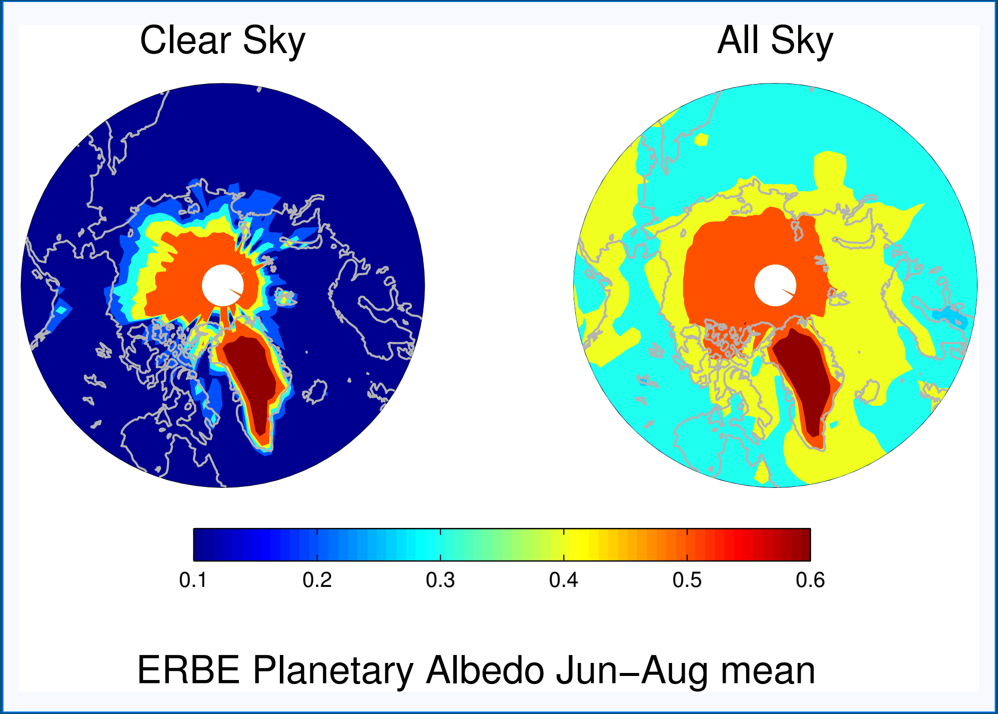
Atmospheric heat transport and surface feedbacks in the Arctic climate system

Cecilia Bitz, Univ. of Washington
and Stephen Vavrus, Univ. of Wisconsin

Feedback strength is often quantified in terms of fluxes at the top of the atmosphere.

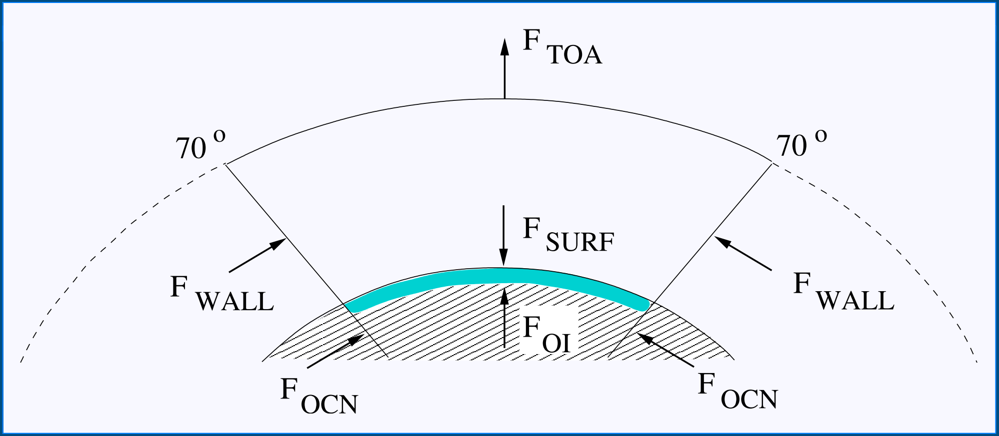
$$\lambda = \partial F_{TOA} / \partial T_{SURF}$$

Problem in the Arctic due to clouds and stable atmosphere



ERBE Planetary Albedo Jun–Aug mean

Key Components of the Polar Climate Response to Climate Forcing



Local Response to Climate Forcing
Depends on Local Feedbacks and Remote Response

Two ways to compute F_{WALL}:

$$F_{WALL} = F_{TOA} + F_{SURF} + \frac{\partial E}{\partial t}$$

F_{TOA} is positive up and F_{SURF} is positive down
E is the total energy stored in the atmosphere

$$F_{WALL} = \int\int_{WALL} \overline{(c_p T + gZ + Lq)v} \, \frac{dx\ dp}{p}$$

Flux of sensible, potential and latent heat
ignoring flux of kinetic energy

Use GCMs forced with CO_2 to investigate the change in $\boldsymbol{F_{WALL}}$ and surface energy budget due climate forcing

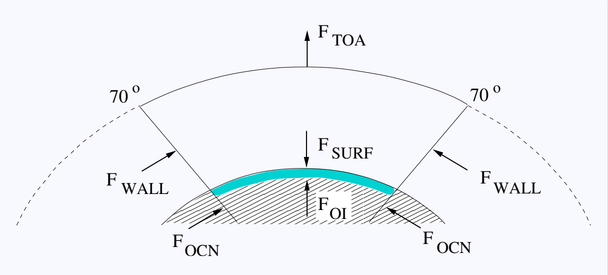
4 Models from Coupled Model Intercomparison Project (CMIP)
All models are coupled atmosphere, ocean, sea ice models
with approximately 3° resolution in the atmosphere

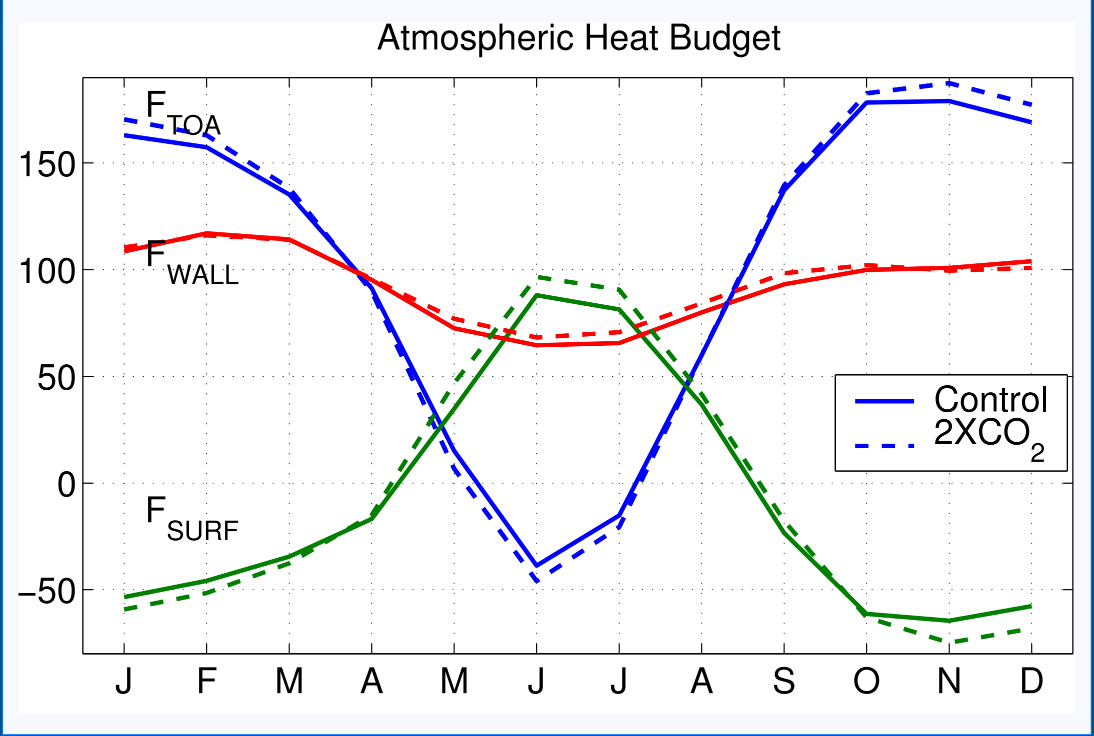
- Control = Pre-industrial CO_2
  80 or more years in length
- Perturbed = Transient increase in CO_2 at 1% per year
  We use averages taken from years 60-80.

5th model is GISS from (Miller and Russell, 2002)

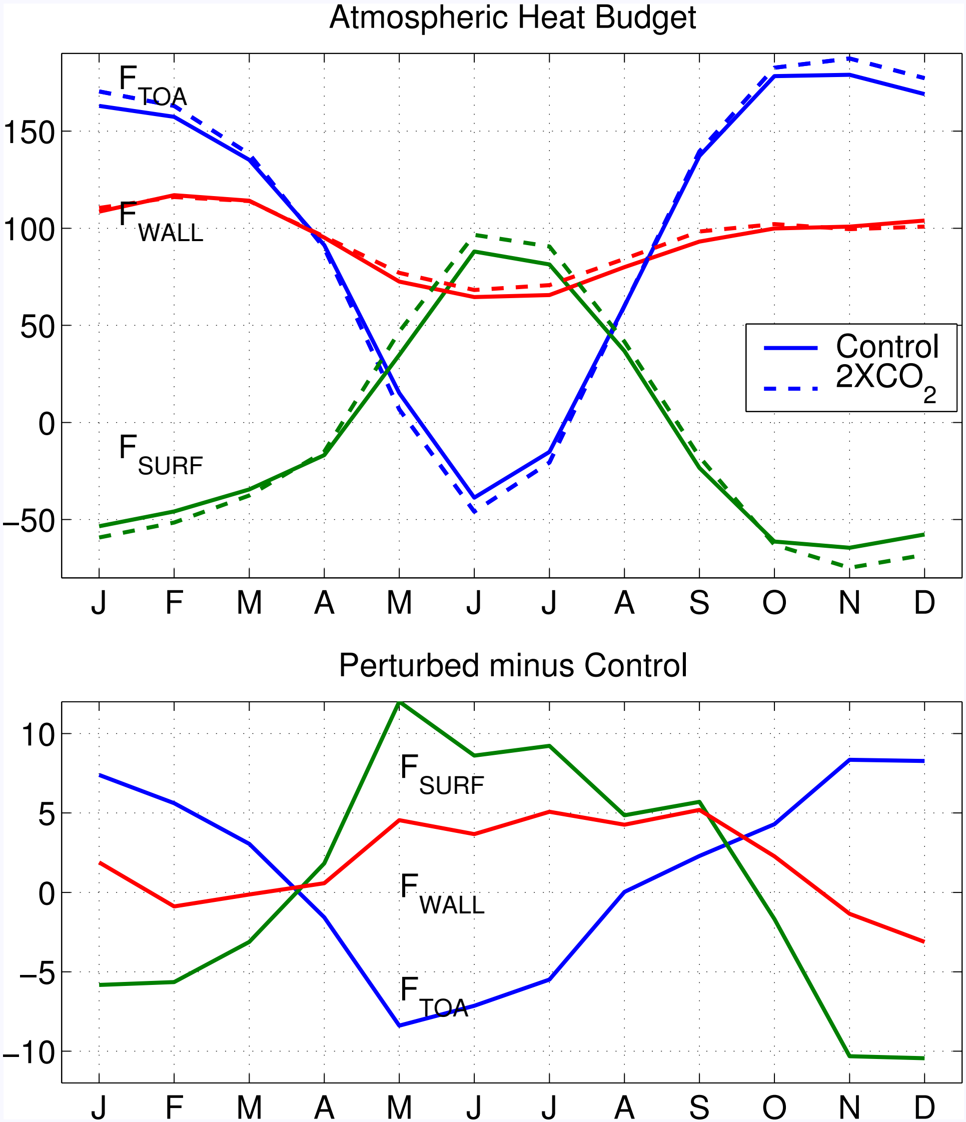
$$F_{WALL} = F_{TOA} + F_{SURF} + \frac{\partial E}{\partial t}$$

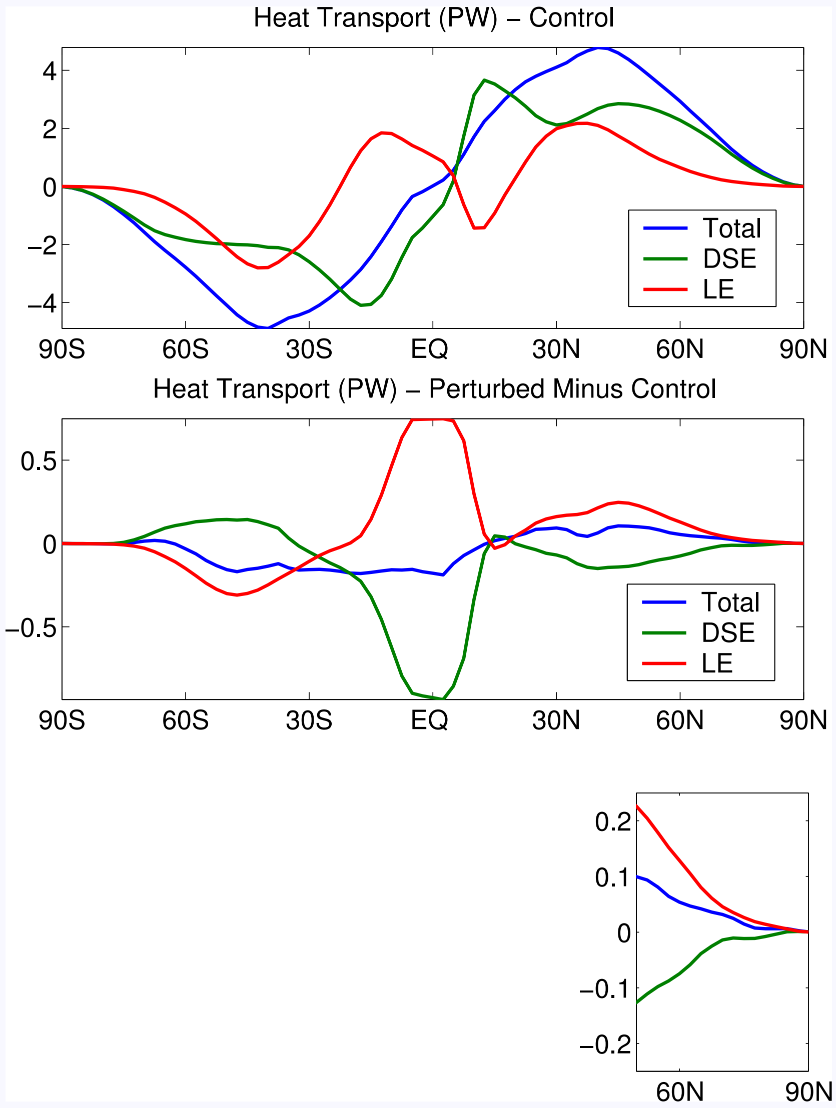
at 70° N




Atmospheric Heat Budget

Hadley Centre Model - HadCM3


Atmospheric Heat Budget
F_{TOA}
F_{WALL}
F_{SURF}
150
100
50
0
–50
J
F
M
A
M
J
J
A
S
O
N
D
Control
$2XCO_2$
Perturbed minus Control
F_{SURF}
F_{WALL}
F_{TOA}
10
5
0
–5
–10
J
F
M
A
M
J
J
A
S
O
N
D



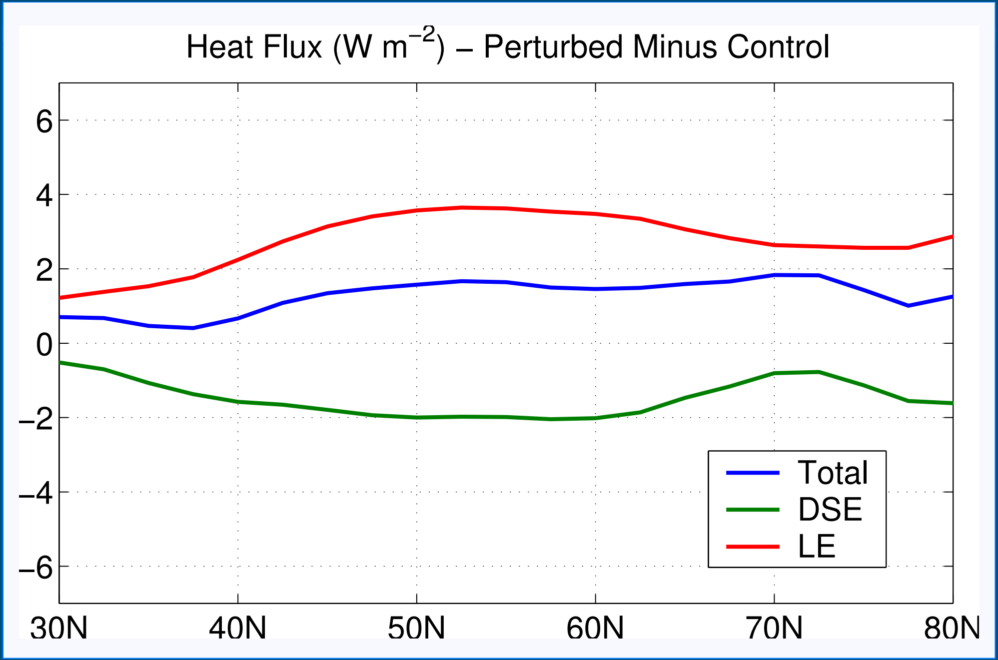
DSE=Dry Static Energy

$c_pTv + gZv$ term

LE=Latent Energy

Lqv term

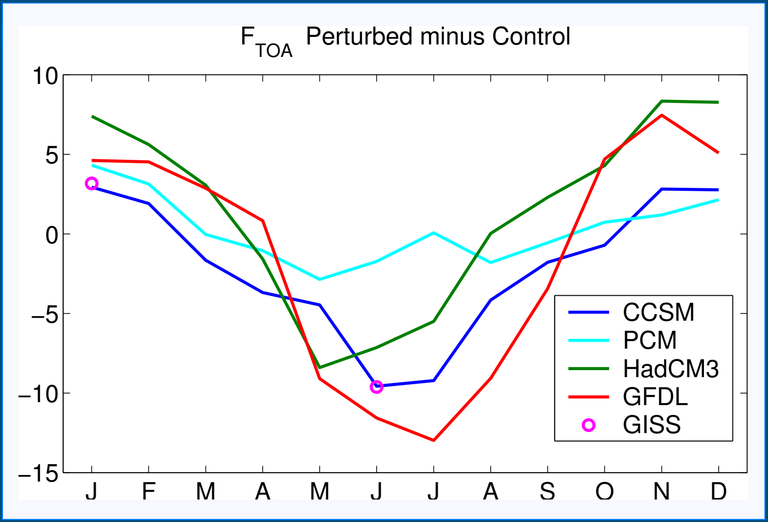
Divide Transport in PW by horizontal area poleward of latitude to get heat flux in Wm^{-2}



Warming at $2XCO_2$ in deg C:

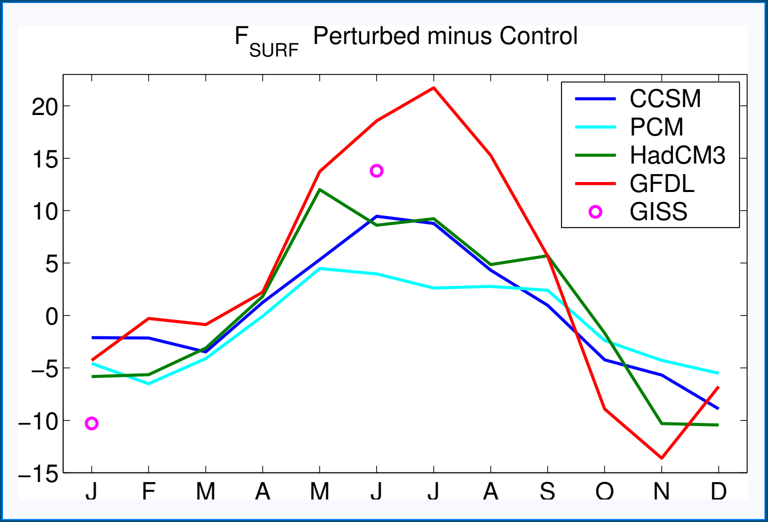
	Transient Response			Equilibrium Response
Model	Global Change	70-90° Change	70-90°/ Global	Global Change
CCSM2	1.1	3.0	2.8	2.4
PCM	1.3	3.0	2.3	1.7
GISS	1.4	3.1	2.2	3.1
GFDL-R30	1.9	3.8	2.0	3.4
HADCM3	2.0	4.9	2.4	3.0

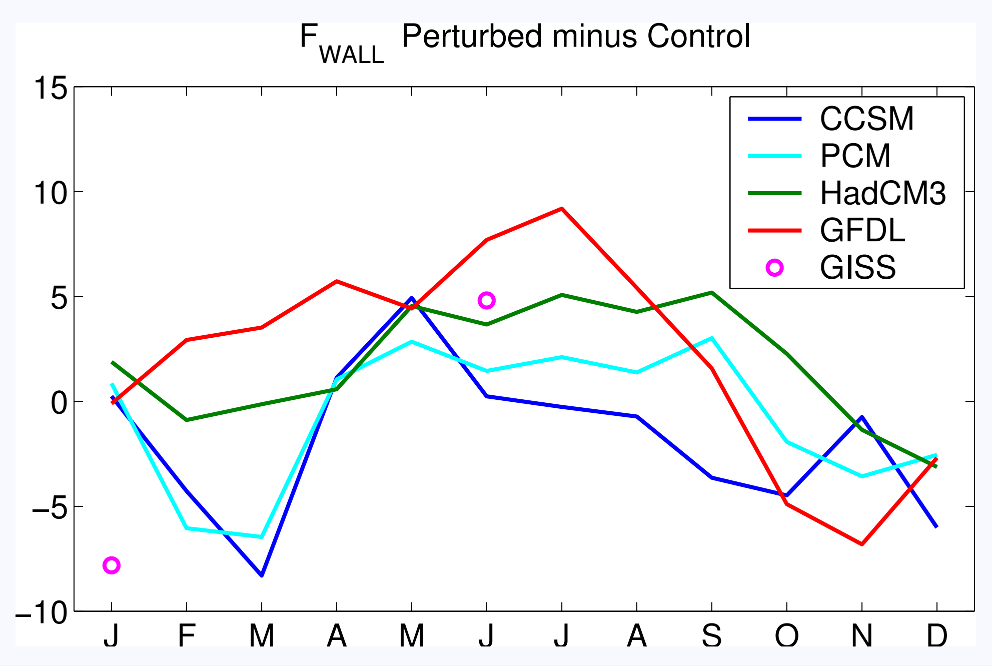
Polar amplification is not positively correlated with global change



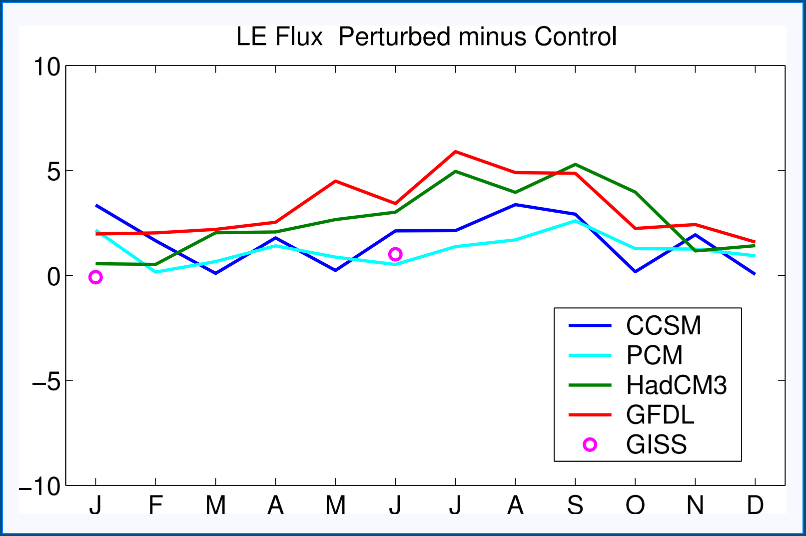
F_{TOA} is positive up and

F_{SURF} is positive down





	70-90°/ Change
CCSM2	2.8
PCM	2.3
GISS	2.2
GFDL-R30	2.0
HADCM3	2.4

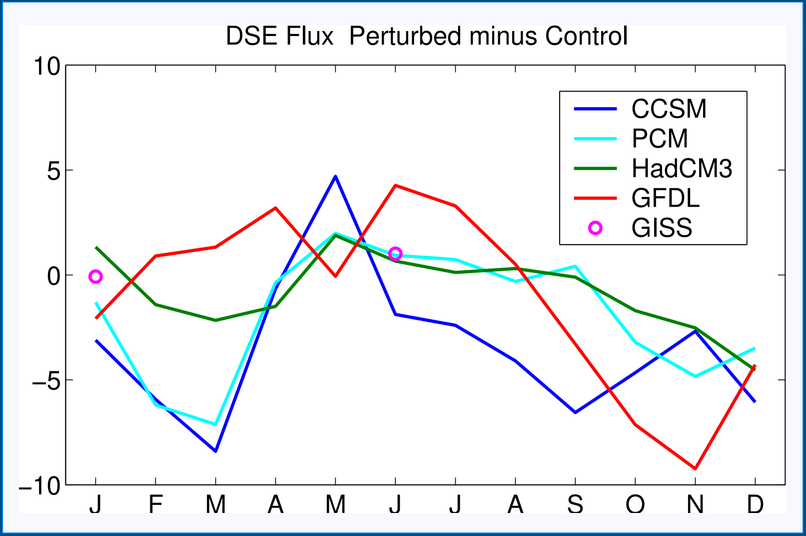


DSE=Dry Static Energy

$c_pTv + gZv$ term

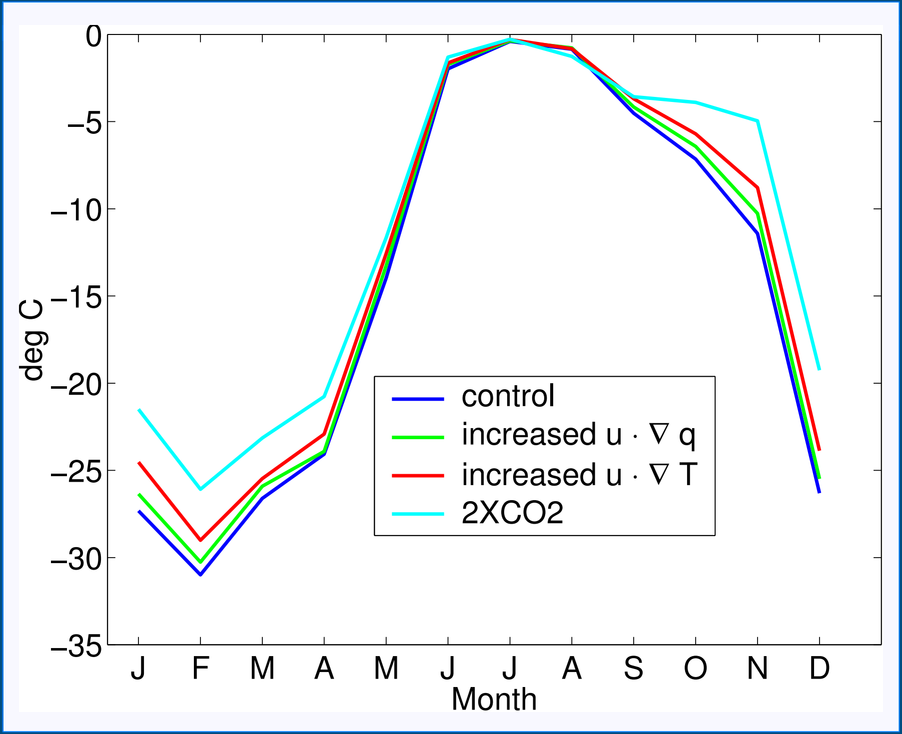
LE=Latent Energy

Lqv term



GISS Jan = -8 and June = 4

Surface Air Temperature

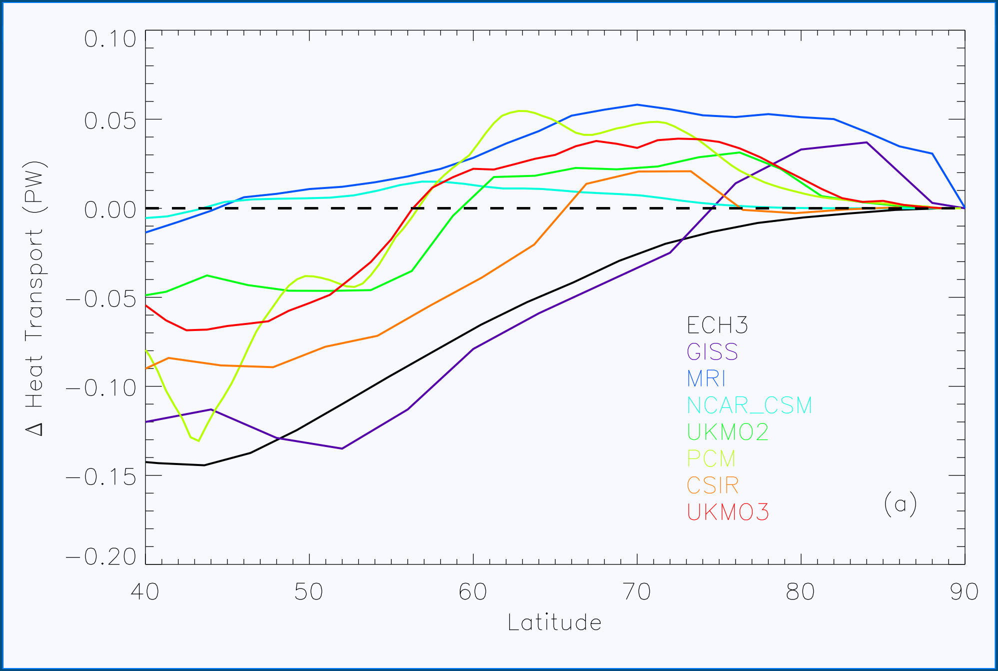


Sensitivity to 2% increase in $u \cdot \nabla q$ is .56°C

Sensitivity to 2% increase in $u \cdot \nabla T$ is 1.36°C

Sensitivity to 2XCO$_2$ is 3.16°C

Ocean Heat Transport



Holland and Bitz (2003) Climate Dynamics

Summary

When surface feedbacks are evaluated from the local TOA energy budget, we must account for changes in F_{WALL}.

Ice-albedo feedback has a nonlocal signature at the TOA. Clouds do not preclude its influence on climate change.

F_{WALL} increases by 2–5 Wm^{-2} in summer and decreases to some extent in winter.

LE Flux increases in almost every month in every model – summertime increase is largest. Models with large global warming have largest increase in LE Flux.

DSE Flux change is more variable. Models with greatest polar amplification tend to have largest decrease in DSE Flux.