominated by the geothermal heating from below (Goodman and Pierrehumbert, 2003) and since the tidal forces must have maintained a residual vertical mixing (Garrett, 2003), this 100-fold decrease in mixing is assumed to be the smallest realistic value. Going below this threshold means that the only remaining vertical mixing is the molecular diffusion. At such low vertical mixing, carbon accumulated in the atmosphere and open ocean has not enough time to mix within the deep sea, thus limiting the ocean acidification and oceanic crust dissolution, and allowing CO_2 levels to rise in the atmosphere. However, accounting for tidal forces and geothermal heating, , this end-member has no physical meaning.

Figure DR2:

CO_2 evolution as a function of glaciation duration for several ocean-atmosphere exchange surfaces (0 for fully ice-covered ocean, to “open” for present day ocean surface 363x10^6 km^2). At 3000km^2, pCO_2 pressures simulated are very close to those reached with the totally ice free ocean (open case), which demonstrates that a very small surface allows a very efficient exchange.

The 0.12 bar dash line represents the deglaciation threshold obtained with an energy-balance climate model with the present day insolation. The 0.29 bar dash line is the deglaciation threshold obtained with the same EBM but using the Neoproterozoic insolation. This last value seems to be underevaluated as demonstrated by (Pierrehumbert, 2004) (see main text)

Figure DR3:

Main parameters used in our model and present day carbon cycle. Red arrows stand for CO_2 sources. A simulation assuming a Neoproterozoic preglacial environment (solar constant reduced by 5 %) leads to a partial pressure of atmospheric CO_2 of 2500 ppmv, with a mean global air temperature of 15°C and a continental runoff of 36 cm/yr.

Equations governing the climate

$$T_{air} = 5.1339 * \ln(pCO_2) - 24.729$$

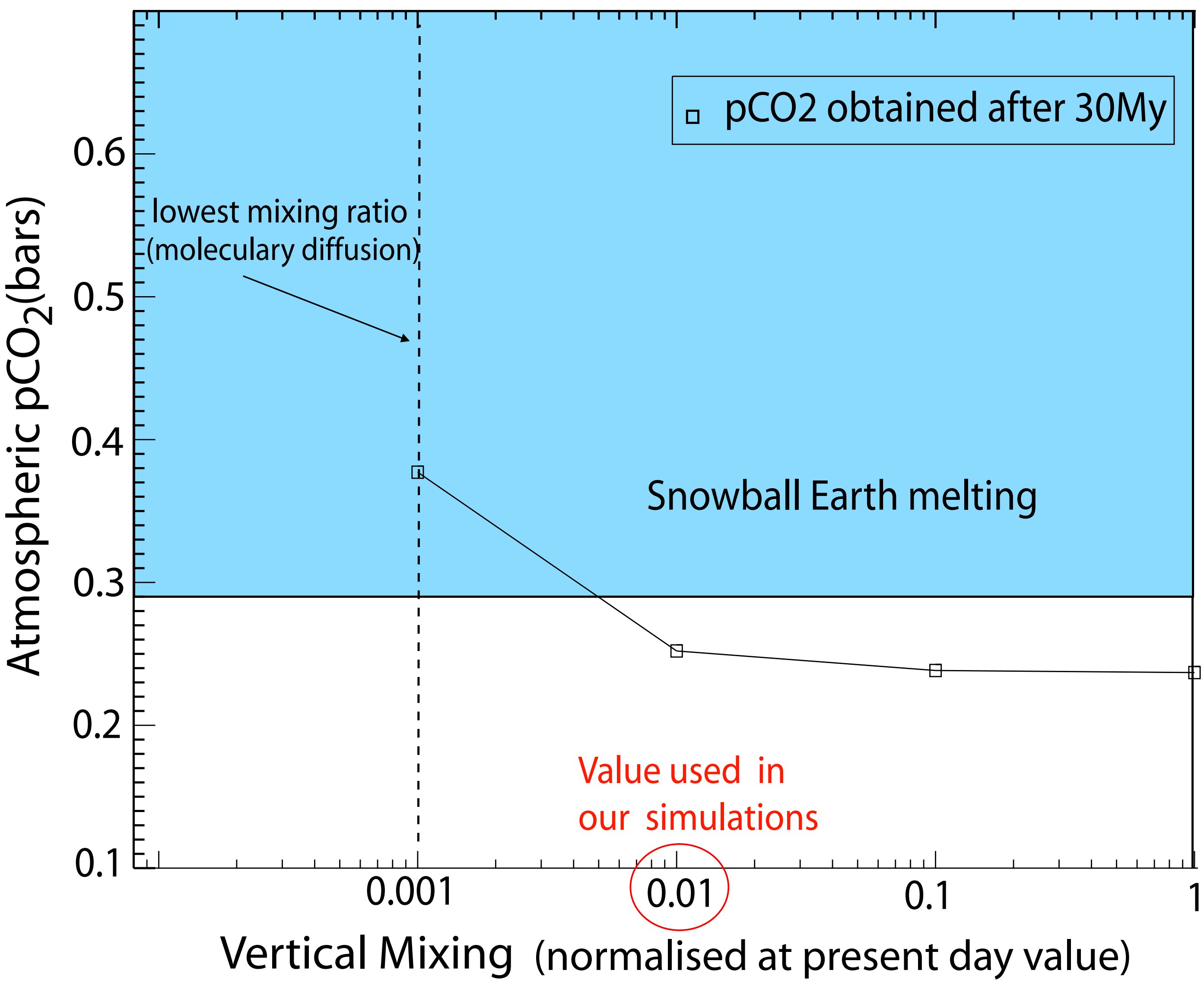
$$Runoff = (1 + 0.038(T_{air} - 288.15))^{0.65}$$

Additional references

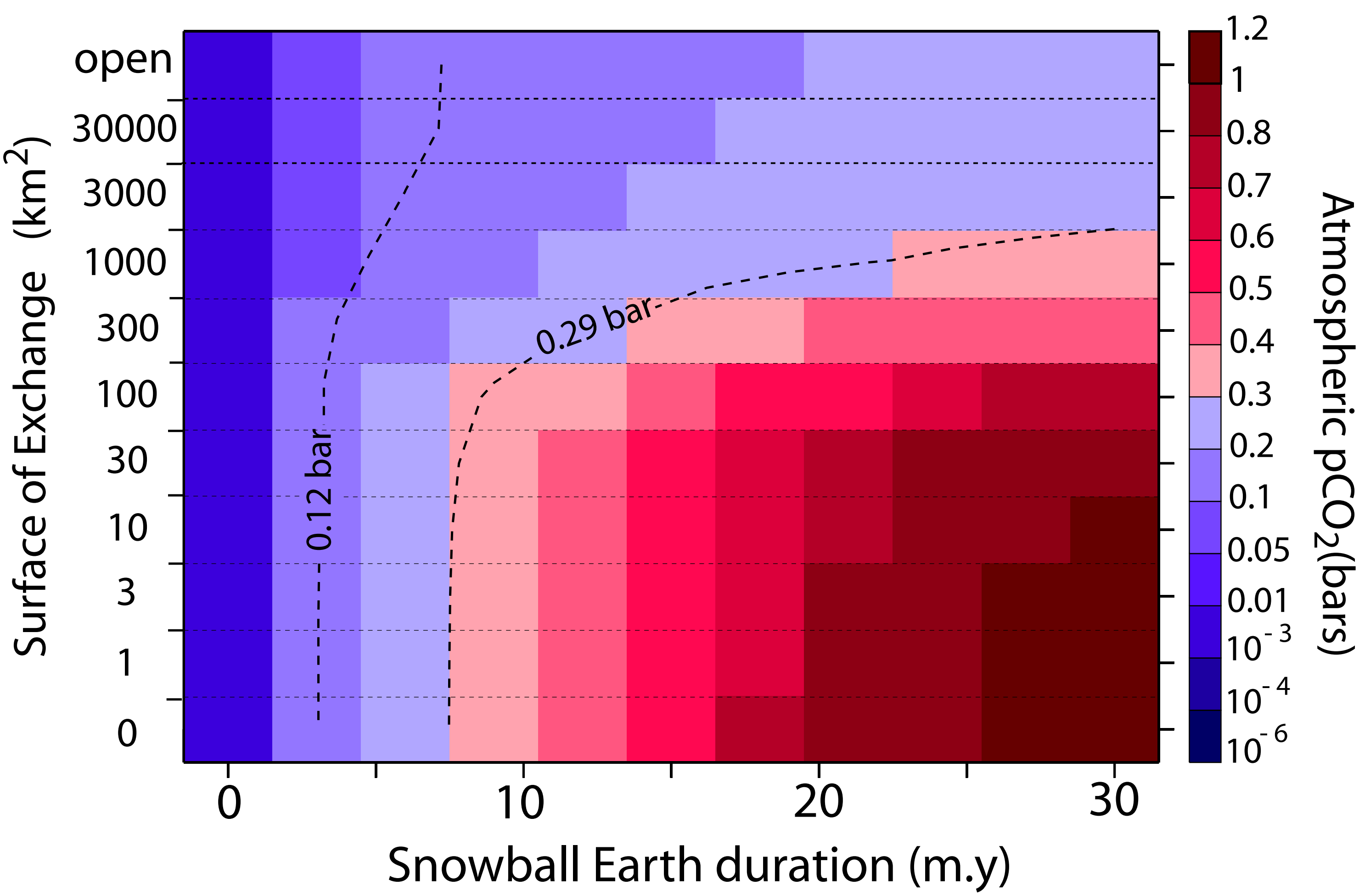
Garrett, C., 2003, Mixing with latitude: Nature, v. 422, p. 477-478.

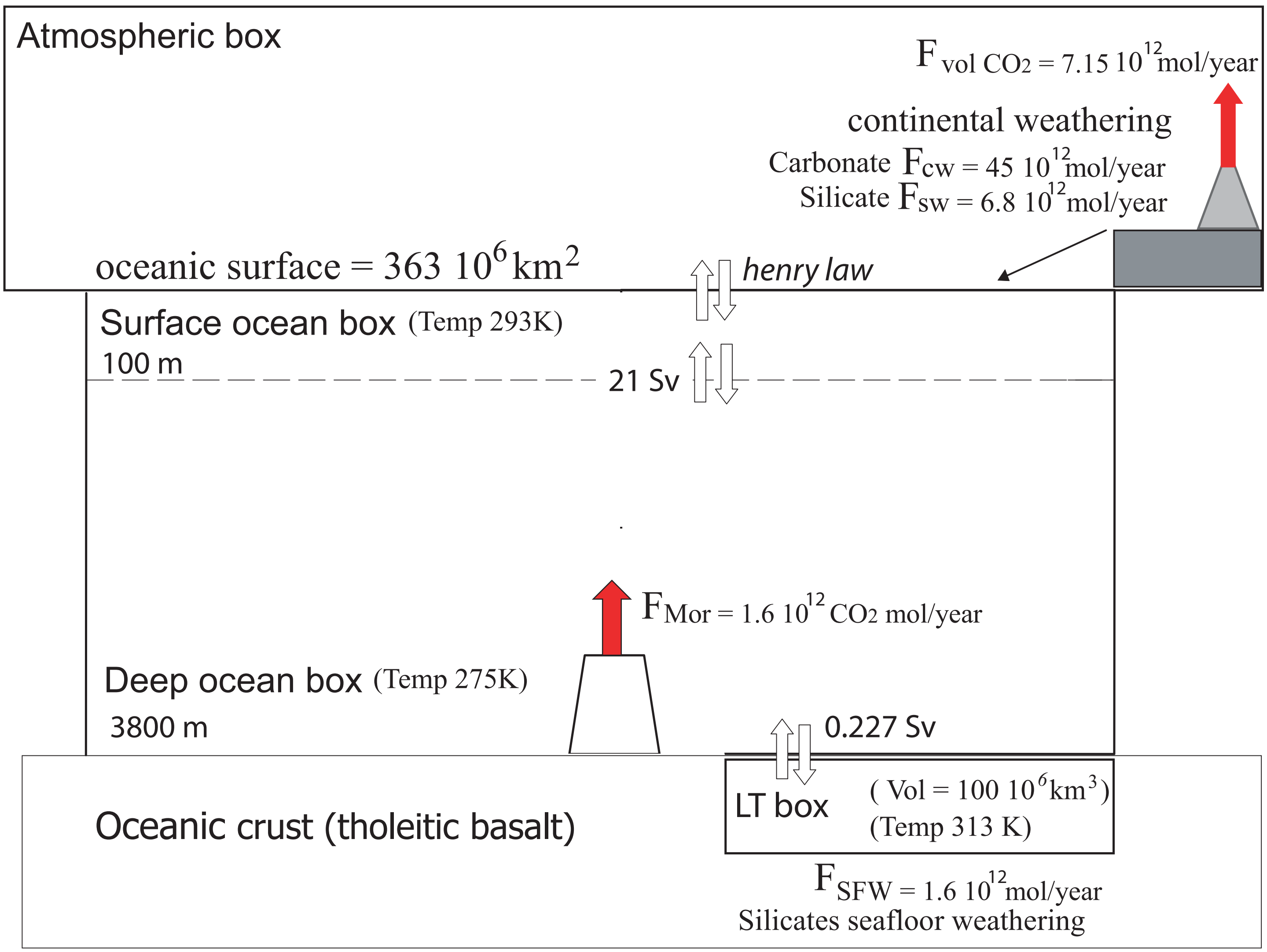
Goodman, J.C., and Pierrehumbert, R.T., 2003, Glacial flow of floating marine ice in "Snowball Earth": Journal Of Geophysical Research-Oceans, v. 108.

Pierrehumbert, R.T., 2004, High levels of atmospheric carbon dioxide necessary for the termination of global glaciation: Nature, v. 429, p. 646-649.


pCO2 obtained after 30My
lowest mixing ratio
(molecular diffusion)
Snowball Earth melting
Value used in
our simulations
0.6
0.5
0.4
0.3
0.2
0.1
Atmospheric pCO_2(bars)
0.001
0.01
0.1
1
Vertical Mixing (normalised at present day value)

DR2008013


open
30000
3000
1000
300
100
30
10
3
1
0
Surface of Exchange (km^2)
0.12 bar
0.29 bar
0
10
20
30
Snowball Earth duration (m.y)
1.2
1
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.05
0.01
10^{-3}
10^{-4}
10^{-6}
Atmospheric pCO_2(bars)



Atmospheric box
F vol CO2 = 7.15 10^12 mol/year
continental weathering
Carbonate Fcw = 45 10^12 mol/year
Silicate Fsw = 6.8 10^12 mol/year
oceanic surface = 363 10^6 km^2
henry law
Surface ocean box (Temp 293K)
100 m
21 Sv
FMor = 1.6 10^12 CO2 mol/year
Deep ocean box (Temp 275K)
3800 m
0.227 Sv
Oceanic crust (tholeitic basalt)
LT box
(Vol = 100 10^6 km^3)
(Temp 313 K)
FSFW = 1.6 10^12 mol/year
Silicates seafloor weathering