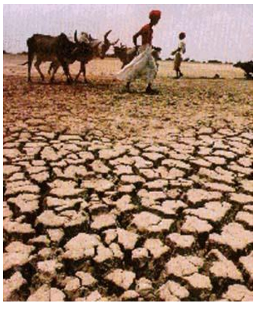
Radiation and Climate Change

- Earth's Energy Balance
- Forcing and Feedback
- Implications for climate change including the global water cycle

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL
Walker INSTITUTE
University of Reading

Introduction / Motivations

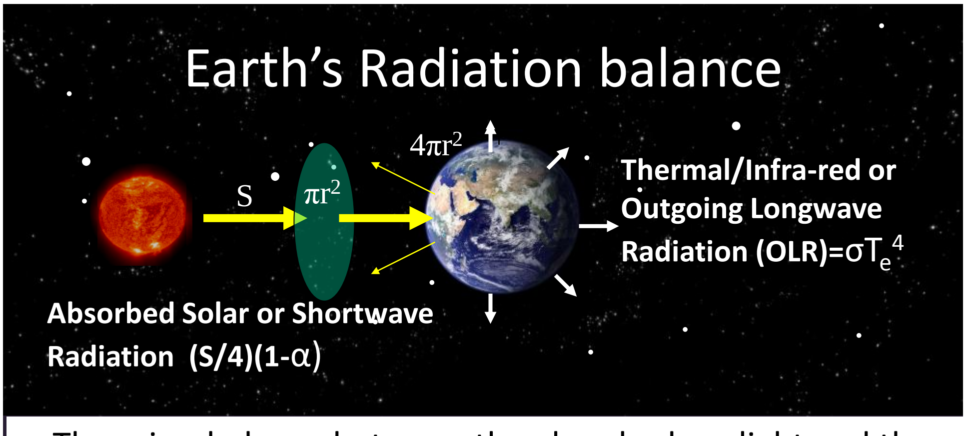




- Past societies
  - e.g. Jared Diamond: Collapse
- Impacts on an already stressed world
- Driver:
  - Earth's radiative energy balance
- How much change?
  - Forcings and feedbacks
- Complexity of the climate systems
  - Need for models

How do we predict climate change?

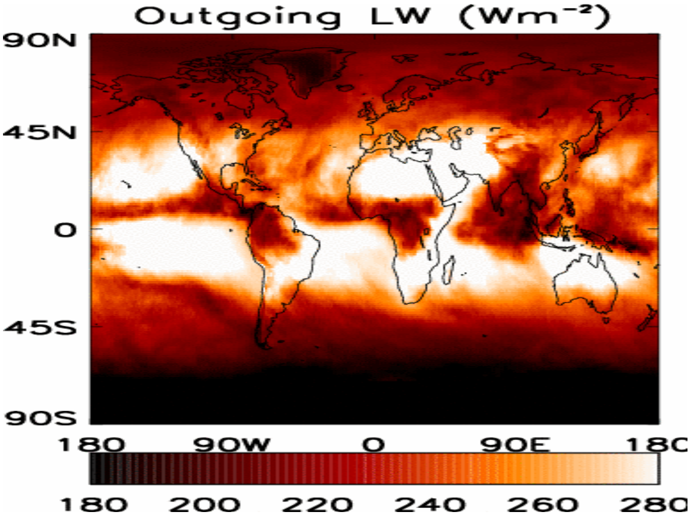
- Need to know what processes are important for determining the present day and past climate change
  - FORCINGS (e.g. solar output)
  - FEEDBACKS (e.g. ice-albedo)
- How will forcings change in the future?
- Will ocean/atmosphere/land processes amplify or retard this forcing of climate?
- What are implications for the global water cycle?



- There is a balance between the absorbed sunlight and the thermal/longwave cooling of the planet
- $(S/4)(1-\alpha) \approx OLR = \sigma T_e^4$
- OLR= $(S \approx 1361\ Wm^{-2},\ \alpha \sim 0.3)$
- T_e= $(\sigma=5.67\times10^{-8}\ Wm^{-2}K^{-4})$

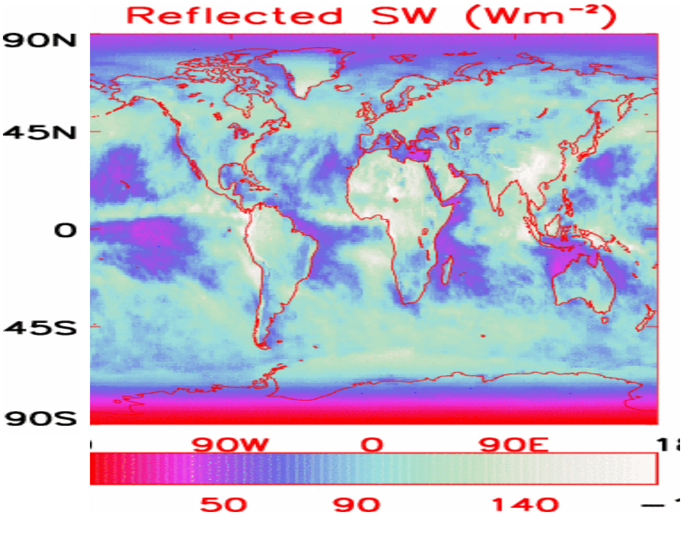
Top of Atmosphere Radiative Energy Fluxes

CERES/TERRA, September 2004



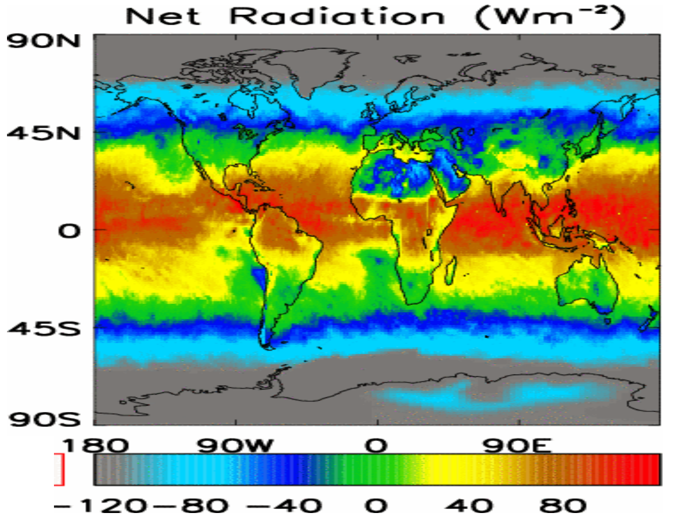
Top of Atmosphere Radiative Energy Fluxes

CERES/TERRA, September 2004

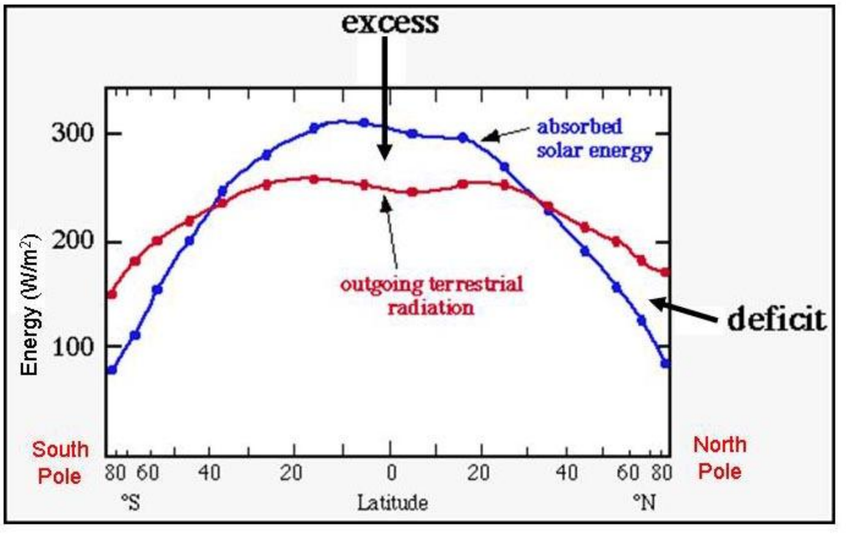


Top of Atmosphere Radiative Energy Fluxes

CERES/TERRA, September 2004



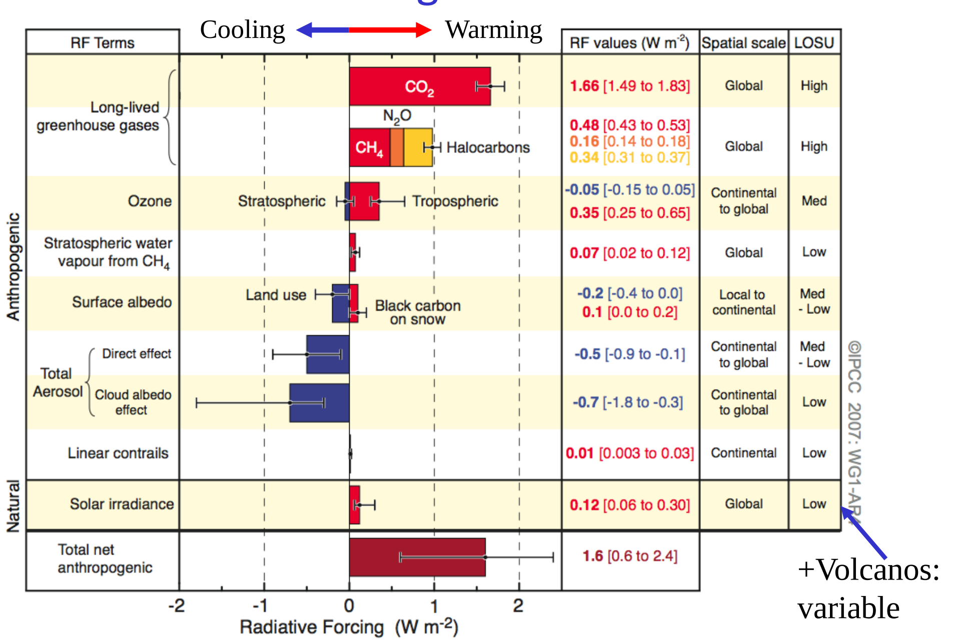
Zonal Mean Radiative Fluxes



Forcing or feedback?

1) Climate forcing, feedback or response?
2) Positive or negative?
   - *Solar output*
   - Water vapour
   - Volcanic eruptions
   - Carbon Dioxide (CO_2)
   - Cloudiness
   - Rainfall
   - Chlorofluorocarbons (CFCs)
   - Sulphate Aerosol
   - Sea Ice
   - Nitrogen (N_2)

Radiative Forcing of Climate since 1750



A Simple Climate Model

$$\Delta R \;=\; \Delta Q + Y\Delta T_s$$

Net top of atmosphere radiation

Radiative forcing

Climate feedback parameter ($Wm^{-2}K^{-1}$)

surface temperature

$$\Delta Q = -Y\Delta T_s$$

At equilibrium

The climate sensitivity parameter, $\lambda=1/Y$ (units: K/Wm^{-2})

A Simple Climate Model

Climate Feedback Parameter (Y)

$$Y = \frac{dR}{dT_s} = \frac{\partial R}{\partial T_s} + \sum_x \frac{\partial R}{\partial x}\frac{\partial x}{\partial T_s} + \cancel{\sum_x \sum_y \frac{\partial^2 R}{\partial x \partial y}\frac{\partial x \partial y}{\partial T_s^{\,2}}} + \ldots.$$

Black body feedback

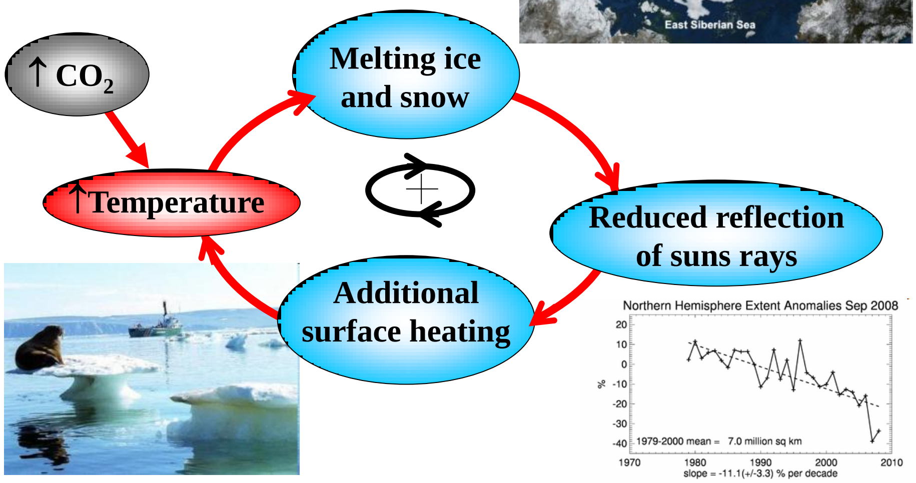
x denotes feedback variable, e.g. cloud, water vapour, ice-albedo, etc. Non-linear effects are ignored.

$$\frac{\partial R}{\partial T_s} \approx -4\sigma T^3$$

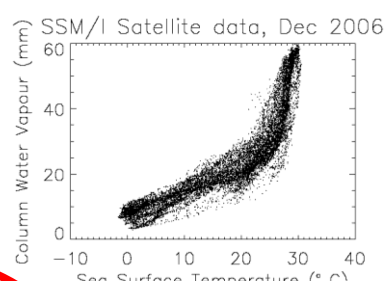
Sometimes referred to as the “no feedback” or “black body” response

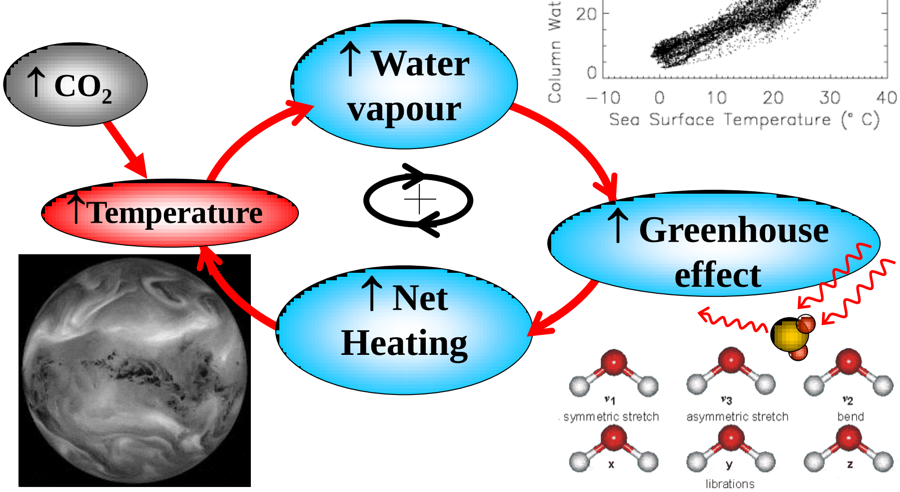
Bony et al. (2006) J Clim - they use λ instead of Y for Climate Feedback Parameter

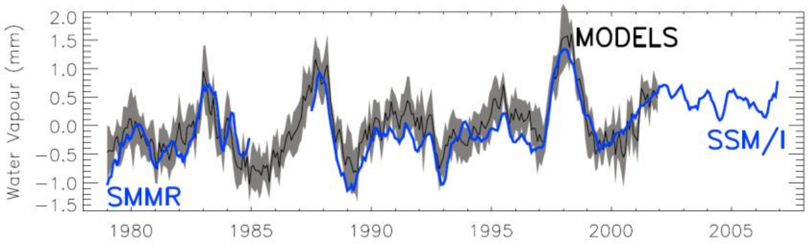
An example of feedback: ice-albedo



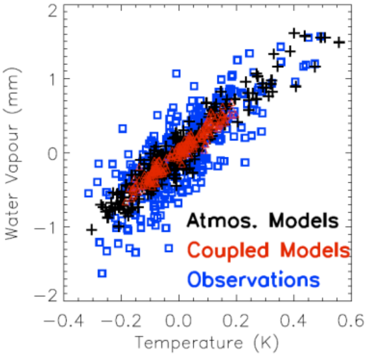
Water vapour Feedback



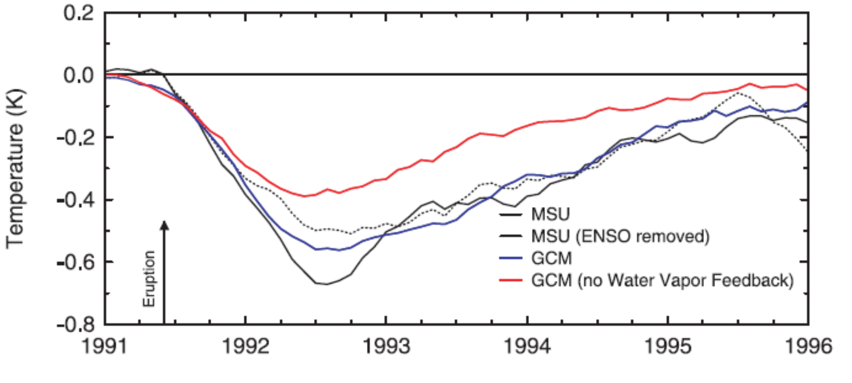




Atmospheric Moisture Rises with Warming in Climate Models and as detected by Satellite Observations

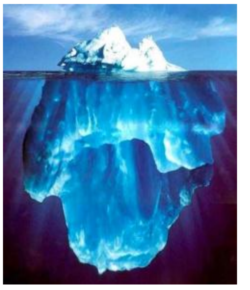


Simulation reproduces water vapour feedback response to Pinatubo volcanic eruption

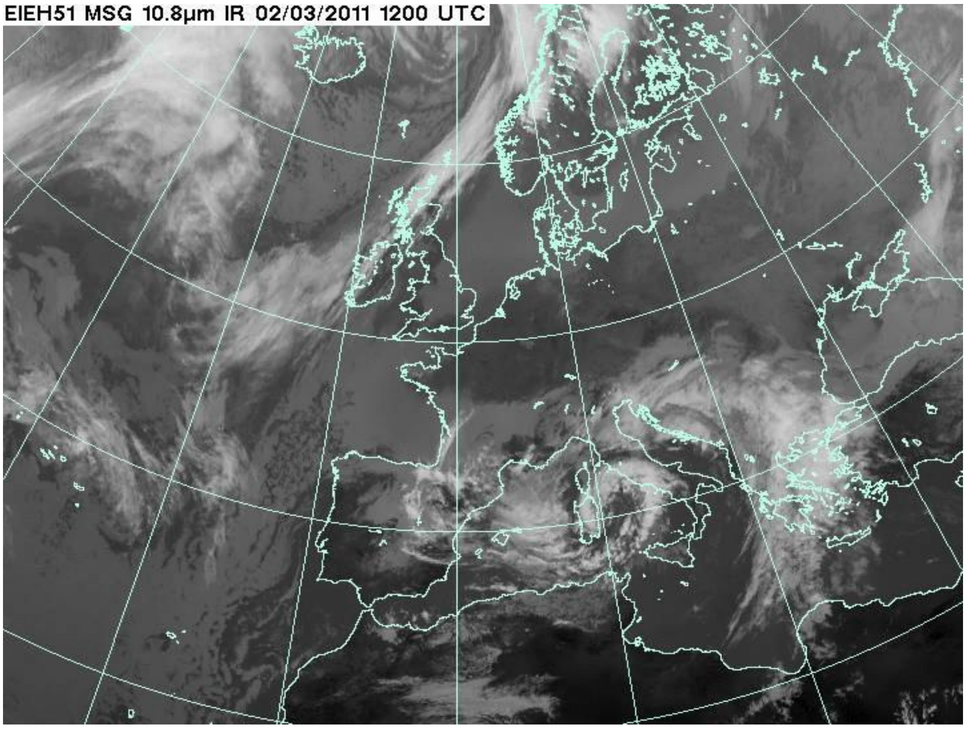


Soden et al. (2002) *Science*

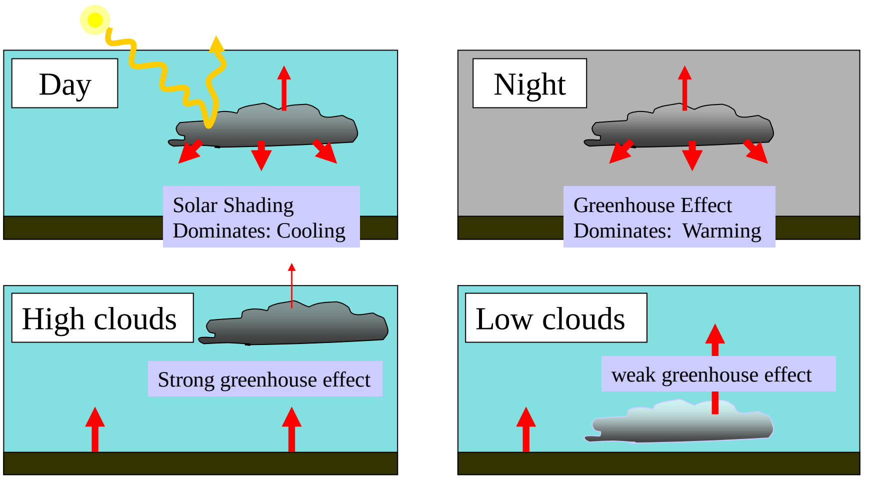
What about liquid and frozen water in the atmosphere?



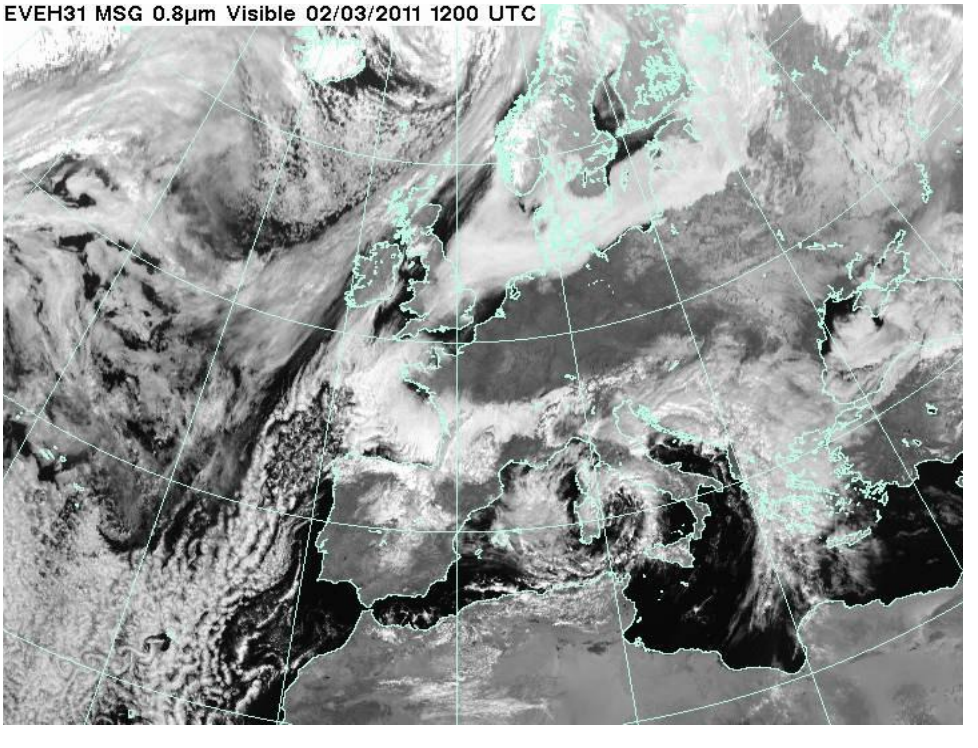
- Most of the water in the atmosphere is gaseous vapour
  – clouds are the tip of the iceberg
  – …water vapour with attitude
- Strong interaction with longwave and shortwave radiation (emission, absorption, scattering)
- Many types of cloud feedbacks are plausible



Contrasting radiative effects of cloud



How will cloud properties respond to warming? Will they amplify or diminish warming? How are cloud height, water content, ice content, droplet sizes, thickness, duration, time of occurrence, expected to vary?



Cloud feedback: a more complex problem

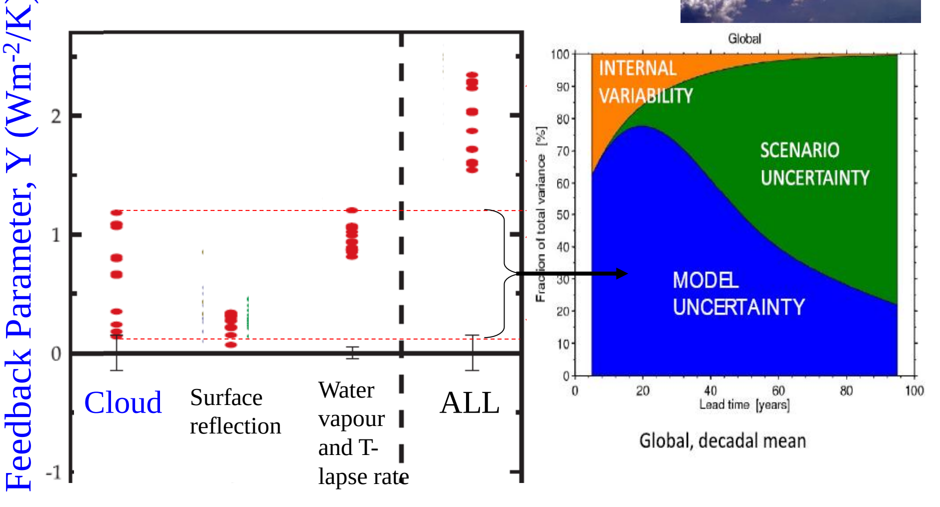
$$\frac{\partial R}{\partial x}\frac{\partial x}{\partial T_s}$$

- Depends on:
  - Type of cloud
  - Height of cloud
  - Time of day/year
  - Surface characteristics

Non-trivial relationship between cloud and temperature

Response of cloud to warming is uncertain

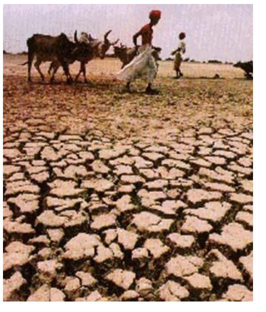
Uncertainty in strength of cloud feedback



After Soden and Held (2006) J. Climate (left) and Hawkins & Sutton (2010) Bull. Americ. Meteorol. Soc. (right)

Implications for the Water Cycle

The radiative and thermodynamic impact of water vapour is central to some of the most important processes for determining climate change including the response of the global water cycle



Radiative-convective equilibrium

If we assume that only radiative processes are operating, the equilibrium surface temperature is very high, tropospheric temperatures very low and the profile is strongly superadiabatic*.

In reality, convection removes heat from the surface, warms the atmosphere and adjusts the lapse-rate towards that observed#.

From the classic paper by Manabe and Wetherald, JAS, 1967

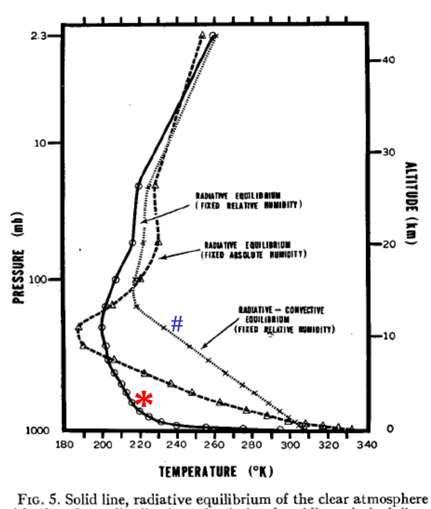
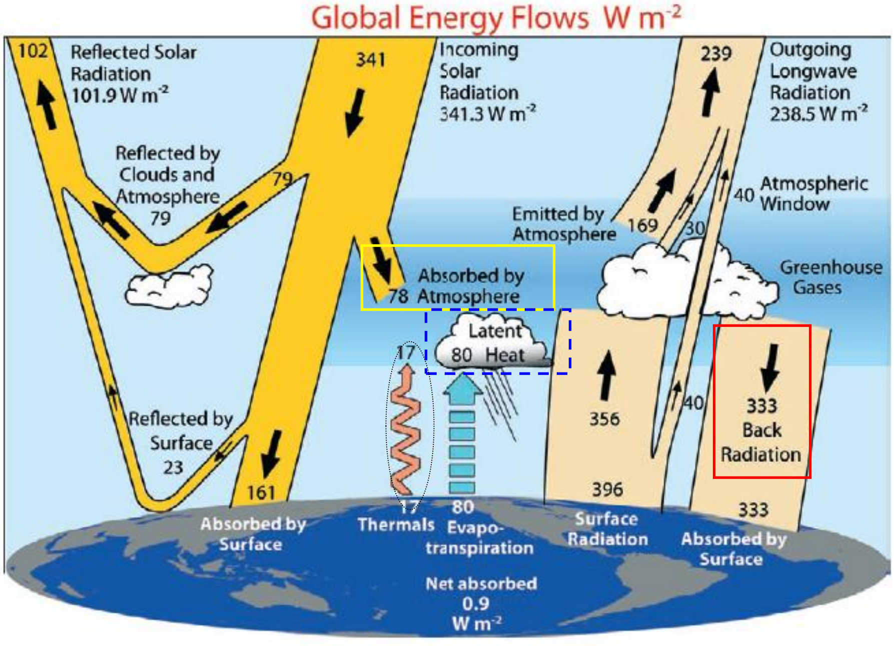
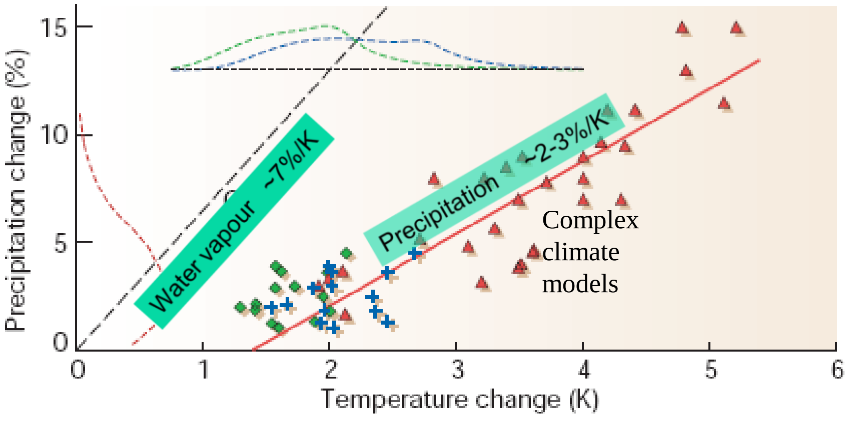


FIG. 5. Solid line, radiative equilibrium of the clear atmosphere with the given distribution of relative humidity; dashed line, radiative equilibrium of the clear atmosphere with the given distribution of absolute humidity; dotted line, radiative convective equilibrium of the atmosphere with the given distribution of relative humidity.



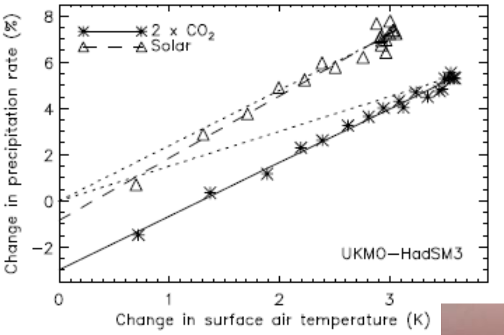
Trenberth et al. (2009) BAMS

How should global precipitation change in a warming world?

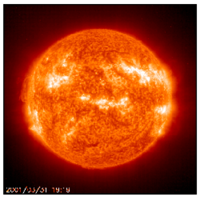


Allen and Ingram (2002) ***Nature***

Precipitation response depends upon radiation: forcing and the feedback



Andrews et al. (2009) J Climate



Partitioning of energy between atmosphere and surface is crucial to the hydrological response

Conclusions

- Radiative Forcing drives climate
- Radiative feedbacks determine response of climate to a forcing (climate sensitivity)

We will explore this further in the activity!

- Radiative-convective balance an important constraint upon future changes in the water cycle
  - crucial for human societies and the ecosystems upon which they depend