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Cloud Thermostats and Anti-Thermostats

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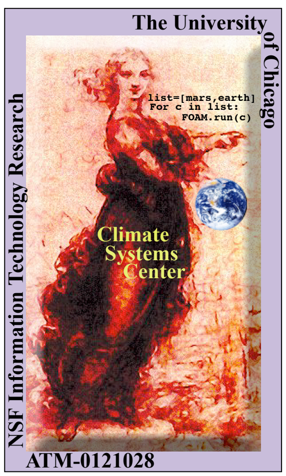
The University of Chicago



Outline of the Talk

- How to characterize a cloud
- Cloud contribution to uncertainty in climate sensitivity
- Faux thermostats
- Clouds in deep time

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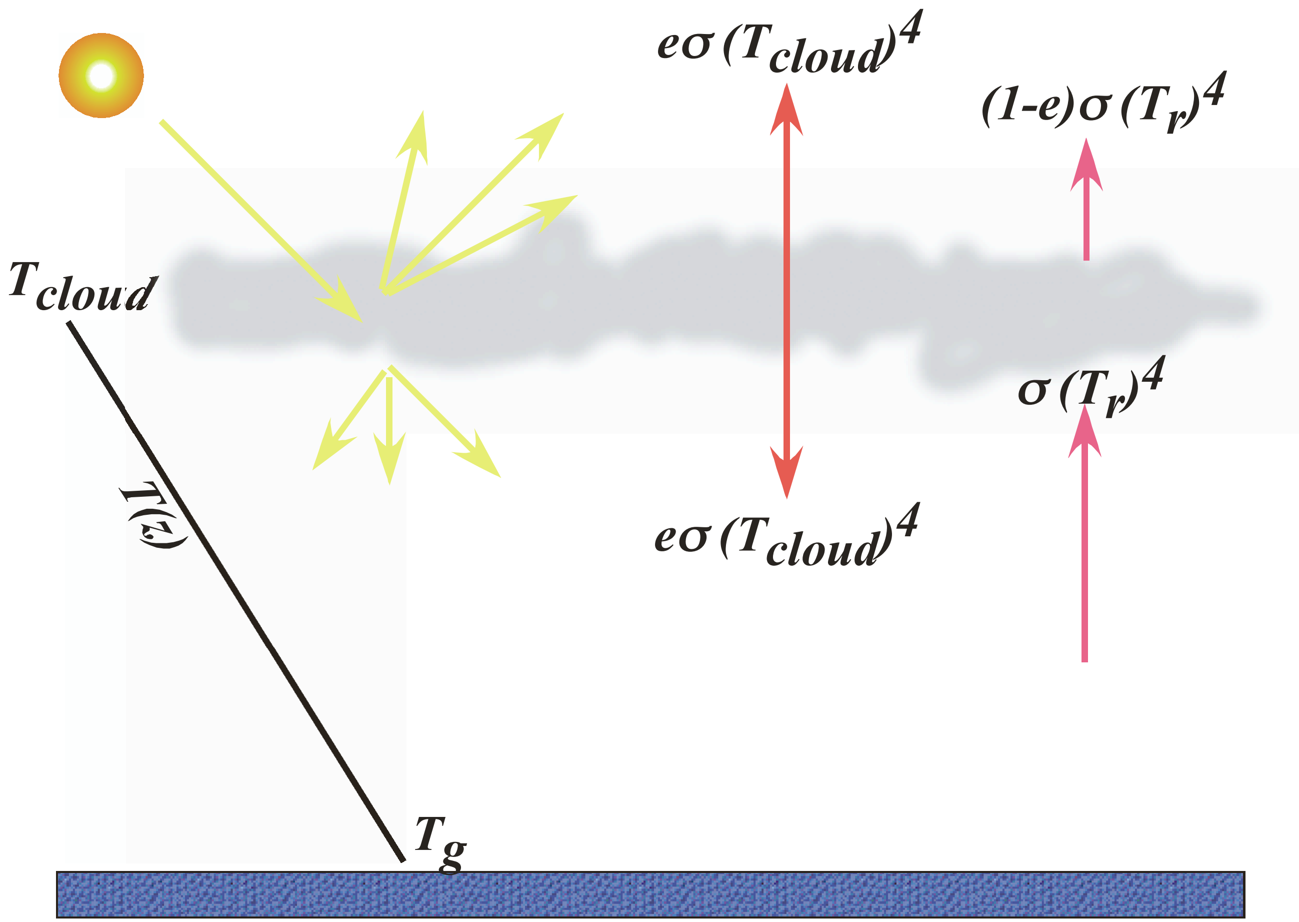
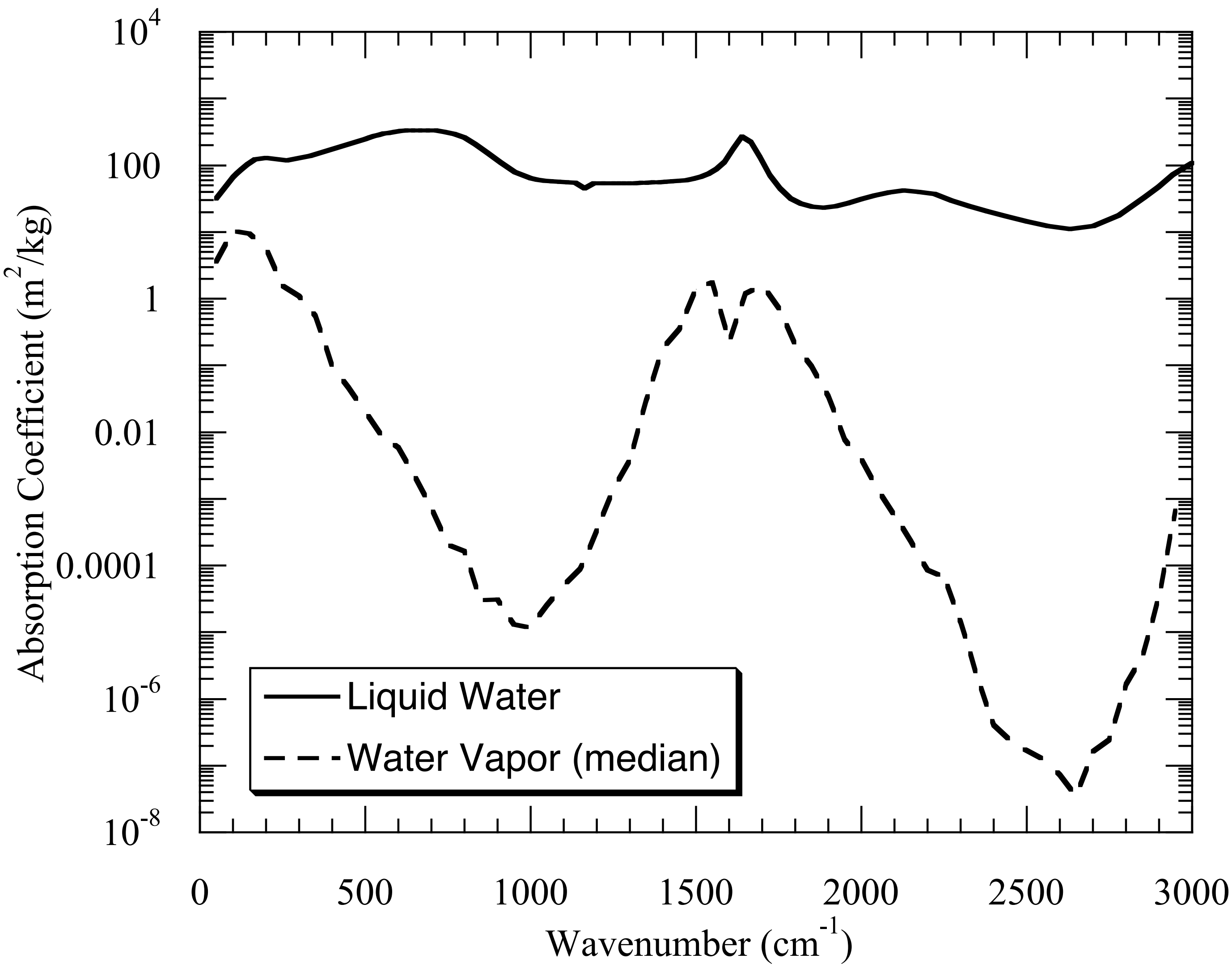
How clouds affect climate



Condensed water is a very strong IR absorber

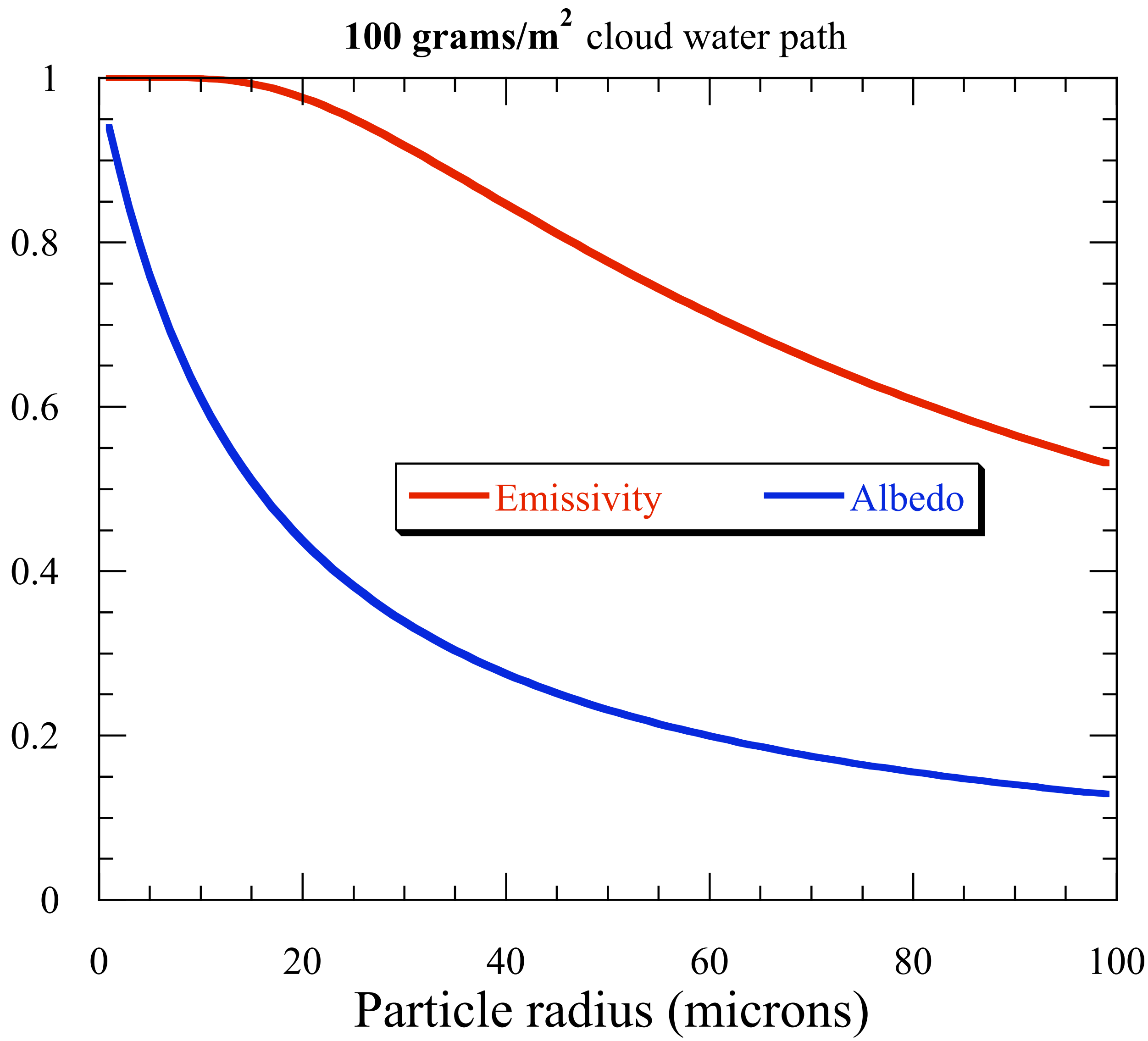


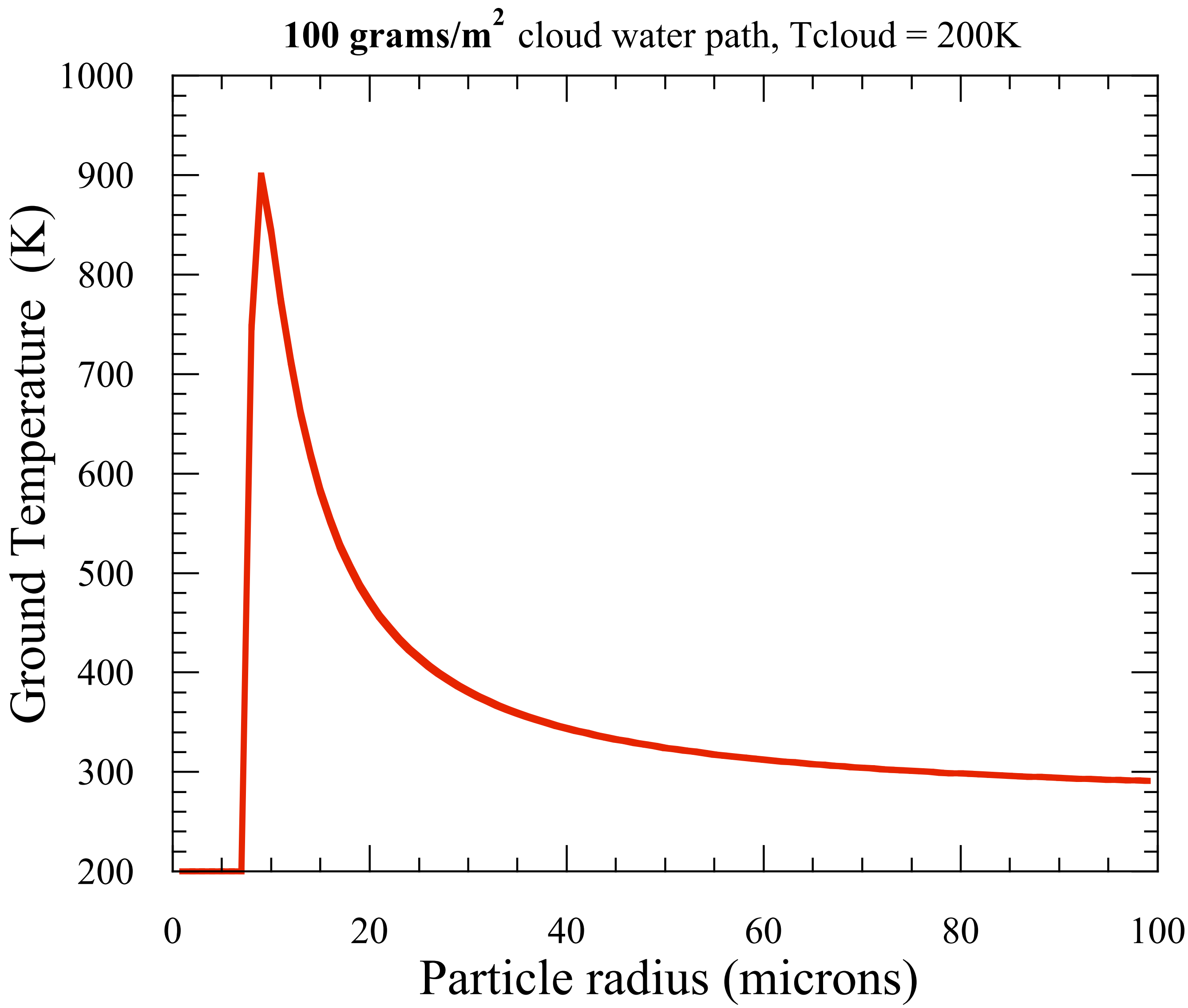
Cloud Characteristics

- Condensed water mass
- Particle size
- Vertical distribution (cloud top temperature)
- Cloud ”fraction”

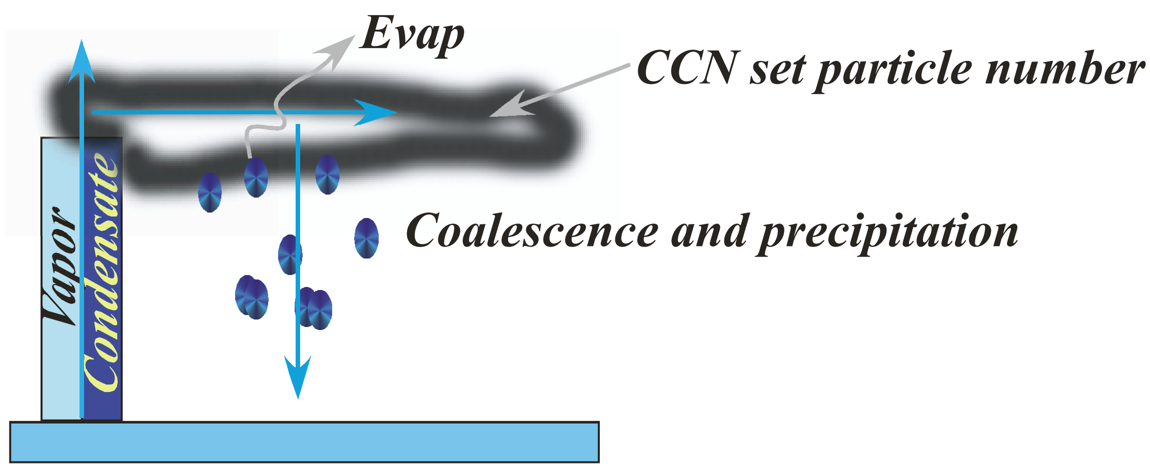
Particle size and LW vs SW effects of clouds

- Multiple scattering $\longrightarrow$ reflectivity $\approx 1 - 1/\tau_{sw}$
- But IR emissivity $\approx 1 - \exp(-\tau_{ir})$
- SW scattering and IR absorption cross-sections $\approx$ particle area.
- Mie theory $\longrightarrow$ forward-peaked scattering. Reduces eff. τ_{sw}

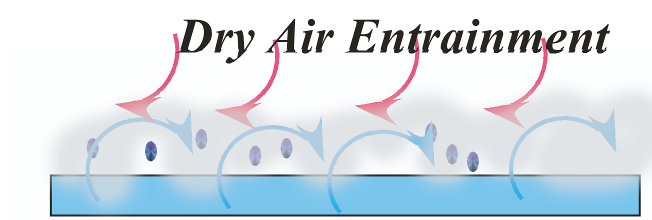

100 grams/m2 cloud water path
Emissivity
Albedo
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
Particle radius (microns)


100 grams/m2 cloud water path, Tcloud = 200K
Ground Temperature (K)
1000
900
800
700
600
500
400
300
200
0
20
40
60
80
100
Particle radius (microns)

What determines cloud properties?



(Midlat version:Lifting by macroturbulence)



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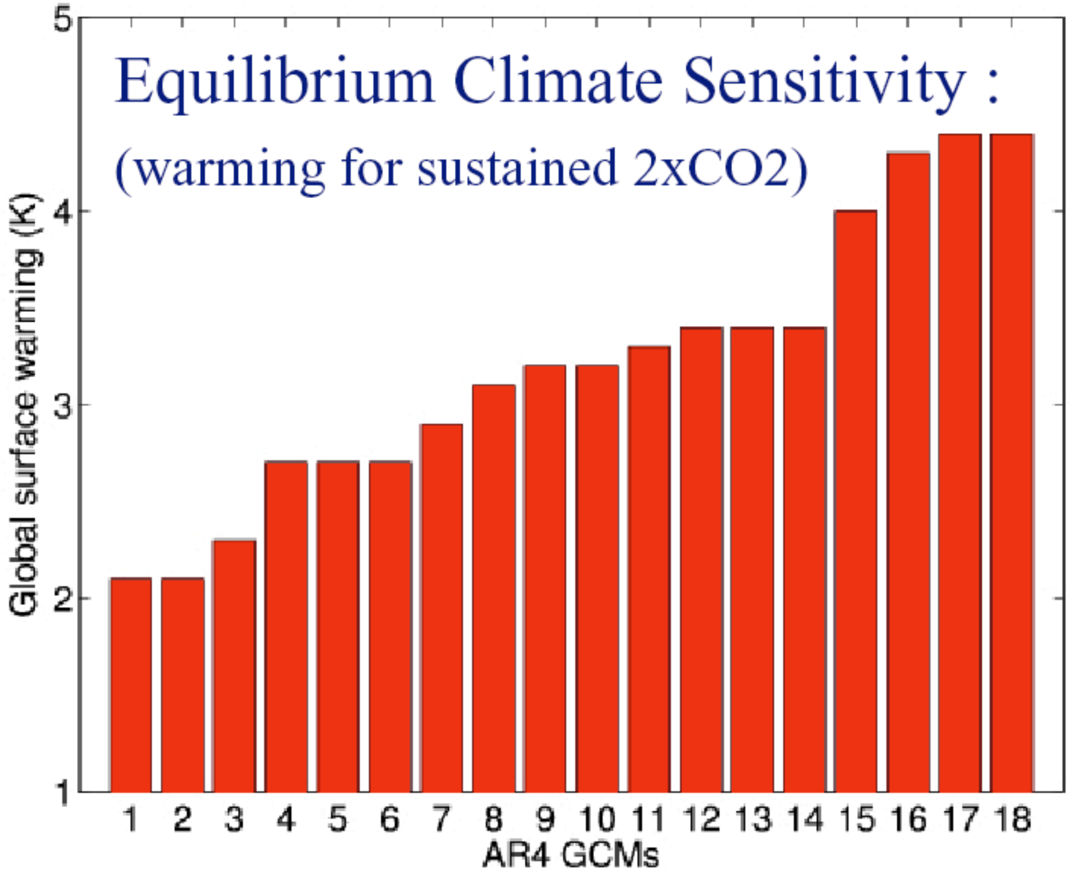
”Type 1” uncertainty in IPCC forecast



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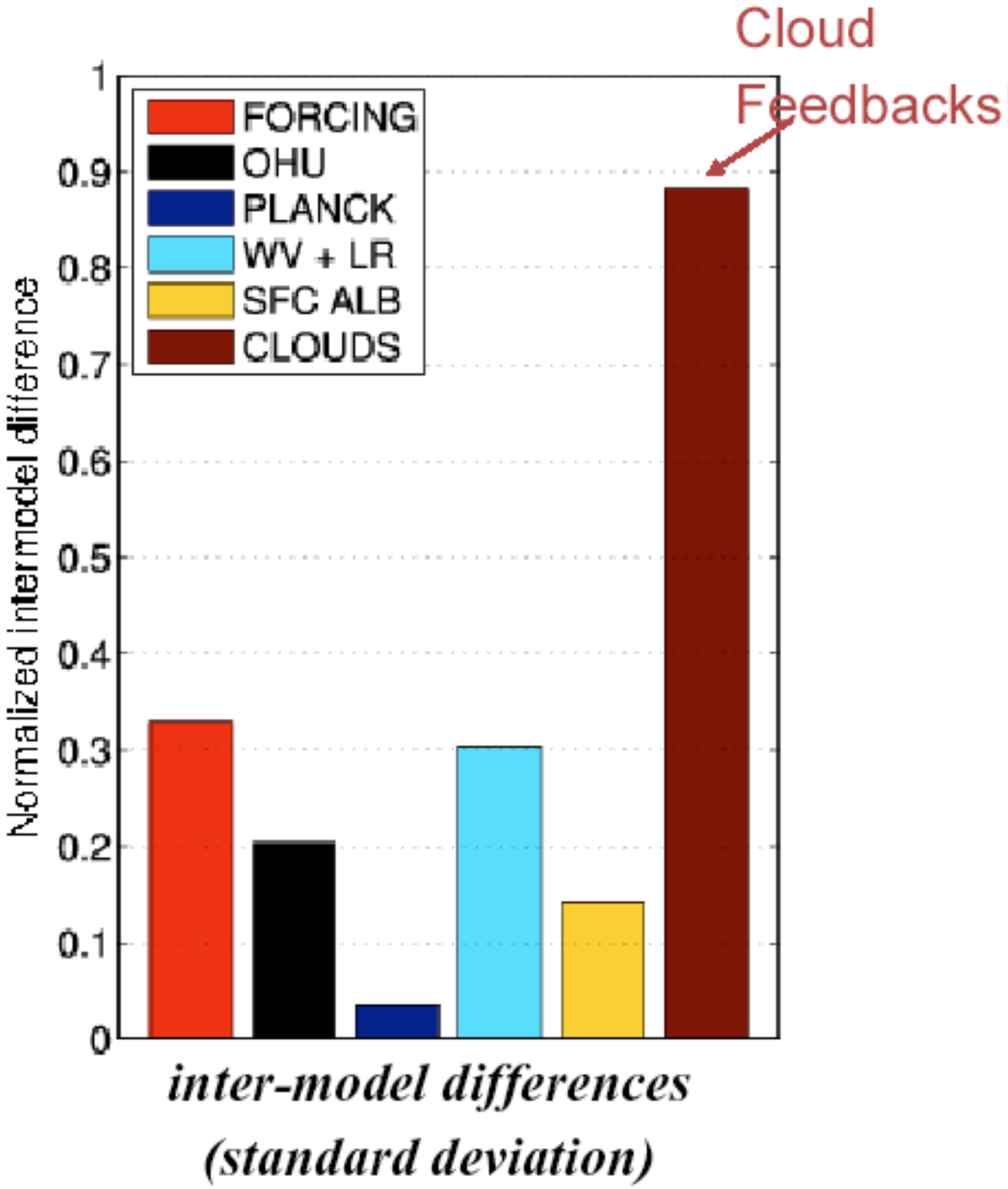
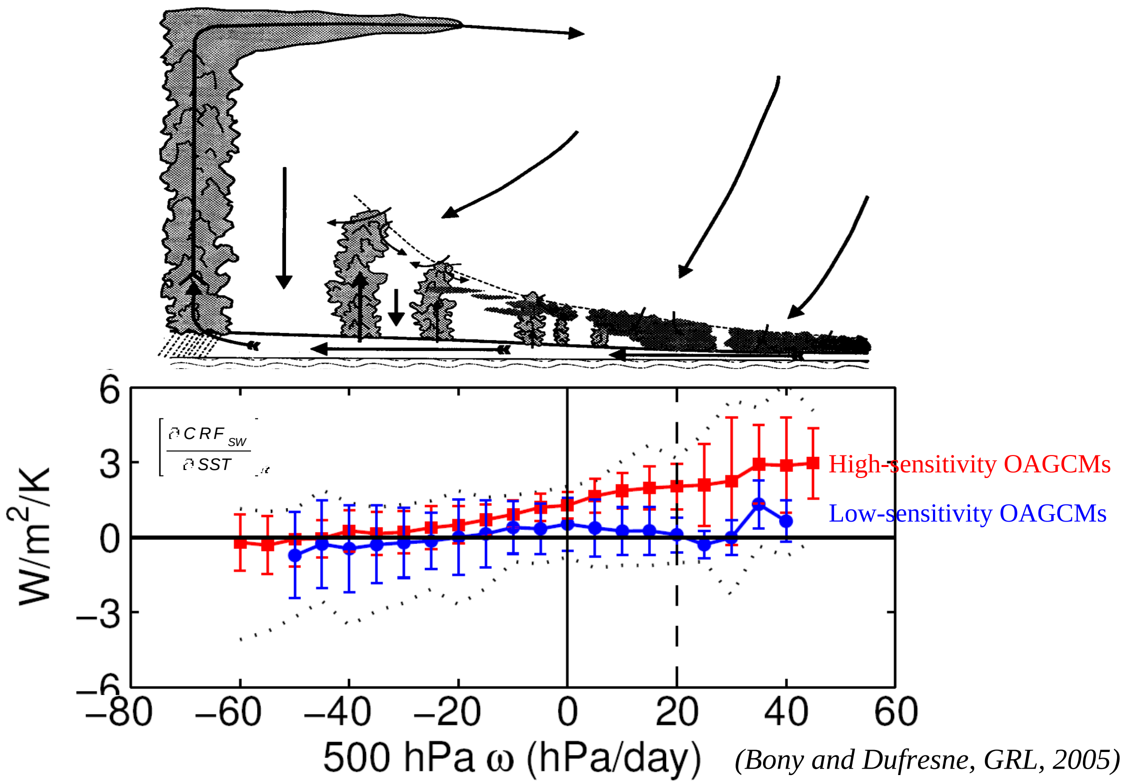
Clouds are the main source of climate projection uncertainty



Bony and DuFresne

In models, low clouds are the main source of disagreement

Sensitivity of the Tropical Cloud Radiative Forcing to Global Warming



(Bony and Dufresne, GRL, 2005)

Bony and DuFresne

Could clouds stabilize climate more than IPCC says?

Yes maybe, *but*...

- Hard to reconcile with climate change of past century
- Hard to reconcile with Southern Hemisphere cooling during last ice age
- Hard to reconcile with Cretaceous warmth and PETM warming
- And most of all ...

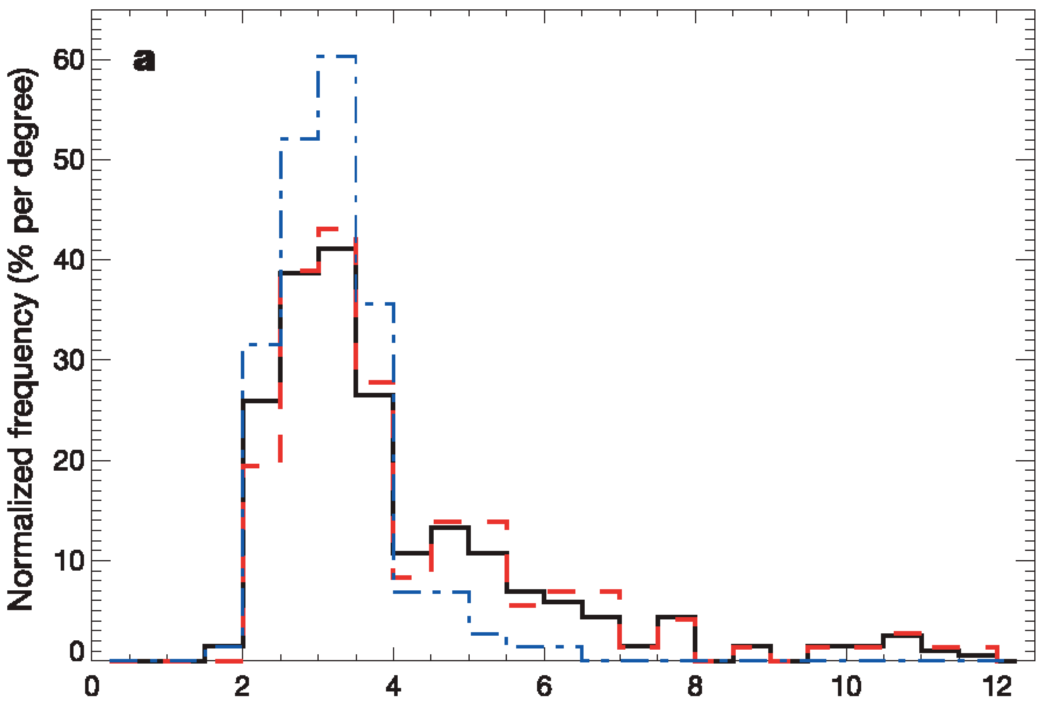
But clouds could also make things *a whole lot worse*

- Net cloud cooling = $20W/m^2$. Take it all away and Earth warms $9C$.
- Earth albedo without clouds is 19%. Absorbed solar = $276W/m^2$, more if ice melts...
- ... but threshold for runaway greenhouse for saturated Earth atmosphere is only $290W/m^2$!

So ...

Clouds and subsaturation are all that keep us from turning into Venus.

From ClimatePrediction.net...



Recall also my toy cloud runaway model

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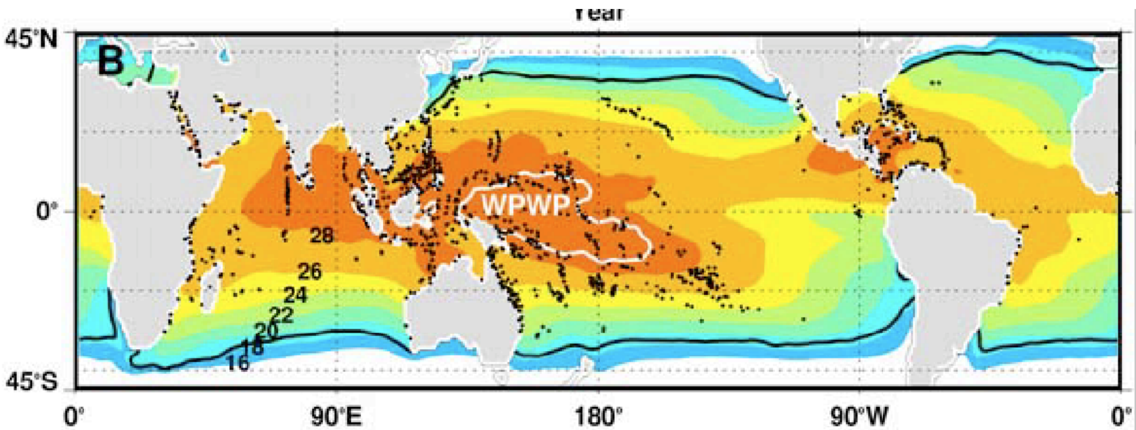
Tropical SST



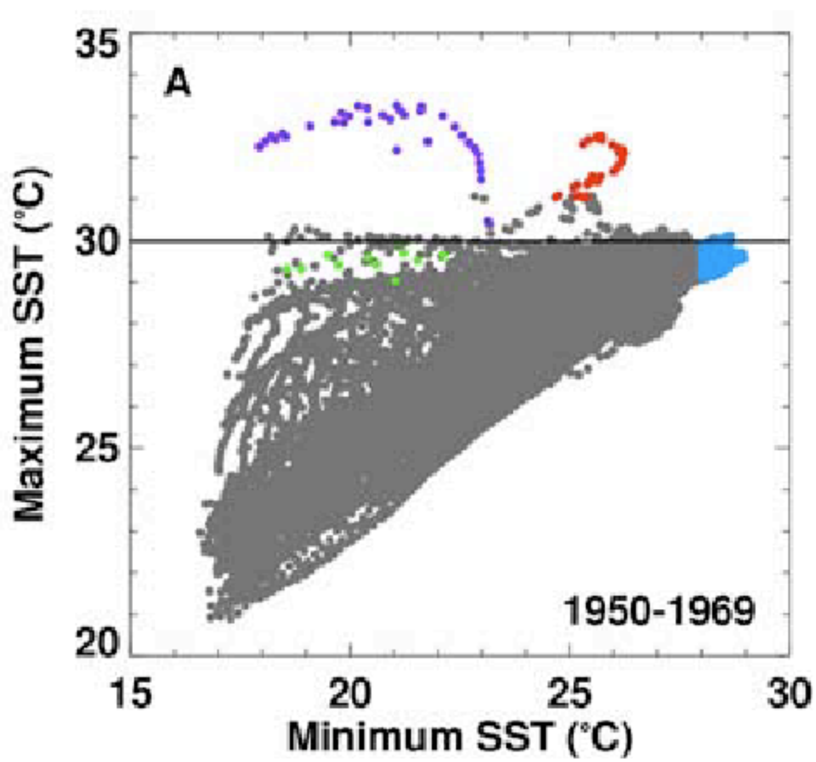
Ram and Collins, *Nature* 1991

- Scatter plots of cloud shortwave forcing show strong increase with SST
- Extrapolated solar to zero, concluded rigid upper bound to SST
- Fallacy 1: Correlation vs Causation
- Fallacy 2: Erroneously neglected cloud greenhouse effect
- All this (and more) pointed out in Pierrehumbert *JAS* 1995.

Bad ideas never die...

Potential role of the ocean thermostat in determining regional differences in coral reef bleaching events

Joan A. Kleypas,[1] Gokhan Danabasoglu,[1] and Janice M. Lough[2]



Analysis of AR4 global warming simulations simulations

- Work done by grad student Ian Williams
- Simulations of climate with GHG increasing over time
- Examine changes in SST histogram and cloud/SST relations
- Will show results for CCSM, but have done others

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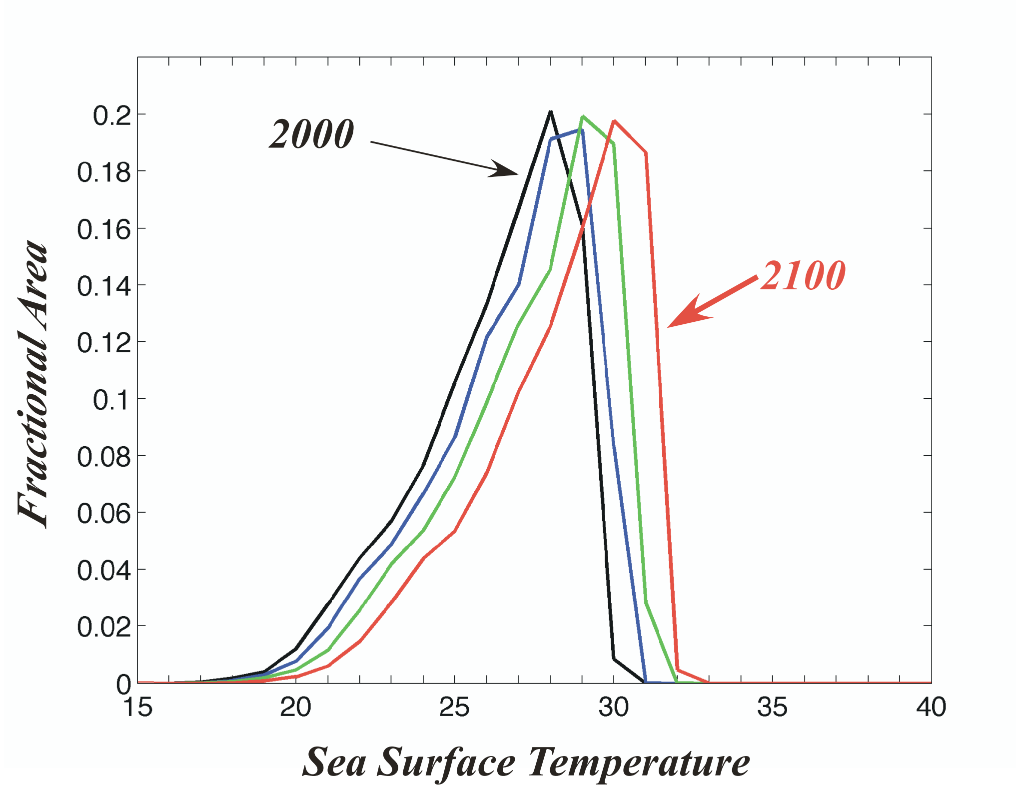
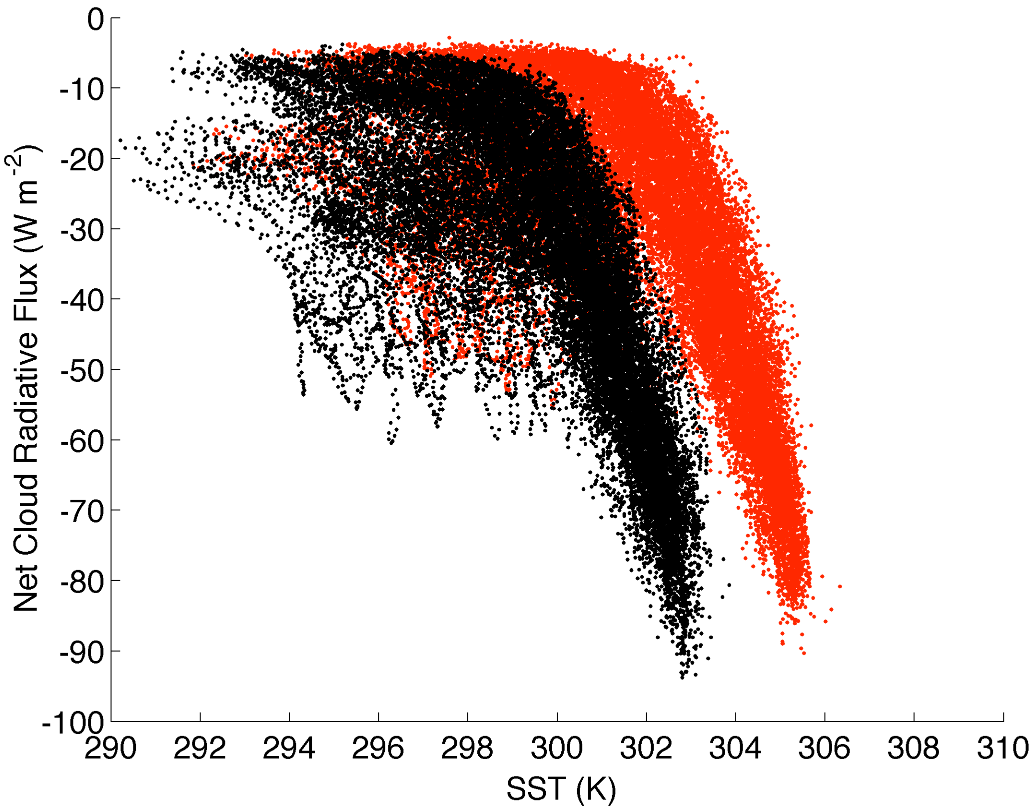
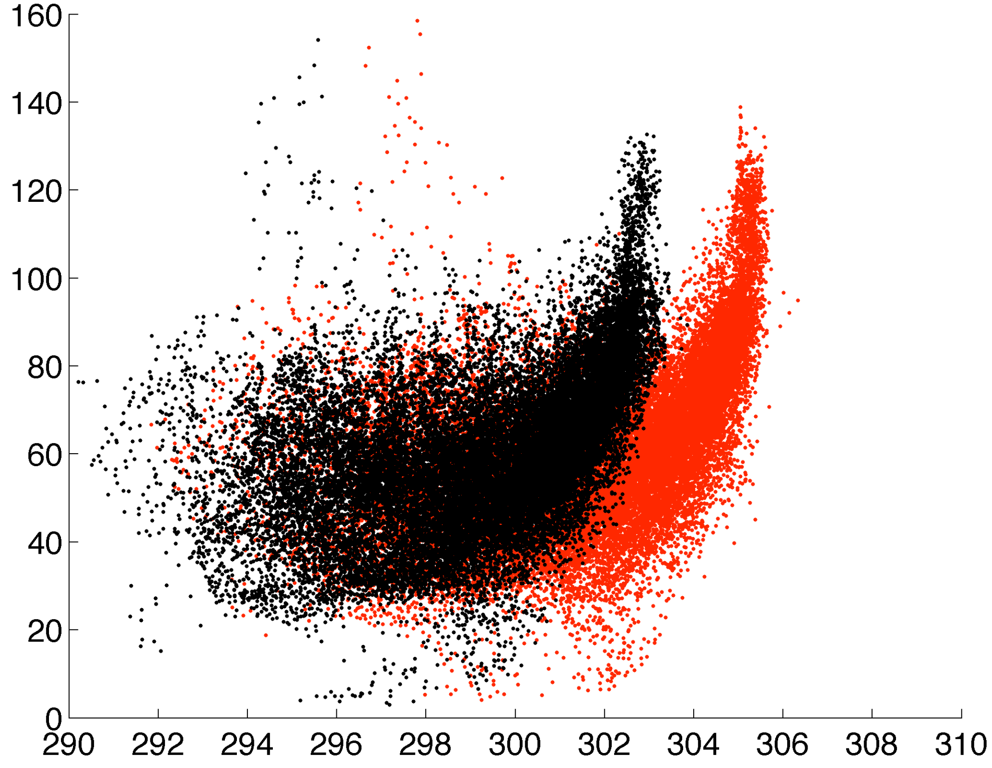
CCSM Tropical SST histogram



CCSM Cloud LW Forcing



CCSM Cloud SW Forcing



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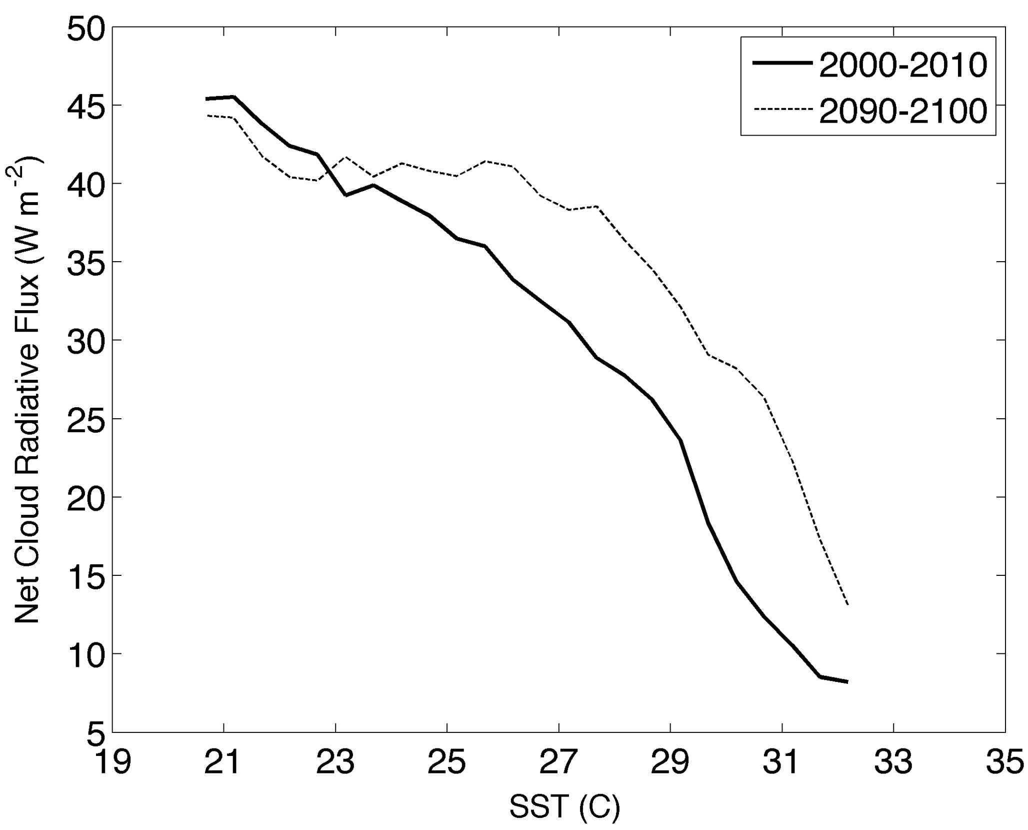
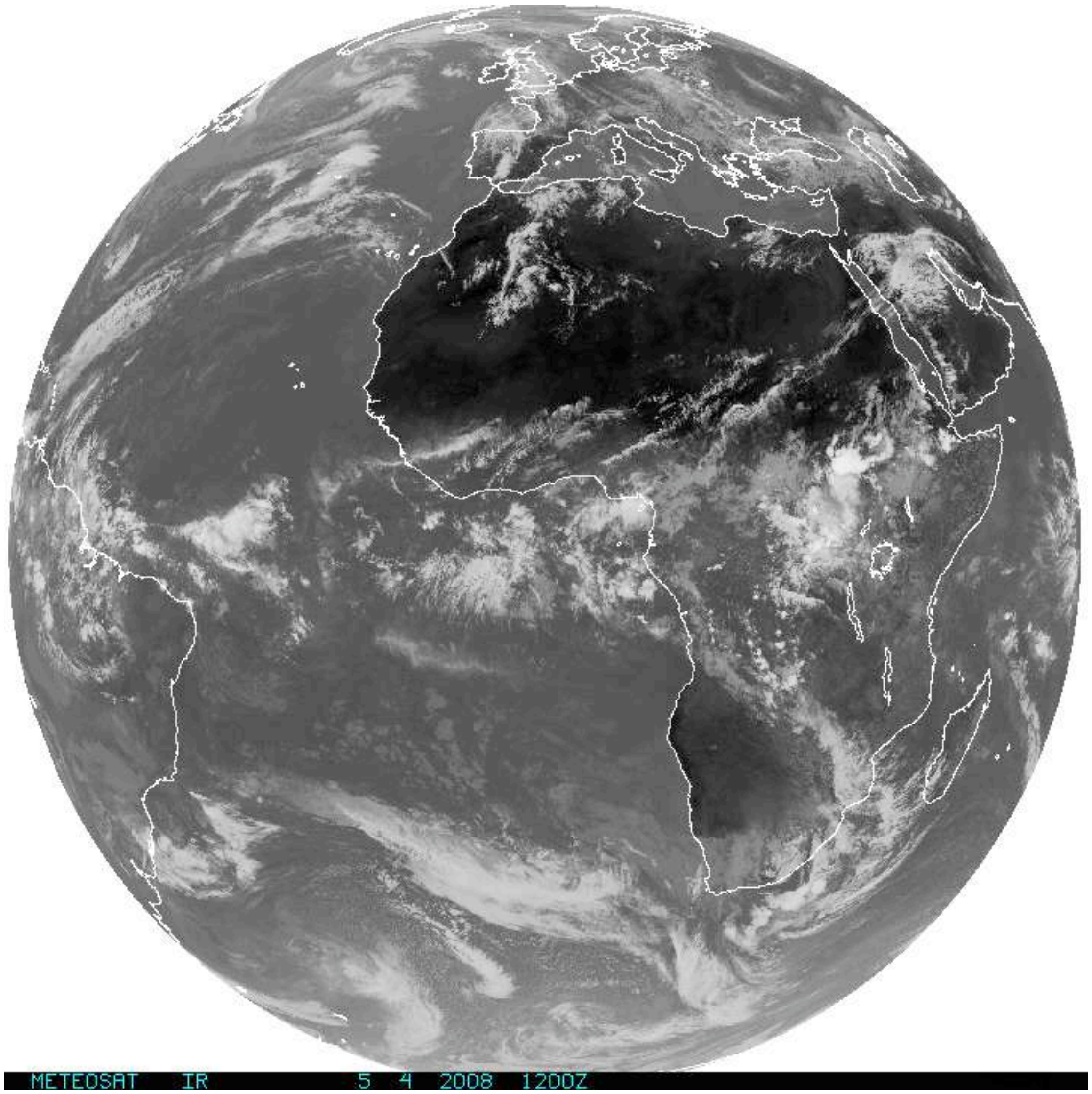
CCSM Mean Net Cloud Forcing vs. SST



Cloud "fraction" is a big mystery



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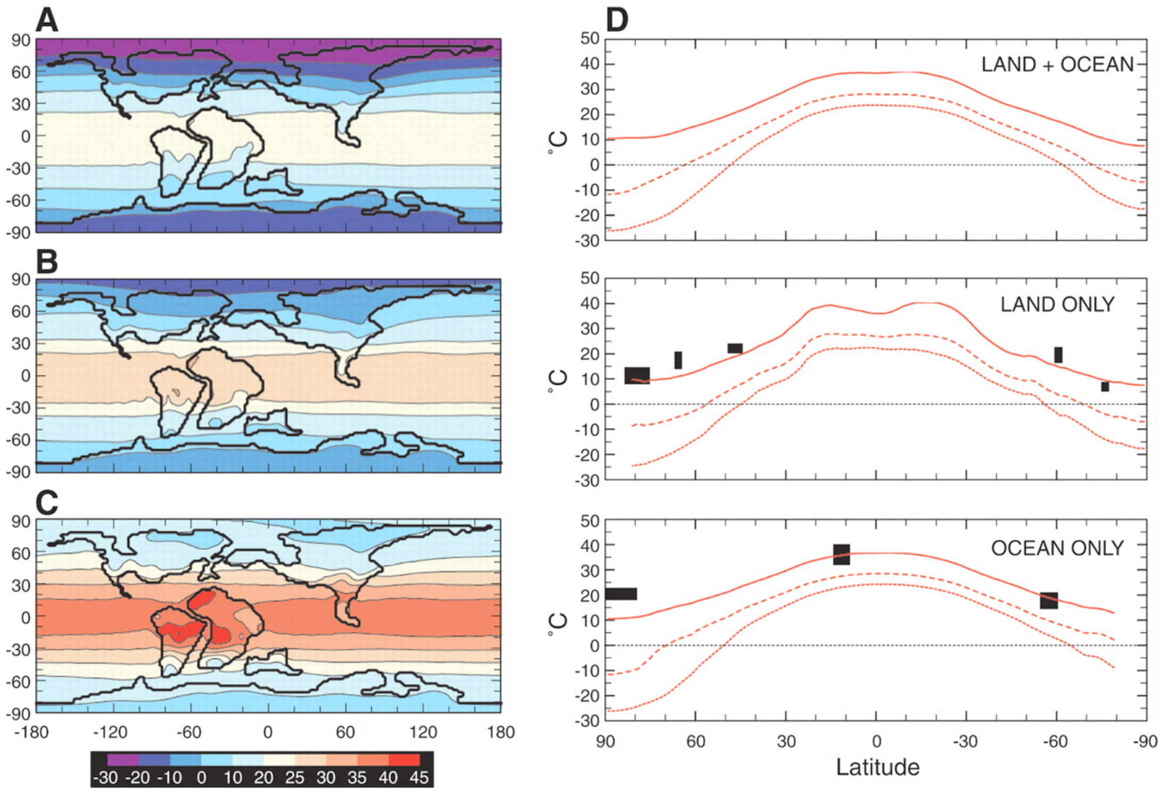
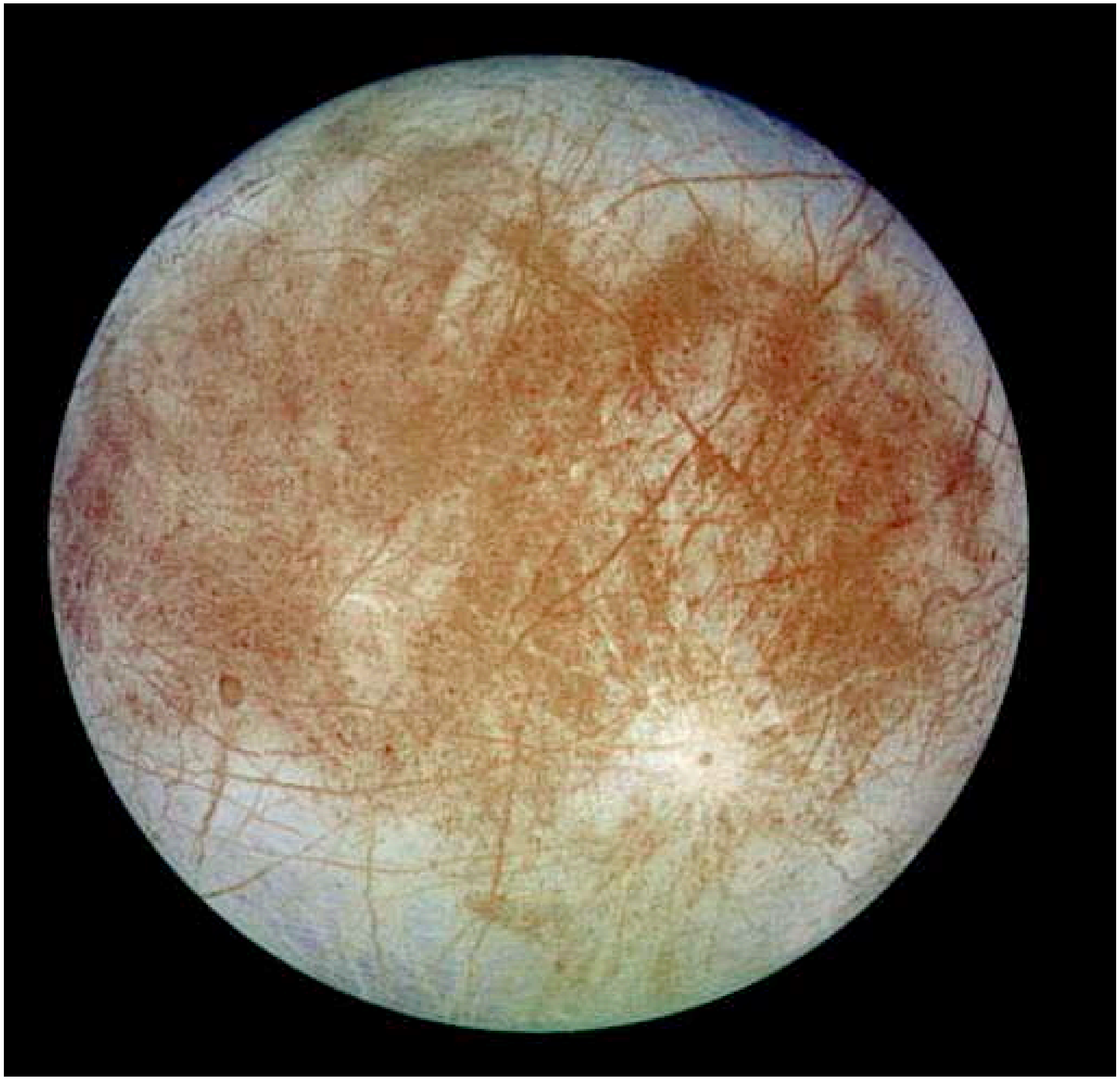
Can darker clouds warm the Eocene? (Kump/Pollard)

Fewer aerosols → less reflective low clouds



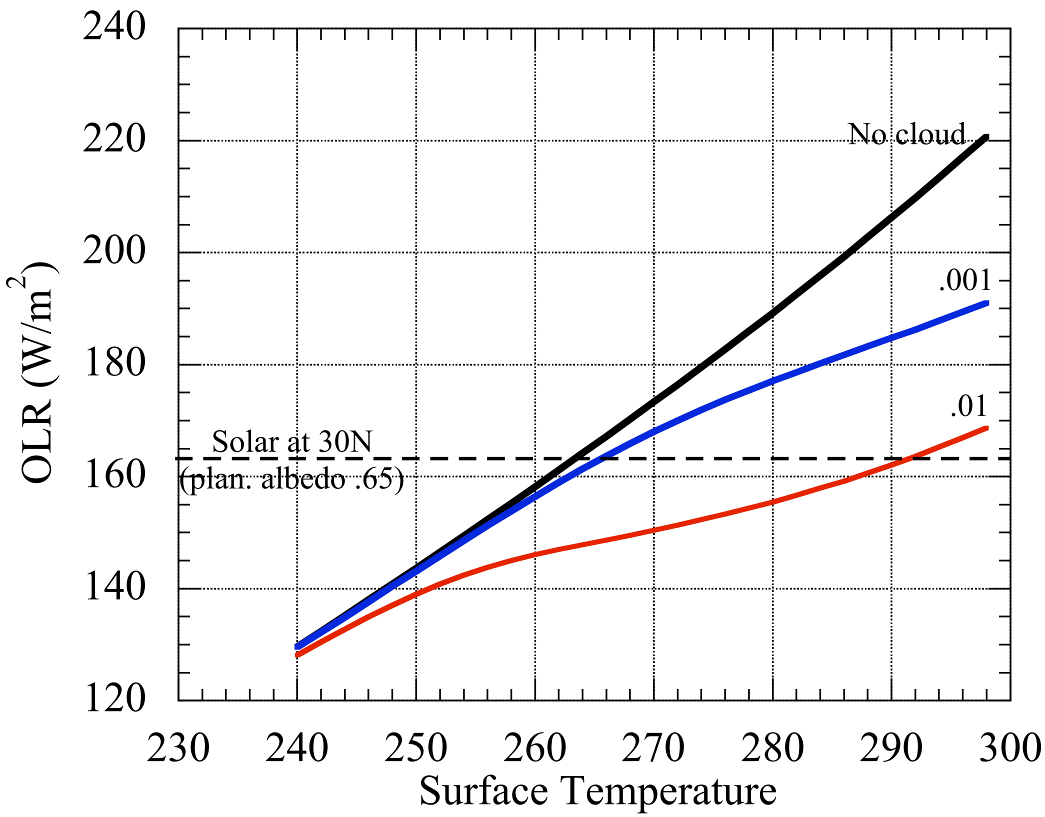
Snowball Earth



Snowball Earth

- 600 million and 2.2 billion years ago, Earth might have frozen over
- CO_2 builds up until deglaciation
- But very high CO_2 levels needed (Pierrehumbert *Nature* 2004,*JGR* 2005)
- Need some help from clouds
- Cloud greenhouse effect dominates, because surface already very reflective

Cloud effects on Snowball energy balance



The cold cloud problem

- Latent heat negligible.
- Moisture mixing by dry convection, sink by particle growth and sinking
- Need to make small particles to keep enough cloud up there

The cold cloud problem

$$(\partial_t + v \cdot \nabla) q_v = -H(q_v - q_{sat}(T))/\tau + H(q_{sat}(T) - q_c)/\tau_1$$

$$(\partial_t + v \cdot \nabla) q_c = +H(q_v - q_{sat}(T))/\tau - H(q_{sat}(T) - q_c)/\tau_1 - w_{fall} \partial_z q_c$$

$v(x, y, z, t), T(x, y, z, t)$ given by dry convective turbulence, indep. of q

Clouds and the Venus runaway greenhouse

- Clear-sky saturated runaway threshold is $290W/m^2$
- Venus runs away early according to this
- Clouds inhibit runaway because:
  - Atmosphere thick. Not much IR left to block
  - Clouds are still very reflective
- Needs dynamical calculation. Nobody's done it.

Clouds can be made of things other than water!

- H_2SO_4 clouds on Venus
- Methane clouds on Titan
- Dry ice clouds on Early Mars
- N_2 clouds on Triton

Concluding remarks

- Clouds have a real potential to increase warming well beyond top of IPCC range
- How well can we rule out the chances they will do so?
- Tropical cloud feedbacks are largely *relative* to mean SST
- These feedbacks increase tropical SST gradients by cooling nonconvective regions
- Snowball clouds are a good physics problem!
- Need to find some way to think about physics of cloud ”fraction”