Global warming and its implications for conservation.

4. Greenhouse gasses and the lapse rate

The layer model is a reasonable heuristic model, but it assumes that the atmosphere acts as a perfect blackbody in the IR range, absorbing and emitting all frequencies.

The take home points to eliminate this assumption, are:

1. The atmosphere is not a blackbody for IR light:

- Most of the gas molecules in the atmosphere don't interact with IR at all.
- The gasses that do interact with IR act differently at different frequencies.

2. So, some bands of light pass the atmosphere as if it wasn't there: the '***atmospheric window***' of frequencies.

3. Some wavelengths are completely absorbed, then re-radiated.

4. Some waevelengths are partially absorbed, then re-radiated.

5. The degree to which a wavelength band is absorbed (***band saturation***) affects the impact (w.r.t. temperature change) of adding a single molecule that absorbs in that frequency.

6. The position of a wavelength that a gas absorbs/emits, relative to the radiation spectrum of earthshine, also affects the impact (w.r.t. temperature change) of adding a single molecule that absorbs in that frequency.

7. In the real atmosphere, gasses absorb light at one temperature (surface temperature) and then re-radiate at a lower temperature (skin temperature). The difference in temperature is the ***lapse rate***, due to ***adiabatic cooling***. Consequently, the EM energy emitted at the atmospheric skin is less than the energy absorbed from the surface. Heat is trapped as a consequence, until the total energy budget is in balance (a negative feedback loop).

Composition of the atmosphere

Because gasses are compressible and change volume depending on pressure, express concentrations as percentage of molecules present, ***the mixing ratio***.

Nitrogen 78.1%
Oxygen 20.9%
CO_2 0.038%

0.038% = 0.00038 = 380 ppm

Equivalently, can express concentrations as ***partial pressures***, measuring the contribution of each component to the total pressure of the gas:

380 ppm = 380 μatm = pCO_2

Atmospheric CO_2 is currently rising 1.5 ppm/year.

Interaction of gasses and EM radiation

Recall earlier discussion of chemical bonds oscillating at characteristic frequency, which allows them to absorb and emit light of that frequency.

The major gasses (nitrogen and oxygen) are present as N_2 and O_2: ***symmetric molecules with two identical atoms*** on each end of a ***single chemical bond***. Stretching or bending these molecules:

- does not create partial charges at different parts of the molecule,
- does not alter the electromagnetic field around the molecule,
- ***invisible to EM radiation***.
- **not** greenhouse gasses.

Ohead: Archer Fig 4.1 & 4.2

H_20 and CO_2 have more than one bond, so stretching or bending them creates partial charges at different parts of the molecule, creating partial charges that interact with the EM field. When light of the correct frequency hits the molecule, it bends or stretches it

- the light is absorbed
- and later re-radiated
- the frequency of absorbed and re-radiated light from the molecule is the same
- the intensity of re-radiation (amount of energy re-radiated) depends on temperatute (Stefan- Boltzmann Law)

Ohead: Archer Fig. 2.4 & Archer Fig 4.3

Note that N and O can be combined into a nitrous oxide N_2O molecule that has two bonds, and if bent or stretched N_20 does alter the EM field, so it does absorb/emit light, and is a greenhouse gas.

Ohead: Goudie Table 7.2

Gasses ***absorb*** IR at one temperature (***surface temperature***) and then ***radiate to space*** at a lower temperature (***skin temperature***). The difference in temperature is the ***lapse rate***, due to ***adiabatic cooling***. Consequently, the EM energy emitted at the atmospheric skin is less than the energy absorbed from the surface. Heat is trapped as a consequence, until the total energy budget is in balance (a negative feedback loop).

Archer Fig. 4.3 shows the profile of IR radiated to space, compared to the blackbody spectrum, for a range of temperatures, 220K → 300K

300K = hot summer day (27C)

(K → C: C = K – 273. C → F: F = C x 1.8 + 32)

220K = coldest point of atmosphere, at the ***tropopause*** about ***15 km ASL*** (-53C, -64F)

IR is absorbed by greenhouse gasses at a mean temperature of ~***270K***, in the lower atmosphere near the surface

IR is radiated to space at ***~220K,*** the skin temperature at the tropopause.

The loss of radiated energy (absorption of energy) due to each gas is shown on the Figure, as a difference between the blackbody spectra for 270K and 220K.

Wavelengths in the atmospheric window (at wave numbers around 900 cycles/cm) pass through freely, so they follow the blackbody spectrum for 270K.

Other wavelengths are absorbed partially or fully (at 270), then re-radiated (at 220) by H_20, CO_2, O_3 and CH_4.

The ***'missing area' measures reduction in outgoing energy flux***.

The ***biggest effect*** of greenhouse gasses on the actual IR spectrum of the earth at the boundary with space is due to CO_2, due to ***bending of*** CO_2 by light w/wave number around ***700 cycles/cm***. Because this is the ***peak of the earthshine spectrum, big reductions in outgoing IR*** arise***.***

Ohead: Archer Fig 4.4

The core of the missing area at 700 cycles/cm due to CO_2 is relatively ***smooth***, in comparison to the missing area due to other gasses. This is characteristic of ***band saturation***, which occurs when a gas is at high enough concentration that adding more has no additional effect, because all of the outgoing IR at that band is already being absorbed & re-radiated.

Ohead: Archer Fig 4.5 & Fig 4.6.

Fig 4.5 – as pCO_2 increases, the effect on IR spectrum is initially large, then smaller

Fig 4.6 – another view of same idea: radiative forcing decreases asymptotically as pCO_2 increases

BUT, the core of the CO2 band is saturated, and the edges of the CO_2 band aren't saturated: CO_2 does not absorb these frequencies as efficiently, so more CO_2 is needed for full absoption. Consequently, increasing CO_2 does alter outgoing IR.

The missing areas due to methane, ozone and water vapor do not show band saturation. ***Differences in the degree of saturation is the major reason that one molecule of CH_4 has 20X more impact than one molecule of CO_2***, even though CH4 lies at a low part of the earthshine spectrum.

Ohead: Goudie p. 201 table in text relative forcing for each gas,

Effect of greenhouse gasses on equilibrium temperature

Ohead: Archer Fig. 4.8

This figure captures the critical point.

Add a greenhouse gas → outgoing IR drops (missing area) → energy budget is temporarily imbalanced → earth warms due to trapped heat → entire spectrum rises (Stefan-Boltzmann) → energy budget is balanced → system equilibrates at this new, higher temperature.

Adiabatic cooling and the lapse rate

It should be obvious by now that the difference in temperature between the surface and skin temperatures is a major factor determining how much outgoing IR is trapped by atmospheric gasses.

Ohead: Archer Fig 5.4 & 5.1

- Gasses are compressible.
- Rising from the earth's surface, gasses have less mass above them, so they expand: atmospheric pressure drops with elevation.

- Pressure ∝ temperature, so temperature drops, even though total heat is constant – this is termed ***adiabatic cooling***.
- The decrease in temperature with elevation is called the ***lapse rate***.

Adiabatic cooling is slightly offset by ***heat transfer*** from low elevations to high elevations by ***water vapor***.

Ohead: Archer Fig 5.9 & Fig 5.5

- H_20 evaporates into the atmosphere at warm surface temperatures.
- The warm air rises, carrying H_20 vapor with it.
- As the air adiabatically cools, it loses capacity to hold water.
- H_20 condenses from vapor to liquid.
- ***Condensation releases the latent heat of vaporization*** (the energy that was needed to vaporize the water).
- This process transfers heat to higher elevations, decreasing the lapse rate. The ***moist adiabat*** is less steep than the ***dry adiabat***.
- Real data follow the moist adiabat.

This raises ***important points for predictive models*** of the way that changing CO_2 will affect temperature:

1. Movement of air masses has a big effect on the temperature structure of the atmosphere.

Ohead: Archer Fig. 6.5

For this reason, one must simulate local weather across the entire globe, in order to accurately predict impact of CO2 on climate. Simulating weather for the entire globe is a major computational challenge. Much of the work of IPCC is to develop, compare and evaluate these Global Climate Models, or ***General Circulation Models (GCMs)***.

Ohead: GCM schematic

Example: ***Hadley Center HadCM3*** is a coupled Atmospheric-Ocean GCM (***AOGCM***) that models pressure, temperature, moisture, wind velocity and direction for a grid of 2.5^o latitude x 3.75^o longitude (96 x 73, or 7008 surface cells). Each cell has 19 vertical layers for ***133,152 cells in the 3D model atmosphere***.

At a time step of 30 minutes, physical laws of physics, chemistry and fluid dynamics are used to predict changes for each variable in each cell.

This is coupled with a similar model for the ocean (HadOM3).

Ohead: Archer Fig 6.11 – an example of one of the outputs from a GCM, in this case a map of surface winds at a given time step.

Model runs then predict the climate. ***Hindcasts*** are used to evaluate the model

Ohead: Hindcast evaluation of HadCM3

Coupled AOGCMs that are evaluated as performing well by the IPCC are then used for forecasting. E.g. evaluating climate with increased CO_2.

Ohead: Forecasts from major models for the SRES A2 scenario (business as usual).

As discussed a few lectures back, averaging across multiple runs of multiple models is one way of reducing error and assessing uncertainty of predictions.

2. Increasing temperature affects the water vapor content, which affects the lapse rate, which affects the temperature. And H_20 vapor is itself a greenhouse gas. ***Feedback loops*** such as this are important in determining the real world consequences of CO_2.

Clouds, ice albedo and ocean circulation are involved in important feedback loops, some positive (amplifying) and some negative (stabilizing).

Ice albedo: warming → sea ice melts → albedo increases → warming accelerates

Clouds: can be positive or negative feedback depending on what type of clouds form, because different clouds block incoming light and outgoing IR to different degrees:

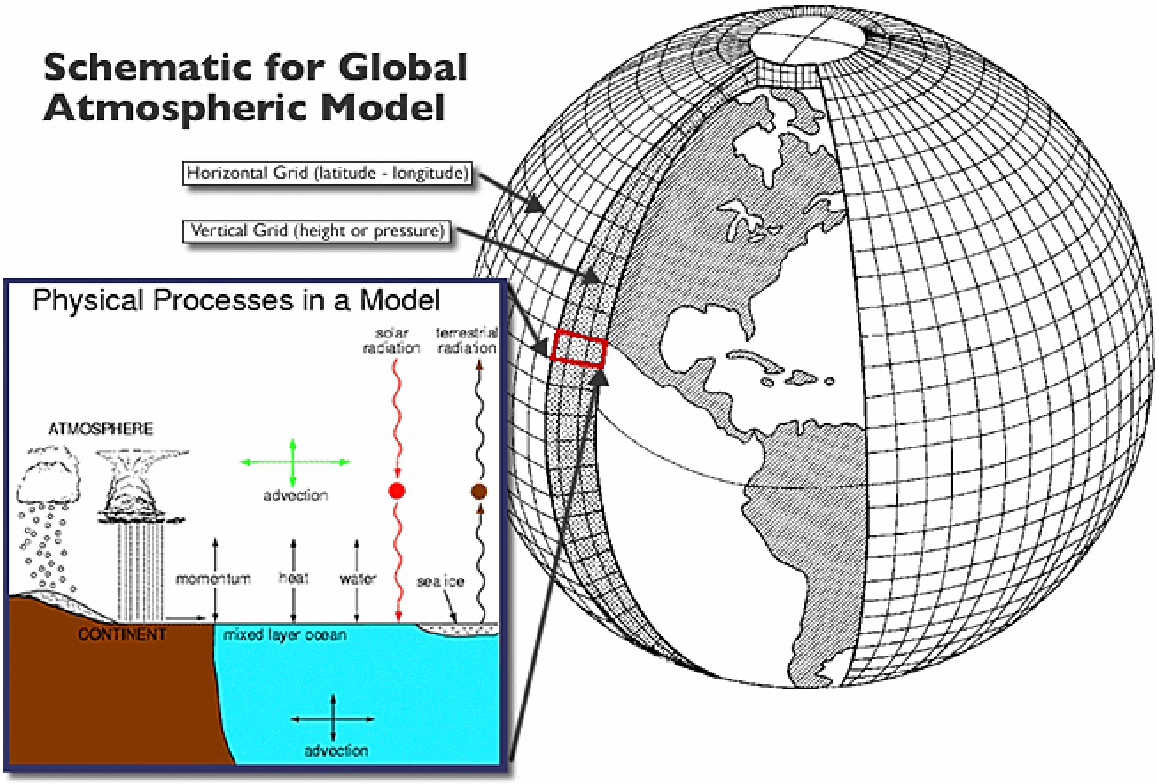
High clouds are warming (positive feedback) because they block little incoming light but have a big IR effect (because they are cold, so re-radiate at low intensity)

Low clouds are cooling: they have little IR effect (because they are low, thus closer to surface temperature) but are usually dense so they have high albedo (cause lots of reflection).

Differences in the modeled effects of these details underlie the uncertainties in the forecast.

Ohead: Goudie Table 8.1 – also first climate change lecture oheads)

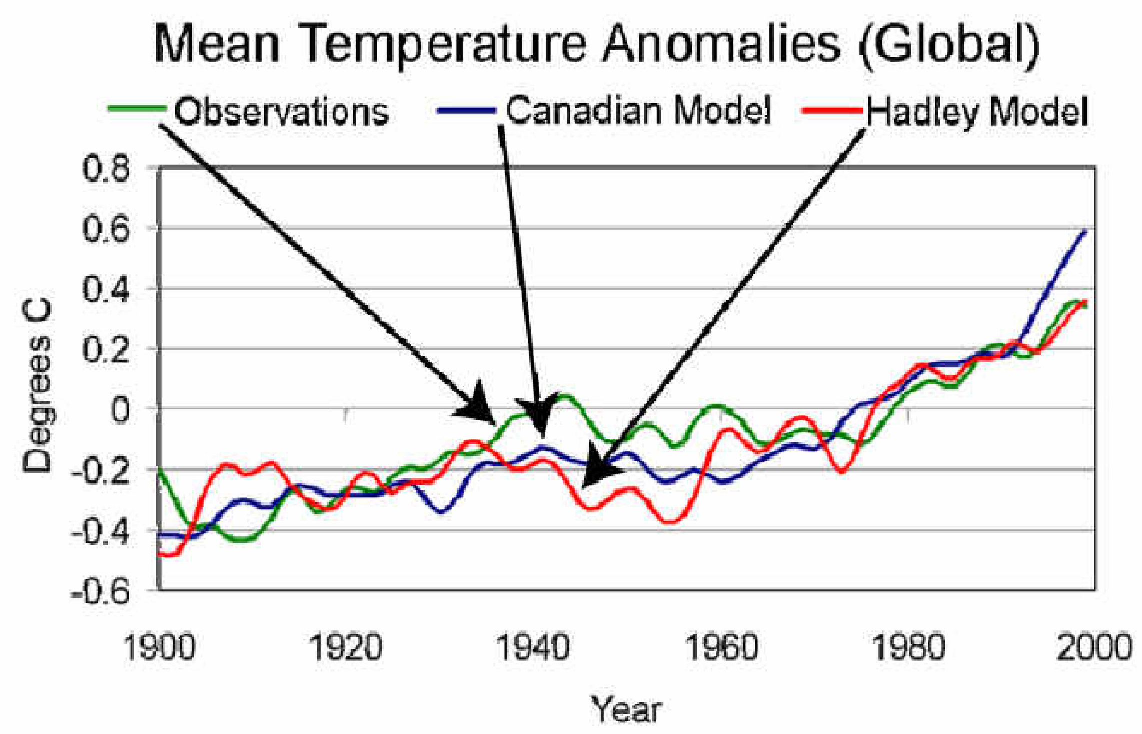
Homework: Archer CH 4 questions 1,2 & 3, using the MODTRAN model of the IR spectrum radiated to space at
http://forecast.uchicago.edu/Projects/modtran.doc.html

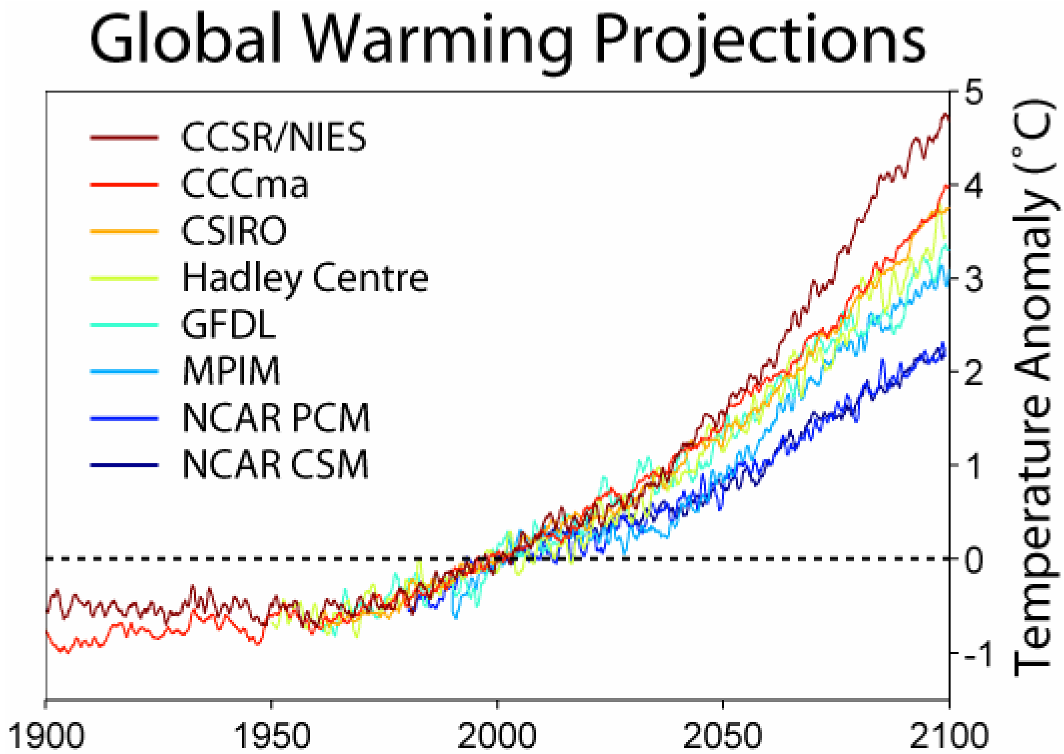


Climate models are systems of differential equations based on the basic laws of physics, fluid motion, and chemistry.

To “run” a model, scientists divide the planet into a 3-dimensional grid, apply the basic equations, and evaluate the results.

Atmospheric models calculate winds, heat transfer, radiation, relative humidity, and surface hydrology within each grid and evaluate interactions with neighboring points.


Mean Temperature Anomalies (Global)
Observations
Canadian Model
Hadley Model
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
Degrees C
1900
1920
1940
1960
1980
2000
Year



Climate model forecasts under the IPCC Special Report on Emissions Scenarios SRES A2 emissions scenario relative to global average temperatures in 2000. The A2 scenario is characterized by a politically and socially diverse world that exhibits sustained economic growth but does not address the inequities between rich and poor nations, and takes no special actions to combat global warming or environmental change issues. This world in 2100 is characterized by large population (15 billion), high total energy use, and moderate levels of fossil fuel dependency (mostly coal).

See http://www.grida.no/climate/ipcc/emission/094.htm for more on this scenario and others.