

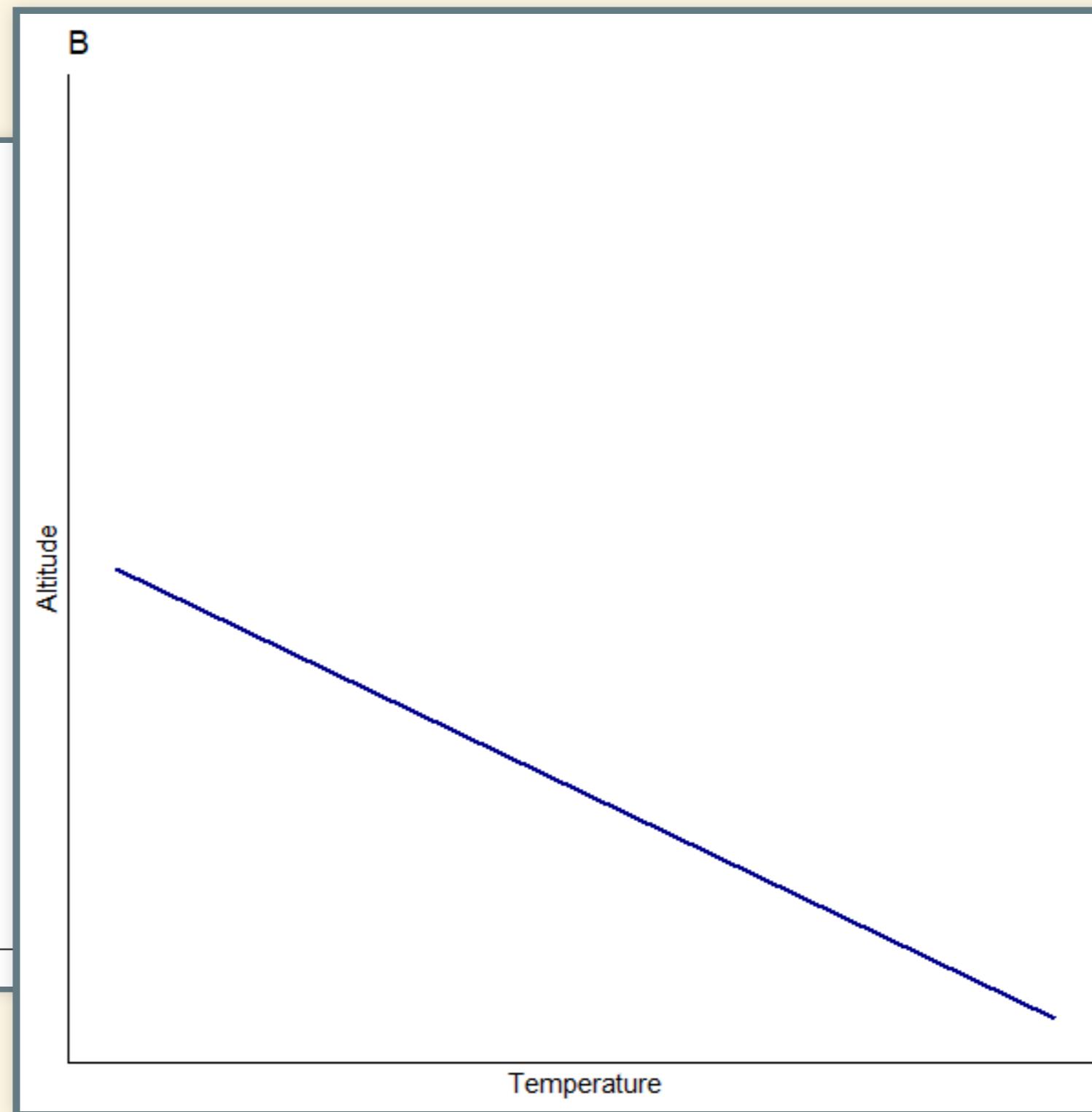
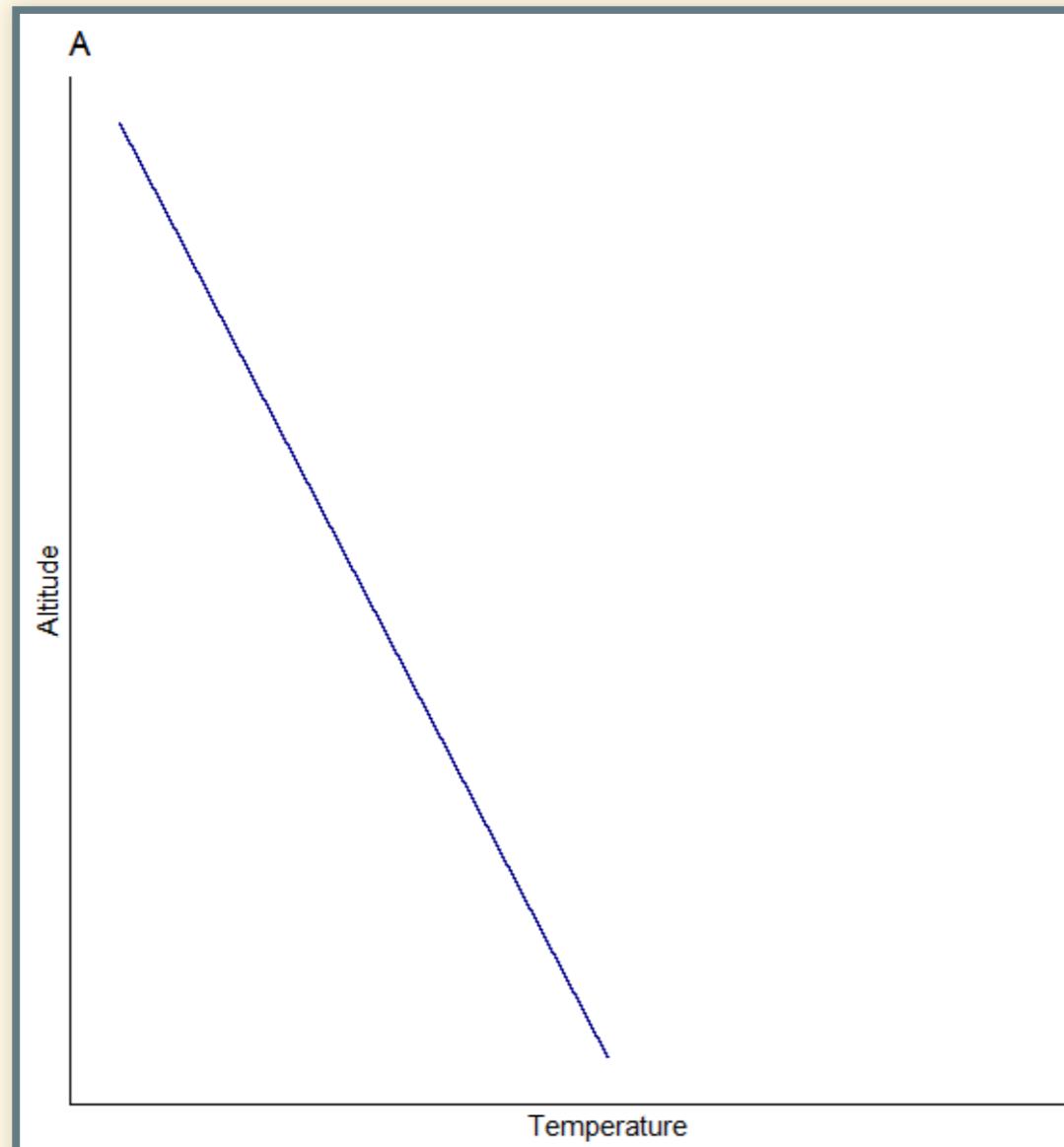
Climate Feedbacks

EES 3310/5310
Global Climate Change
Jonathan Gilligan

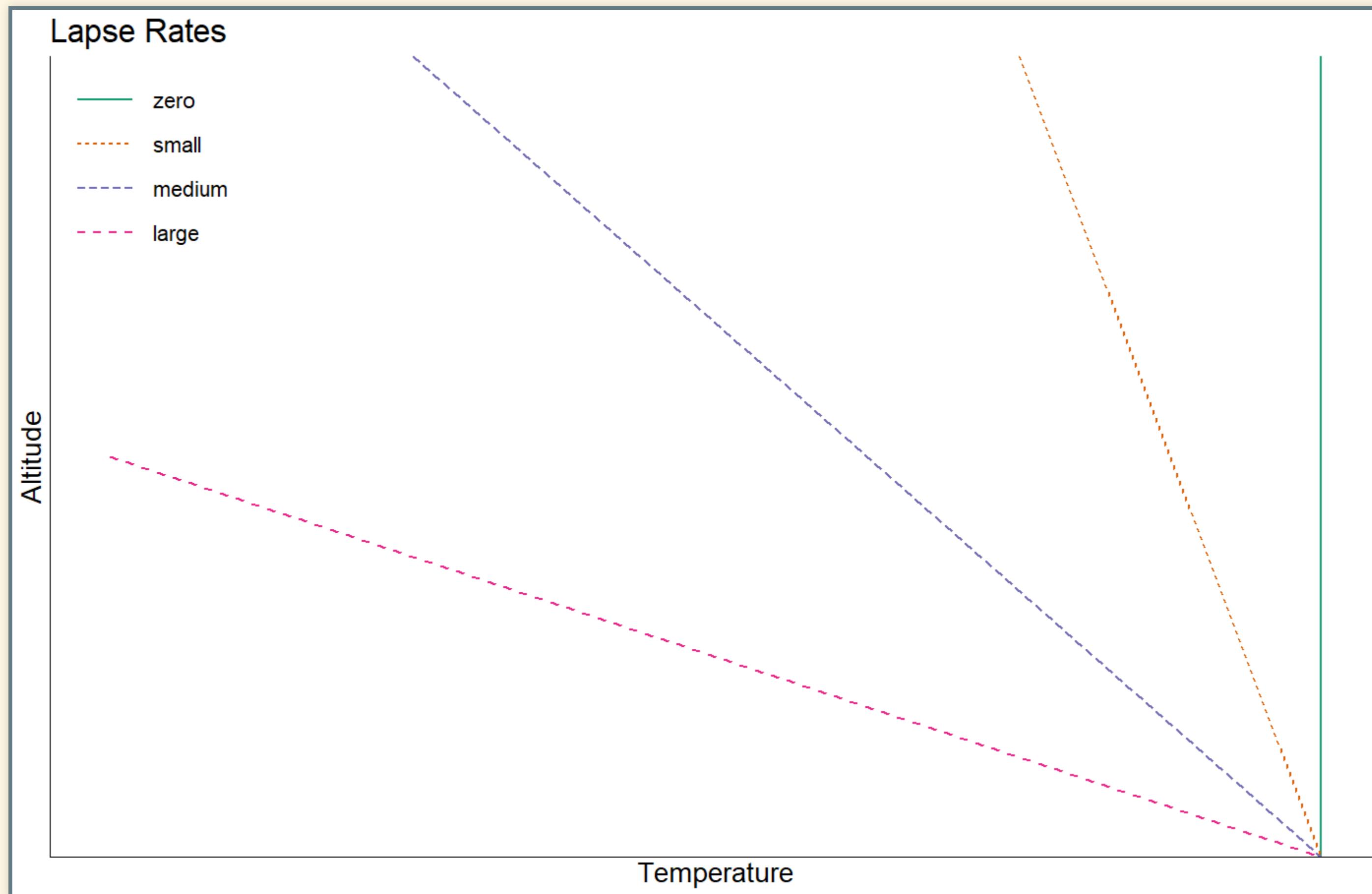
Class #8: Wednesday, February 10 2021

Lapse Rates

Which lapse rate is greater?



Lapse Rates



Feedback

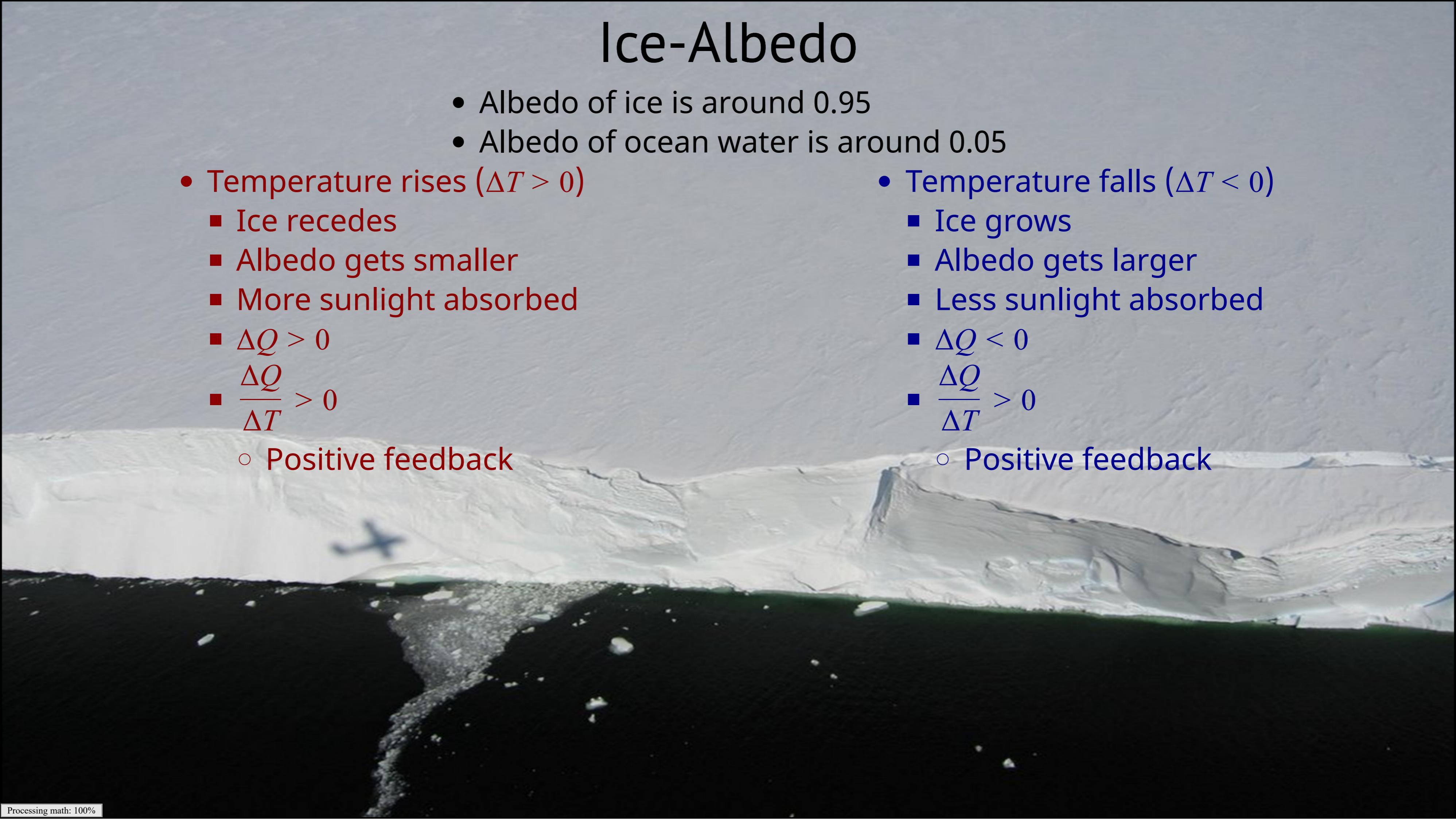
Feedback

- Q is net heat flow into the earth:
 - $Q = I_{\text{in}} - I_{\text{out}}$
- **At Start:** $Q = I_{\text{in}} - I_{\text{out}} = 0$,
 - $T_{\text{ground}} = T_0$.
- **Forcing:** change $Q \rightarrow Q_{\text{forcing}} > 0$
 - What happens?
- **Response:** $T_{\text{ground}} \rightarrow T_0 + \Delta T$
 - **Normally**, ΔT brings I_{out} back to balance with I_{in} .
 - **With feedback**, ΔT causes a new forcing,
$$\Delta Q_{\text{feedback}} = f\Delta T$$
 - $\Delta Q_{\text{feedback}}$ causes further change in T_{ground} .

Examples of feedbacks

Ice-Albedo

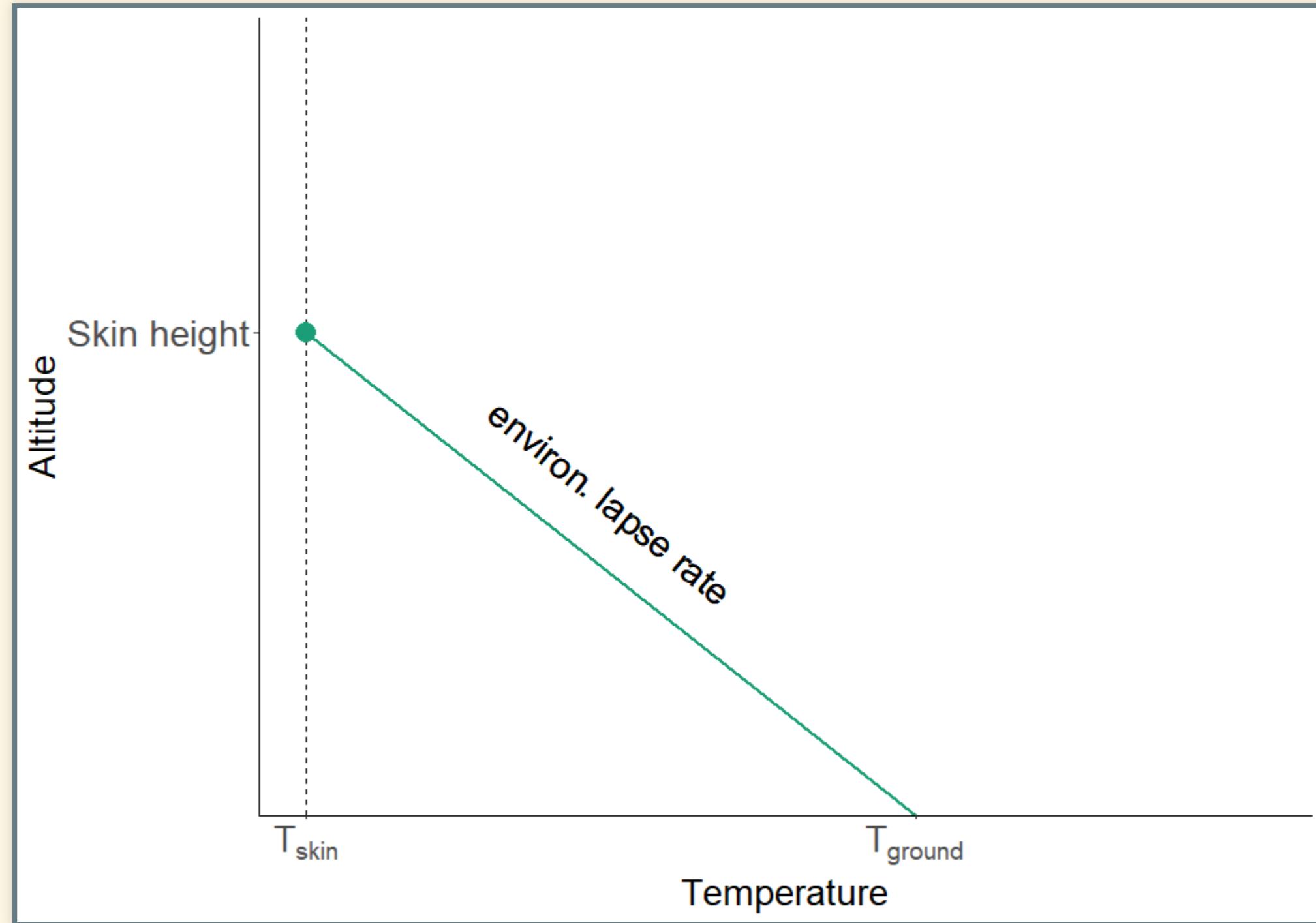
- Albedo of ice is around 0.95
- Albedo of ocean water is around 0.05
- Temperature rises ($\Delta T > 0$)
 - Ice recedes
 - Albedo gets smaller
 - More sunlight absorbed
 - $\Delta Q > 0$
 - $\frac{\Delta Q}{\Delta T} > 0$
 - Positive feedback
- Temperature falls ($\Delta T < 0$)
 - Ice grows
 - Albedo gets larger
 - Less sunlight absorbed
 - $\Delta Q < 0$
 - $\frac{\Delta Q}{\Delta T} > 0$
 - Positive feedback



Water-vapor

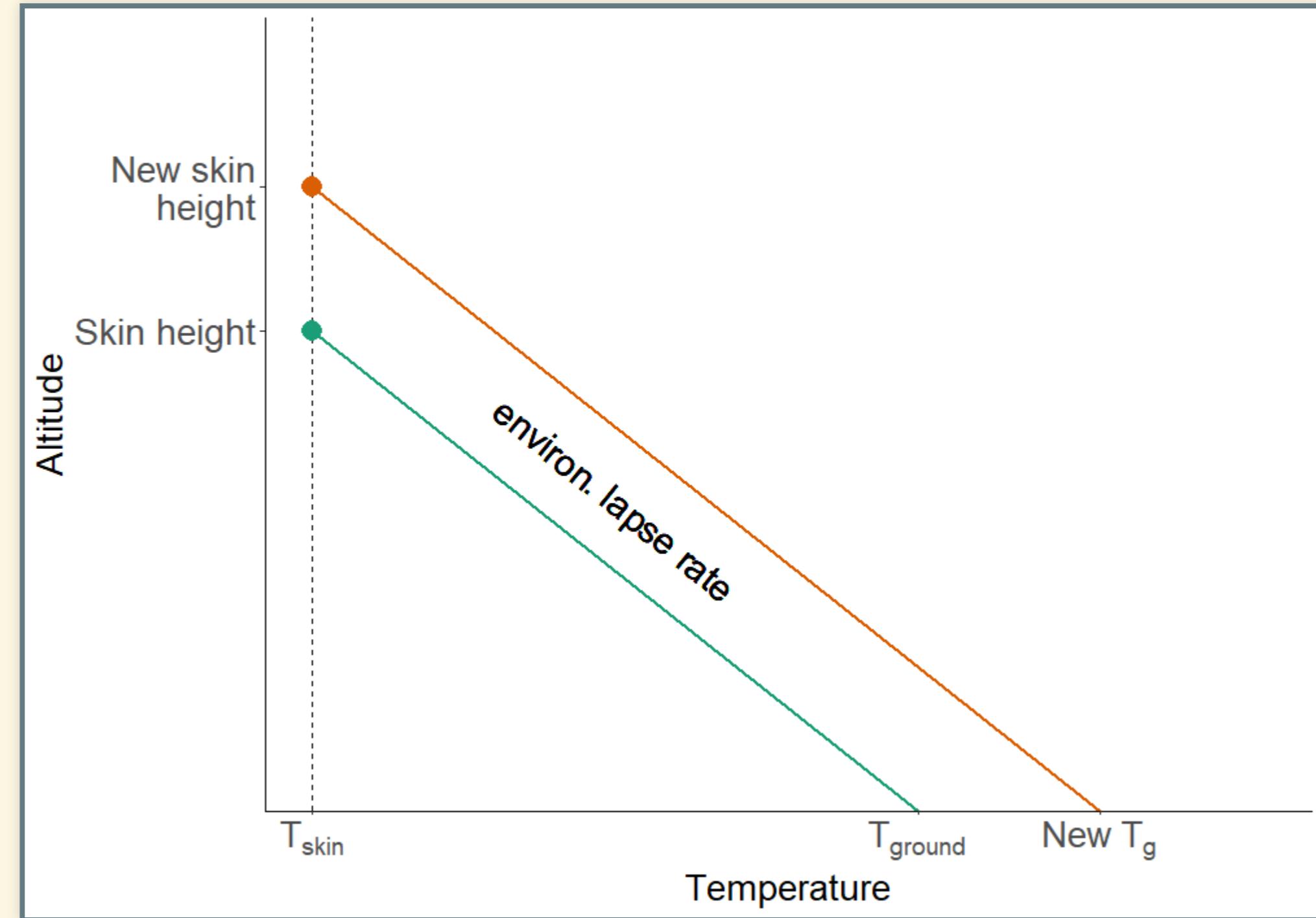
- Temperature rises
- What happens to humidity?
 - Humidity rises: more water vapor
- How does this affect ΔQ ?
 - More water vapor → bigger greenhouse effect
 - I_{out} gets smaller
 - $\Delta Q = \Delta(I_{\text{in}} - I_{\text{out}}) > 0$
 - Positive $\Delta T \rightarrow$ Positive ΔQ
 - $f = \Delta Q / \Delta T > 0$: positive feedback

Greenhouse effect



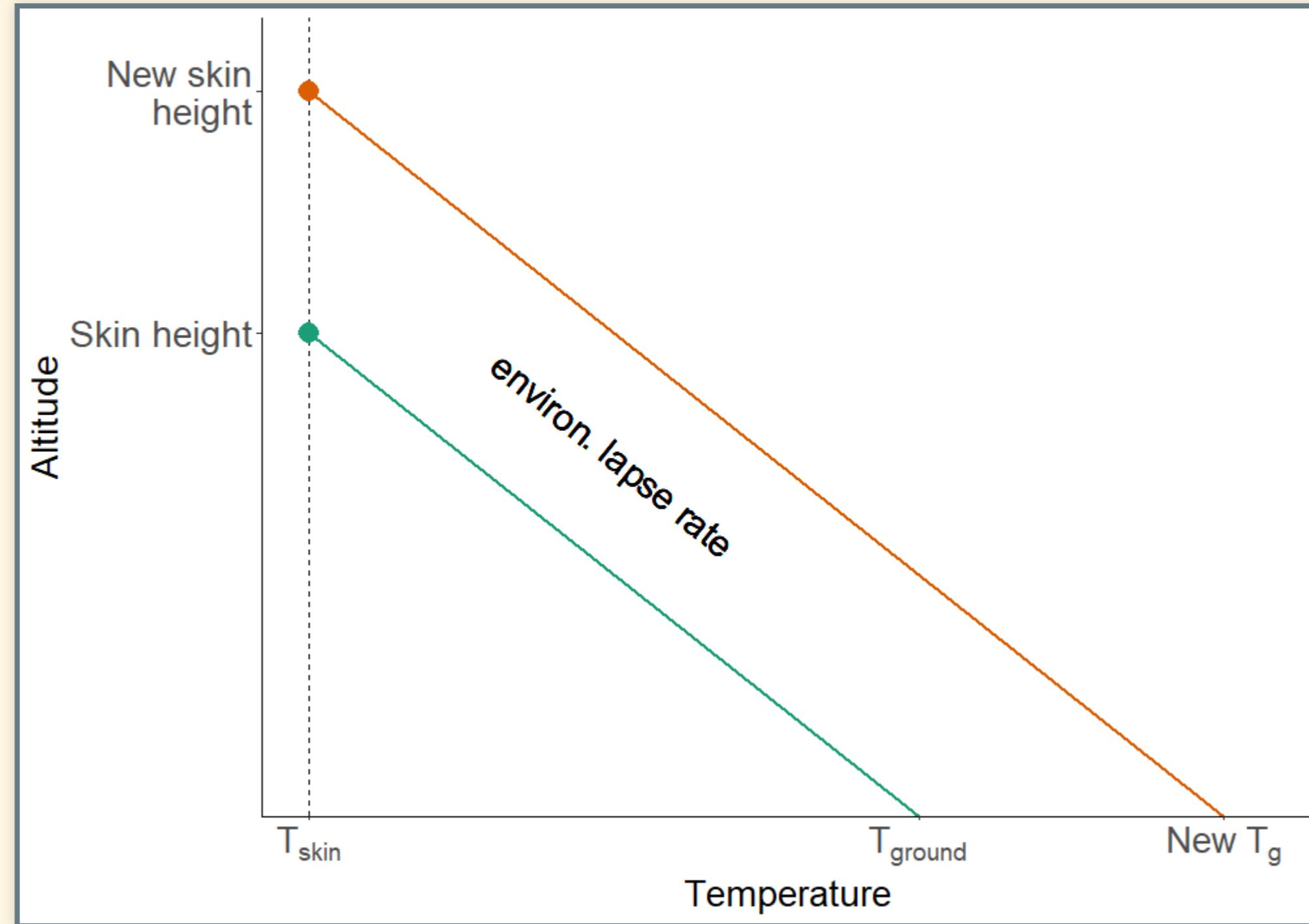
- Ground temp: $T_{\text{ground}} = T_{\text{skin}} + h_{\text{skin}} \times \text{env. lapse}$

Global warming



- Greater $\text{CO}_2 \rightarrow$ greater skin height.
- Warming: $\Delta T_{\text{ground}} = \Delta h_{\text{skin}} \times \text{env. lapse}$
- What does rising temperature do to water vapor?

Water Vapor Feedback



- Rising temperature → greater humidity
- Greater humidity → skin height rises even higher
- $\Delta T_{\text{ground}} = \Delta h_{\text{skin}} \times \text{Lapse}$

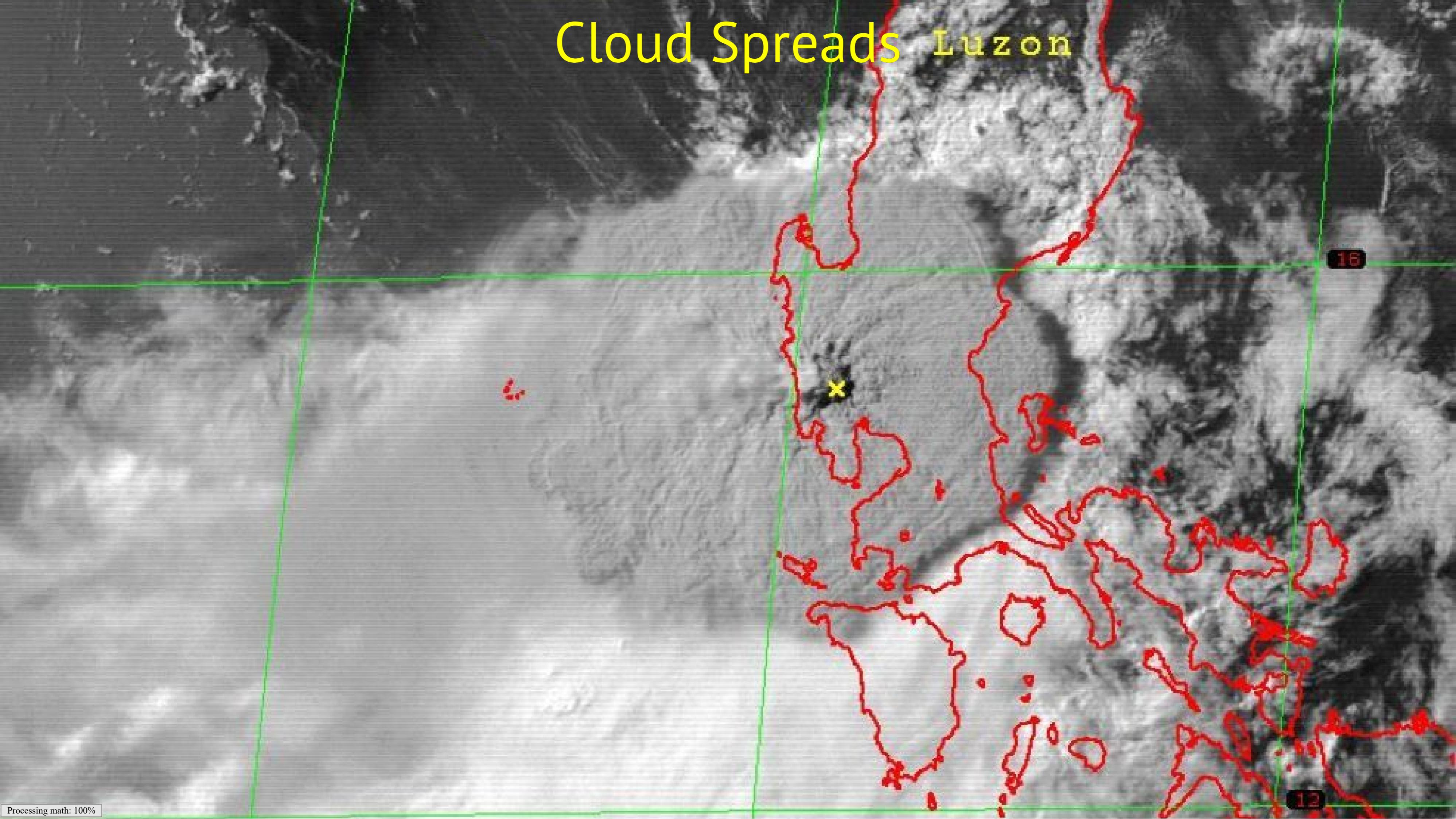
Interlude: Volcanic & Nuclear Winter



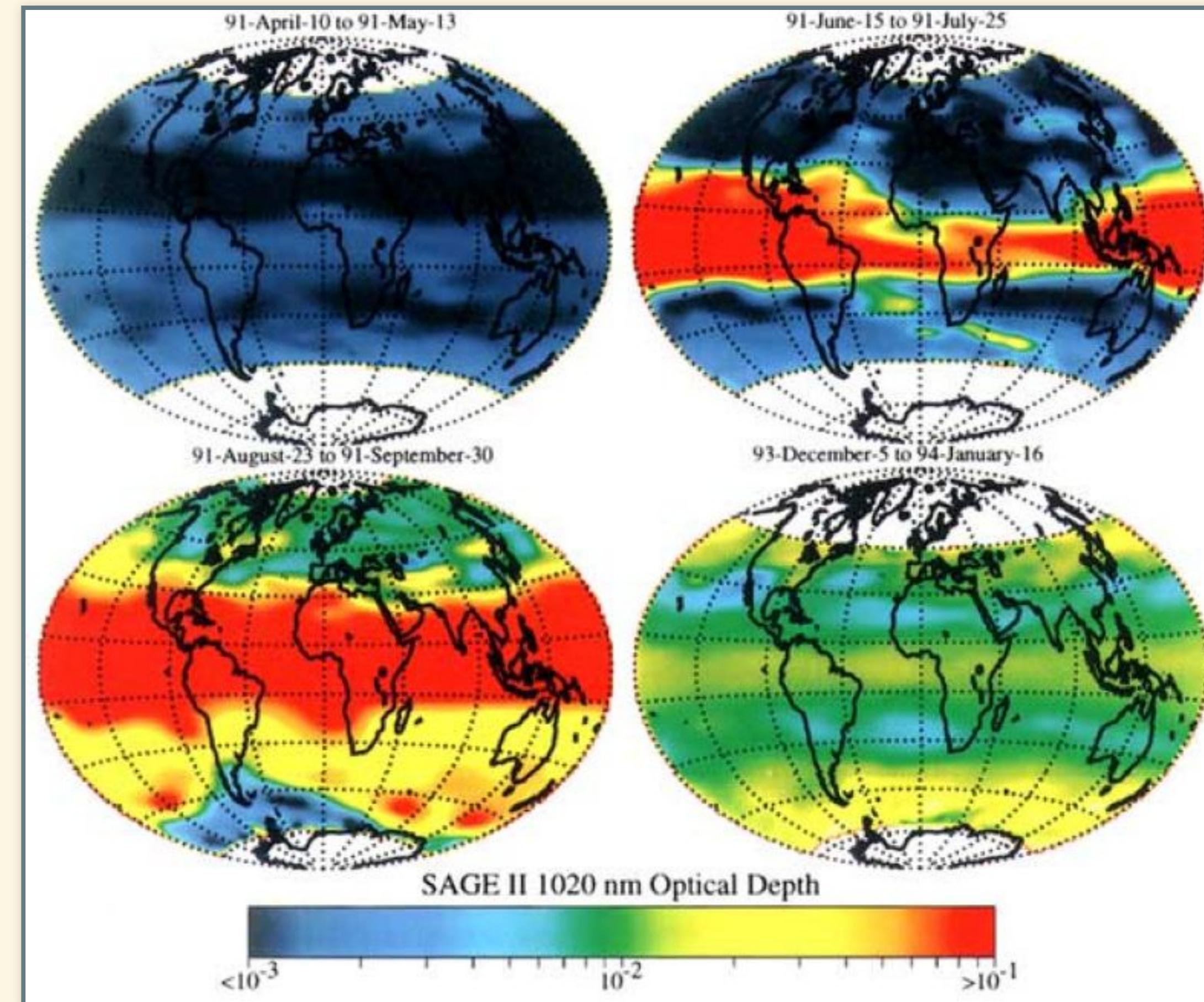
Mt. Pinatubo, Philippines, 1991



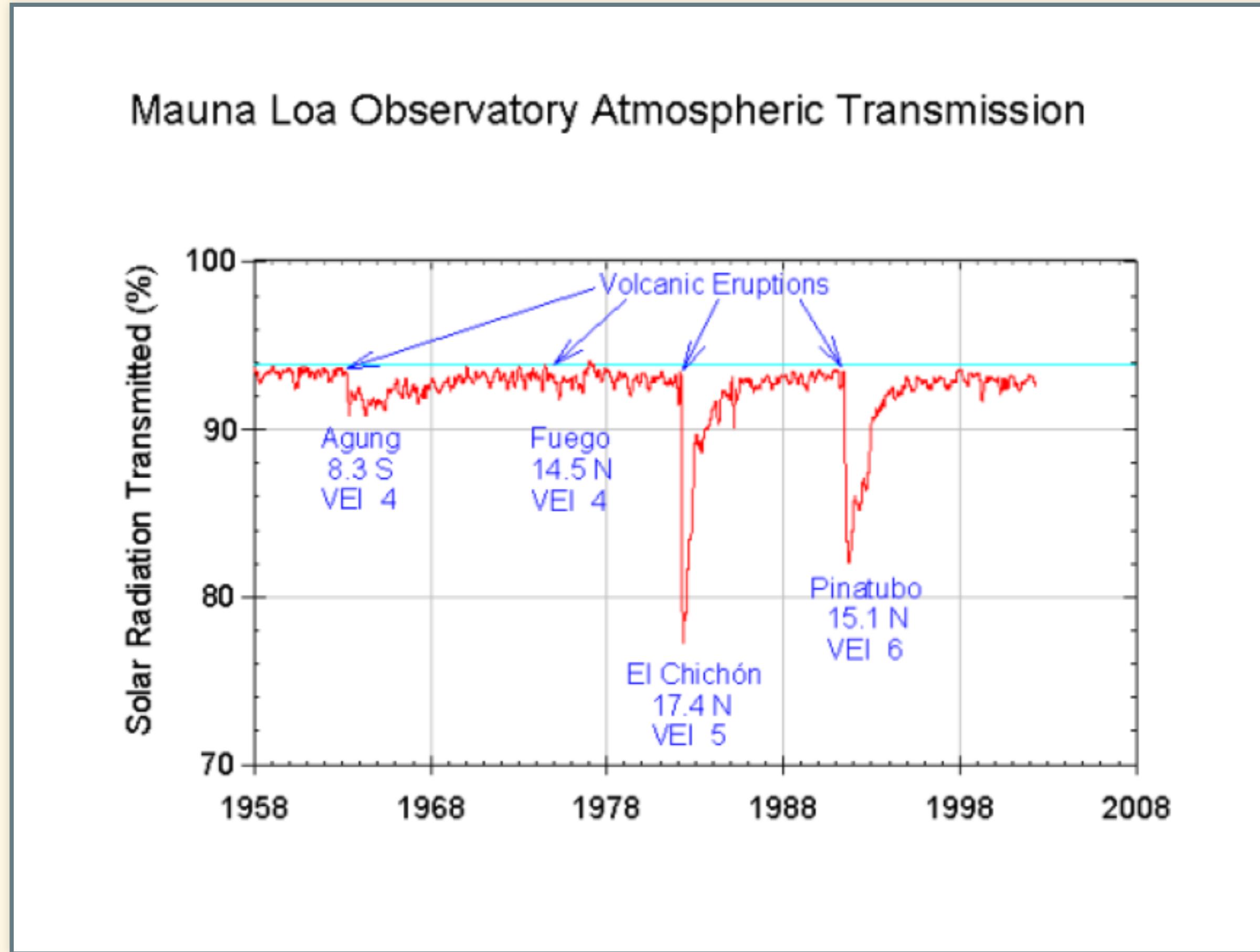
Cloud Spreads Luzon



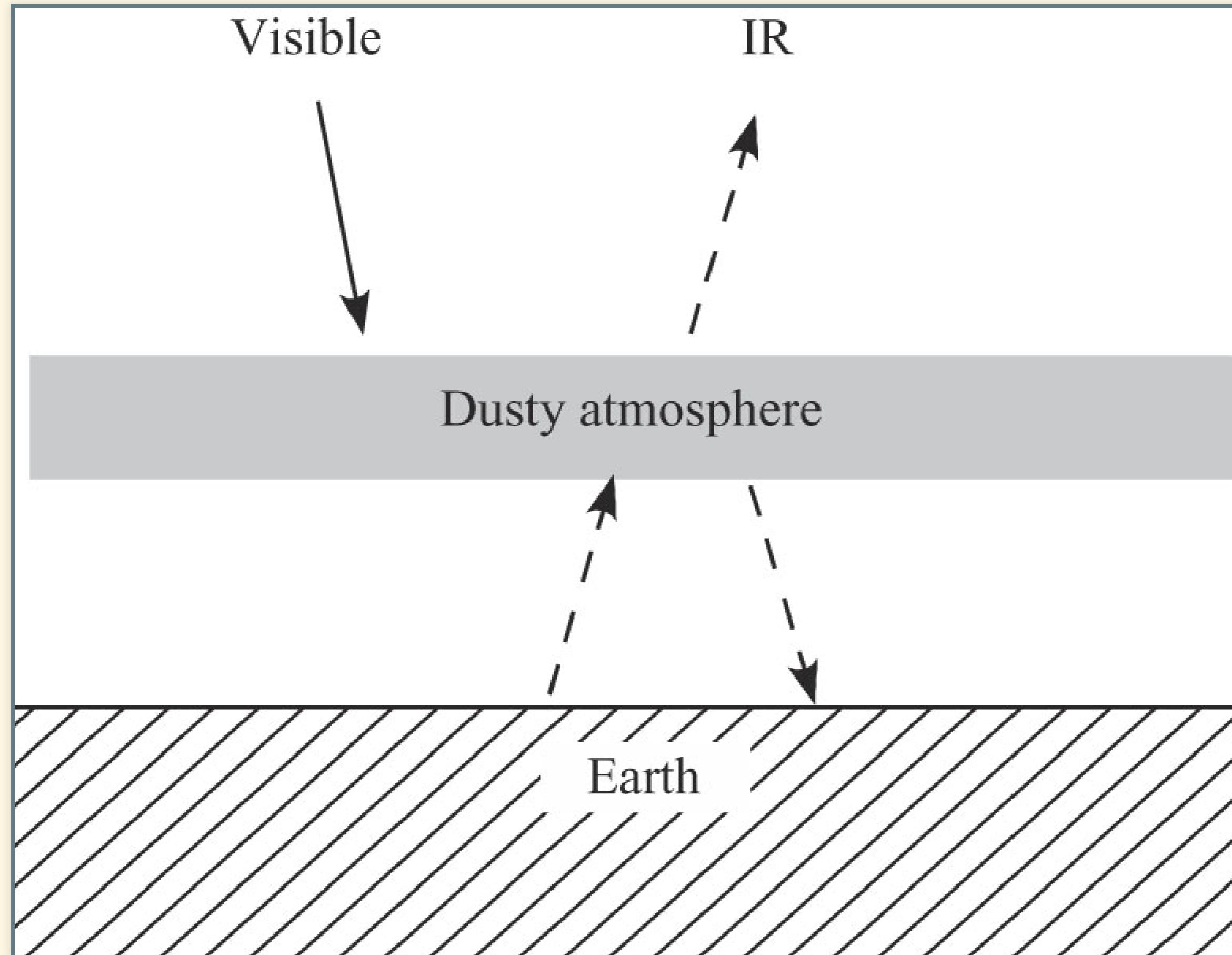
Around the planet



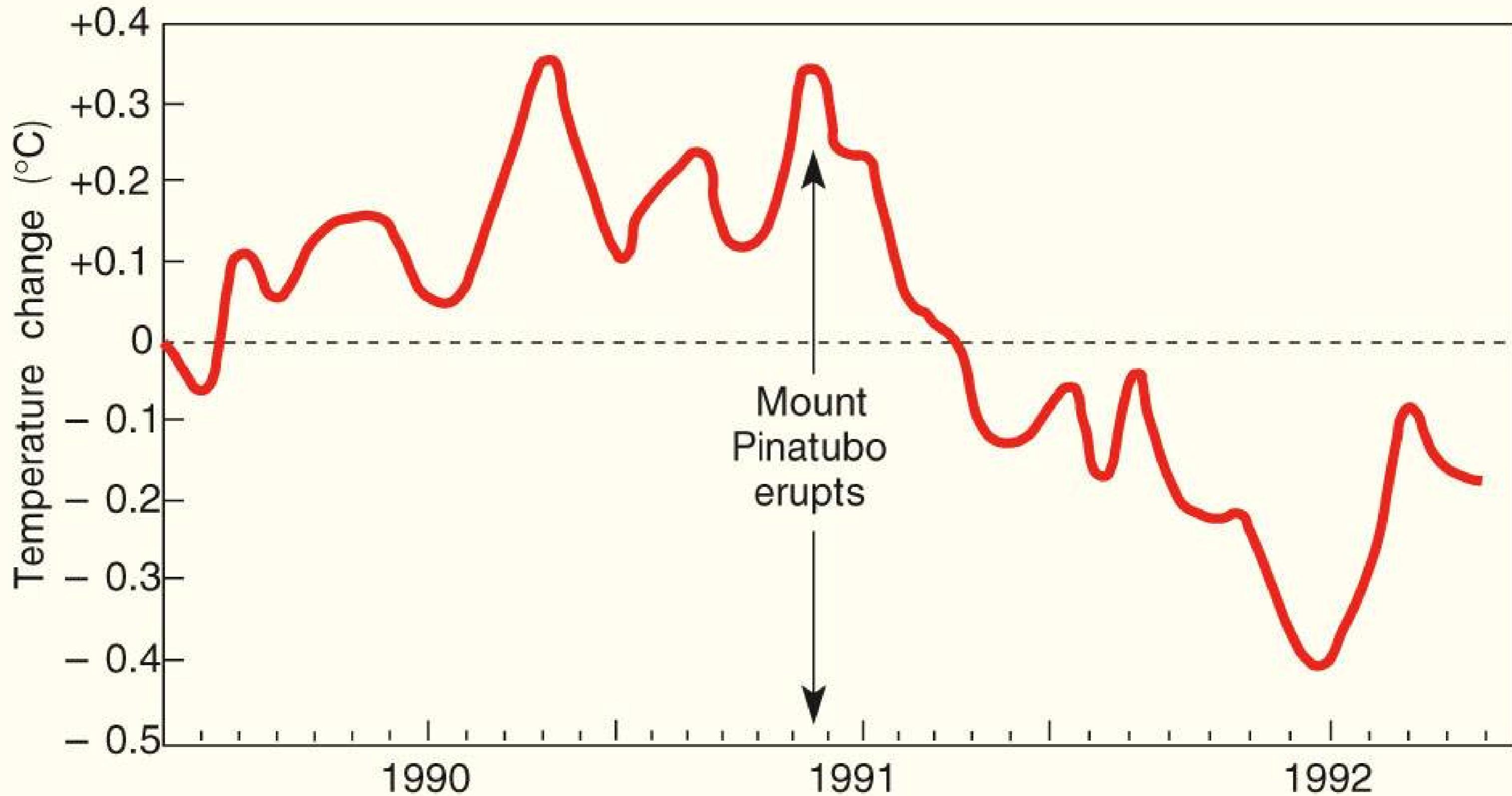
Cloud blocks sunlight



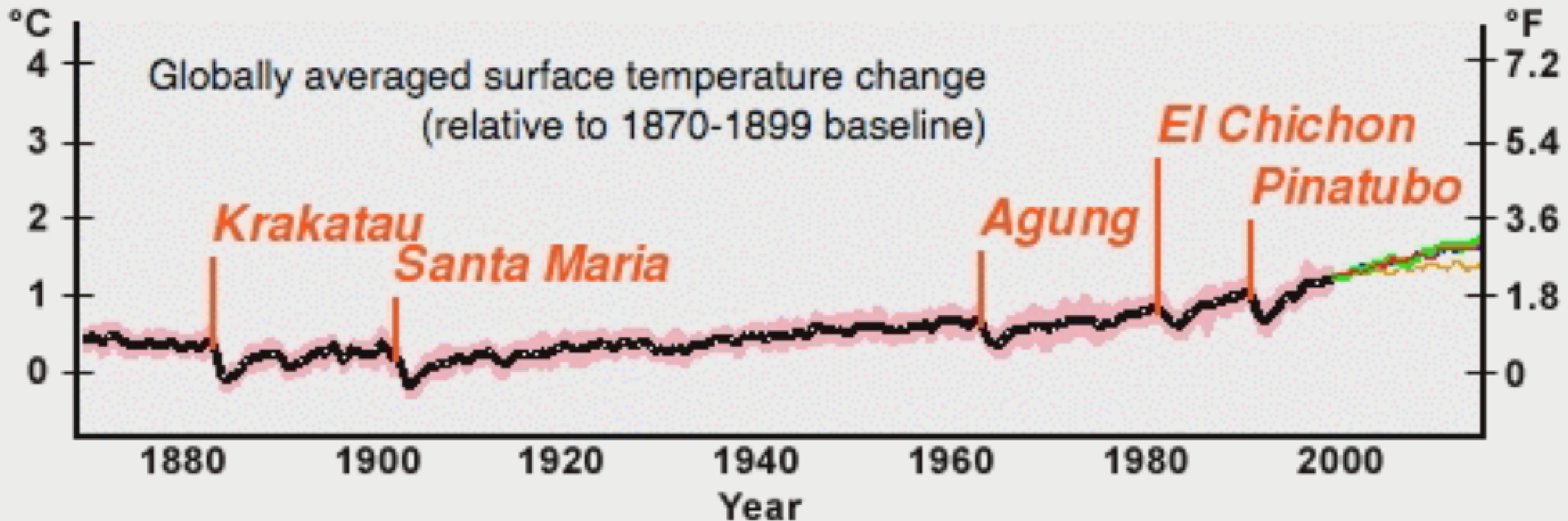
Exercise 3-3



Temperature drops



Volcanoes and Temperature

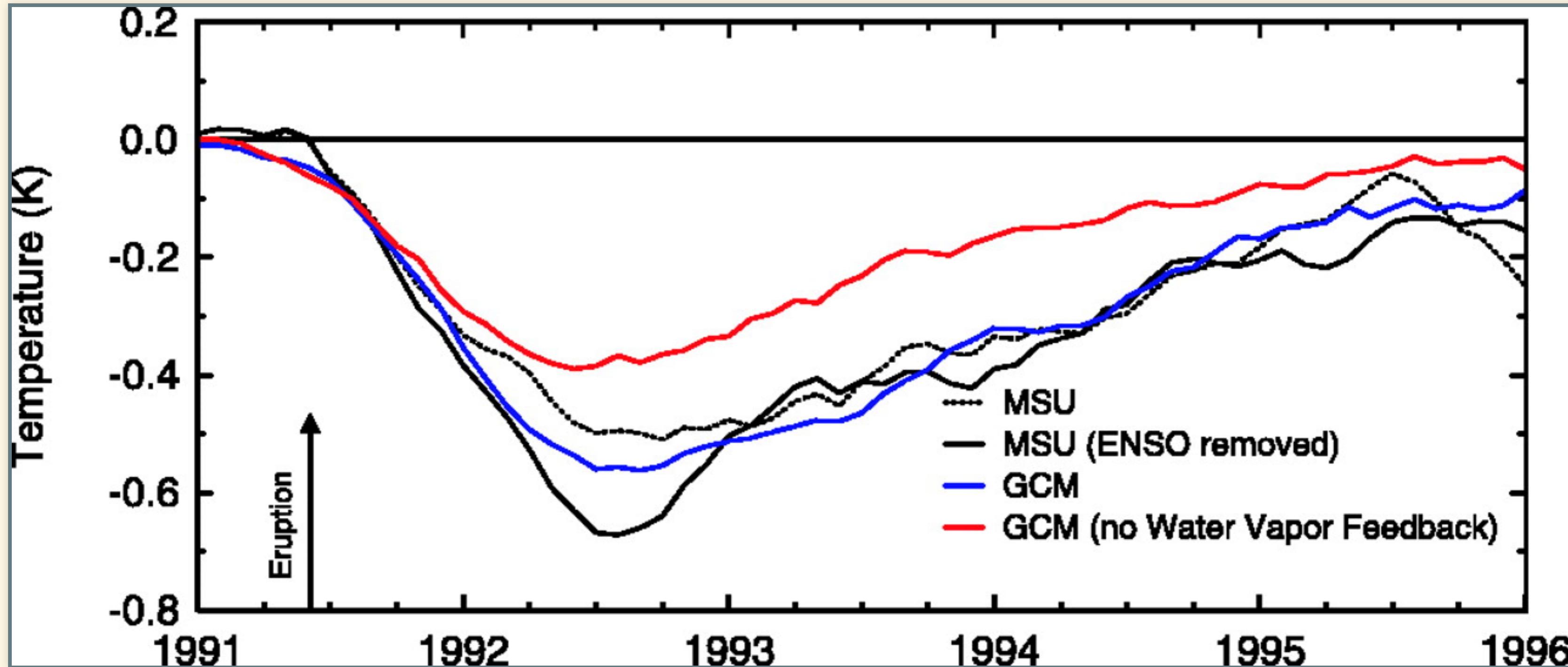


Gary Strand (NCAR / DOE)

1816: The Year Without a Summer

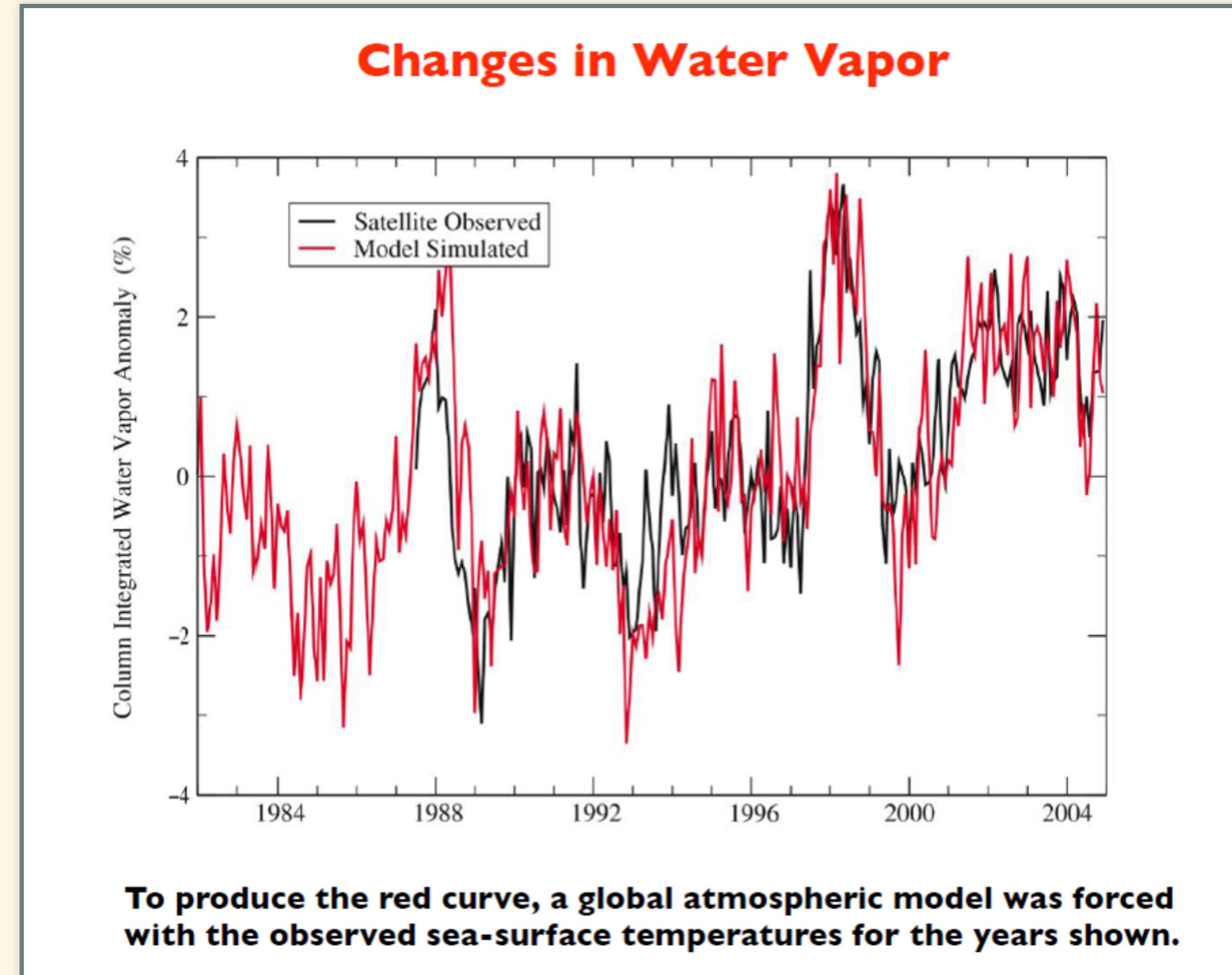


Testing Theory of Water-Vapor Feedback

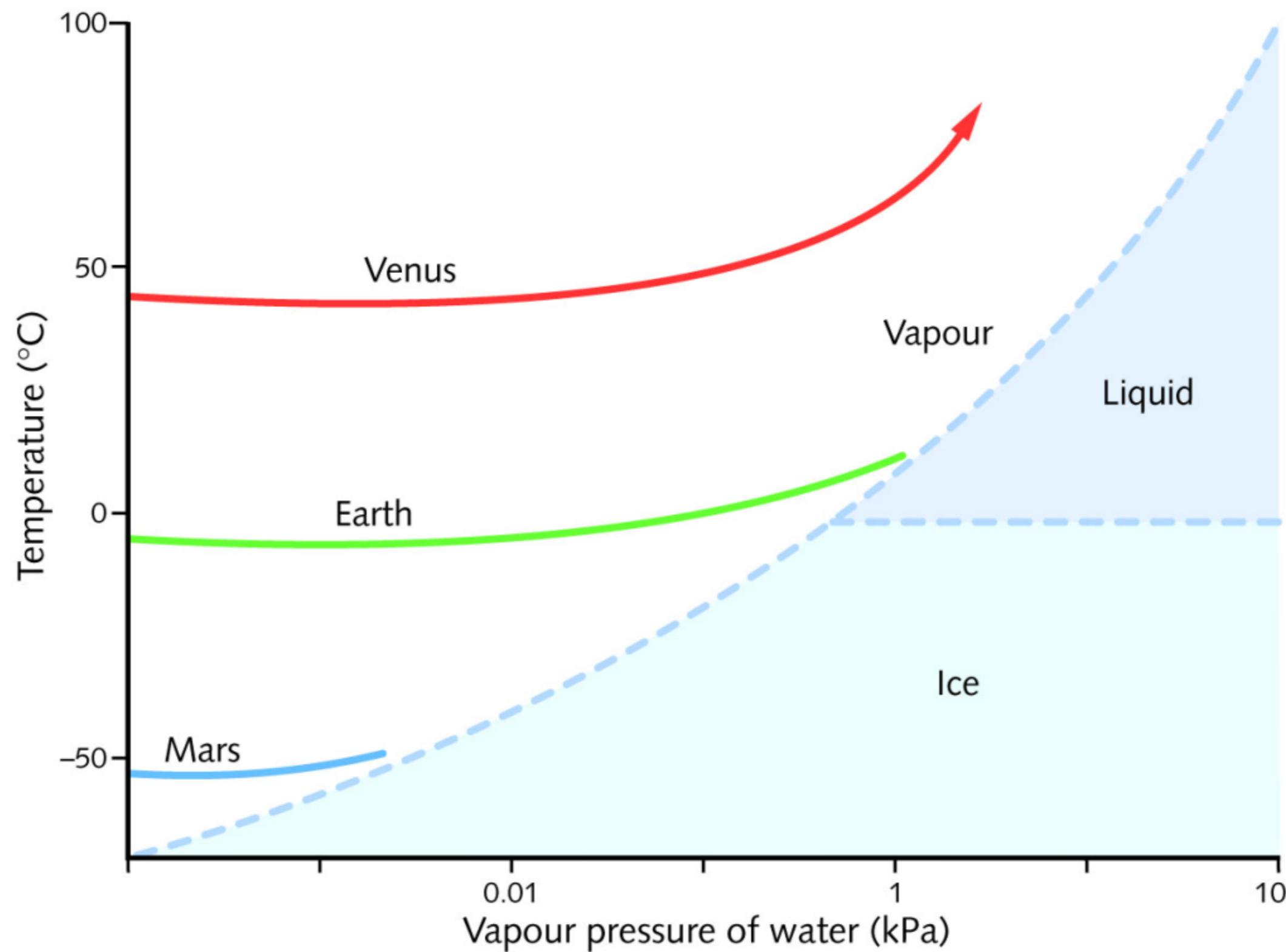


- Pinatubo erupts
- Model calculations with water vapor feedback correctly predict cooling
- Turn off water vapor feedback: incorrect predictions

Additional Tests



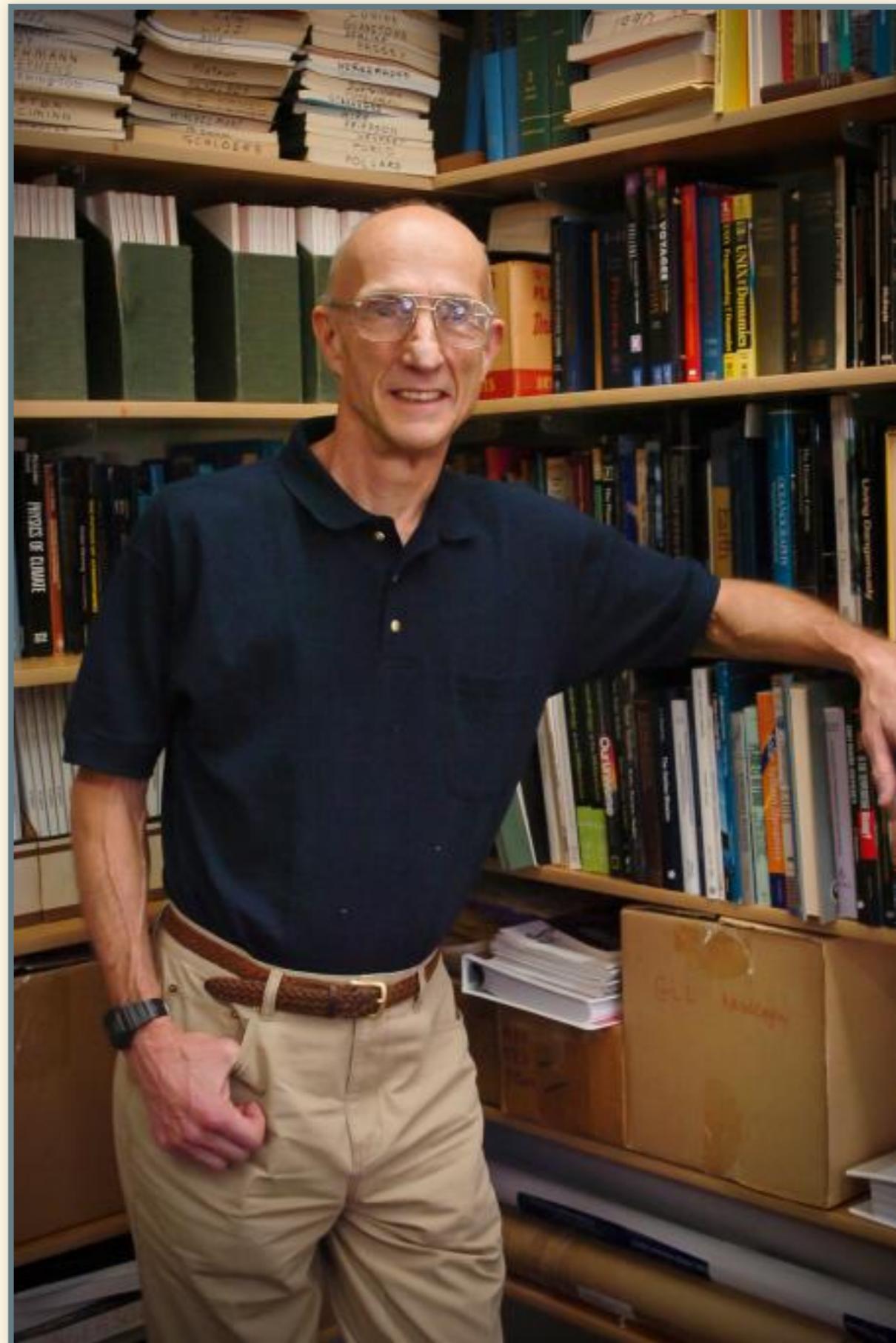
Runaway Greenhouse



Andrew Ingersoll & Runaway Greenhouse

1967: First class he ever taught

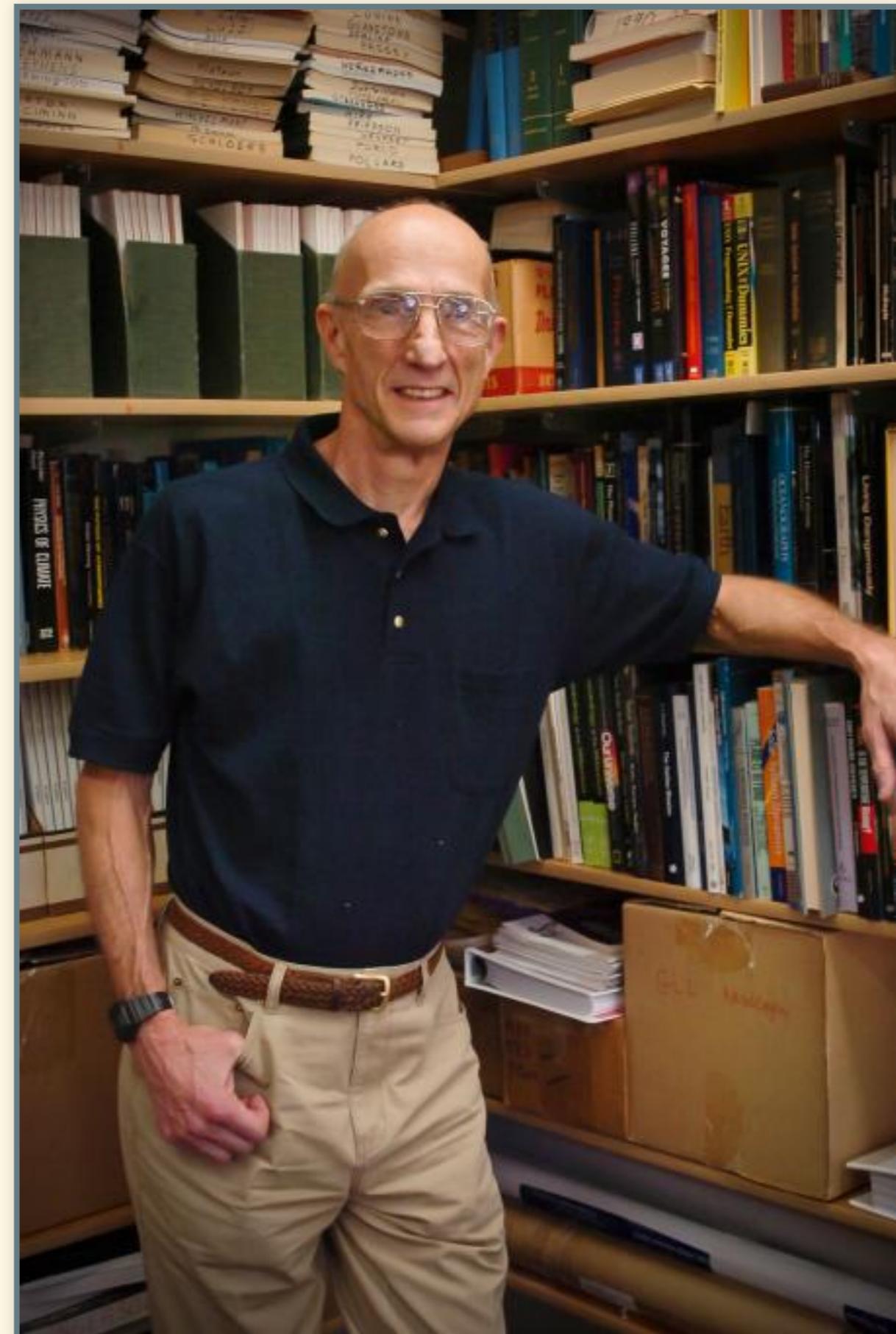
- Assigned homework:
 - Calculate water vapor feedback
- Students couldn't solve problem
- Fixed problem so students could solve it
- It worked for Earth, but not Venus
- Hmm...
 - It would work for Venus if all the oceans boiled dry.



Andrew Ingersoll & Runaway Greenhouse

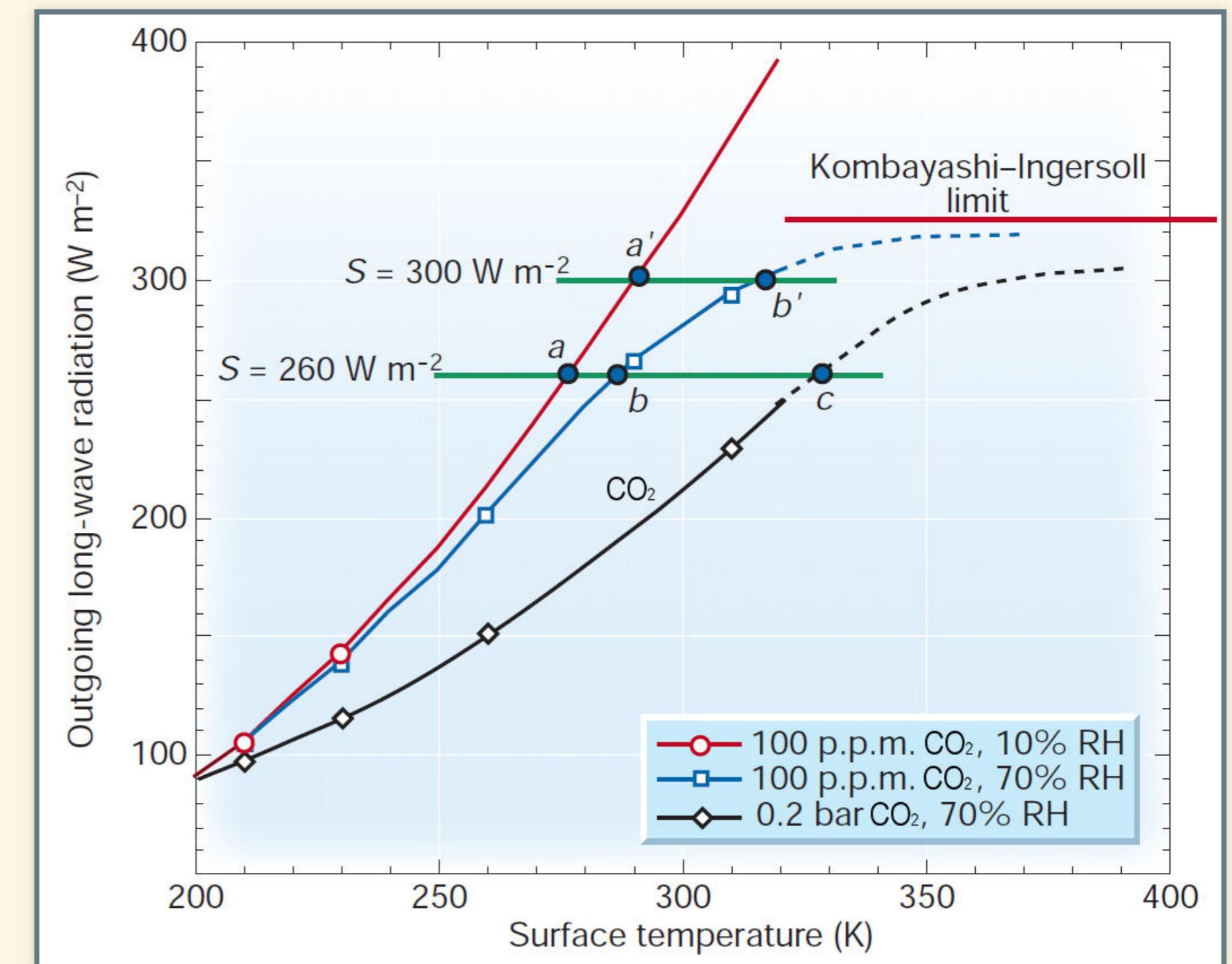
Wrote up results for publication

- Rejected by journal
- Submitted to another journal
 - Rejected again
- Submitted to a third journal
 - Accepted
- Now a classic paper
 - Cited more than 200 times



Kombayashi-Ingersoll Limit

- S = Incoming sunlight
- Outgoing long-wave has to balance incoming sunlight S
- Curves = relationship between temperature and outgoing radiation
 - no feedback, feedback, feedback + high CO₂
- Brighter sun → hotter → more water vapor
- Water vapor absorbs outgoing radiation
- Absorption → hotter → more vapor
- Kombayashi-Ingersoll limit:
 - Sunlight below limit, there is a stable equilibrium with liquid water
 - Sunlight above limit, oceans boil dry



Cloud Feedbacks



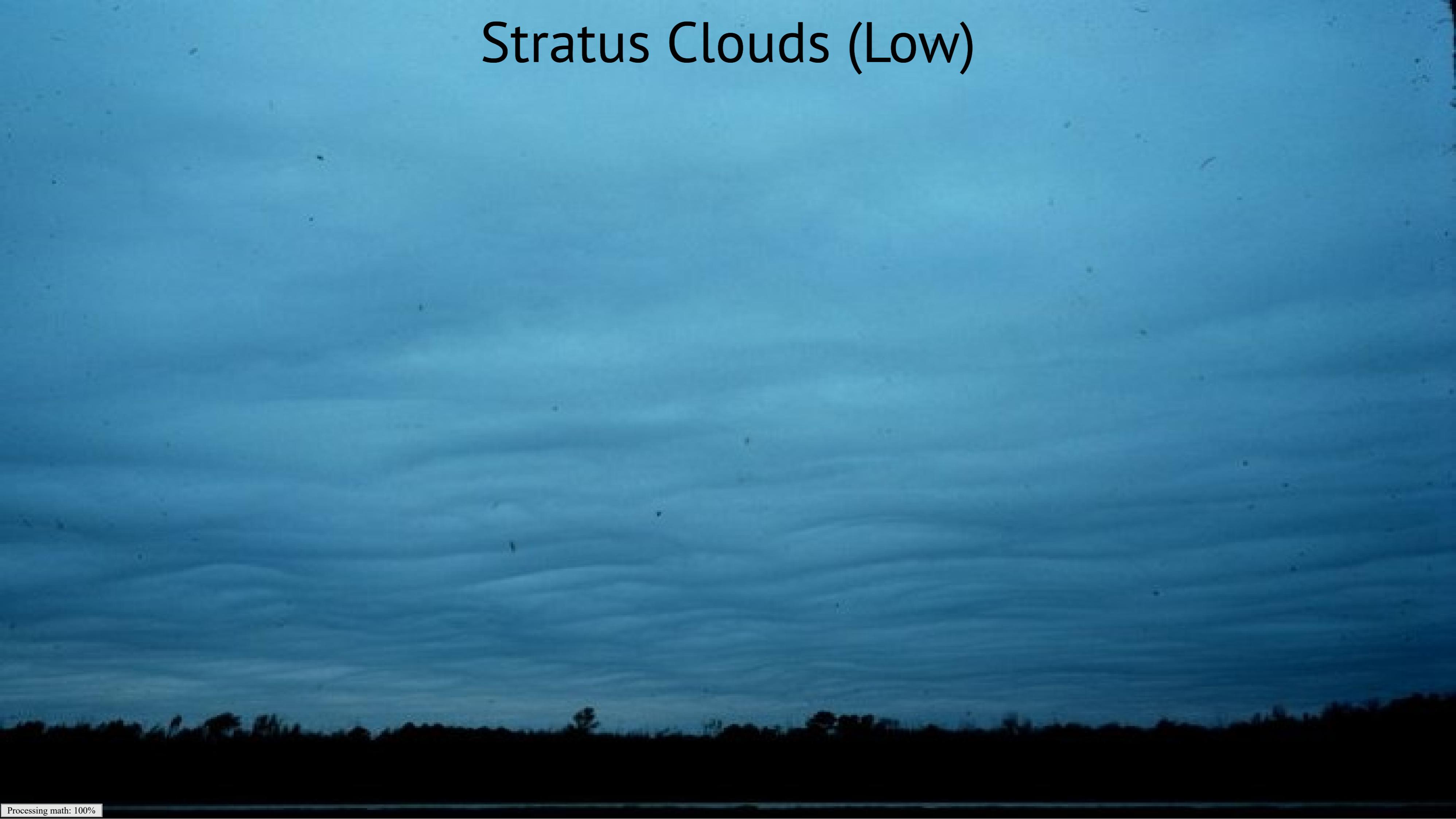
Cloud Feedbacks

- What effect do clouds have on climate?
- What effects does climate have on clouds?
- Warmer → more clouds
- More clouds:
 - Higher albedo
 - cools earth: negative feedback)
 - High emissivity: blocks longwave light
 - warms earth: positive feedback)
- Which effect is bigger?

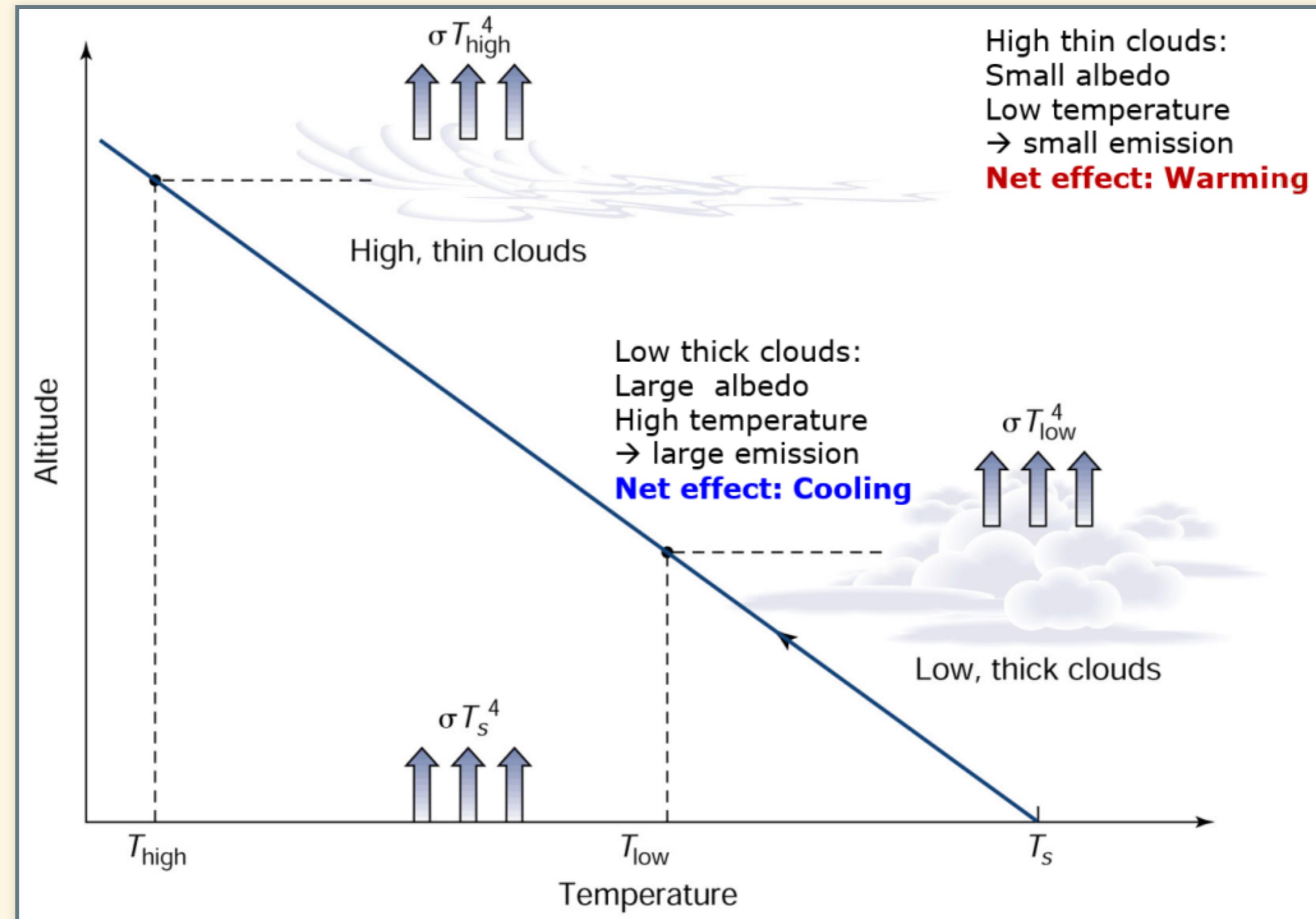
Cirrus Clouds (High)



Stratus Clouds (Low)

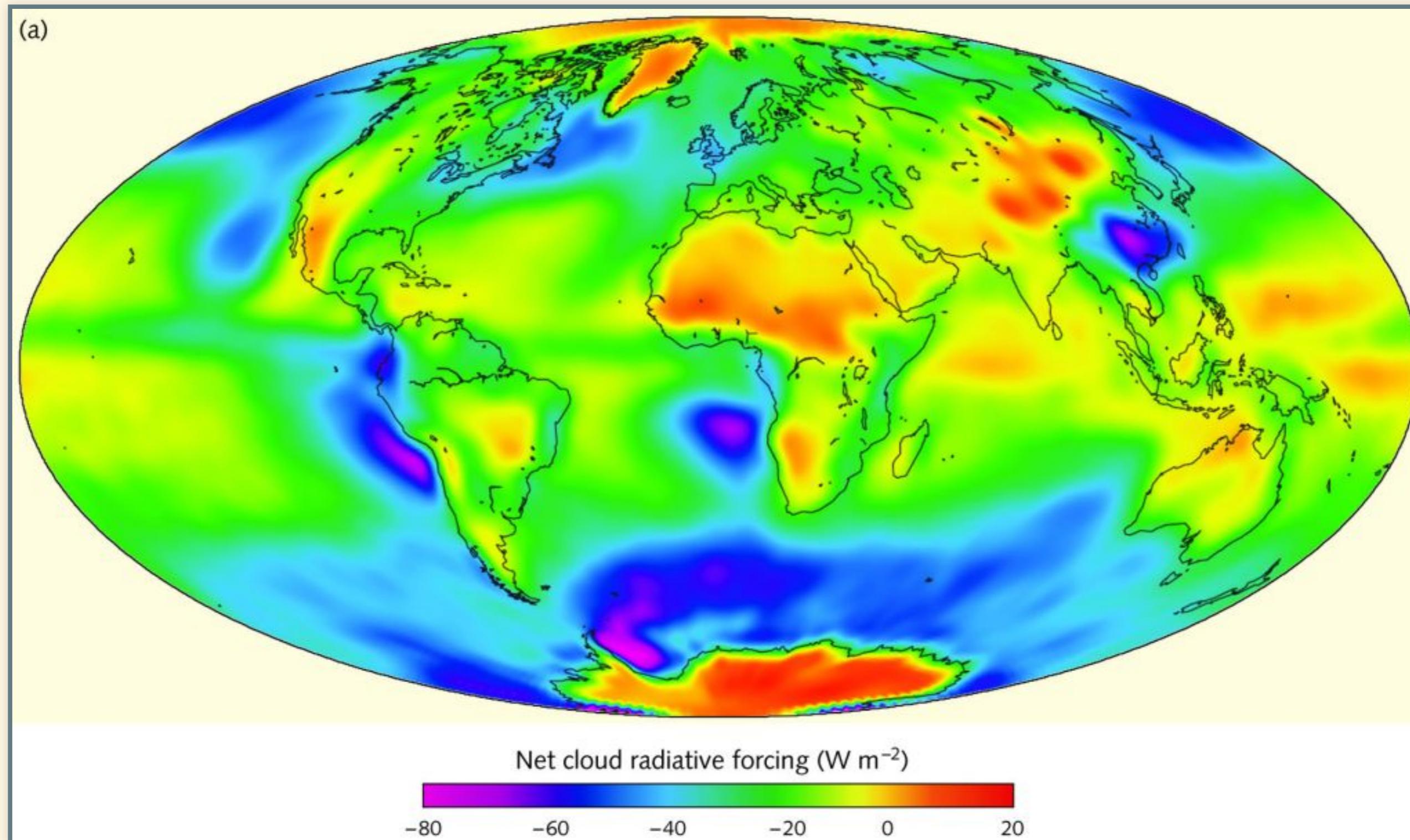


Cloud Feedbacks



Satellite Measurements

Radiative forcing by clouds

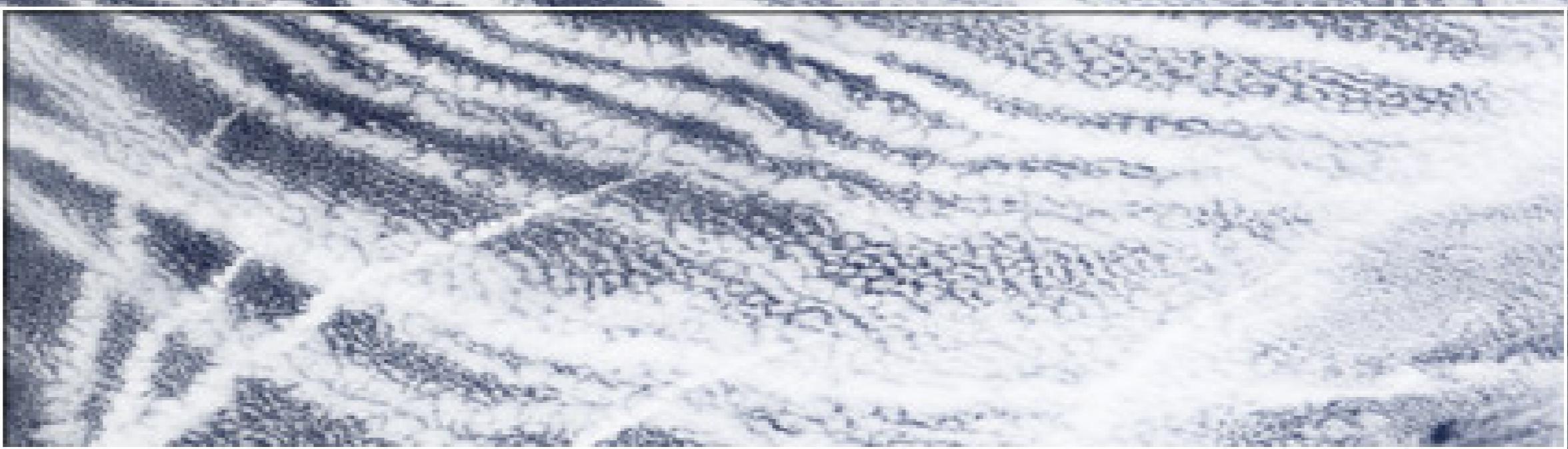


(negative = cooling, positive = warming)

Indirect Aerosol Effect

—ship track

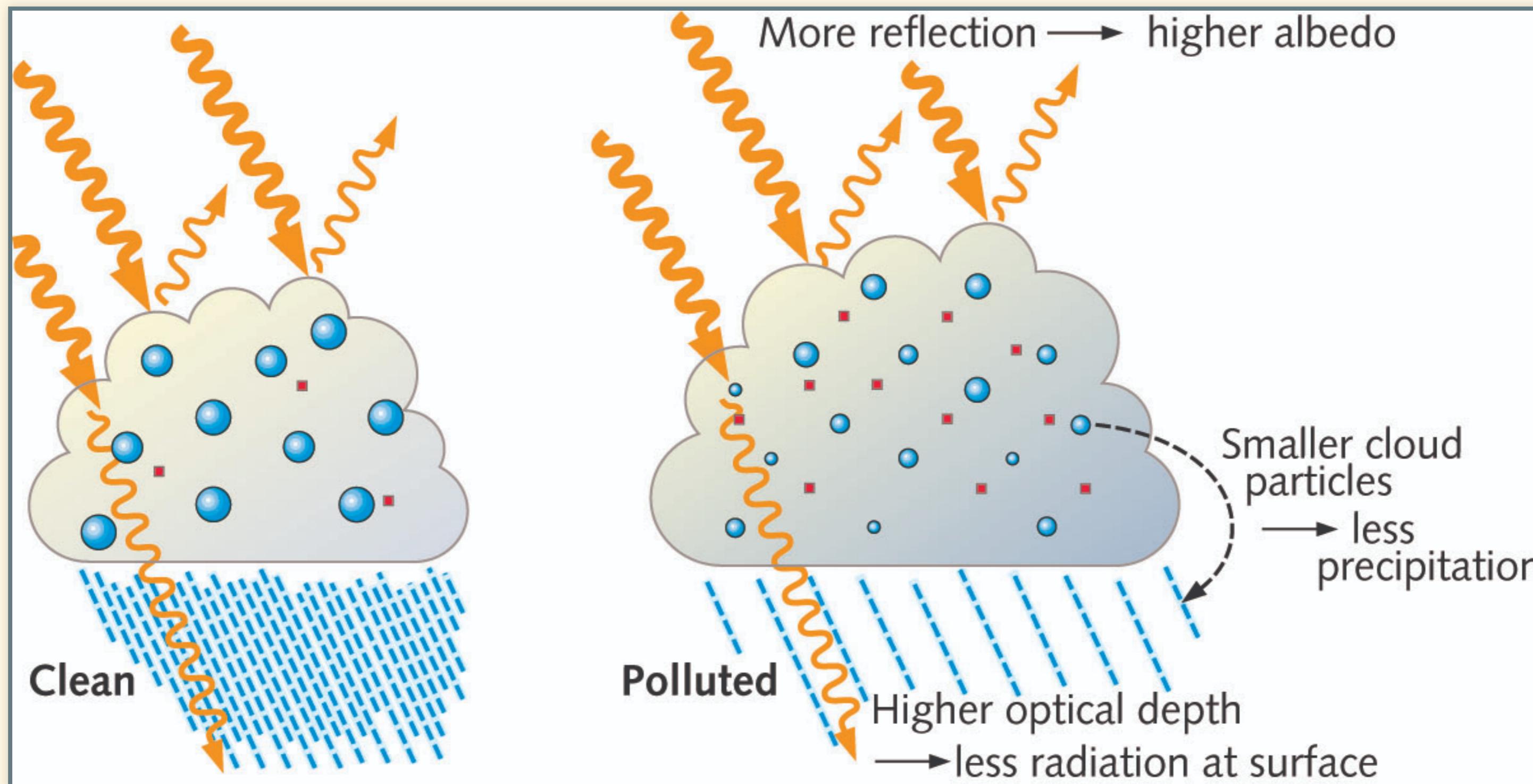
marine layer



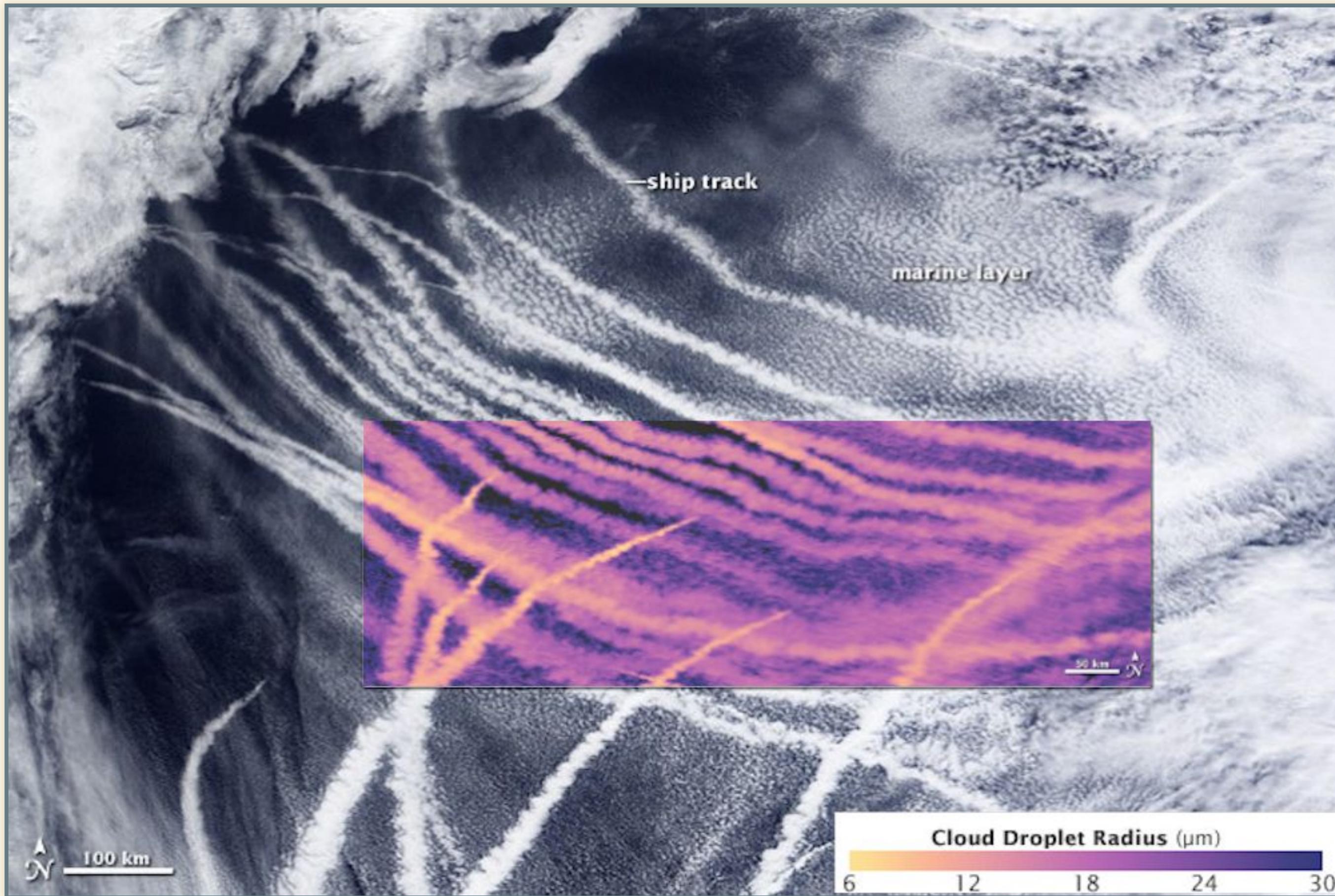
100 km

Indirect Aerosol Effect

- Aerosol particles → more, smaller droplets
- Smaller droplets → greater albedo, longer lifetime
- More droplets → greater albedo, more absorption



Indirect Aerosol Effect



Summary of Feedbacks

Summary of Feedbacks

- Ice-Albedo has been extensively studied:
 - It's known to be moderately positive.
- Water vapor has been studied:
 - It's known to be strongly positive (factor of 2).
- There is some uncertainty about clouds:
 - Most likely they're positive,
 - Strength is very uncertain

Stefan-Boltzmann Feedback

- The biggest feedback in the climate system is the Stefan-Boltzmann feedback.
- Stefan-Boltzmann equation: $I = \varepsilon\sigma T^4$
 - $Q = Q_{\text{in}} - Q_{\text{out}}$
 - Higher temperature \rightarrow more heat out to space
 - Q_{out} gets larger, so $\Delta Q < 0$
 - $\Delta T > 0 \rightarrow \Delta Q < 0$
 - $f = \frac{\Delta Q}{\Delta T} < 0$: negative feedback
- Creates stable climate

Stability of the Climate

- Most feedbacks we've discussed are positive:
 - Ice-albedo
 - Water vapor
 - Clouds (mostly)
- Why don't these positive feedbacks make the climate unstable?
 - (e.g., runaway greenhouse)
 - They are smaller than the negative Stefan-Boltzmann feedback
 - so the total feedback remains negative.
 - Positive feedbacks amplify warming:
 - More than we'd get with just Stefan-Boltzmann feedback,
 - But they are too small to destabilize the planet.
- Many scientists worry about a possible "tipping point":
 - Is there a temperature threshold where positive feedbacks become greater than Stefan-Boltzmann?
 - This would destabilize the climate.