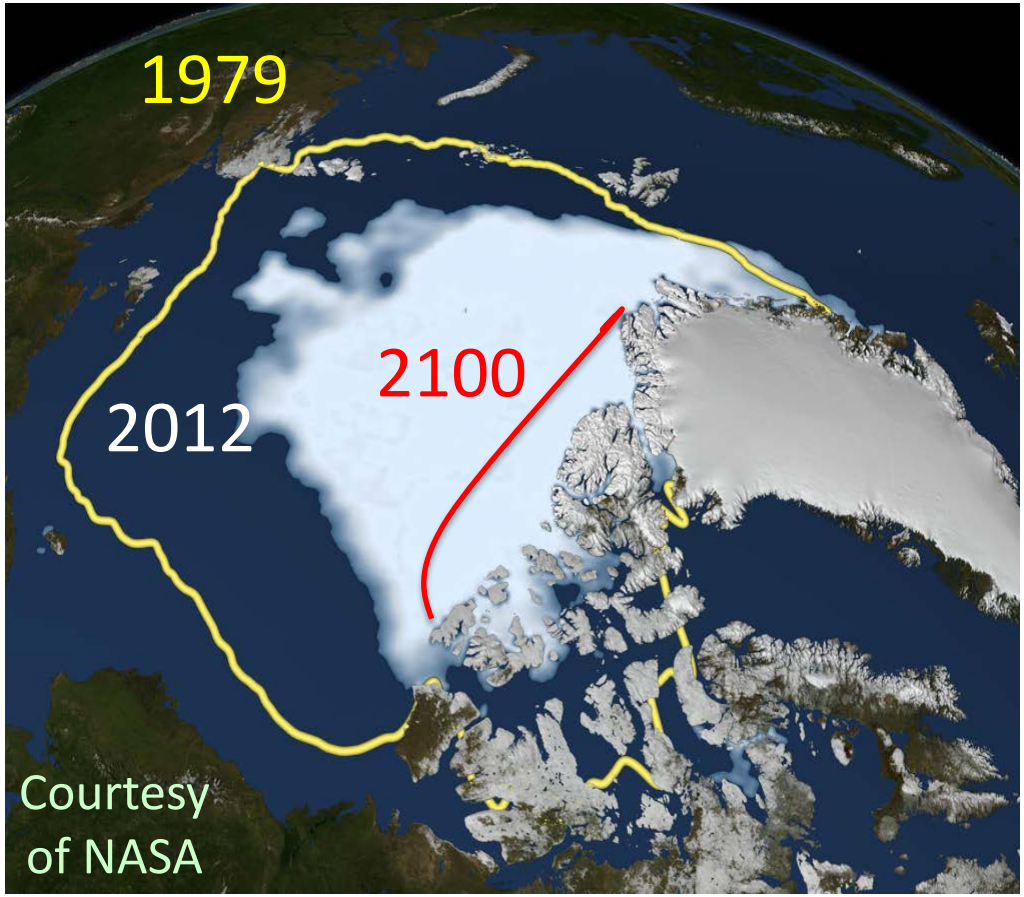
Global Climate Response to Arctic Sea Ice Loss: The role of ocean-heat transport



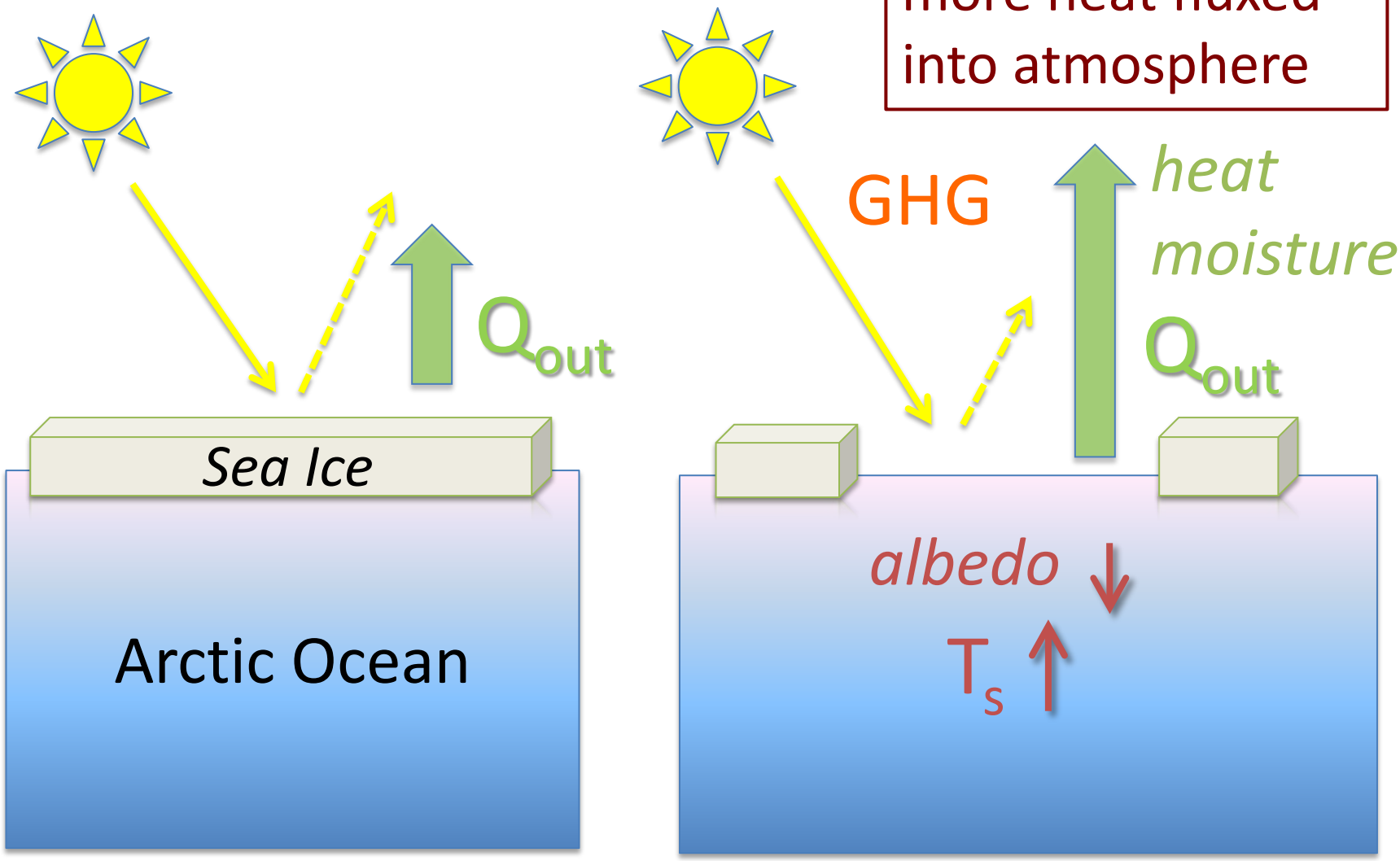
Implications for using SOM for Paleo-climate simulations

Bob Tomas, Clara Deser and Lantao Sun

J. Of Clim. In Review

Response of surface energy exchange to Arctic sea ice loss

Less sea ice -> more heat fluxed into atmosphere

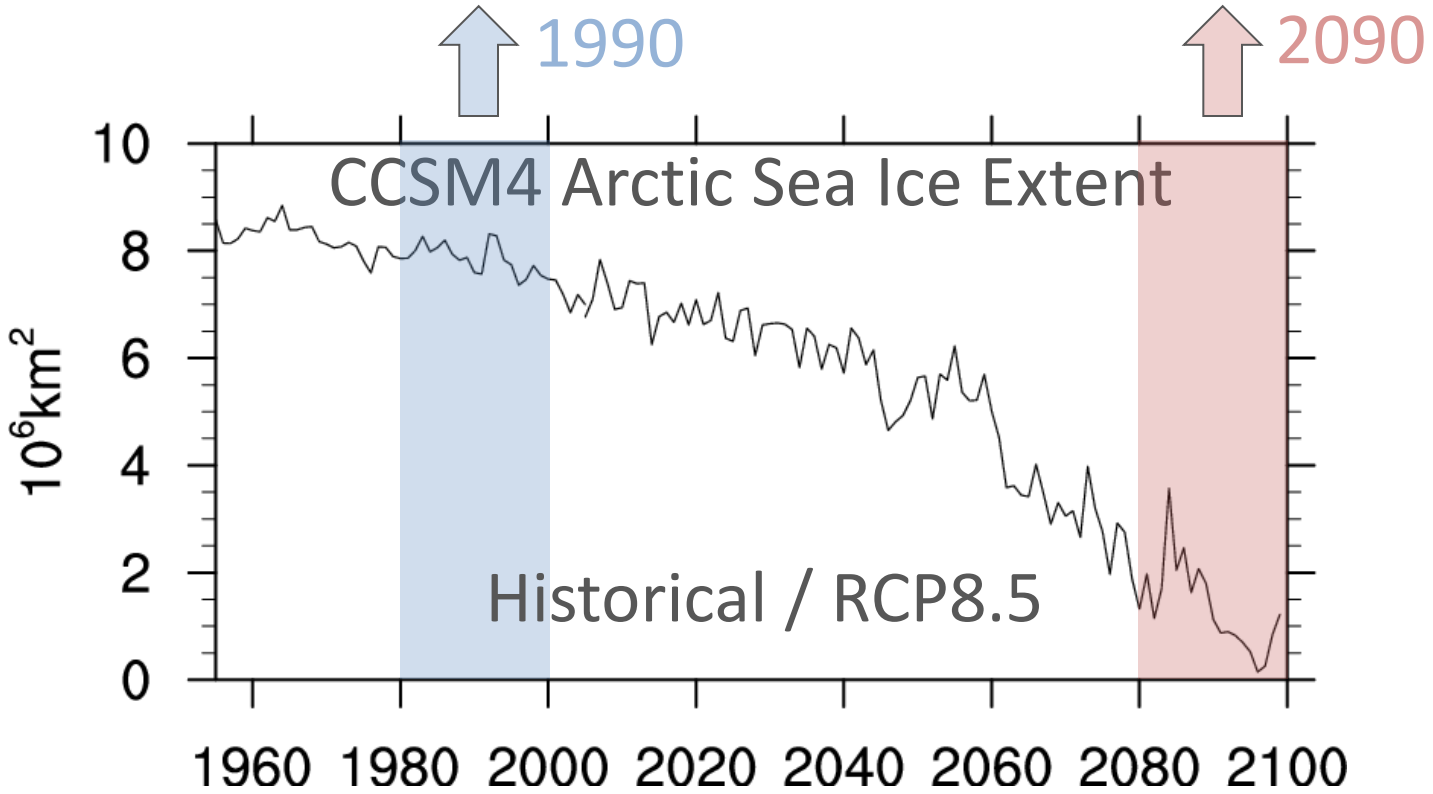


Model Experiments (CESM 1°)

Coupled dynamical ocean (FOM)

Coupled slab ocean (SOM)

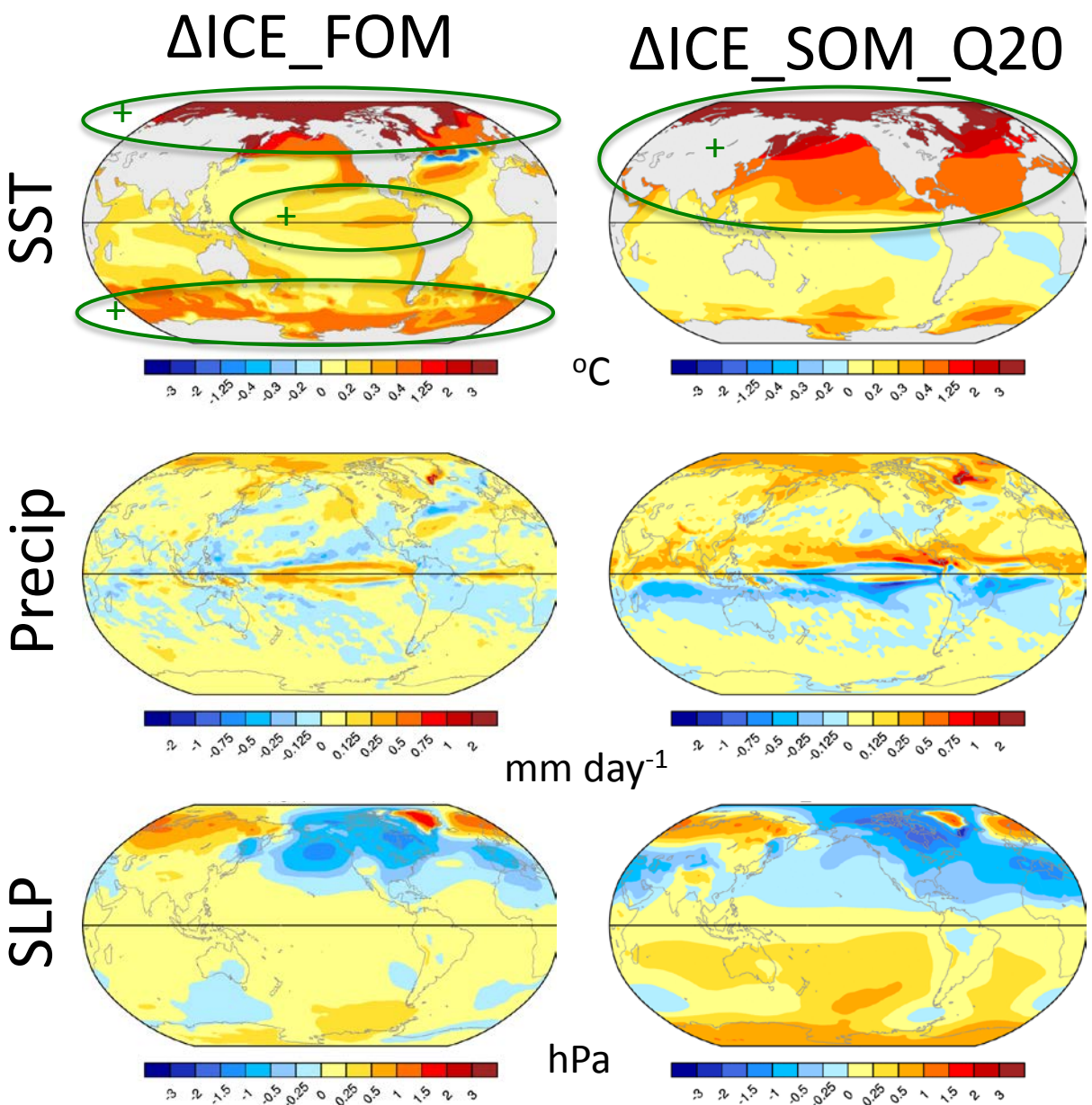
Fix GHG at 1990 levels to isolate impact of Arctic sea ice loss



Model Experiments (cont.)

- Artificially control the Arctic sea ice concentration and thickness by imposing a LW flux to the ice model
- This flux is seen only by the ice model and is proportional to the ice in a grid box
- All experiments run for 360 years, analyzed last 260 years

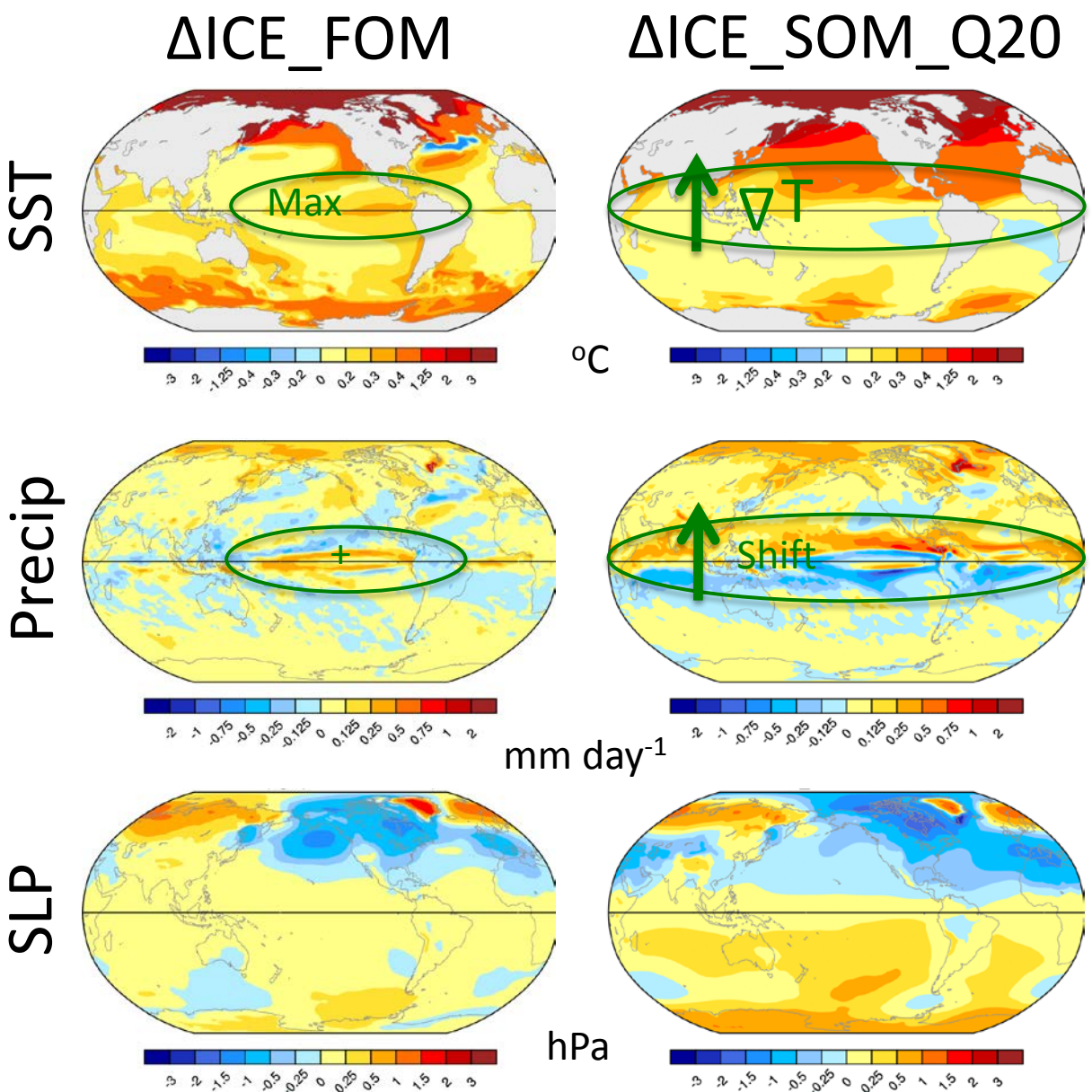
Annual Global SST Response



ΔICE_FOM: warming with equatorial symmetry

ΔICE_SOM_Q20: NH warming but little in SH

Annual Tropical Response



ΔICE_FOM:
SST warming max in EQ Pac & local precip intensification

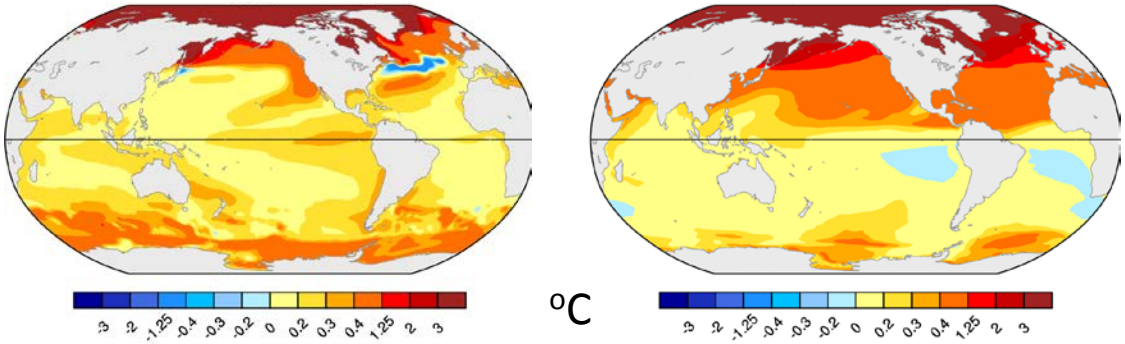
ΔICE_SOM_Q20:
Nortward SST gradient and shift of precip

Annual SLP Response

ΔICE_FOM

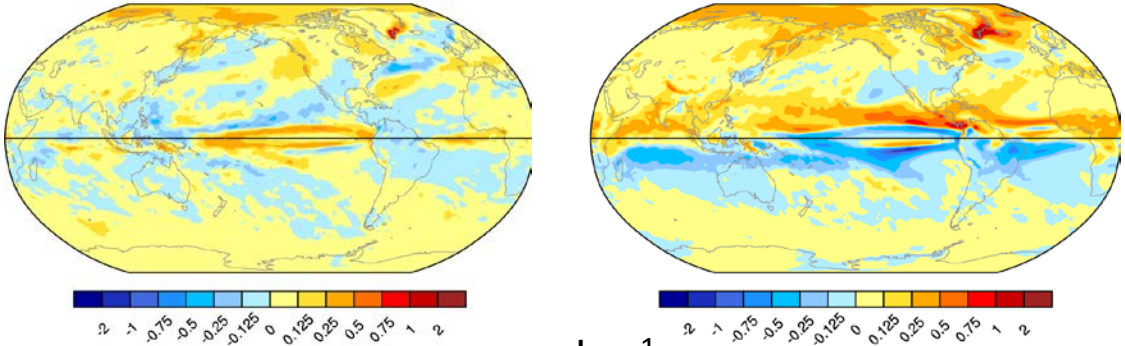
ΔICE_SOM_Q20

SST



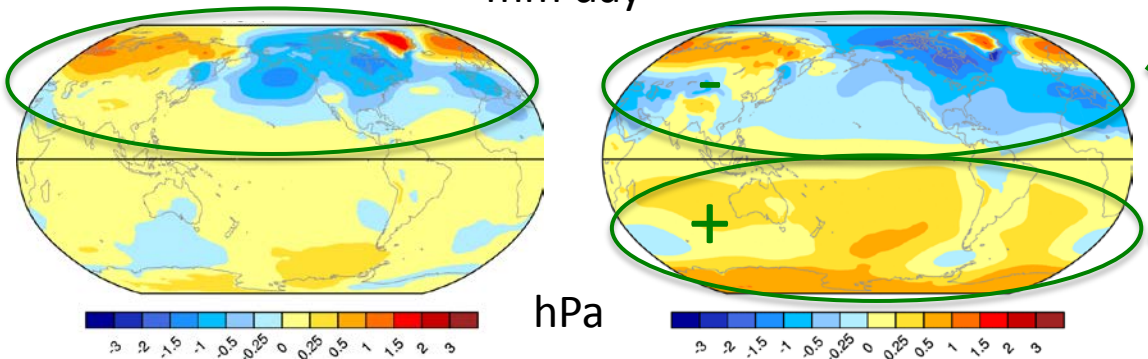
°C

Precip



mm day^{-1}

SLP



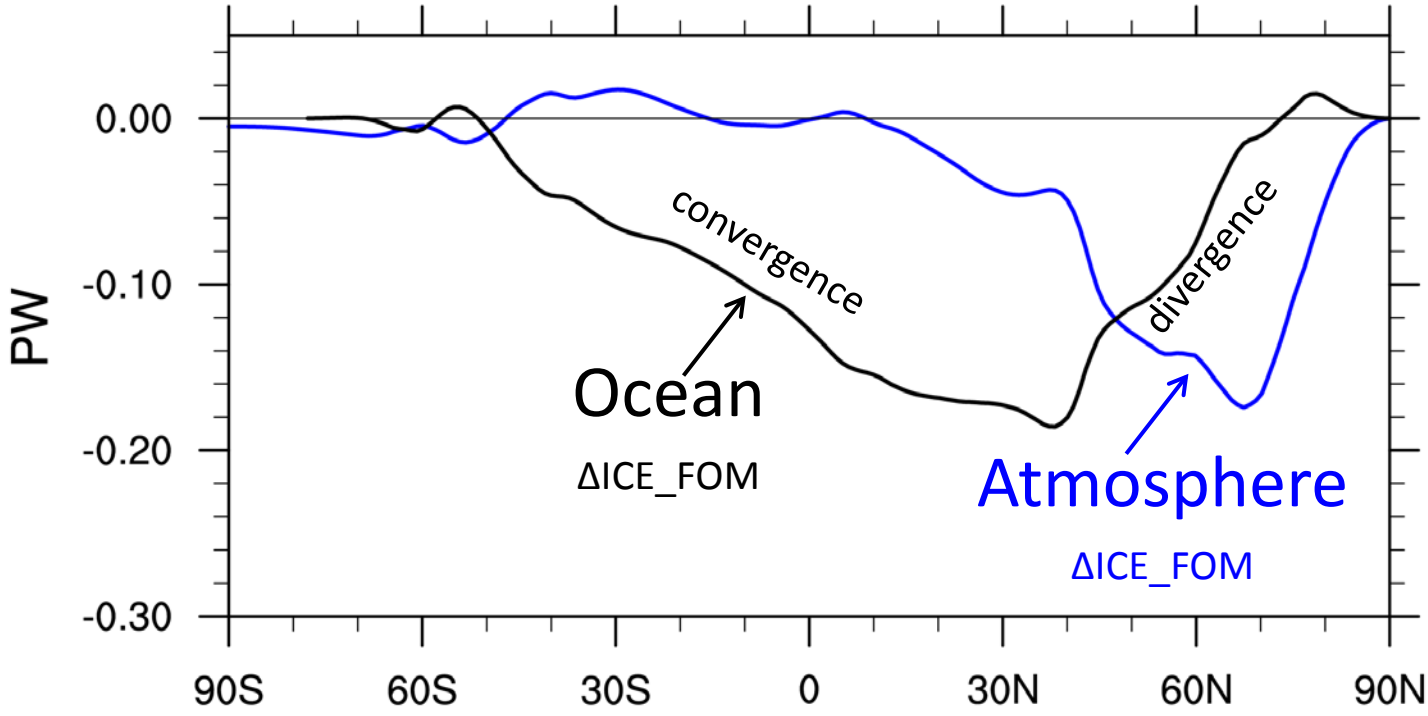
hPa

Mass

Both model configurations show similar wavy patterns in the NH…

… but ΔICE_SOM_Q20 displays a shift of mass out of NH into SH

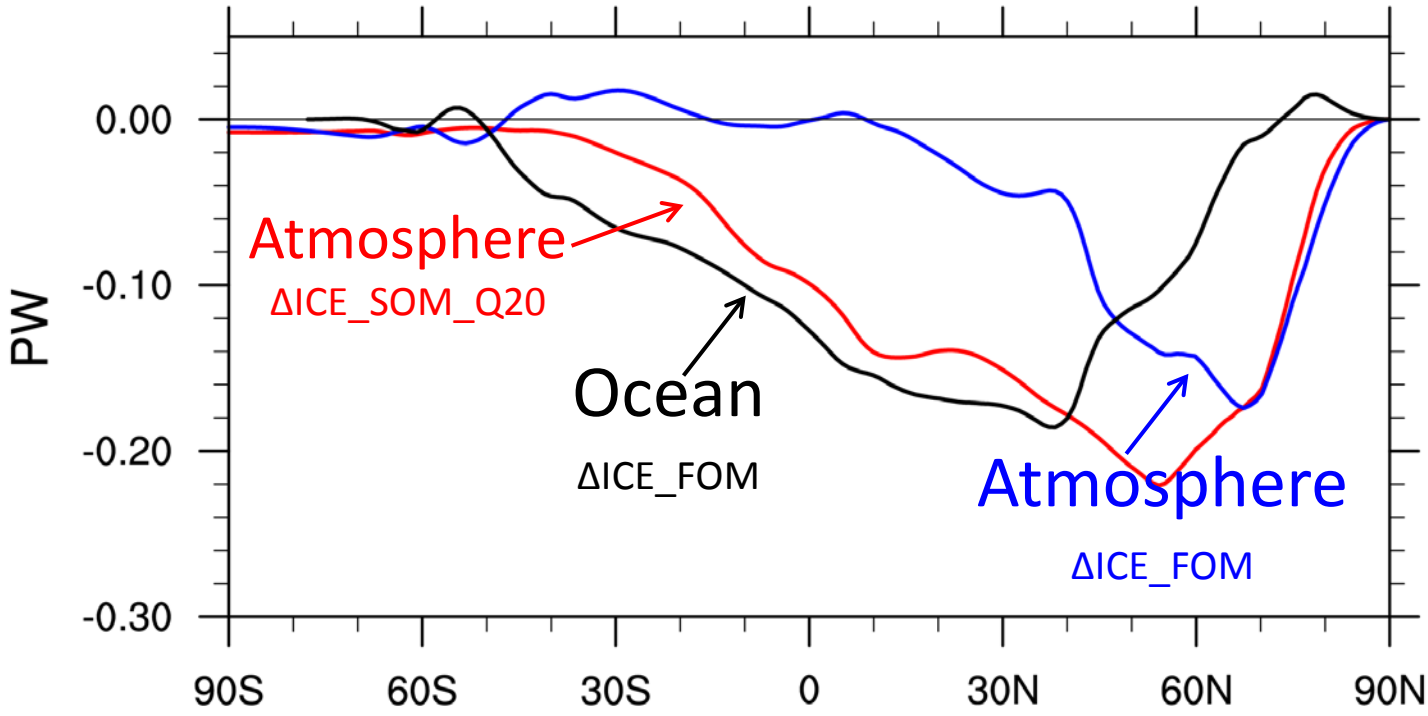
Northward Energy Transport



Atmosphere transports heat to mid-latitudes

Ocean transports heat into the tropics and SH

Northward Energy Transport

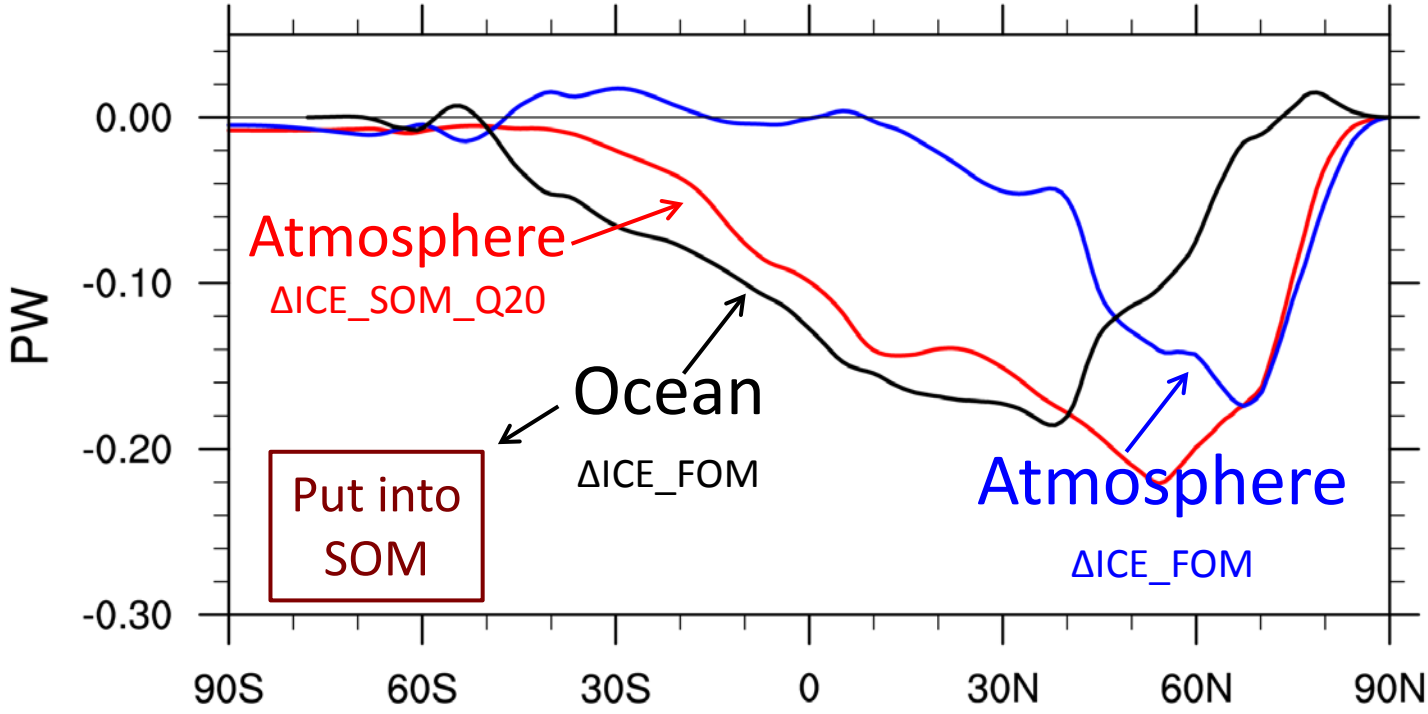


Atmosphere transports heat to mid-latitudes

Ocean transports heat into the tropics

Slab ocean: atmosphere has to do all the work

Northward Energy Transport



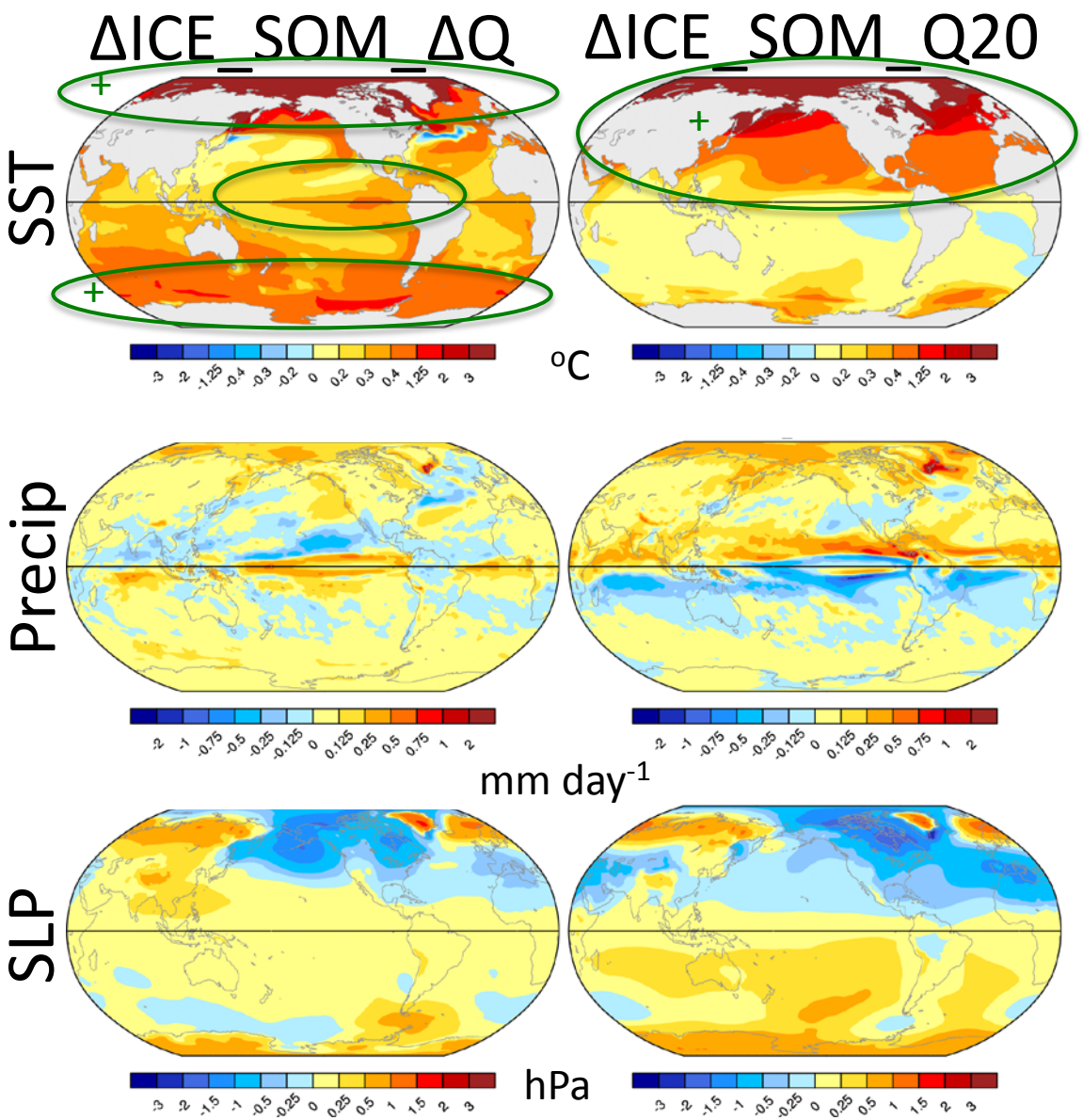
Atmosphere transports heat to mid-latitudes

Ocean transports heat into the tropics

Slab ocean: atmosphere has to do all the work

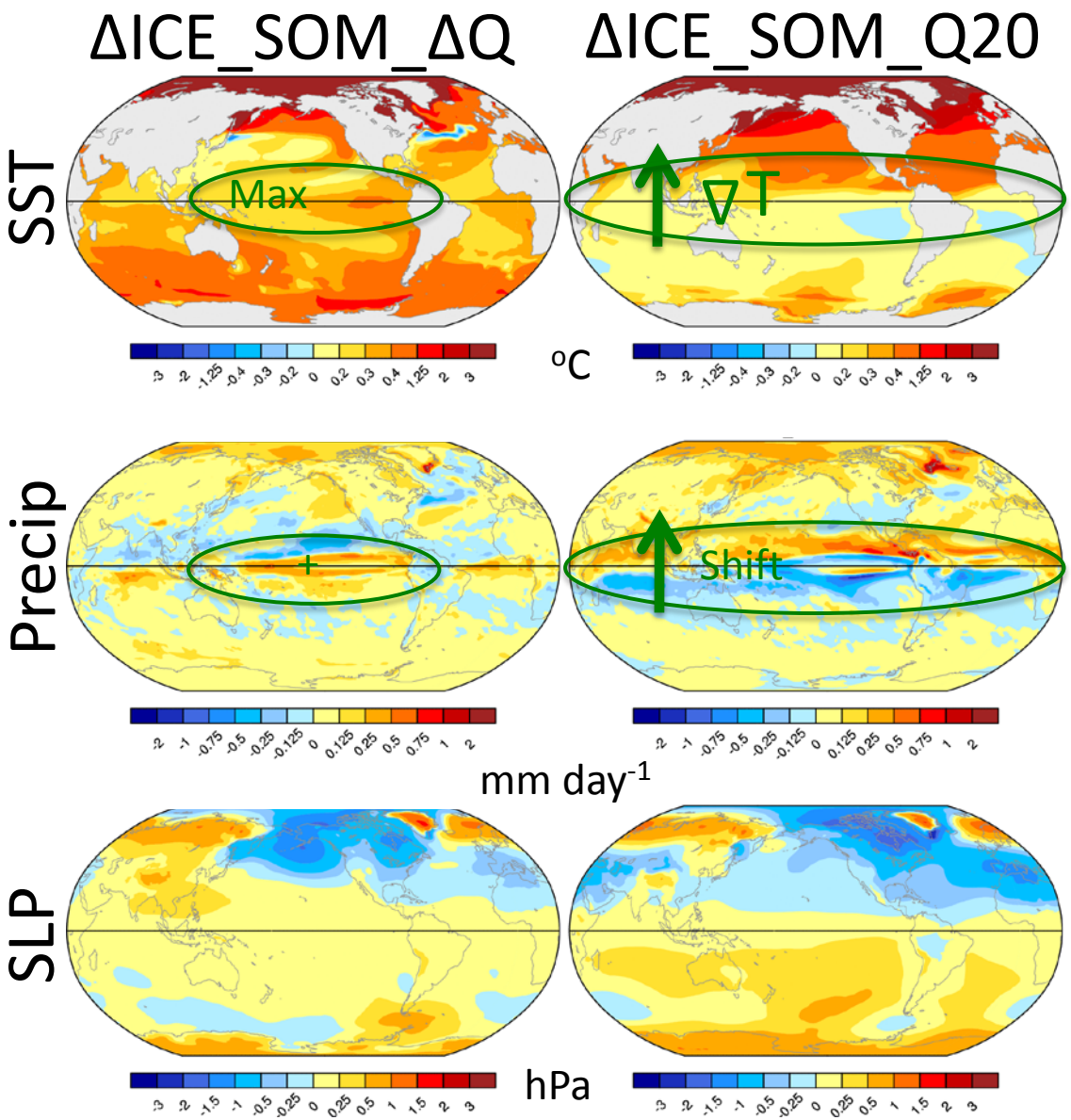
SOM Annual Surface Climate Response

w/ΔOHT



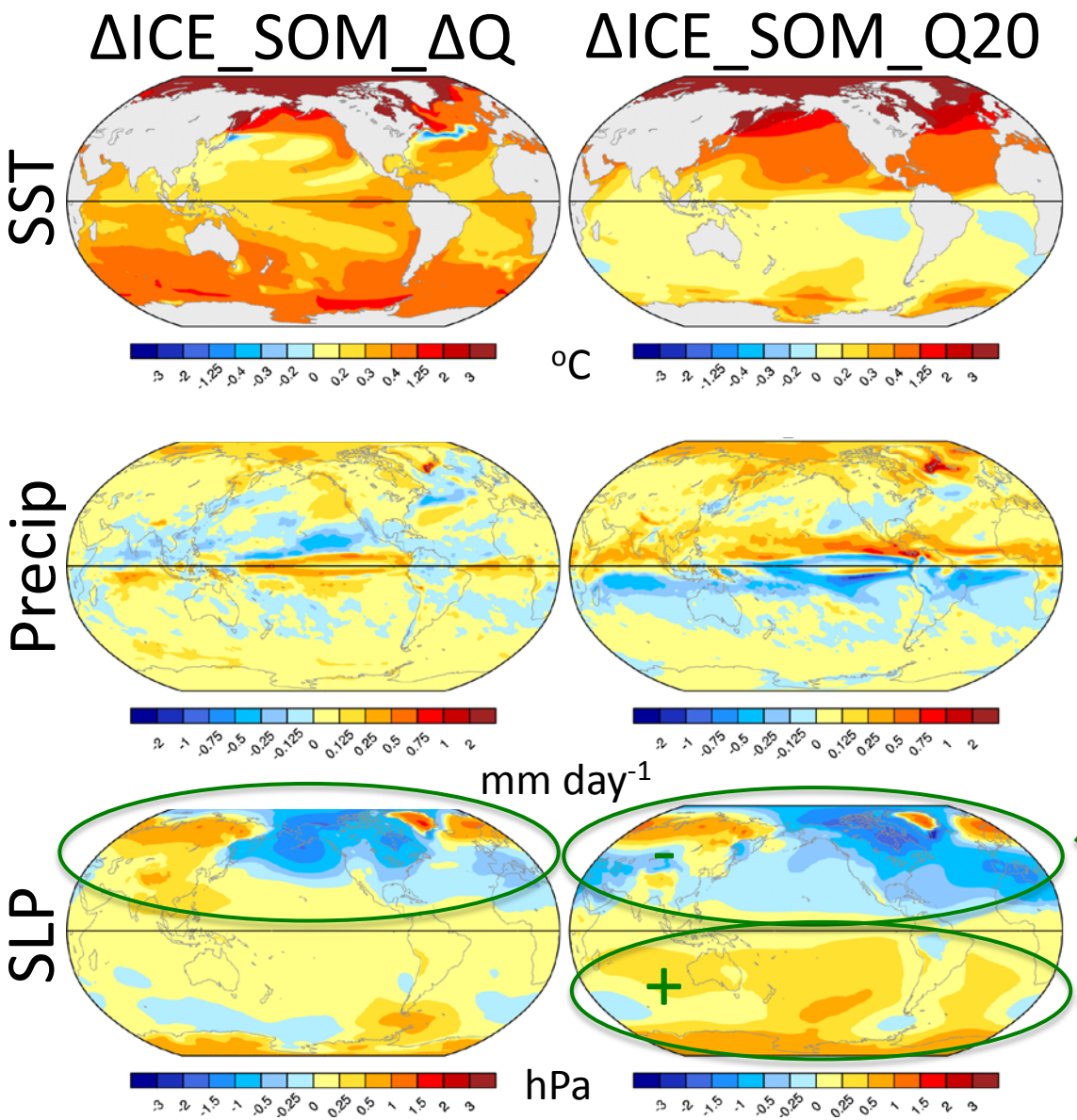
ΔOHT in fully coupled simulation explains symmetric global response

SOM Annual Surface Response to Arctic Sea Ice Loss



ΔOHT in fully coupled simulation explains symmetric global response

SOM Annual Surface Response to Arctic Sea Ice Loss

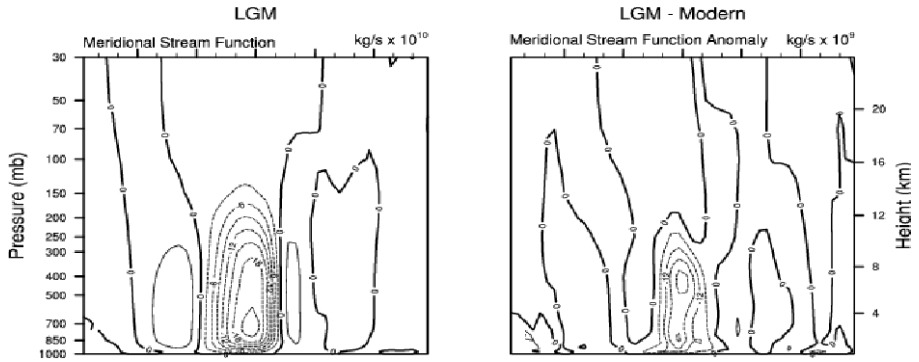


ΔOHT in fully coupled simulation explains symmetric global response

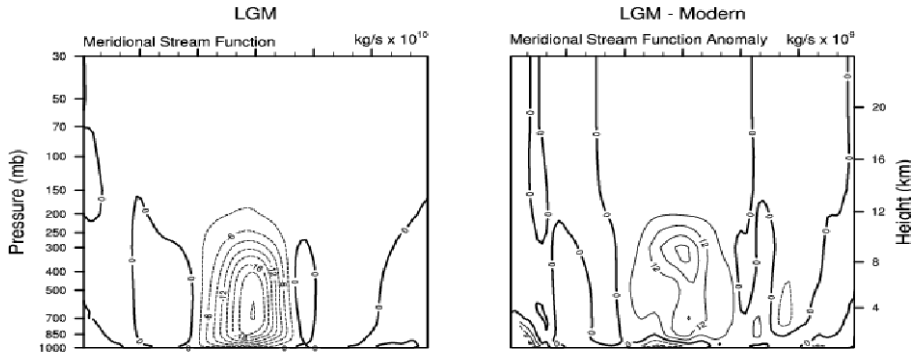
LGM: JJA Hadley Cell Response using FOM & SOM

- Ice sheets over NA and Europe
- Reduce GHG

FOM - CSM



SOM - GFDL



"The Sensitivity of the Hadley Circulation to Past and Future Forcings in Two Climate Models",Bette Otto-Bliesner and Amy Clement, 2004

FOM: increase in Hadley Circulation

SOM: decrease in Hadley Circulation

"It is suggested that the origin of this different response in the JJA cell is related to the type of ocean model used"

LGM: Tropical SST and Precipitation using SOM

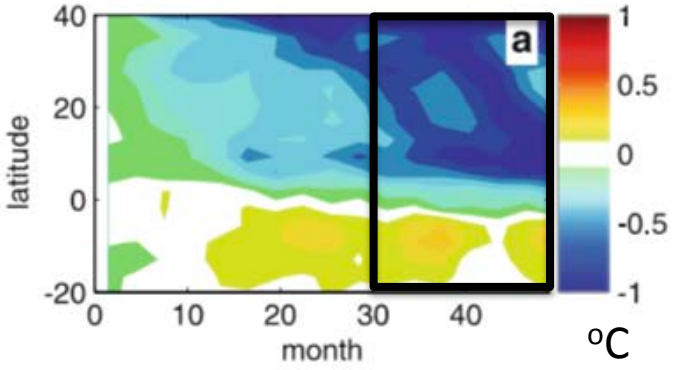
John C. H. Chiang · Cecilia M. Bitz

Influence of high latitude ice cover on the marine Intertropical Convergence Zone

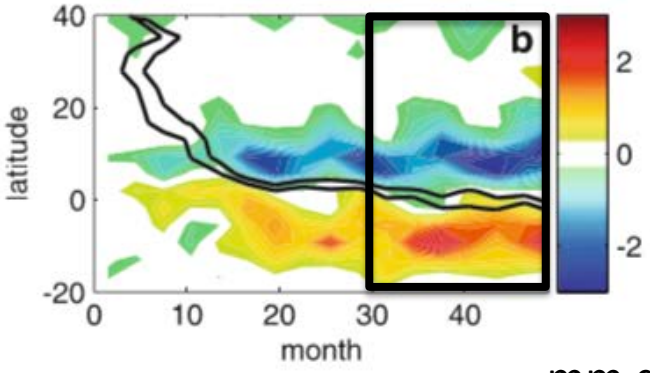
Clim. Dyn. 2005

CCSM3

SST



Precip



- Asymmetric tropical response more cooling NH
- ITCZ shifts away from hemisphere w/ cooling
- This response sets up relatively fast (3-4 years)

LGM: Global TS using FOM & SOM

Last Glacial Maximum and Holocene Climate in CCSM3

BETTE L. OTTO-BLIESNER AND ESTHER C. BRADY

National Center for Atmospheric Research, Boulder, Colorado

GABRIEL CLAUZET

Department of Physical Oceanography, University of São Paulo, São Paulo, Brazil

ROBERT TOMAS, SAMUEL LEVIS, AND ZAV KOTHAVALA

National Center for Atmospheric Research, Boulder, Colorado

J. of Clim. 2006

Ann Surface Temp LMG - PI

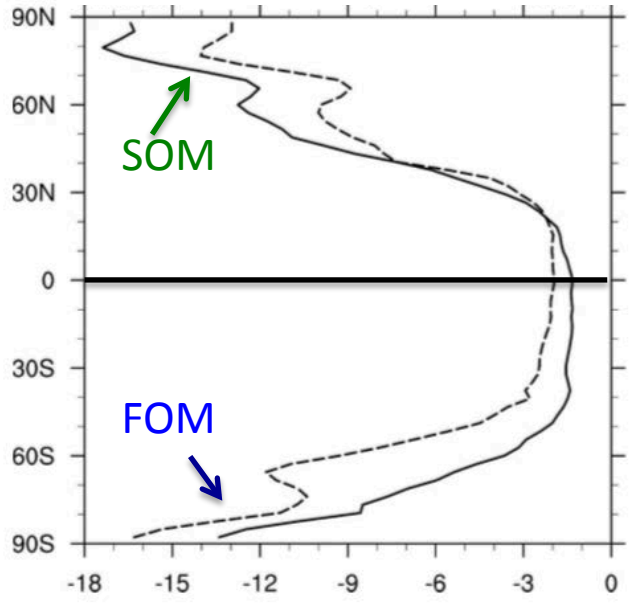


FIG. 4. Zonally averaged surface temperature changes (°C), LGM minus PI, simulated by the slab ocean (solid) and coupled ocean (dashed) versions of CCSM3.

FOM: more symmetric response, ~same cooling in NH & SH

SOM: Asymmetric response, NH cooler, than SH

Similar to Hewitt et al., 2003

Summary & Conclusions

- These results highlight the global interconnectivity inherent in the coupled climate system

- Arctic sea ice loss induces a remote global and tropical response via ocean heat transport changes (FOM)

- Without ocean heat transport (SOM), the global and tropical responses differ considerably

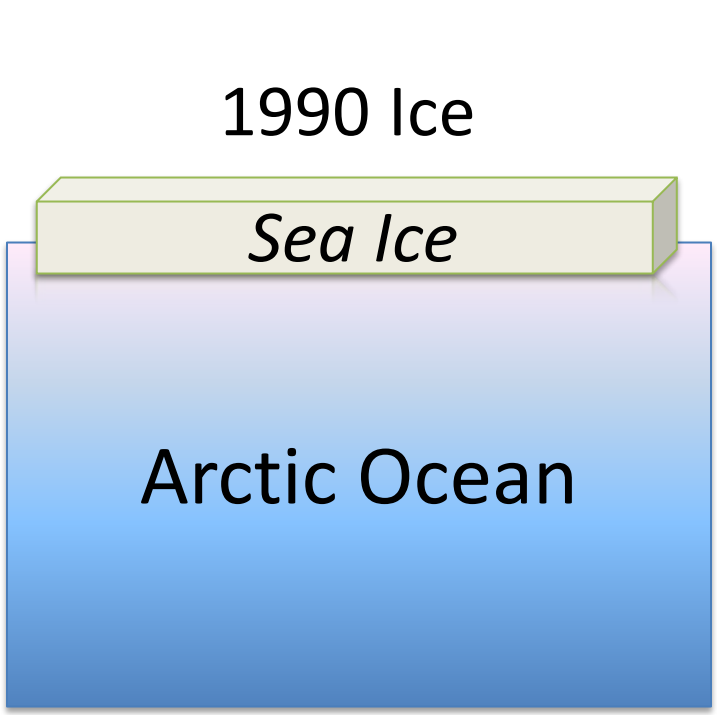
- These results suggest that studies based on slab ocean-models may potentially misconstrue the true nature of
- the equilibrium global climate response to a given forcing, including those relevant for paleo climate applications

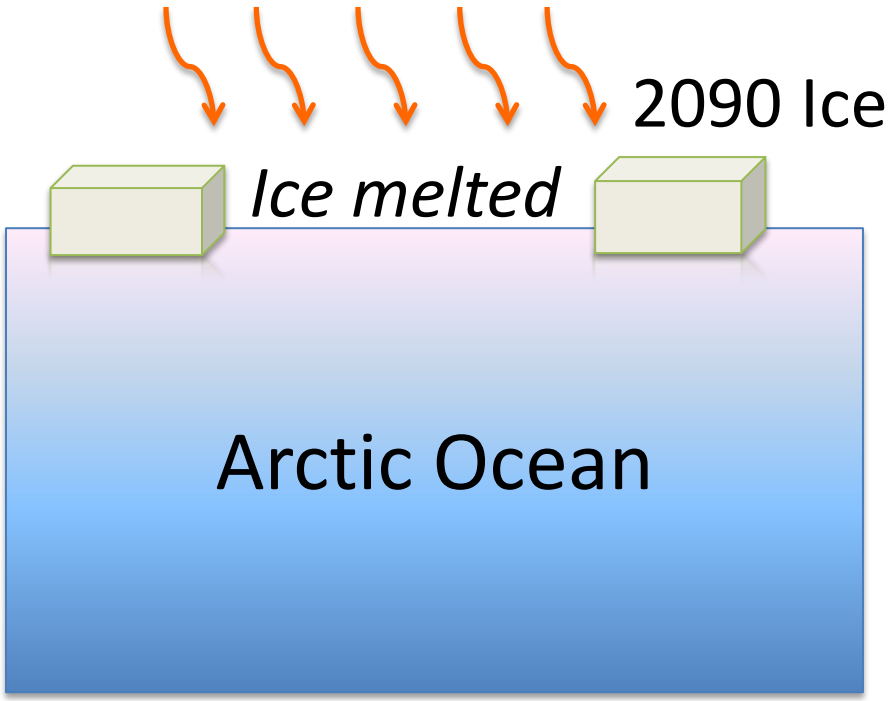
Artificially Control Ice

Only ice “sees” the extra long wave

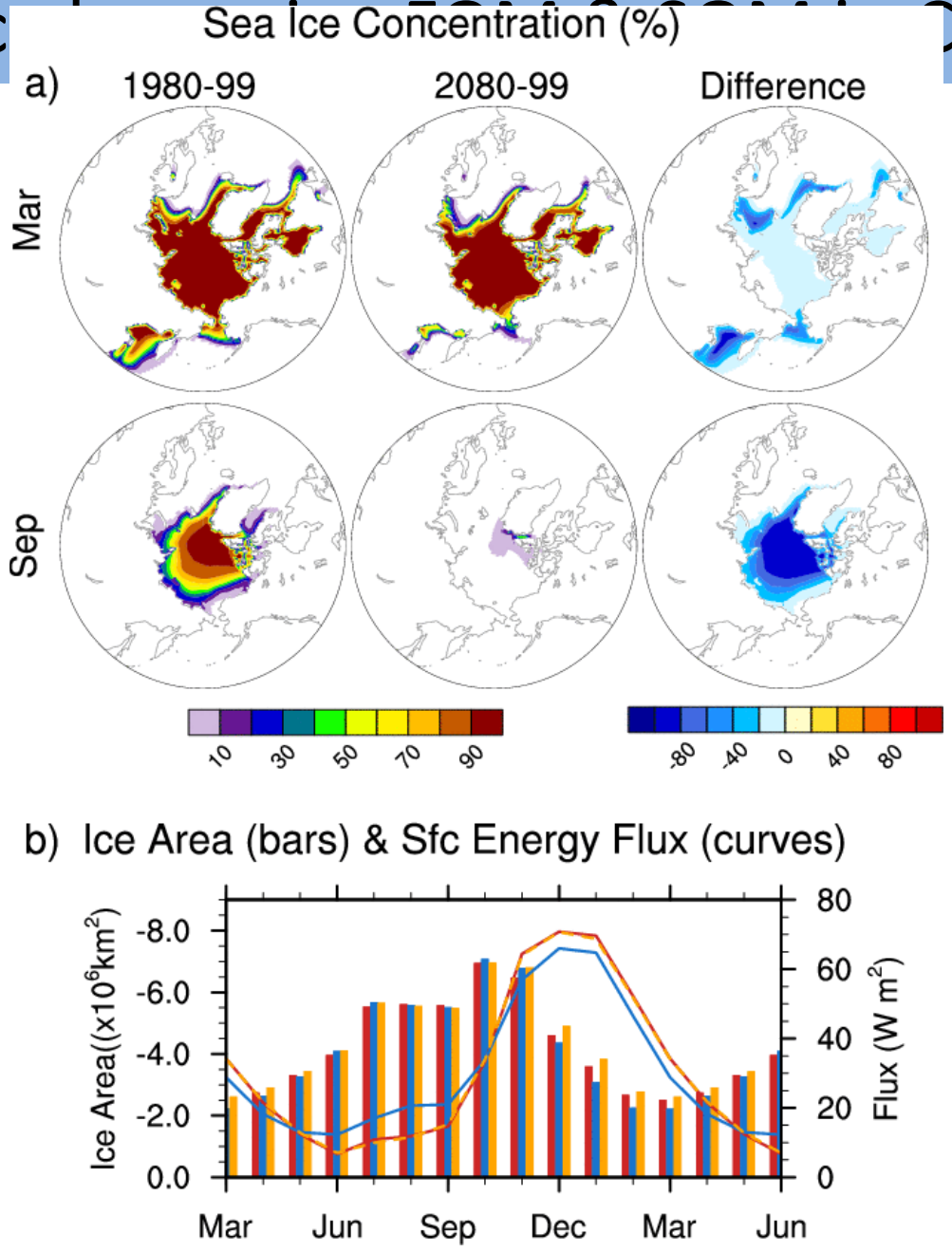
Want to remove some ice cover?

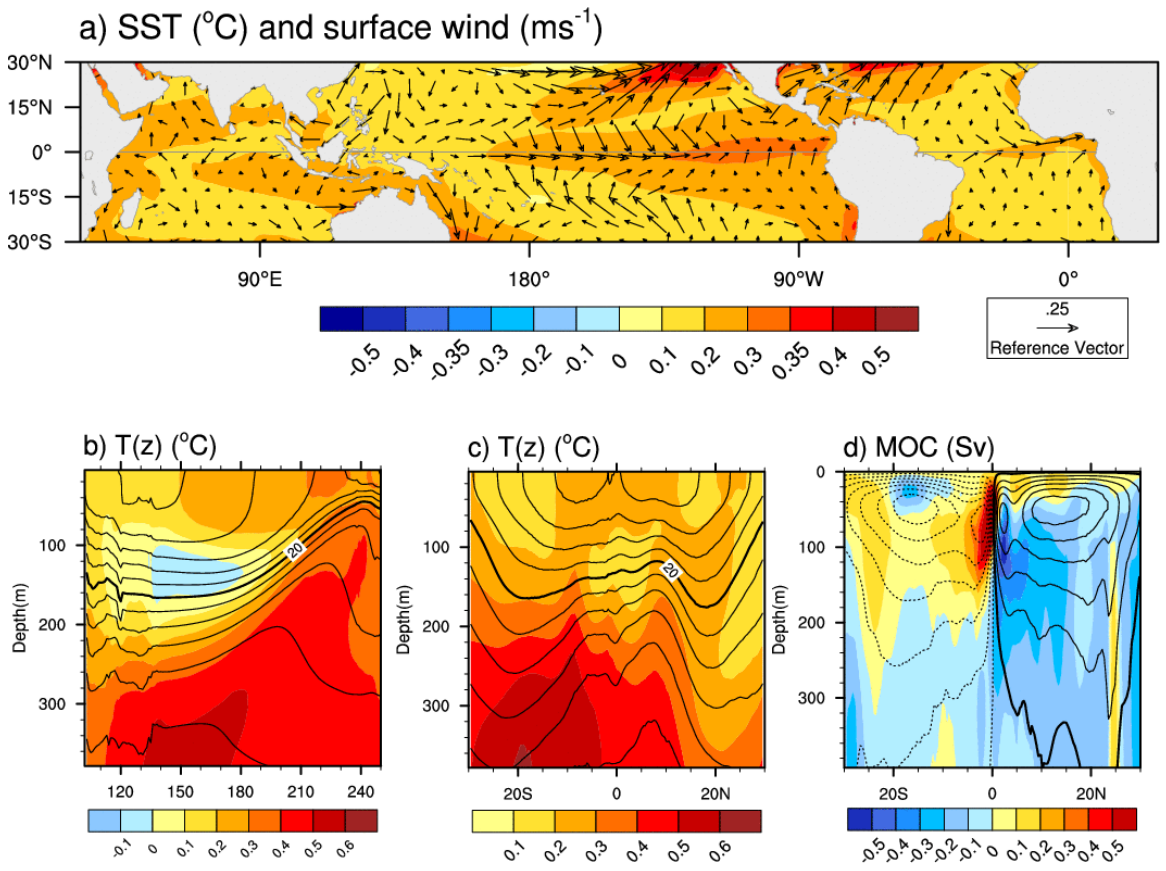
Add long wave radiation into ice model code

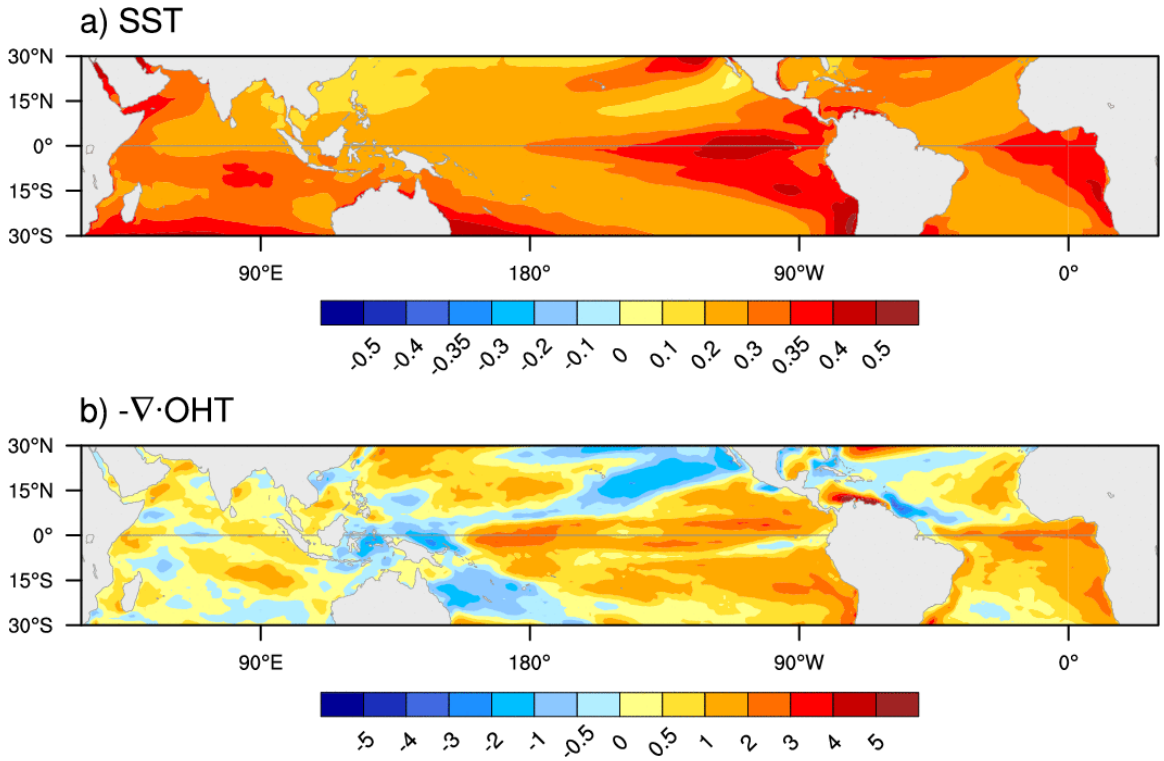




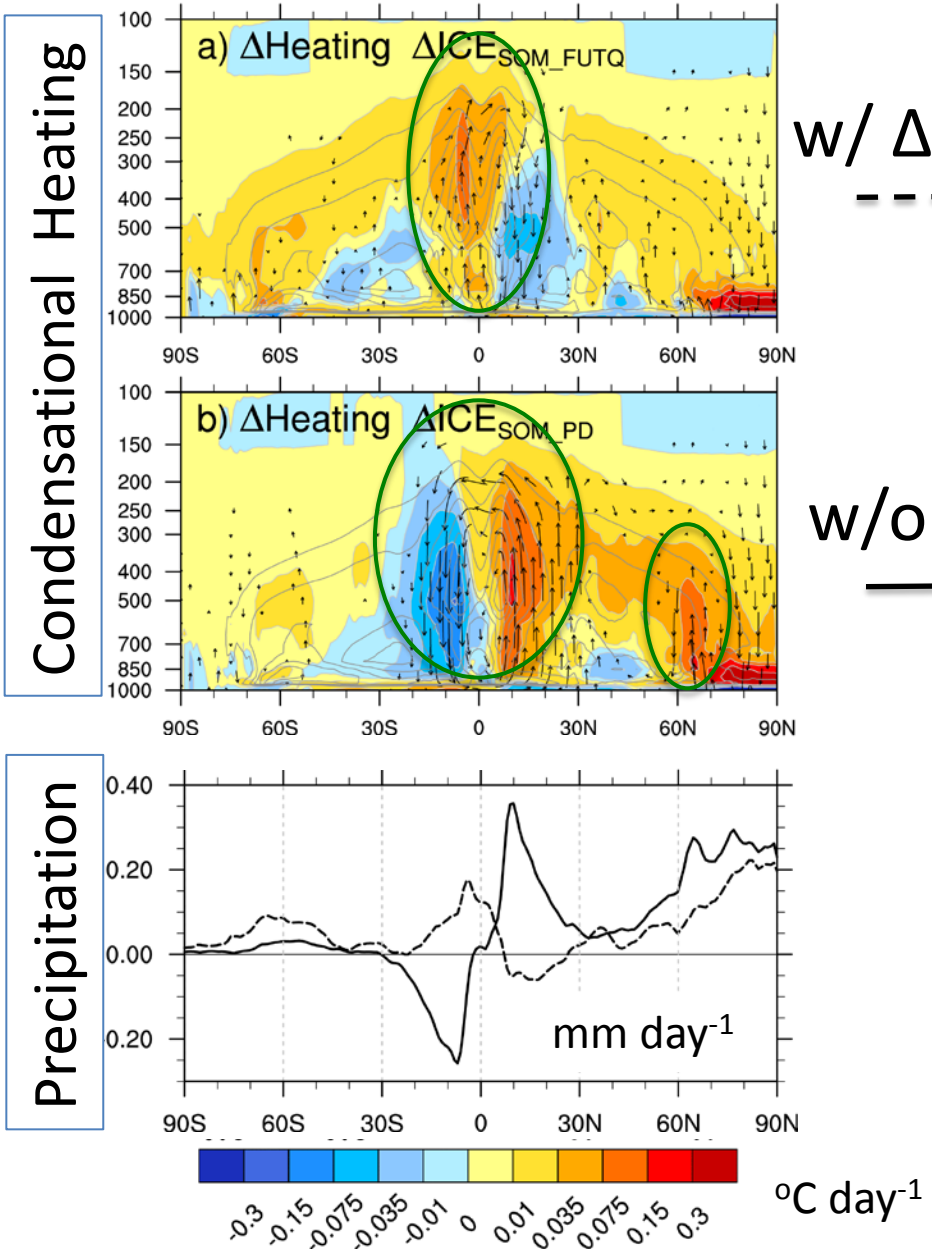
Arctic sea-ic CCSM4




a) SST (°C) and surface wind (ms-1)
30°N
15°N
0°
15°S
30°S
90°E
180°
90°W
0°
-0.5 -0.4 -0.35 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.35 0.4 0.5
.25
Reference Vector
b) T(z) (°C)
Depth(m)
100
200
300
20
120 150 180 210 240
-0.1 0 0.1 0.2 0.3 0.4 0.5 0.6
c) T(z) (°C)
Depth(m)
100
200
300
20
20S 0 20N
0.1 0.2 0.3 0.4 0.5 0.6
d) MOC (Sv)
Depth(m)
0
100
200
300
20S 0 20N
-0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5


a) SST
30°N
15°N
0°
15°S
30°S
90°E
180°
90°W
0°
-0.5
-0.4
-0.35
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.35
0.4
0.5
b) -∇·OHT
30°N
15°N
0°
15°S
30°S
90°E
180°
90°W
0°
-5
-4
-3
-2
-1
-0.5
0
0.5
1
2
3
4
5

SOM Annual Zonal Mean Response to Arctic Sea Ice Loss



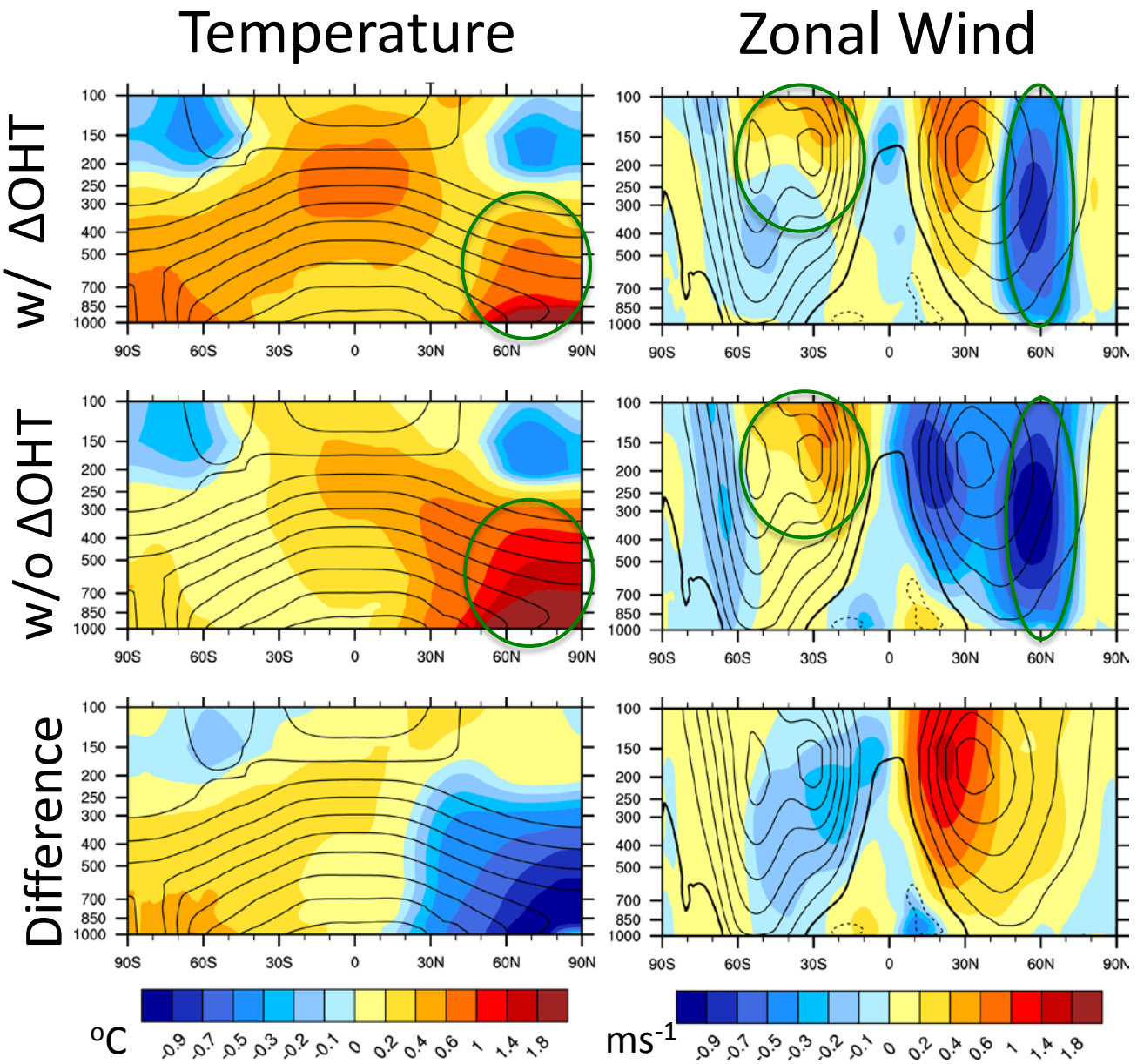
w/ ΔOHT

w/o ΔOHT

w/ ΔOHT: precip. increases slightly equatorward & above clim. maxima

w/o ΔOHT: ITCZ "shifts" into NH - transports energy from NH -> SH

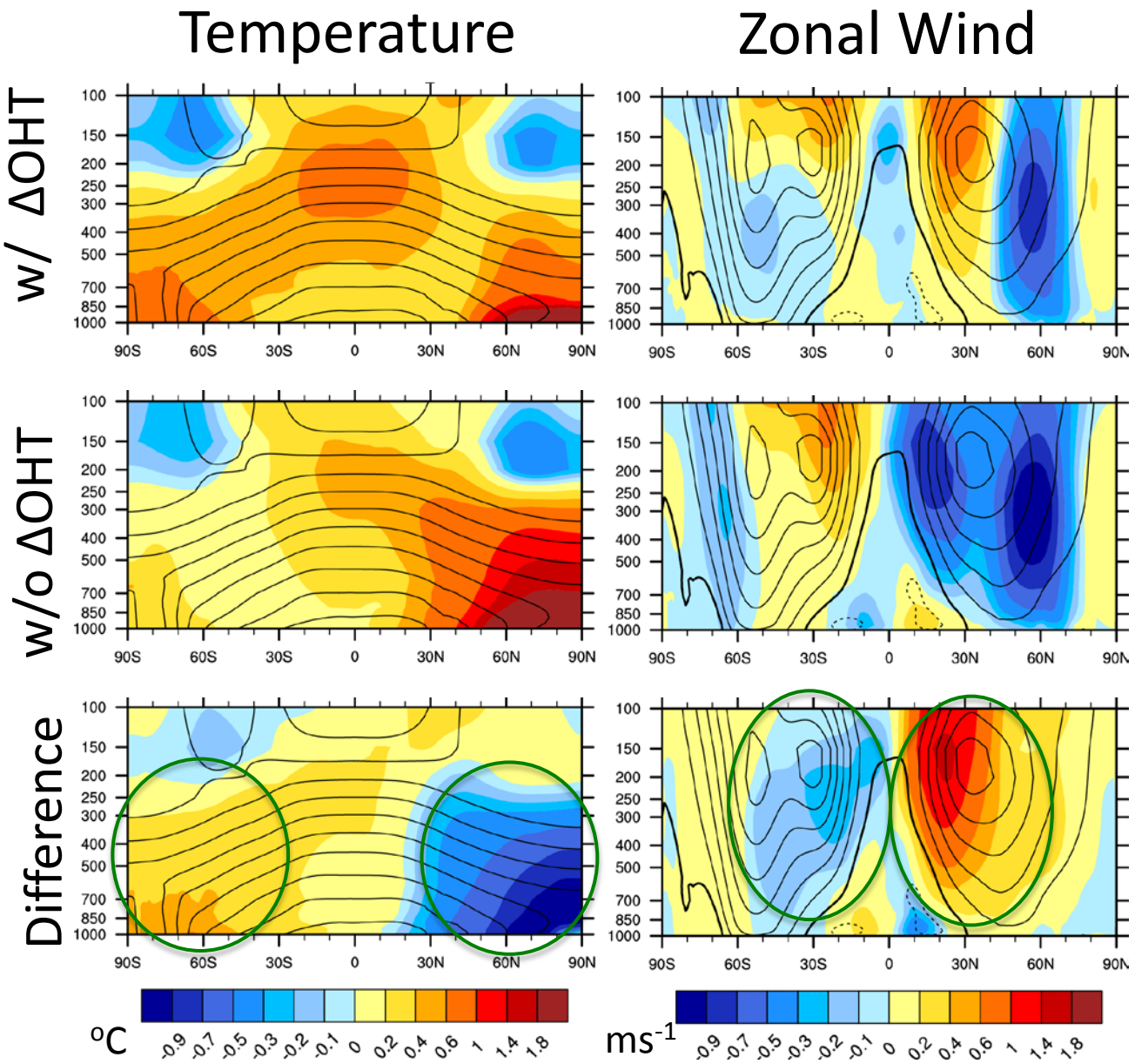
SOM Annual Zonal Mean Response to Arctic Sea Ice Loss



Some common features in troposphere response …

Role of ΔOHT

SOM Annual Zonal Mean Response to Arctic Sea Ice Loss



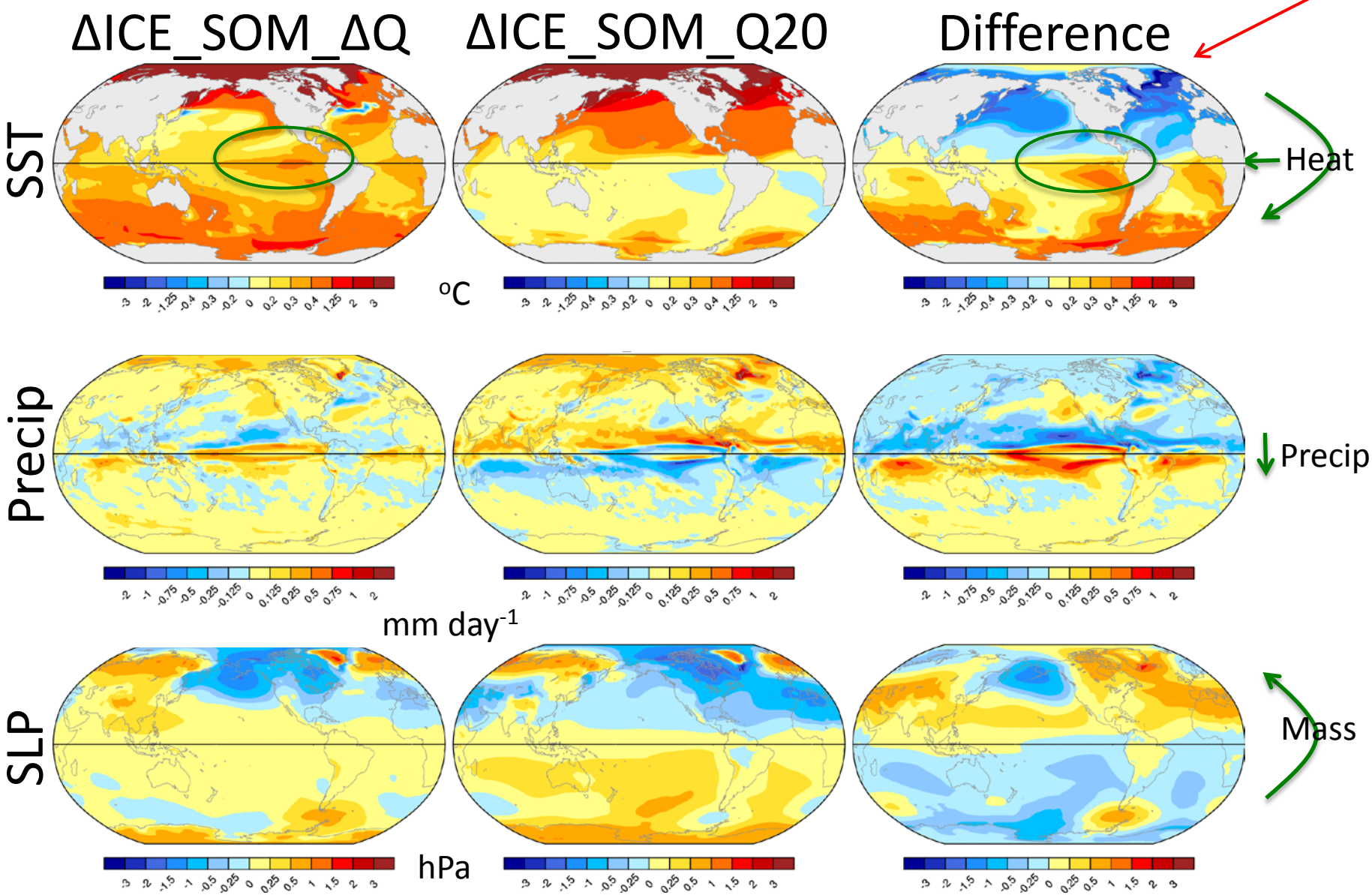
… also differences

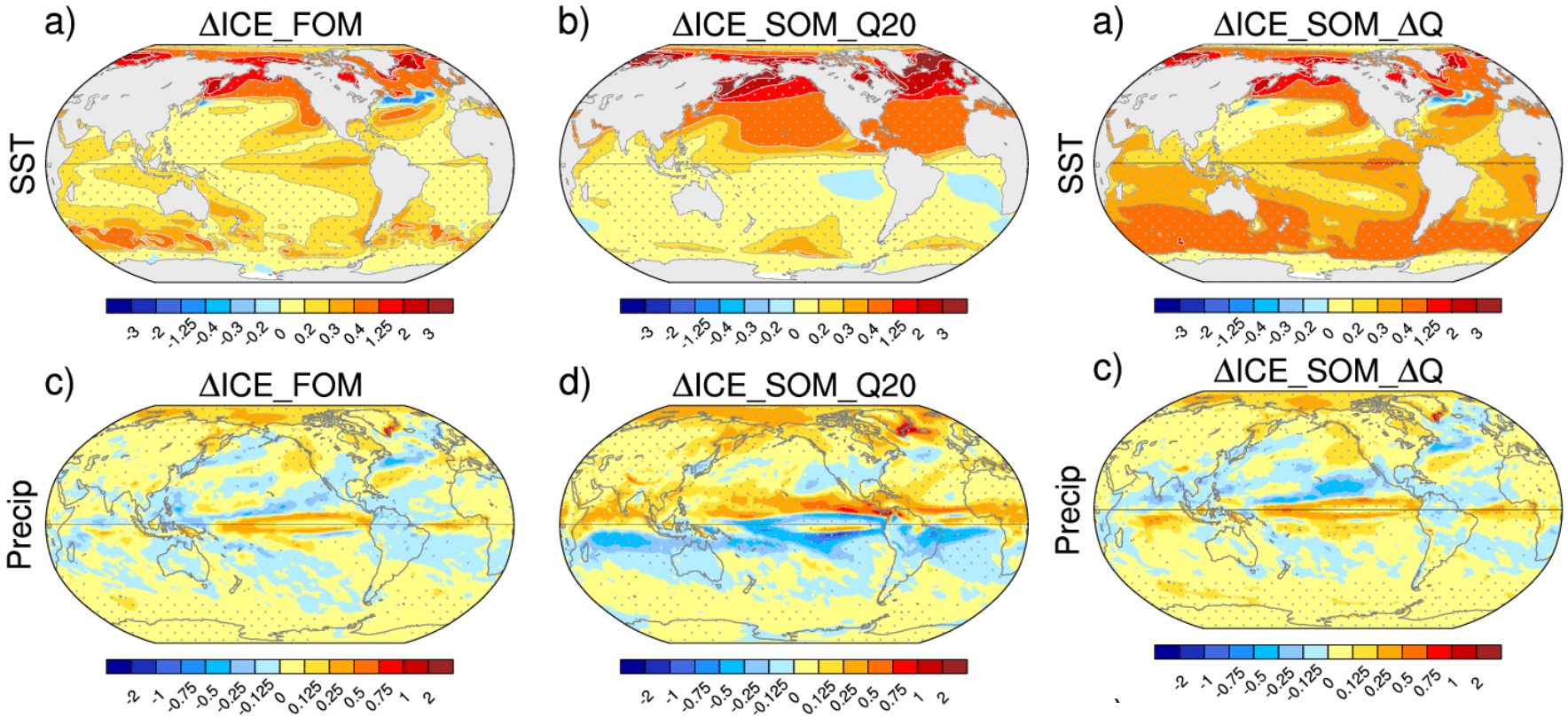
ΔOHT impacts climate response throughout troposphere

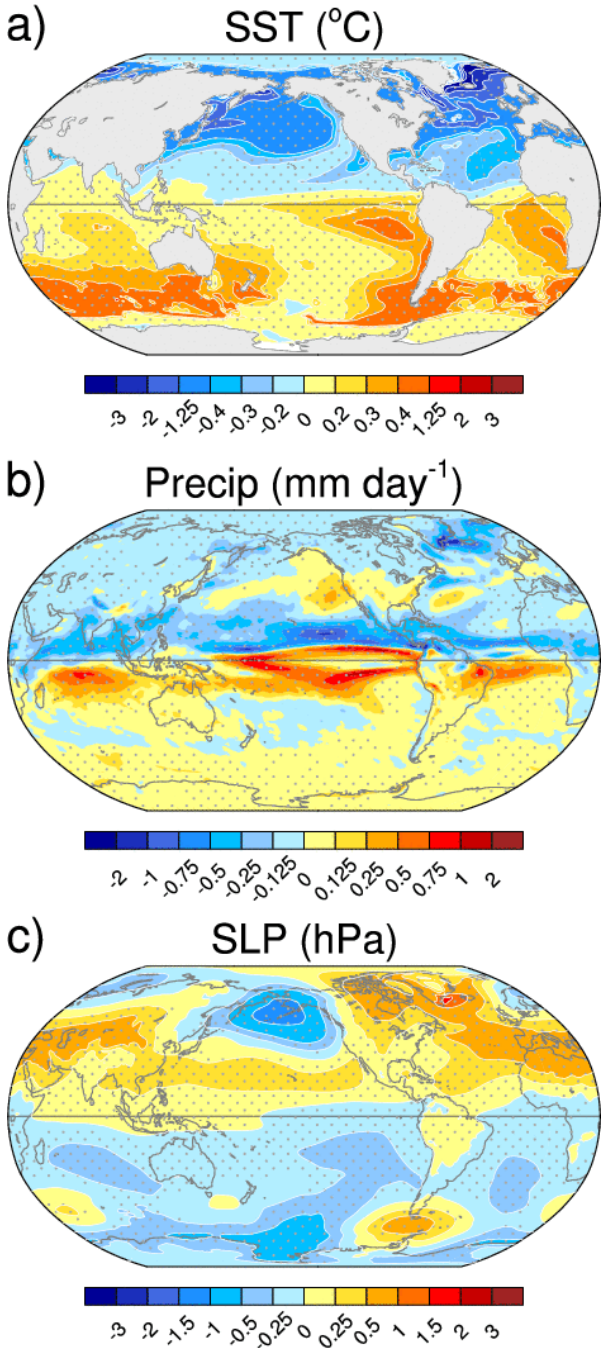
Role of ΔOHT

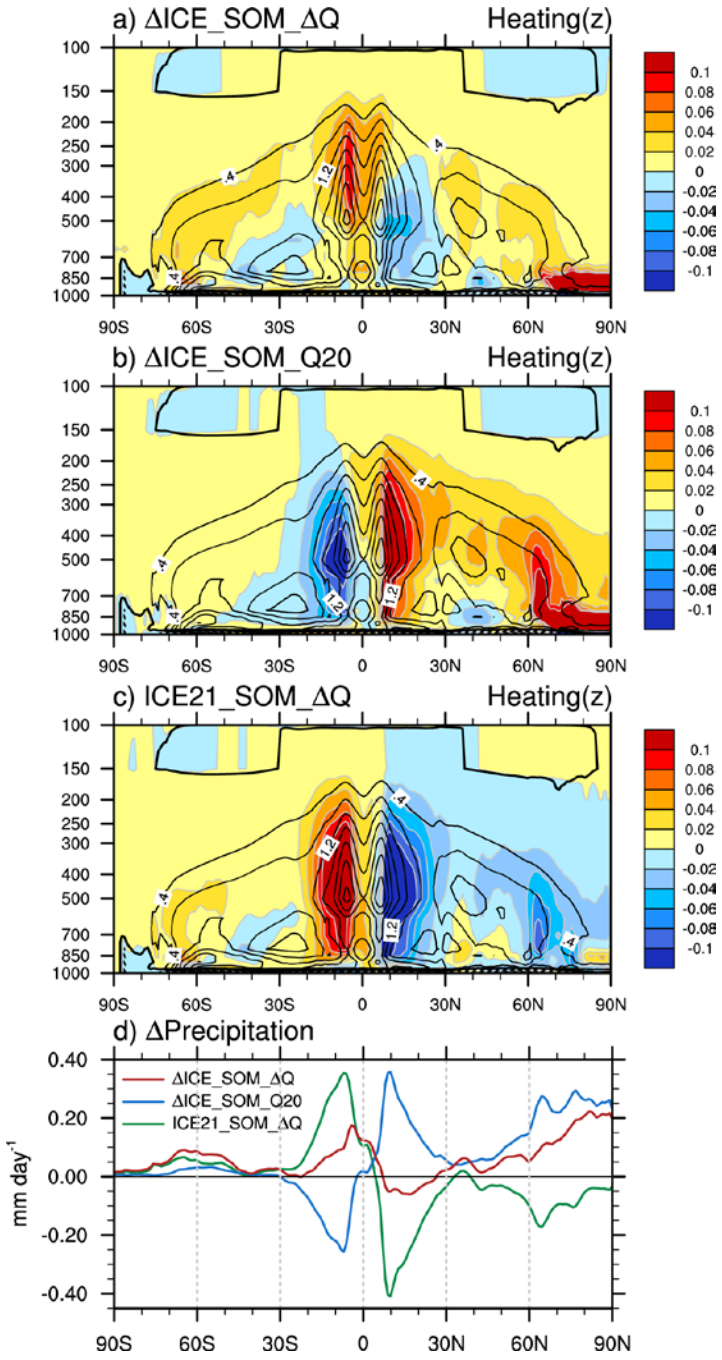
SOM Annual Surface Response to Arctic Sea Ice Loss

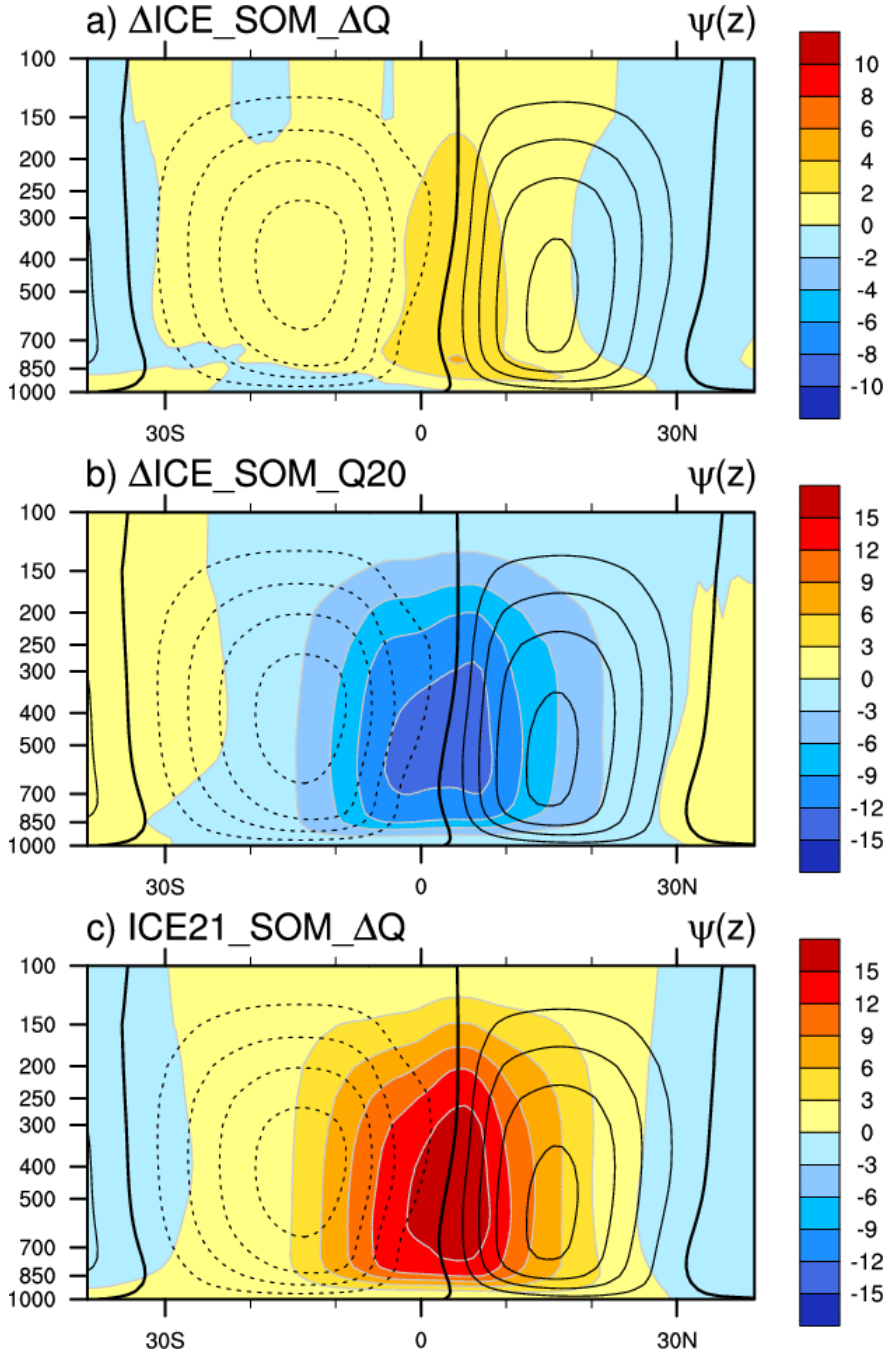
Role of ΔOHT

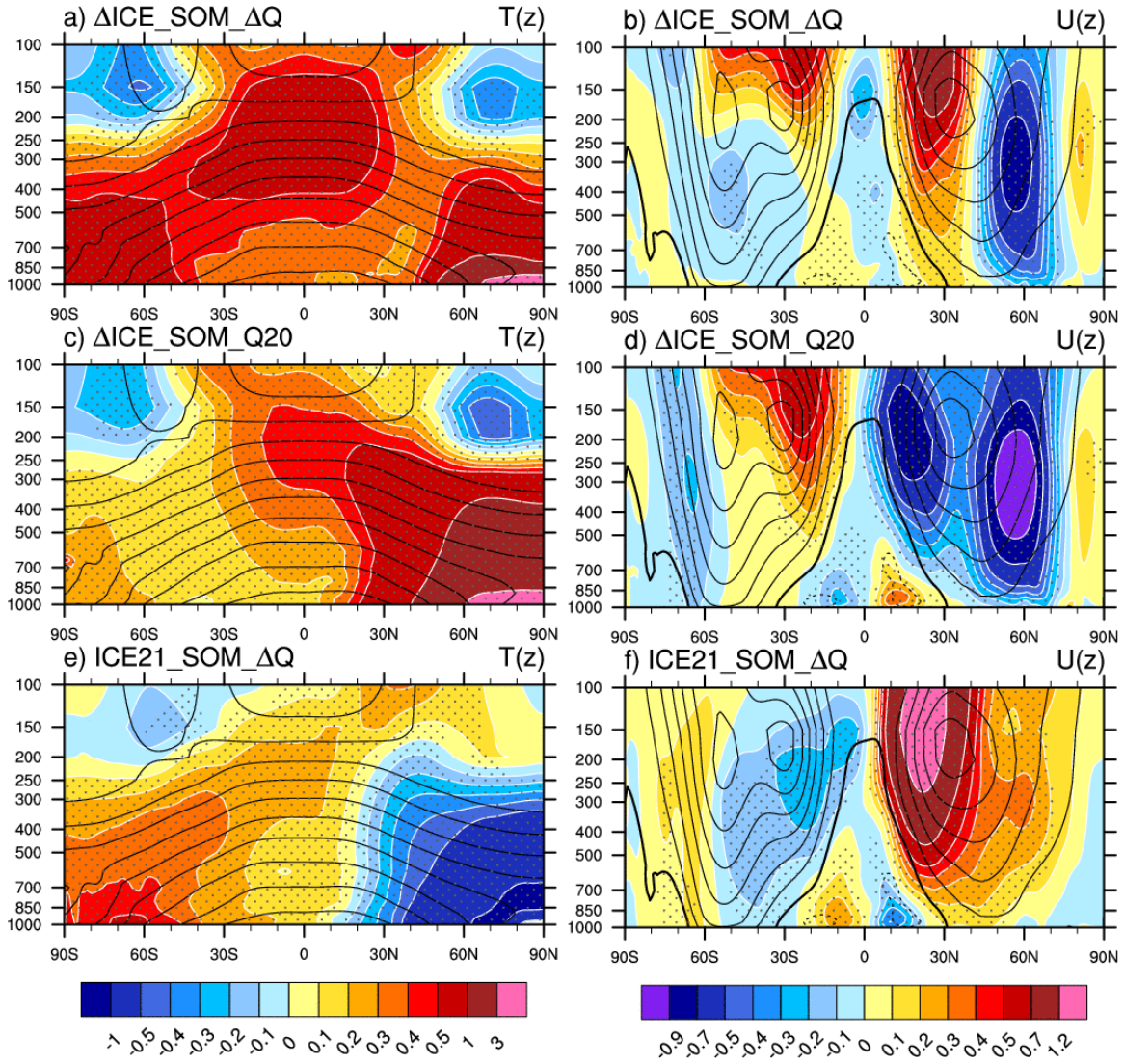


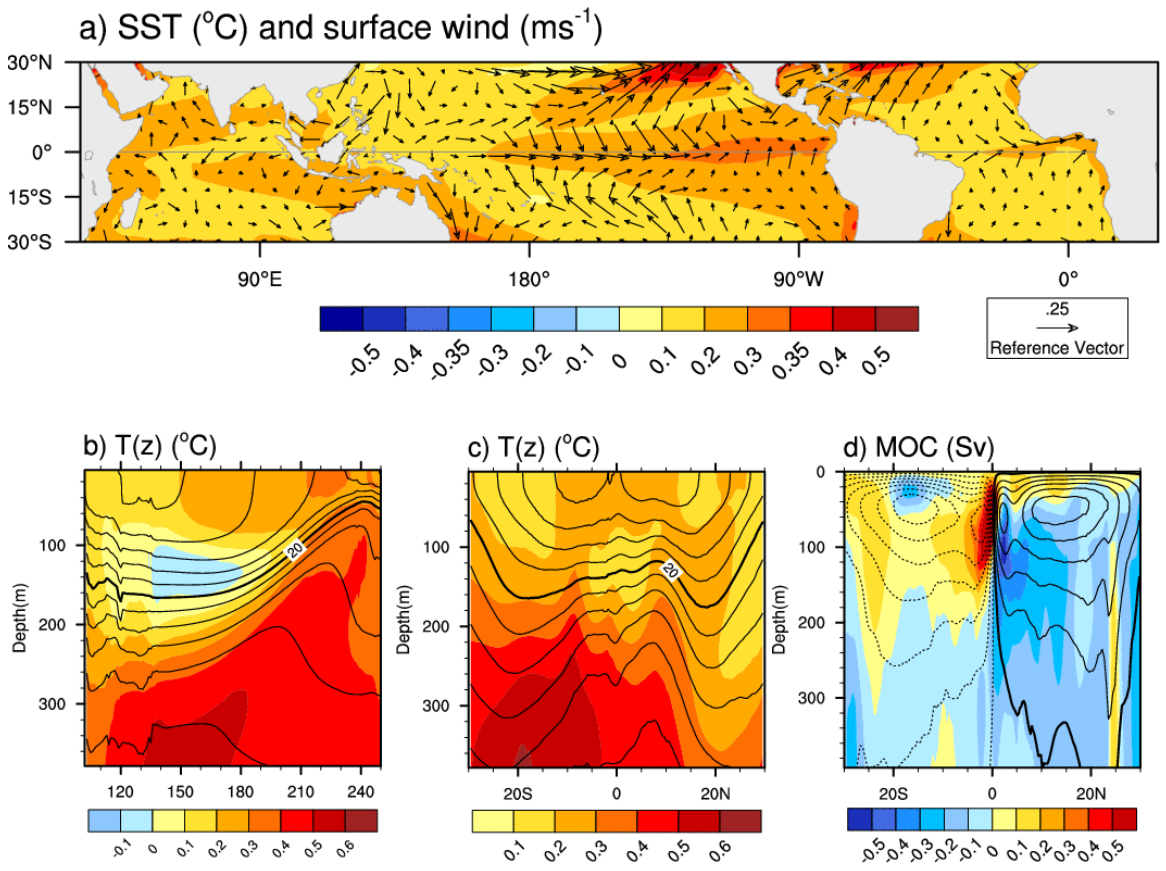

a)
ΔICE_FOM
b)
ΔICE_SOM_Q20
a)
ΔICE_SOM_ΔQ
SST
-3 -2 -1.25 -0.4 -0.3 -0.2 0 0.2 0.3 0.4 1.25 2 3
c)
ΔICE_FOM
d)
ΔICE_SOM_Q20
c)
ΔICE_SOM_ΔQ
Precip
-2 -1 -0.75 -0.5 -0.25 -0.125 0 0.125 0.25 0.5 0.75 1 2

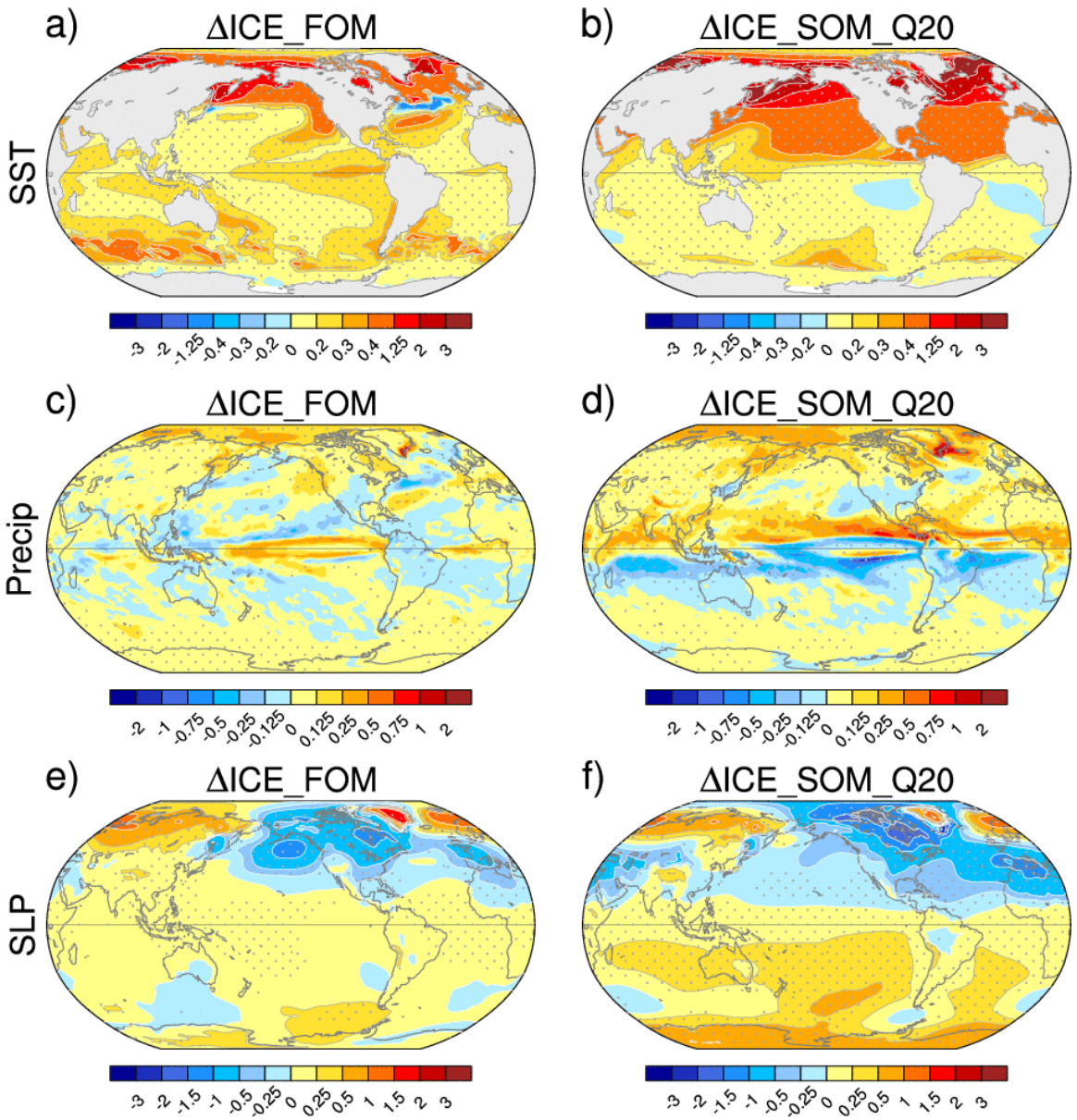

a)
SST (°C)
-3 -2 -1.25 -0.4 -0.3 -0.2 0 0.2 0.3 0.4 1.25 2 3
b)
Precip (mm day-1)
-2 -1 -0.75 -0.5 -0.25 -0.125 0 0.125 0.25 0.5 0.75 1 2
c)
SLP (hPa)
-3 -2 -1.5 -1 -0.5 -0.25 0 0.25 0.5 1 1.5 2 3

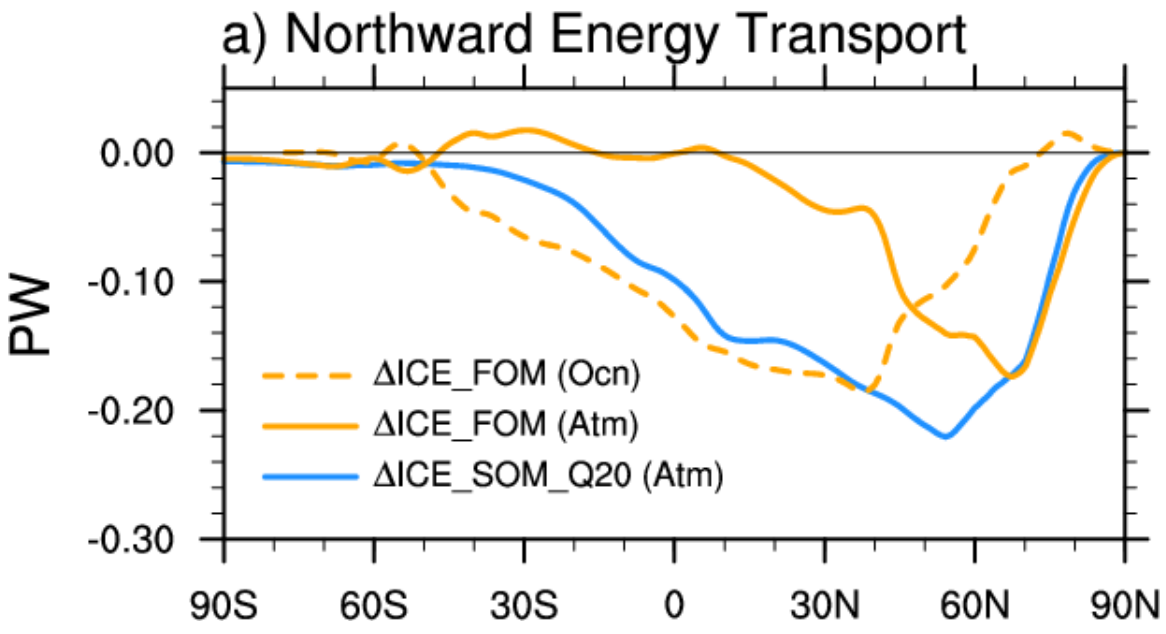

a) ΔICE_SOM_ΔQ
Heating(z)
b) ΔICE_SOM_Q20
Heating(z)
c) ICE21_SOM_ΔQ
Heating(z)
100
150
200
250
300
400
500
700
850
1000
90S
60S
30S
0
30N
60N
90N
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
d) ΔPrecipitation
ΔICE_SOM_ΔQ
ΔICE_SOM_Q20
ICE21_SOM_ΔQ
mm day-1
0.40
0.20
0.00
-0.20
-0.40

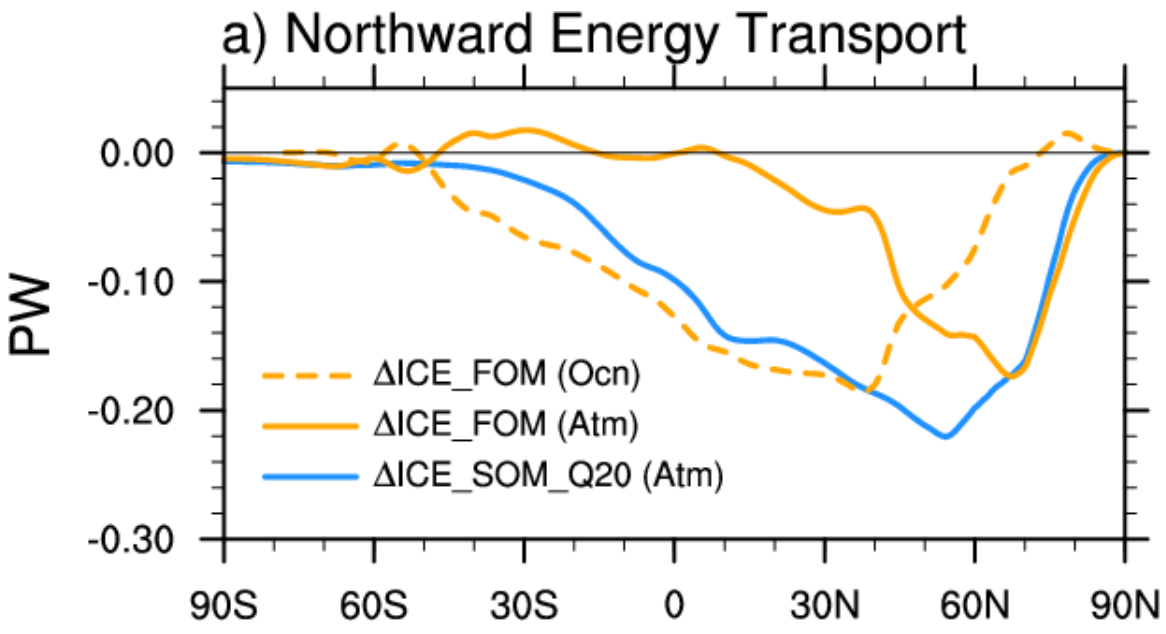

a) ΔICE_SOM_ΔQ
ψ(z)
100
150
200
250
300
400
500
700
850
1000
30S
0
30N
10
8
6
4
2
0
-2
-4
-6
-8
-10
b) ΔICE_SOM_Q20
ψ(z)
100
150
200
250
300
400
500
700
850
1000
30S
0
30N
15
12
9
6
3
0
-3
-6
-9
-12
-15
c) ICE21_SOM_ΔQ
ψ(z)
100
150
200
250
300
400
500
700
850
1000
30S
0
30N
15
12
9
6
3
0
-3
-6
-9
-12
-15

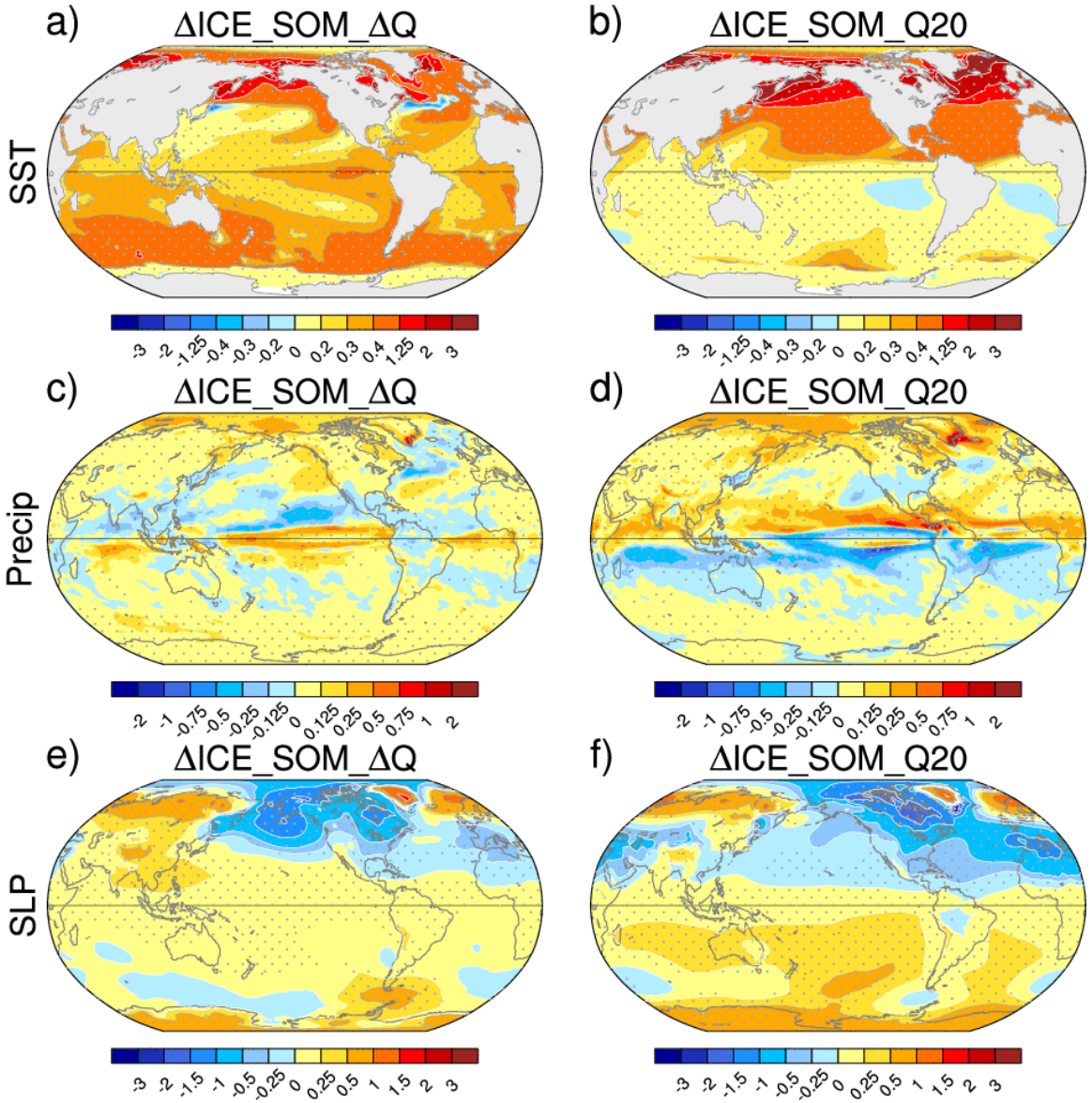

a) ΔICE_SOM_ΔQ
T(z)
b) ΔICE_SOM_ΔQ
U(z)
c) ΔICE_SOM_Q20
T(z)
d) ΔICE_SOM_Q20
U(z)
e) ICE21_SOM_ΔQ
T(z)
f) ICE21_SOM_ΔQ
U(z)
100
150
200
250
300
400
500
700
850
1000
90S
60S
30S
0
30N
60N
90N
-1
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
1
3
-0.9
-0.7
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
0.7
1.2


a) SST (°C) and surface wind (ms-1)
30°N
15°N
0°
15°S
30°S
90°E
180°
90°W
0°
-0.5 -0.4 -0.35 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.35 0.4 0.5
.25
Reference Vector
b) T(z) (°C)
Depth(m)
100
200
300
20
120 150 180 210 240
-0.1 0 0.1 0.2 0.3 0.4 0.5 0.6
c) T(z) (°C)
Depth(m)
100
200
300
20
20S 0 20N
0.1 0.2 0.3 0.4 0.5 0.6
d) MOC (Sv)
Depth(m)
0
100
200
300
20S 0 20N
-0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5


a)
ΔICE_FOM
b)
ΔICE_SOM_Q20
SST
-3 -2 -1.25 -0.4 -0.3 -0.2 0 0.2 0.3 0.4 1.25 2 3
c)
ΔICE_FOM
d)
ΔICE_SOM_Q20
Precip
-2 -1 -0.75 -0.5 -0.25 -0.125 0 0.125 0.25 0.5 0.75 1 2
e)
ΔICE_FOM
f)
ΔICE_SOM_Q20
SLP
-3 -2 -1.5 -1 -0.5 -0.25 0 0.25 0.5 1 1.5 2 3


a) Northward Energy Transport
PW
0.00
-0.10
-0.20
-0.30
90S
60S
30S
0
30N
60N
90N
ΔICE_FOM (Ocn)
ΔICE_FOM (Atm)
ΔICE_SOM_Q20 (Atm)


a) Northward Energy Transport
PW
0.00
-0.10
-0.20
-0.30
90S
60S
30S
0
30N
60N
90N
ΔICE_FOM (Ocn)
ΔICE_FOM (Atm)
ΔICE_SOM_Q20 (Atm)


a)
ΔICE_SOM_ΔQ
b)
ΔICE_SOM_Q20
SST
-3 -2 -1.25 -0.4 -0.3 -0.2 0 0.2 0.3 0.4 1.25 2 3
c)
ΔICE_SOM_ΔQ
d)
ΔICE_SOM_Q20
Precip
-2 -1 -0.75 -0.5 -0.25 -0.125 0 0.125 0.25 0.5 0.75 1 2
e)
ΔICE_SOM_ΔQ
f)
ΔICE_SOM_Q20
SLP
-3 -2 -1.5 -1 -0.5 -0.25 0 0.25 0.5 1 1.5 2 3