Cecilia away on Thursday. For HW8 welcome to work together Thurs. Enough info to do without me. Email or come to office hours on Monday Mar 4.

HW7 due Tues Mar 5 since I can’t collect it Thursday

Discuss figures in preview

Confess tidally locked planet do not necessarily have a synchronous orbit. Only true if eccentricity of orbit is zero. Other orbits tend to be in spin-orbit resonance, like Mars
Aquaplanet runs in HW6 and 7 are with CAM3. Sea ice is fairly simple. No land.

Global climate model simulations in HW8 are with Community Climate System Model Version 4 (CCSM4) – these are for IPCC AR5. It has CAM4 plus full fancy sea ice and land components (hence called a “system” model)

The runs in HW6 - HW8 employ a Slab Ocean Model (SOM) rather than the full Ocean General Circulation Model (OGCM).
Which pair of curves are from CCSM4 with an OGCM/SOM?

How can you tell?

In the 2XCO2 runs, CO2 is doubled instantly at the start.
Which pair of curves are from CCSM4 with an OGCM/SOM?

How can you tell?

In the 2XCO2 runs, CO2 is doubled instantly at the start.
In the OGCM Is the 2XCO2 run equilibrated yet?

How can you tell?

USED TO INVESTIGATE TRANSIENT CLIMATE RESPONSE

Years into Run

Global Mean Surface Temperature - deg C

2XCO2

1XCO2
What are the slowest timescales in the SOM version?

**2xCO2**

USED TO INVESTIGATE EQUILIBRIUM CLIMATE RESPONSE

**1xCO2**
“zero-dimensional” Model of Planet with No Atmosphere - Model A

Incident SW \[ S\pi R^2 \]

Reflected SW \[ S\pi R^2 \alpha \]

Outgoing LW \[ \sigma T^4 4\pi R^2 \]

Planet

\[ F_{IN} = F_{OUT} \]

\[ S\pi R^2 (1-\alpha) = \sigma T^4 4\pi R^2 \]

Balance of total Fluxes

\[ \frac{S}{4} (1-\alpha) = \sigma T^4 \]

Balance of Fluxes per unit area

Model A

\[ T = \sqrt[4]{\frac{S(1-\alpha)}{4\sigma}} \]

Model A, solved for T

R=Radius of planet
S=Flux from sun at R
\alpha=Stefan Boltzmann const.
\alpha=planetary albedo

Balance of total Fluxes
Earth with a Simple 1-Layer, Zero-Dim. Atmosphere - Model B
Earth with a Simple 1-Layer, Zero-Dim. Atmosphere - Model B

Notice that at equilibrium outgoing LW is equal to the downwelling LW toward the surf. in this simple atmosphere approximation
Enhanced or Anthropogenic GHE

Even Model B is too simple because it doesn’t change if there are more GHGs

Because the atmosphere is emitting the same longwave flux up and down. In reality the atmosphere doesn’t because there is a temperature and density profile.
Earth with Multi-Layer Atmosphere Model C

Adding More Greenhouse Gases initially reduces Outgoing Longwave Radiation (OLR)

Causes an energy imbalance and the planet has more heat entering than leaving.

Nature abhors energy imbalances. Warming acts to eliminate it by raising OLR back to balance net absorbed solar.
Now consider a model of just the TOA energy balance

If we parameterize the outgoing LW flux ($F_{out}$) accordingly, we sweep a lot of these issues under the carpet.

Try $F_{out} = A + B T$, $T =$ surface temperature

A can be reduced to mimic the anthropogenic GHE

The required balance $F_{in} = F_{out}$ demands that $T$ rise -> “global warming”

Recall $F_{in} = S/4 (1 - \alpha)$ if $\alpha$ changes with $T$, we can even mimic ice-albedo feedback by letting $\alpha$ be higher if $T < -10$ deg C
Imagine the CO2 Level Doubled Instantly

Less heat escapes, so

\[ F_{\text{OUT}} \text{ decreases} \]

“Radiative Forcing”

\[ \Delta Q = F_{\text{IN}} - F_{\text{OUT}} = 3.7 \, \text{W/m}^2 \]

(estimated to within a few tenths)
Exchange with surface
Local TOA imbalance drives dynamical heat flux such that the TOA imbalance is equal to the heat flux divergence. The imbalance is small relative to $F$ or $Q_0(1-\alpha)$ in most regions, except at the poles.
Northward Heat Transport
(integral over latitudes of local TOA imbalance)
Feedback Theory

δΔT = ΔQ

Note:
Δ: common symbol to refer to change in some quantity

ΔQ: radiative forcing (or instantaneous change in energy balance)
ΔT: response (change in surface temperature)
λ: total climate feedback (everything else)

λ: does not represent the wavelength of light here!