Land Component of GCM

- **Must contain heat and moisture balance equations and a snow cover model**

- **GCMs have been shown to be very sensitive to surface albedo and moisture characteristics**

Ocean Component of GCM

- **Similar governing equations as atmosphere except:**
  - **Oceans are liquid**
  - **Ocean basin geometry is more complex**

- **Many important features in the ocean are too small to be realized in today's models**
  - **Gulf Stream, Kuroshio currents less than 1° wide**

Sea Ice Models

- **Sea ice:**
  - **Increases surface albedo**
  - **Inhibits exchanges of heat, moisture, and momentum**
  - **Alters local salinity**
- **Assume ice forms if sea surface temperature < -2°C**
- **Also should predict movement of ice**

Image courtesy of NOAA.

Image courtesy of NOAA.

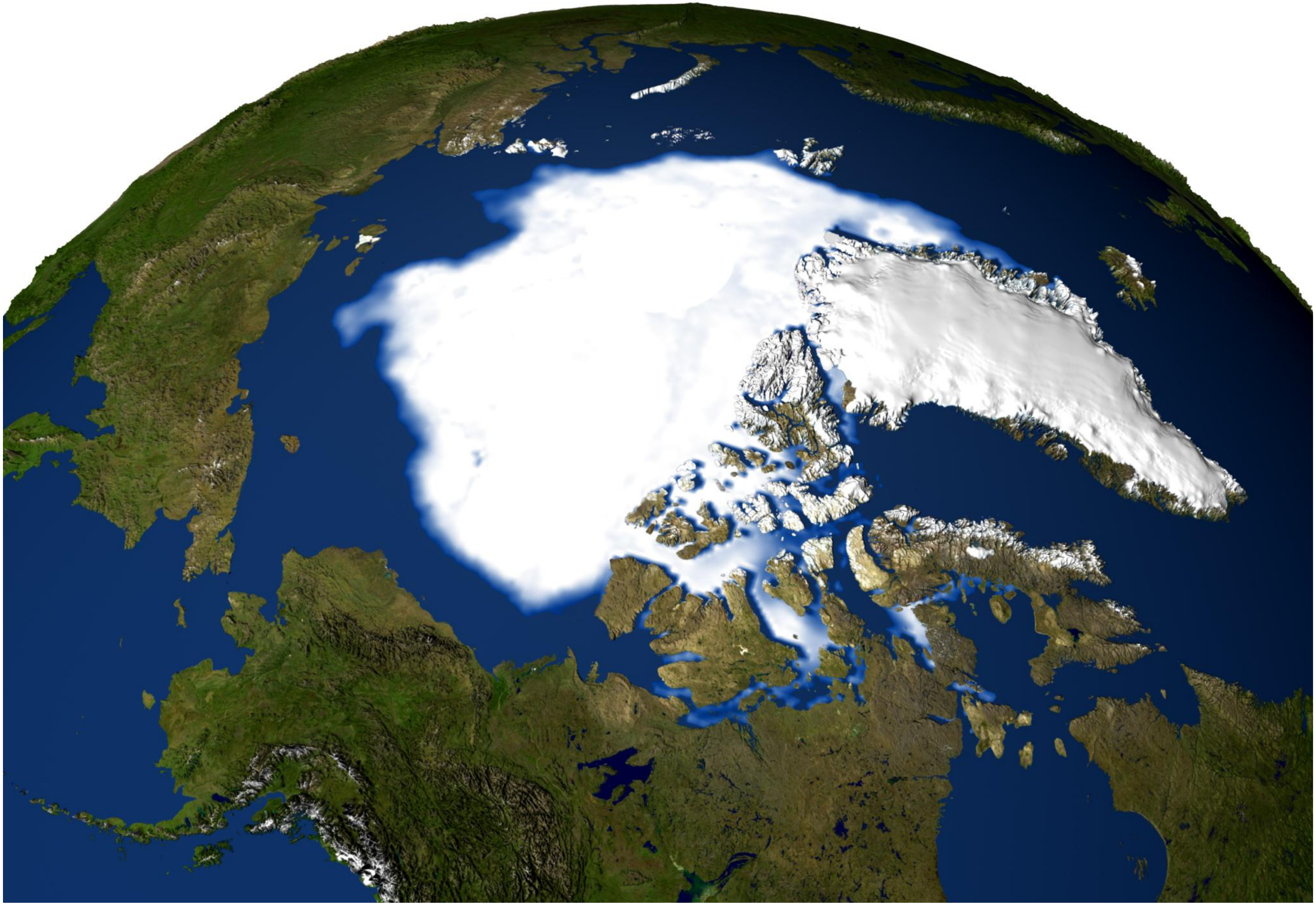


Image courtesy of NASA.

Unresolved physical processes must be handled parametrically

- Convection
- Thin and/or broken clouds
- Cloud microphysics
- Aerosols and chemistry (e.g. photochemical processes, ozone)
- Turbulence, including surface fluxes
- Sea ice
- Land ice
- Land surface processes

Process Models and Parameterization

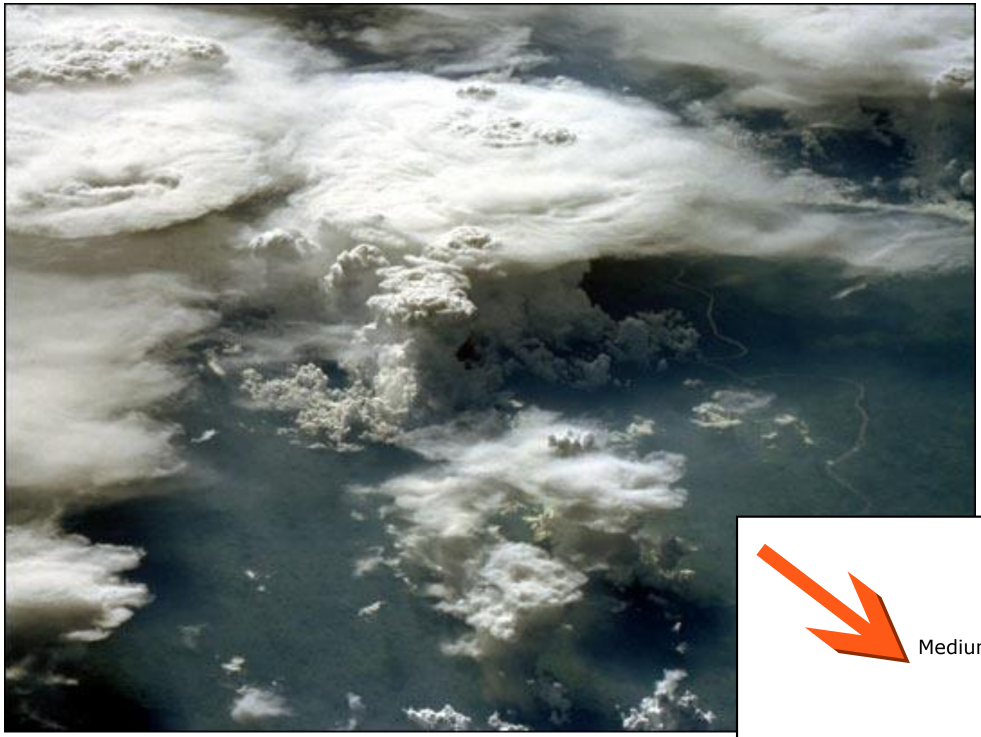
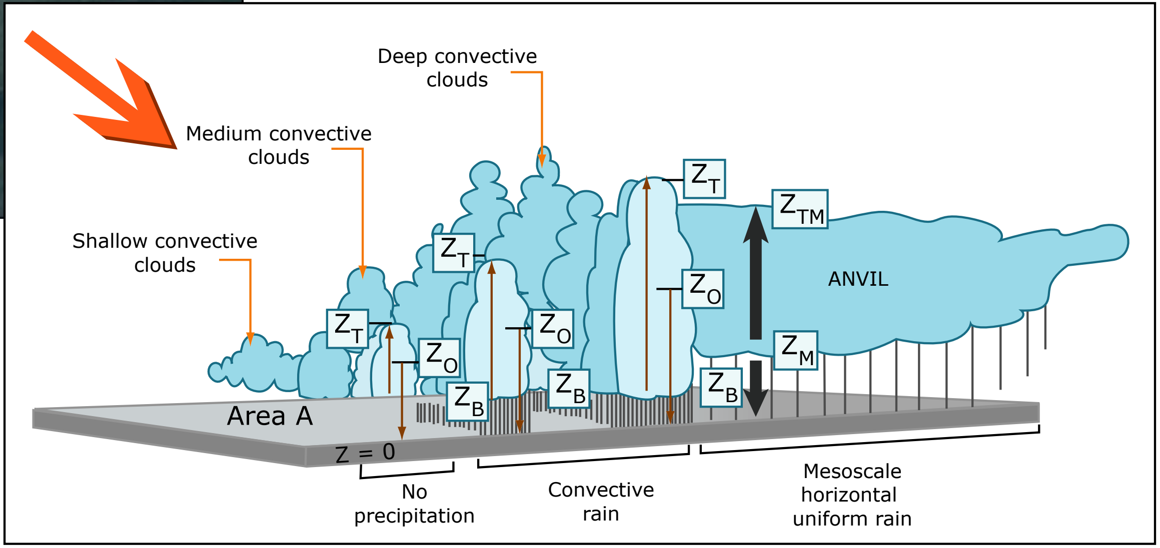


Image courtesy of NASA.

- Boundary Layer
- Clouds
    - Stratiform
    - Convective
- Microphysics



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Thin and broken clouds

Altocumulus

Image courtesy of NASA.

Altostratus

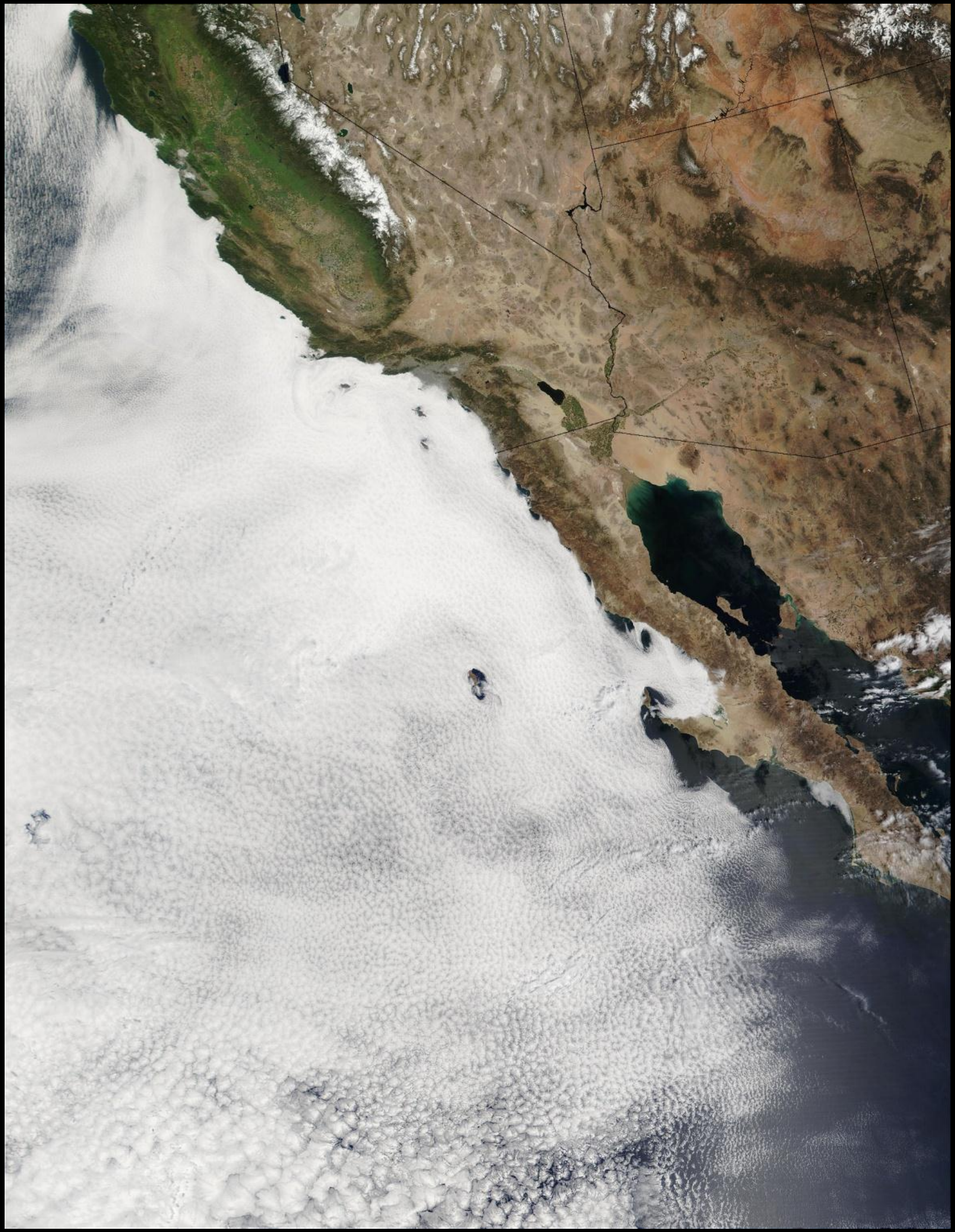
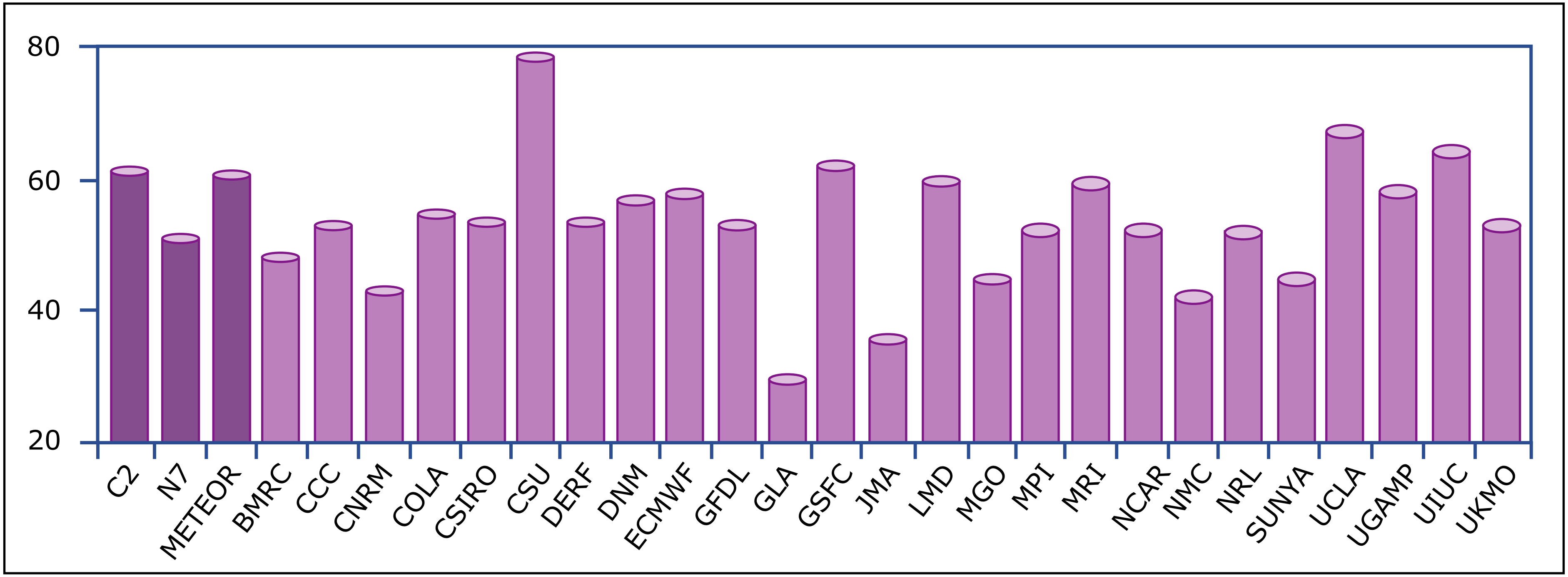


Image courtesy of NASA.

Stratocumulus

Parameterization of Clouds

Cloud amount (fraction) as simulated by 25 atmospheric GCMs



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Low Clouds Over the Ocean

Change in low cloud with 2xCO2

2 Models: Changes are OPPOSITE!

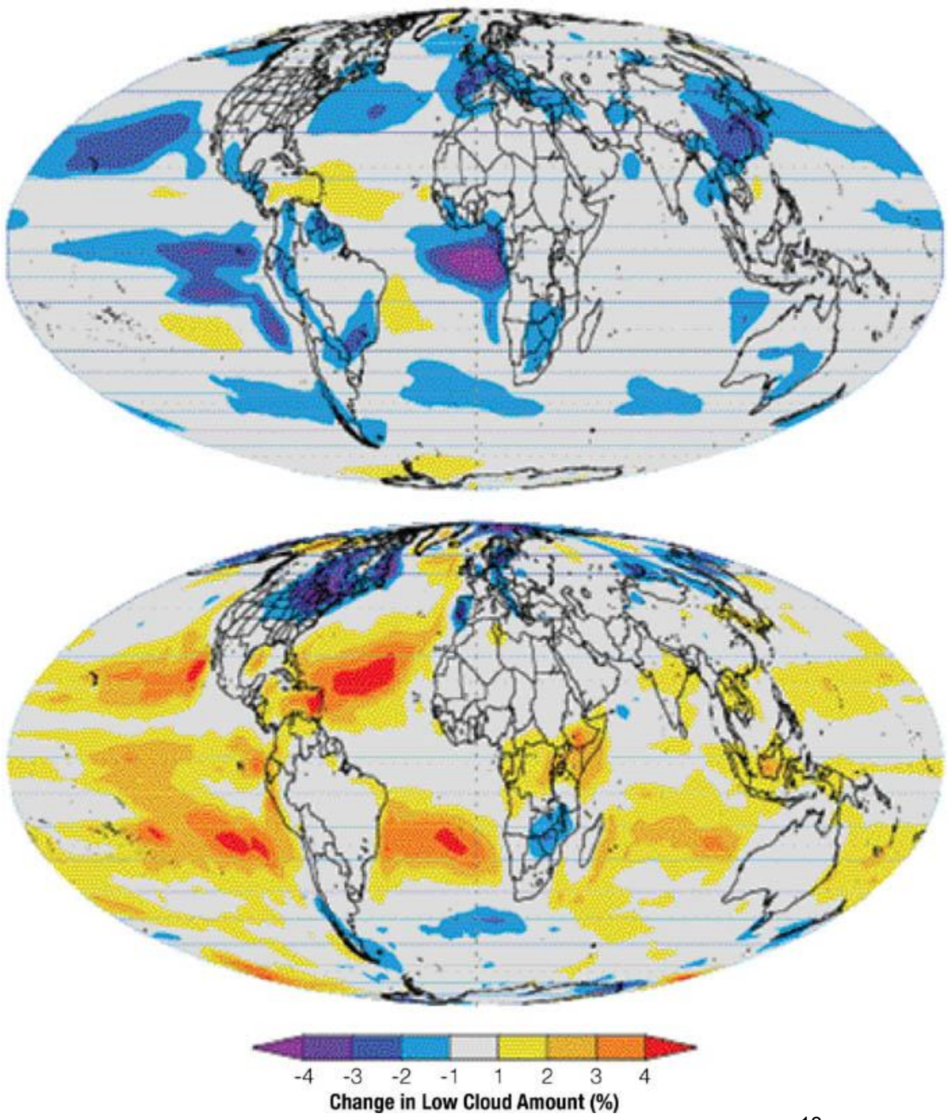
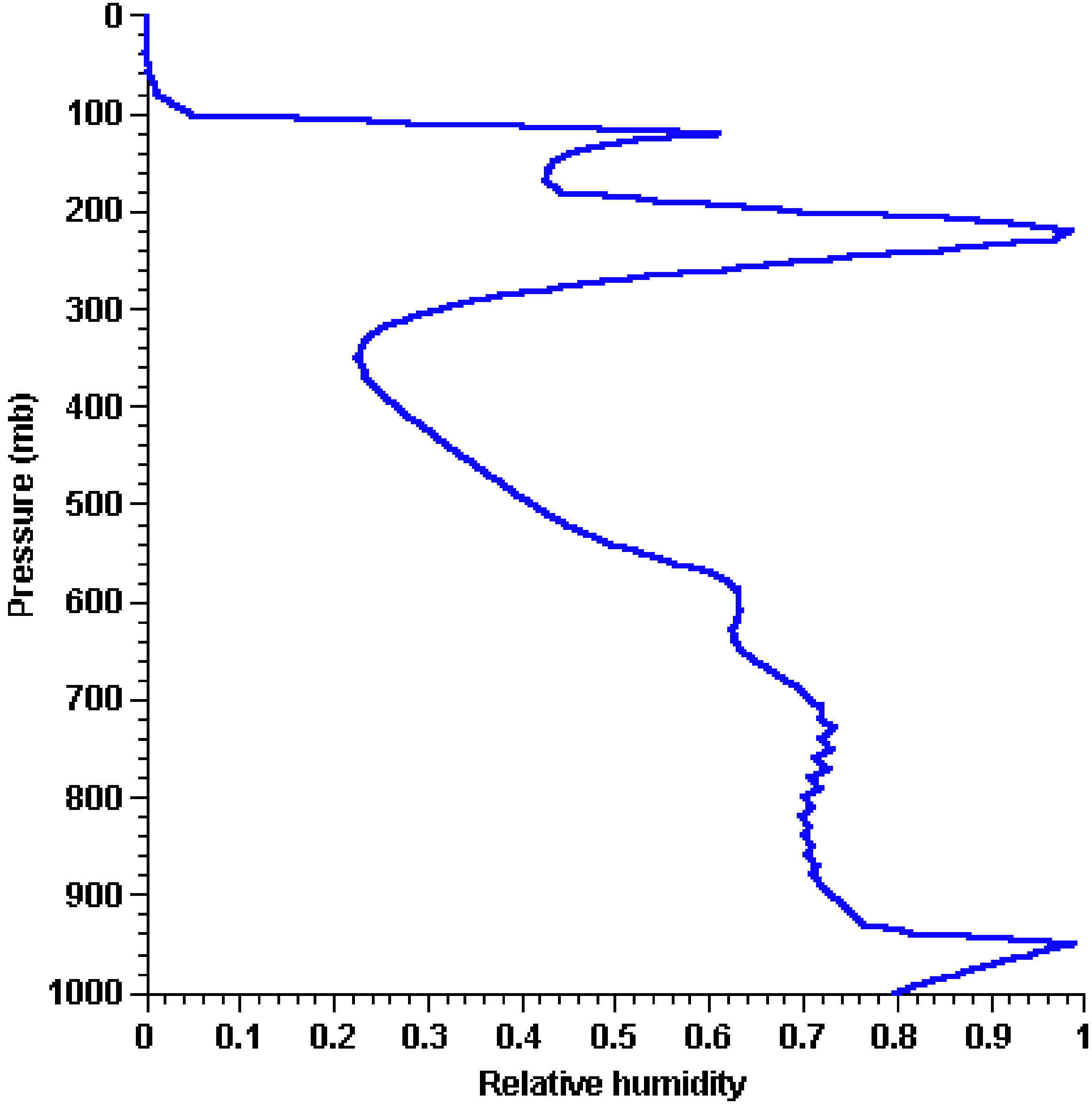
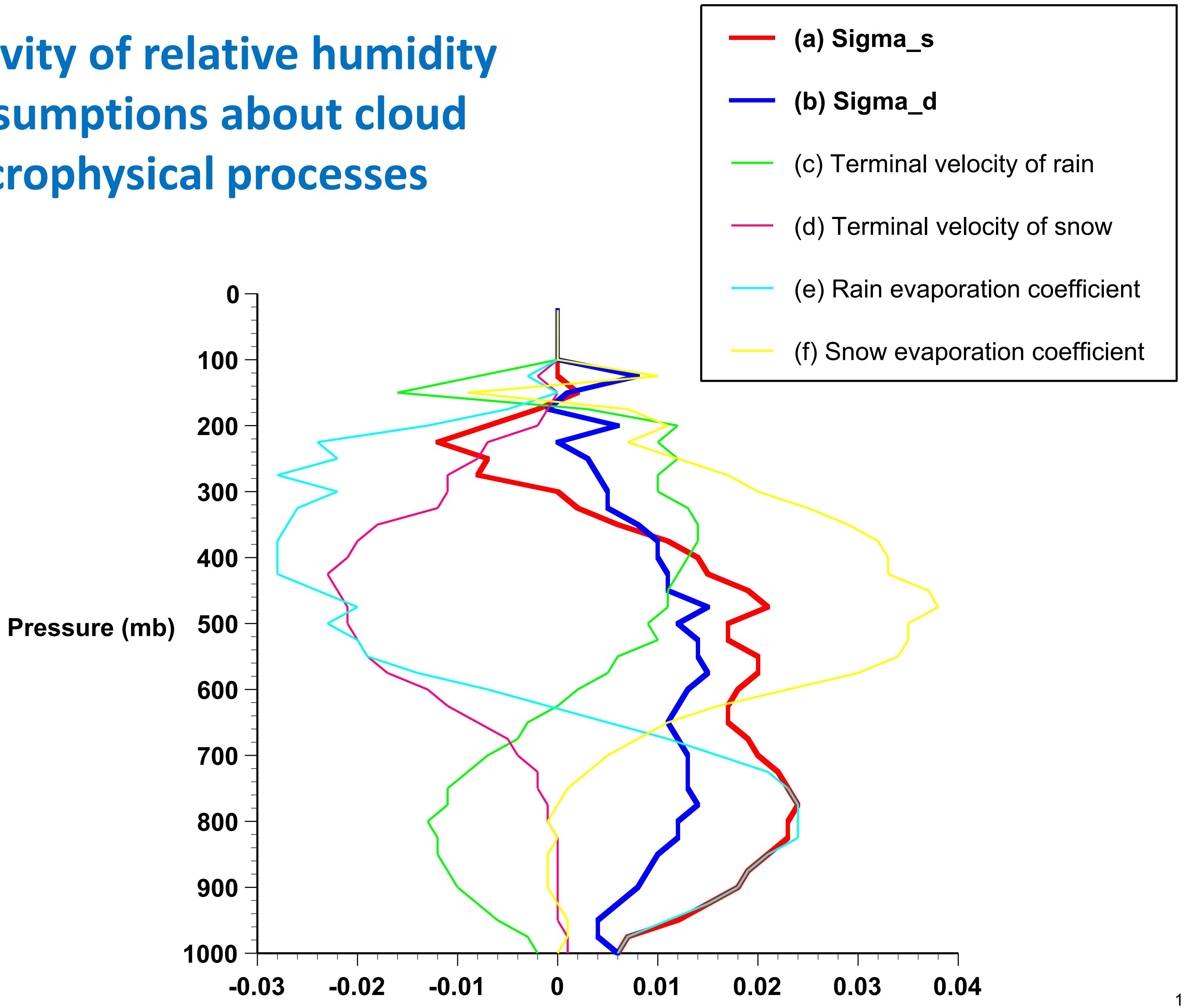


Image courtesy of climatescience.gov.

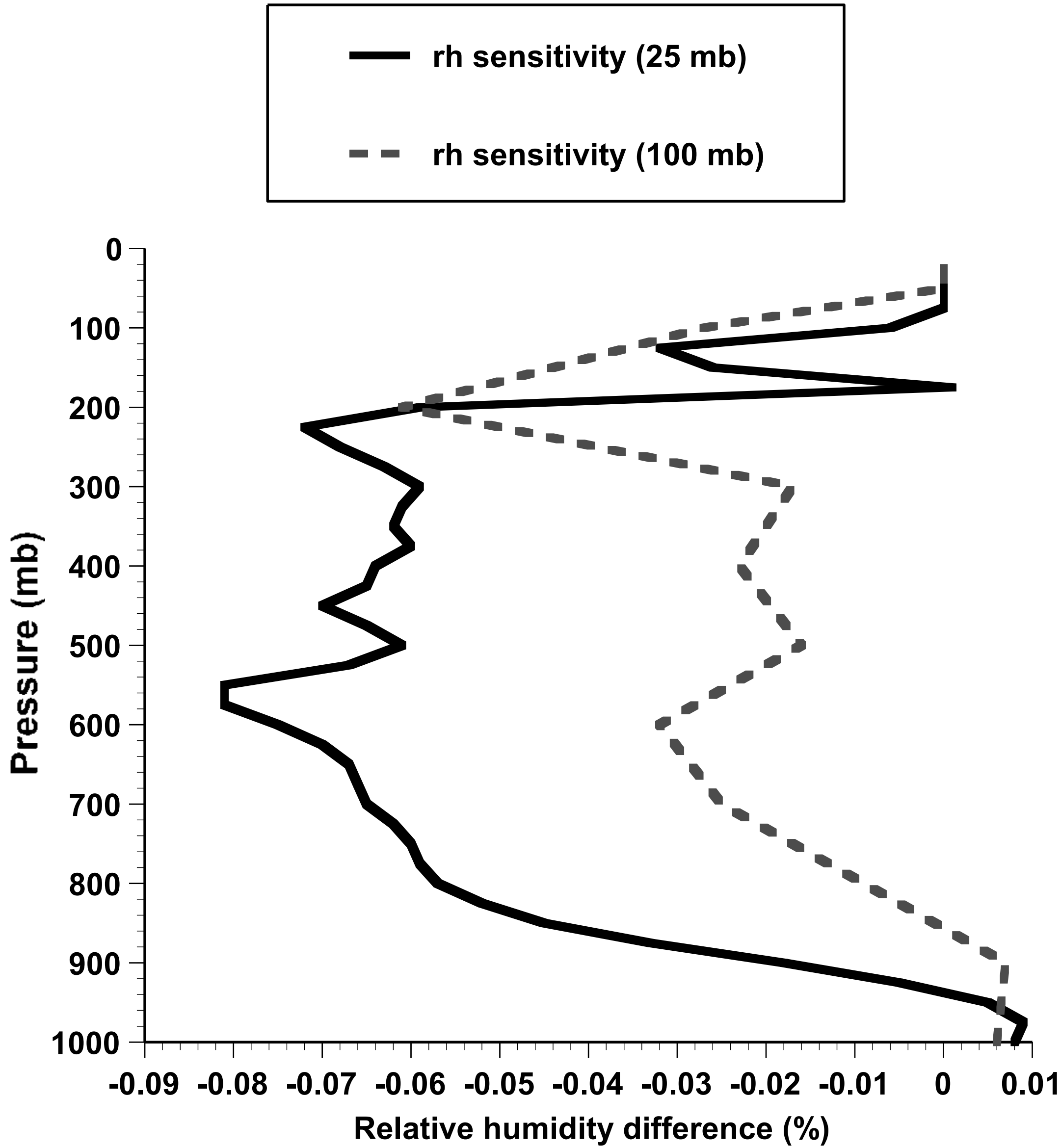
Sensitivity to cloud microphysics



Sensitivity of relative humidity to assumptions about cloud microphysical processes



Sensitivity to microphysics increases with vertical resolution of model



Numerical convergence of water vapor profiles

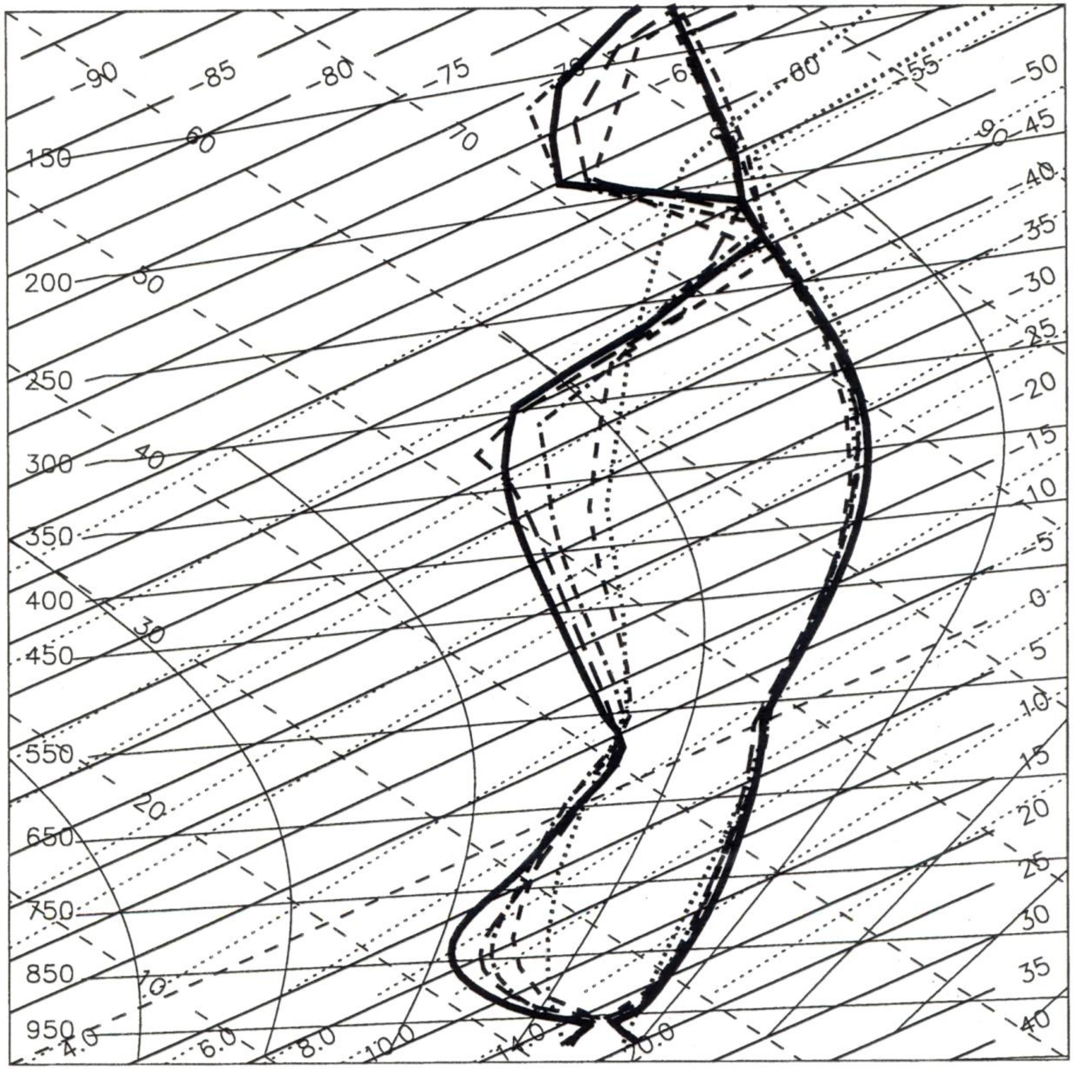


Figure 8. Tephigram plotting equilibrium temperature (lines on right) and moisture (lines on left) for the Emanuel model using 10 vertical layers (dotted lines), 20 vertical layers (dashed lines), 30 vertical layers (dot-dash lines), 40 vertical layers (long dash lines). 50 vertical layers (solid lines), in addition to the 10 layers placed above 100 hPa. The lines for the highest resolution at 50 layers are enhanced.

GCMs have difficulty handling water vapor. (Sun and Held, 1996)

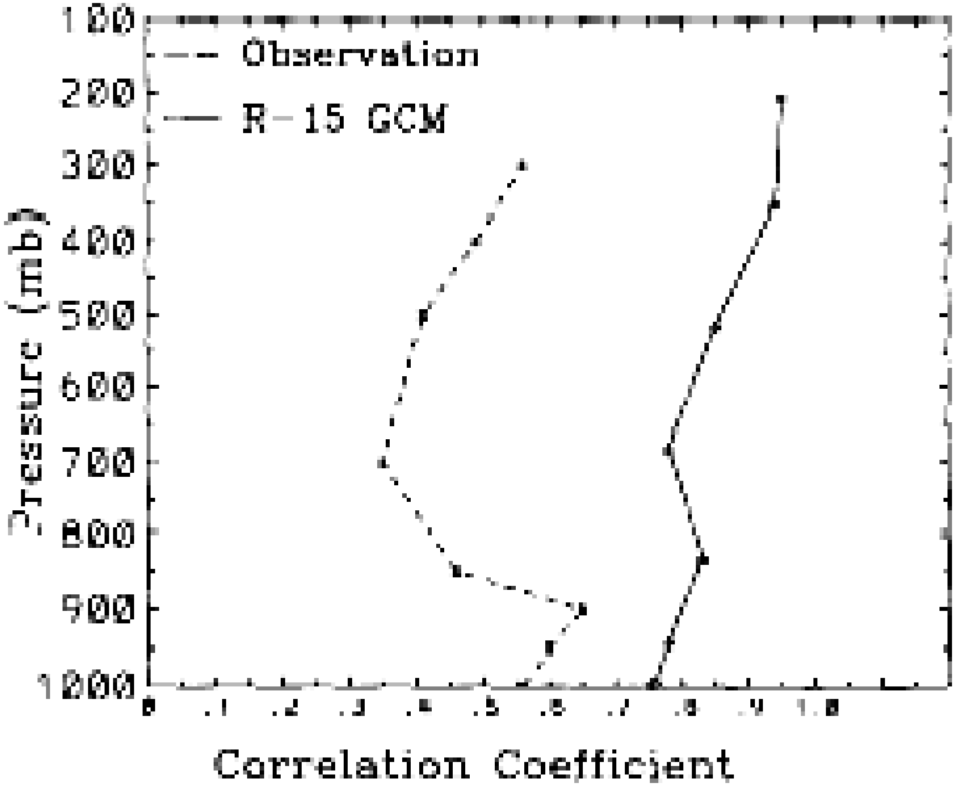


FIG. 4. Vertical structure of correlations between variations of (T_s) and (q_s) from the model simulations (solid line) and observations (dashed line). The pressure levels for which the calculations were made are marked by "+" for the observations and "○" for the model simulations.

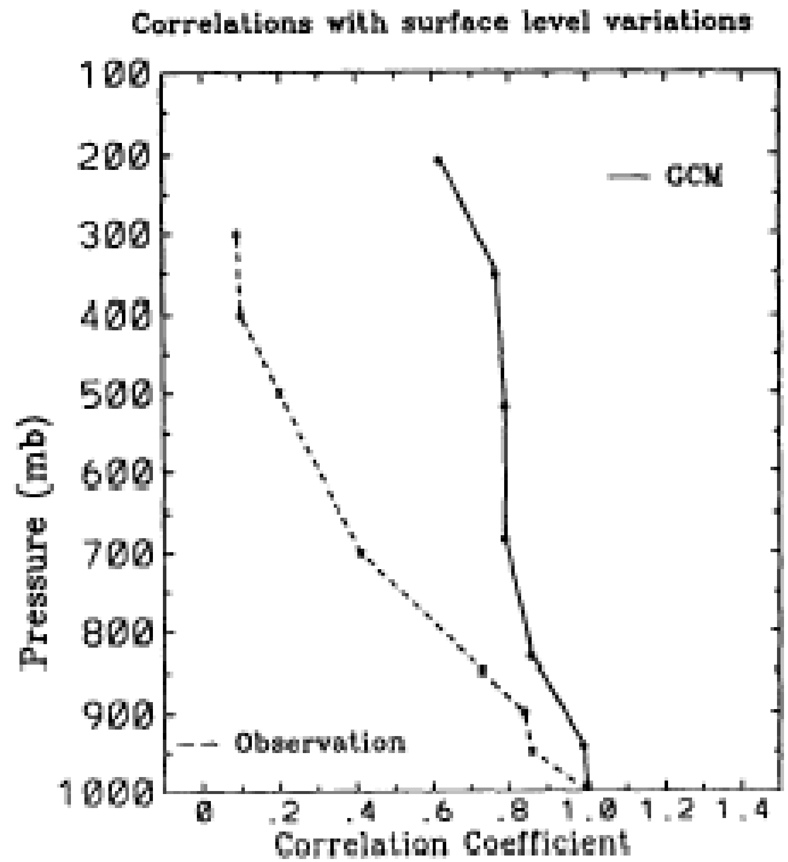


FIG. 9. Correlations between variations of (q_s) and those at the lowest level. Symbols "+" and "○" have the same meaning as in Fig. 4.

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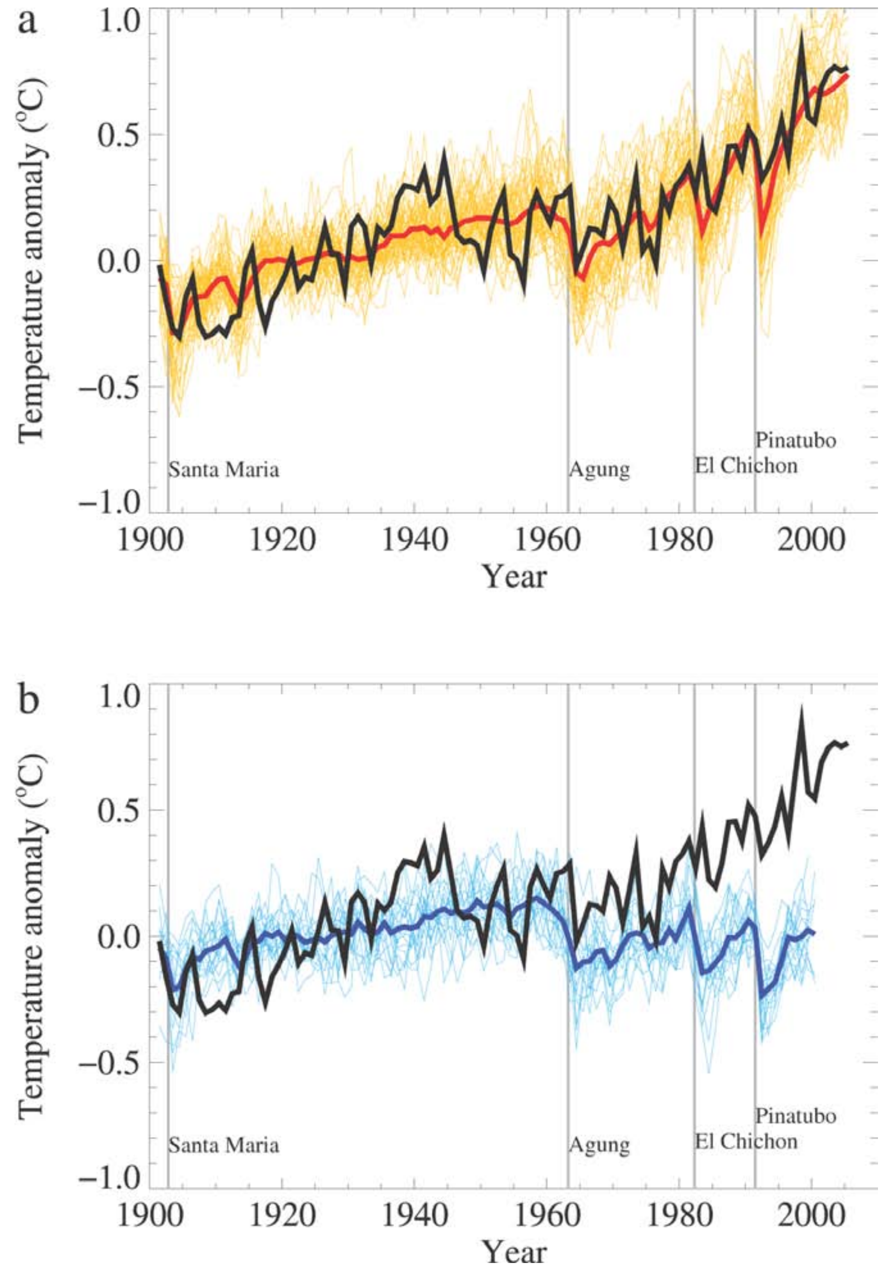
How Do We Know If We Have It Right?

- Very few tests of model as whole: annual and diurnal cycles, weather forecasts, 20th century climate, response to orbital variations
- Fundamentally ill-posed: More free parameters than tests
- Alternative: Rigorous, off-line tests of model subcomponents. Arduous, unpopular: Necessary but not sufficient for model robustness: Model as whole may not work even though subcomponents are robust

Global mean temperature (black) and simulations using many different global models (colors) including all forcings

To some extent, “success” of 20th century simulations is a result of model curve fitting

Same as above, but models run with only natural forcings



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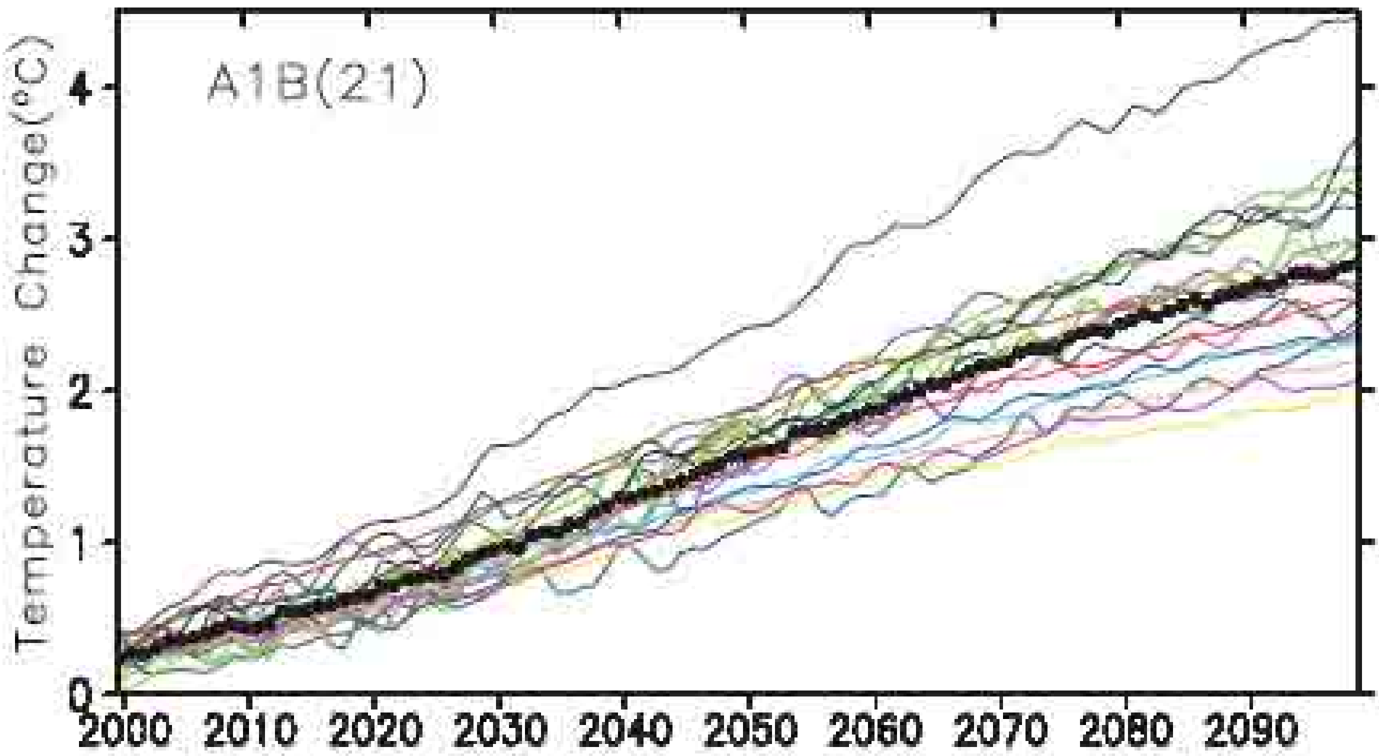
Ensemble of climate models, Scenario A1b



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Root-mean-square error in zonally and annually averaged SW radiation (top) and LW radiation (bottom) for individual AR4 models (colors) and for ensemble mean (black dashed)

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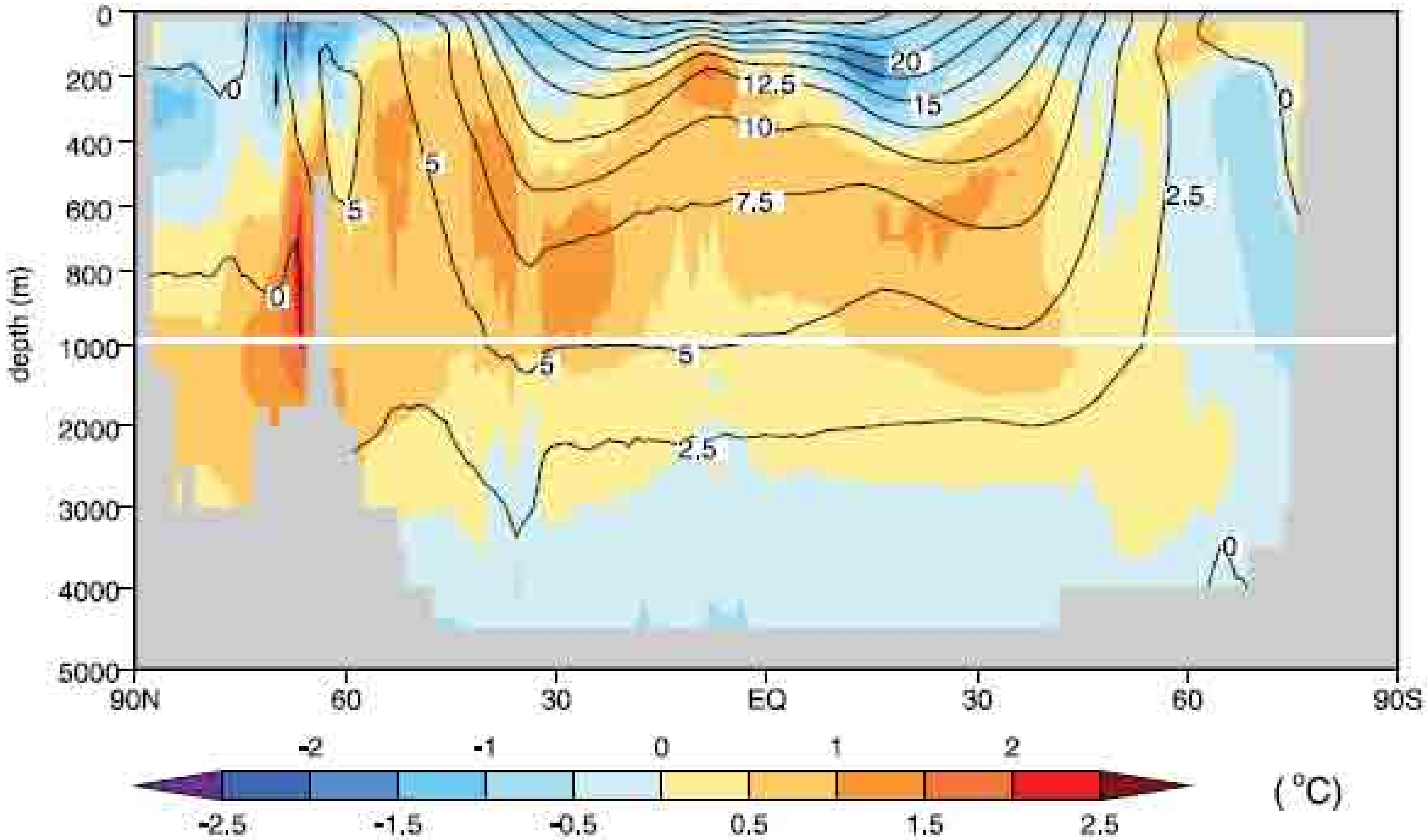
Observed time mean, zonally averaged ocean temperature (black contours), and model-mean minus observed temperature (colors) for the period 1957-1990



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