Future increases in Arctic precipitation and their effect on the AMOC

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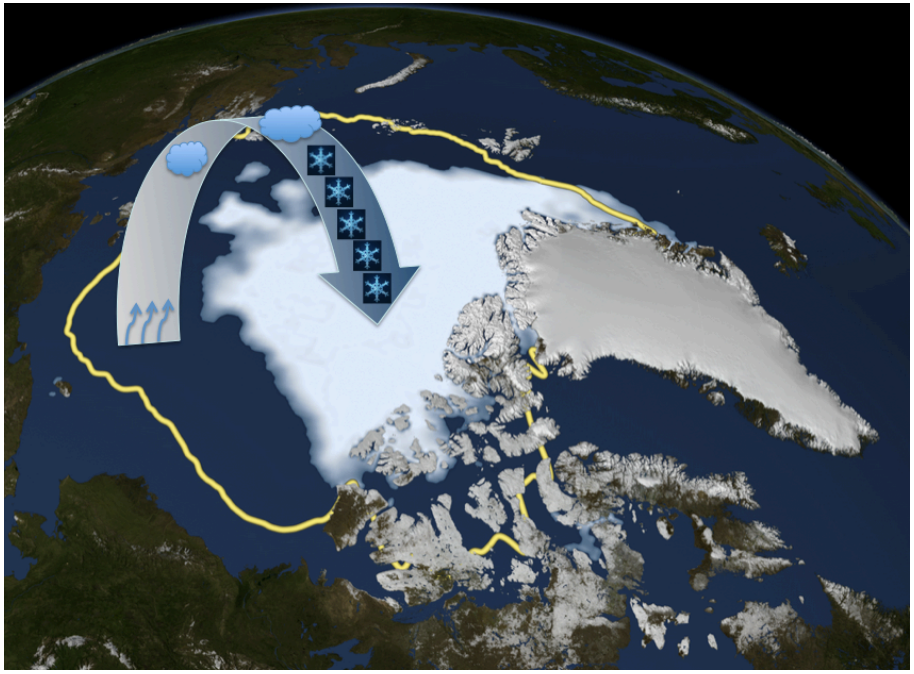
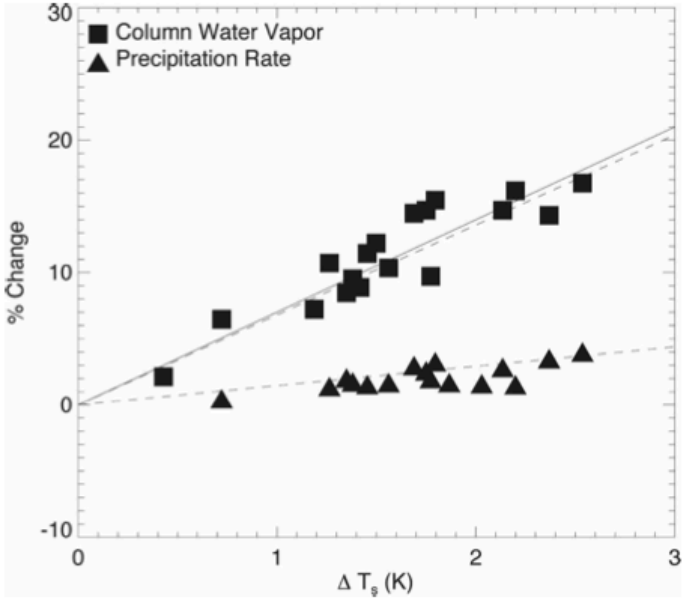


Nature, **509**, 479-482

Precipitation changes – global perspective

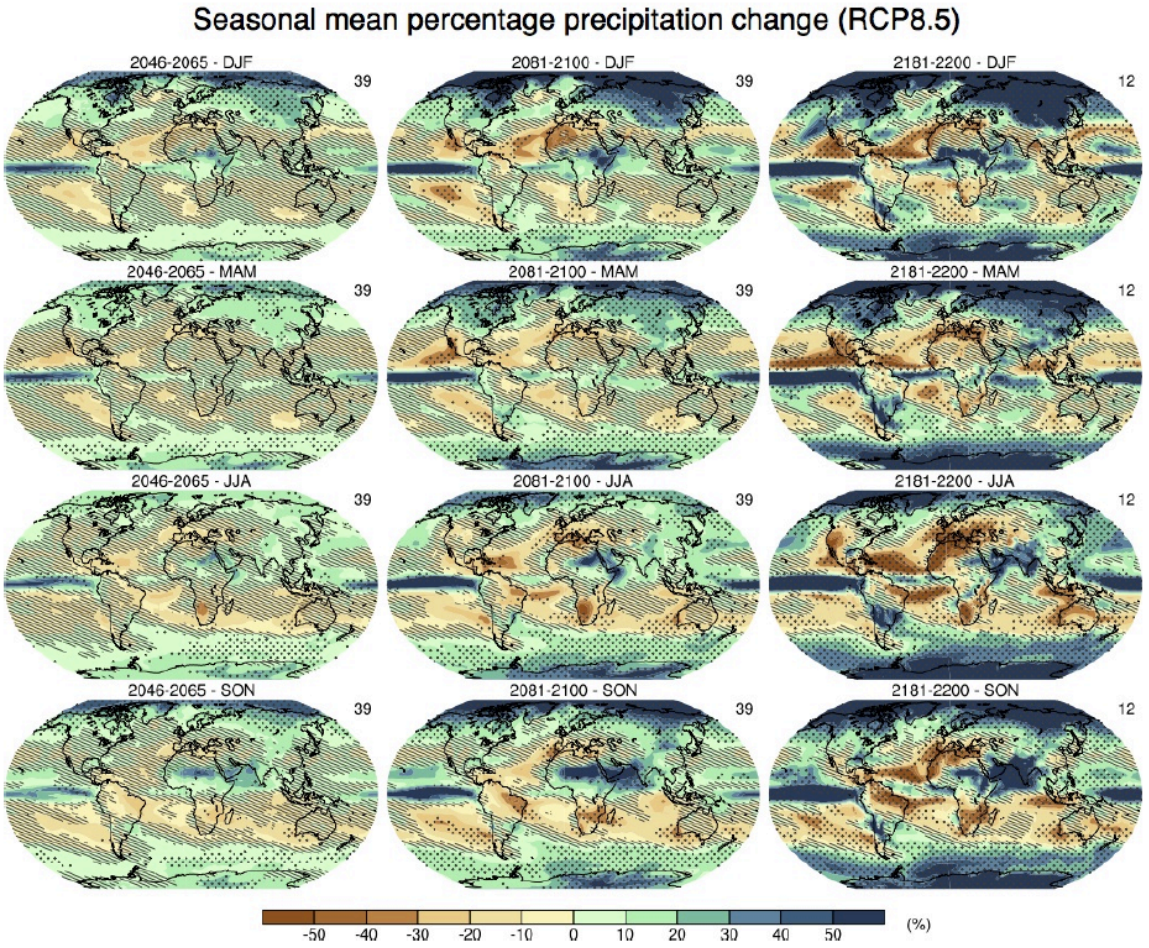


~7 %/K

~2 %/K

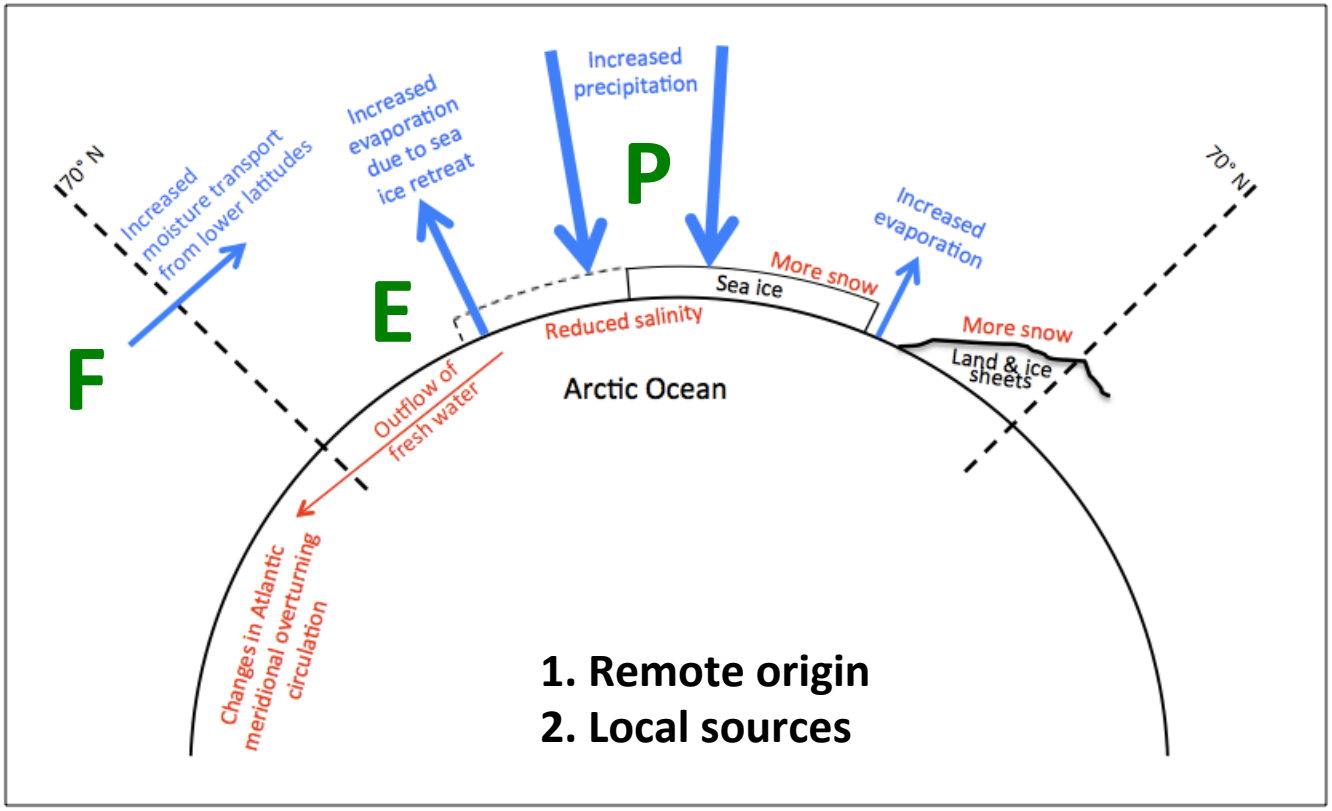
Stephens and Ellis (2008)

Precipitation changes – regional perspective



Collins et al. (2013)

Question: why will Arctic precipitation increase?



Bengtsson et al. (2011): based on ECHAM5 – mainly remote sources

Approach

– Arctic: $\varphi > 70°N$

– 37 CMIP5 models, fields of **E**, **P**, **Q** (**Q** = Arctic atmospheric water content)

– Moisture budget of Arctic atmosphere: $\partial Q/\partial t = F + E - P$

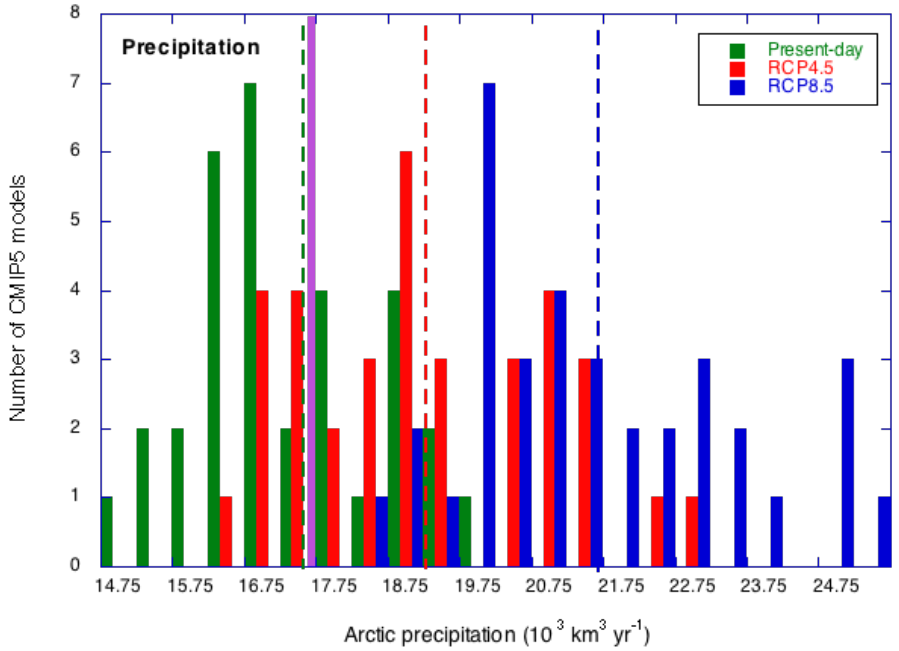
– Moisture holding capacity (**Q**) of Arctic atmosphere is very small

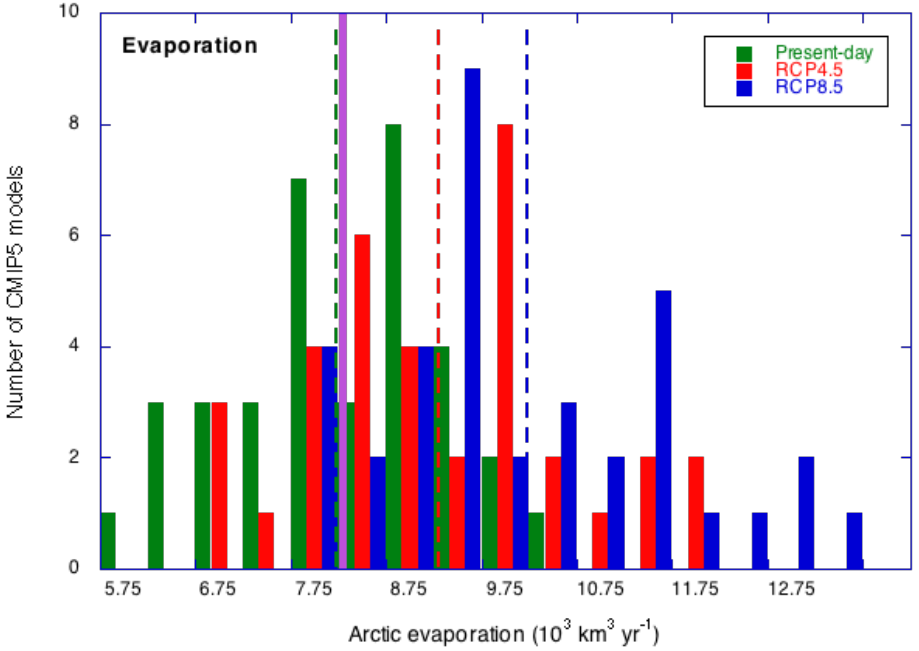
– $\partial Q/\partial t << P, E, F$

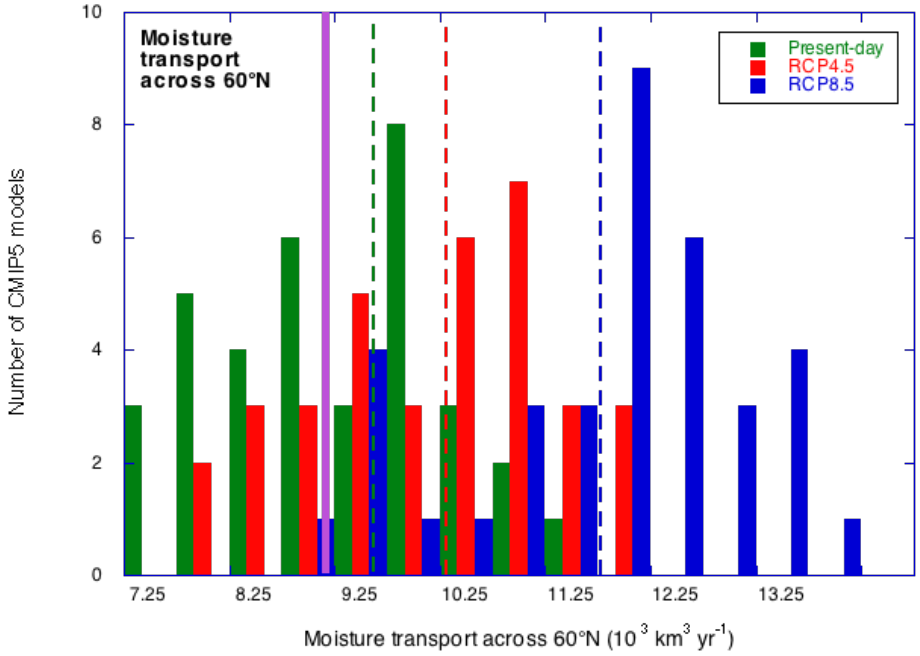
– Hence, **F = P - E** to a very good approximation (Bengtsson et al., 2011)

– Consider present-day (2006-2015), future (2091-2100) for RCP4.5 and RCP8.5

– Changes are defined as future minus present-day

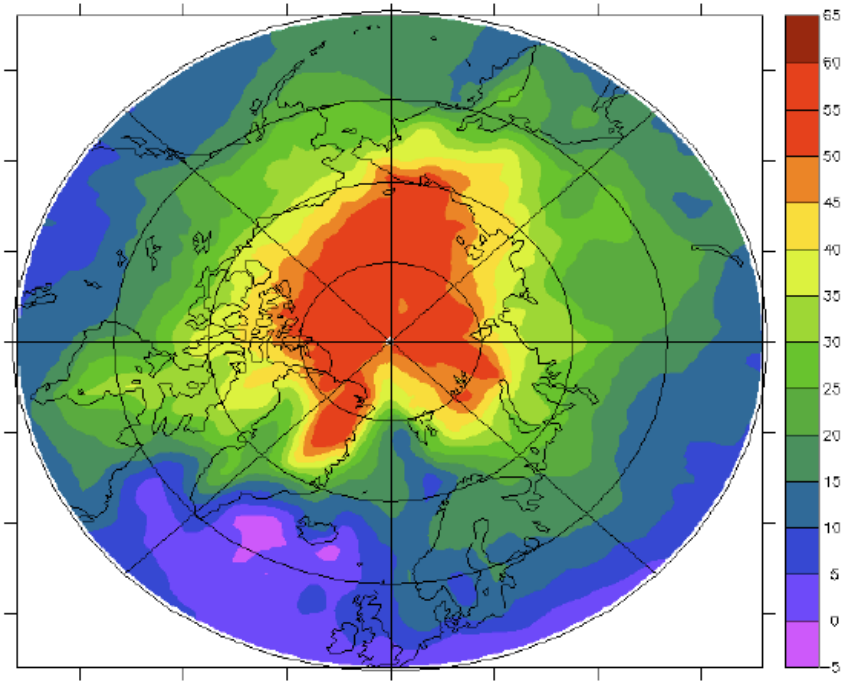

Precipitation
Present-day
RCP4.5
RCP8.5
Number of CMIP5 models
Arctic precipitation (10 3 km3 yr-1)
14.75
15.75
16.75
17.75
18.75
19.75
20.75
21.75
22.75
23.75
24.75


Evaporation
Present-day
RCP4.5
RCP8.5
Number of CMIP5 models
Arctic evaporation (10 3 km3 yr-1)
5.75
6.75
7.75
8.75
9.75
10.75
11.75
12.75

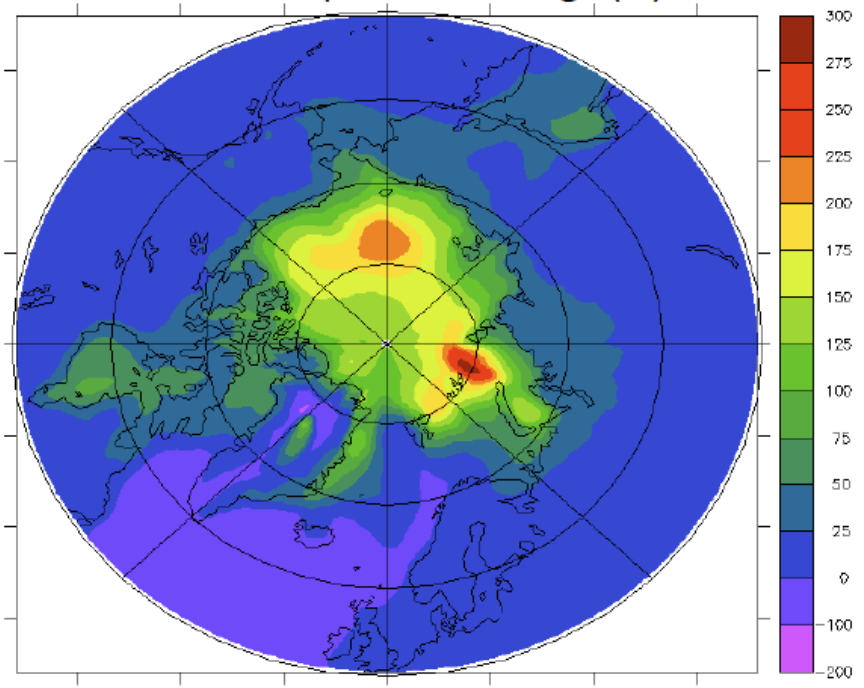

Moisture transport across 60°N
Present-day
RCP4.5
RCP8.5
Number of CMIP5 models
Moisture transport across 60°N (10 3 km3 yr-1)
7.25
8.25
9.25
10.25
11.25
12.25
13.25

Purple = ERA

Precipitation change (%)

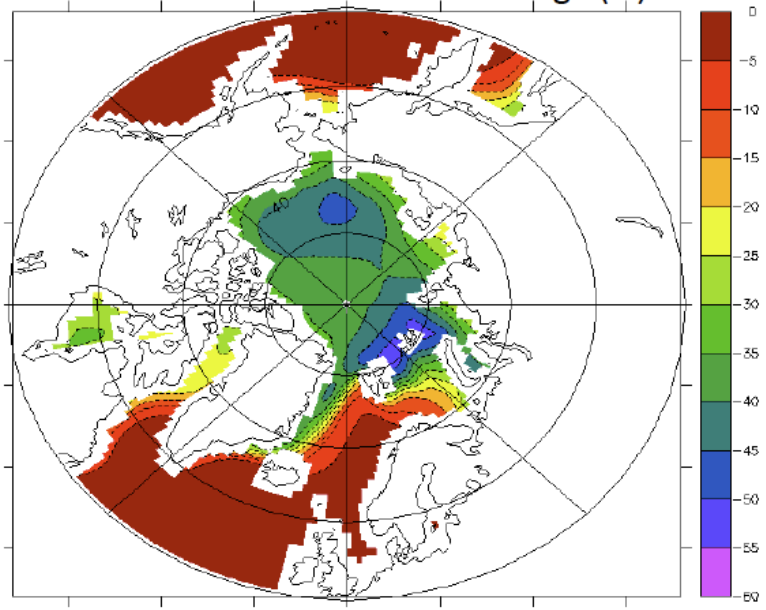


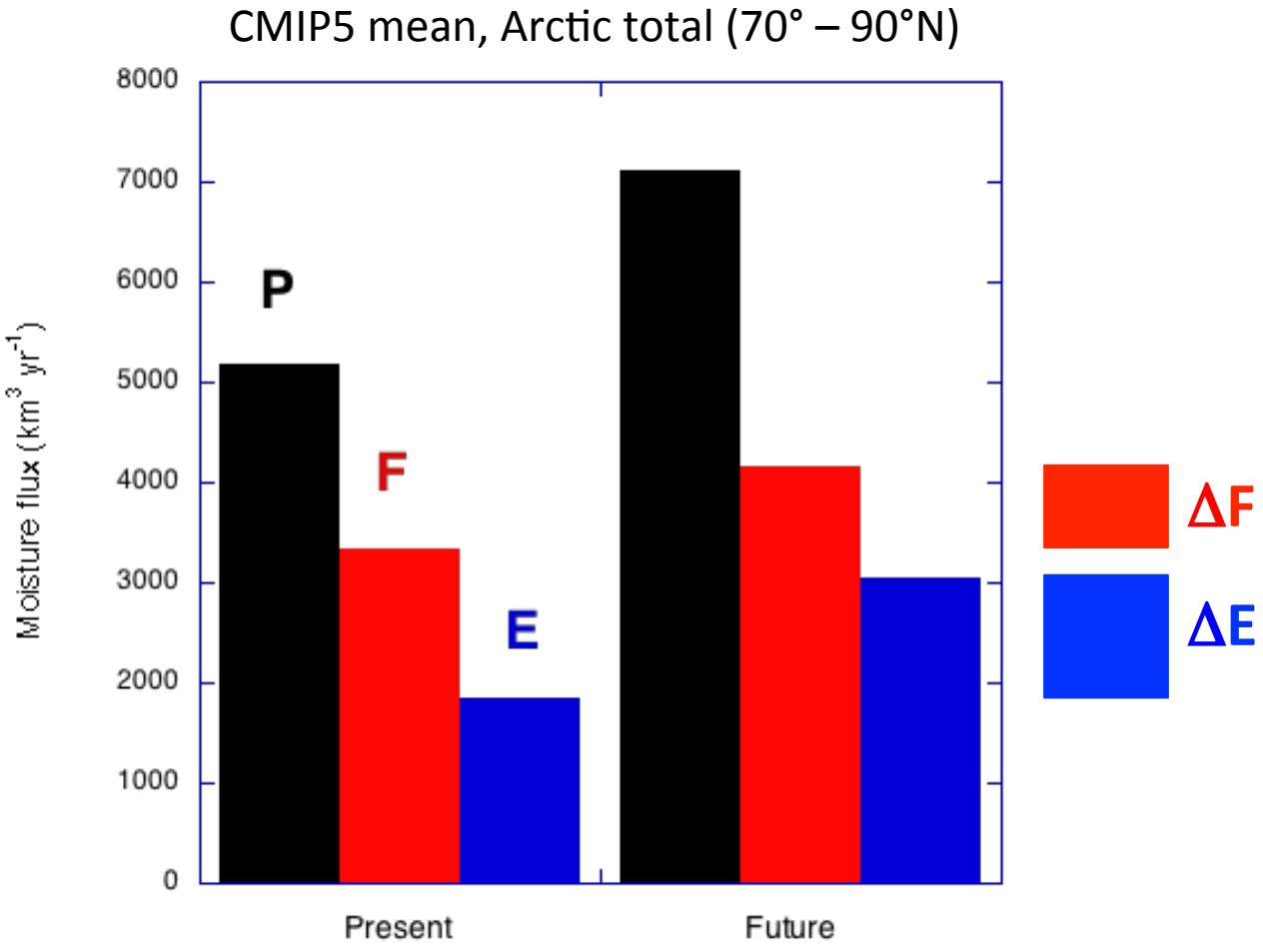
Surface evaporation change (%)

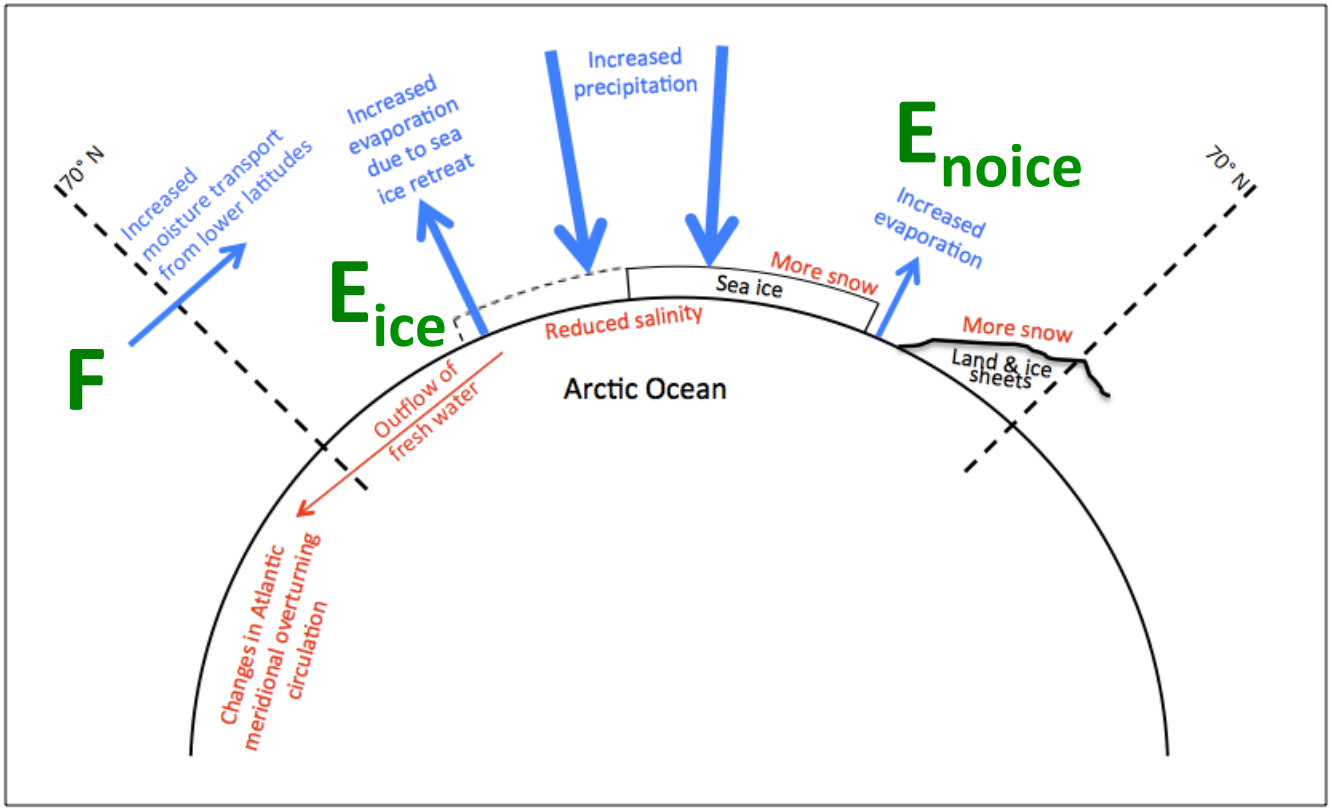


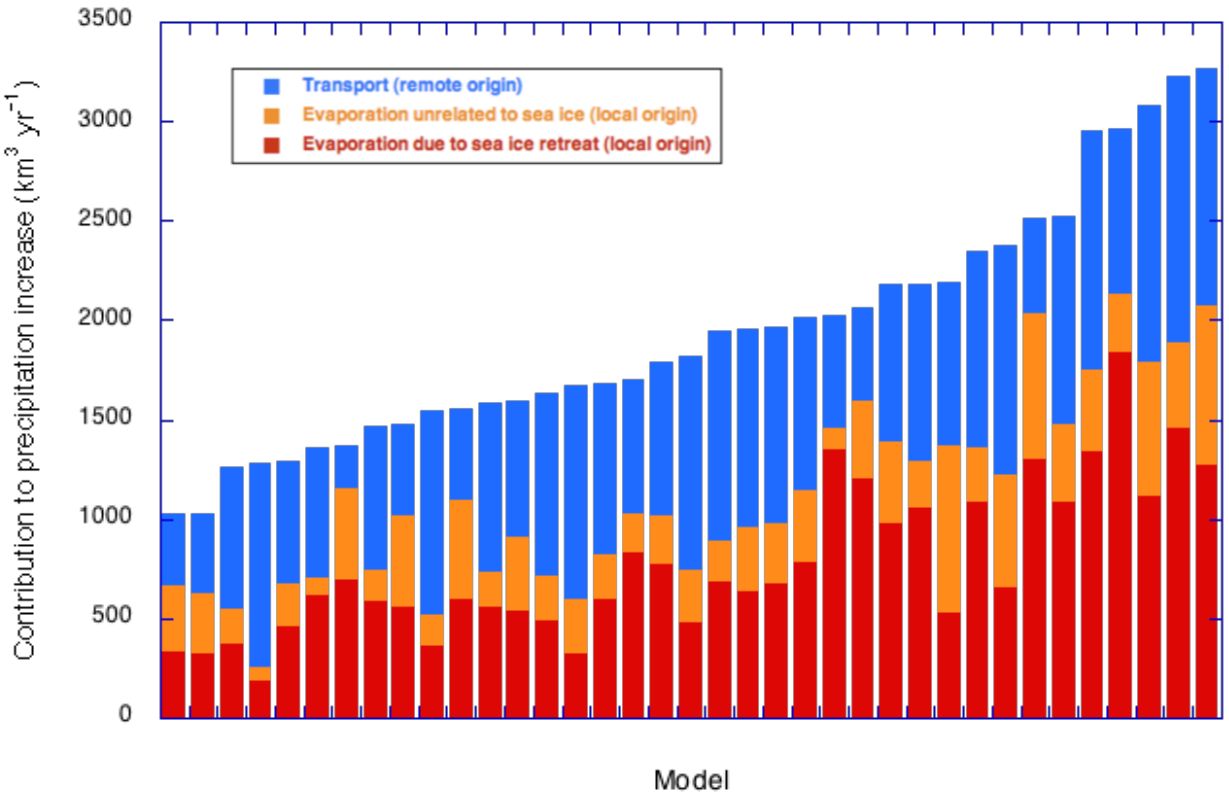
RCP8.5

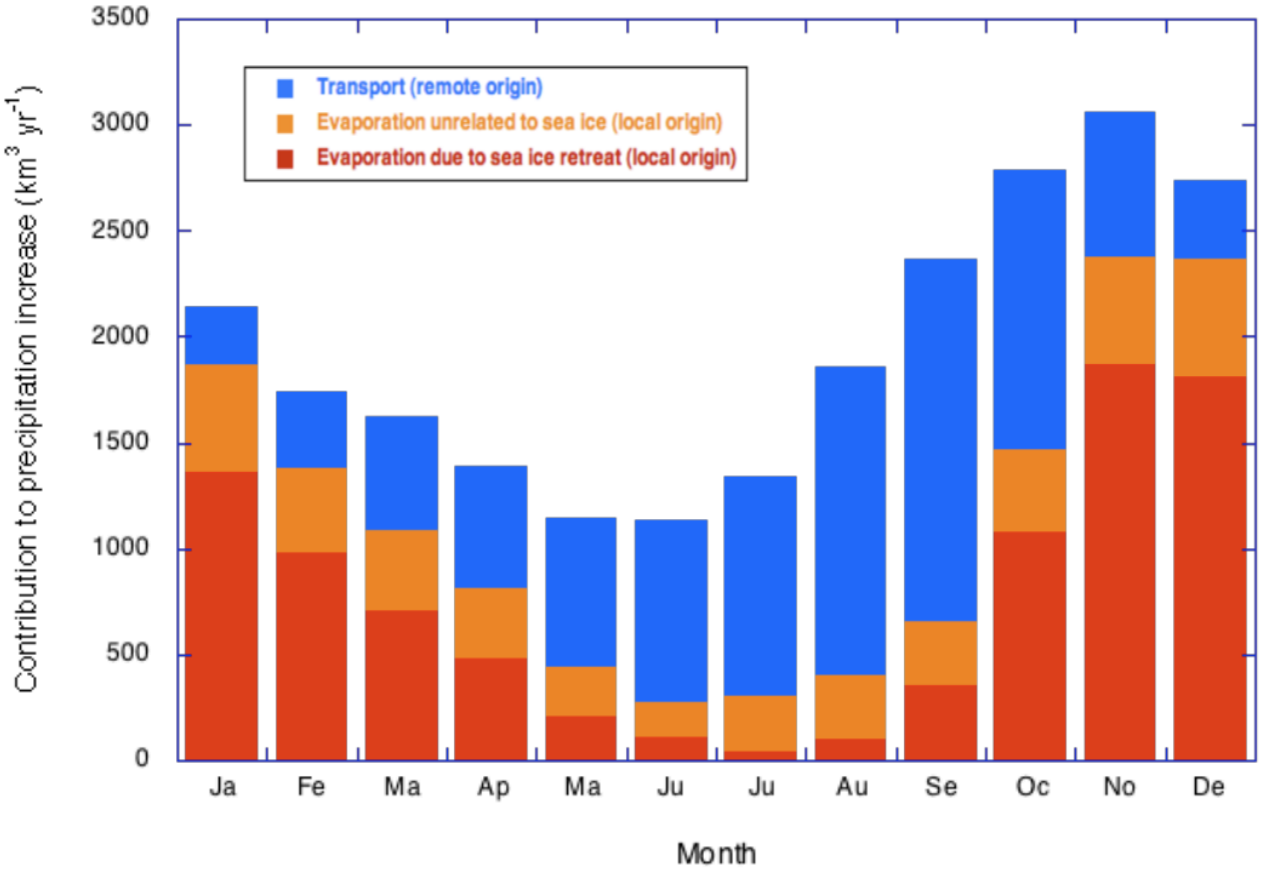
Fractional sea ice cover change (%)

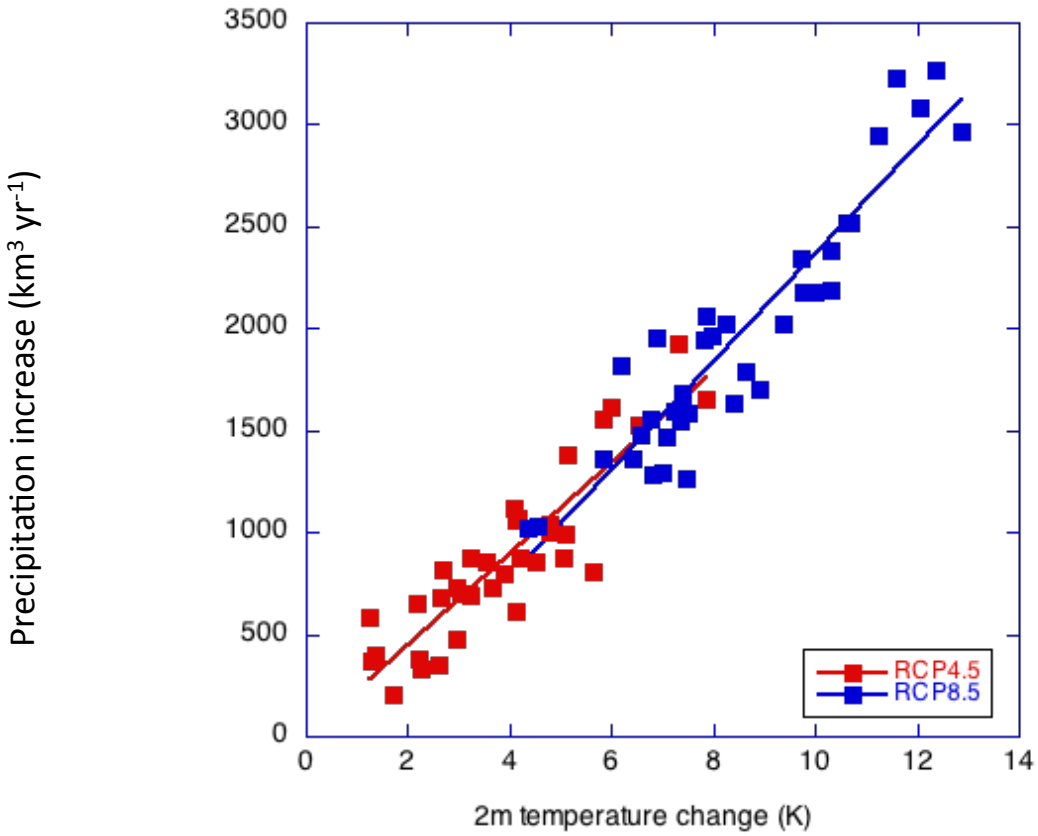



CMIP5 mean, Arctic total (70° – 90°N)
Moisture flux (km3 yr-1)
8000
7000
6000
5000
4000
3000
2000
1000
0
P
F
E
Present
Future
ΔF
ΔE


70° N
Increased moisture transport from lower latitudes
F
Increased evaporation due to sea ice retreat
E ice
Increased precipitation
E noice
Increased evaporation
More snow
Sea ice
Reduced salinity
More snow
Land & ice sheets
70° N
Outflow of fresh water
Arctic Ocean
Changes in Atlantic meridional overturning circulation


Transport (remote origin)
Evaporation unrelated to sea ice (local origin)
Evaporation due to sea ice retreat (local origin)
Contribution to precipitation increase (km^3 yr^{-1})
3500
3000
2500
2000
1500
1000
500
0
Model


Transport (remote origin)
Evaporation unrelated to sea ice (local origin)
Evaporation due to sea ice retreat (local origin)
Contribution to precipitation increase (km^3 yr^{-1})
3500
3000
2500
2000
1500
1000
500
0
Ja
Fe
Ma
Ap
Ma
Ju
Ju
Au
Se
Oc
No
De
Month


Precipitation increase (km^3 yr^{-1})
3500
3000
2500
2000
1500
1000
500
0
0
2
4
6
8
10
12
14
2m temperature change (K)
RCP4.5
RCP8.5

Possible consequences of increased Arctic precipitation

– More snowfall on adjacent continents and ice sheets (NE Greenland); Δsea level

– Arctic Ocean freshening

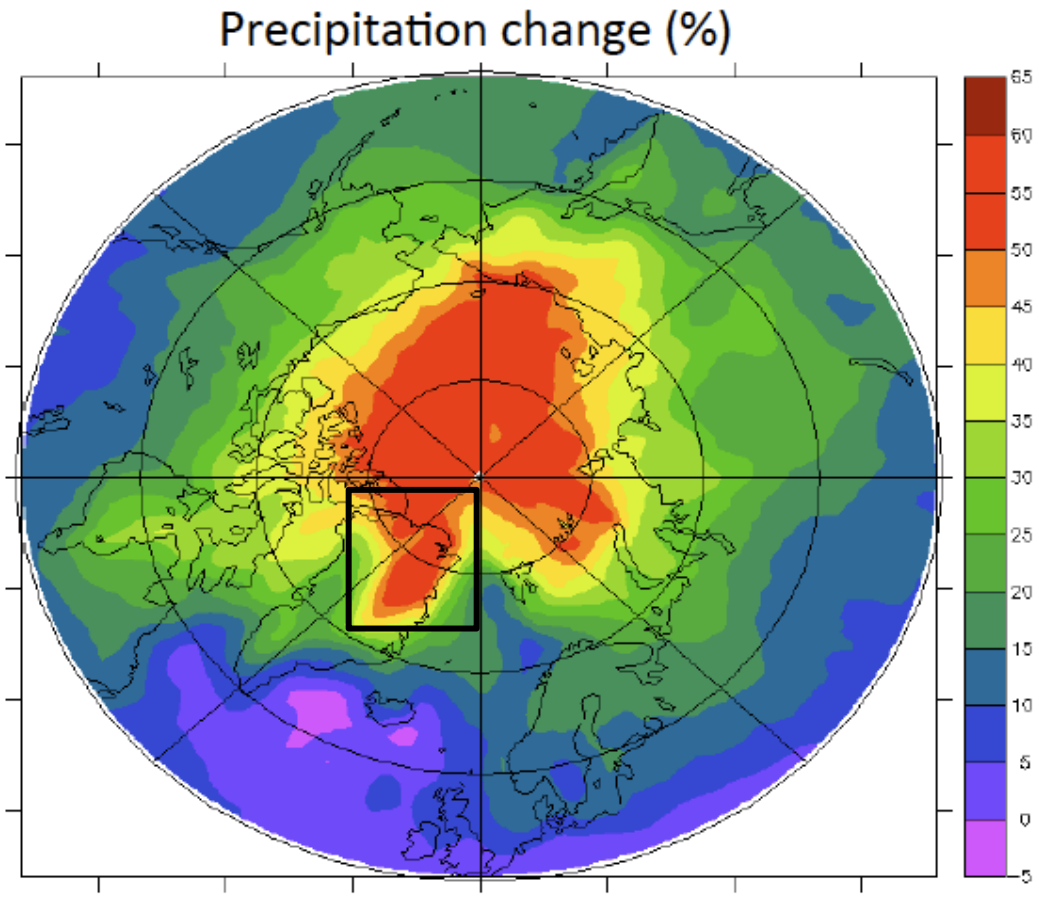
– enhanced river discharge and freshening

– Atlantic Meridional Overturning Circulation (AMOC) changes

– enhanced water vapour and cloud feedbacks, reinforcing Arctic warming

– more snowfall on sea ice, affecting the ice-albedo feedback and thermal insulation

– biological and ecological implications due e.g. to altered water availability


Precipitation change (%)
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5

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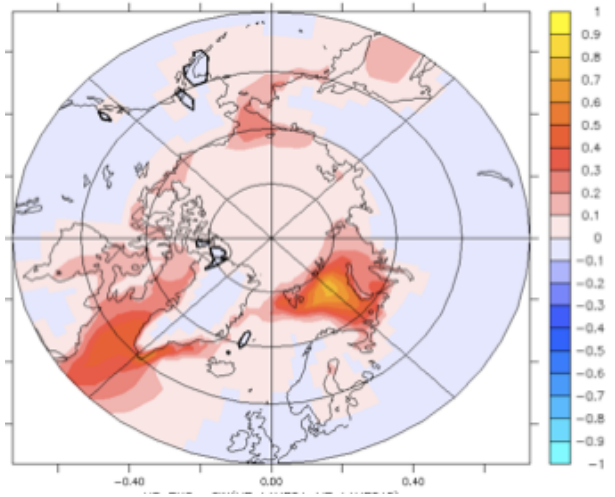
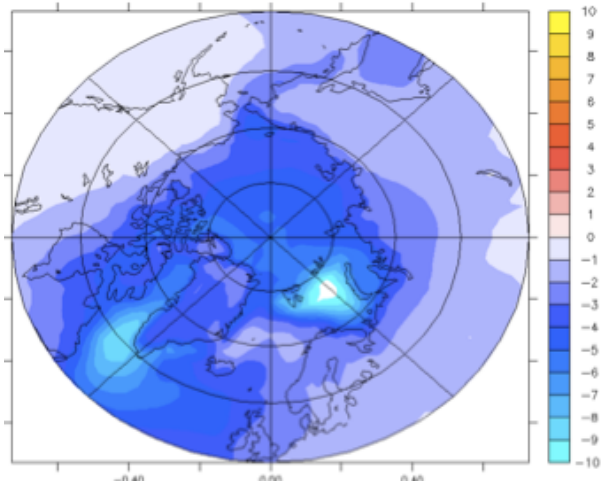
Increased Arctic precipitation leads to lower temperatures and more sea ice

Sea ice cover



Surface air temperature



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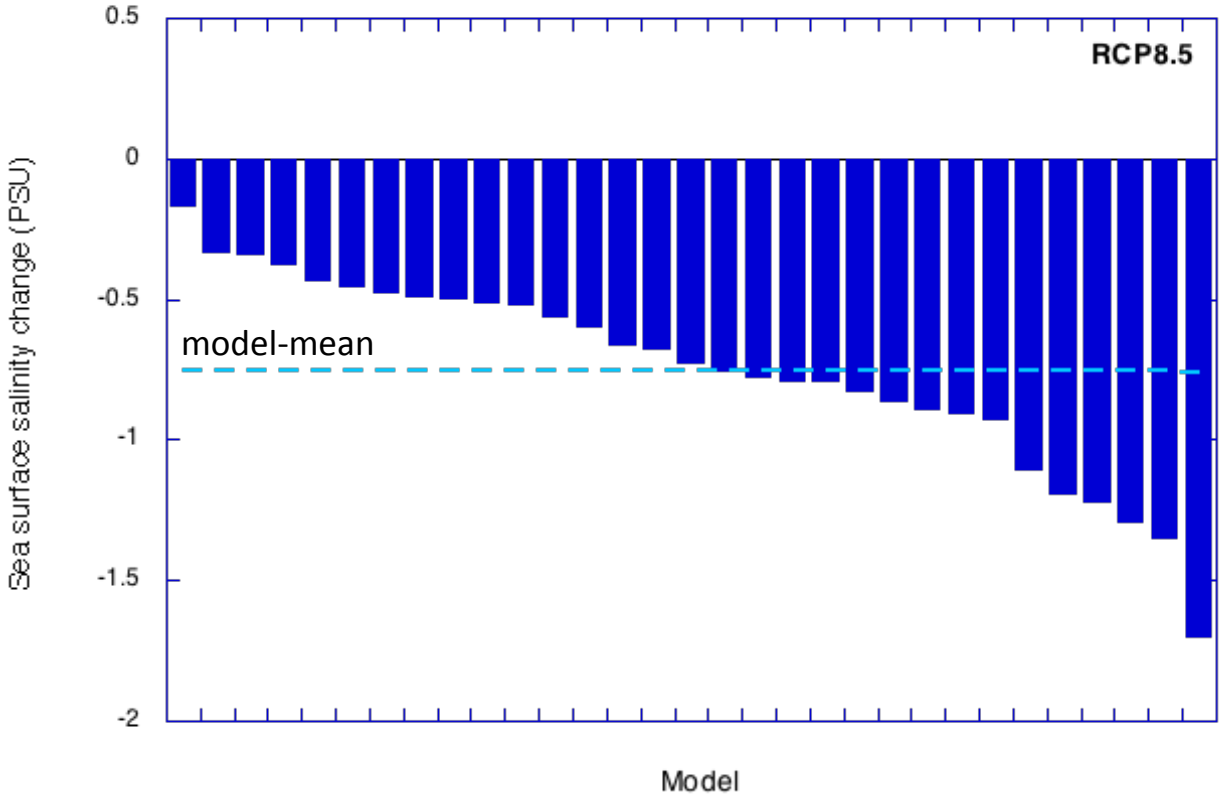
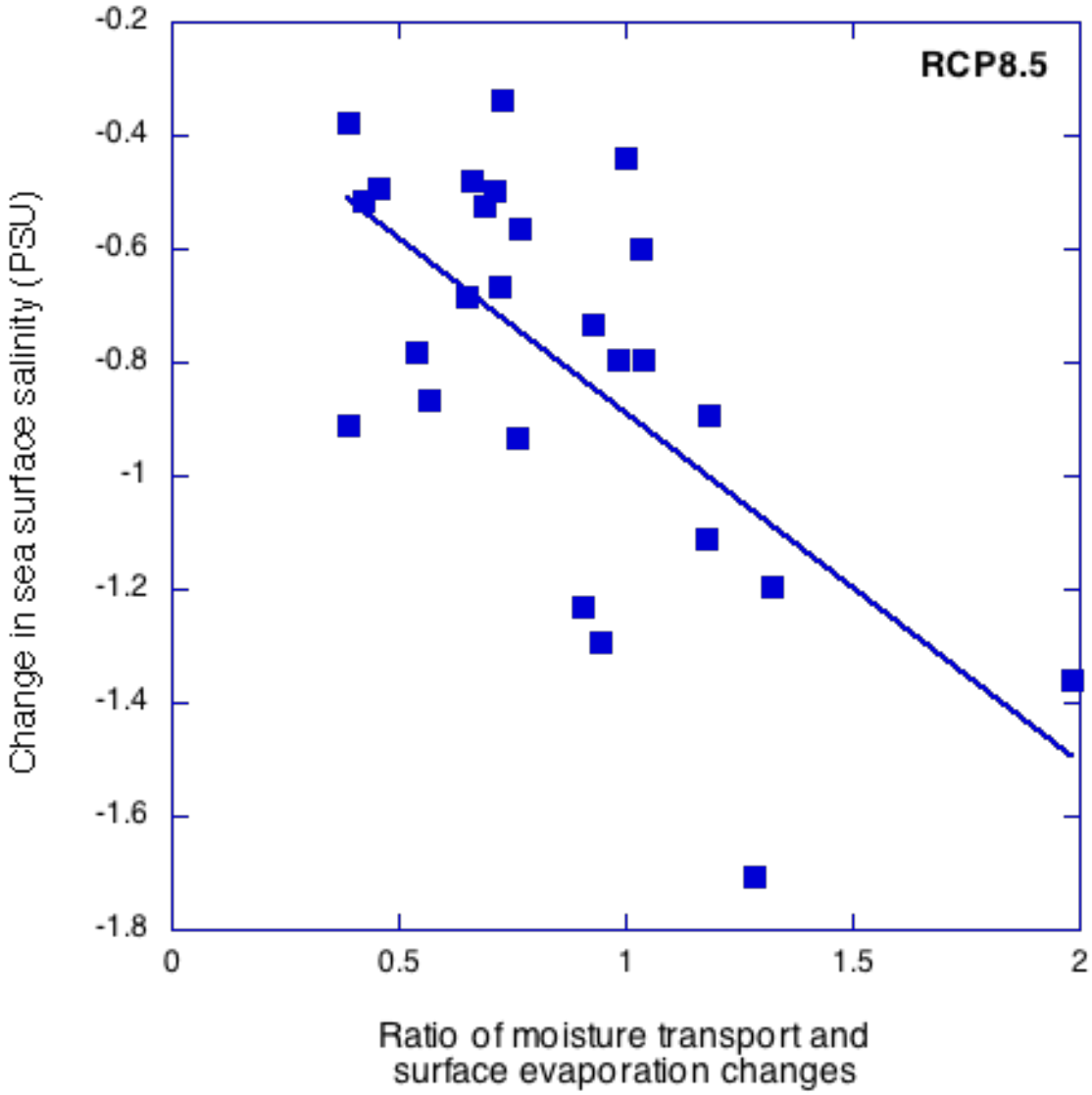
Arctic Ocean sea surface salinity changes – CMIP5



Does ΔSSS depend on remote (F) vs local (E) contributions?



Arctic Ocean salinity changes (and their effect on the AMOC) are not only due to

– enhanced precipitation (remote origin)

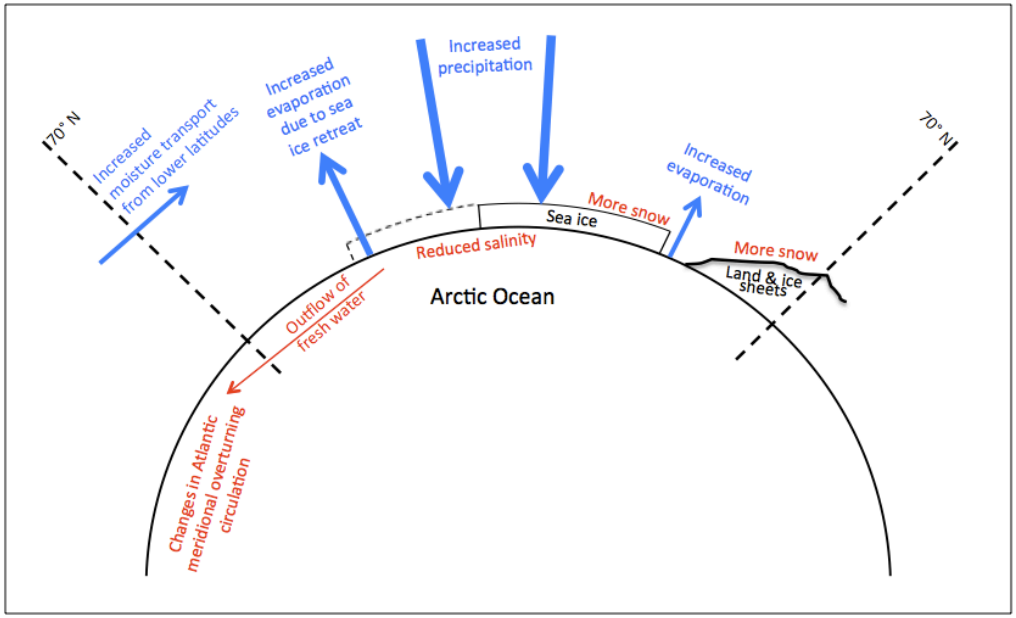
but also to

– enhanced river discharge

– sea ice formation/melt

– ocean transport and mixing

– more things...?



To isolate the effect of increased Arctic precipitation on AMOC changes we did/used

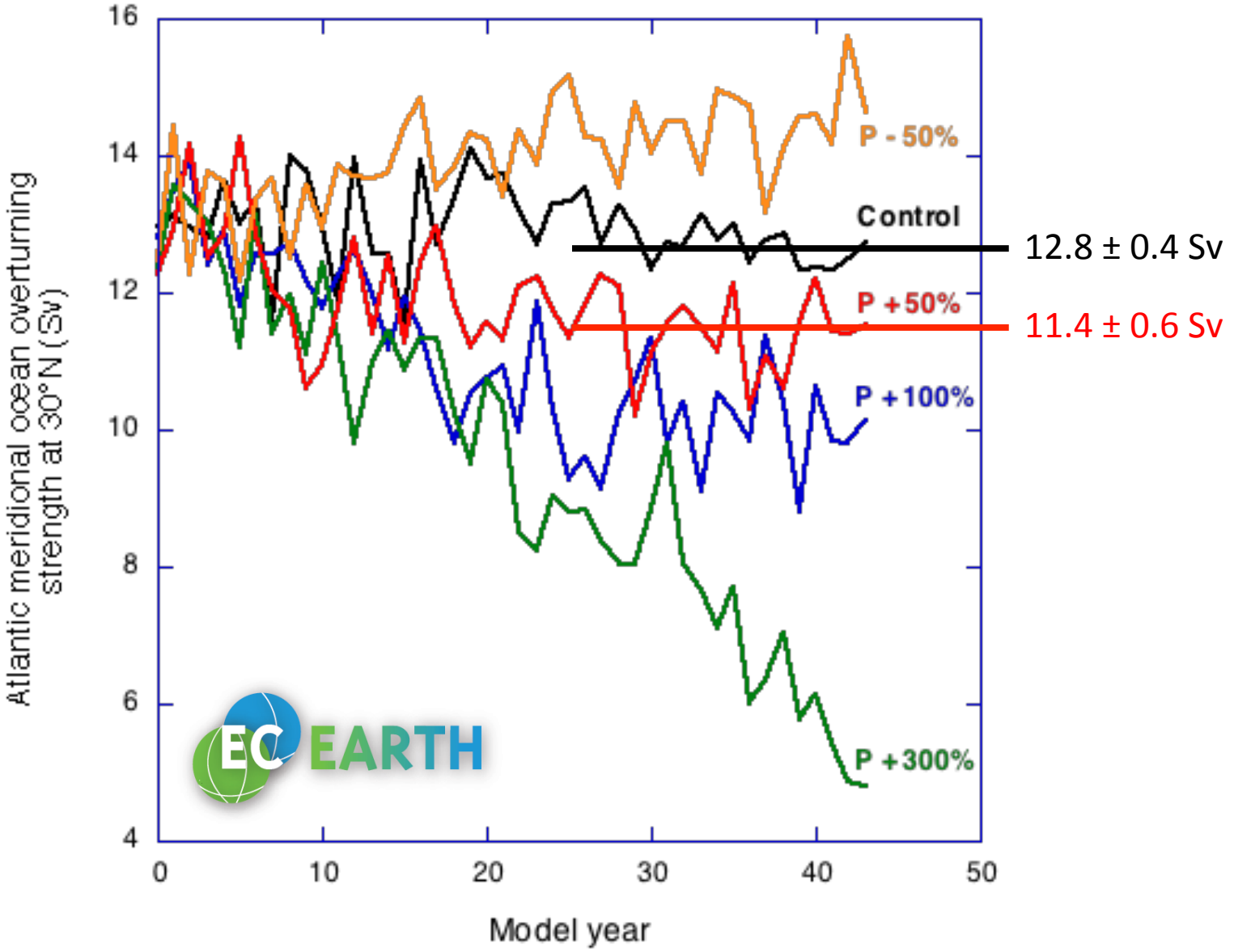
– EC-Earth V2.3, the coupled global climate model (part of CMIP5)

– 44 year runs with perpetual 2006 forcing

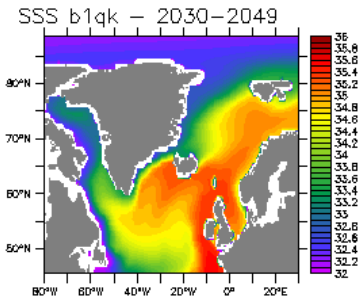
– Artificially changed precipitation (P) over the oceans north of 70°N

– Five simulations: P/2, Px1, Px1.5, Px2, Px4

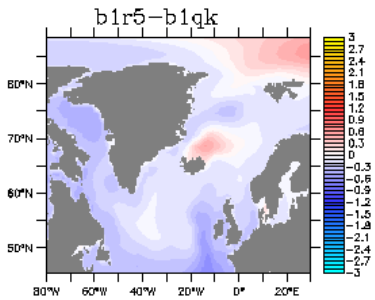
– Look at SSS and AMOC


Atlantic meridional ocean overturning strength at 30°N (Sv)
16
14
12
10
8
6
4
0
10
20
30
40
50
Model year
P - 50%
Control
P +50%
P +100%
P +300%
12.8 ± 0.4 Sv
11.4 ± 0.6 Sv
EC EARTH

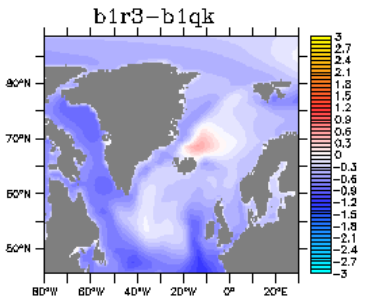
Control SSS



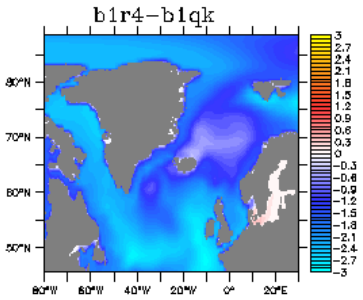
ΔSSS, P * 1.5



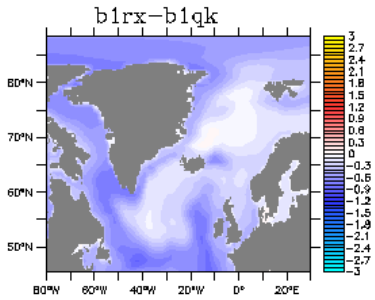
ΔSSS, P * 2.0



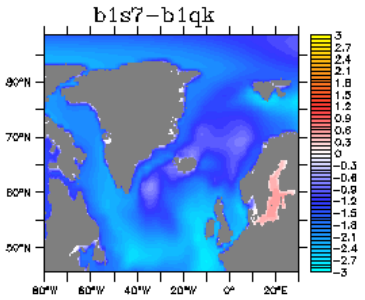
ΔSSS, P * 4.0

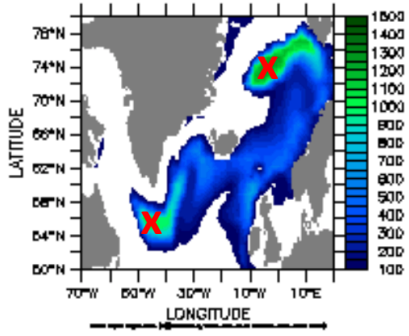


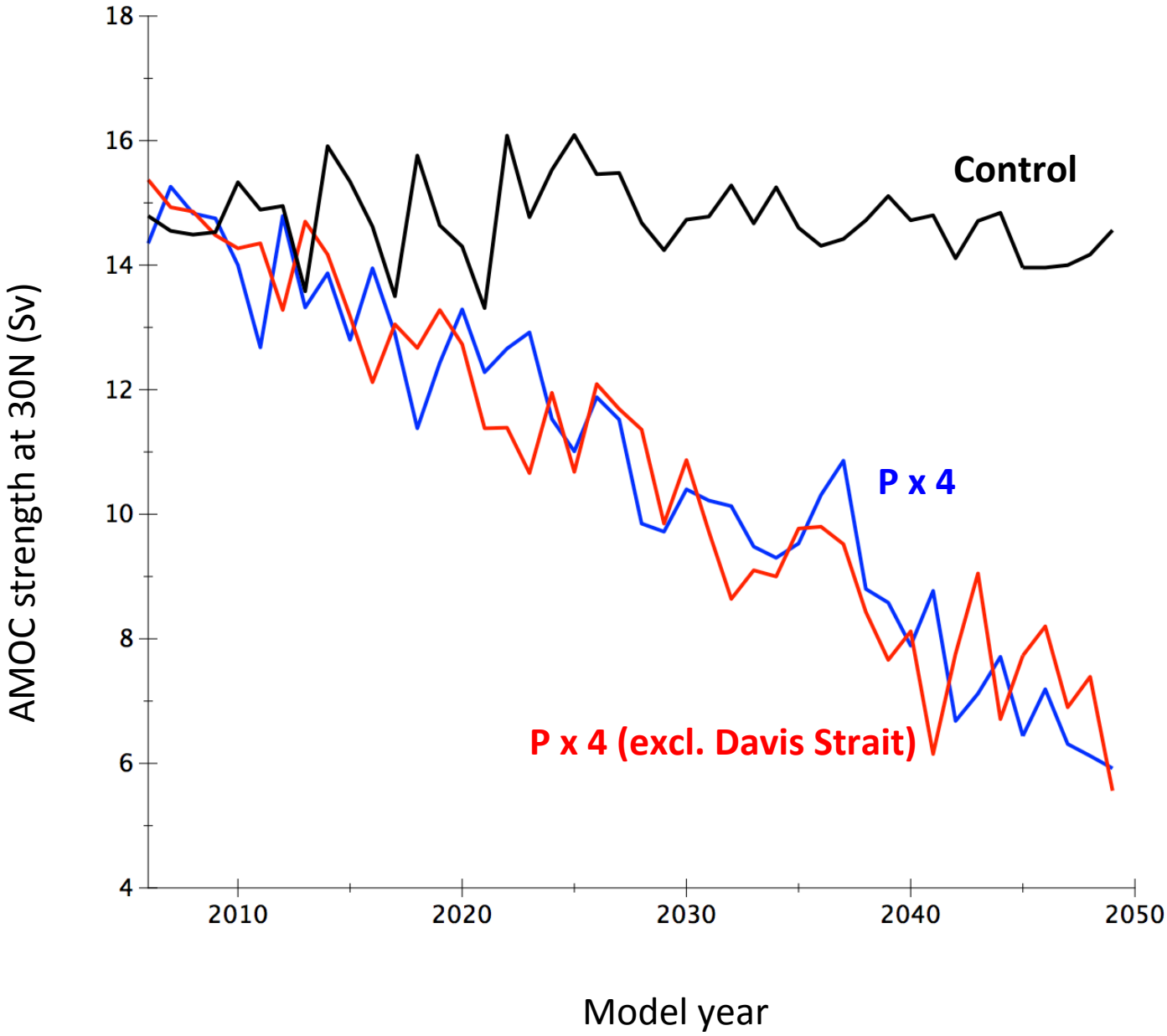
ΔSSS, P * 4.0 (ϕ > 80N)



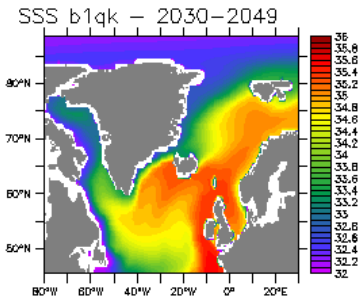
ΔSSS, P * 4.0 (excl. Davis St.)



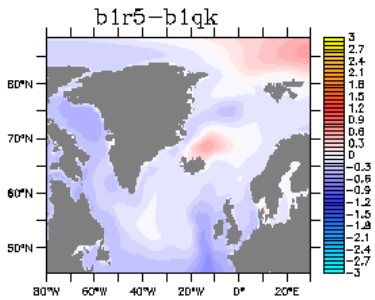



AMOC strength at 30N (Sv)
18
16
14
12
10
8
6
4
2010
2020
2030
2040
2050
Model year
Control
P x 4
P x 4 (excl. Davis Strait)

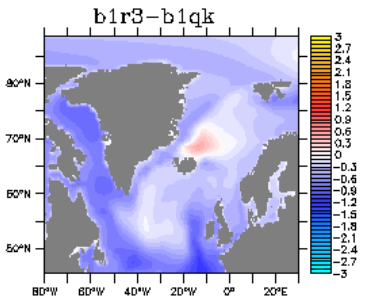
Control SSS



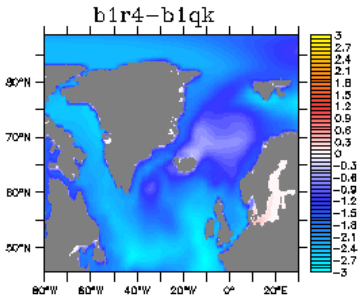
ΔSSS, P * 1.5



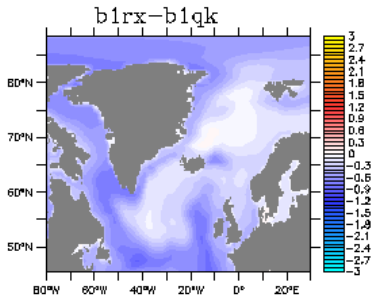
ΔSSS, P * 2.0



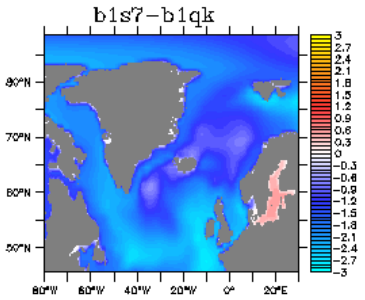
ΔSSS, P * 4.0

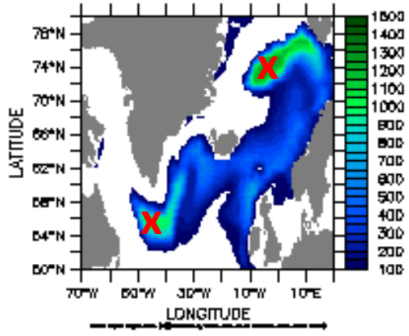


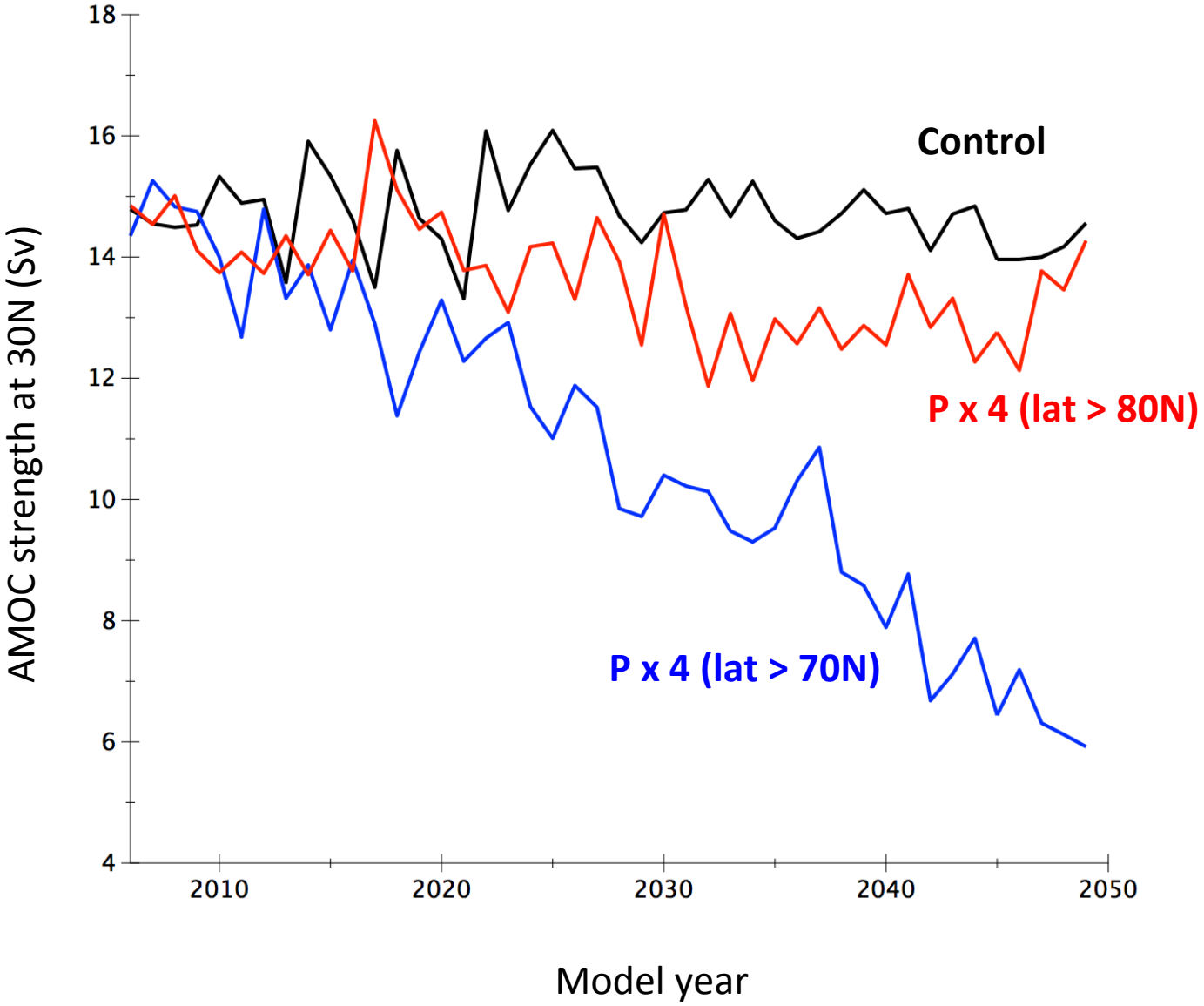
ΔSSS, P * 4.0 (ϕ > 80N)



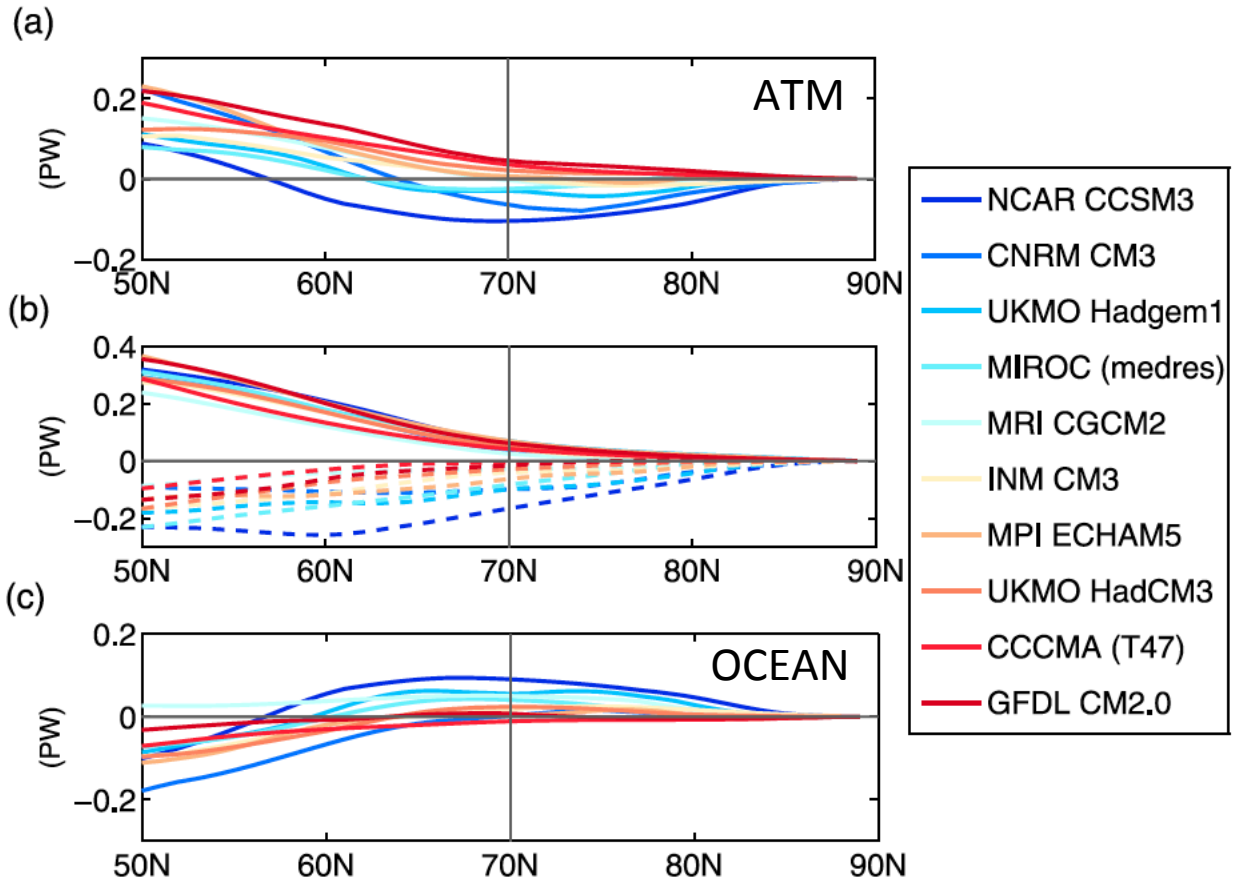
ΔSSS, P * 4.0 (excl. Davis St.)






AMOC strength at 30N (Sv)
18
16
14
12
10
8
6
4
2010
2020
2030
2040
2050
Model year
Control
P x 4 (lat > 80N)
P x 4 (lat > 70N)

Northward heat transports



Hwang et al., 2011

Conclusions

– Arctic precipitation will strongly increase over the 21st century

– Main contributor is local evaporation (~60%) in relation to sea ice retreat

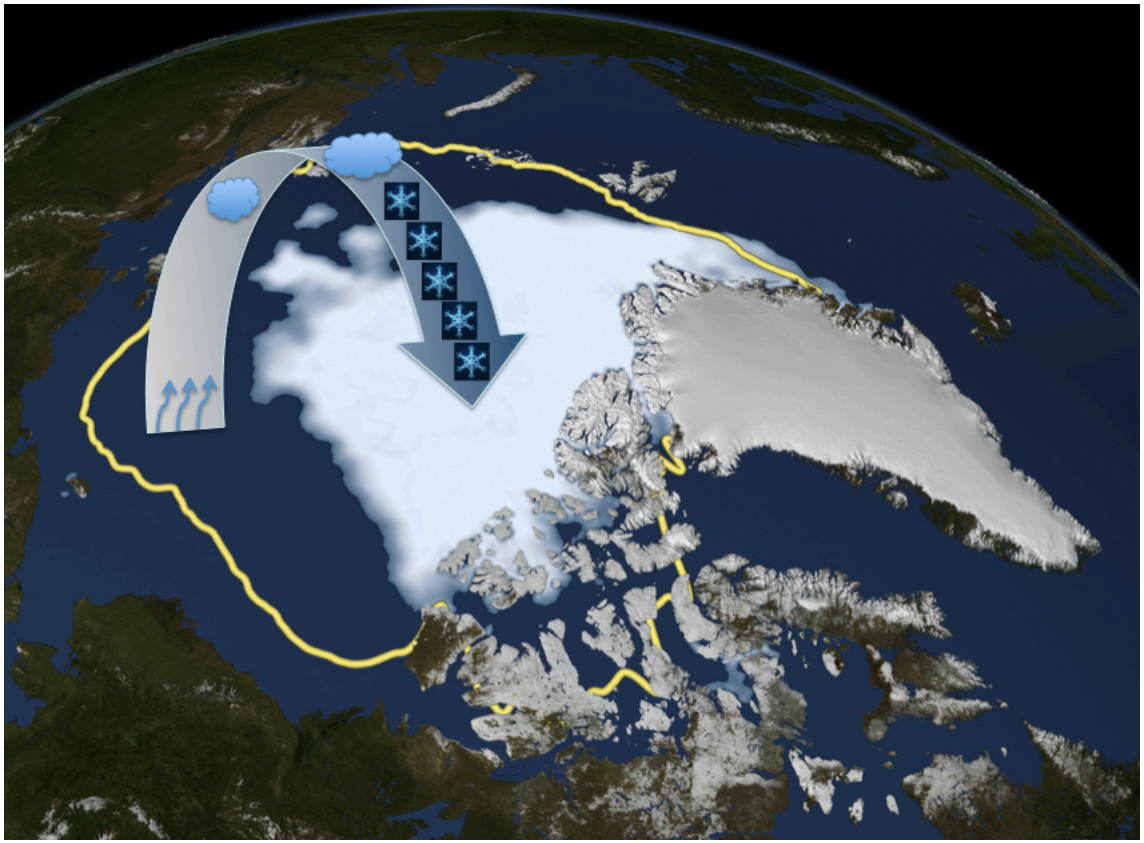
– Hence, precipitation increase is strongly linked to polar warming

– Pronounced seasonal cycle (evaporation increases mostly in winter, transport in late summer)

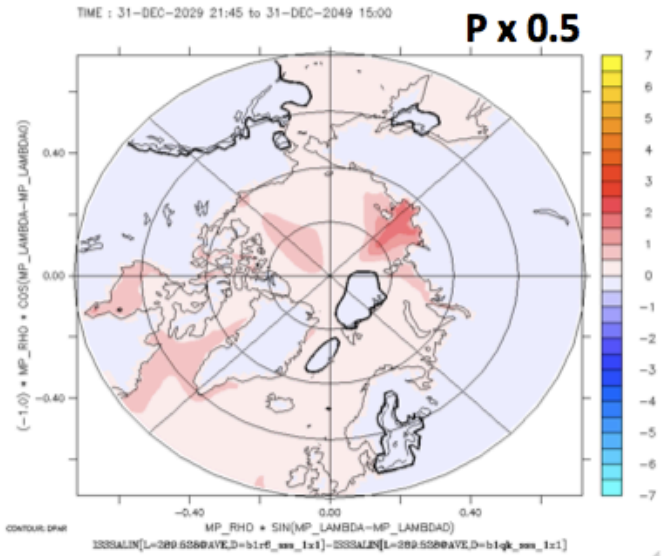
– Arctic precipitation sensitivity (4.5%/K) >> global mean (~2%/K)

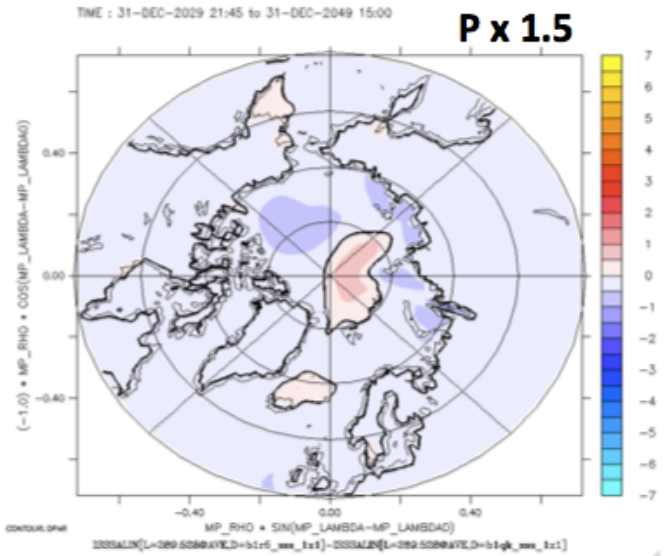
– Increased precipitation reduces sea surface salinity and AMOC strength (futher study needed...)

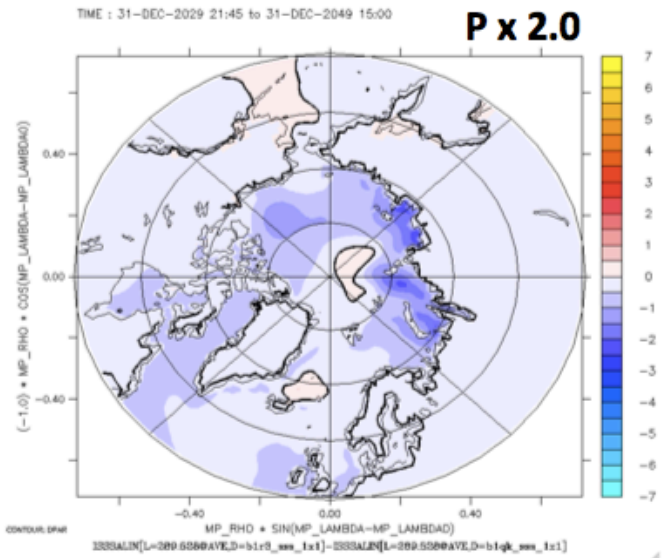
Thank you

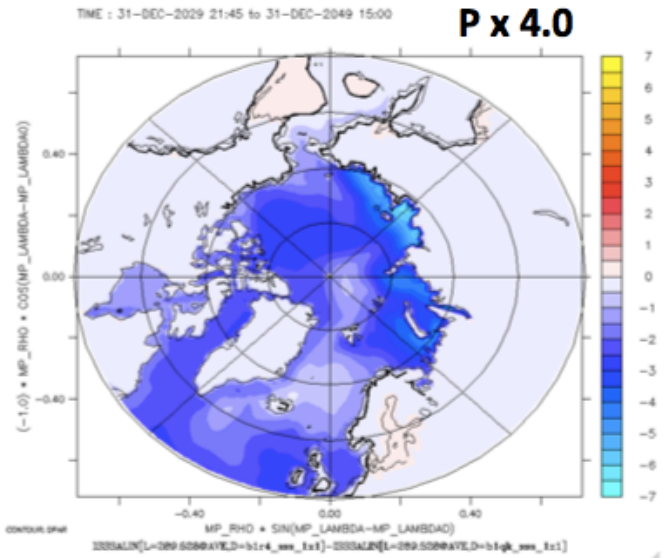
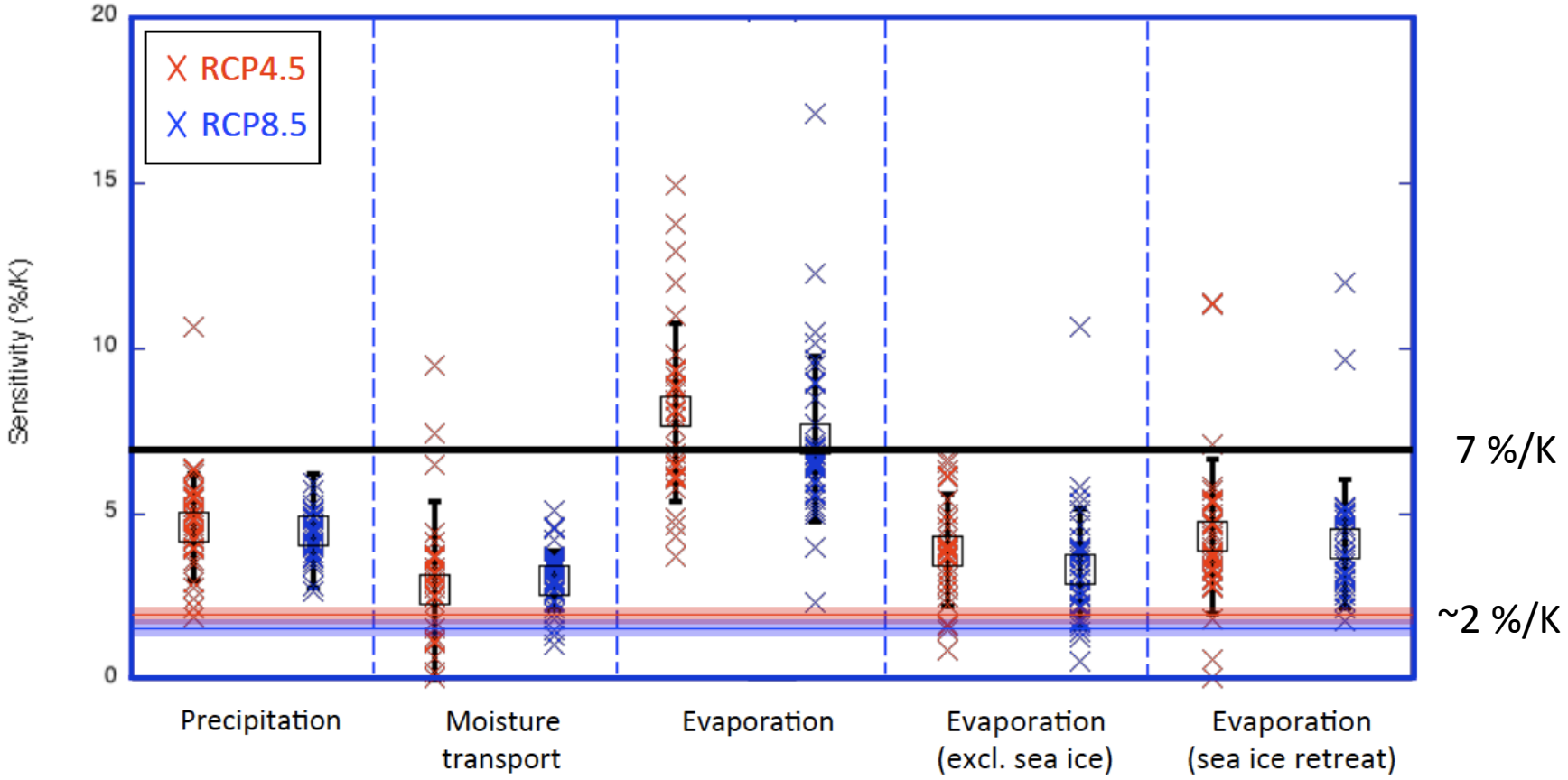


Bintanja, R. and F.M. Selten, 2014: Future increases in Arctic precipitation linked to local evaporation and sea ice retreat. *Nature*, **509** 479-482, doi:10.1038/nature13259.


TIME : 31-DEC-2029 21:45 to 31-DEC-2049 15:00
P x 0.5
(-1.0) * MP_RHO * COS(MP_LAMBDA-MP_LAMBDA0)
MP_RHO * SIN(MP_LAMBDA-MP_LAMBDA0)
CONTOUR: DPAR


TIME : 31-DEC-2029 21:45 to 31-DEC-2049 15:00
P x 1.5
(-1.0) * MP_RHO * COS(MP_LAMBDA-MP_LAMBDA0)
MP_RHO * SIN(MP_LAMBDA-MP_LAMBDA0)
CONTOUR: DPAR


TIME : 31-DEC-2029 21:45 to 31-DEC-2049 15:00
P x 2.0
(-1.0) * MP_RHO * COS(MP_LAMBDA-MP_LAMBDA0)
MP_RHO * SIN(MP_LAMBDA-MP_LAMBDA0)
CONTOUR: DPAR


TIME : 31-DEC-2029 21:45 to 31-DEC-2049 15:00
P x 4.0
(-1.0) * MP_RHO * COS(MP_LAMBDA-MP_LAMBDA0)
MP_RHO * SIN(MP_LAMBDA-MP_LAMBDA0)
CONTOUR: DPAR

Sensitivity = ∂X/(XΔT)
Arctic means