Climate Dynamics (PCC 587): Feedbacks & Clouds

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Feedbacks

- Climate **forcings** change global temperatures directly
  - E.g., solar changes, volcanoes, aerosols, greenhouse gases
  - We'll discuss these in more detail next lecture…
- Climate **feedbacks** *respond* to temperature changes but *also change* temperature themselves
- We've discussed many climate feedbacks already
  - Water vapor feedback is confidently positive
  - Lapse rate feedback is confidently negative

Ice-Albedo Feedback

- Warming → ice melting → dark open ocean visible → more warming
- Similar feedback is present for snow (revealing darker land surfaces below)

Very important for local Arctic temperatures

Not nearly as strong as water vapor feedback in global importance

Cloud Feedbacks

- **Clouds**: suspended liquid water **droplets** or ice **crystals** in air
  - Don't confuse clouds (liquid or solid) with water vapor (a gas)
  - Essentially, if you can see it, it's a liquid/solid

Clouds happen when humid air cools (often due to rising motion)

Cloud condensation nuclei (CCN) are necessary too: small particles the liquid or ice can stick to

Convective clouds growing over Tiger Mountain (Prof. Dale Durran)

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


UFO clouds!
(actually lenticular clouds,
formed from lee waves
downwind of mountains)

Cloud Effects

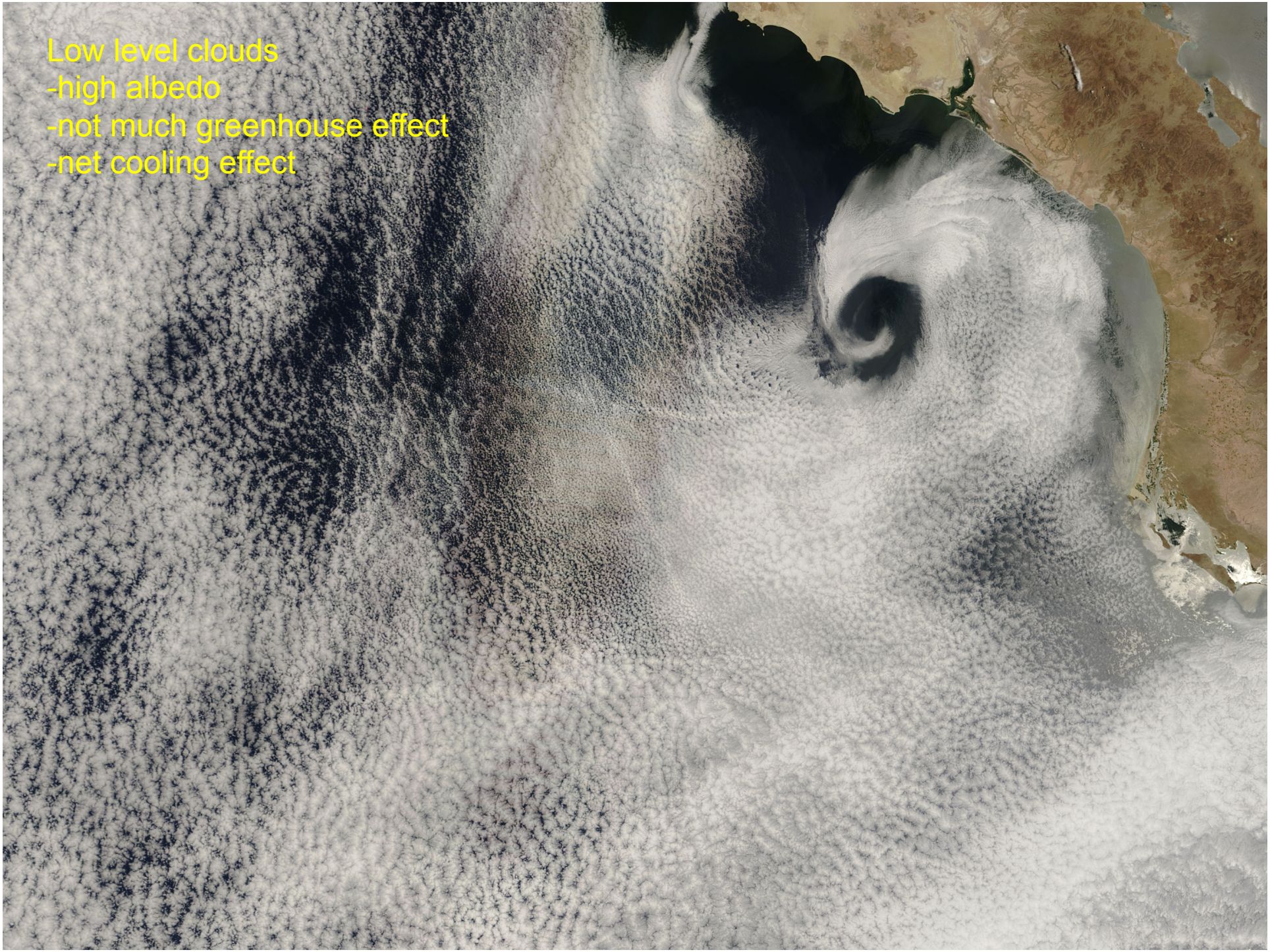
- Two opposite effects:
  - Reflecting solar radiation (cooling)
    - Based on their **thickness**
  - Greenhouse effect (warming)
- Can either have warming or cooling effect depending on type!

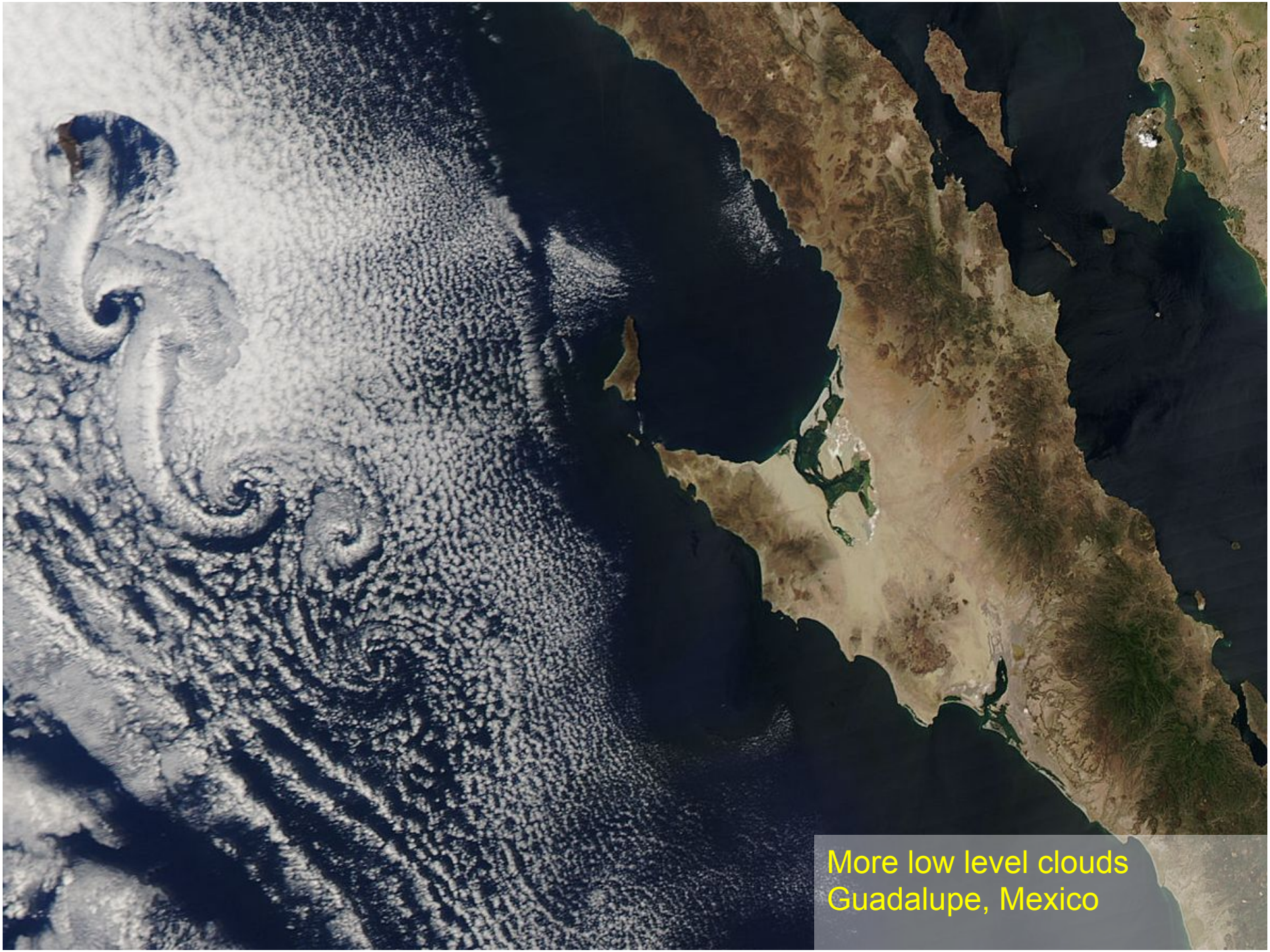
Longwave Effects

- Clouds emit essentially like blackbodies in the infrared:

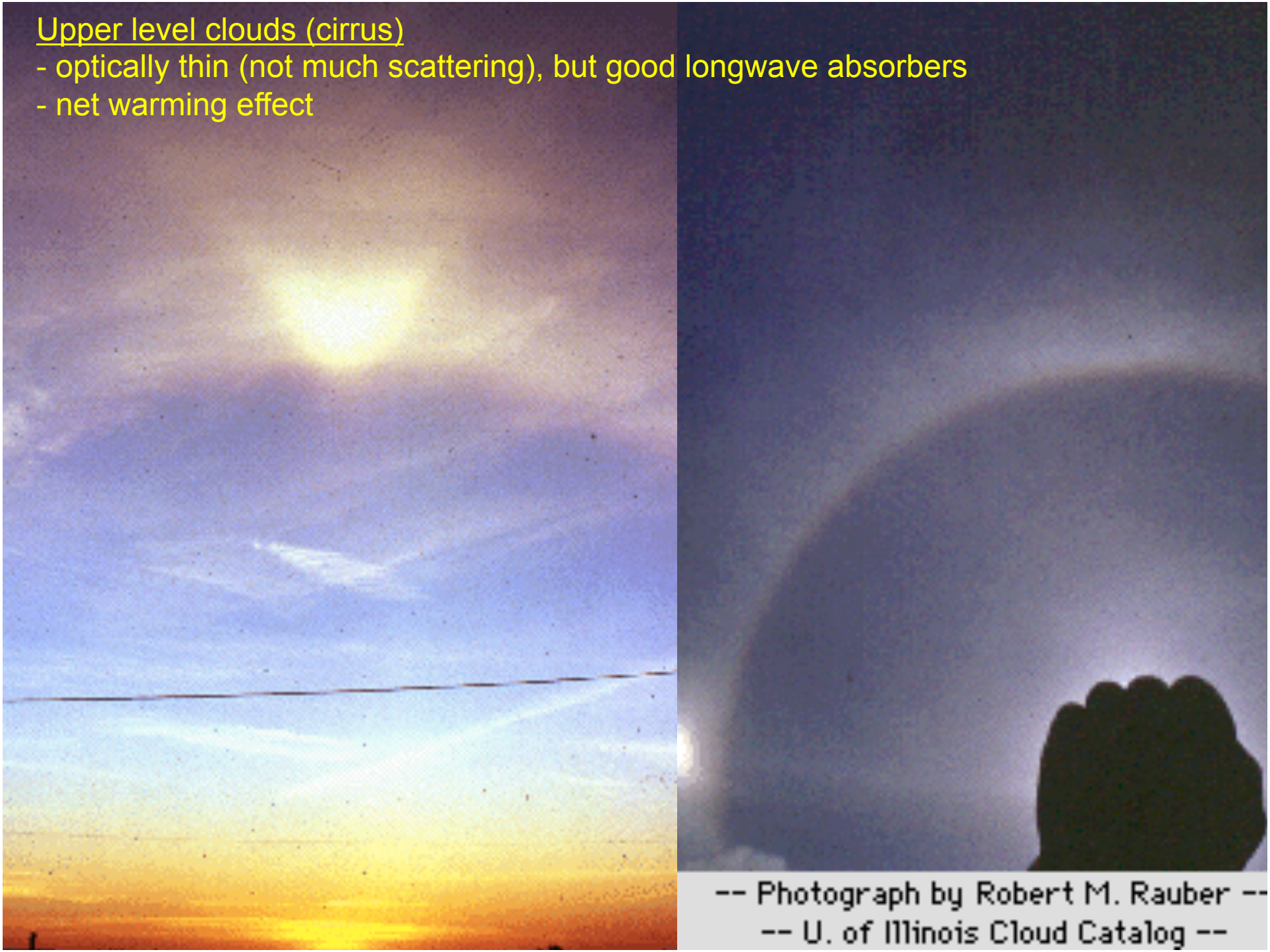
$$E = \sigma T^4$$

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


Low level clouds
-high albedo
-not much greenhouse effect
-net cooling effect

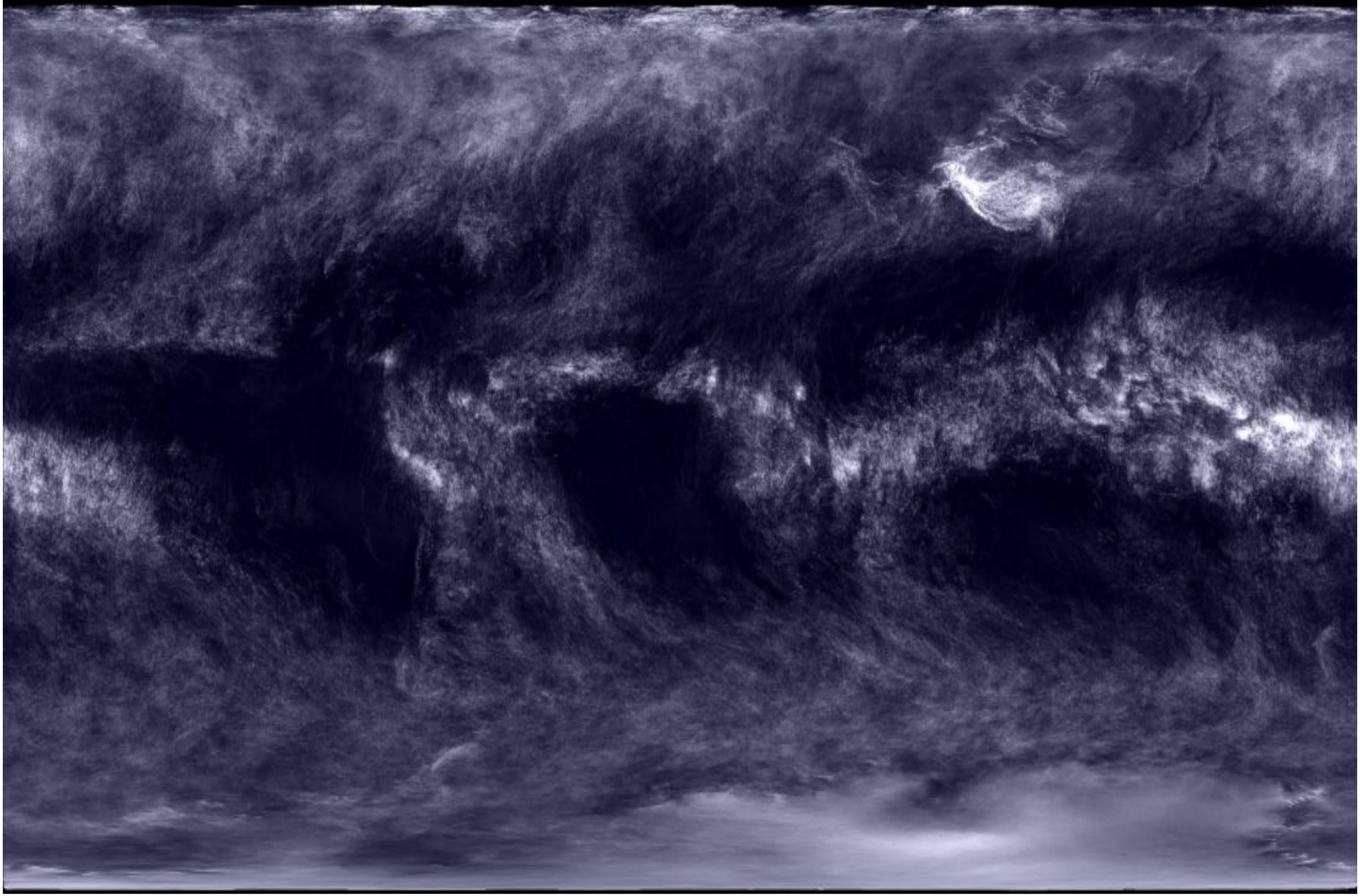

More low level clouds
Guadalupe, Mexico

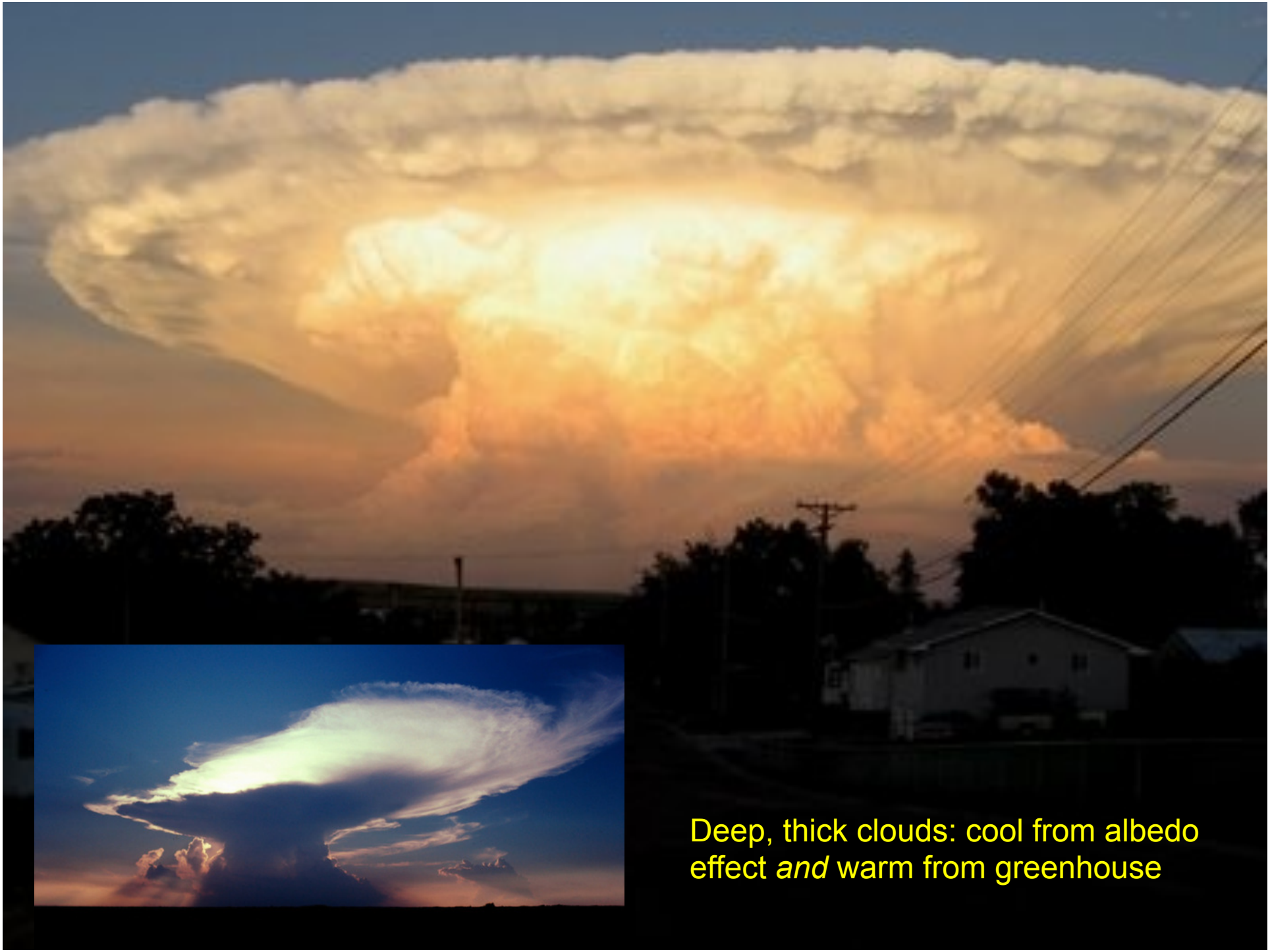

“Open cell” vs “closed cell”
low clouds


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

Cirrus around the world…

Modis satellite

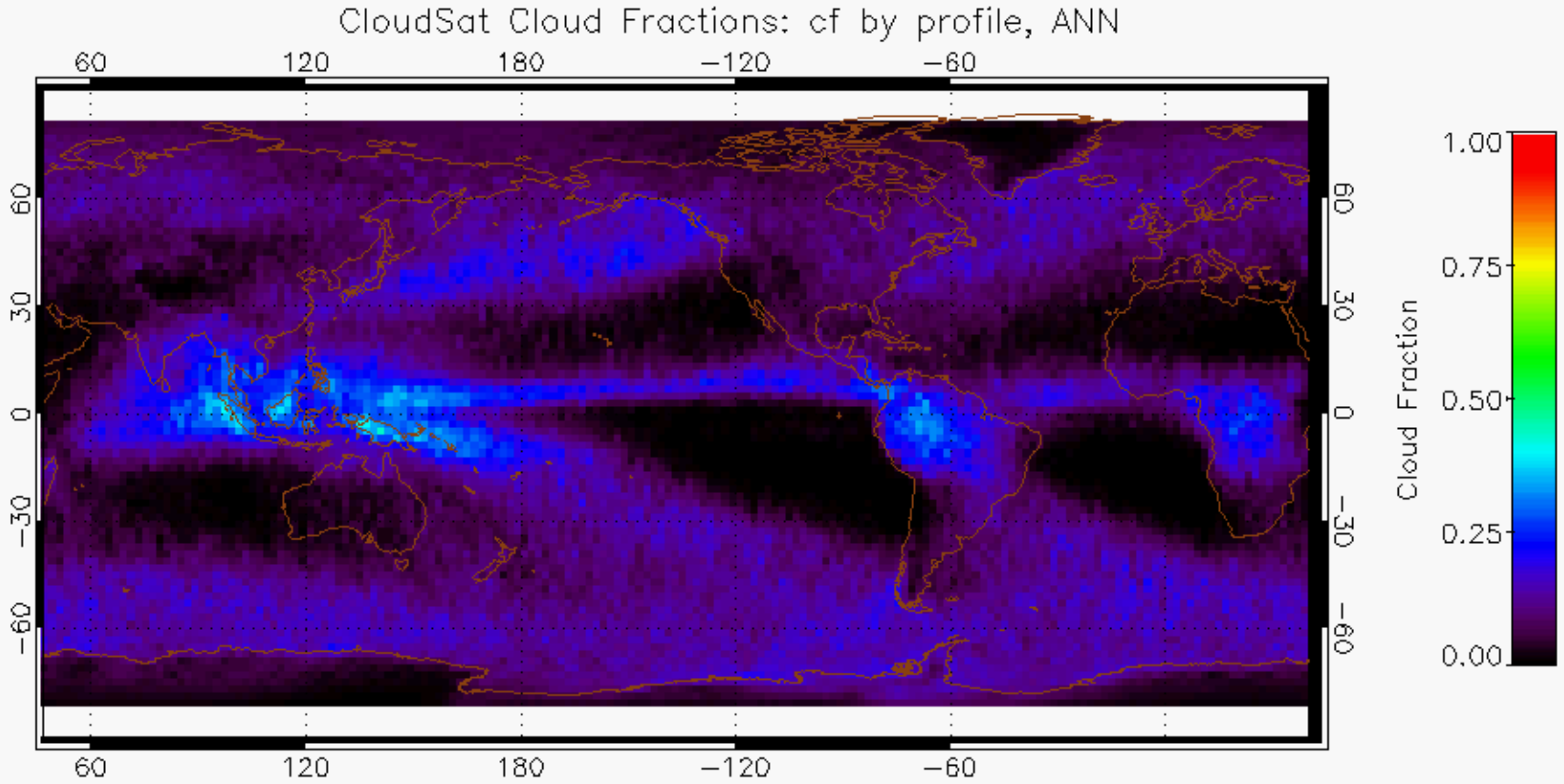



Deep, thick clouds: cool from albedo
effect *and* warm from greenhouse


Deep convection in the tropics hitting the tropopause

Cloud Fraction

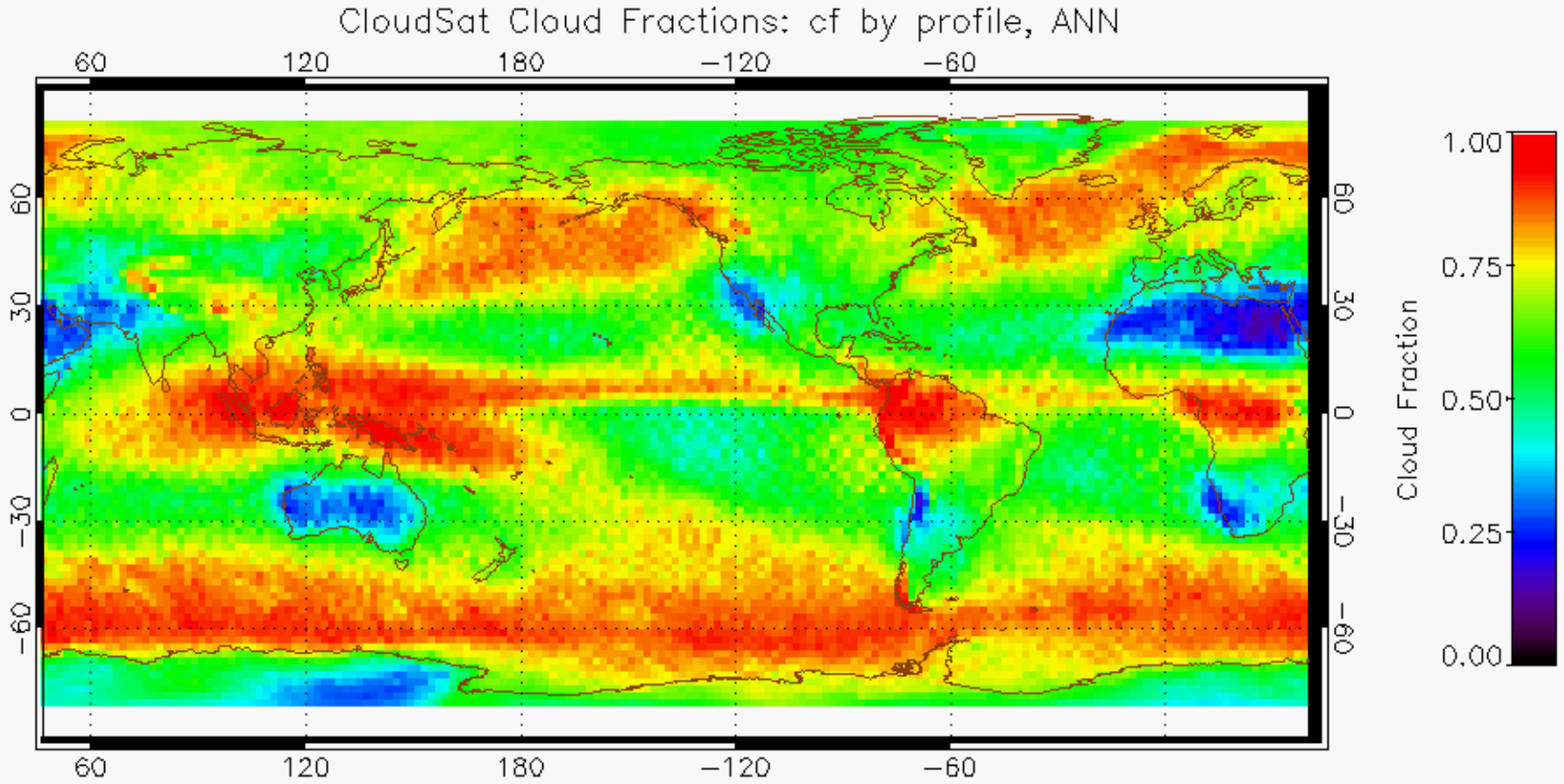
- Thick cloud fraction on Earth:



CloudSat & CALIOP data from Jen Kay

Cloud Fraction

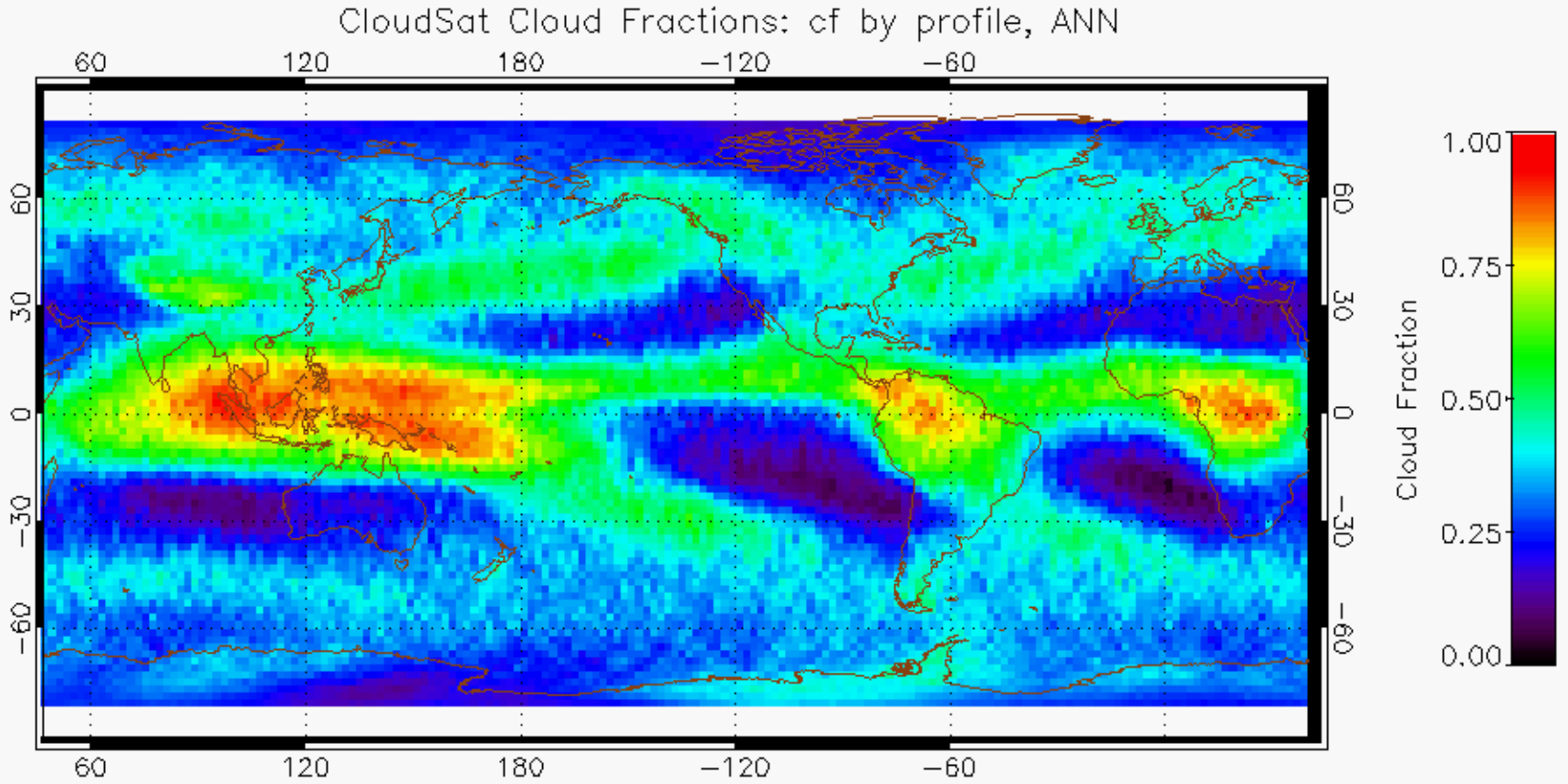
- All cloud fraction:



CloudSat & CALIOP data from Jen Kay

High Cloud Fraction

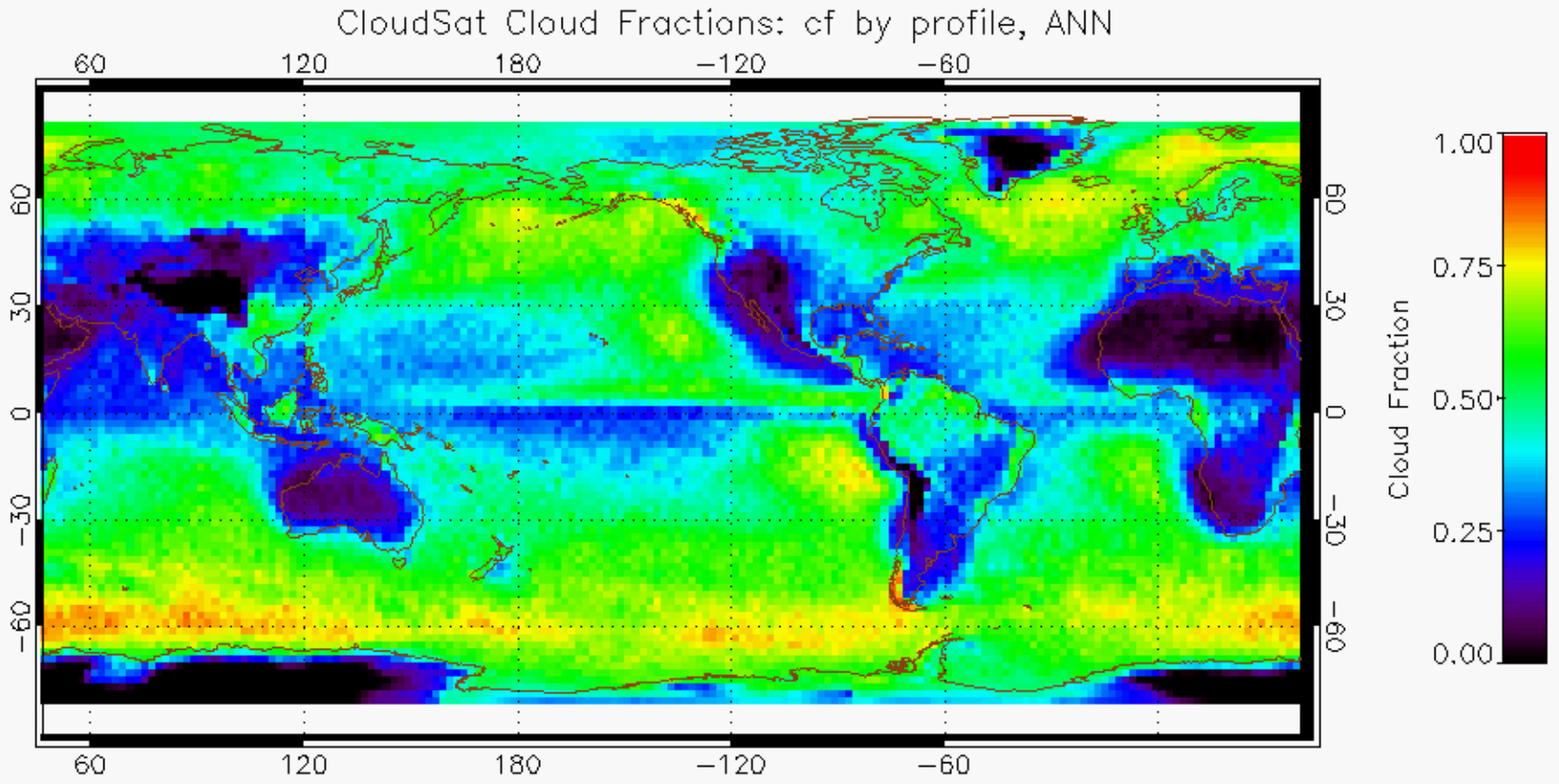
- High clouds (above 400 mbar)



CloudSat & CALIOP data from Jen Kay

Low Cloud Fraction

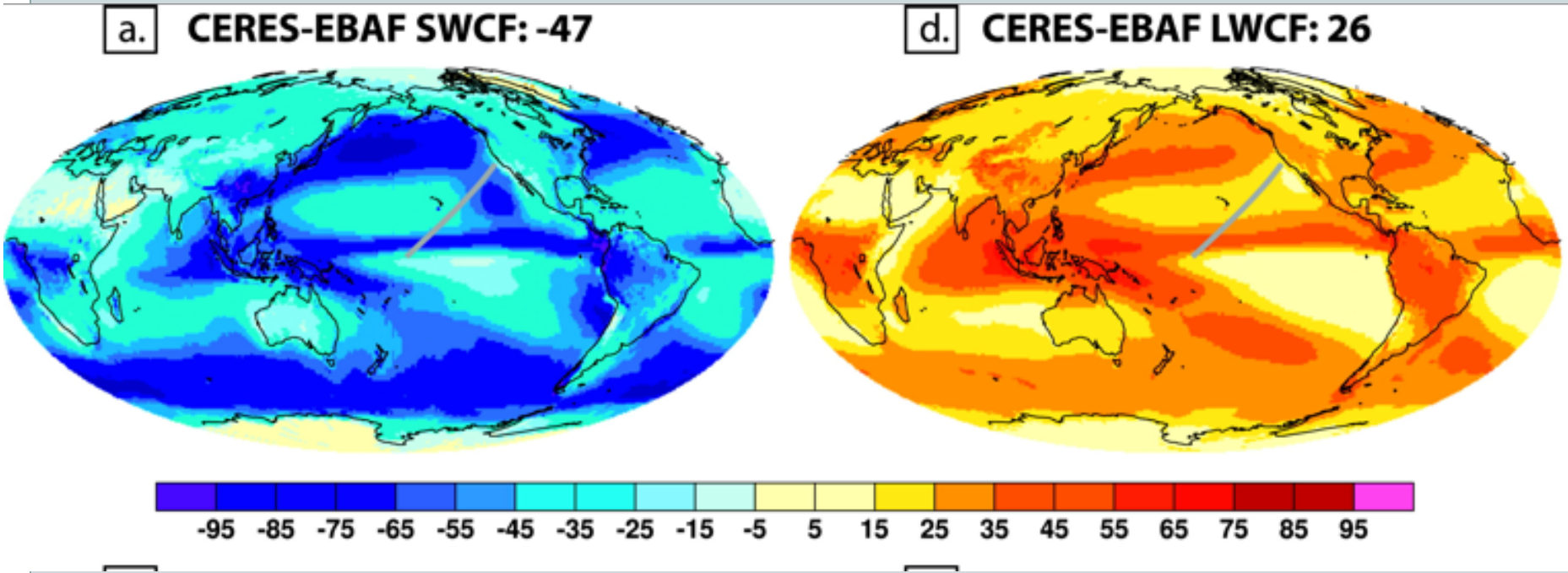
- Low cloud fraction



CloudSat & CALIOP data from Jen Kay

Cloud Radiative Forcing

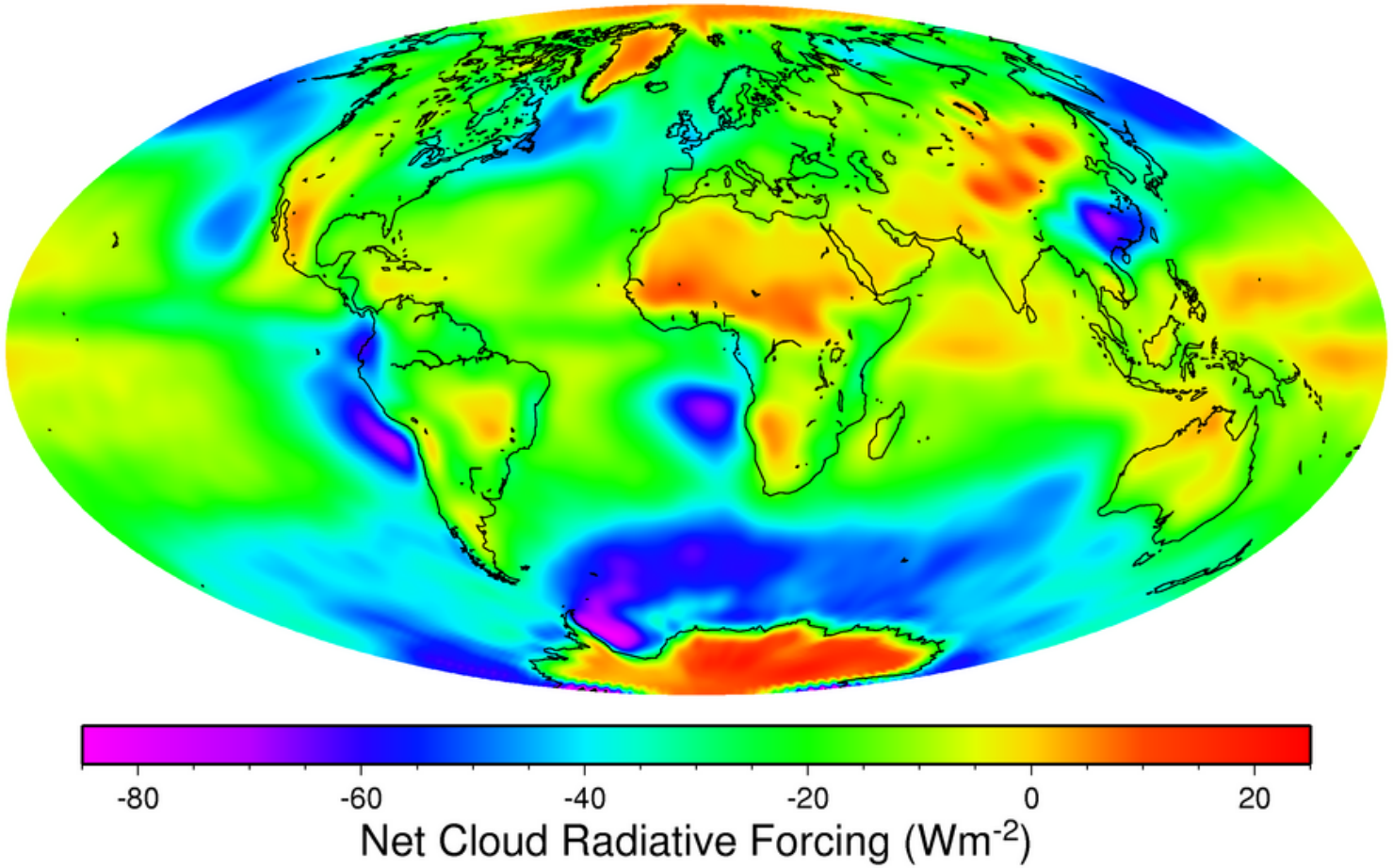
- Effect of clouds on longwave and shortwave radiation



Kay et al 2012

Net Cloud Radiative Forcing

- Shortwave plus longwave:

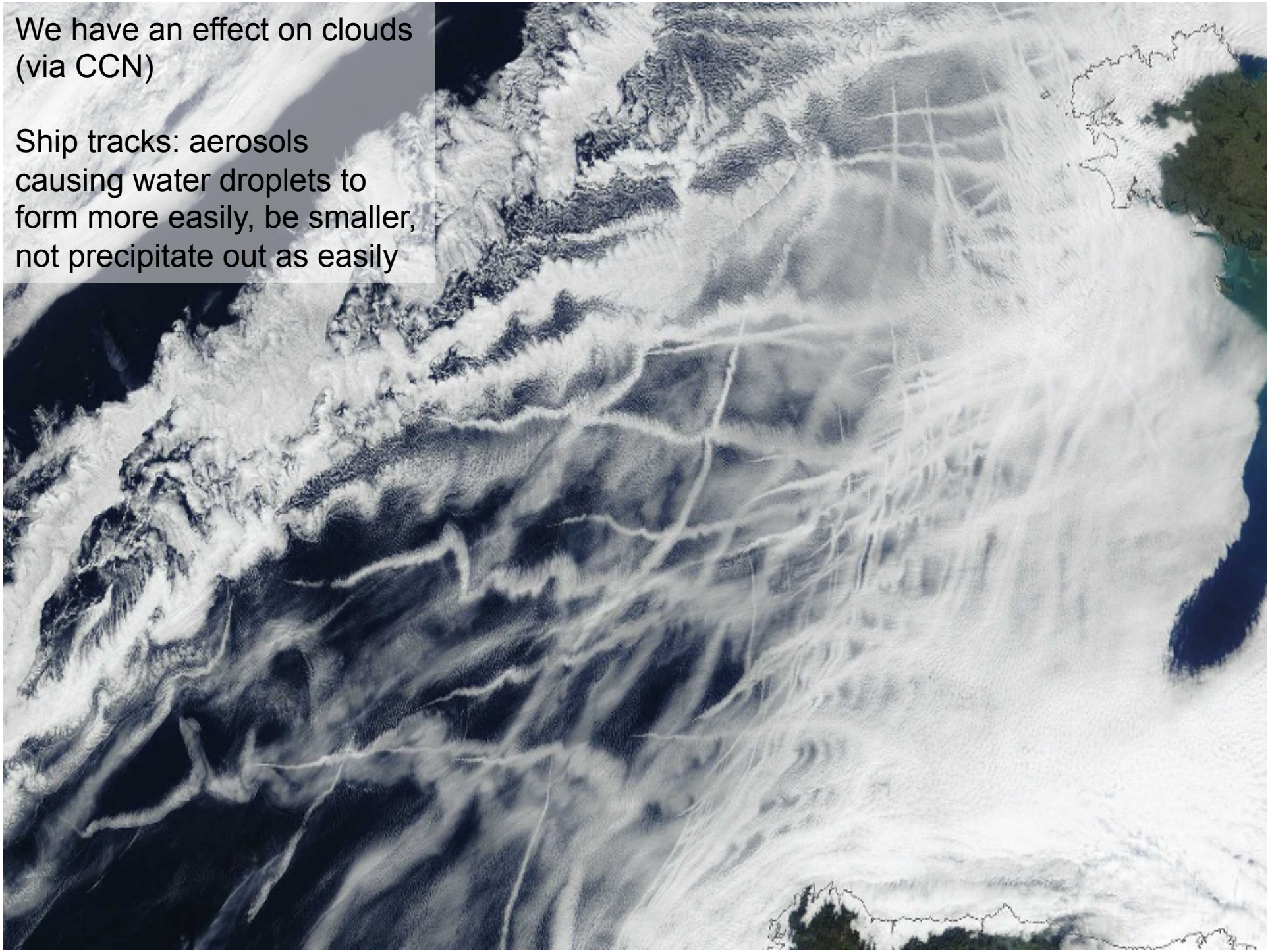


Total Cloud Forcing

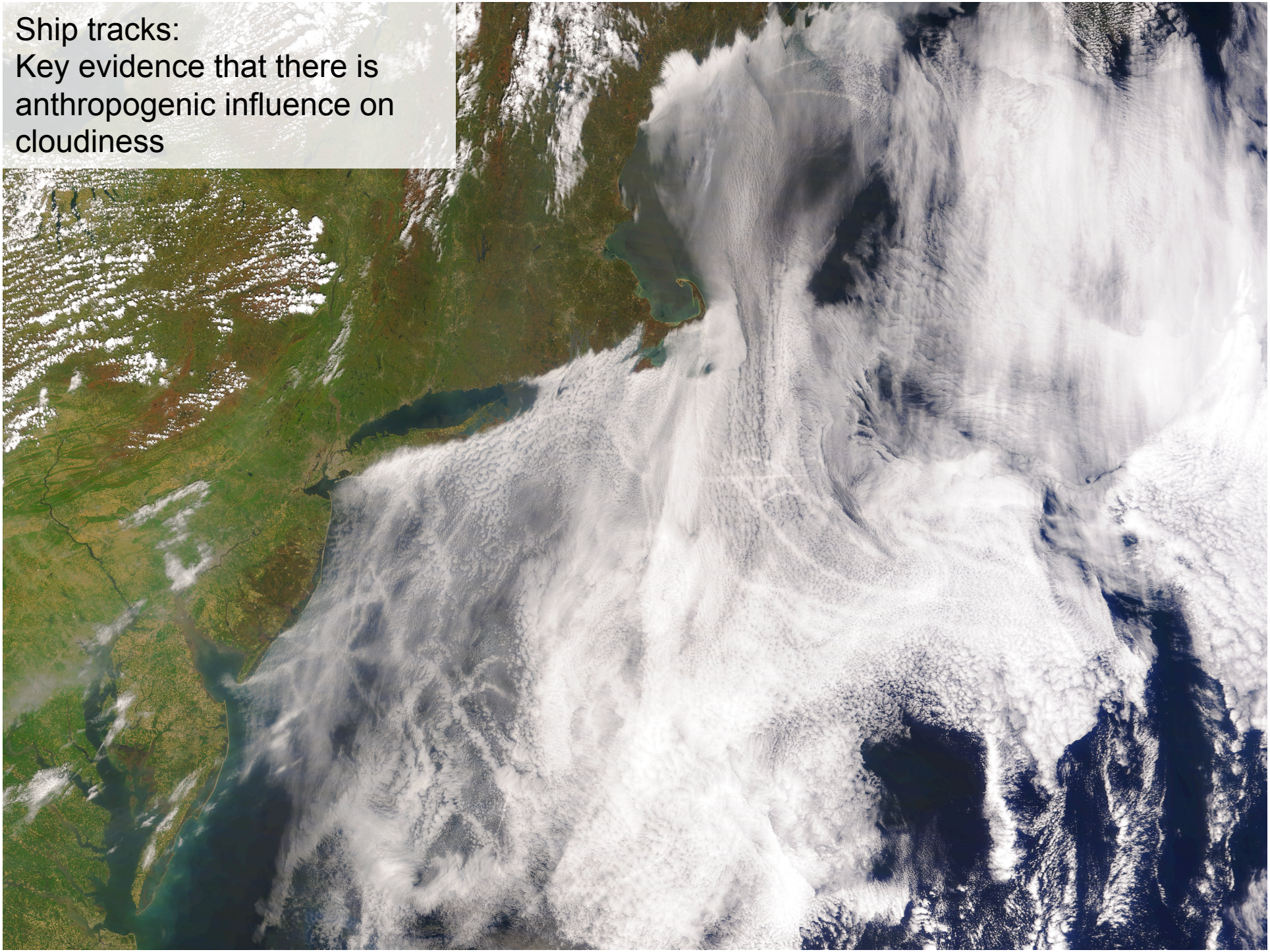
- Cloud forcing = Average value – cloud free value
  - OLR: +26 W/m2
  - Solar: -47 W/m2
  - Net: -21 W/m2
- Clouds have net cooling effect on climate

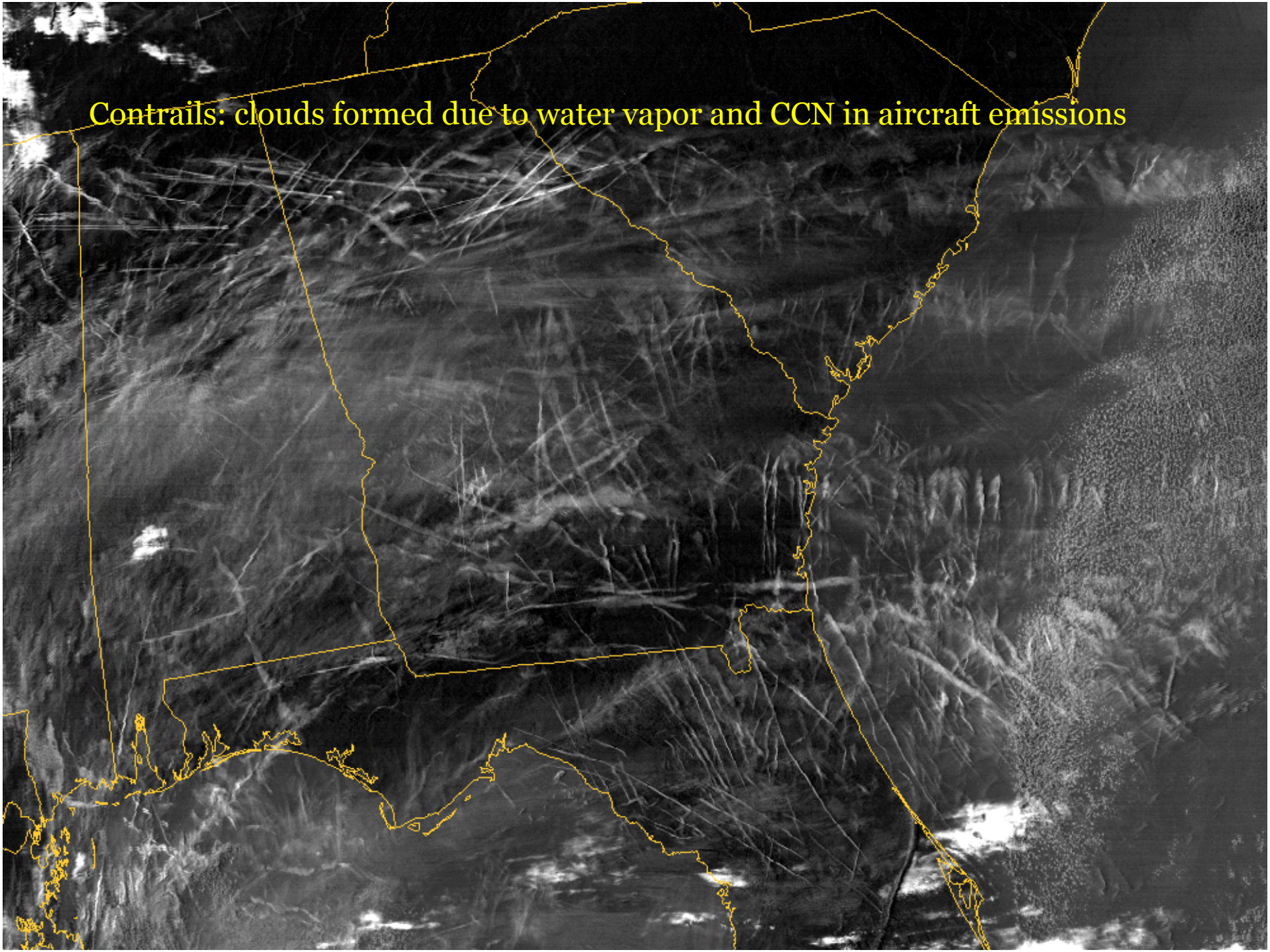
Cloud Feedbacks?

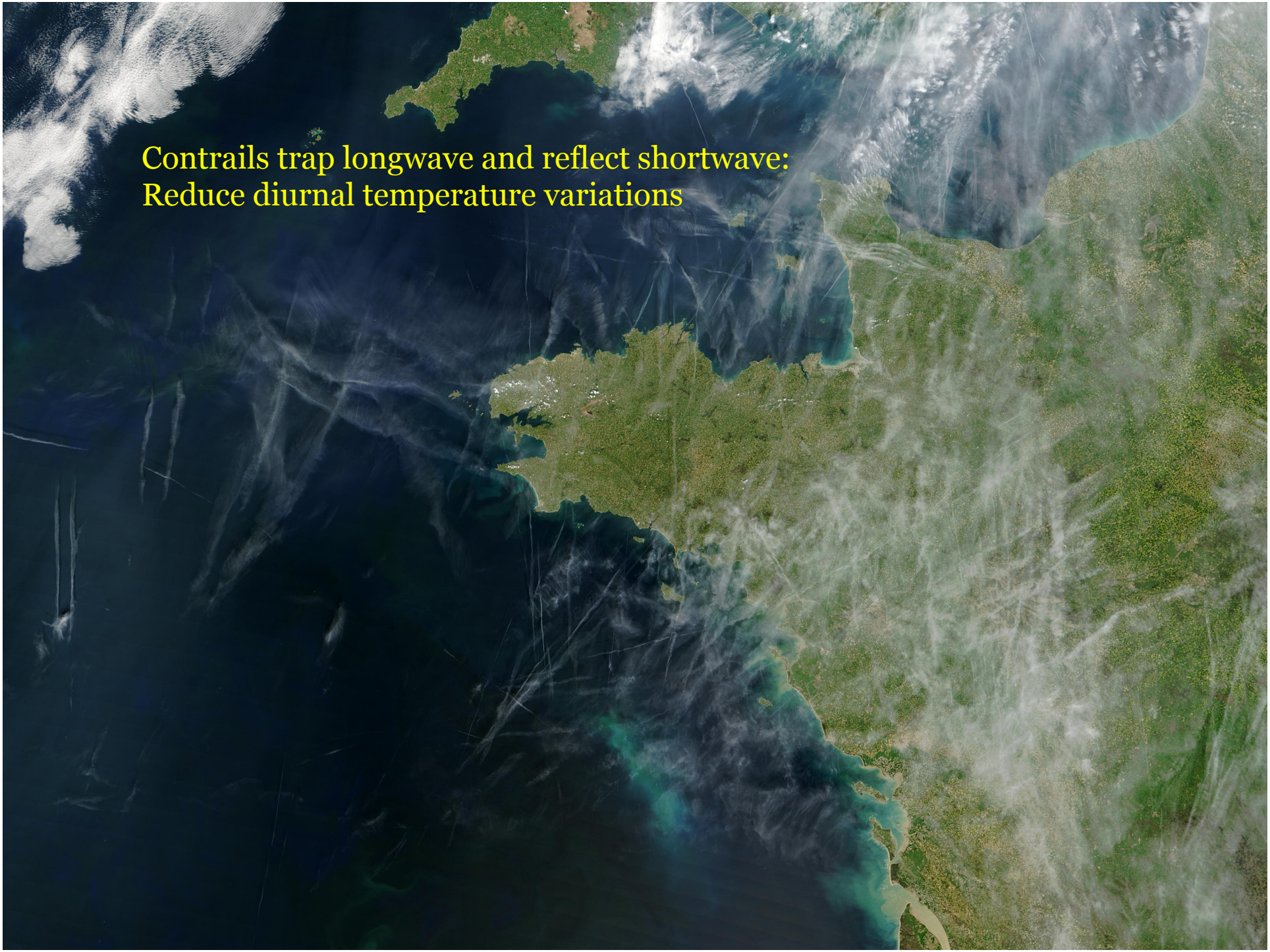
- If low clouds disappear w/ global warming, cloud feedback would be positive
- If instead low clouds increase => negative feedback
- High clouds may change too…
  - High clouds getting **higher** (due to tropopause rise) is a robust positive cloud feedback
- Clouds can be *directly* changed by humans though too…

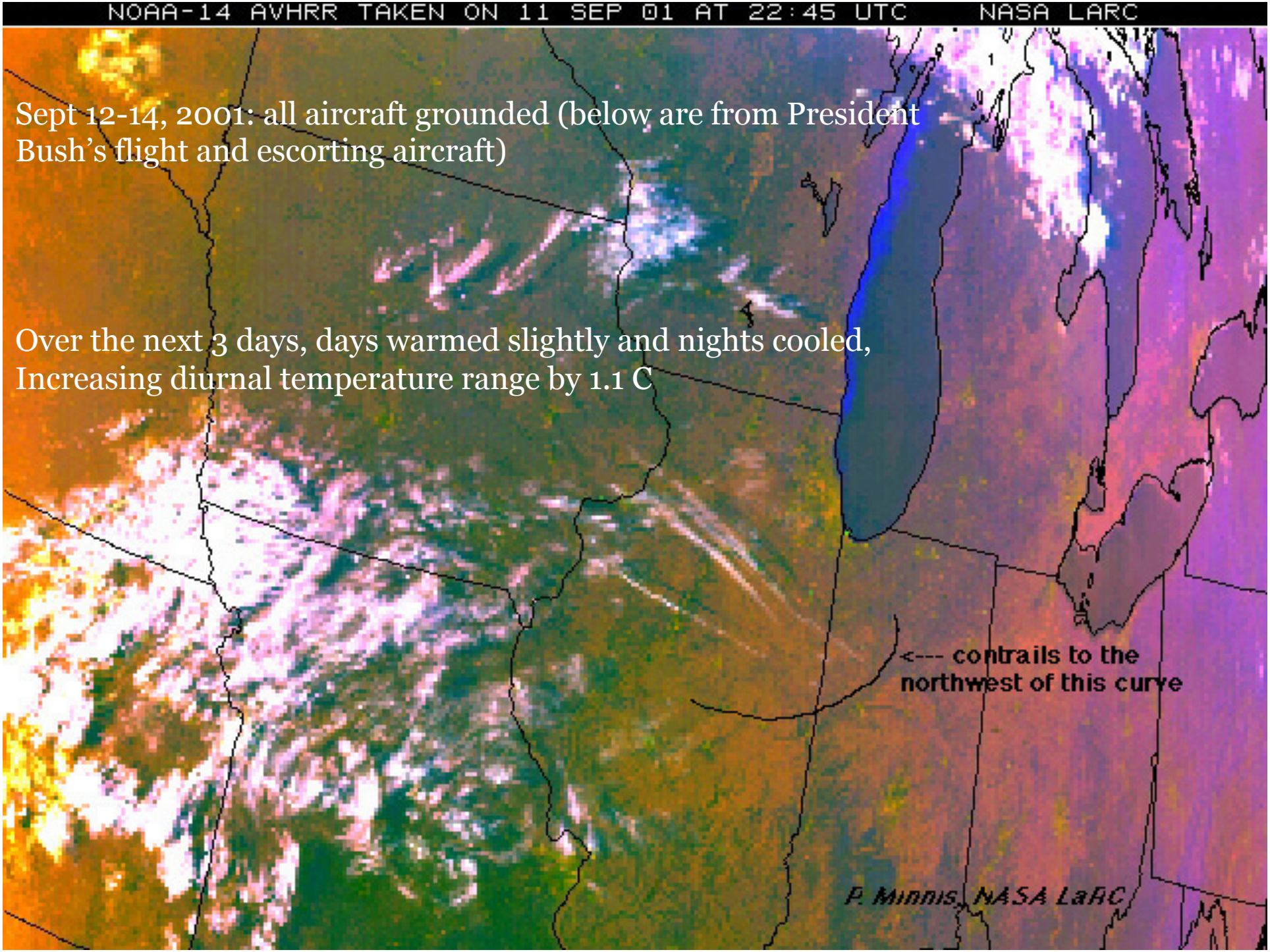

We have an effect on clouds
(via CCN)
Ship tracks: aerosols
causing water droplets to
form more easily, be smaller,
not precipitate out as easily

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 warmed slightly and nights cooled, 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)