

Climate Dynamics (PCC 587): Clouds and Feedbacks

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Today...

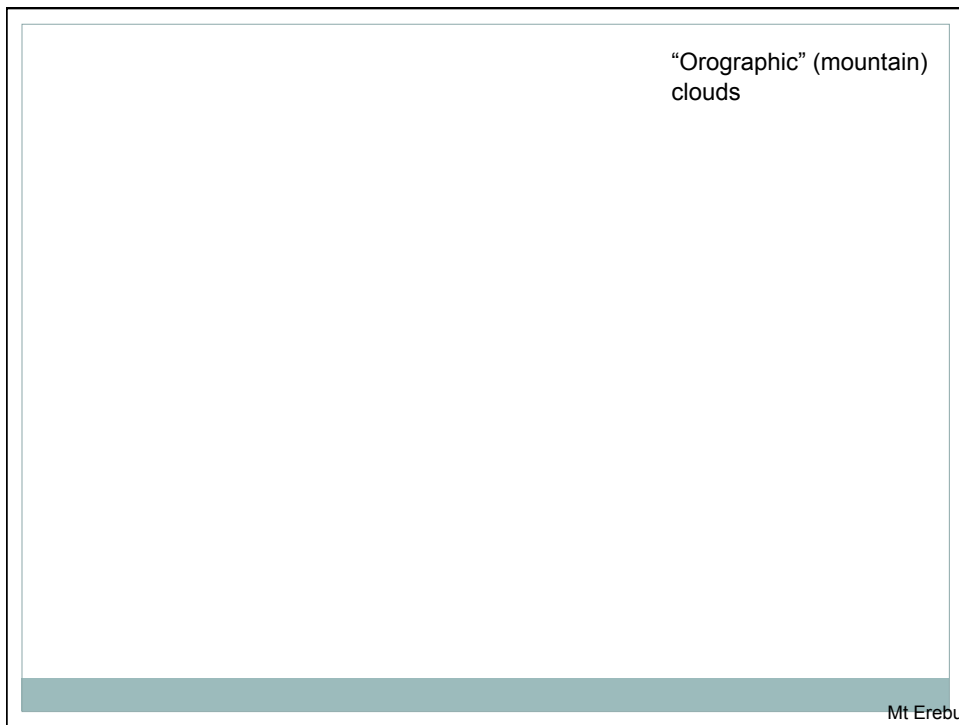
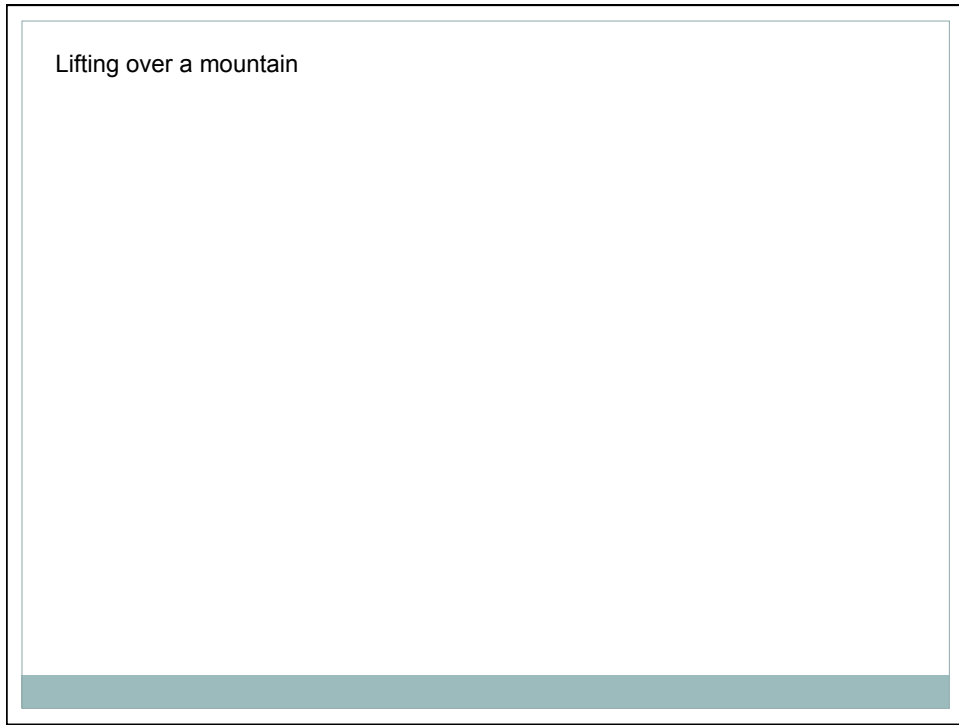
- **A summary of feedbacks**
 - Water vapor, lapse rate, ice-albedo
 - Clouds and their feedbacks: can be positive or negative
- **How to estimate climate sensitivity given different feedbacks**
 - And what is climate sensitivity

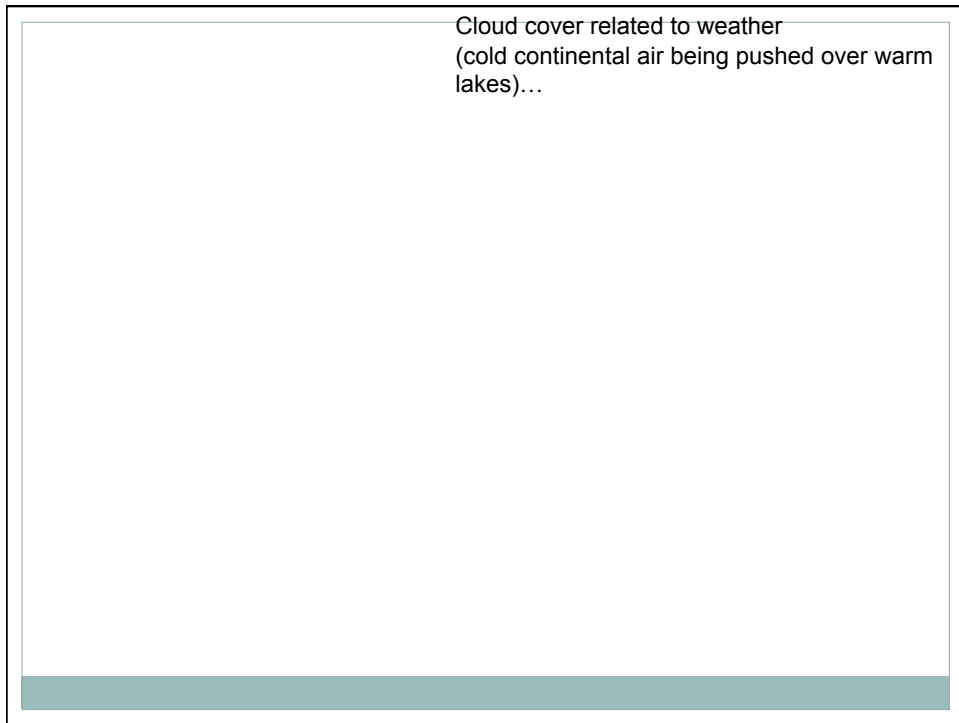
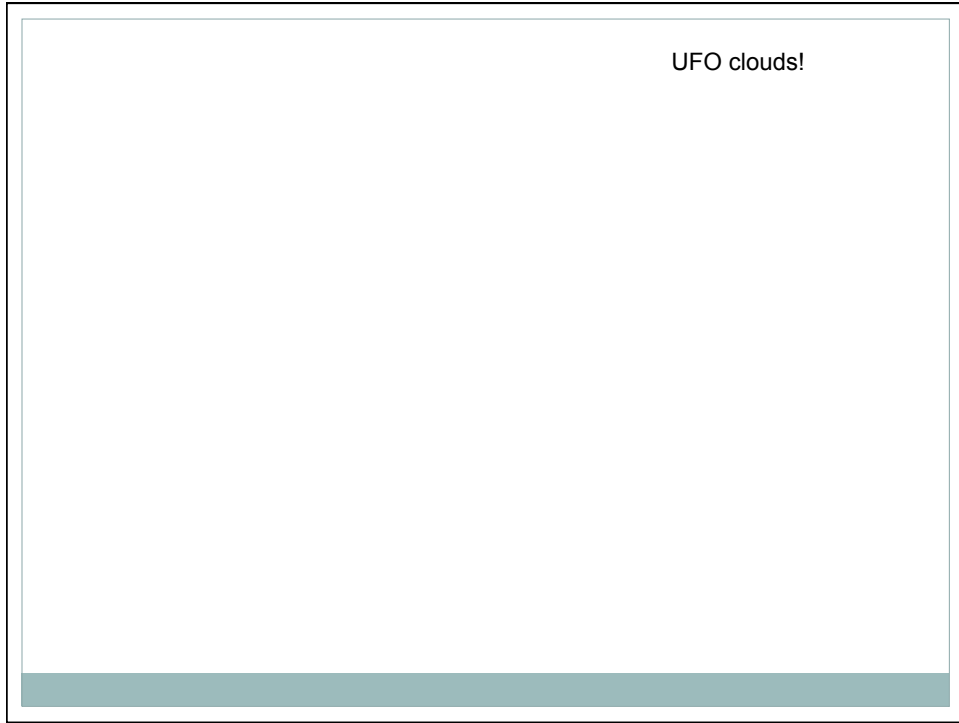
We've shown clouds
have a large impact on
albedo...

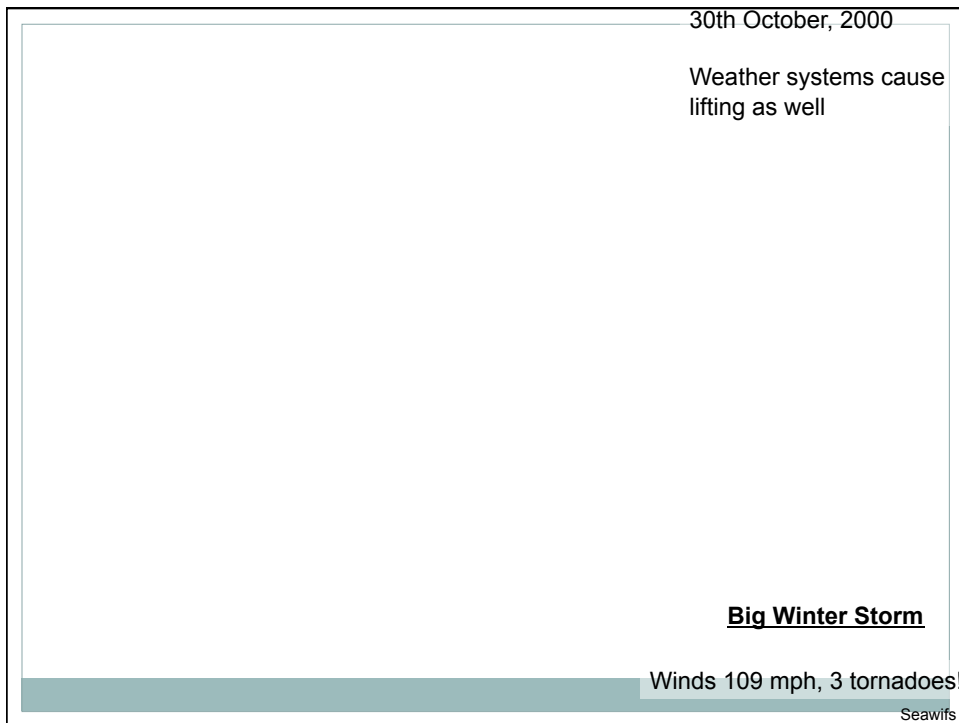
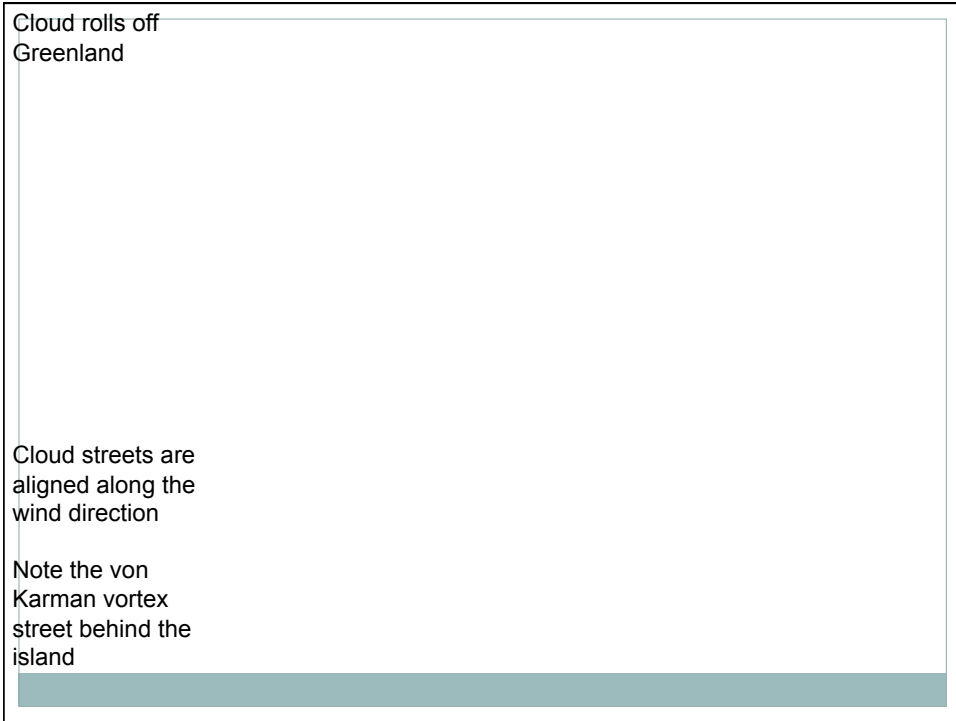
Pic of earth

Clouds

- Condensed water droplets or frozen crystals suspended in air
- Cloud formation happens when...
 - Moist air cools (so saturation is reached)
 - ✦ Often by lifting
 - Cloud condensation nuclei (stuff that droplets/ice can stick to) help the process
 - ✦ Without CCN, supersaturation can occur





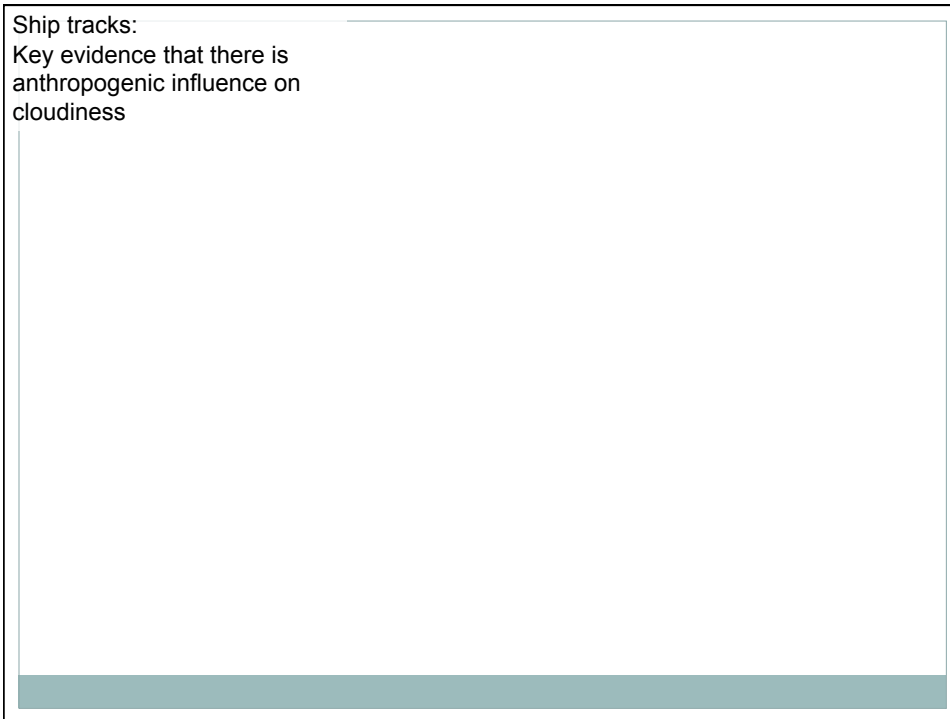


Hurricane Isabel, 2003

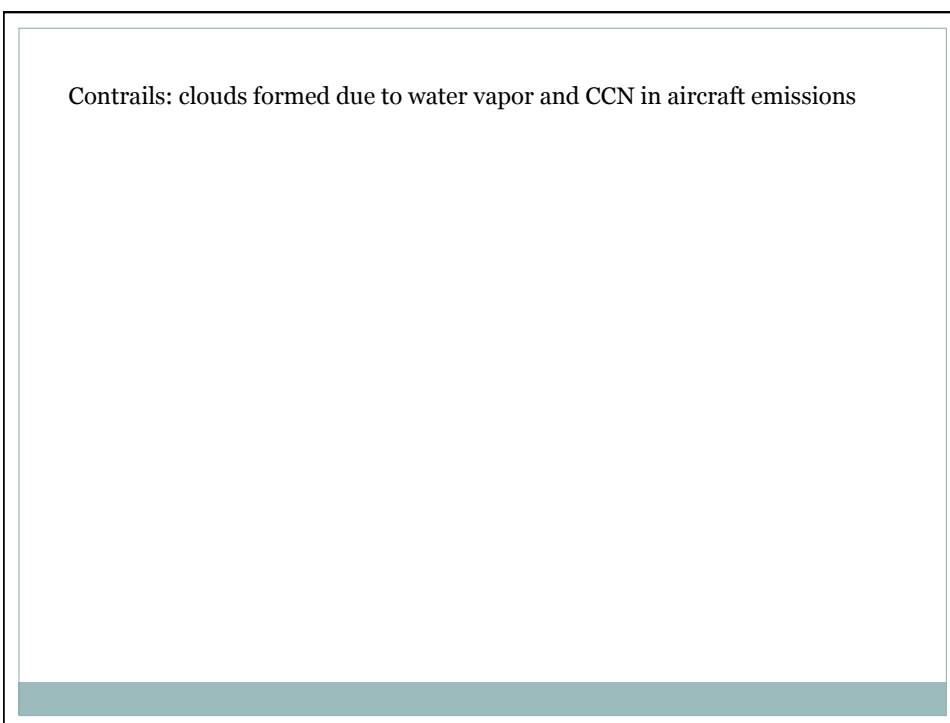
We have an effect on clouds
(via CCN)

Ship tracks: aerosols
causing water droplets to
form more easily, be smaller,
not precipitate out as easily

Ship tracks:
Key evidence that there is anthropogenic influence on cloudiness



Contrails: clouds formed due to water vapor and CCN in aircraft emissions



Contrails trap longwave and reflect shortwave:
Reduce diurnal temperature variations

Sept 12-14, 2001: all aircraft grounded (below are from President
Bush's flight and escorting aircraft)

Over the next 3 days, days cooled slightly and nights warmed,
Increasing diurnal temperature range by 1.1 C

Contrail Effects

- **Net contrail effects:**
 - Small warming effect on climate (around 0.01 W/m^2 of radiative forcing)
 - Nighttime flights are especially important for warming (25% of flights, 60-80% of warming), as are flights in winter (22% of flights, 50% of forcing)

Ash clouds (just because they're awesome)

Chaiten volcano, Chile

Cloud Effects


- **Two opposite effects:**
 - Reflecting solar radiation (cooling)
 - ✦ Based on their thickness
 - Greenhouse effect (warming)
- **Can either have warming or cooling effect depending on type!**

Longwave Effects

- **Clouds emit essentially like blackbodies in the infrared:**
$$E = \sigma T^4$$
- **High clouds (cold tops):**
 - Very small OLR
 - Trap heat effectively
- **Low clouds (warm tops):**
 - OLR isn't changed much

Low level clouds
-high albedo
-not much effect on OLR
-net cooling effect

- Low clouds near Baja California

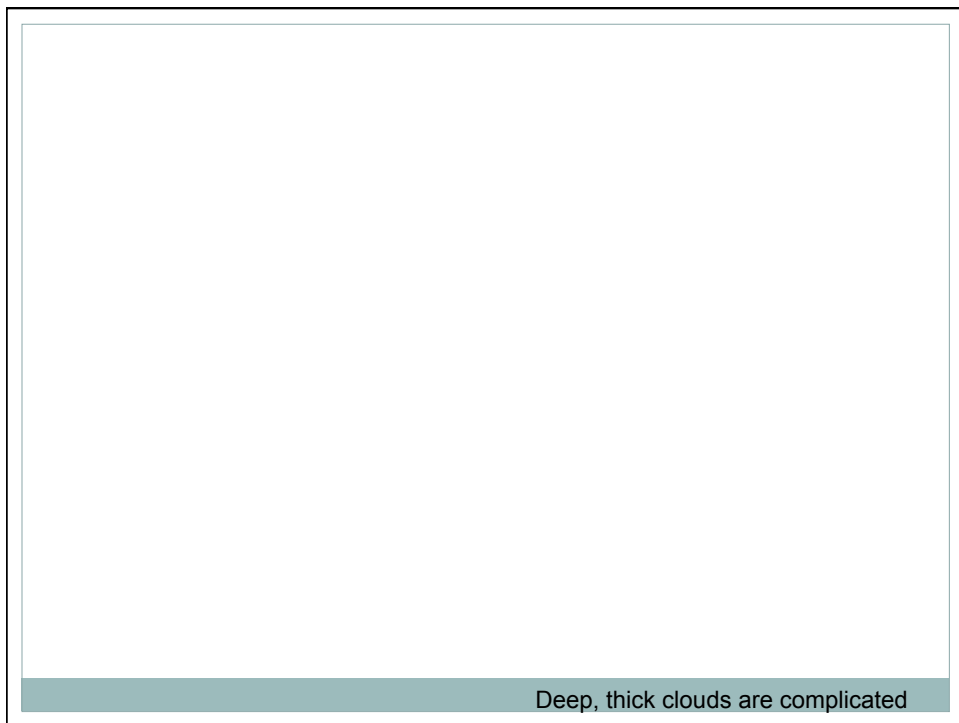
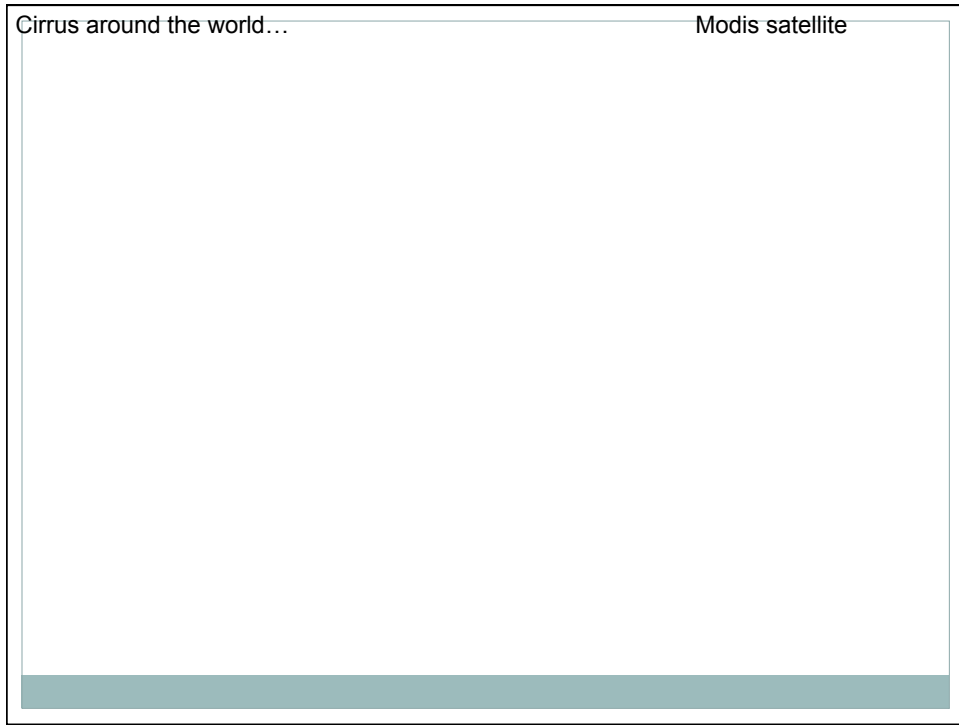


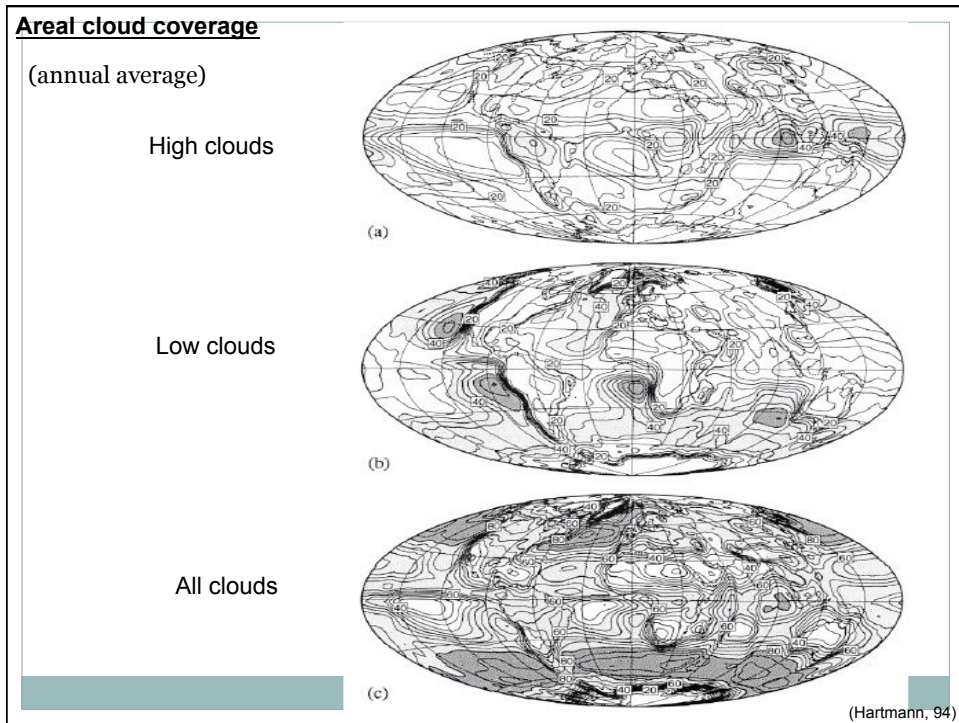
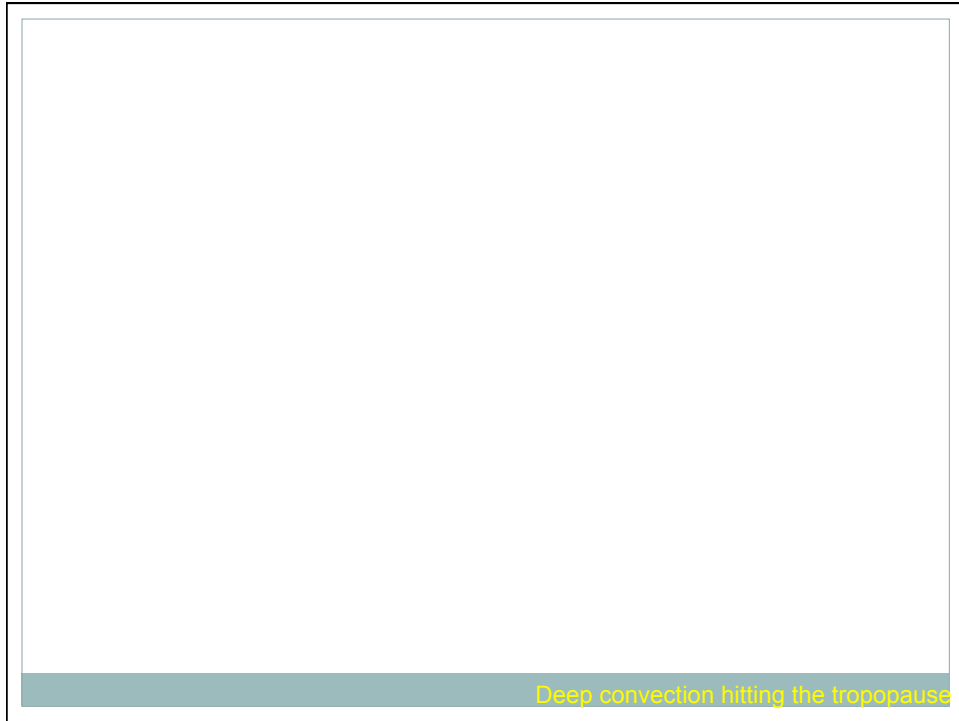
More low level clouds
Guadalupe, Mexico

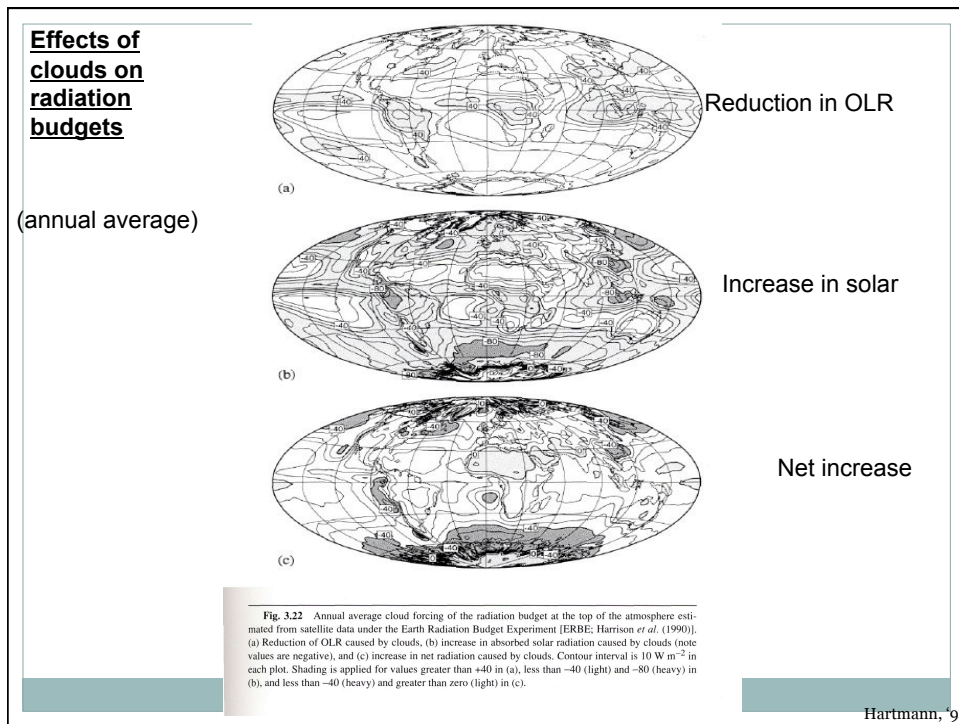
“Open cell” vs “closed cell” vs
“actinoform”

Upper level clouds

- optically thin (not much reflection), but good longwave absorbers
- warming effect







Total Cloud Forcing

- Cloud forcing = Average value – cloud free value
 - OLR: $+31 \text{ W/m}^2$
 - Solar: -48 W/m^2
 - Net: -17 W/m^2
- Clouds have net cooling effect on climate

Cloud Feedbacks?

- If low clouds disappear w/ warmer temperatures, cloud feedback would be positive
- If low clouds increase => negative feedback
- High clouds may change too...
- Next, let's discuss *forcings vs feedbacks*

Forcings vs Feedbacks

- **Forcings:**
 - Things that change climate directly
 - × CO₂, methane, solar, aerosols, etc
- **Feedbacks:**
 - Things that respond to a change in temperature
 - × Water vapor
 - × Lapse rate
 - × Ice coverage (sea and land)
 - × Clouds
 - These would presumably respond similarly to any forcing
 - × In a *per degree warming* manner

Radiative Forcing

- Remember we can calculate radiative transfer very accurately
- **Radiative forcing:** a useful method of quantifying climate forcing of different agents
 - Keep temperatures the same, instantaneously change forcing, and calculate effect on radiation
 - Ex 1: if solar radiation was decreased by 2 W/m^2
 - ✦ Radiative forcing would be -2 W/m^2
 - Ex 2: if CO_2 was instantly doubled, OLR decreases by 4 W/m^2
 - ✦ Radiative forcing is 4 W/m^2

Radiative Forcing and Temperature Response

- Temperatures must respond to a radiative forcing
 - Positive radiative forcing \rightarrow temperatures must increase
 - This will then reduce the radiative imbalance
- How much temperature response depends on feedbacks though
 - Radiative forcing is defined so it doesn't depend on feedbacks

Feedbacks

- For instance, say lots of ice was on the verge of melting
 - Then any small warming would be strongly amplified
- On the other hand, say the lapse rate feedback could act strongly (warming the upper troposphere really quickly)
 - Then the surface temperature might only need to increase a tiny bit to respond to the forcing

Feedbacks

- **Remember:**
 - A positive temperature change is always required to balance a positive forcing
 - ✦ Could be very small though if there are many strong negative feedbacks
 - If there are many strong positive feedbacks, system could spiral out of control
 - ✦ “Runaway greenhouse effect”: Earth keeps getting hotter & hotter until all the oceans evaporate
 - ✦ Not going to happen on Earth, but happened on Venus?

Climate Sensitivity

- **Climate sensitivity:**
 - The total temperature change required to reach equilibrium with the forcing
 - Depends on feedbacks! (unlike radiative forcing)
 - Refers to equilibrium state
 - × Real climate change is transient: we'll discuss this later

Climate Sensitivity and Feedbacks

- **How does each feedback affect radiation**
 - E.g., how much decrease in OLR per unit increase in humidity
- **And how fast does a temperature rise cause the quantity to increase**
 - E.g., water vapor content increases 7%/K
- **Derivations on the board...**