Getting an ocean model to obey: Prescribing and perturbing exact fluxes of heat and fresh water

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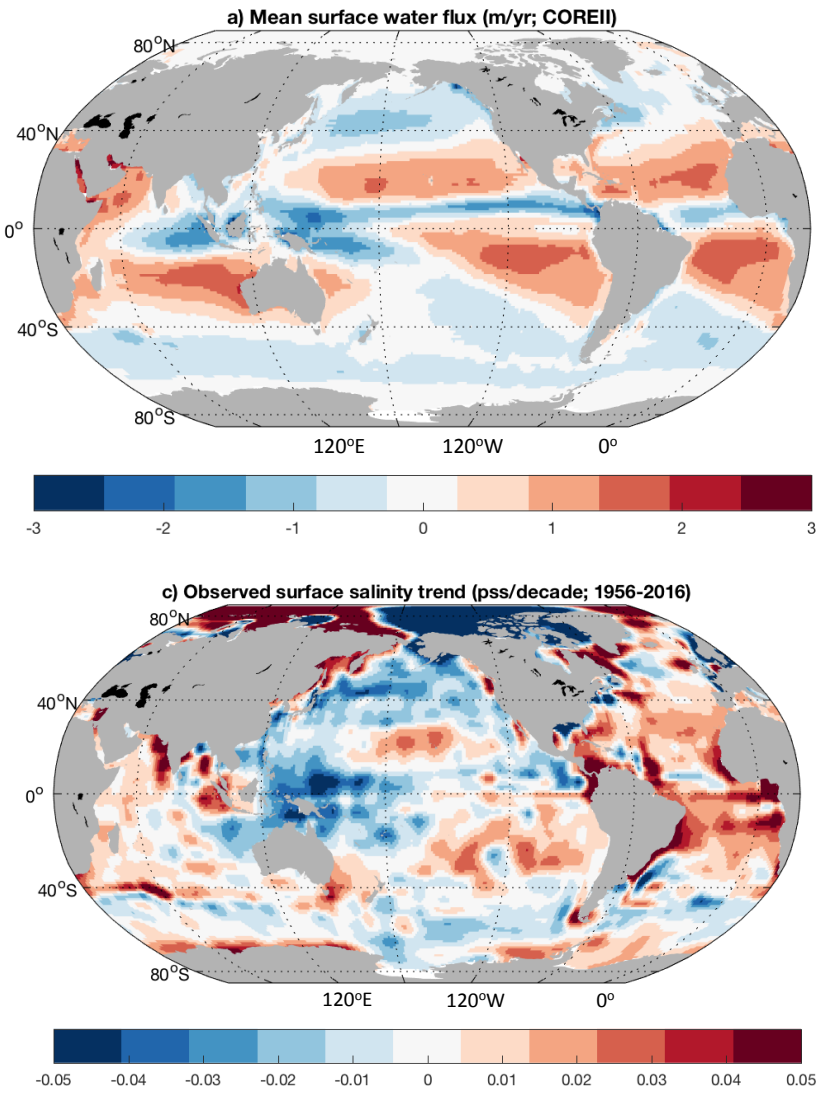
Adam Blaker, George Nurser and Simon Josey (NOCS)
and Nikolaos Skliris and Bob Marsh (U Southampton).

Primary Motivation: Ocean salinity and water cycle change



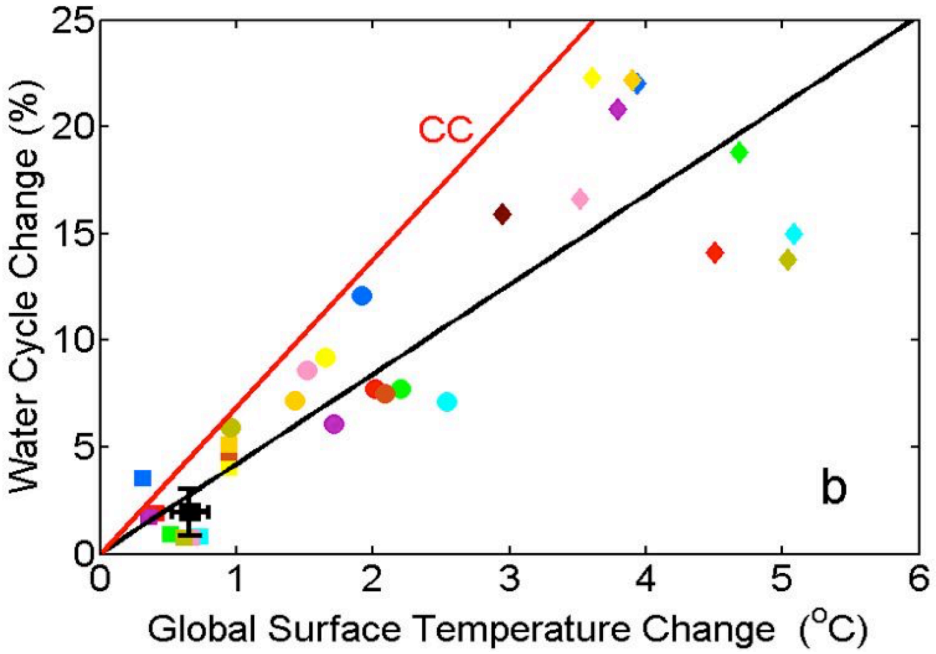
Salinity Change

Mixing (damping)

$$\frac{dW}{dt} = \frac{2\bar{S}}{V_0} F_w(\bar{S}) - \frac{1}{\tau} W .$$

Water Cycle

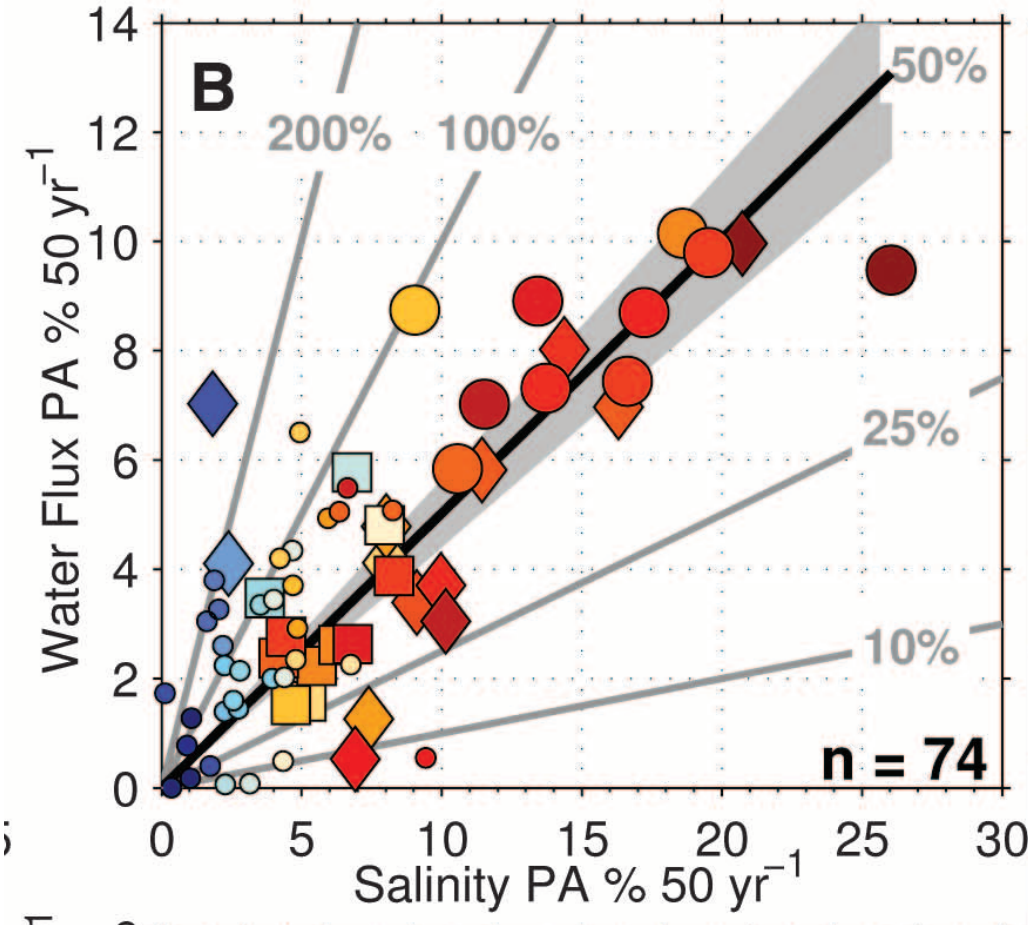
Water cycle change vs. warming (CMIP5 and Obs.)



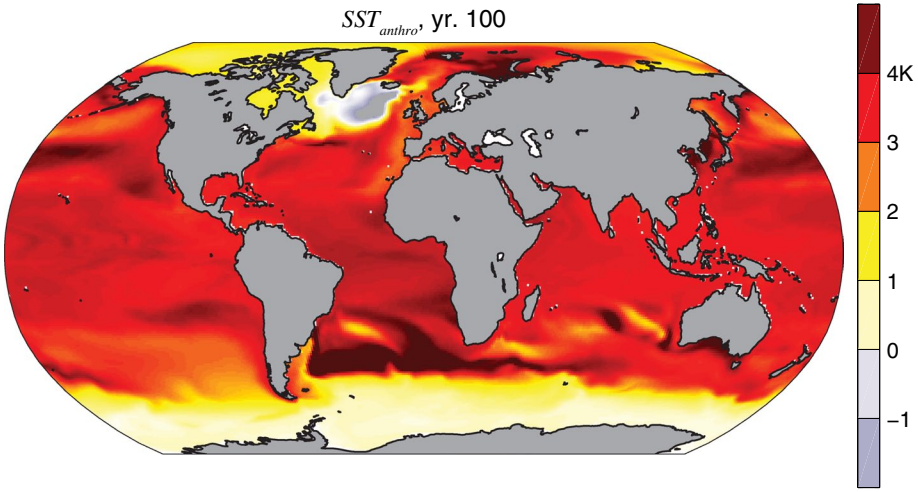
Helm et al. (2010), Durack et al. (2012), Zika et al. (2015), Lago et al. (2016), Skliris et al. (2016)

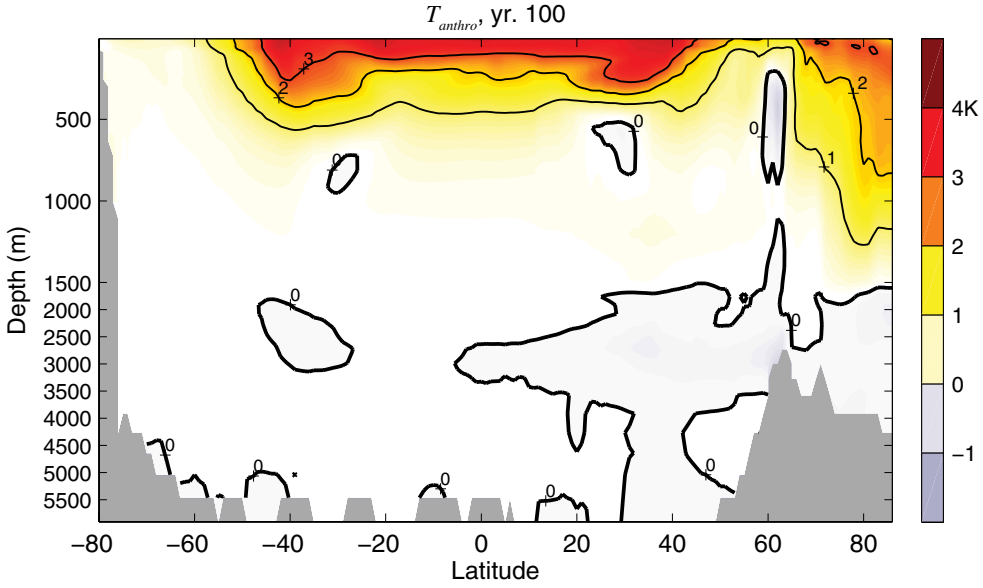
Puzzle:

In climate models and apparently in observations a global warming induced water cycle change of X% is associated with a surface salinity pattern change of ~2X%



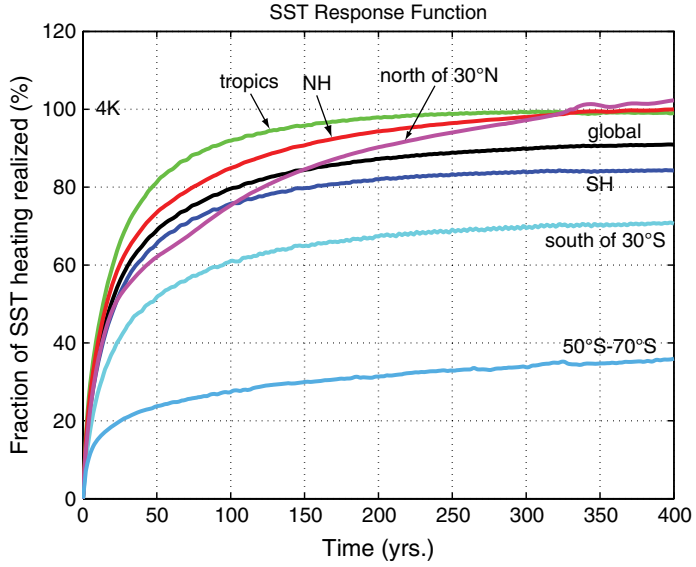
Approach inspired by Marshall et al.





$$\frac{D_{res}}{Dt}(T_c + T_{anthro}) = Q(\mathcal{H}_c + \mathcal{H}_{anthro}) - \gamma(SST - SST_c) + R(T_c + T_{anthro}). \quad (2)$$

Here γ is a prescribed parameter which damps SST_{anthro} at a rate chosen to be proportional to the global radiative feedback within coupled models. This can be seen by writing

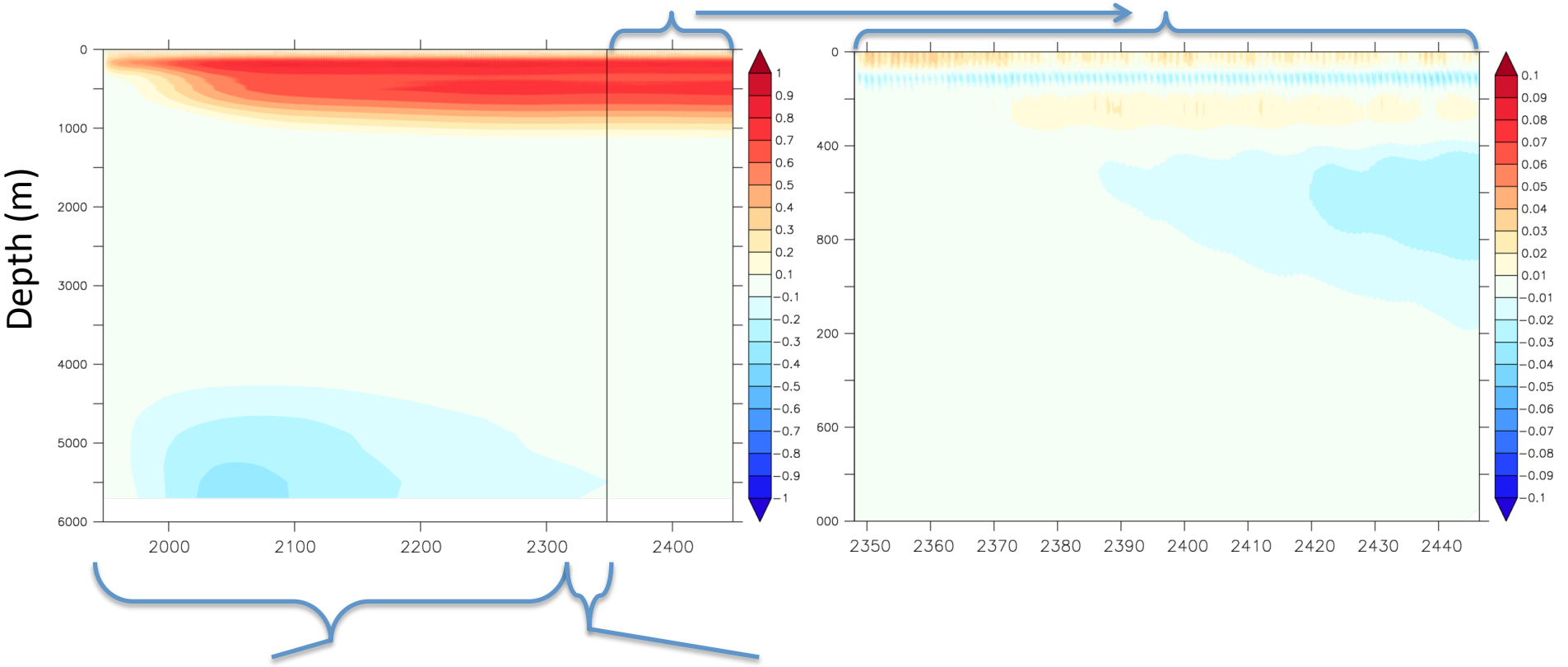


Marshal et al. (2014)

NEMO 1º

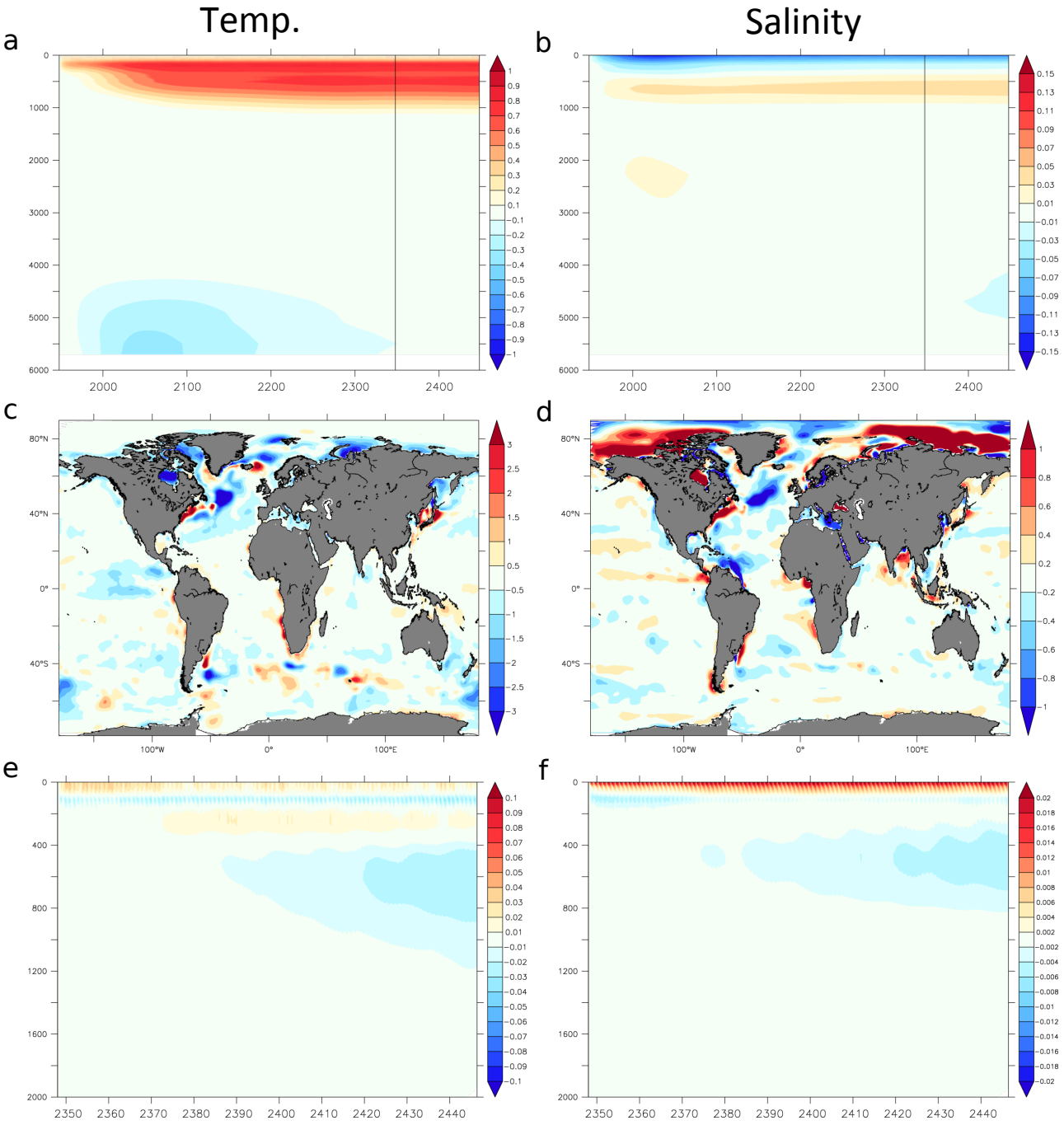
Potential Temperature Anomaly (Cº)

Fluxes prescribed explicitly



Spin up with bulk formula
CORE 'Normal Year' Forcing

Fluxes saved at every
time-step for 10 years.


Temp.
Salinity
a
b
c
d
e
f
0
1000
2000
3000
4000
5000
6000
2000
2100
2200
2300
2400
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
−0.1
−0.2
−0.3
−0.4
−0.5
−0.6
−0.7
−0.8
−0.9
−1
0.15
0.13
0.11
0.09
0.07
0.05
0.03
0.01
−0.01
−0.03
−0.05
−0.07
−0.09
−0.11
−0.13
−0.15
80°N
40°N
0°
40°S
100°W
0°
100°E
3
2.5
2
1.5
1
0.5
−0.5
−1
−1.5
−2
−2.5
−3
0.8
0.6
0.4
0.2
−0.2
−0.4
−0.6
−0.8
400
800
1200
1600
2000
2350
2360
2370
2380
2390
2400
2410
2420
2430
2440
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
−0.01
−0.02
−0.03
−0.04
−0.05
−0.06
−0.07
−0.08
−0.09
−0.1
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
−0.002
−0.004
−0.006
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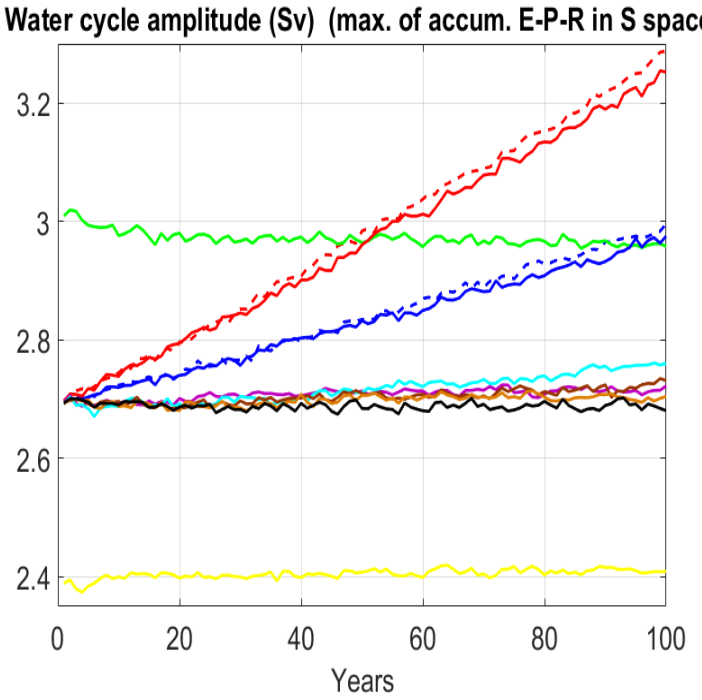
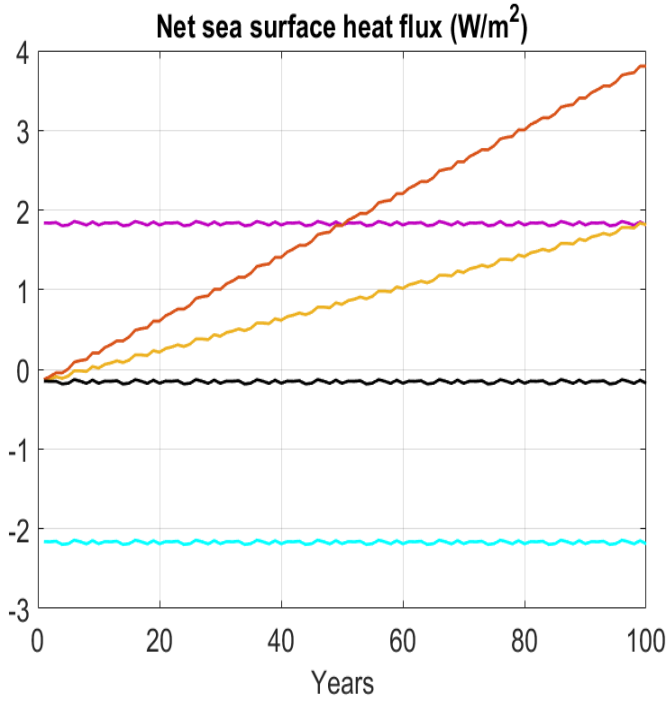
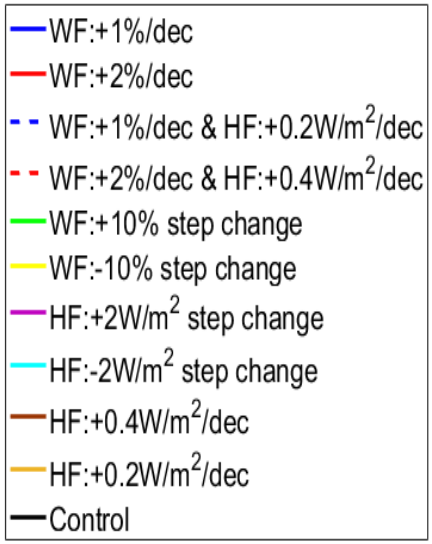
−0.012
−0.014
−0.016
−0.018
−0.02

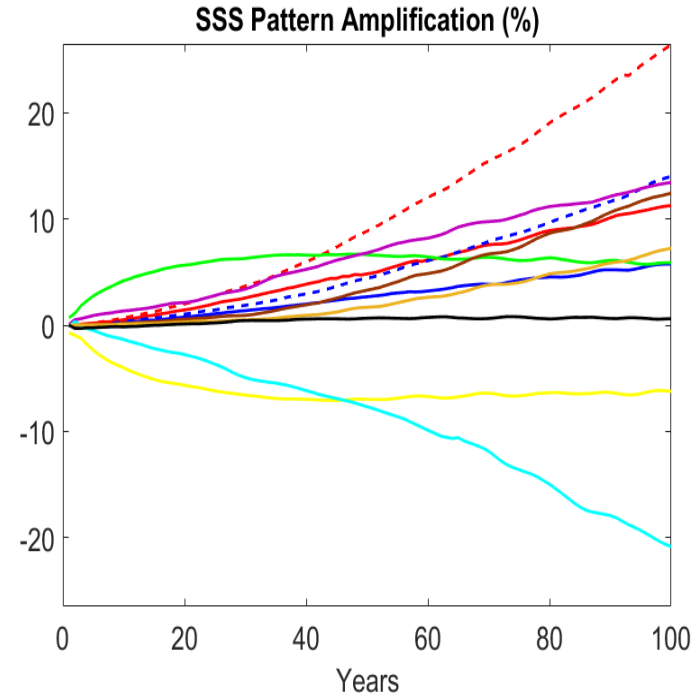


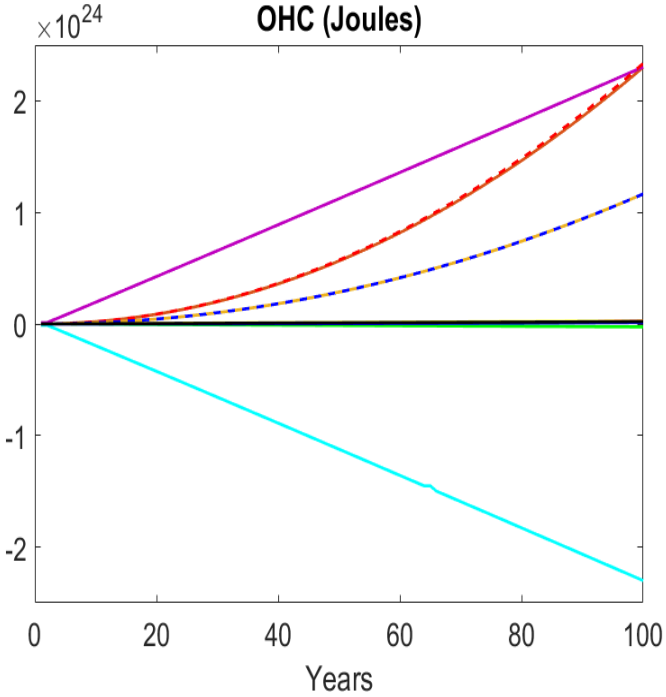


WF= Water Flux

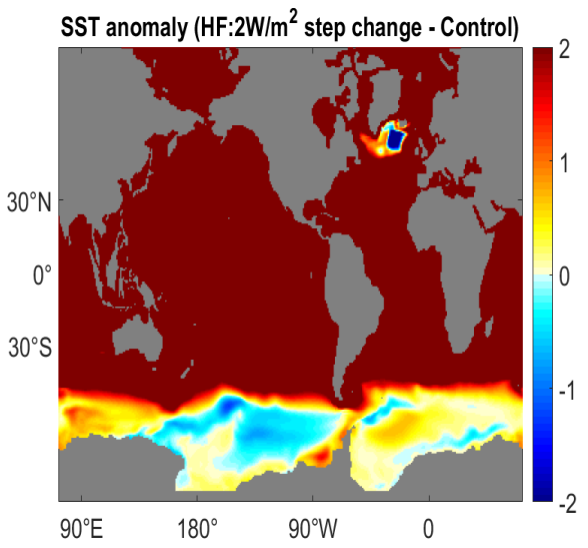
HF= Heat Flux

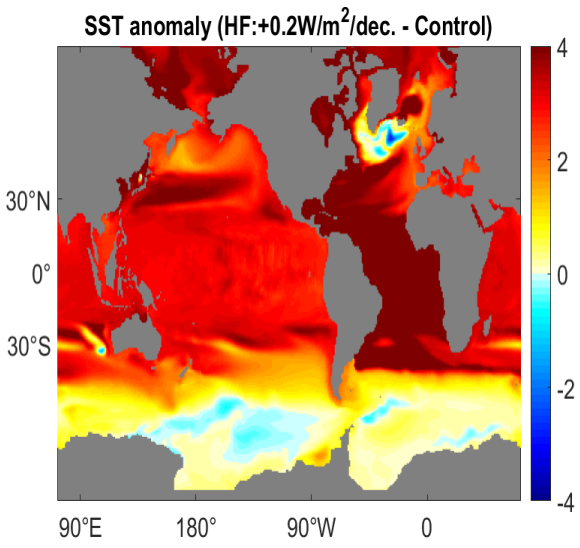


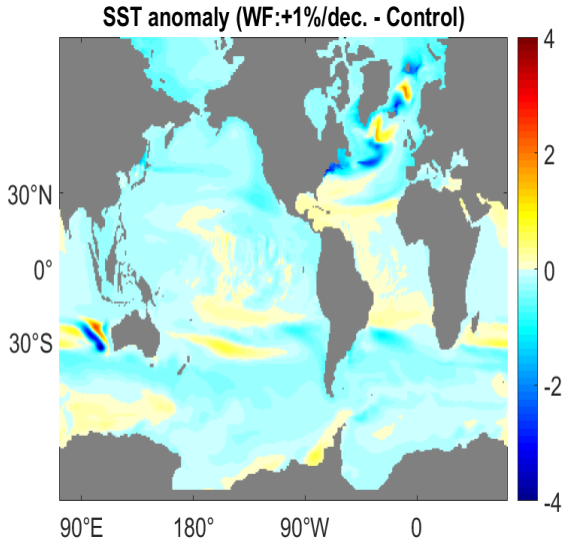


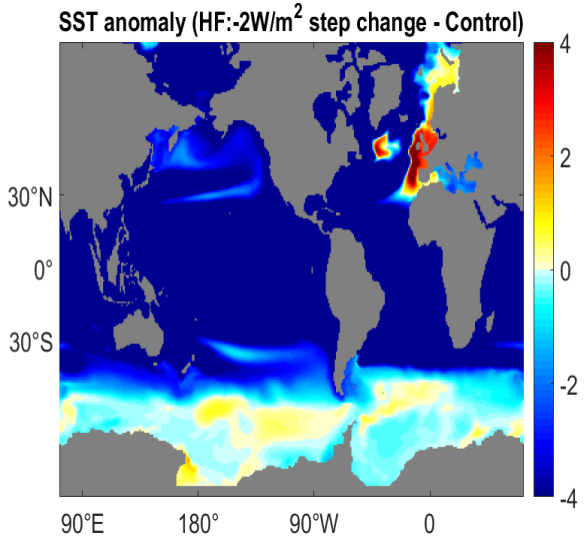


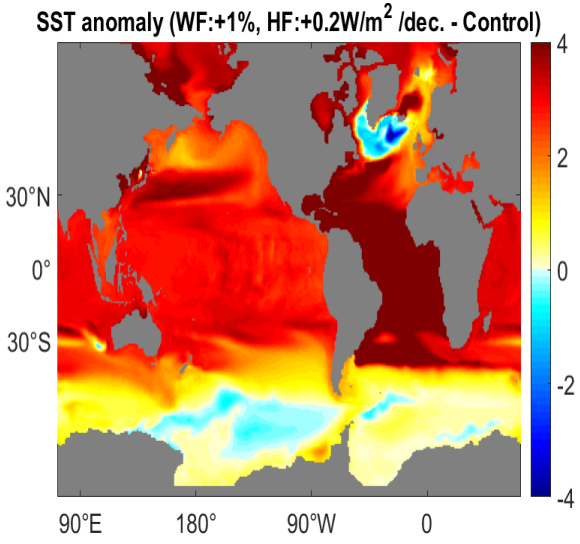
Anomalies with respect to control after 100yrs

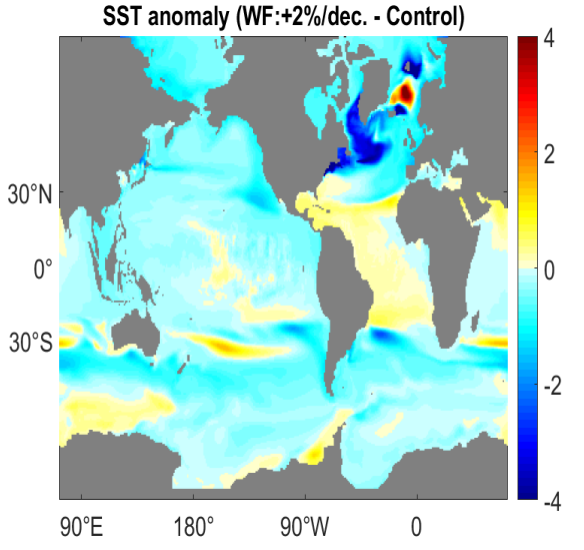




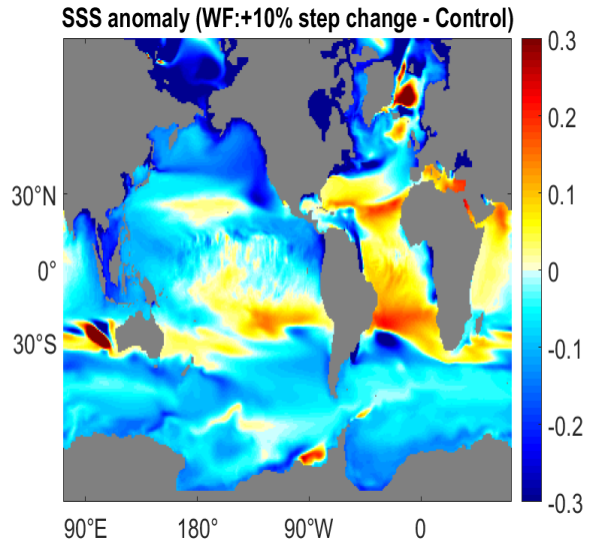


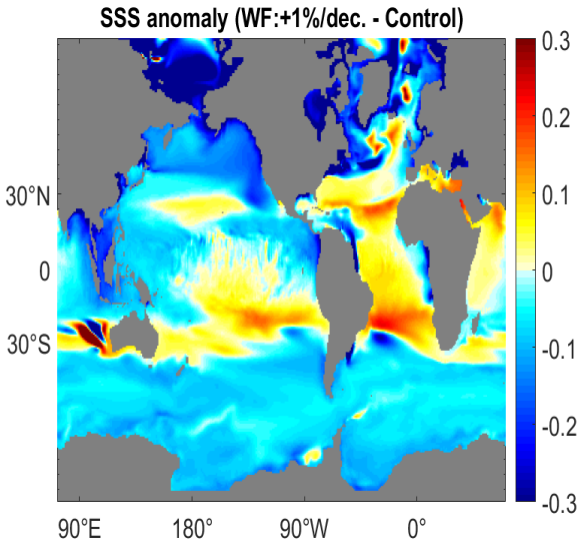


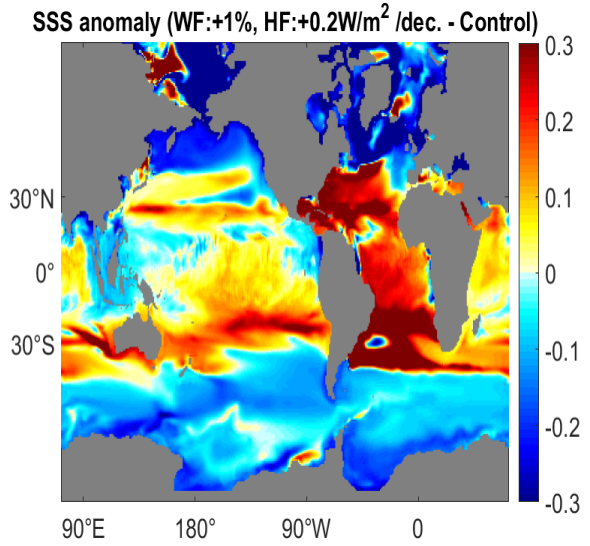


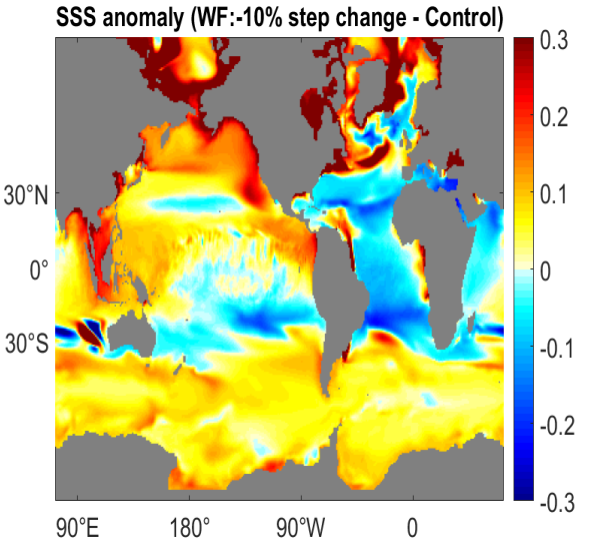


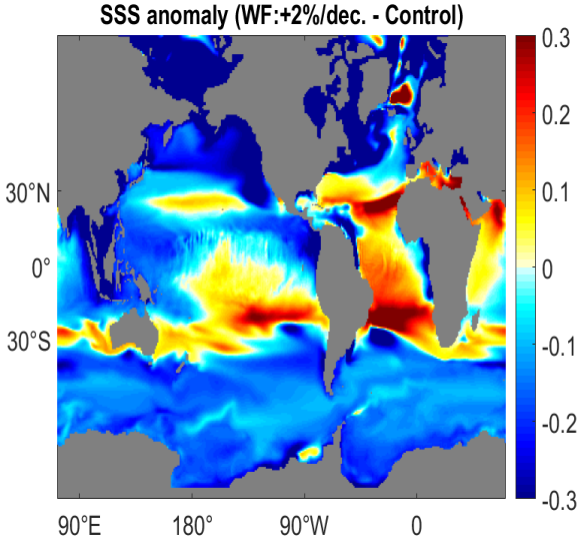
Anomalies with respect to control after 100yrs

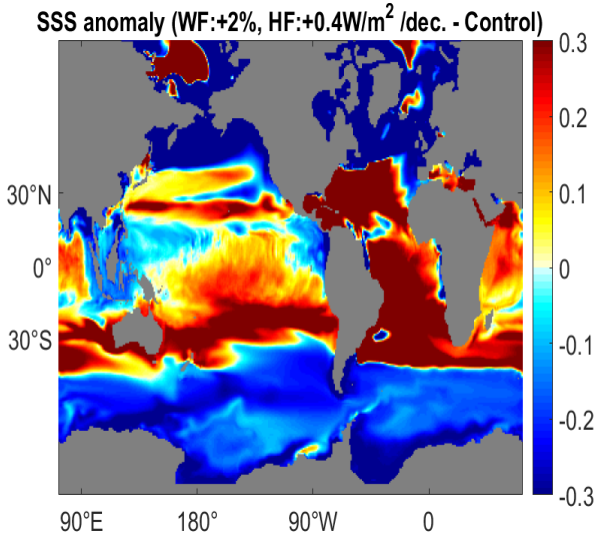






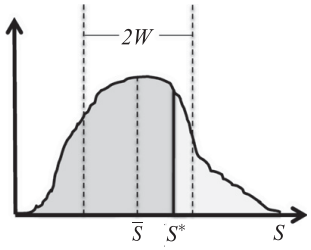






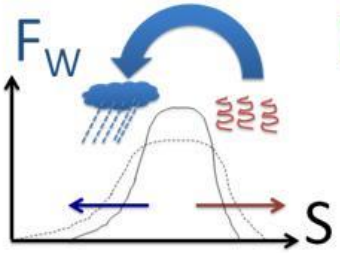
Testing a simple water cycle / salinity model

Total displacement of fresh water. Related to $W = mean(|S-S_0|)$

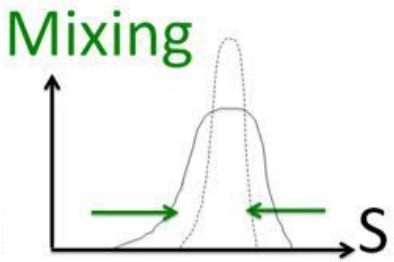


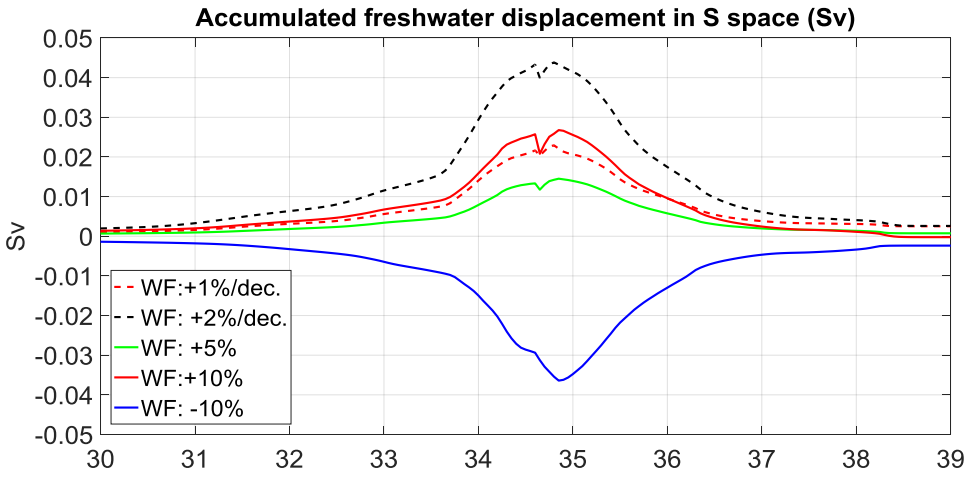
$$\frac{dW}{dt} = \frac{2\bar{S}}{V_0} F_w(\bar{S}) - \frac{1}{\tau} W .$$

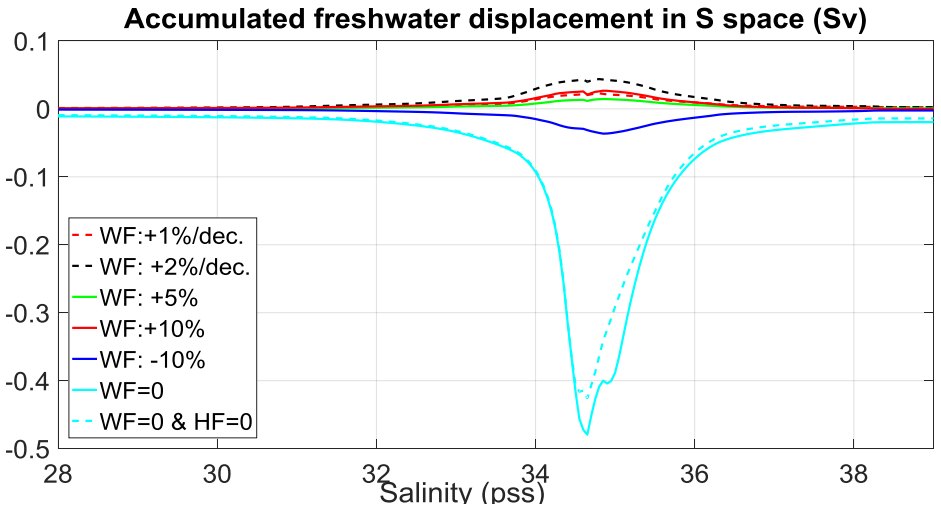
Water moved from saline to fresh. Increases $|S-S_0|$

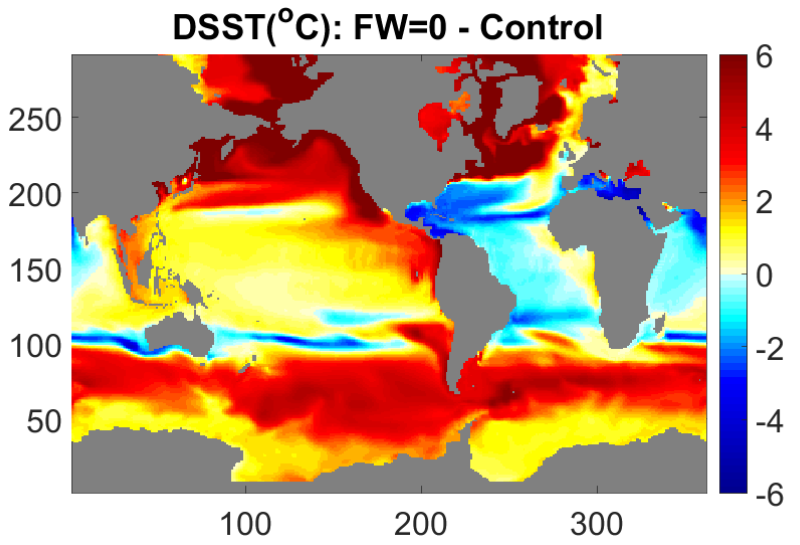


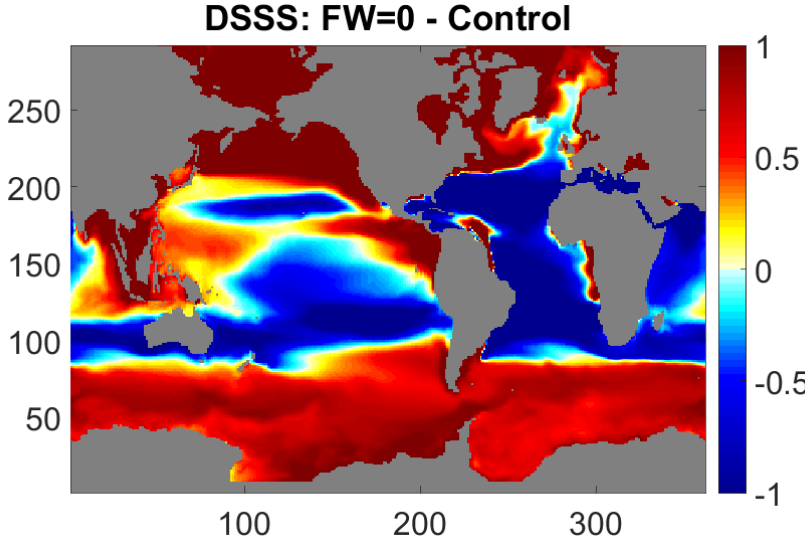
Diffusive flux from saline to fresh. Decreases $|S-S_0|$

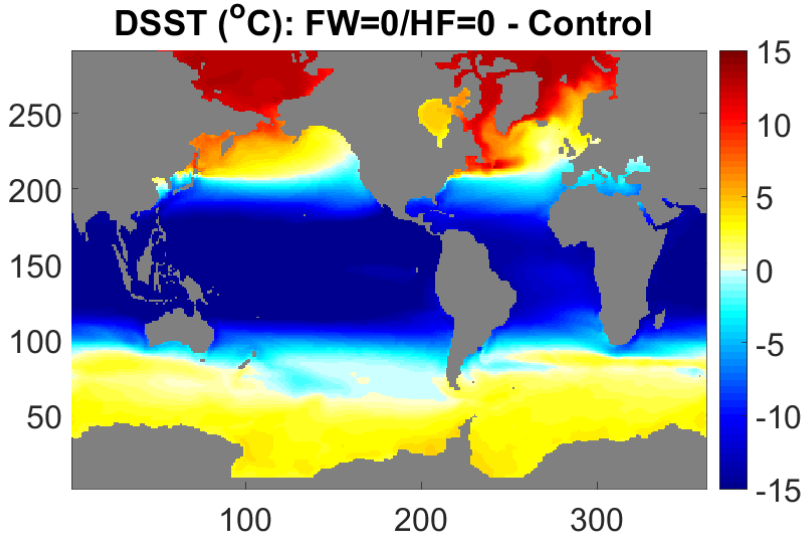


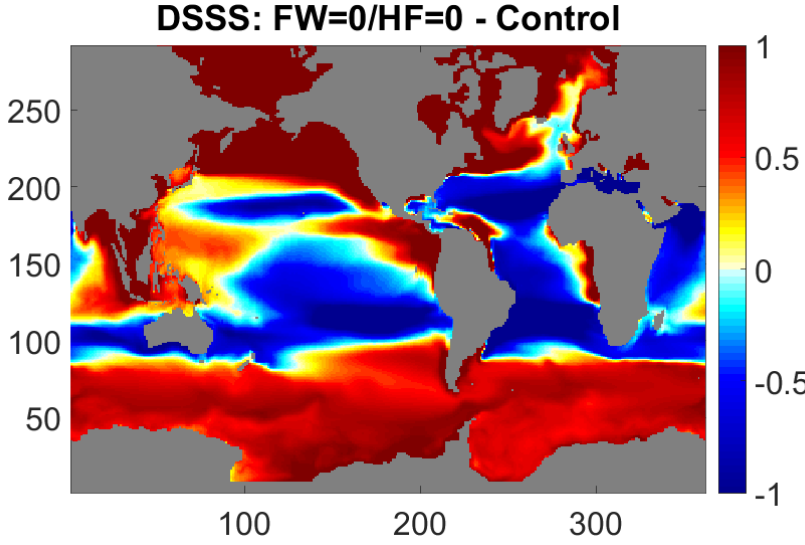





DSST(°C): FW=0 - Control
250
200
150
100
50
100
200
300
6
4
2
0
-2
-4
-6


DSSS: FW=0 - Control
250
200
150
100
50
100
200
300
1
0.5
0
-0.5
-1


DSST (°C): FW=0/HF=0 - Control
250
200
150
100
50
100
200
300
15
10
5
0
-5
-10
-15

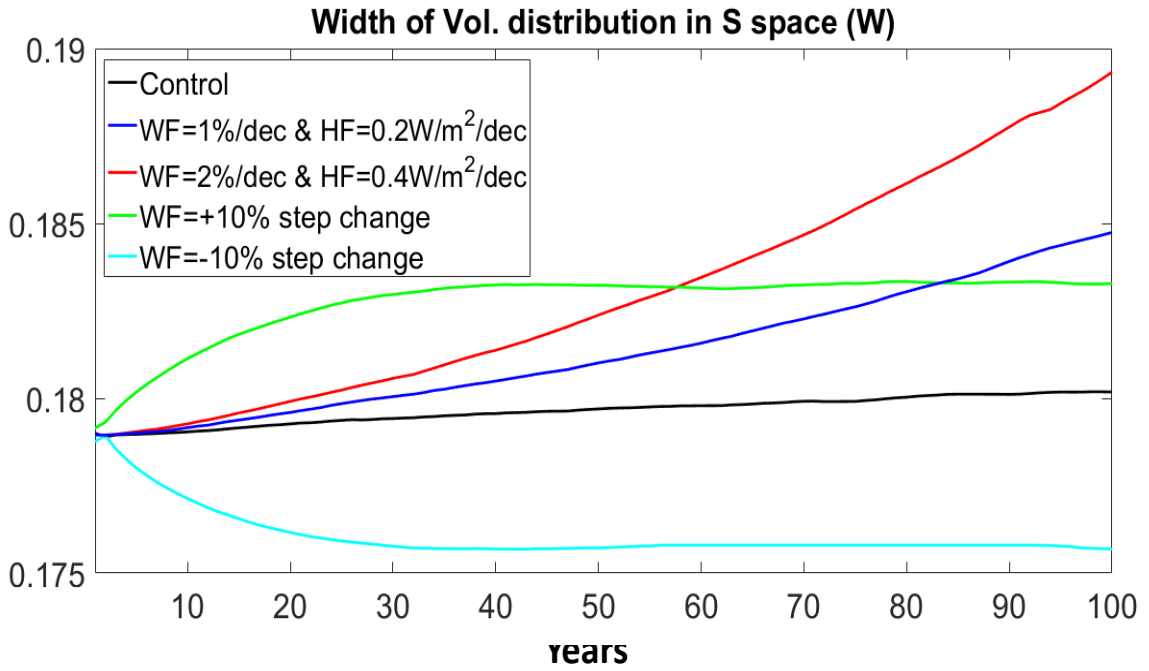

DSSS: FW=0/HF=0 - Control
250
200
150
100
50
100
200
300
1
0.5
0
-0.5
-1

Testing a simple water cycle / salinity model

$$\frac{dW}{dt} = \frac{2\overline{S}}{V_0} F_w(\overline{S}) - \frac{1}{\tau} W .$$

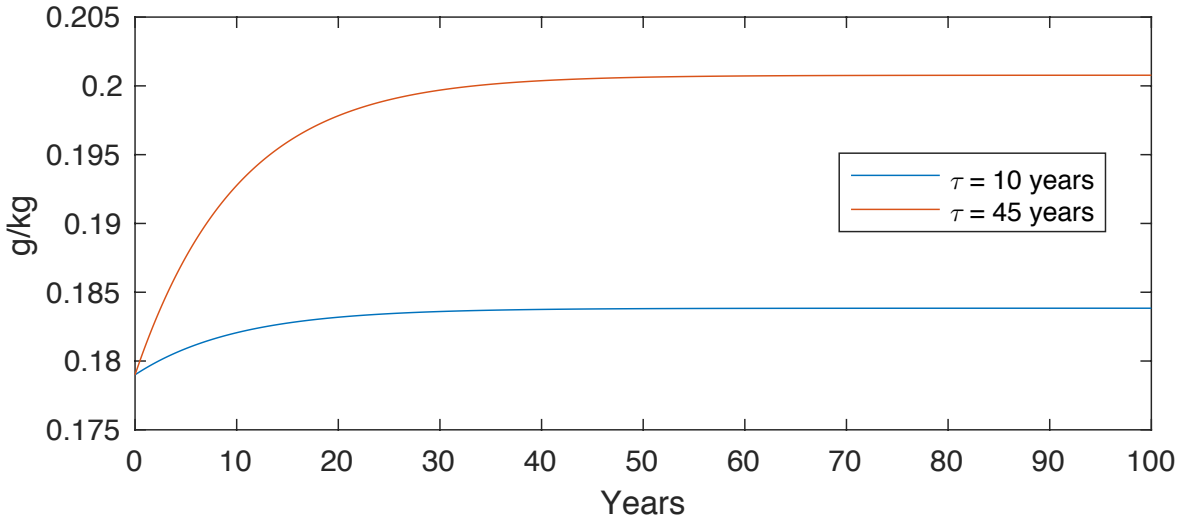
Step change case

$$W' = \frac{2\overline{S}}{V_0} \tau F'_w (1 - e^{-t/\tau}) .$$



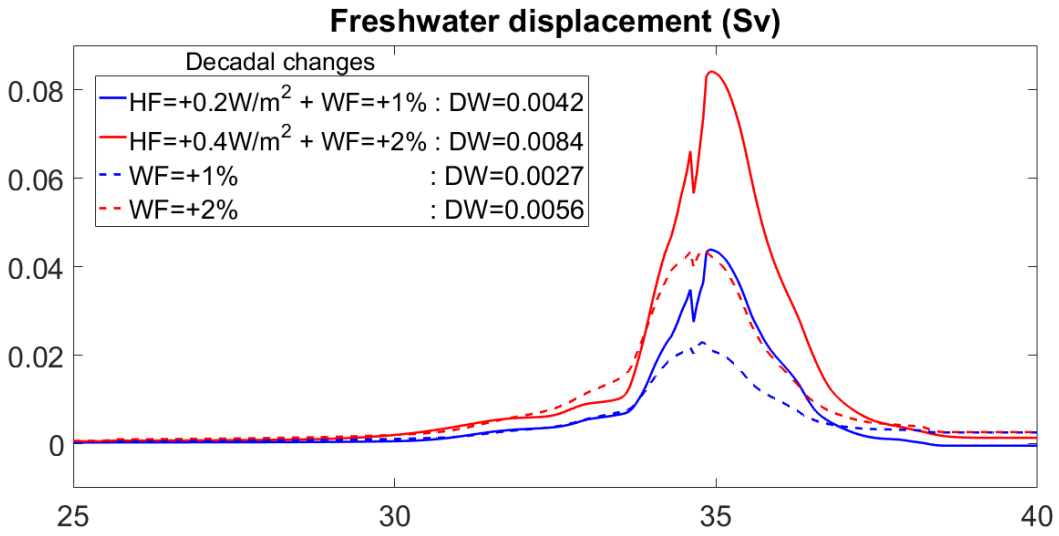
We previously estimated estimated tau=48 years (obs. mean state; Zika et al 2015) and tau = 42 years (CMIP5 mean and RCP scenarios).

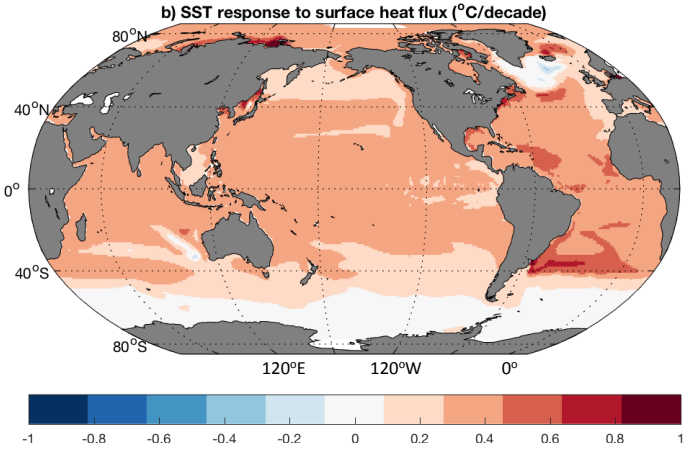
Unfortunately the ocean doesn't depend on one parameter ☹.

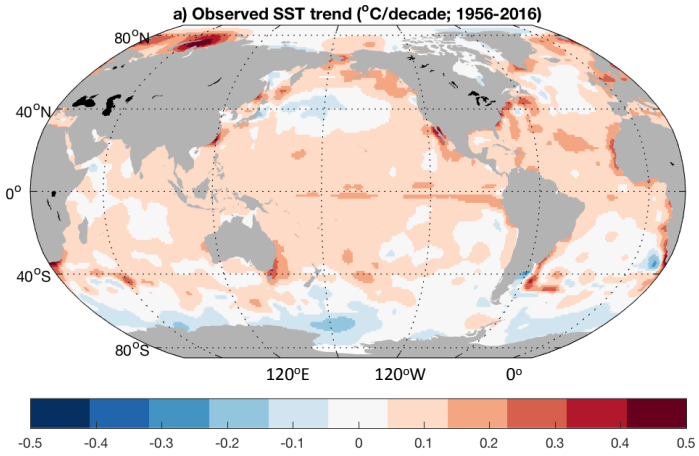


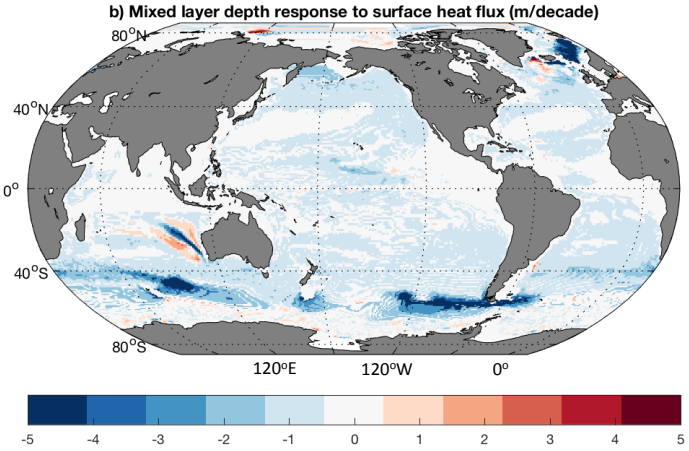
Ocean warming reduces mixing

WF change vs. WF+HF combined change experiments
Freshwater displacement and W change after 100 yrs with respect to Control

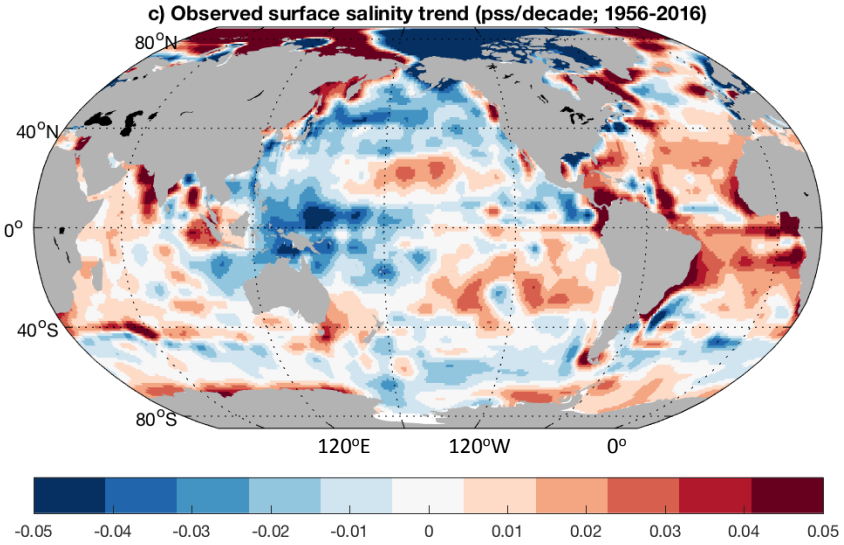


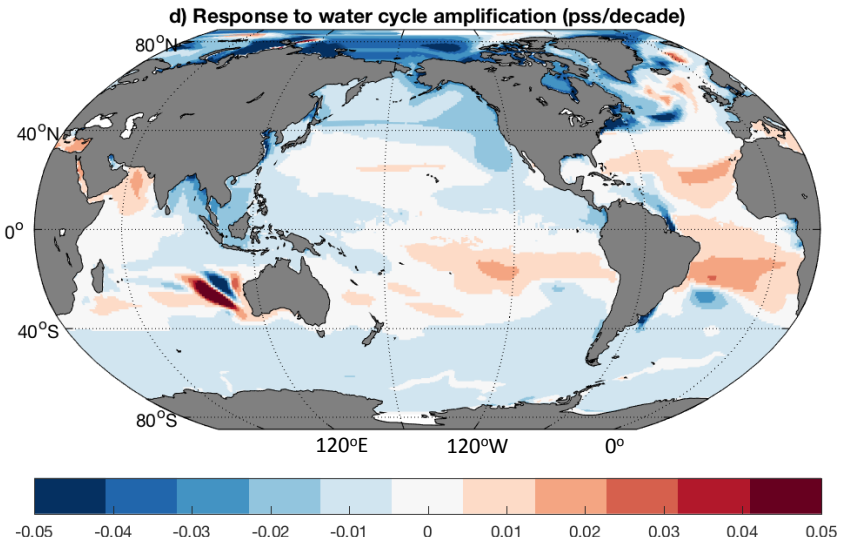


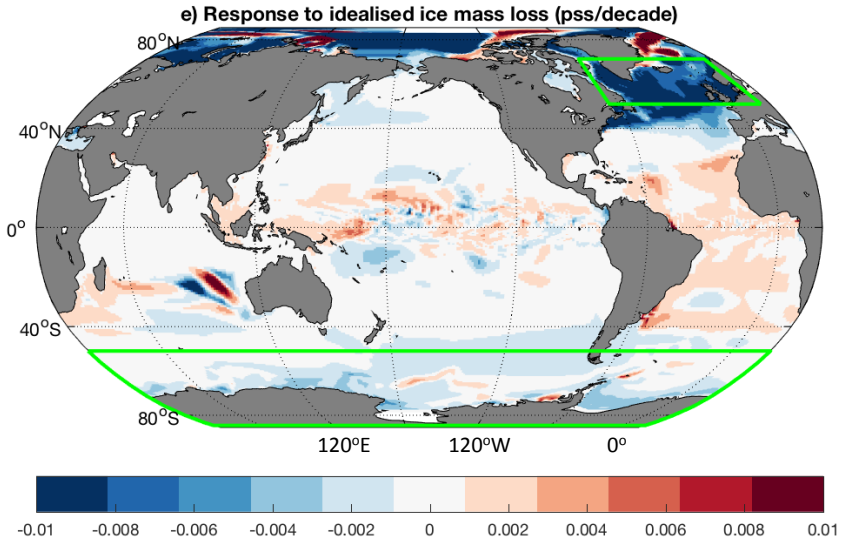


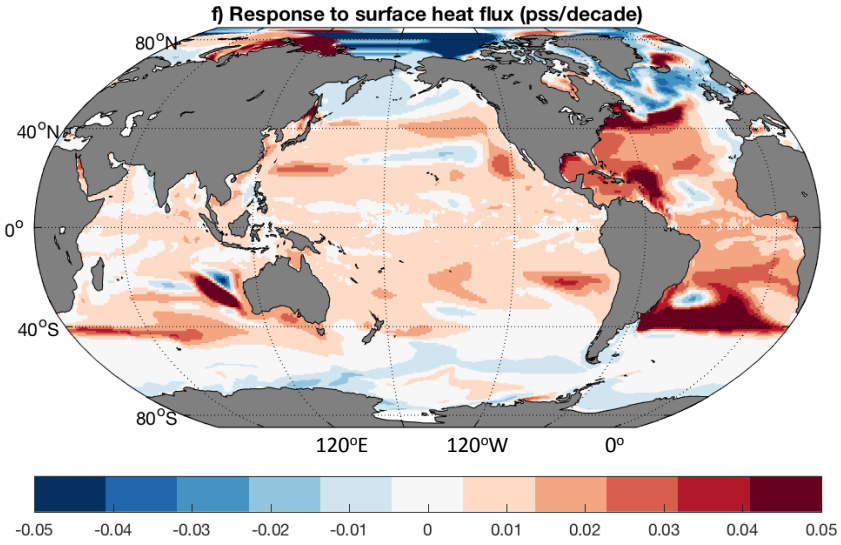


Water cycle, warming and ice mass loss contribute to salinity pattern change

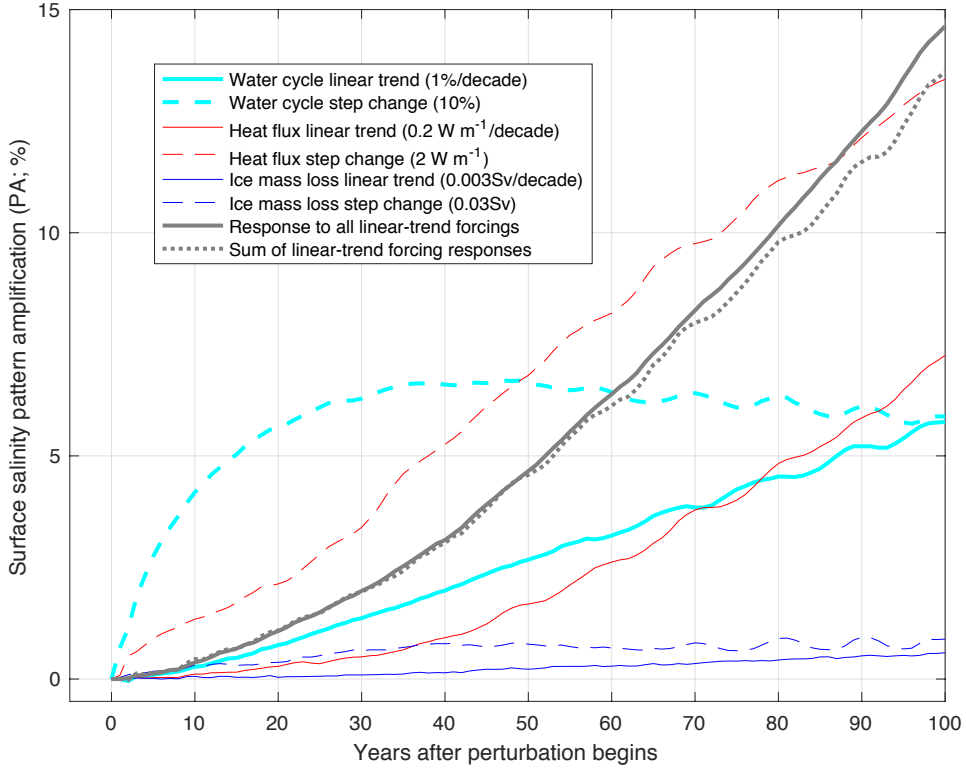


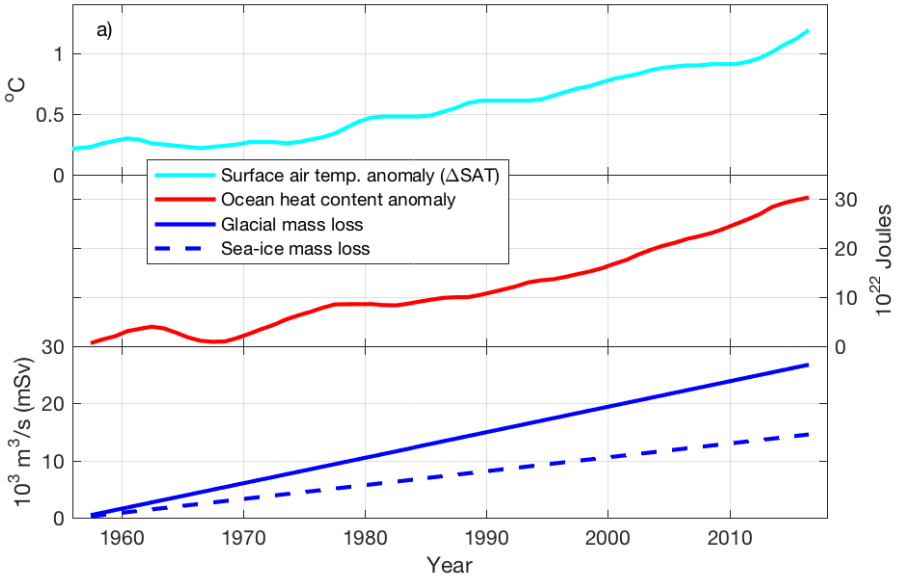


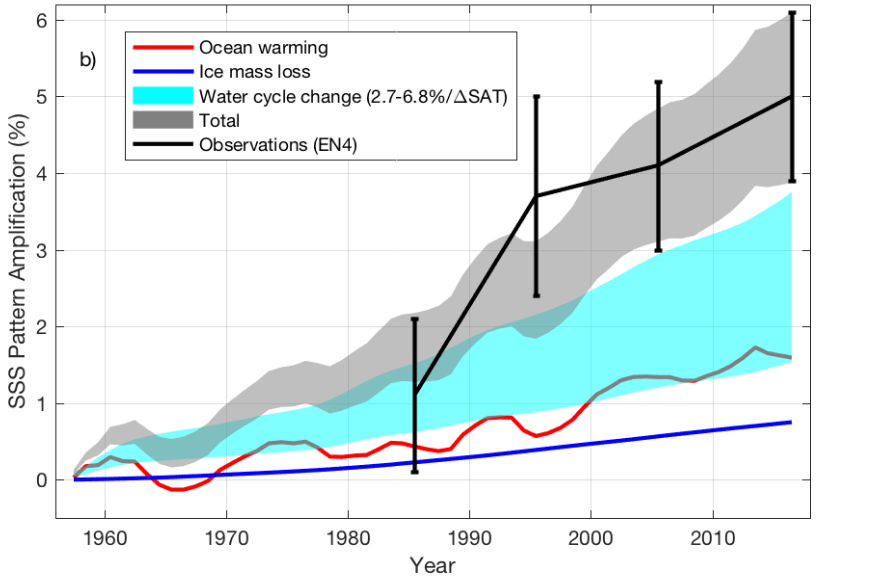




Based on observational estimates of warming, ice mass loss, salinity change and global temp we estimate the water cycle has changed by 3-7% per ^{o}C warming.







Conclusions

- Prescribing exact fluxes is doable;
- Water cycle change does not affect SST much but warming affects SSS a lot;
- Global salinity contrast has fast and slow effects (no single timescale);
- Warming reduces mixing, causing approximately 30-50% of SSS pattern change;
- Salinity pattern change suggests 3-7%.