Modeling the influence of the stratosphere on tropospheric climate

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Why use models?

- Prediction
  - Days to weeks
  - Climate change

- Understanding mechanisms
  - Model sensitivity experiments
  - Long integrations to give good statistics

Modeling limitations

- Understanding the response can be complicated because of inherent nonlinearities

- Mechanisms may not be relevant to the real atmosphere because of unrealistic model climate

Example case studies

- Changes in mean state from:
  - Upper boundary condition
  - Stratospheric ozone
  - Climate change
- Variability
- Predictability

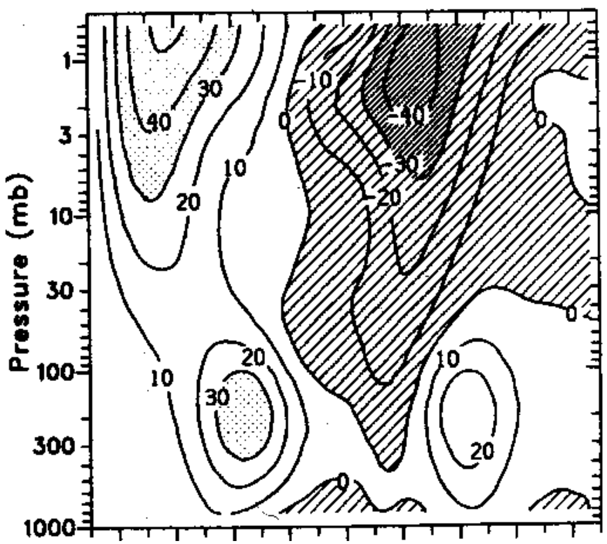
Upper boundary condition

- Early version of CCM
- Control with upper boundary at 0.1 hPa
- Low top with upper boundary at 10 hPa
- Rayleigh friction in mesosphere
- Perpetual January

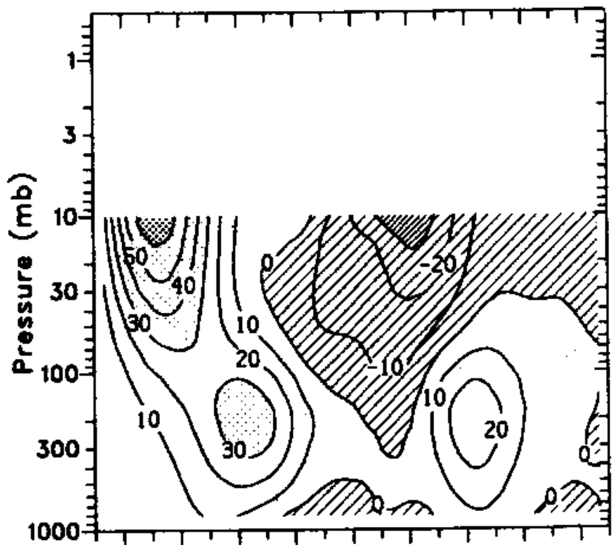
Boville and Cheng (1988)

Zonal Mean Winds

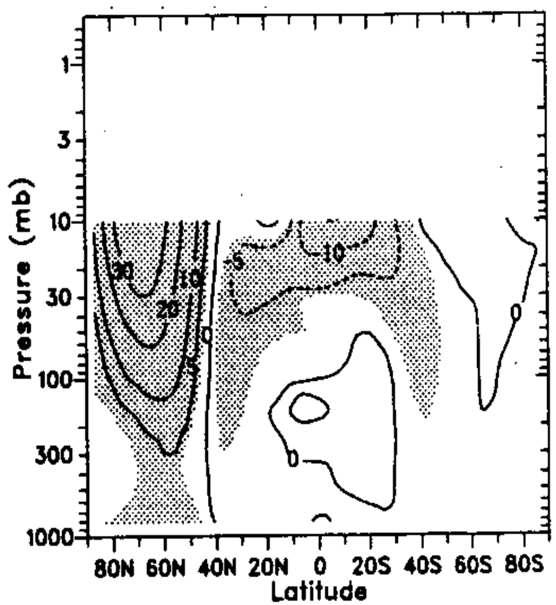
Control



Low top

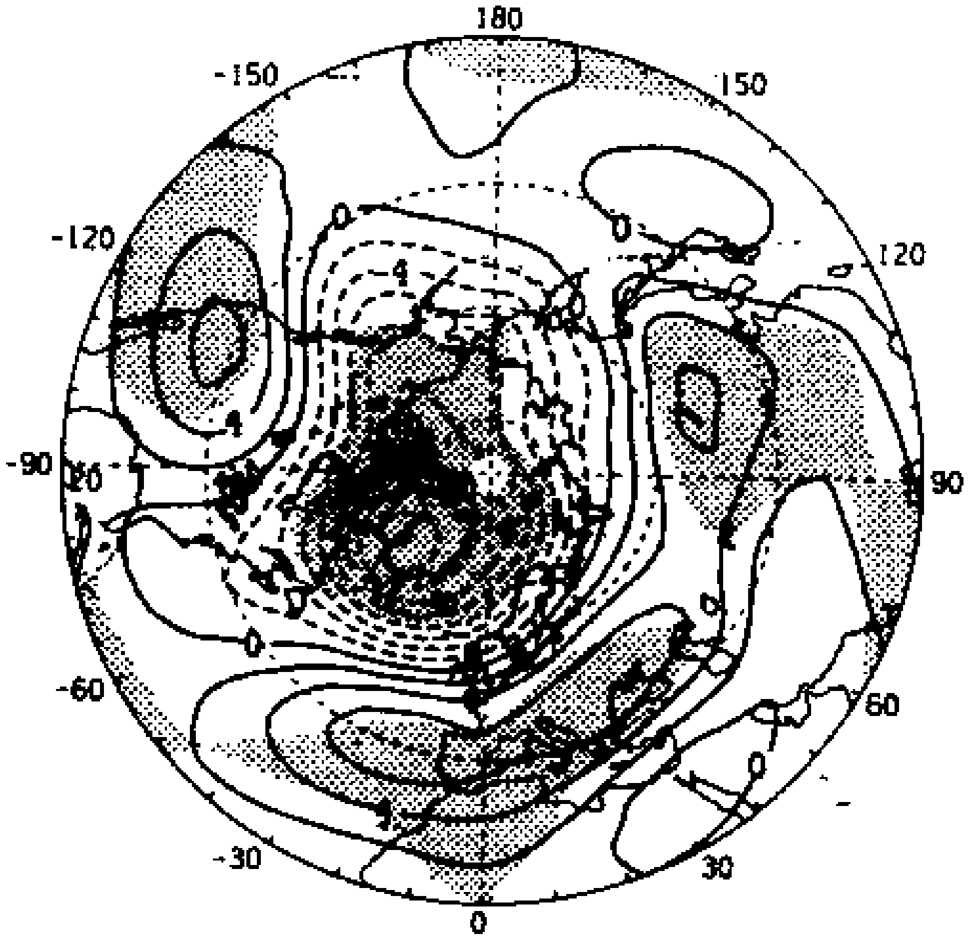


Difference



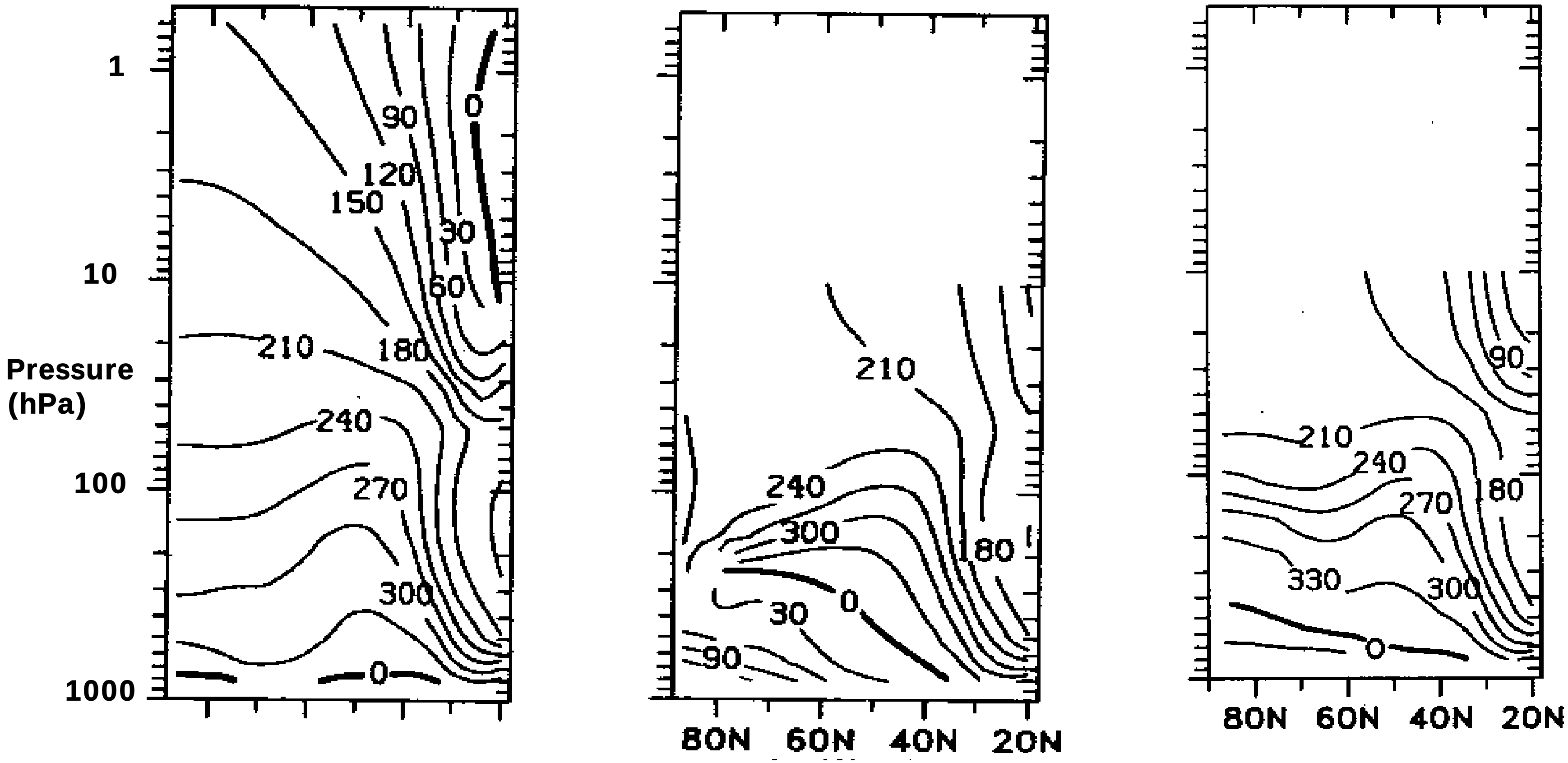
- Change in eddy momentum fluxes results in stronger jet
- Significant response extends to surface

500 hPa height difference



Phase of wave 1

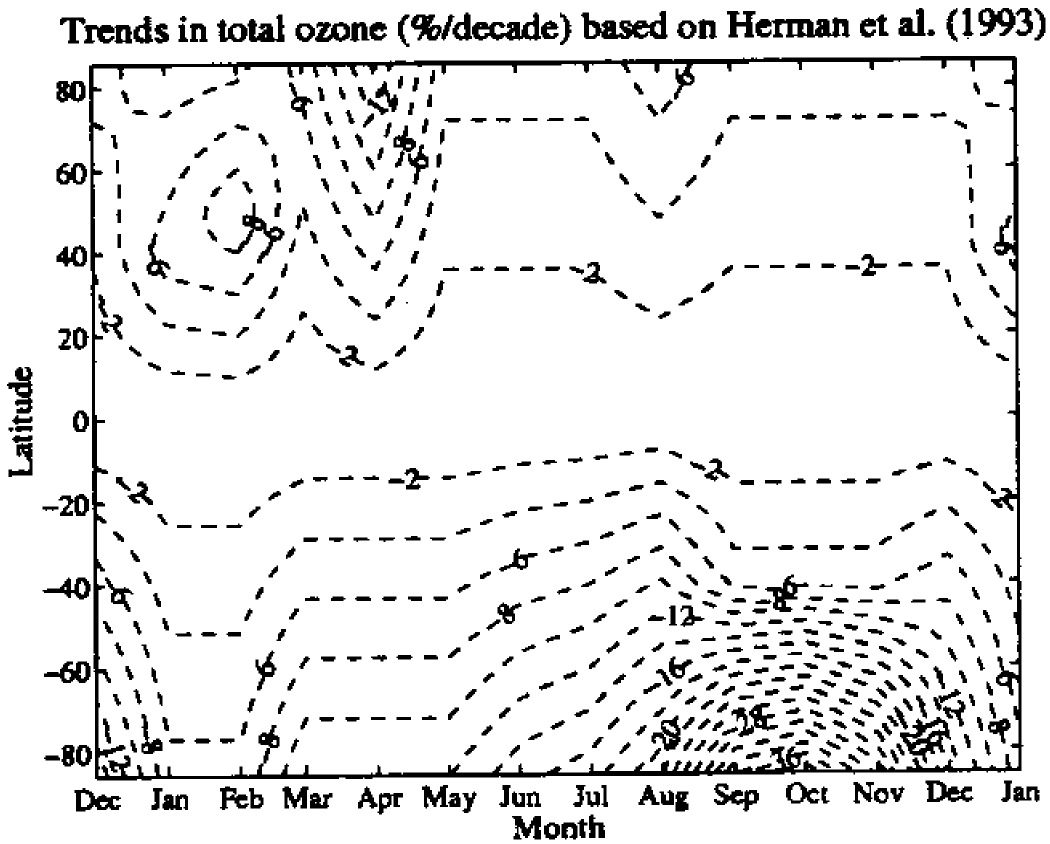
Control | Low top | Relaxed stratospheric mean winds



- Low top reflects stratospheric stationary waves
- Tropospheric stationary waves respond to mean wind distribution

Stratospheric ozone loss

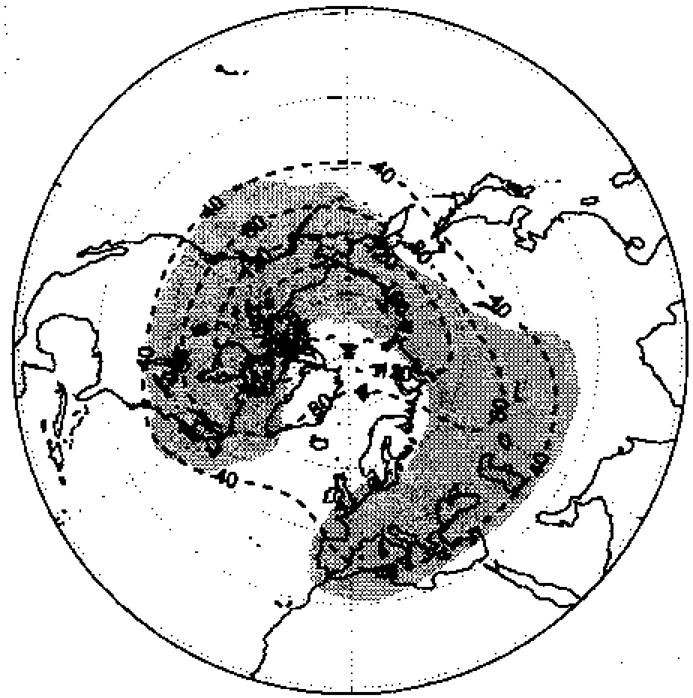
- ARPEGE GCM
- Control and ozone loss experiments



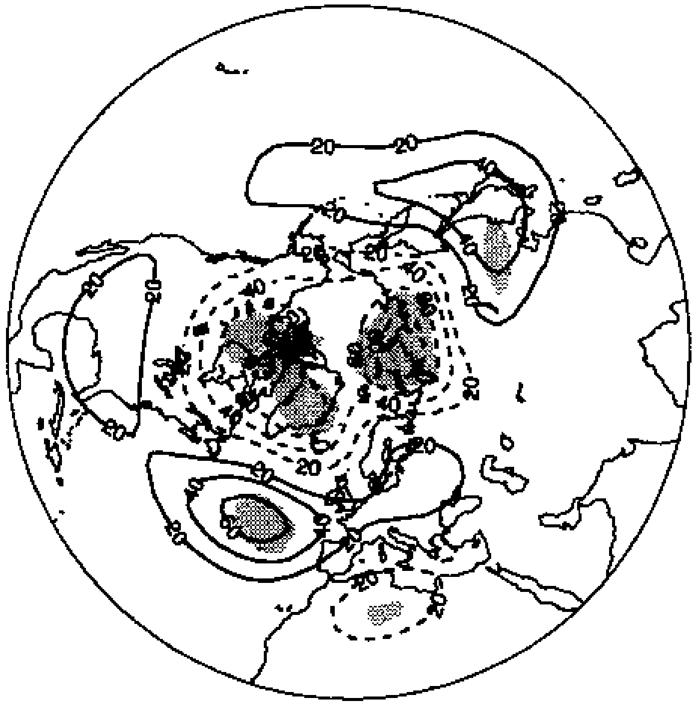
Kindem and Christiansen (2001)

March mean height difference

50 hPa



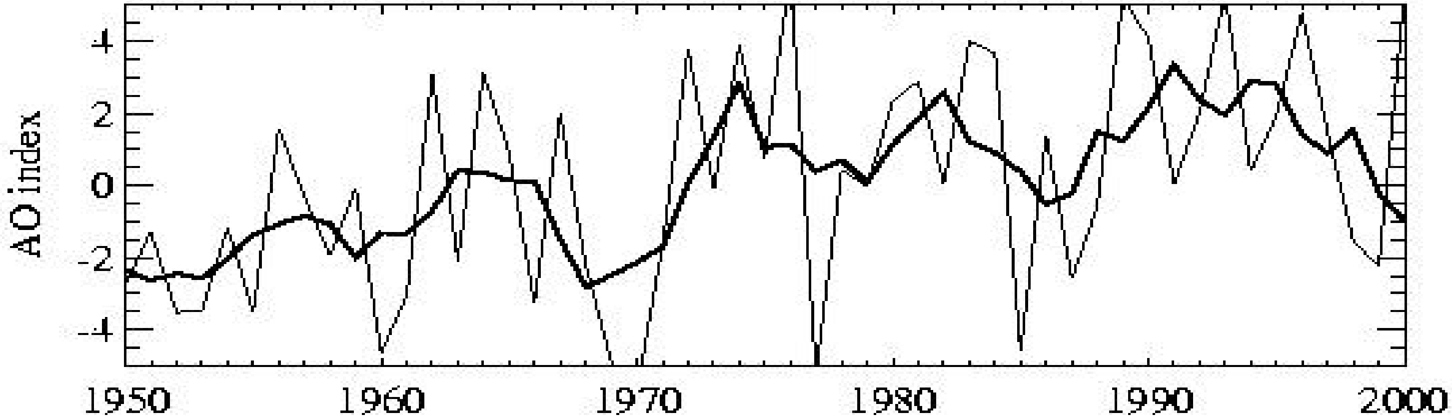
500 hPa



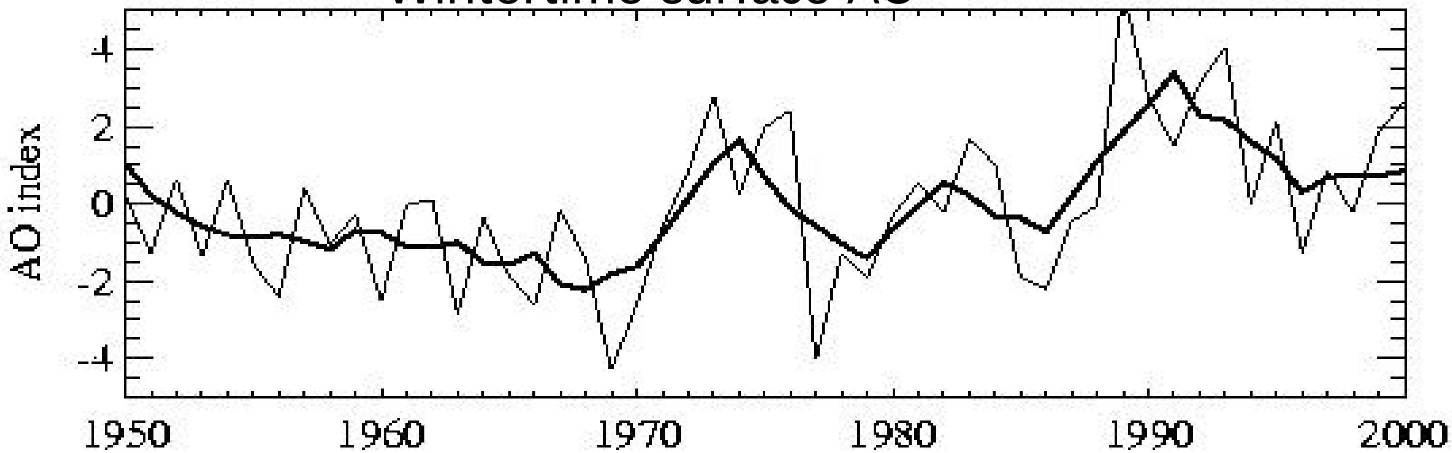
- Strengthened polar vortex leads to +ve NAM response in the troposphere

Climate change

Wintertime NAM at 50 hPa

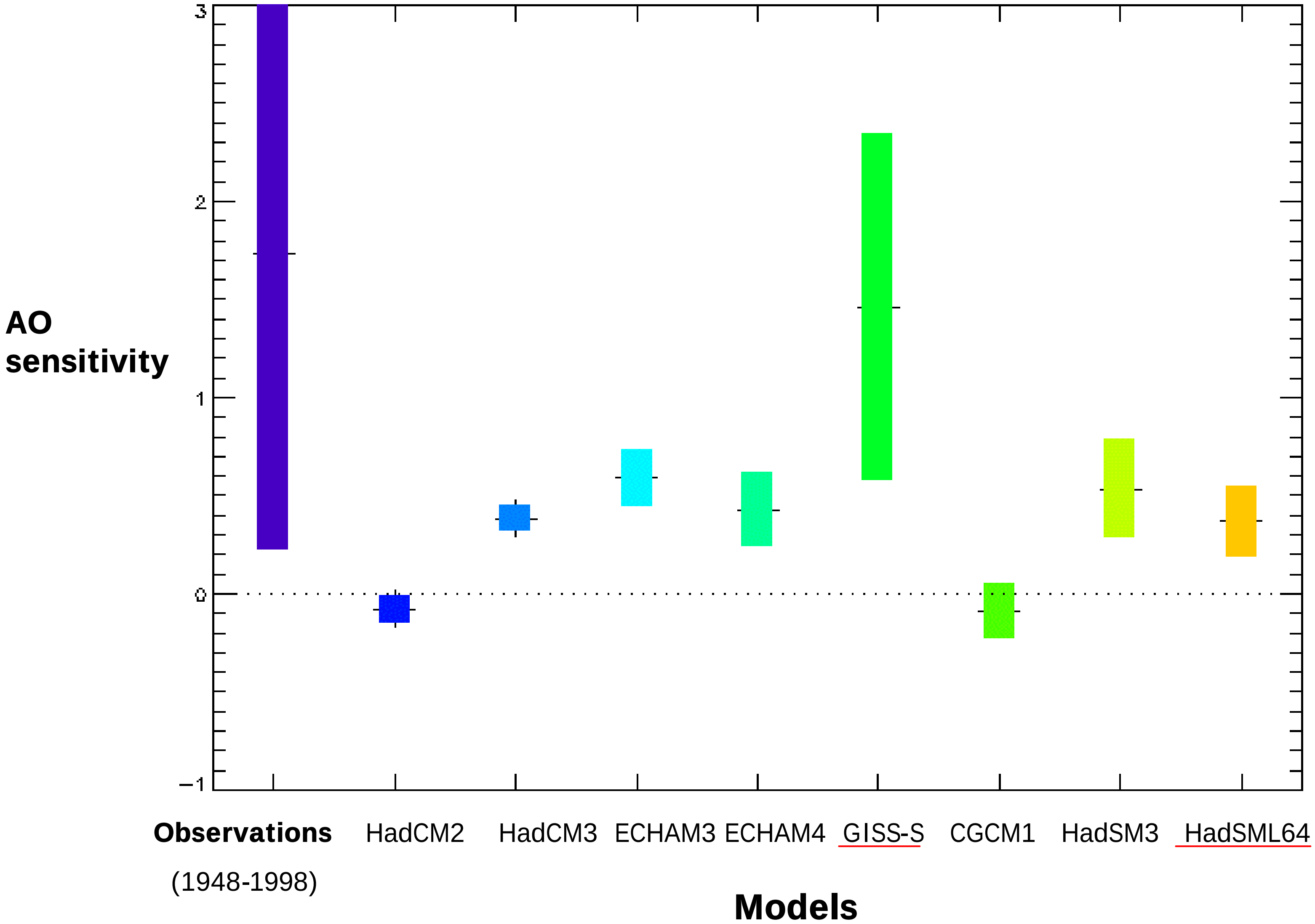


Wintertime surface AO



- What is the role of the stratosphere in the increasing surface AO?

Predictions of change in surface AO with increased greenhouse gas forcing



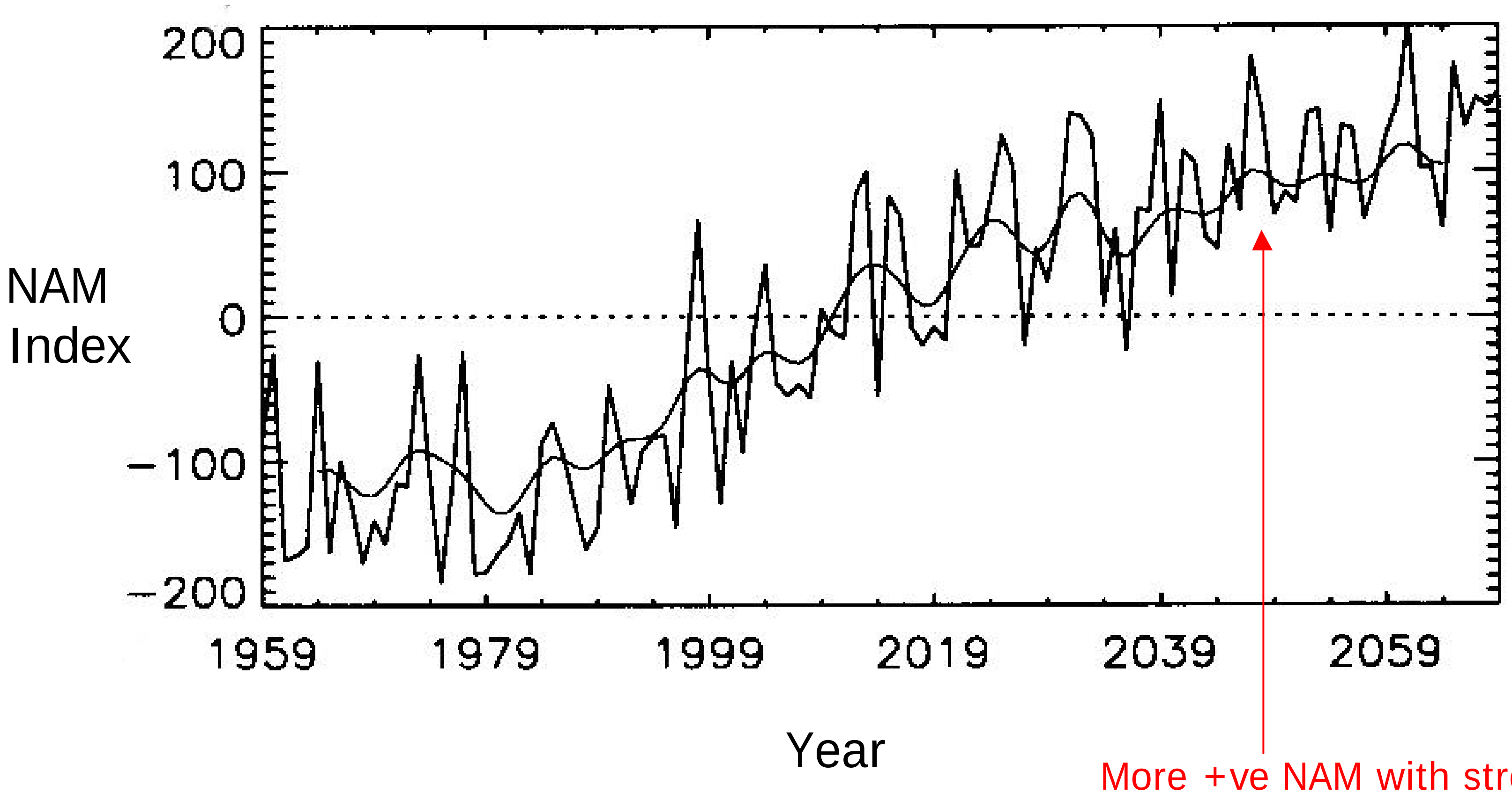
Gillett et al. (2001)

Modeling climate change:
GISS model

- 100 year model run with increasing greenhouse gases
- Two versions of model
  - 23 layer model with good representation of the stratosphere
  - 9 layer model with poor stratosphere

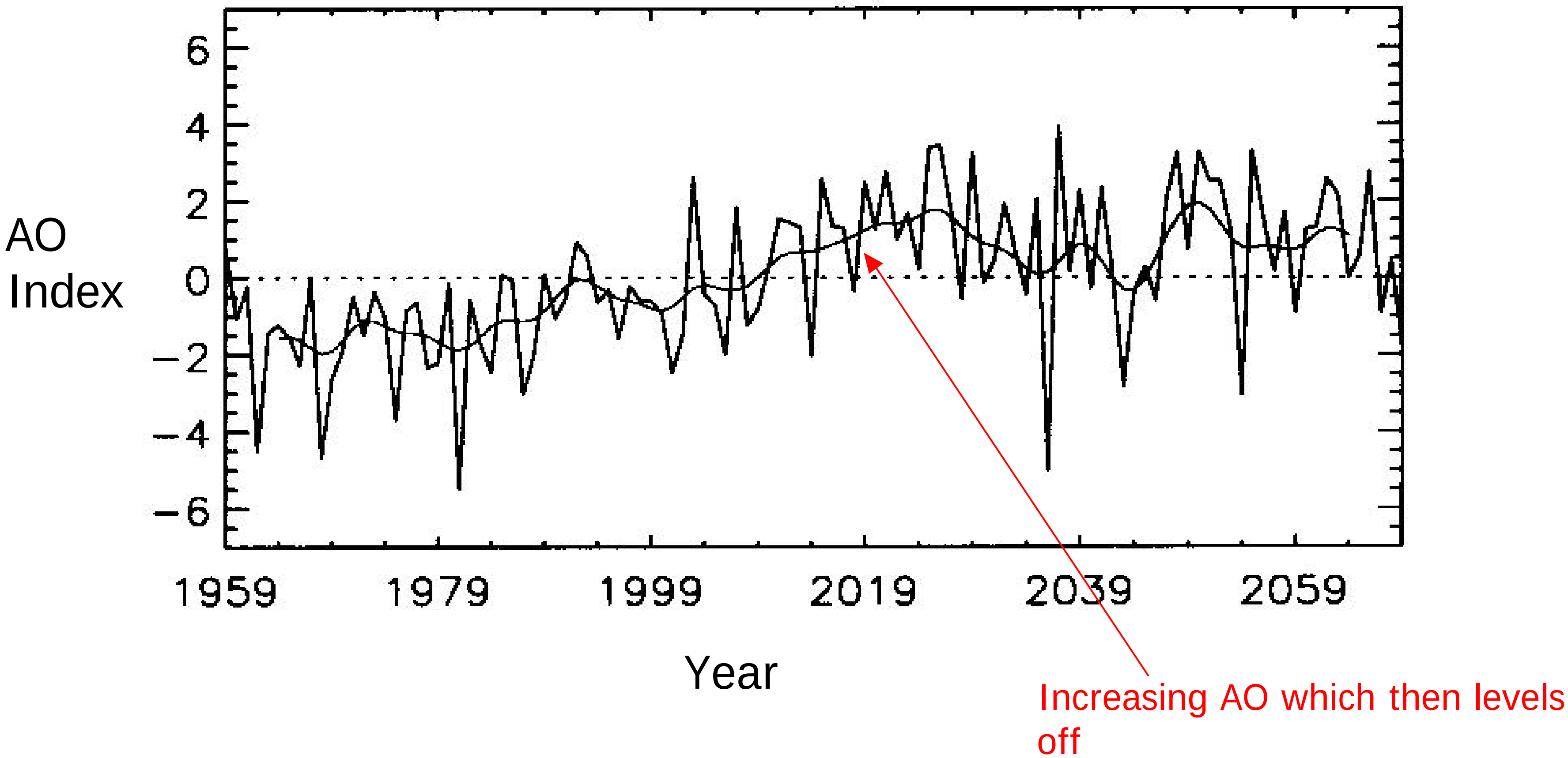
Shindell et al. (1999)

Stratospheric NAM (23 layer model)

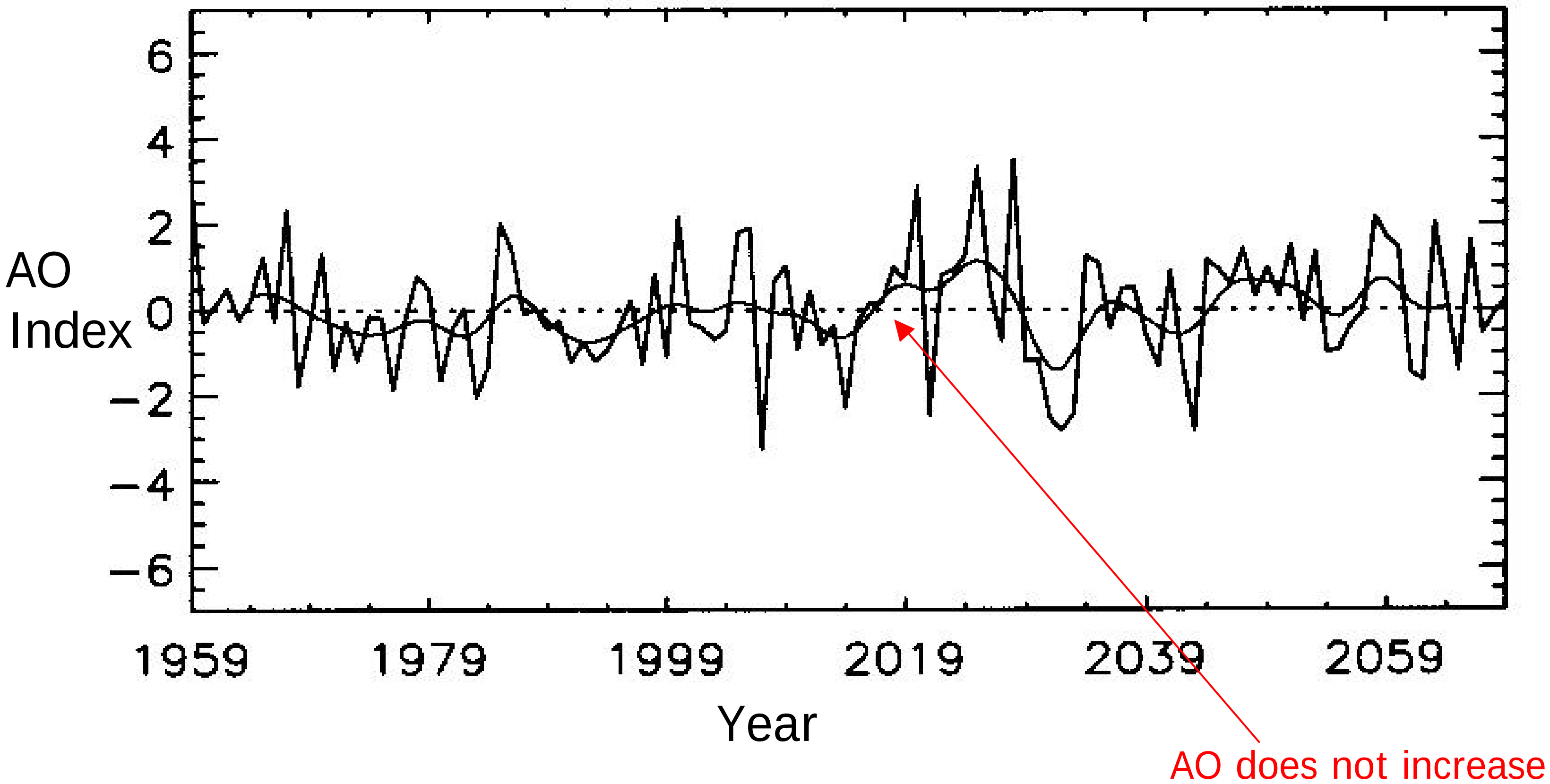


More +ve NAM with stronger polar vortex and increased westerly winds

Surface Arctic Oscillation (23 layer model)



Surface Arctic Oscillation (9 layer model)



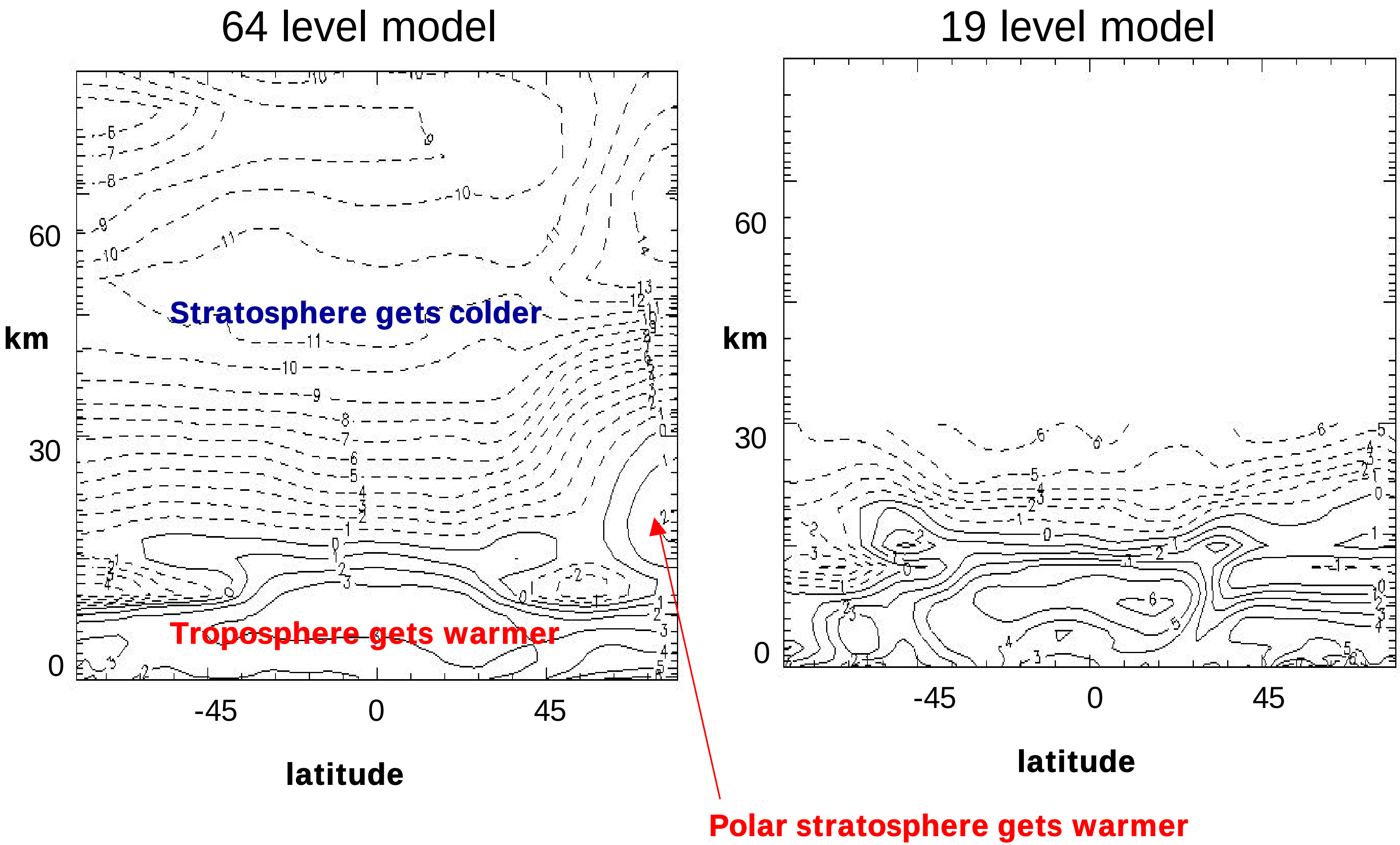
- Stratospheric wave refraction leads to stronger polar vortex
- Stratosphere important in surface AO trend

Modeling climate change: Hadley Centre Model

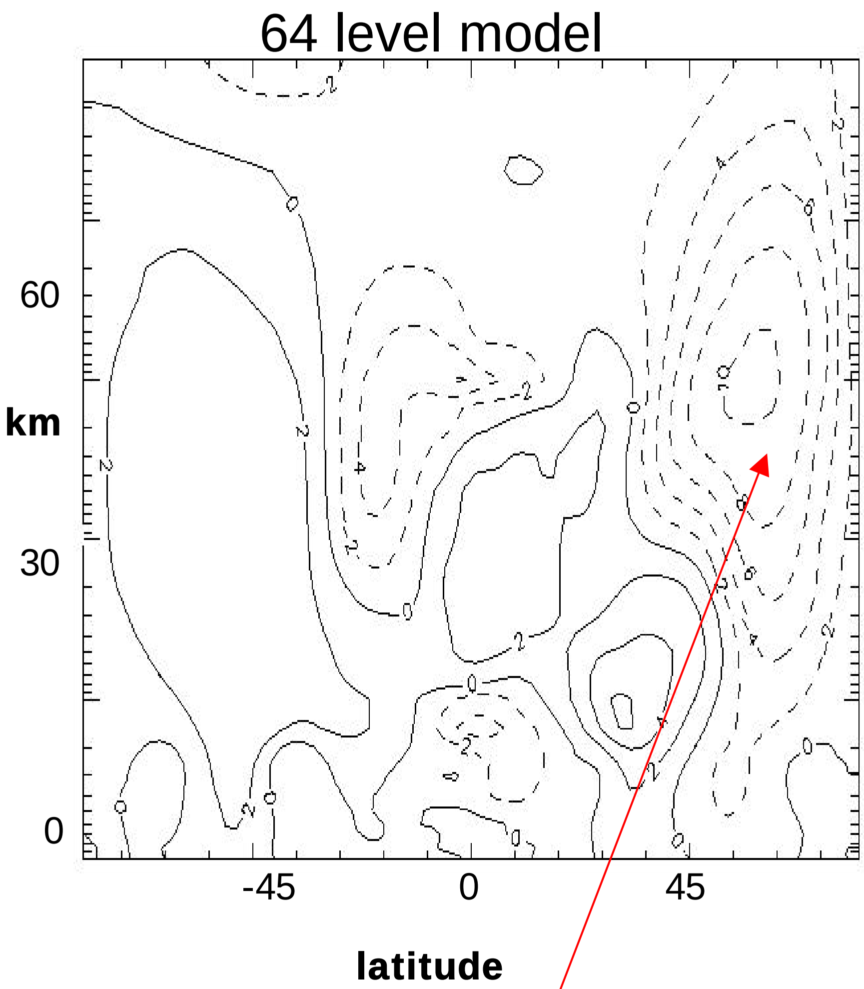
- Model runs with pre-industrial and $2XCO_2$ levels of greenhouse gases
- Two versions of model
  - 64 layer model with good representation of the stratosphere
  - 19 layer model with poor stratosphere

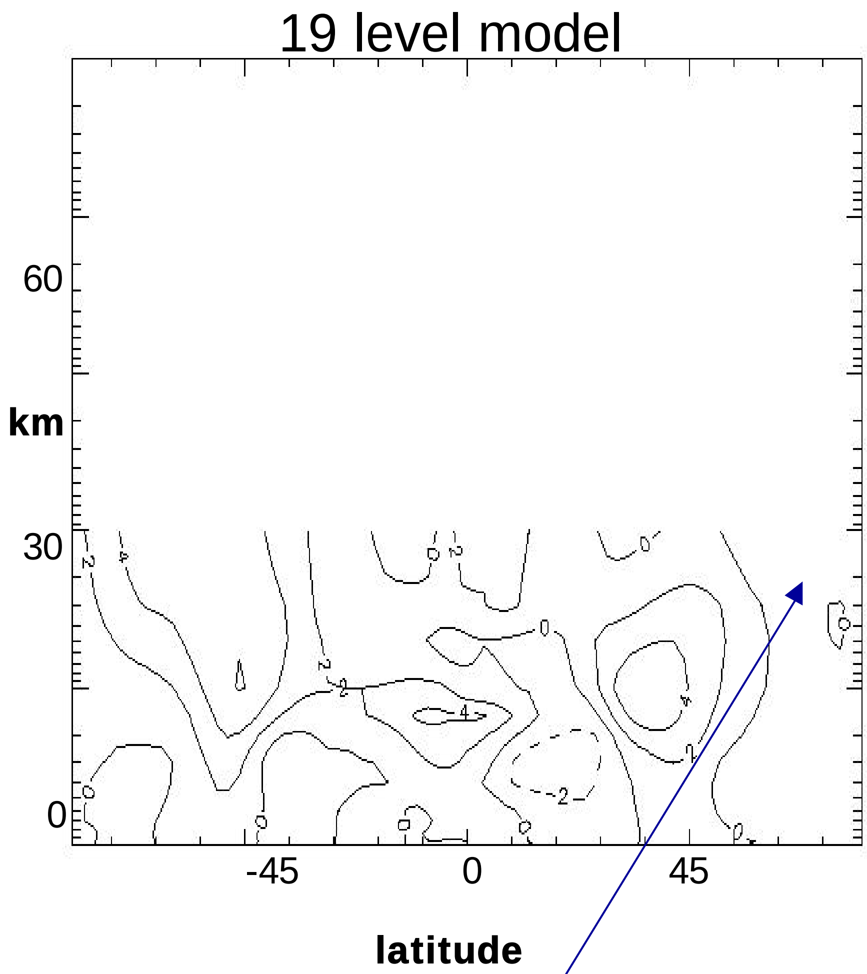
Gillett et al. (2002)

Difference in January Temperatures



Difference in January Winds



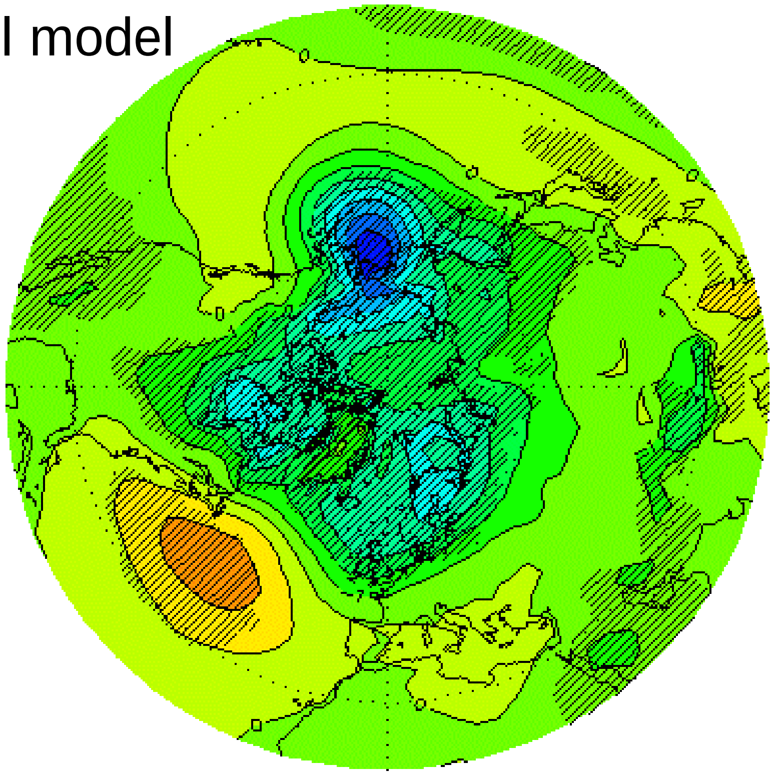


Reduced westerly winds leading to reduced stratospheric NAM

Different in 19 level model

Difference in surface pressure

19 level model

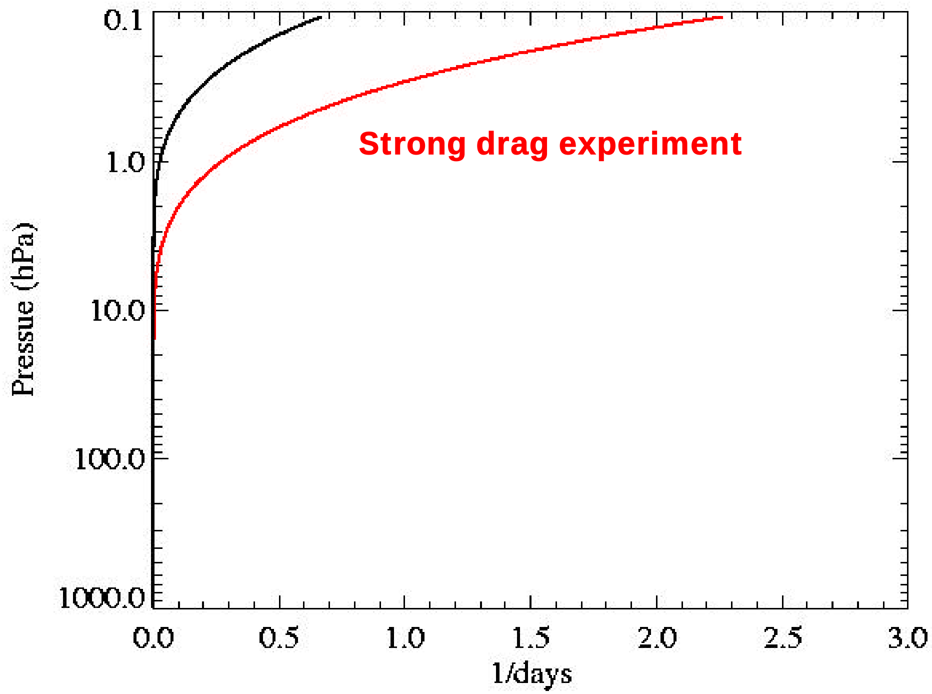


- **Blue decrease**
- **Yellow increase**
- **Shaded regions significant**

- Results for 64 layer model are not distinguishable from 19 layer model
- Increased planetary wave-driving of the stratosphere
- Stratosphere not important in surface AO trend

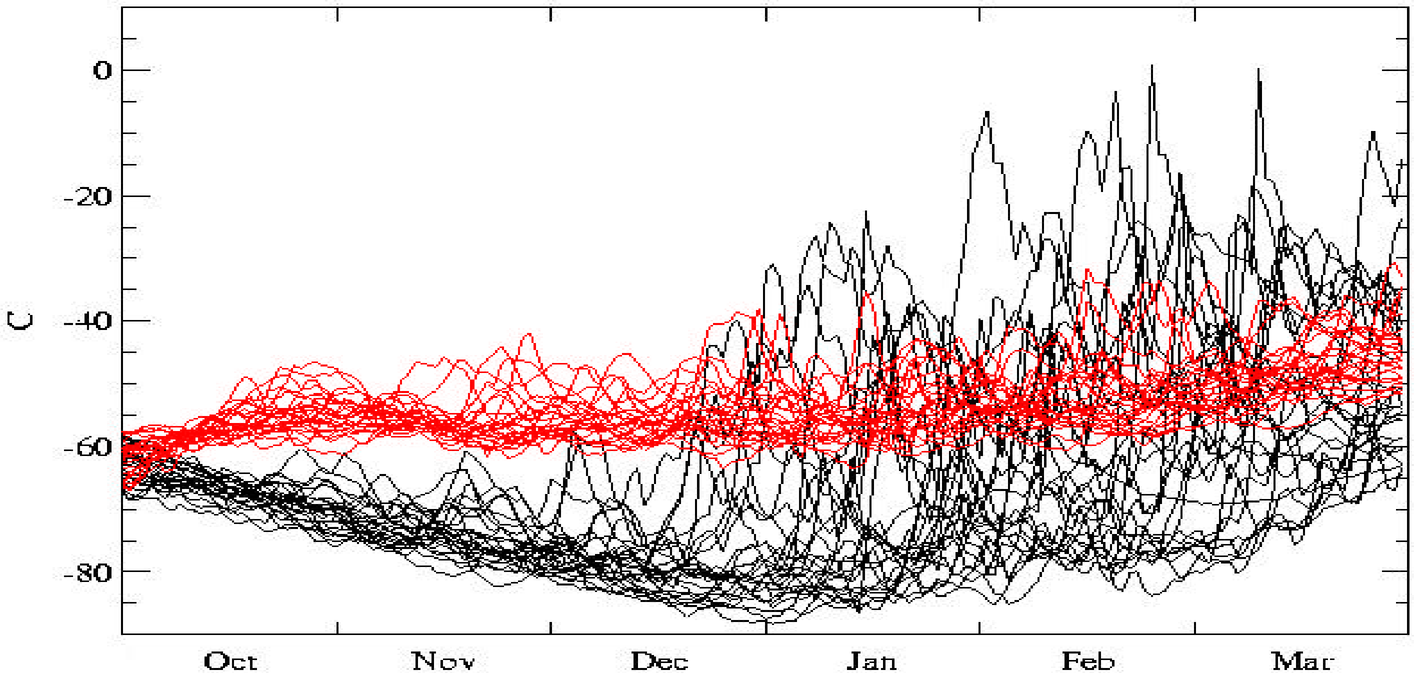
Variability

- Hadley Centre model
- 26 member ensemble experiments
- Control – normal Rayleigh friction (RF)
- Strong drag – RF profile moved down 10 km



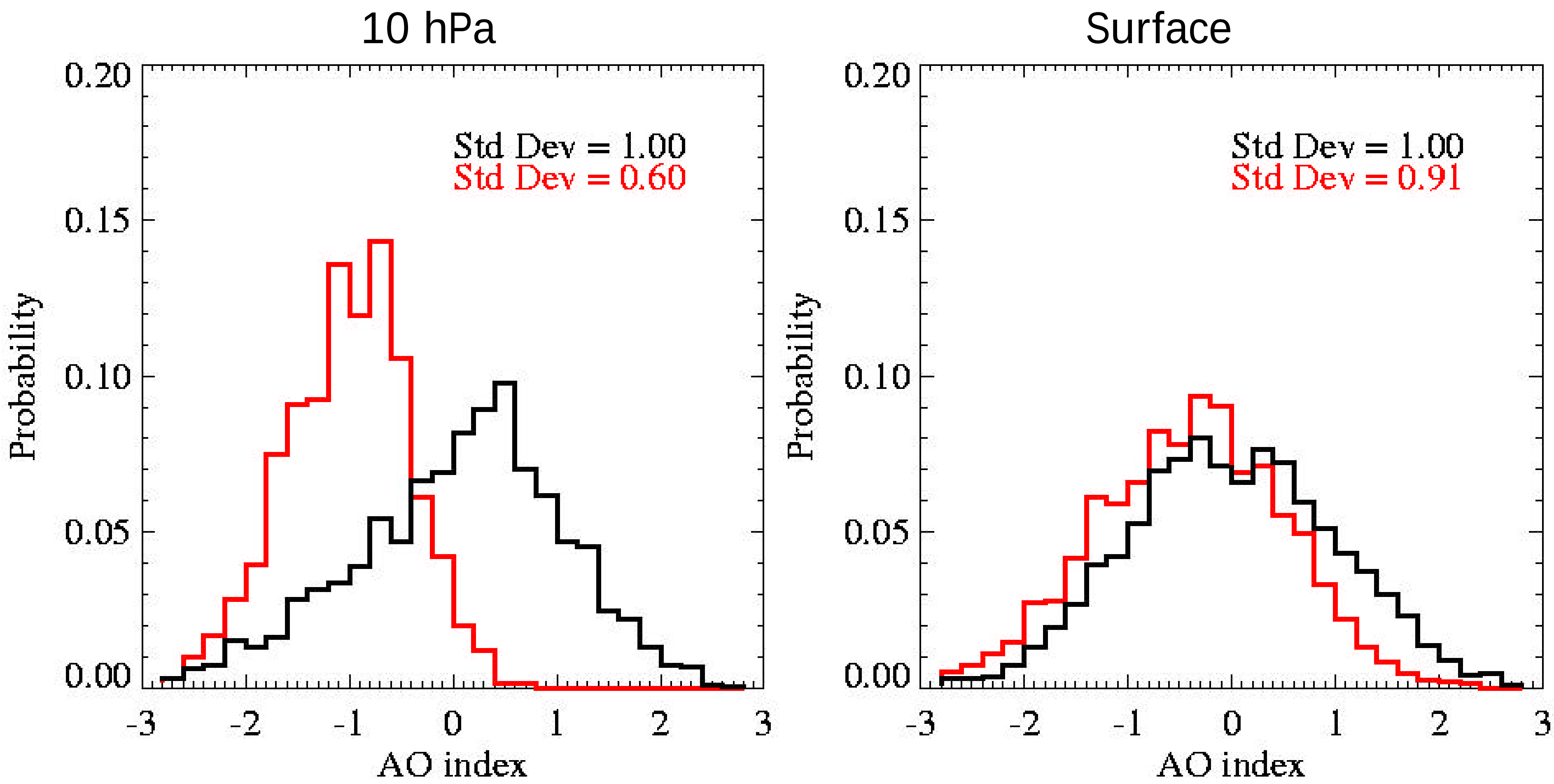
Norton (2003)

North Pole Temperatures at 30 km



- Damping of planetary waves in upper stratosphere
- Change in mean state
- Lead to no stratospheric warmings in strong drag experiment

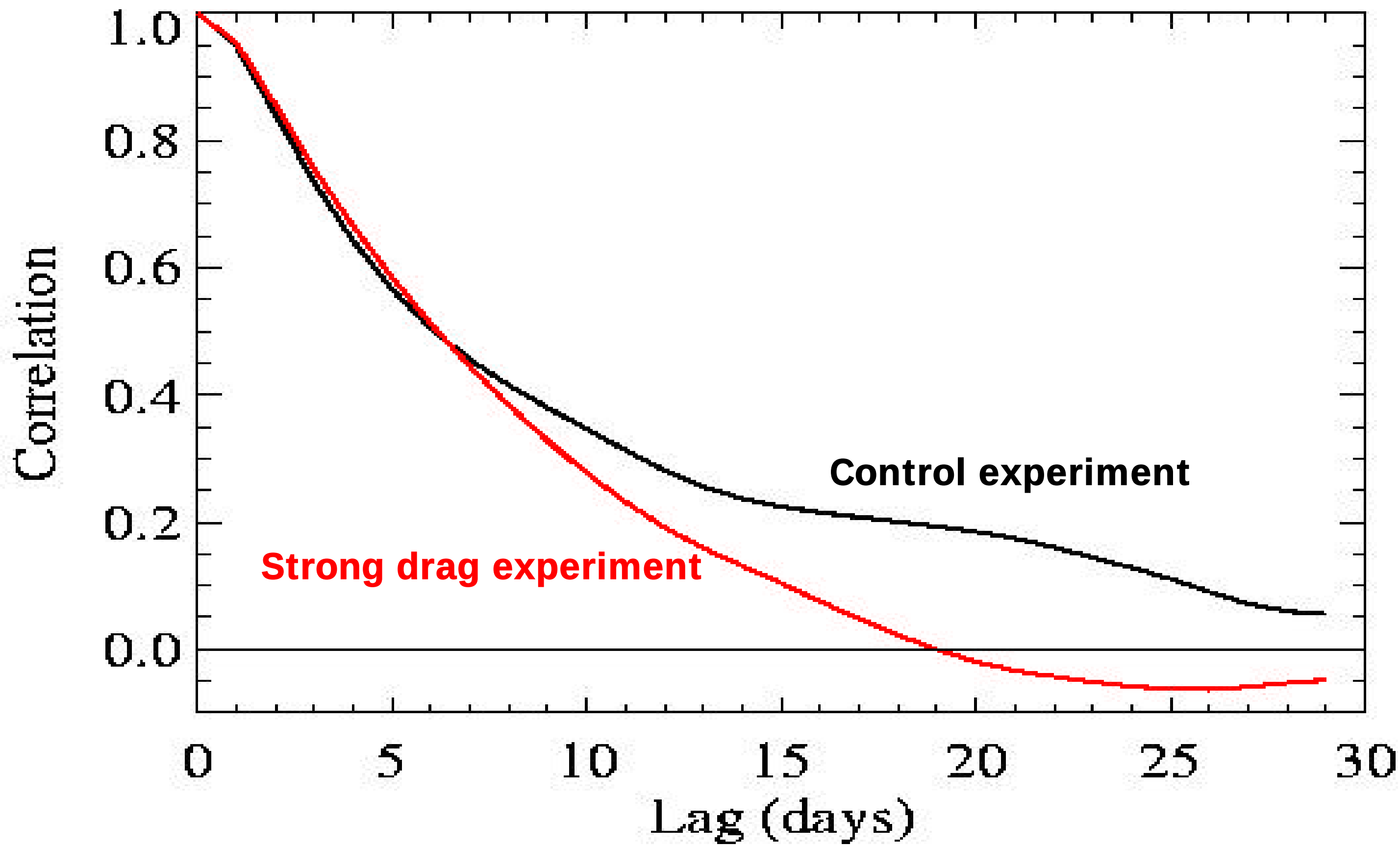
Histograms of daily NAM Index for November-March



Strong drag experiment at both 10 hPa and surface has:

- Shift in mean NAM to –ve values
- Less variability

Autocorrelation of daily surface AO index



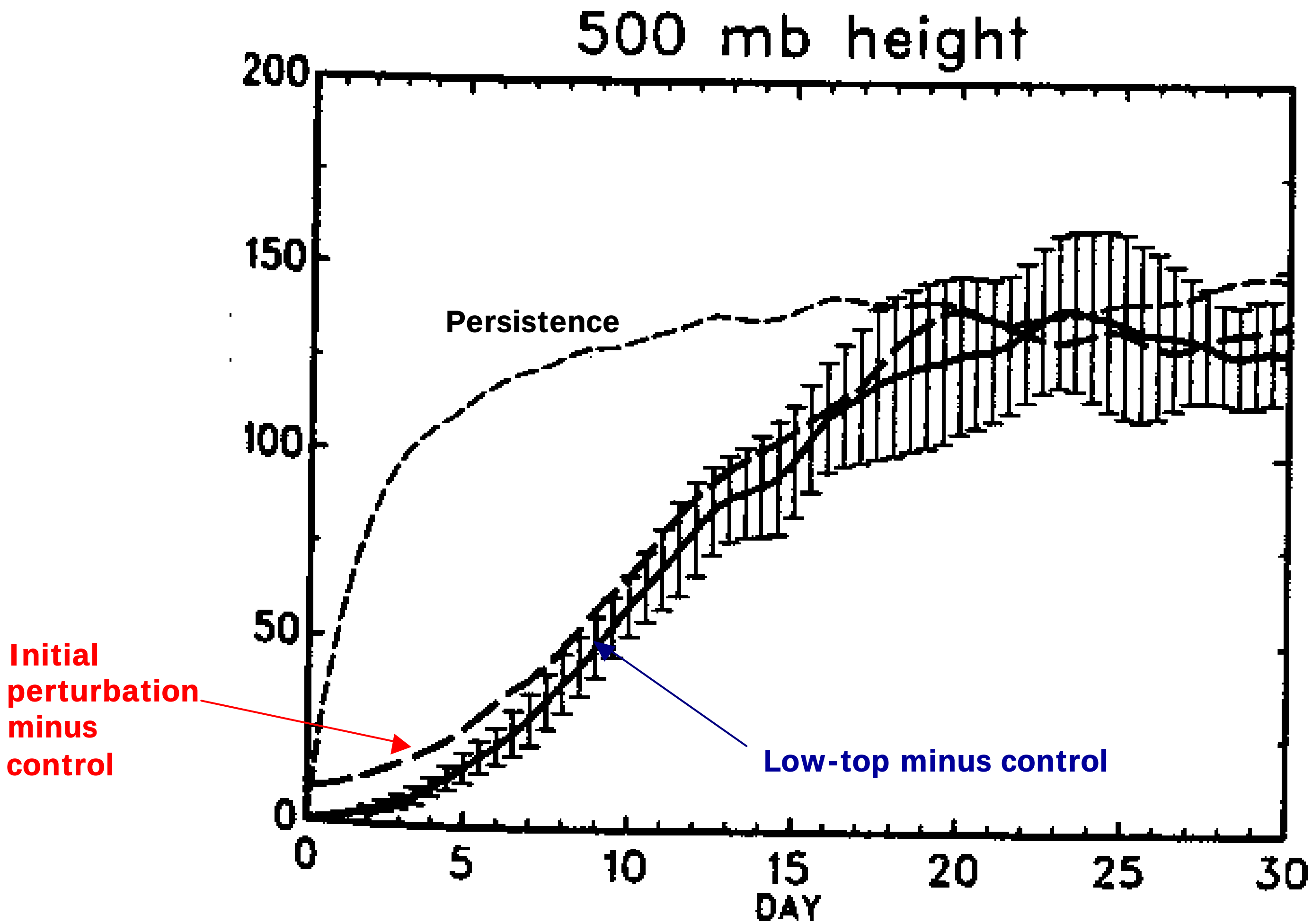
• Reduction in memory of surface AO from less variable stratosphere

Predictability

- CCM1
- McFarlane GWD with weak Rayleigh friction in mesosphere
- Model twin experiments run every 10 days from control integration
- Compare errors from initial value perturbations and low-top version of model

Boville and Baumhefner (1990)

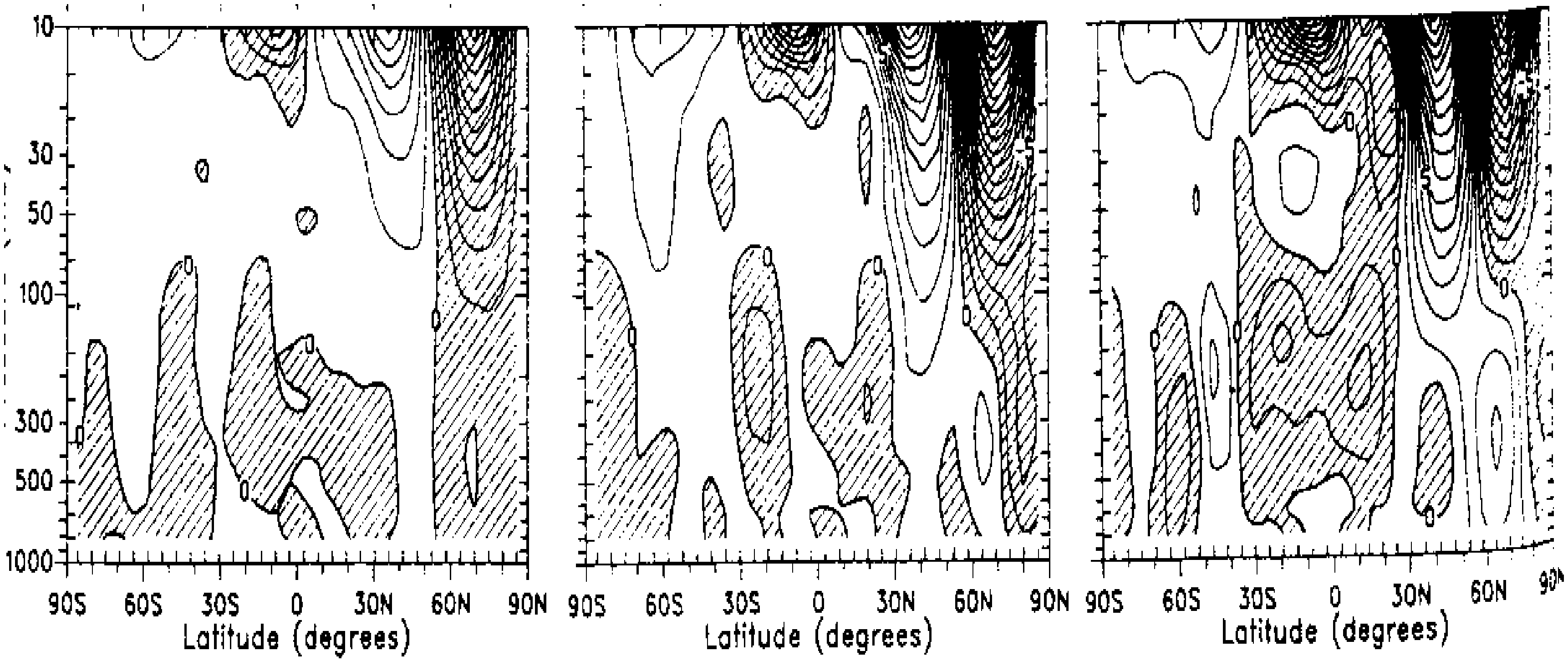
Error Growth



• Errors from low-top model similar to initial value perturbations after 10-15 days

Zonal mean wind error
low-top minus control

Days 0-10 Days 10-20 Days 20-30



- Equatorward shift of stratospheric jet, opposite shift in troposphere
- Difference in stratospheric mean response from Boville & Cheng due to inclusion of GWD scheme?

Questions

- How good a representation of the stratosphere is needed to accurately model tropospheric climate and climate change?

- What are the mechanisms (in models) by which the stratosphere influences the mean, variability and predictability of the troposphere?

- How sensitive are these mechanisms to the physical formulation in models?

- How to design experiments and compare models to understand the role of the stratosphere on tropospheric climate change?

Downward propagation of errors