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

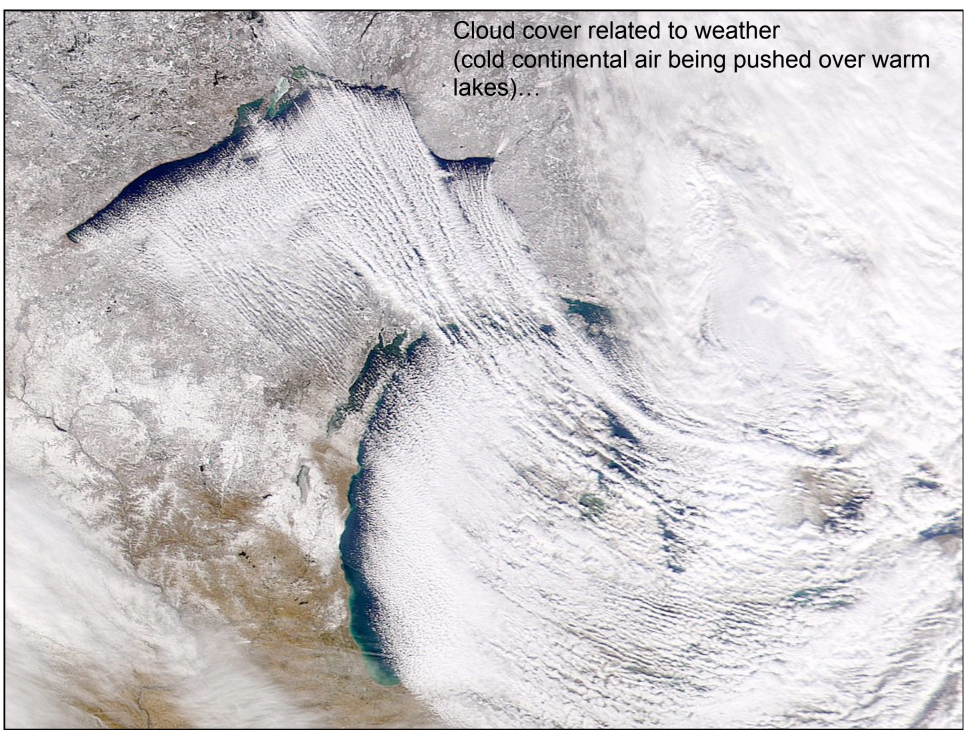
Clouds

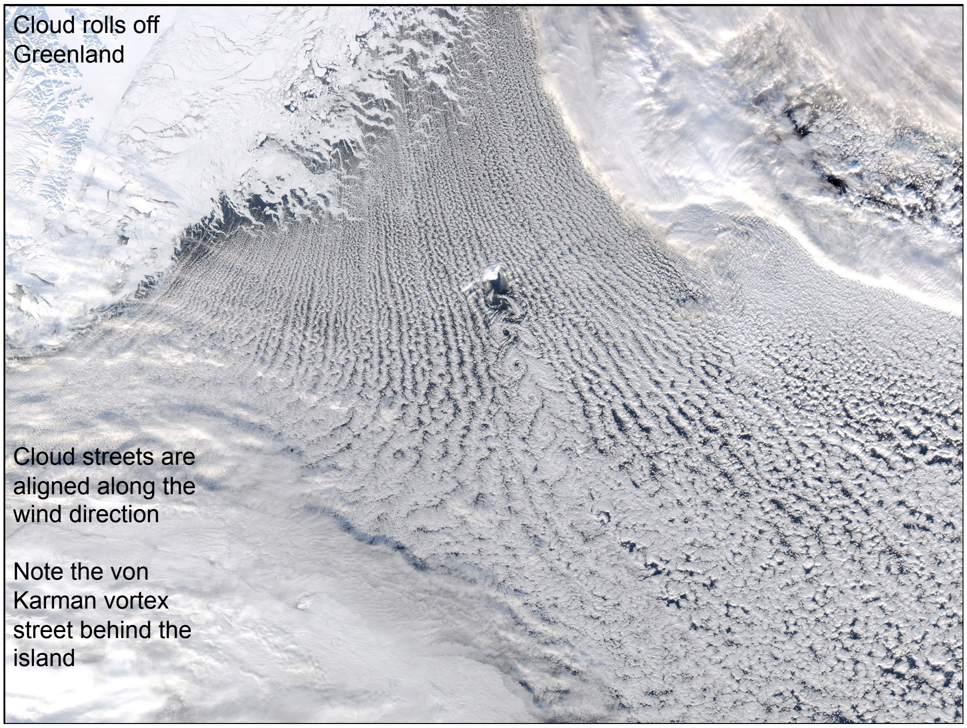
- Condensed water droplets or frozen crystals suspended in air
- Cloud formation happens when…
  - Moist air cools (so saturation is reached)
    - Often by lifting
  - Cloud condensation nuclei (stuff that droplets/ice can stick to) help the process
    - Without CCN, supersaturation can occur

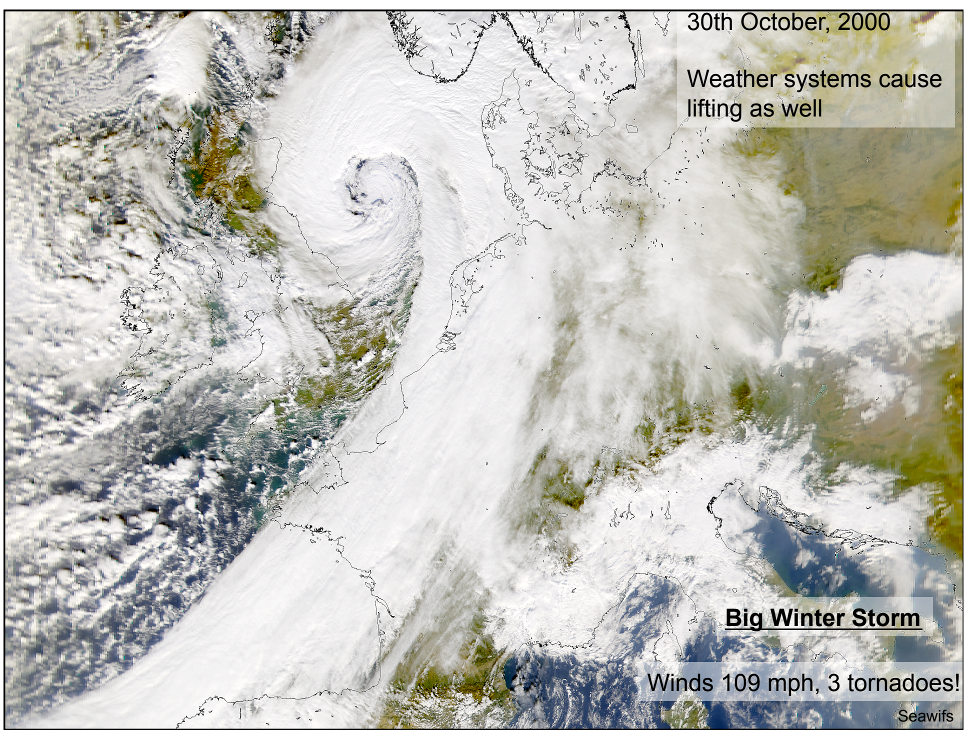

Lifting over a mountain

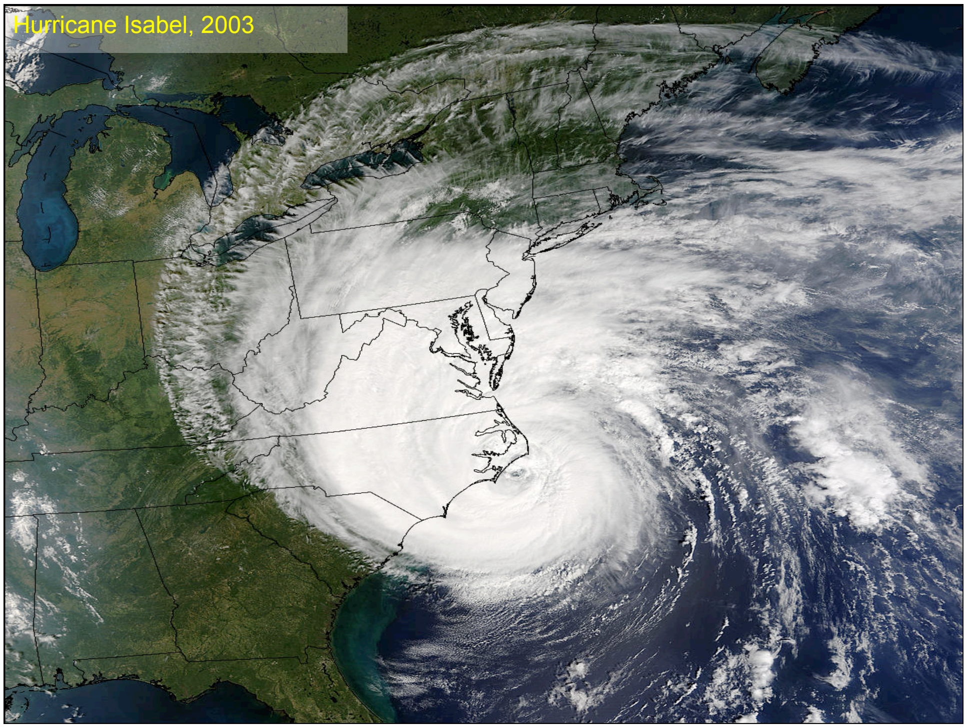

"Orographic" (mountain)
clouds
Mt Erebu

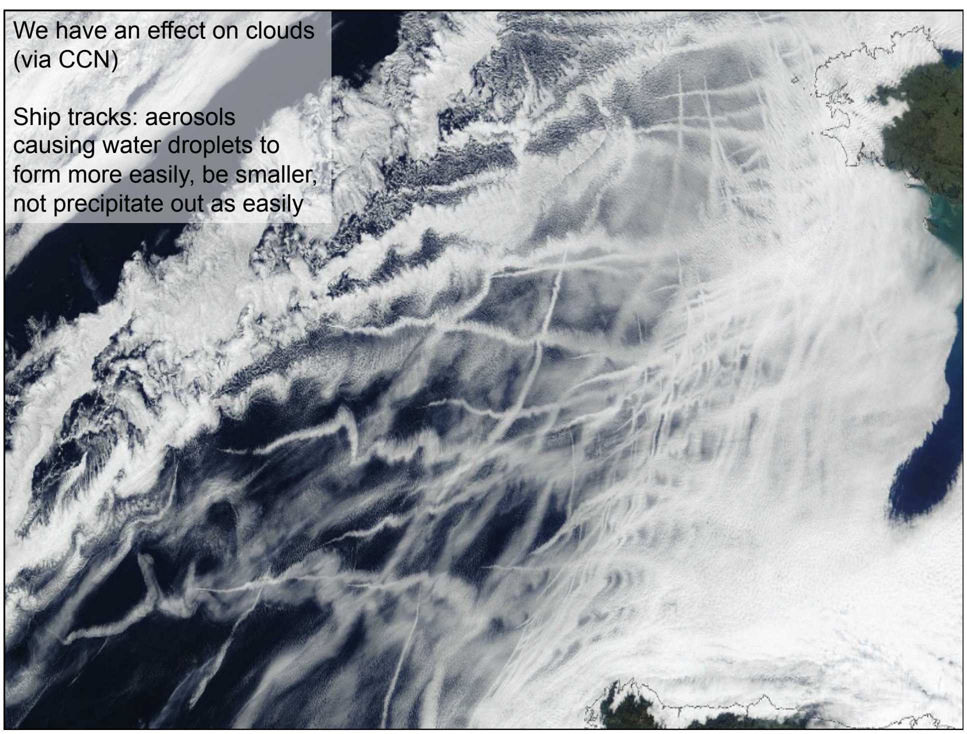

UFO clouds!

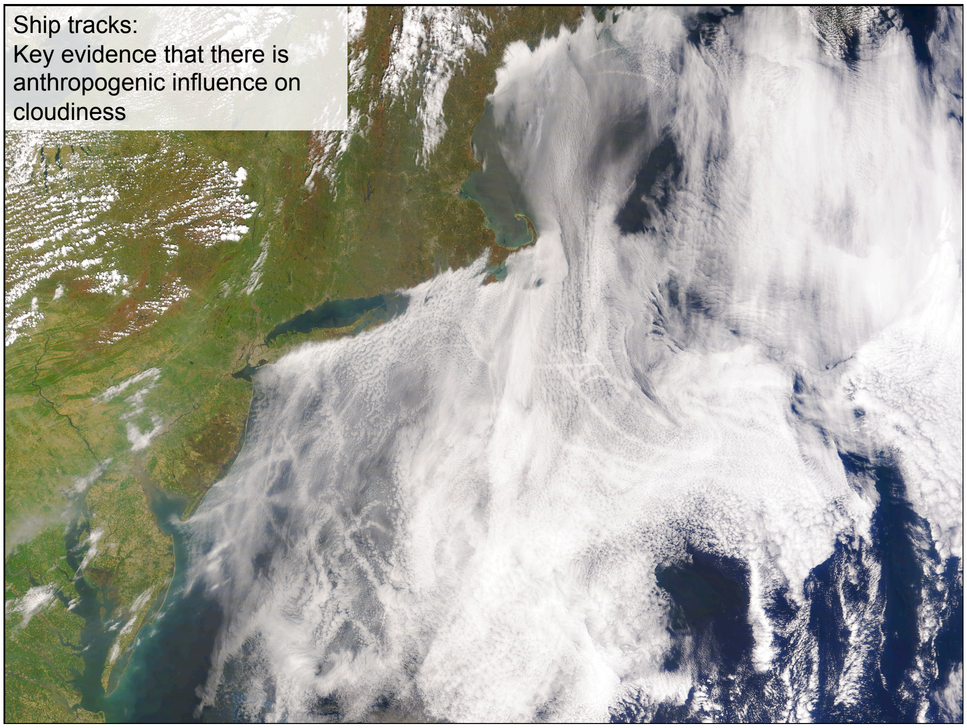

Cloud cover related to weather
(cold continental air being pushed over warm lakes)…

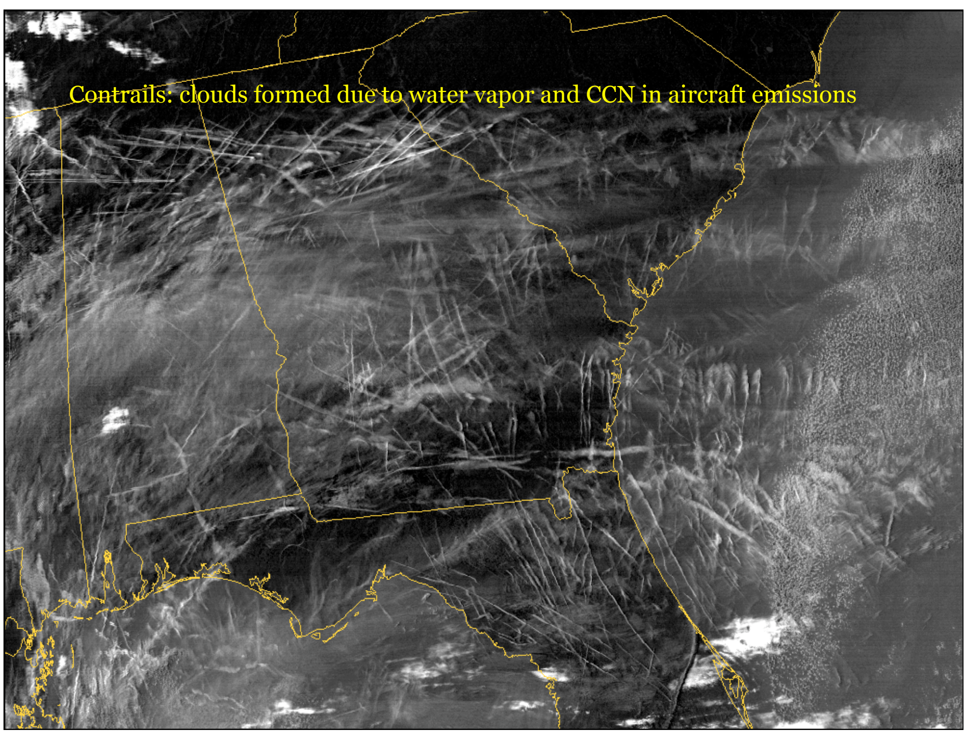

Cloud rolls off Greenland
Cloud streets are aligned along the wind direction
Note the von Karman vortex street behind the island


30th October, 2000
Weather systems cause lifting as well
Big Winter Storm
Winds 109 mph, 3 tornadoes!
Seawifs

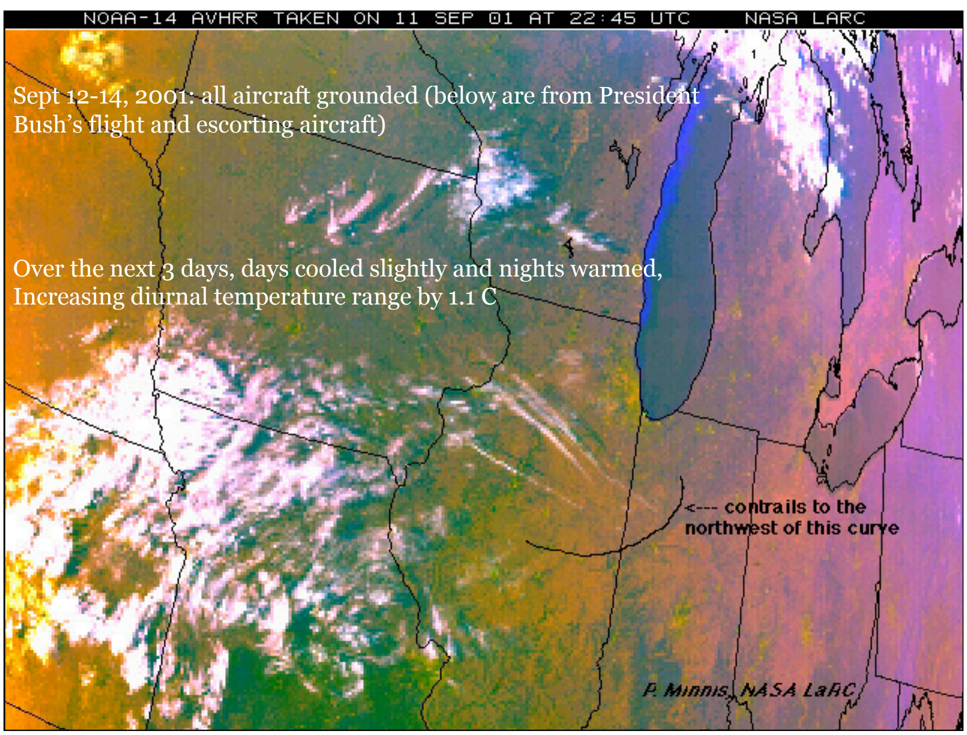

Hurricane Isabel, 2003


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


NOAA-14 AVHRR TAKEN ON 11 SEP 01 AT 22:45 UTC NASA LARC
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
<--- contrails to the northwest of this curve
P. Minnis, NASA LaRC

Contrail Effects

- Net contrail effects:
  - Small warming effect on climate (around 0.01 W/m2 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

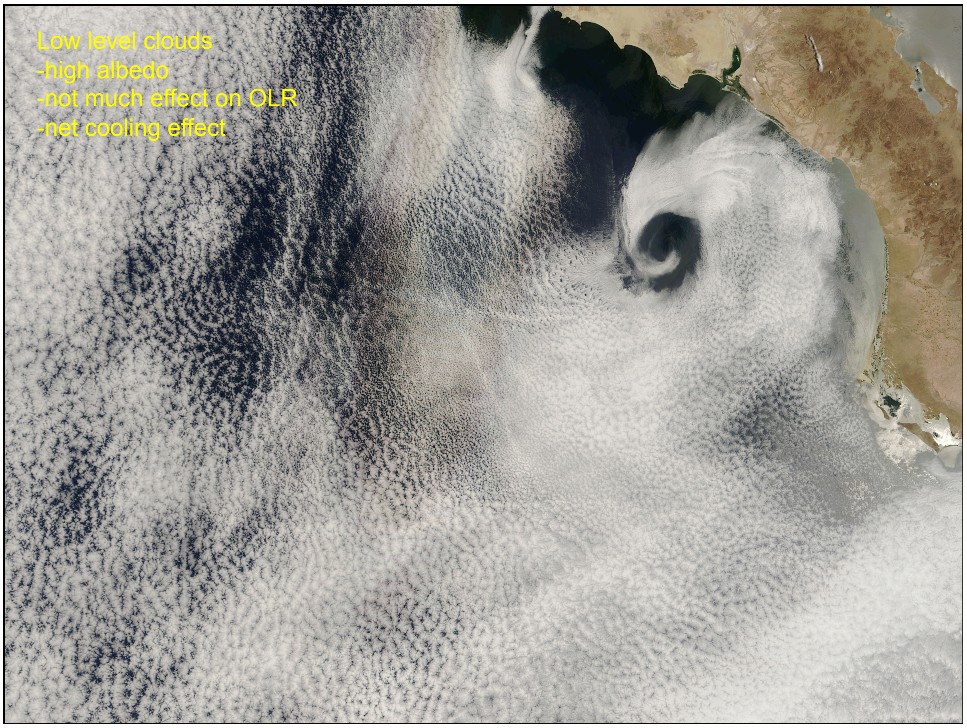
- Two opposite effects:
  - Reflecting solar radiation (cooling)
    - Based on their thickness
  - Greenhouse effect (warming)
- Can either have warming or cooling effect depending on type!

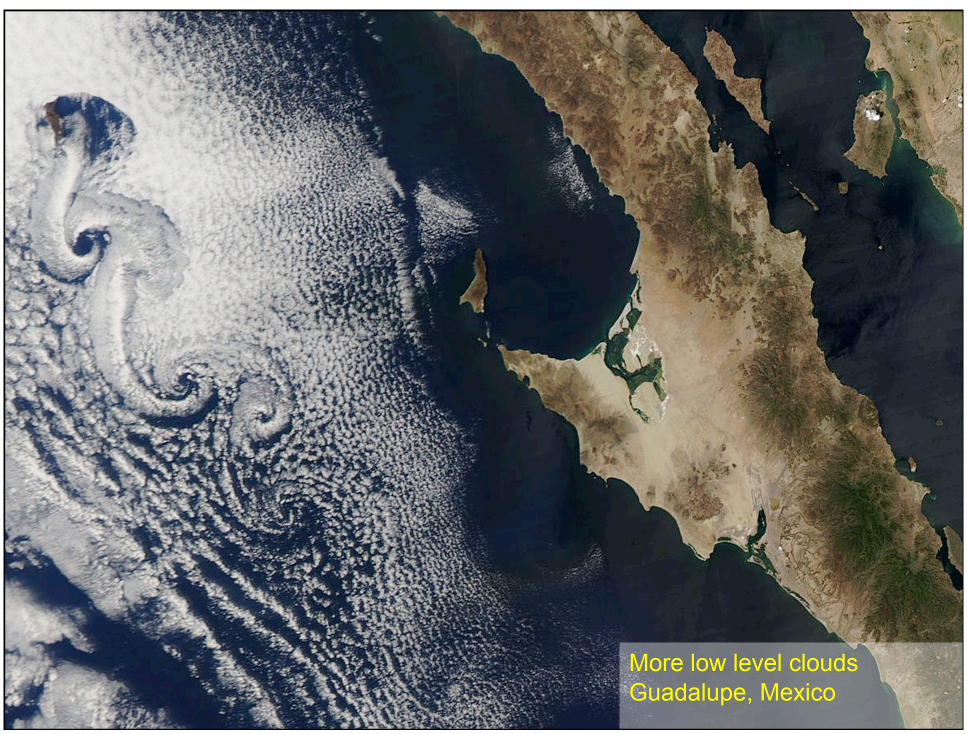
Longwave Effects

- Clouds emit essentially like blackbodies in the infrared:

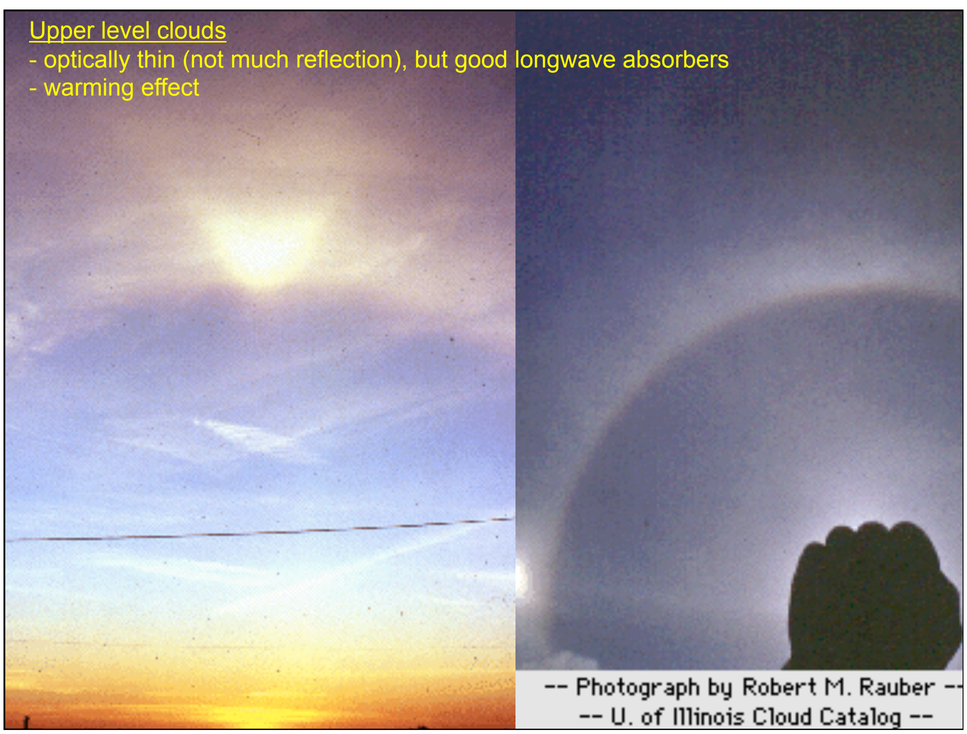
$$E = \sigma T^4$$

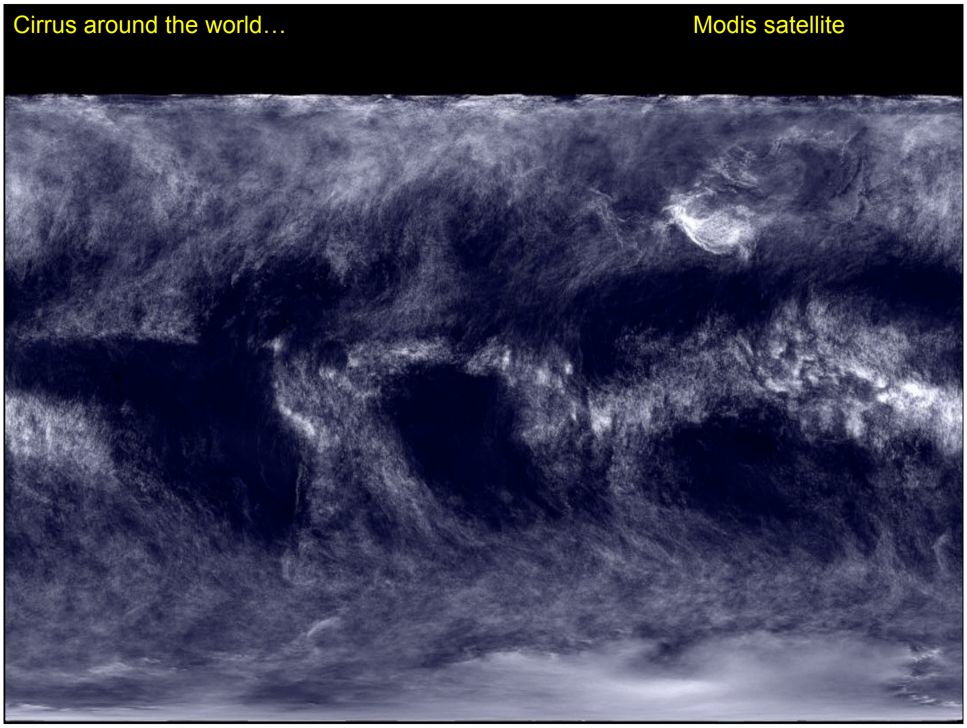
- High clouds (cold tops):
  - Very small OLR
  - Trap heat effectively
- Low clouds (warm tops):
  - OLR isn't changed much


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

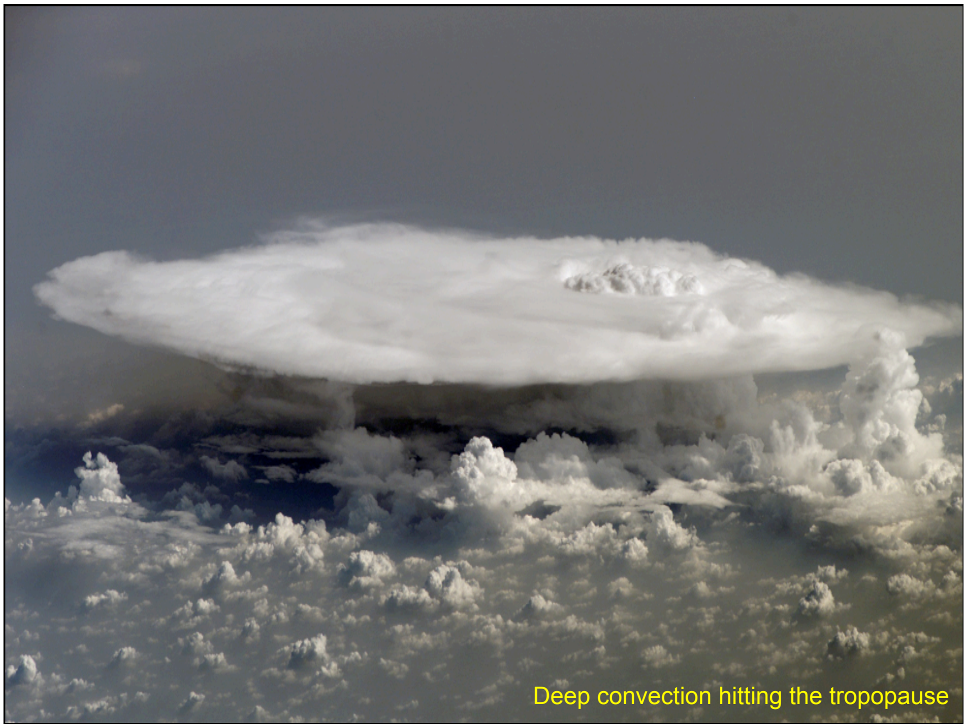

More low level clouds
Guadalupe, Mexico


"Open cell" vs "closed cell" vs
"actinoform"


Upper level clouds
- optically thin (not much reflection), but good longwave absorbers
- warming effect
-- Photograph by Robert M. Rauber --
-- U. of Illinois Cloud Catalog --


Cirrus around the world…
Modis satellite


Deep, thick clouds are complicated



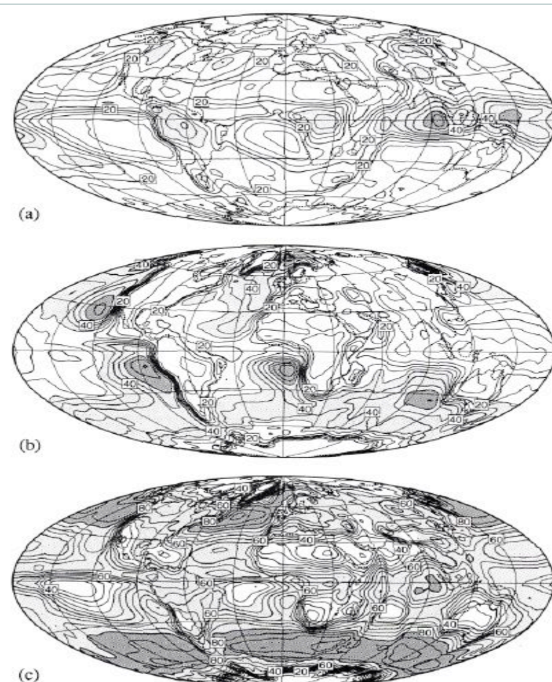
Areal cloud coverage

(annual average)

High clouds

Low clouds

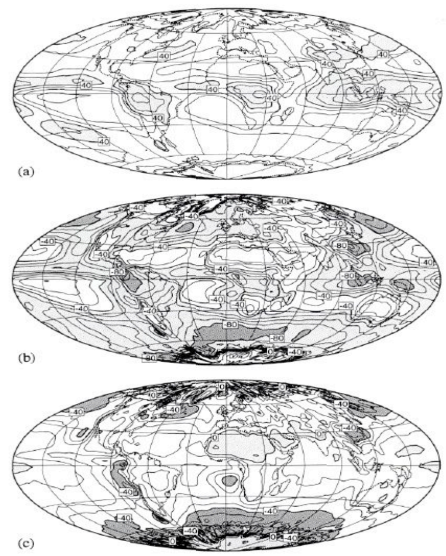
All clouds



(Hartmann, 94)

Effects of clouds on radiation budgets

(annual average)



Reduction in OLR

Increase in solar

Net increase

Fig. 3.22 Annual average cloud forcing of the radiation budget at the top of the atmosphere estimated from satellite data under the Earth Radiation Budget Experiment [ERBE; Harrison *et al.* (1990)]. (a) Reduction of OLR caused by clouds, (b) increase in absorbed solar radiation caused by clouds (note values are negative), and (c) increase in net radiation caused by clouds. Contour interval is 10 W m^{-2} in each plot. Shading is applied for values greater than +40 in (a), less than −40 (light) and −80 (heavy) in (b), and less than −40 (heavy) and greater than zero (light) in (c).

Hartmann, '94

Total Cloud Forcing

- Cloud forcing = Average value – cloud free value
  - OLR: +31 W/m2
  - Solar: -48 W/m2
  - Net: -17 W/m2
- 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
    - CO_2, 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/m2
    - Radiative forcing would be -2 W/m2
  - Ex 2: if CO2 was instantly doubled, OLR decreases by 4 W/m2
    - Radiative forcing is 4 W/m2

Radiative Forcing and Temperature Response

- Temperatures must respond to a radiative forcing
  - Positive radiative forcing → 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…