Evidence for Climate Change in the Satellite Cloud Record

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Collaborators

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Funders

NOAA, NSF, and NASA

Outline

- Importance of cloudiness
- Challenge of assessing cloud changes
- Consistent cloud changes in global climate models
- Cloud changes in satellite observations
- Subtropical stratocumulus

Climate Sensitivity

$\Delta T = \Delta E \lambda$

where ΔT is temperature change

ΔE is external anthropogenic radiative forcing

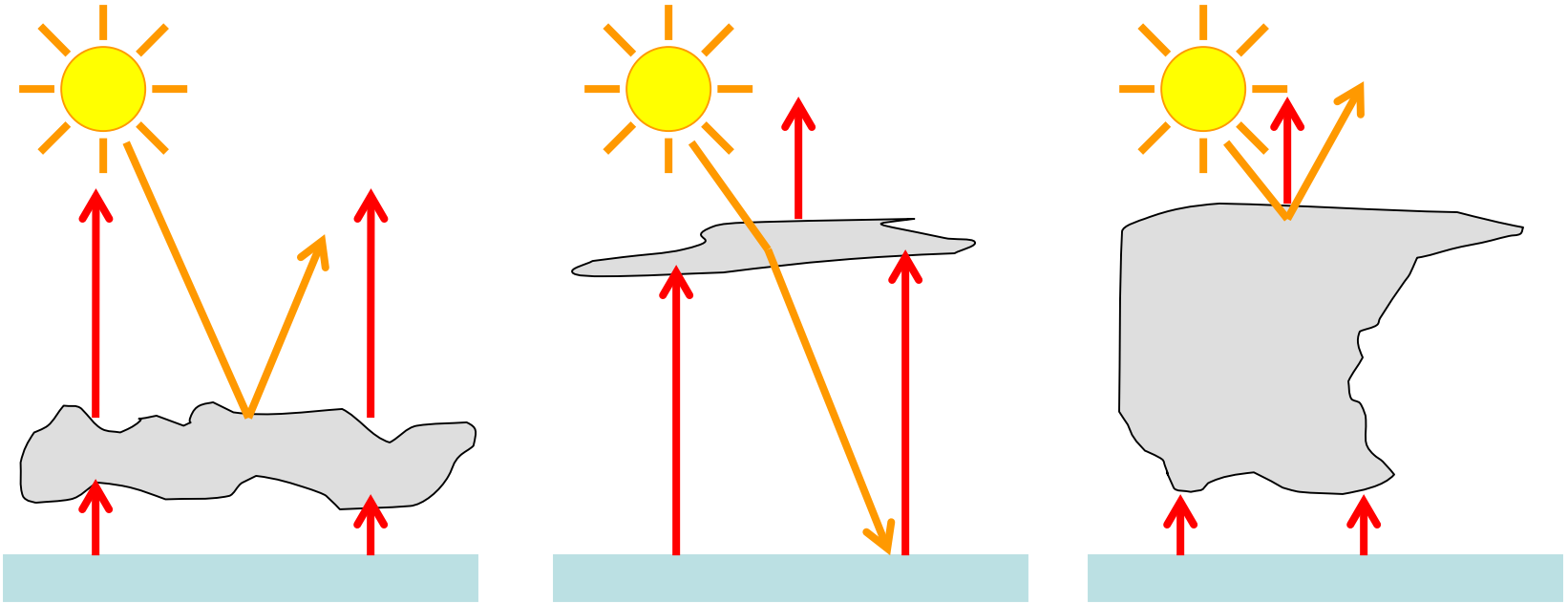
λ is climate sensitivity

higher λ à greater ΔT

How much warming by 2100? Need to know λ *!*

What is λ *? Need to know response of climate system to warming!*
(feedbacks)

Clouds as a Reflective Blanket



<u>low-level cloud</u>

strong reflection

weak greenhouse

cools the earth

<u>high-level cloud</u>

weak reflection

moderate greenhouse

warms the earth

<u>thick cloud</u>

strong reflection

strong greenhouse

near-zero effect

Global Cloud Radiative Effect

- Current solar reflection by clouds: +48 W m^{-2}
- Current thermal reduction by clouds: −31 W m^{-2}
- Current net effect of clouds: +17 W m^{-2} more radiation to space

1.6 W m^{-2} (40% increase in CO_2) equal to:

- 3% change in solar reflection by clouds
- 5% change in thermal reduction by clouds

0.4% change in cloudiness could balance 4% increase in CO_2

Small changes in clouds are important!

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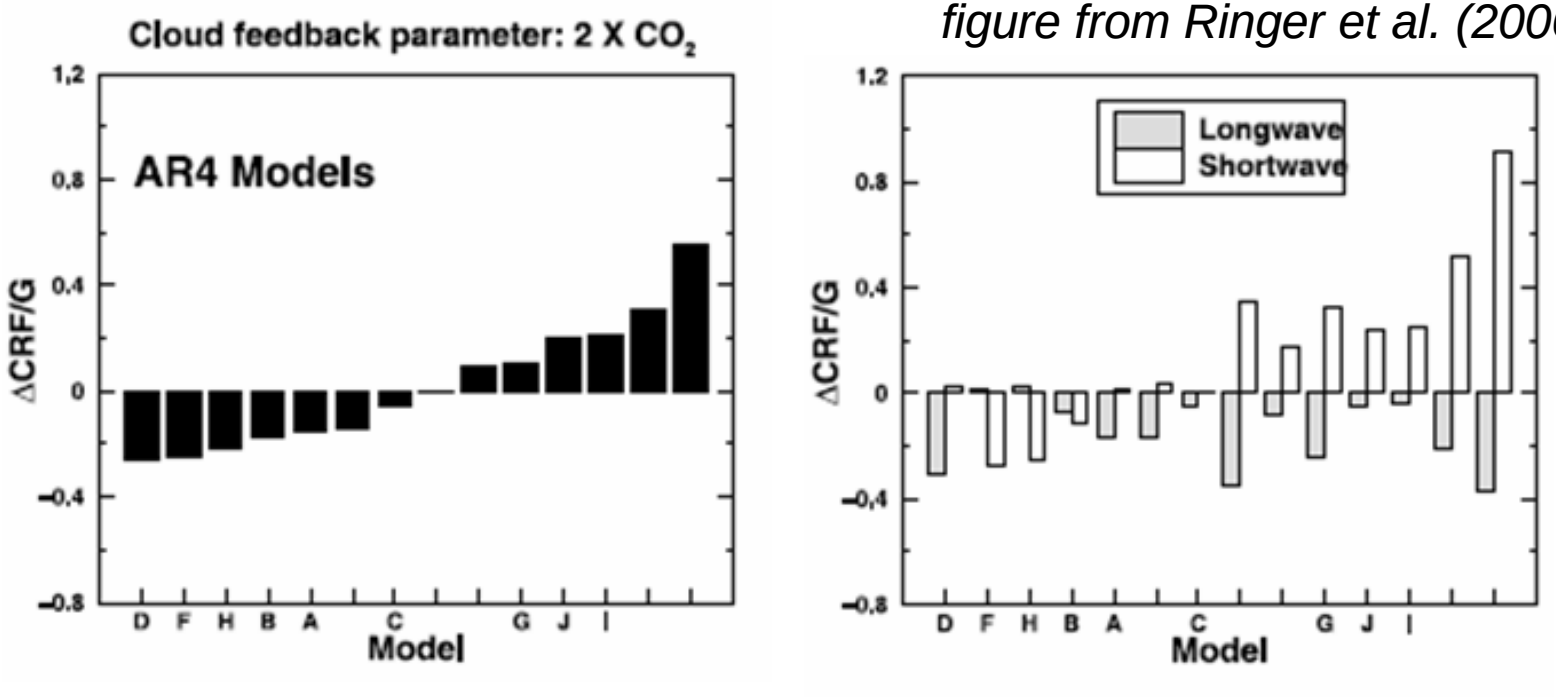
Cloud Feedbacks in Models

Substantial disagreement over net cloud feedback

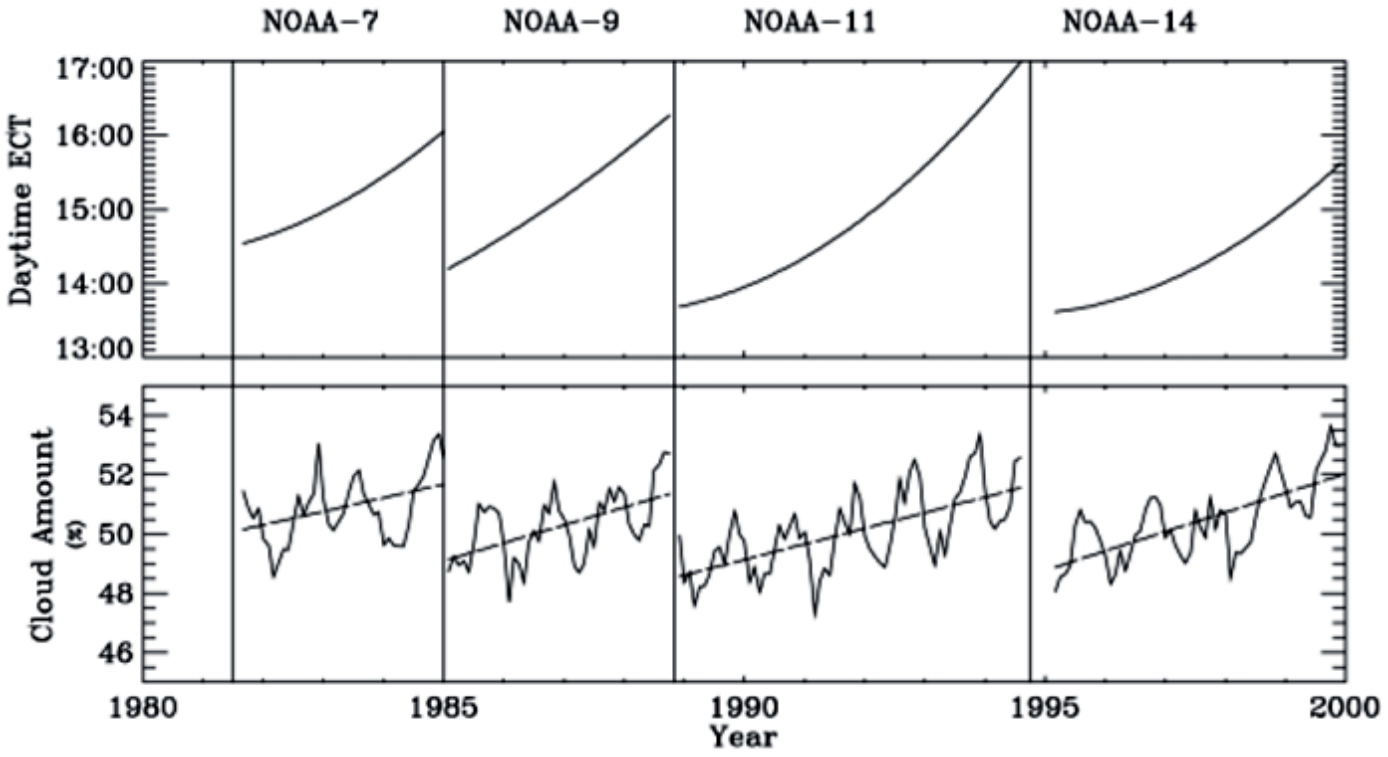
figure from Ringer et al. (2006)



But substantial agreement for certain cloud feedbacks

PATMOS Satellite Cloud Record

From Jacobowitz et. al. (2003)



Obvious artifacts associated with satellite transitions and drift through local time of equatorial crossing

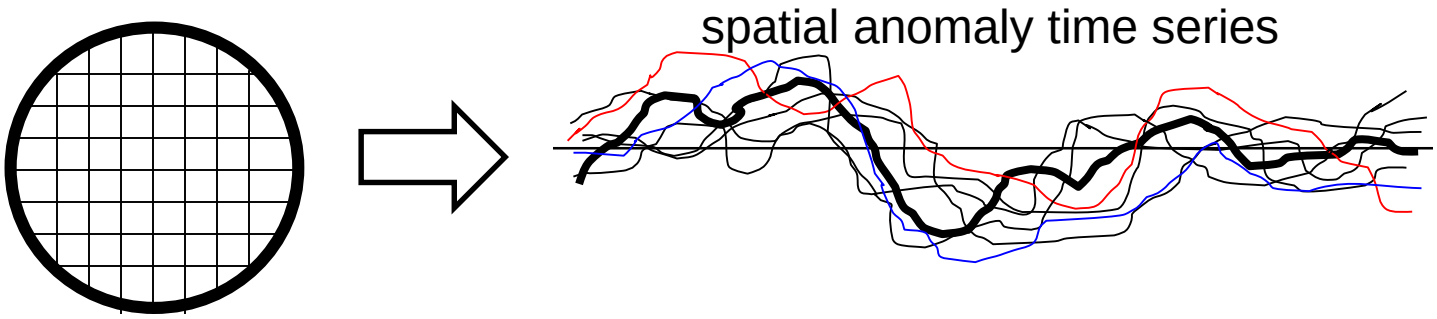
Correcting for Calibration Problems

- Calibration and other problems produce artificial cloud changes that are spatially coherent at very large scales
- Local differences from the large-scale mean are mostly real

à Subtract large-scale mean time series from local time series

Can examine regional cloud changes

Cannot examine global mean cloud changes



The Way Forward

- Focus on cloud feedback patterns for which most models agree
- Examine observed regional patterns of cloud change

- Do multiple models and multiple observational datasets agree?

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Projected Poleward Storm Track Cloud Shift

Most models project decreasing cloud cover at the subtropical boundary as tropics expand and storm tracks retreat poleward

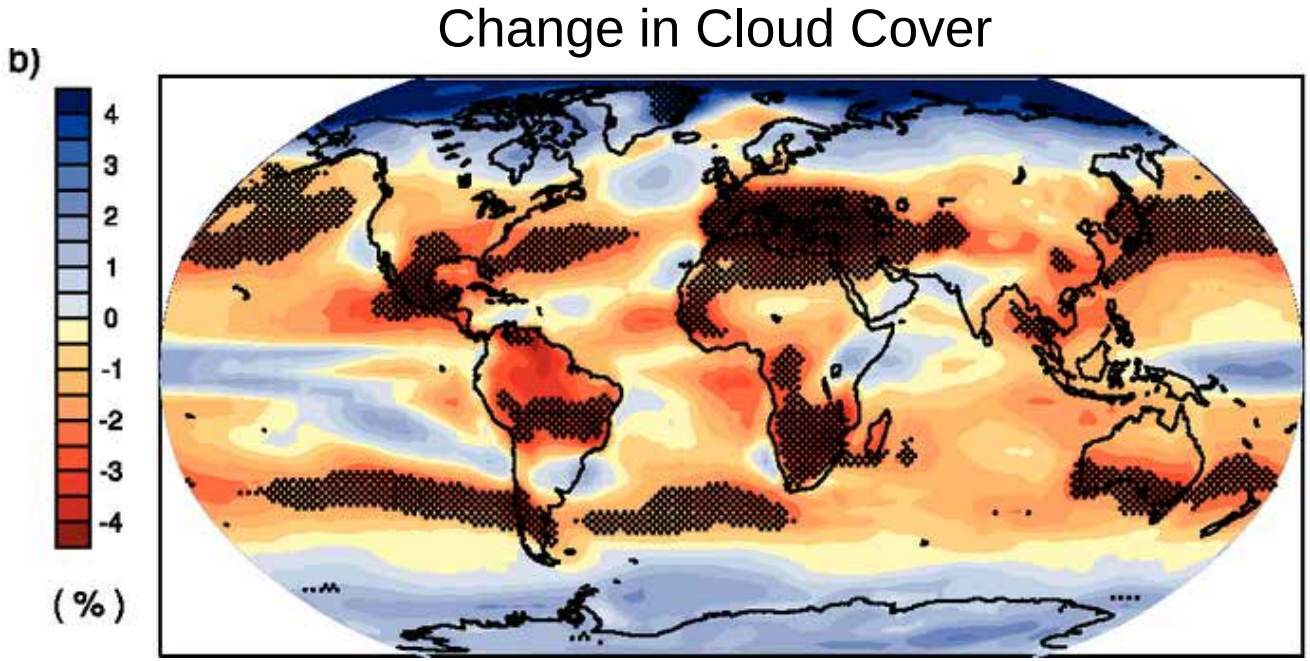
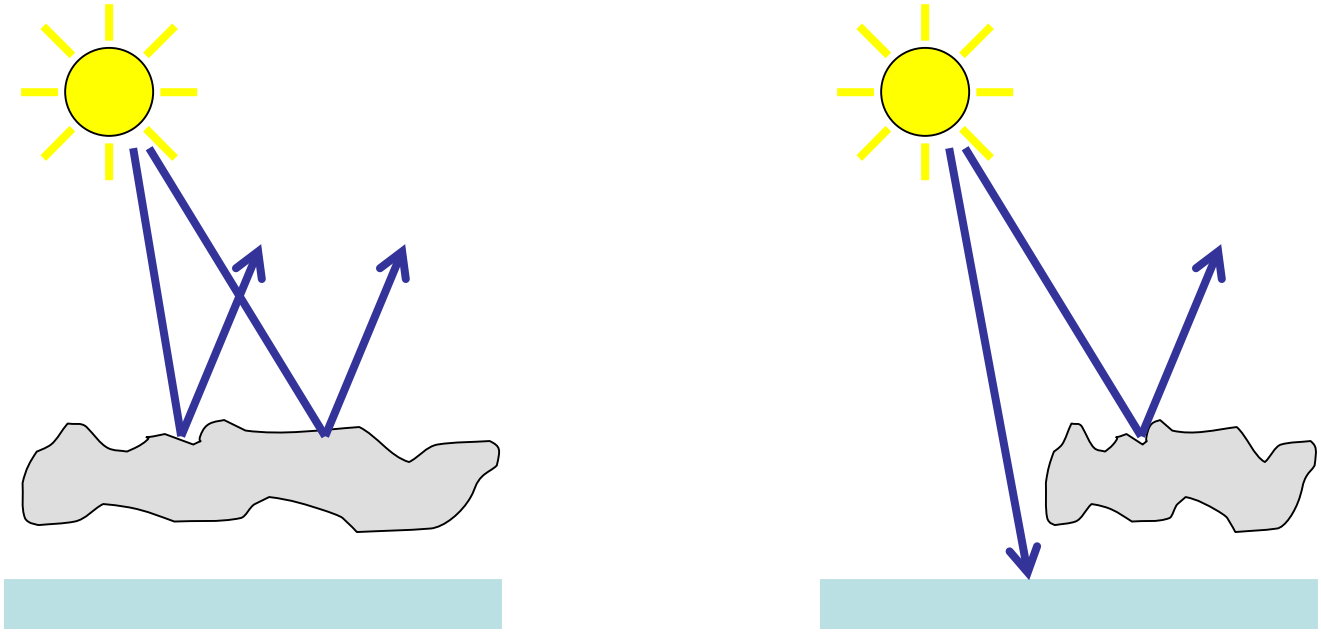


Fig. 10.10 from IPCC AR4 WG I Report

Projected Poleward Storm Track Cloud Shift

- Subtropical dry zone expands
- Less solar reflection at lower latitudes
- **Positive feedback, exacerbates global warming**

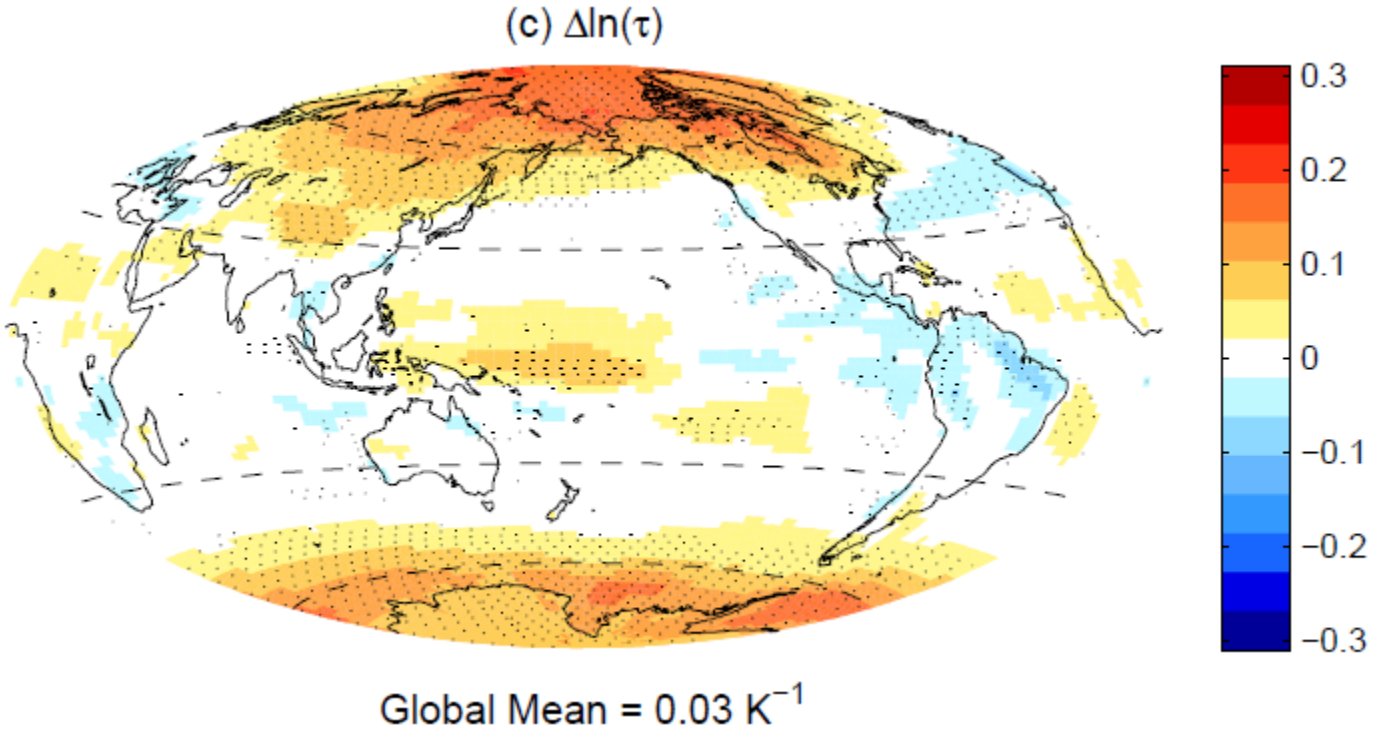


Before

After

Enhanced High-Latitude Optical Thickness

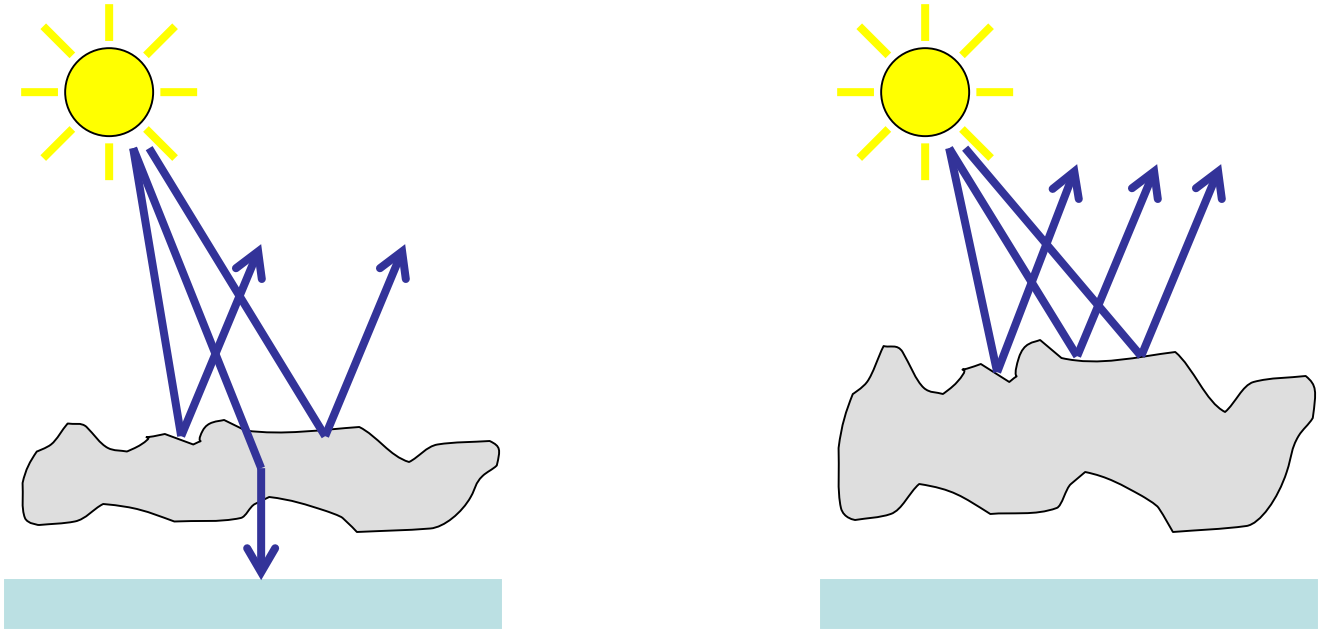
Most models project increasing cloud optical thickness at high latitudes due to more liquid and less ice



From Zelinka et. al. (2012)

Enhanced High-Latitude Optical Thickness

- Thicker high latitude clouds reflect more solar radiation
- **Weak negative feedback, mitigates global warming**



Before

After

Projected High-Level Cloud Top Rise

Most models project increasing high-level cloud top height due to rising tropopause or level of zero radiative cooling

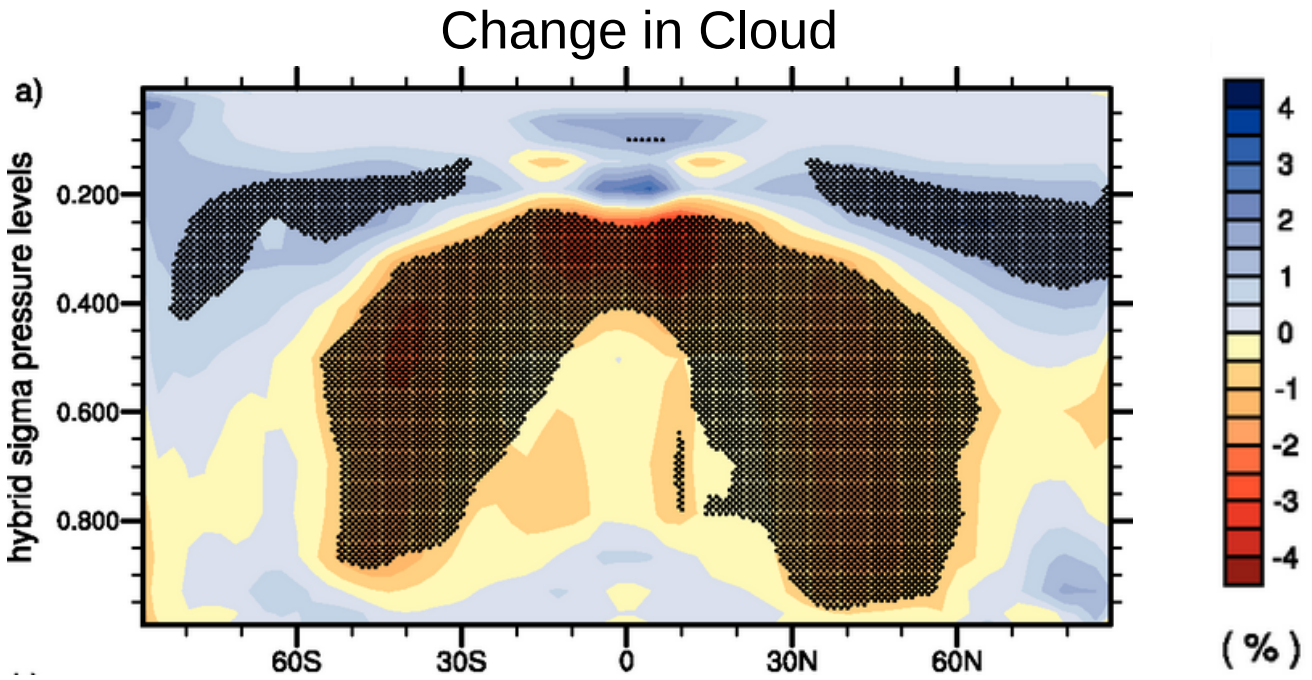
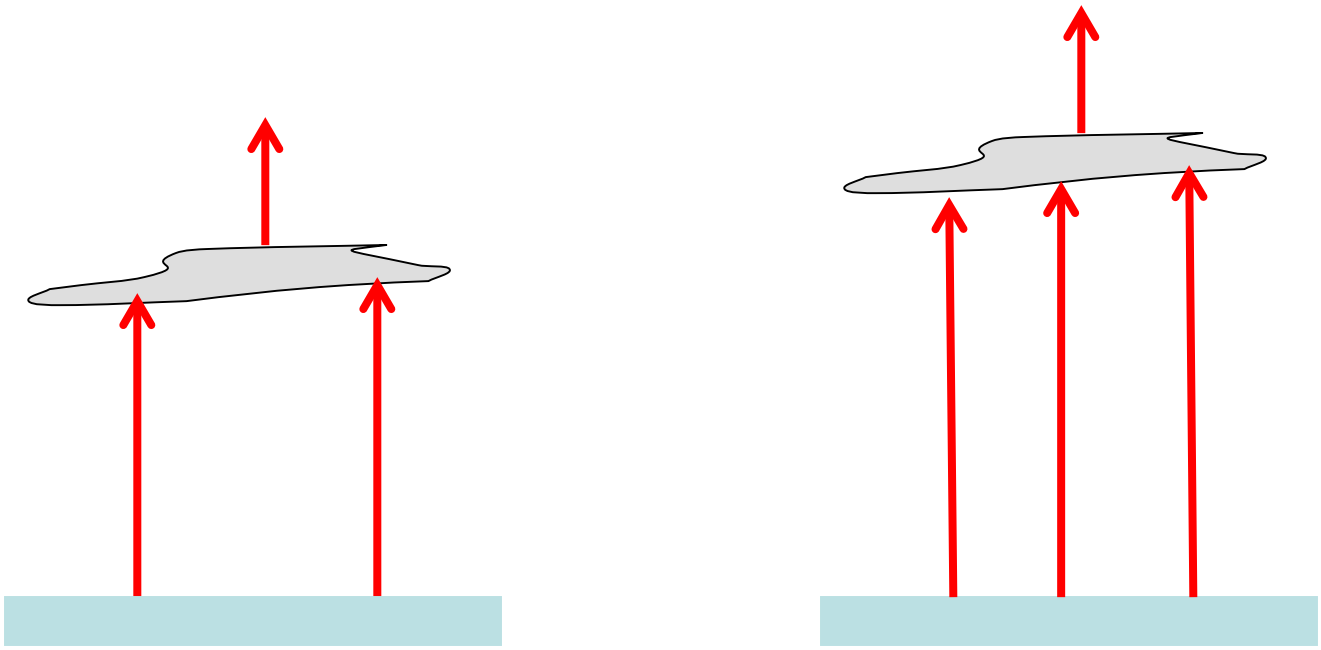


Fig. 10.10 from IPCC AR4 WG I Report

Projected High-Level Cloud Top Rise

- Less thermal emission by higher cold clouds relative to lower and warmer surface
- **Positive feedback, exacerbates global warming**



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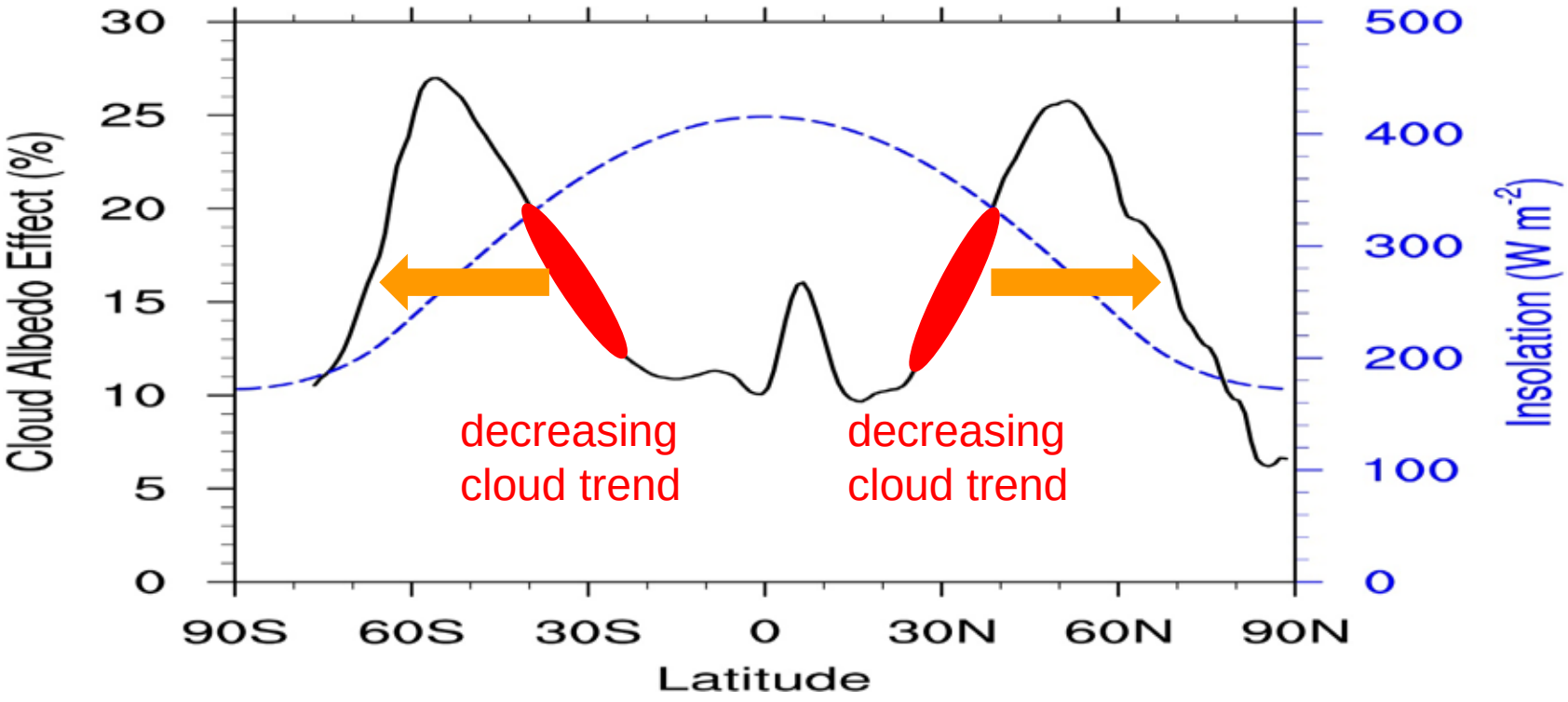
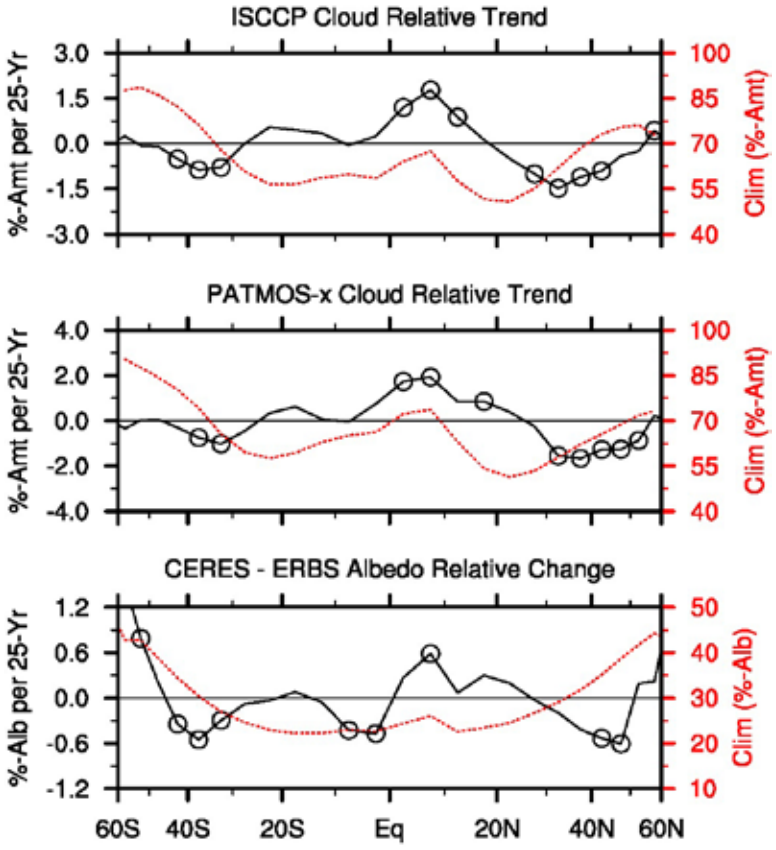


ocean-only CERES cloud albedo

Poleward Storm Track Cloud Shift

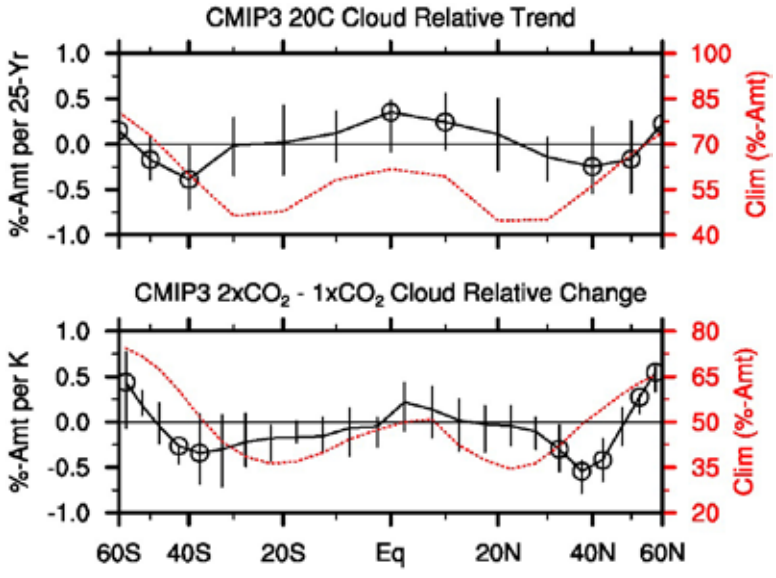


Observations

circles show 95% significance

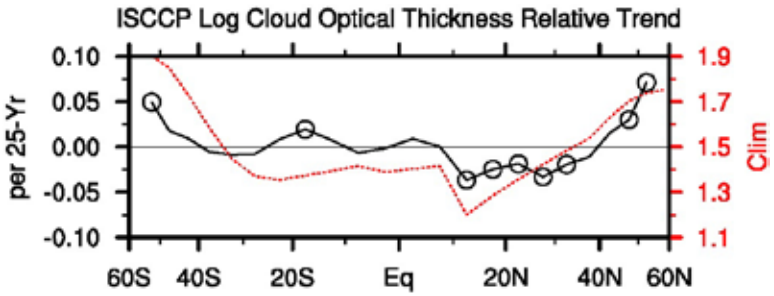
bars show 25-75% range of model changes

global mean change removed

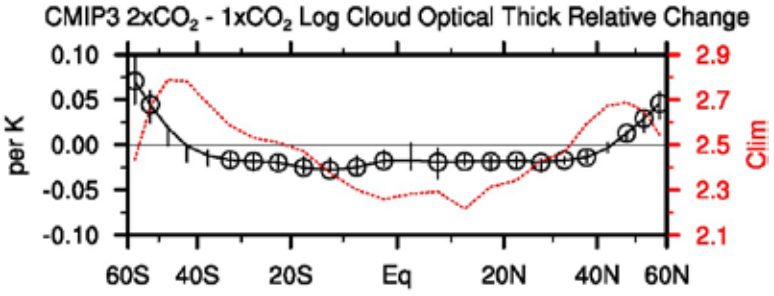


Models

Enhanced High Latitude Optical Thickness



Observations



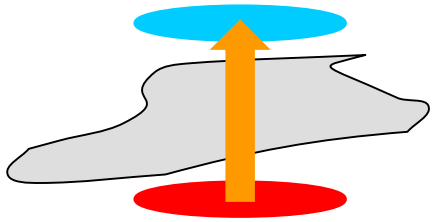
Models

circles show 95% significance

bars show 25-75% range of model changes

global mean change removed

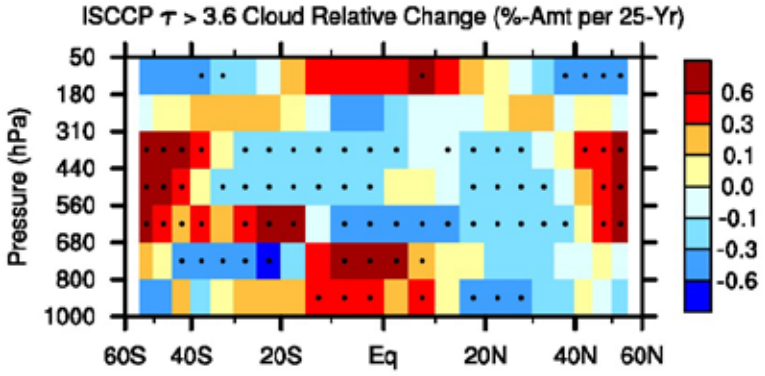
Rise of High-Level Cloud Top



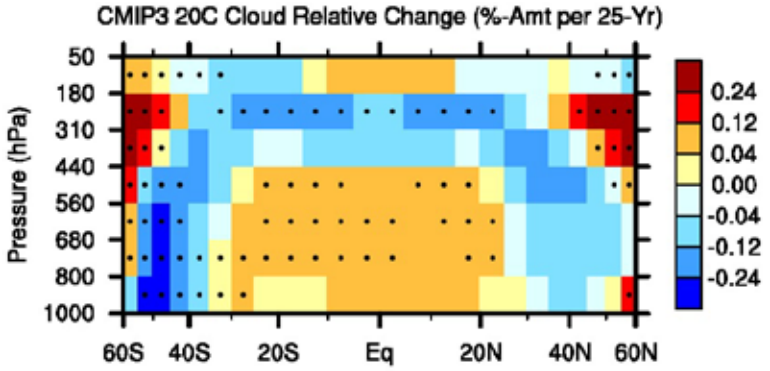
increasing
cloud trend

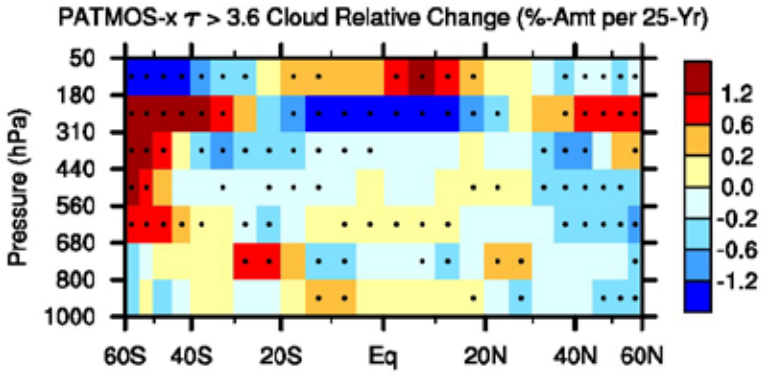
decreasing
cloud trend

Rise of High-Level Cloud Top

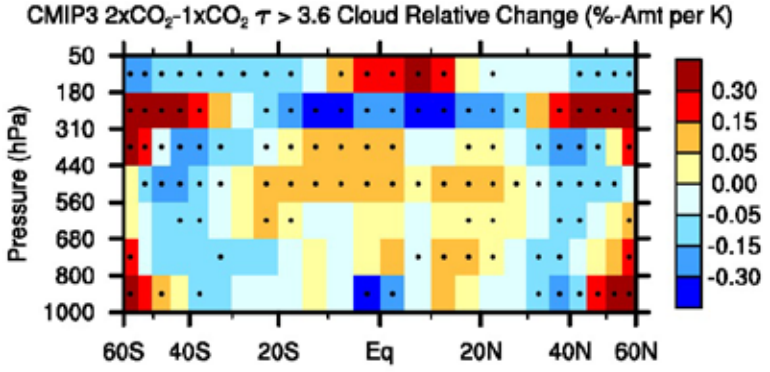


dots show 95% signif.





dots show 8 out of 11 models agree



Observations

Models

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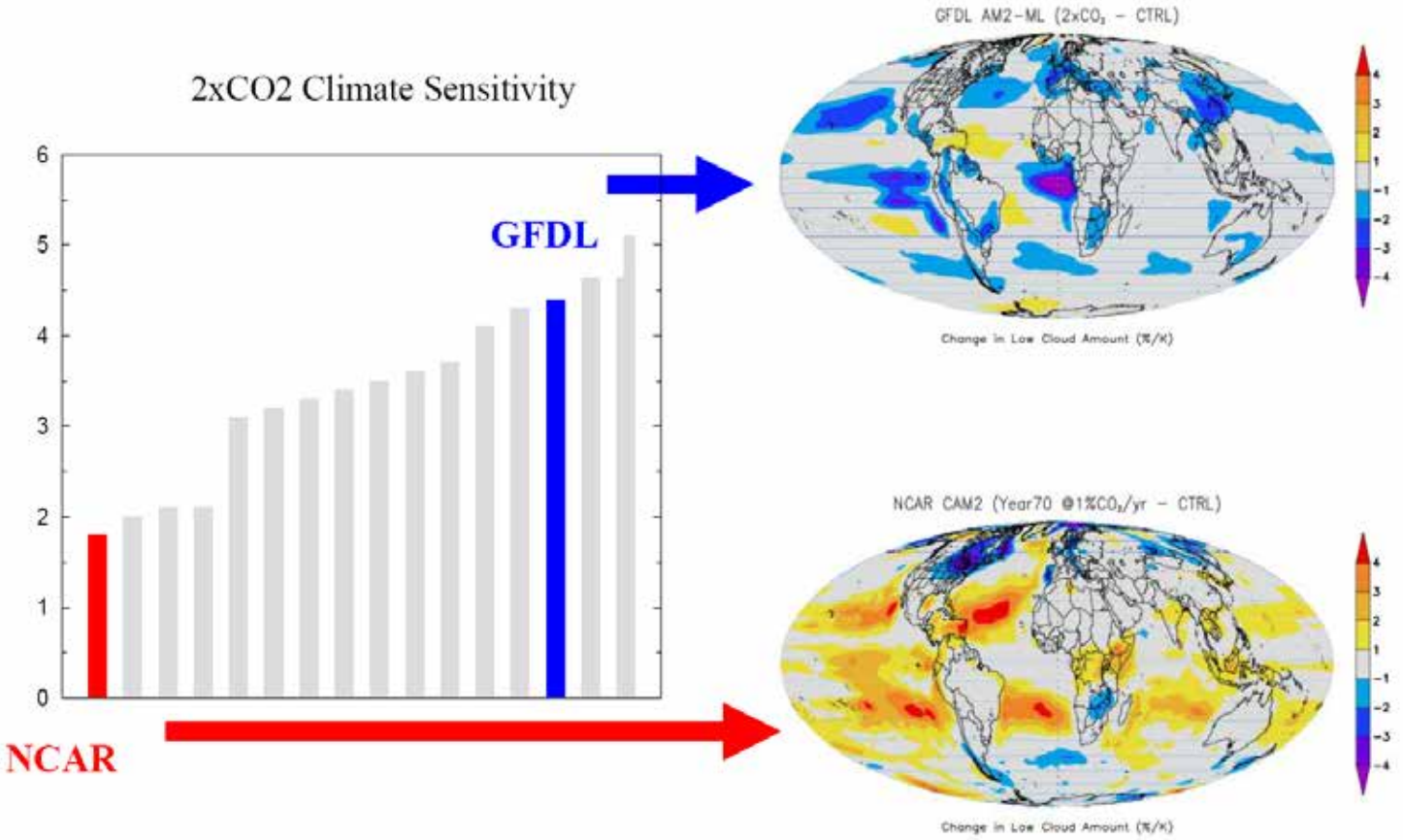
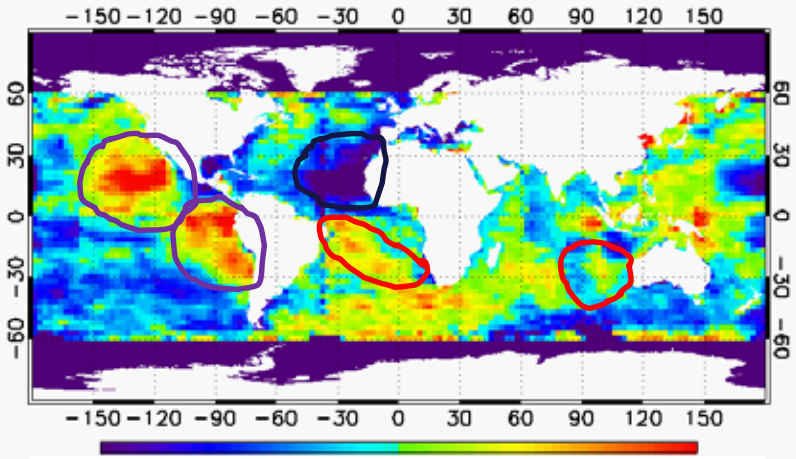
Simulated Cloud Change for 2´ CO_2



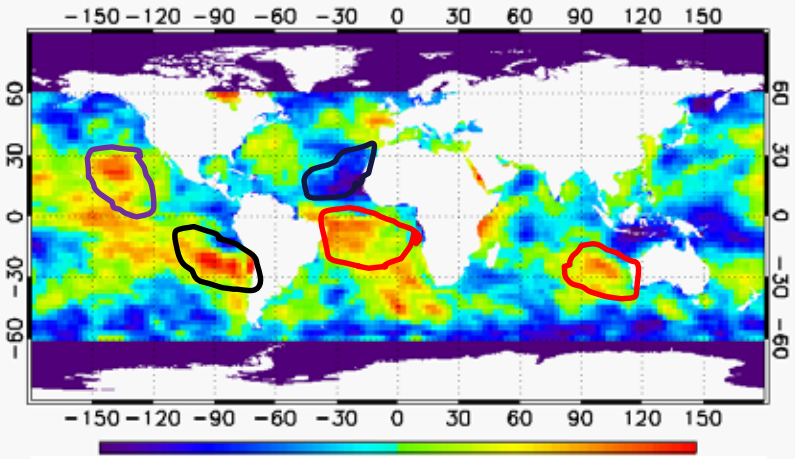
Courtesy of Brian Soden

Models predict different signs of cloud change

What about Subtropical Stratocumulus?



ISCCP Low-Cloud Trend

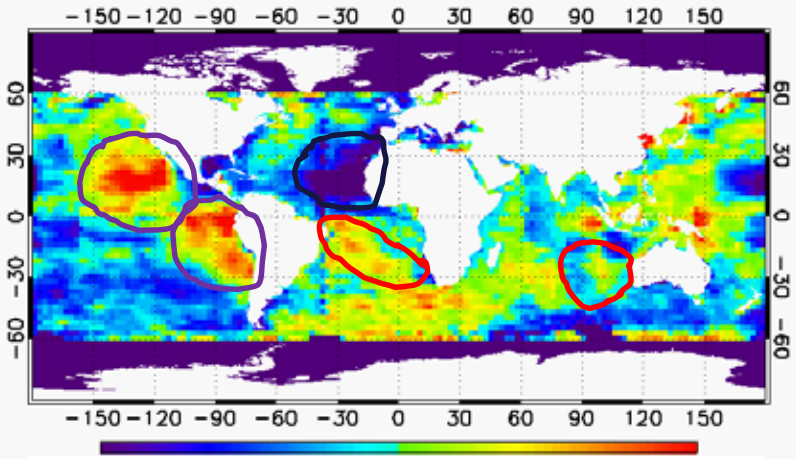


PATMOS-x Low-Cloud Trend

1983-2008 trends

Low-level cloud amount *increasing* in 4 out of 5 subtropical stratocumulus regions

Consistent with Meteorological Changes



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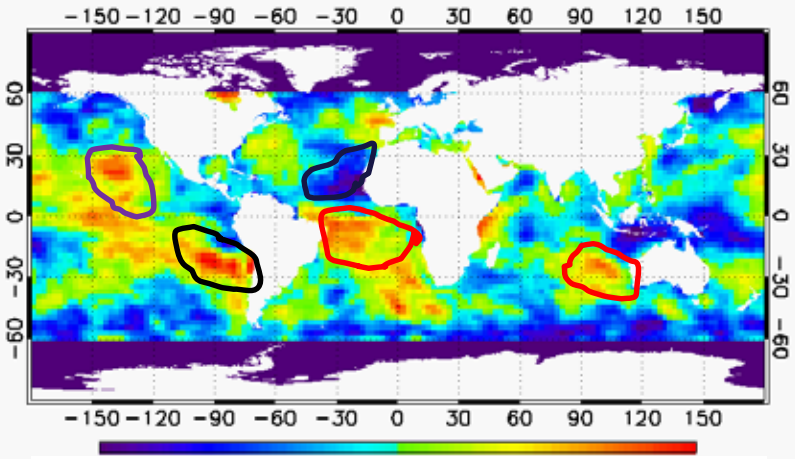

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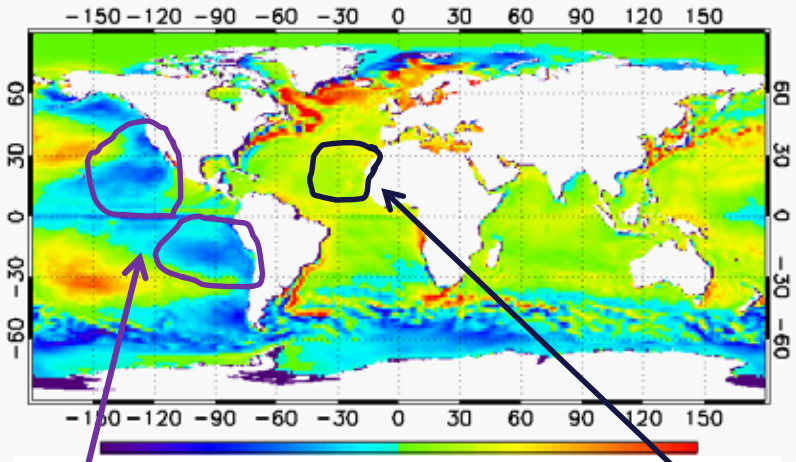
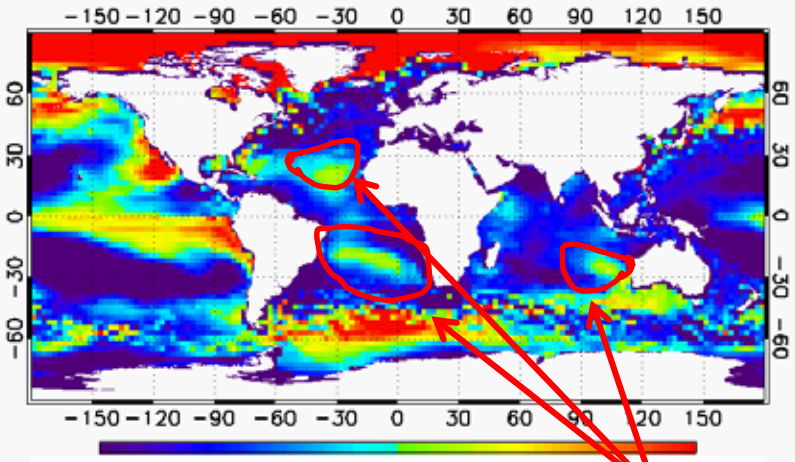


SST Trend

colder SST

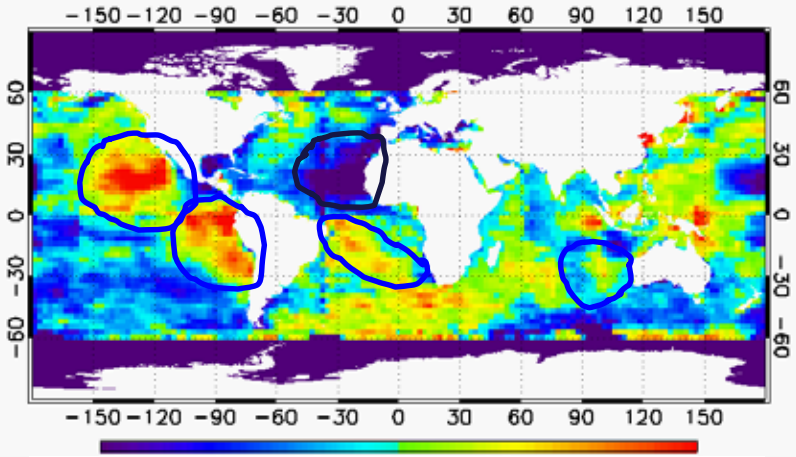
warmer SST



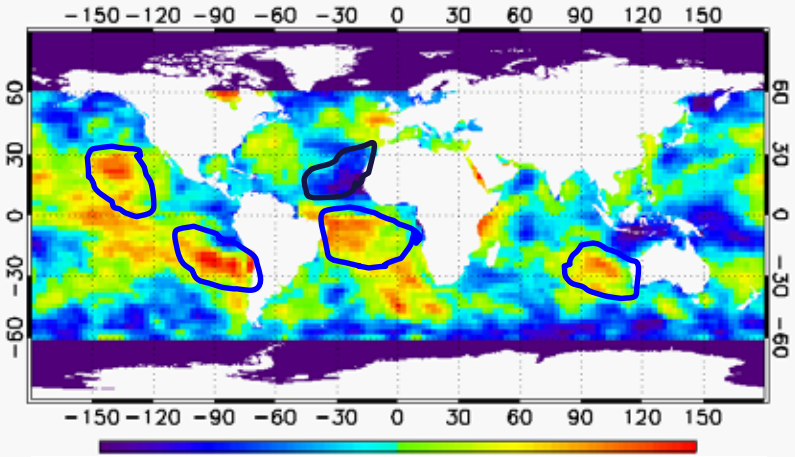
EIS Trend

stronger EIS

Consistent with Meteorological Changes



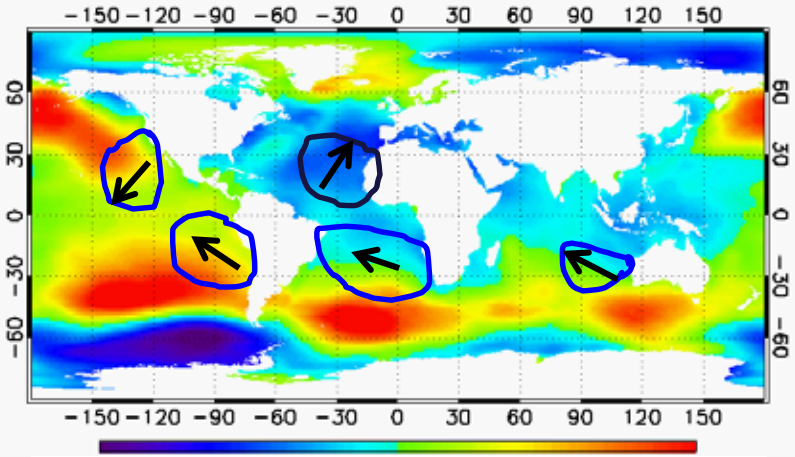
ISCCP Low-Cloud Trend



PATMOS-x Low-Cloud Trend

Stronger SLP gradient in every basin except NE Atlantic

Implied stronger trade winds



SLP Trend

What about Subtropical Stratocumulus?

- Increasing in 4 out of 5 regions between 1983 and 2008
- Cloud trends appear physically consistent with trends in sea surface temperature, inversion strength, and sea level pressure
- No single dominant meteorological cause for cloud changes in all regions – instead combination of various factors of varying strength
- Meteorological trends resemble multidecadal variability rather than changes associated with global warming

Summary

- Consistent patterns of cloud change *relative to the global mean* found in multiple independent cloud datasets
- Observed patterns resemble model projections for global warming
- Observational support for the primary cloud feedbacks robustly predicted to occur by models
  - Poleward shift of storm tracks (positive)
  - Increase of high-latitude cloud optical thickness (negative)
  - Rise of high-level cloud top (positive)
- Subtropical stratocumulus increased in 4 out of 5 regions, but may be natural multidecadal variability

- If the 1983-2008 cloud changes are a result of global warming, observed magnitude much stronger than projected per K warming.

Thank You!