Climatology and climate sensitivity in AR6 DECK simulations with NorESM2: What is the sensitivity to changes in CAM6?

Presentation at the
CESM AMWG/WAWG/CCWG meeting 9-11 March 2020
NCAR Mesa Lab, Boulder CO
9 March 2020

Ada Gjermundsen, Øyvind Seland, Thomas Toniazzo, and the NorESM2 development team

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OUTLINE

I. Evaluation of CMIP6 integrations with NorESM2

(Seland et al. 2020, GMD discussions https://doi.org/10.5194/gmd-2019-378)

II. Analysis of NorESM2's different (transient) climate sensitivity compared to CESM2

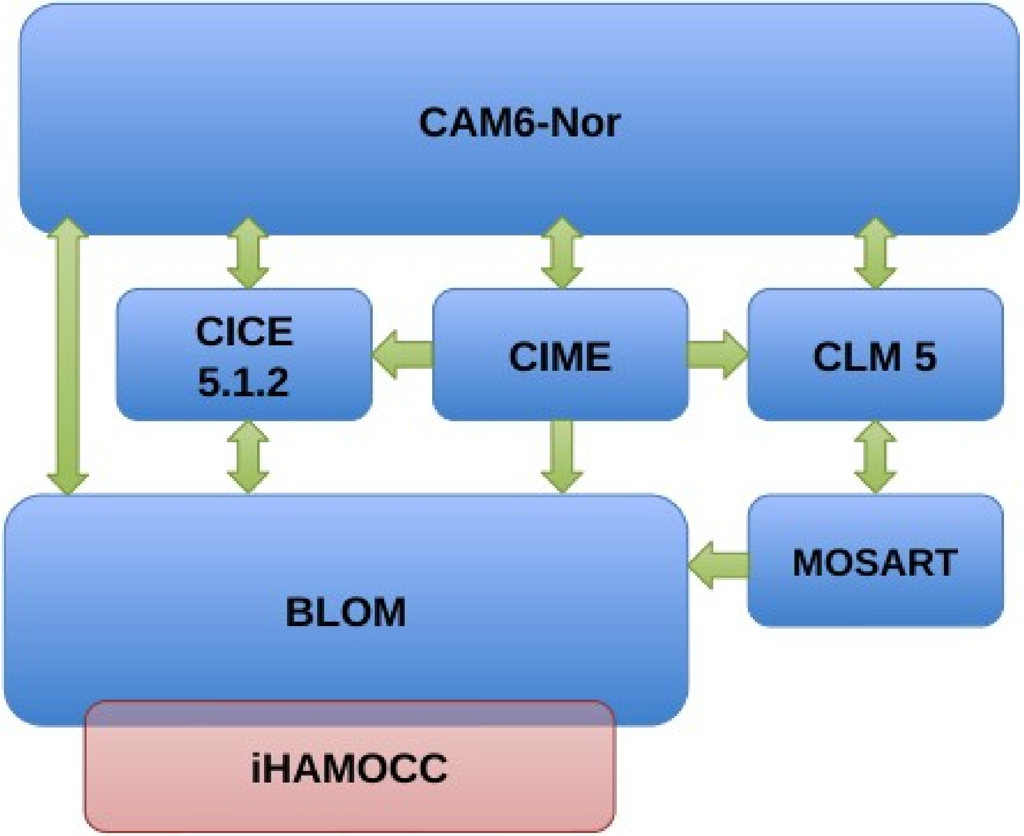
(Gjermundsen et al., in preparation)

III. CAM6-Nor changes in moist physics and its impacts

(Toniazzo et al., in preparation)

I. Evaluation of CMIP6 integrations with NorESM2 (Seland et al. 2020, GMD discussions https://doi.org/10.5194/gmd-2019-378)

Components of Nor(C)ESM2



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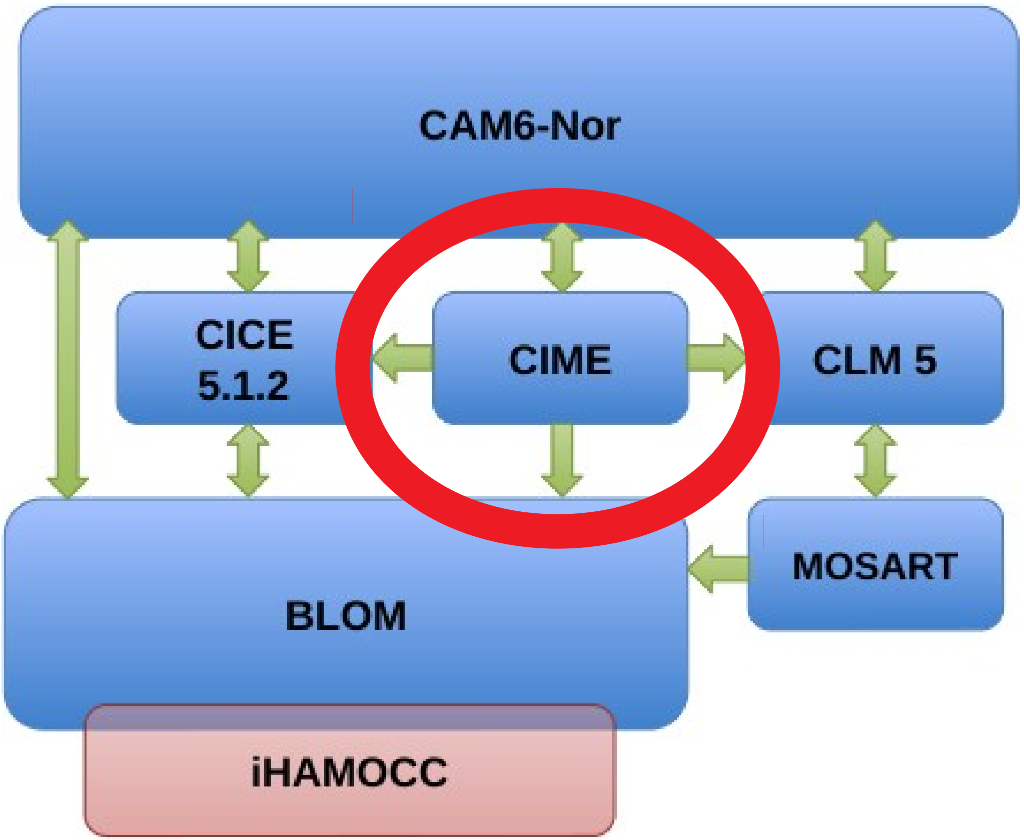
Components of Nor(C)ESM2



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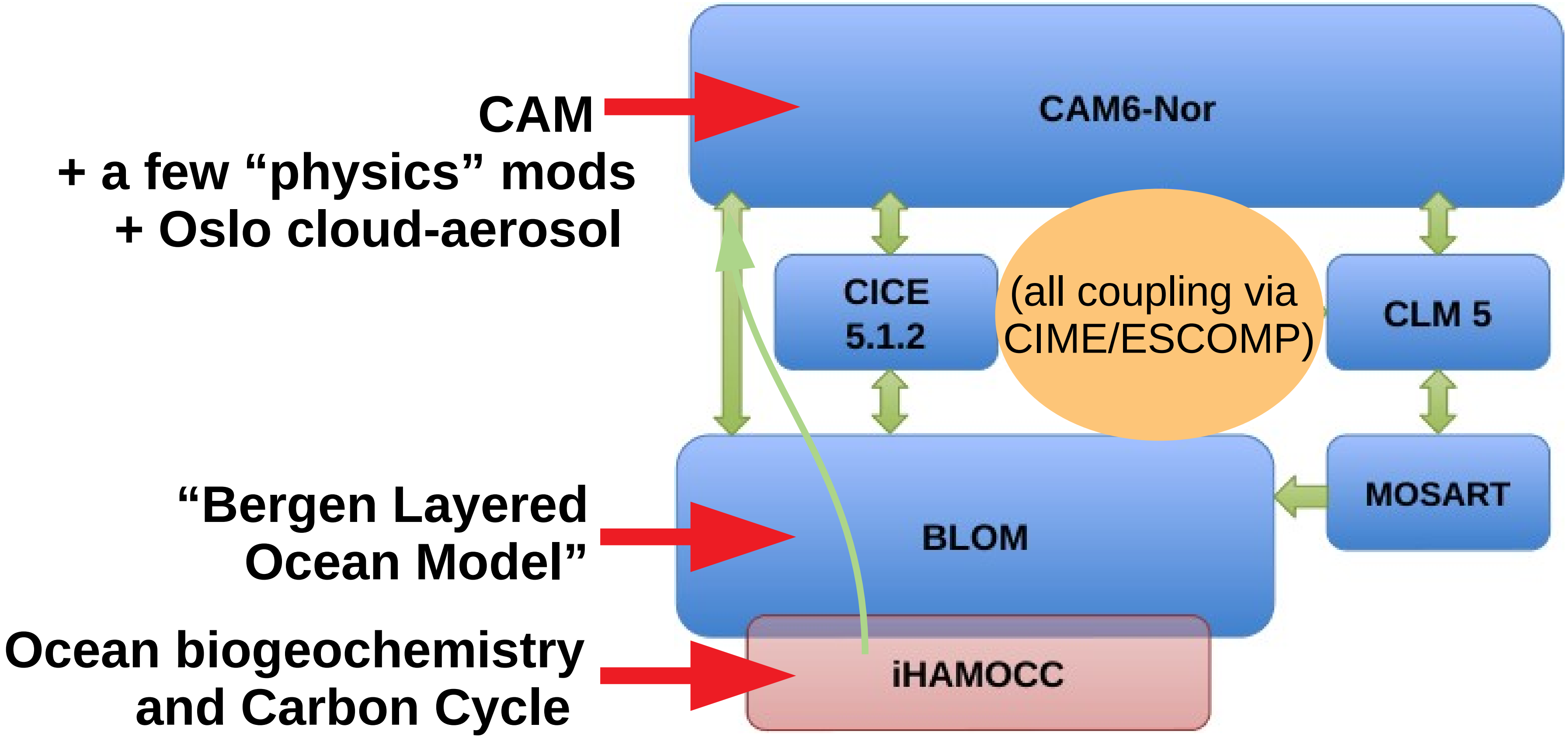
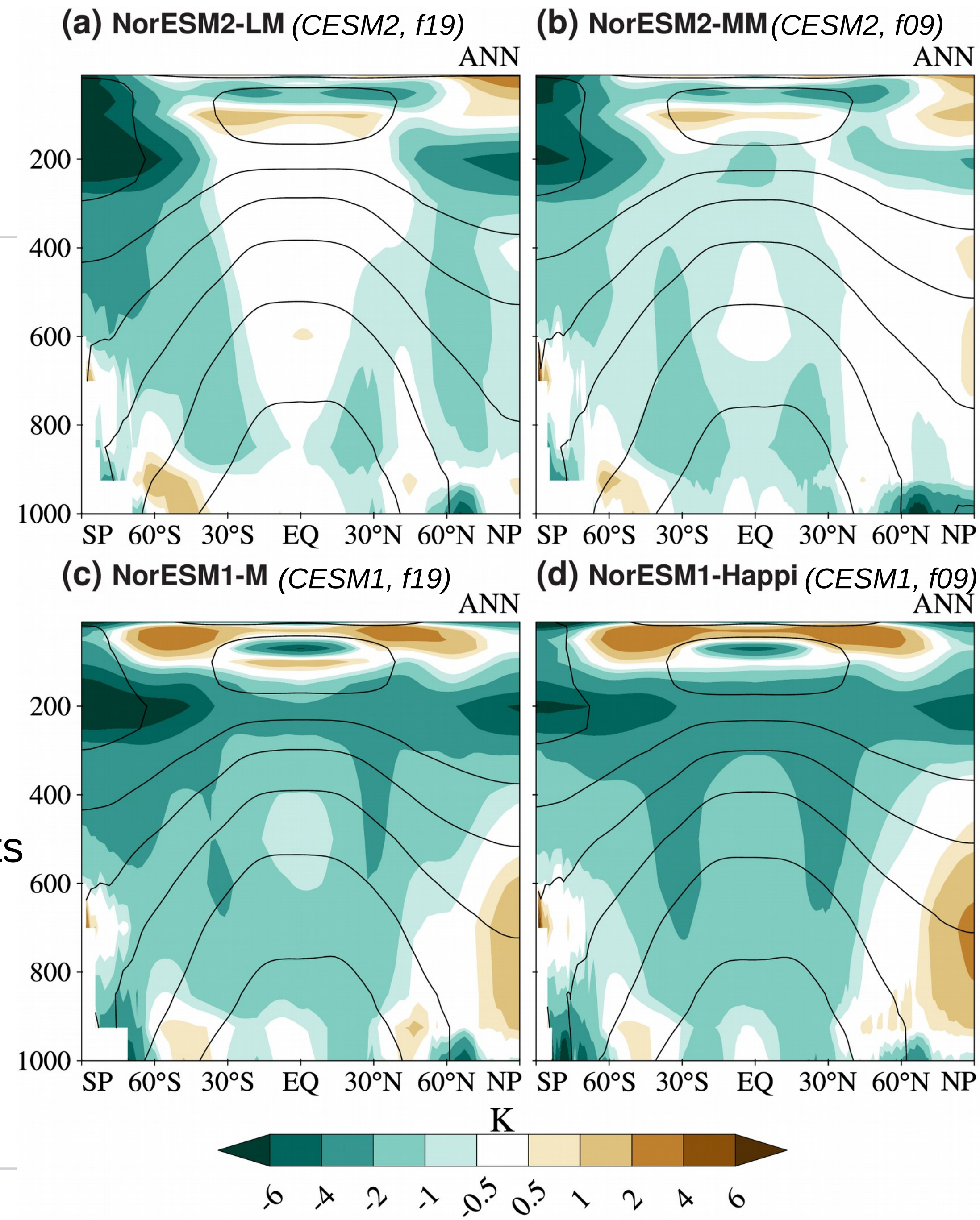


Zonal-mean air temperature bias in HIST integrations (last 30 years)

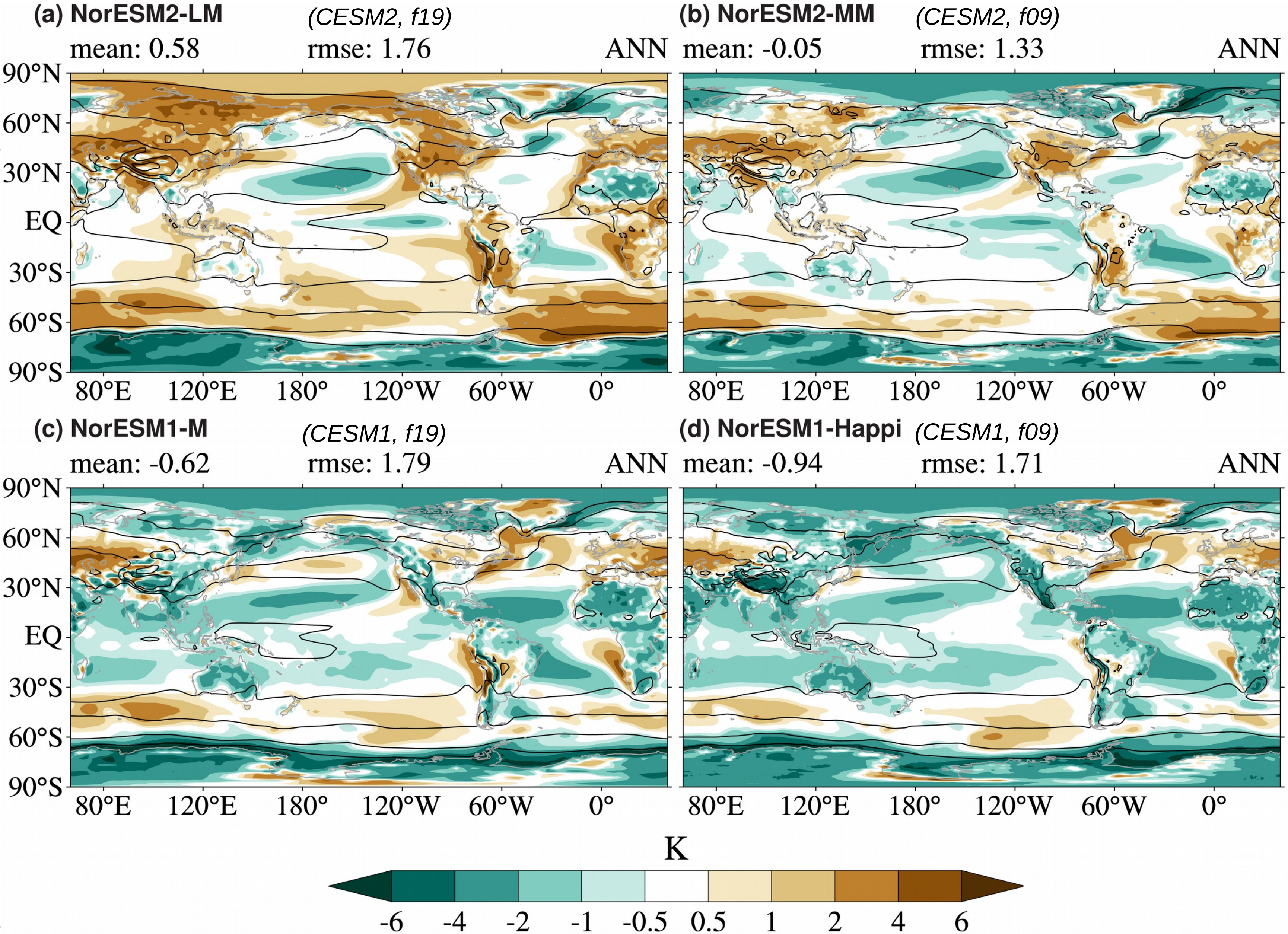
“LM” = FV19
“MM”= FV09
Same science, different tuning
Other components identical

NorESM1 = CMIP5 version (CESM1/CAM4) FV19

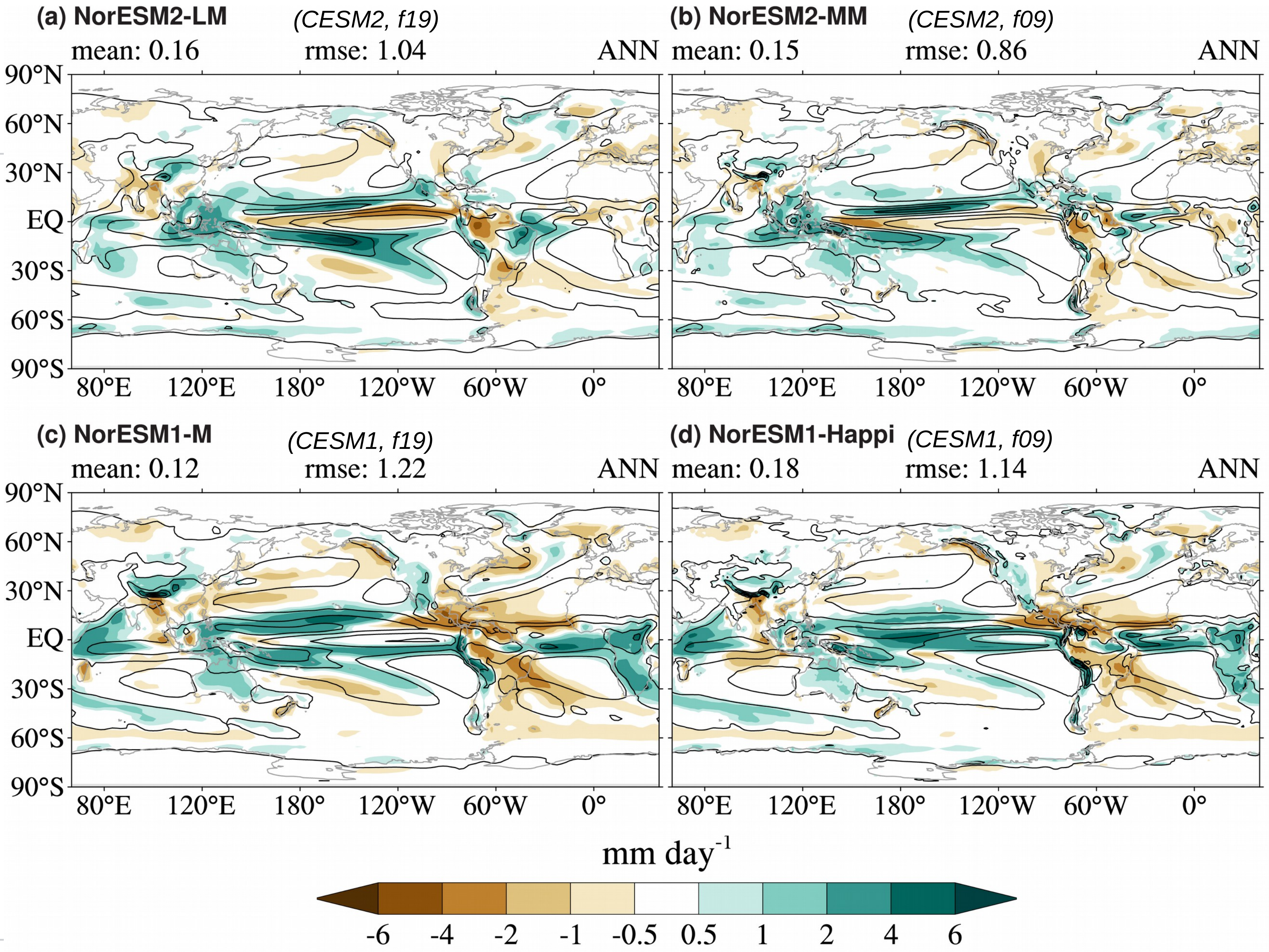
NorESM-Happi = FV09 based on NorESM1 +minor adjustments



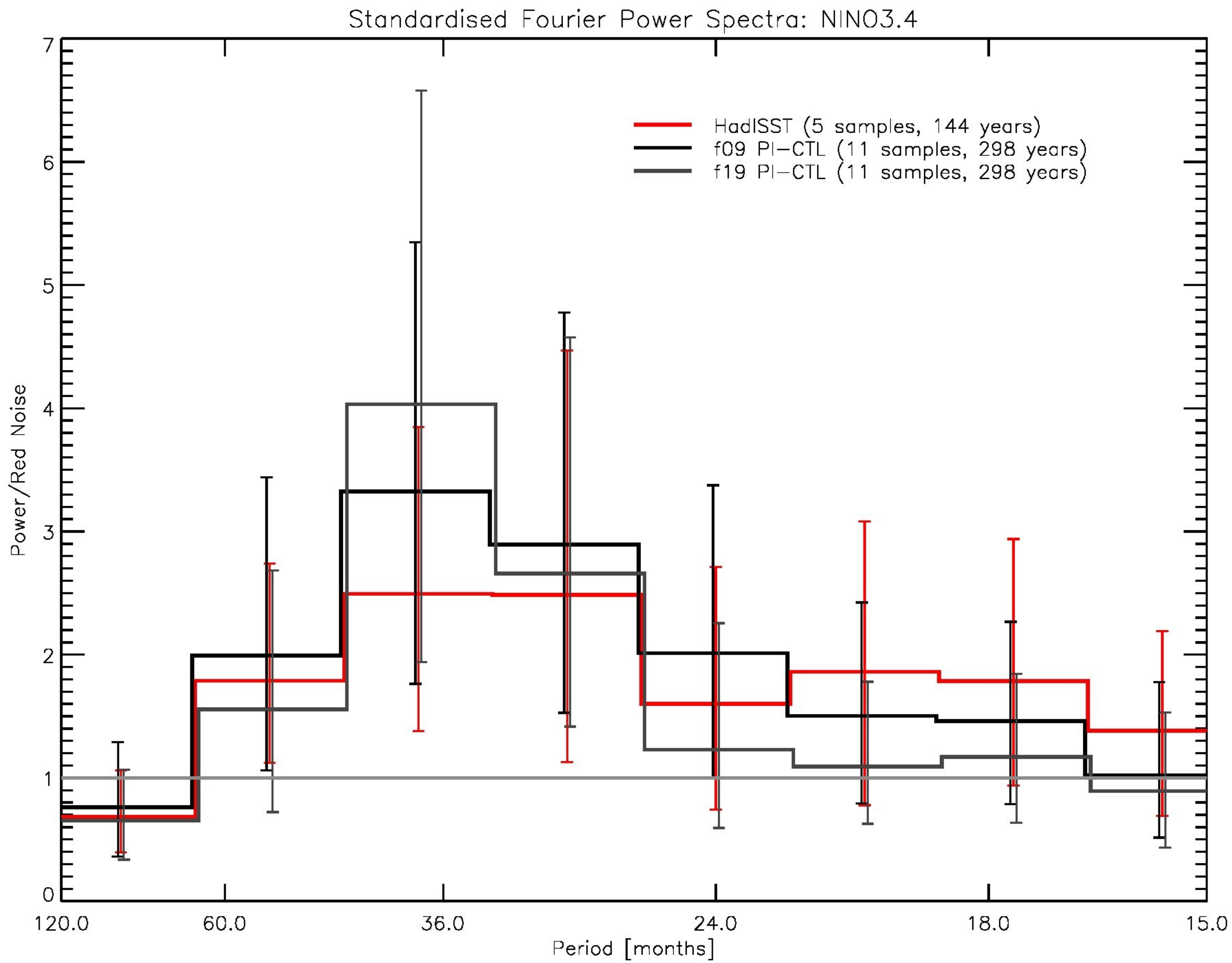
Near-surface air temperature bias in HIST integrations (last 30 years)



Total precipitation bias in HIST integrations (last 30 years)



A look at ENSO (PI)



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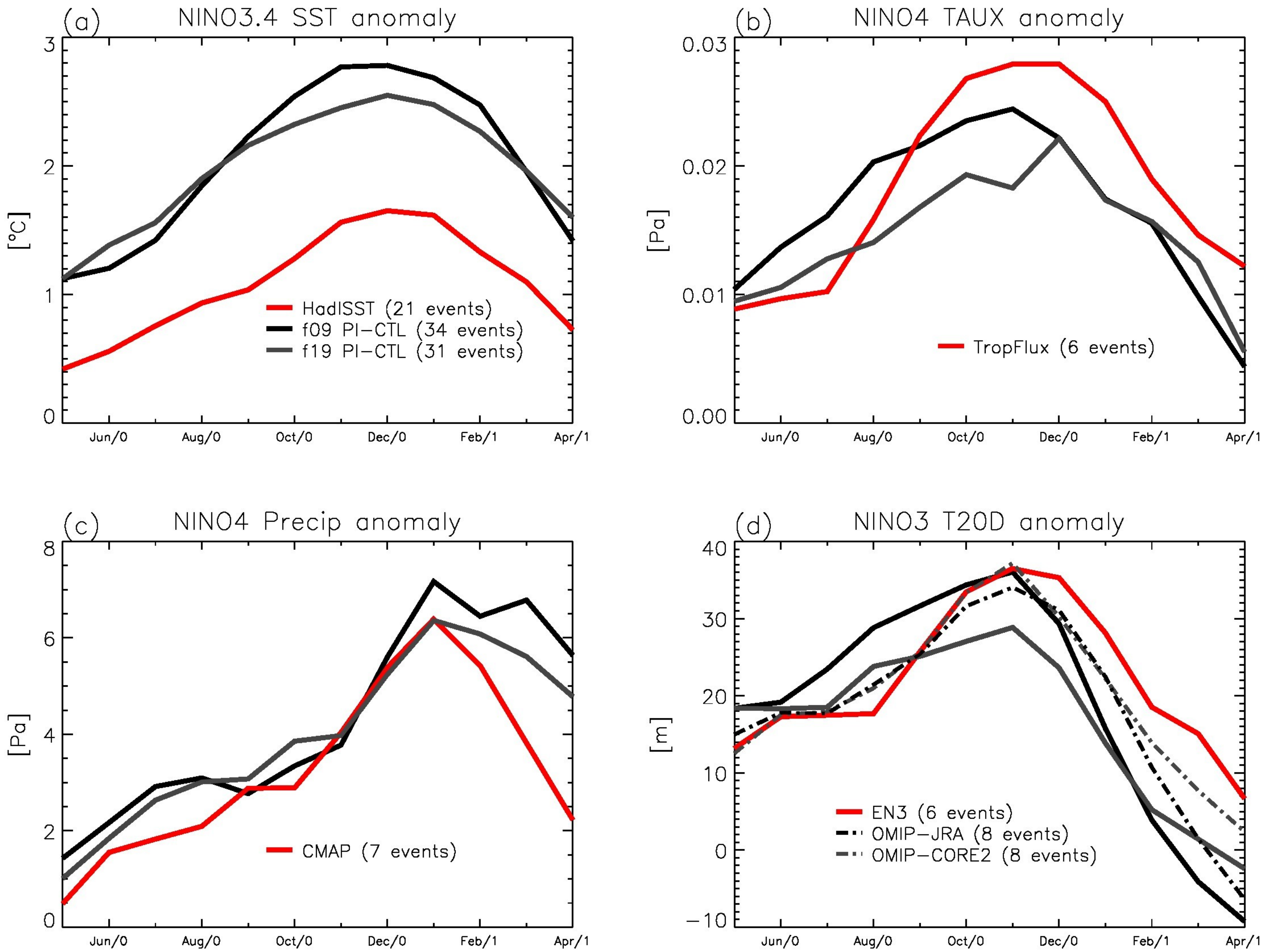

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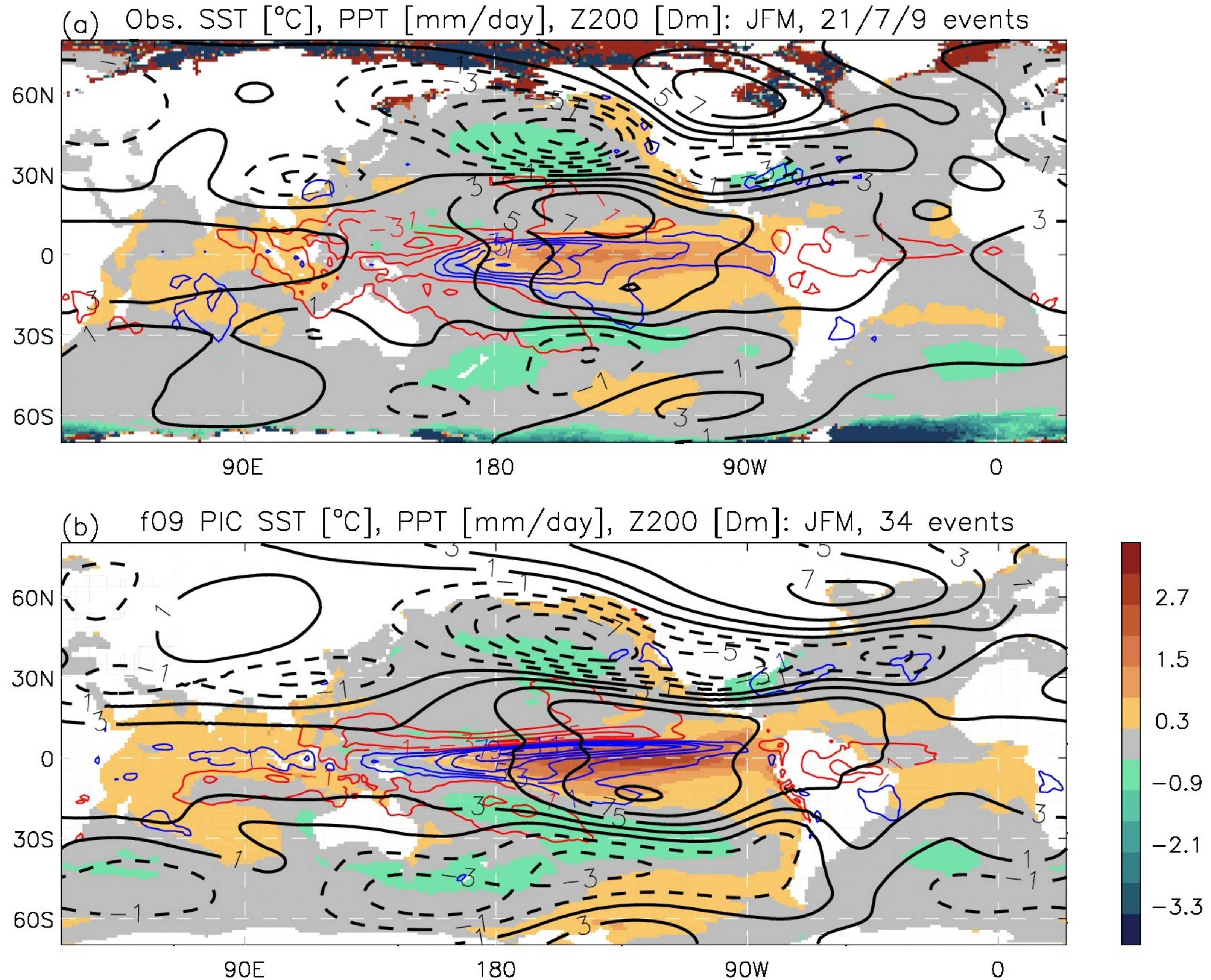
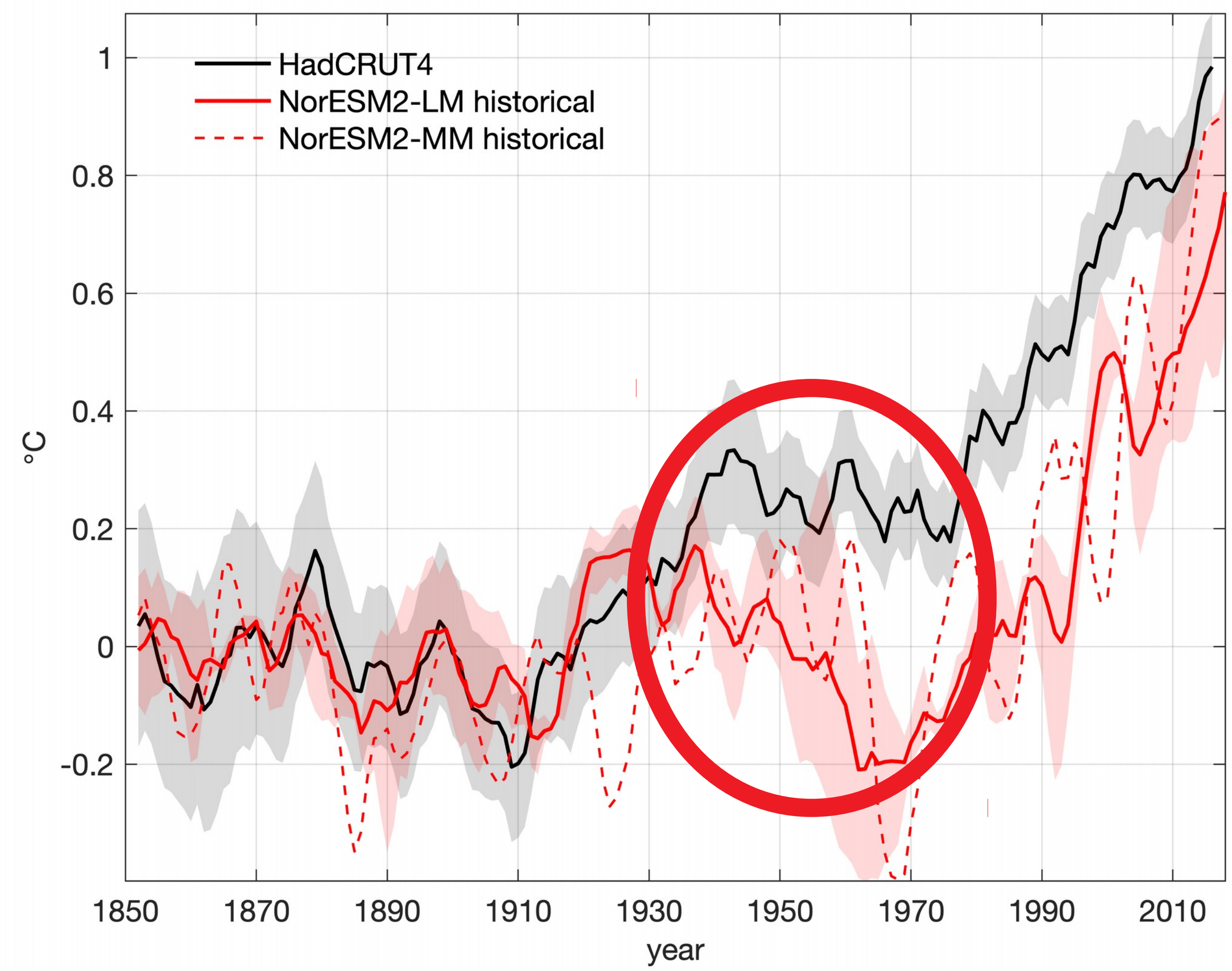


Simulated evolution of historical global-average near-surface temperature



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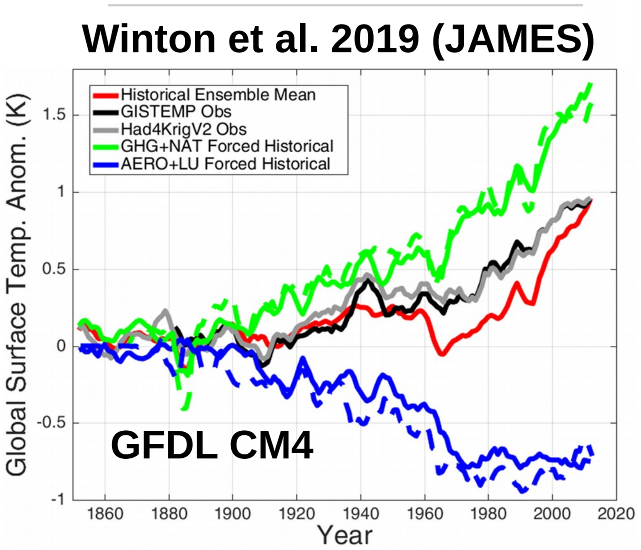
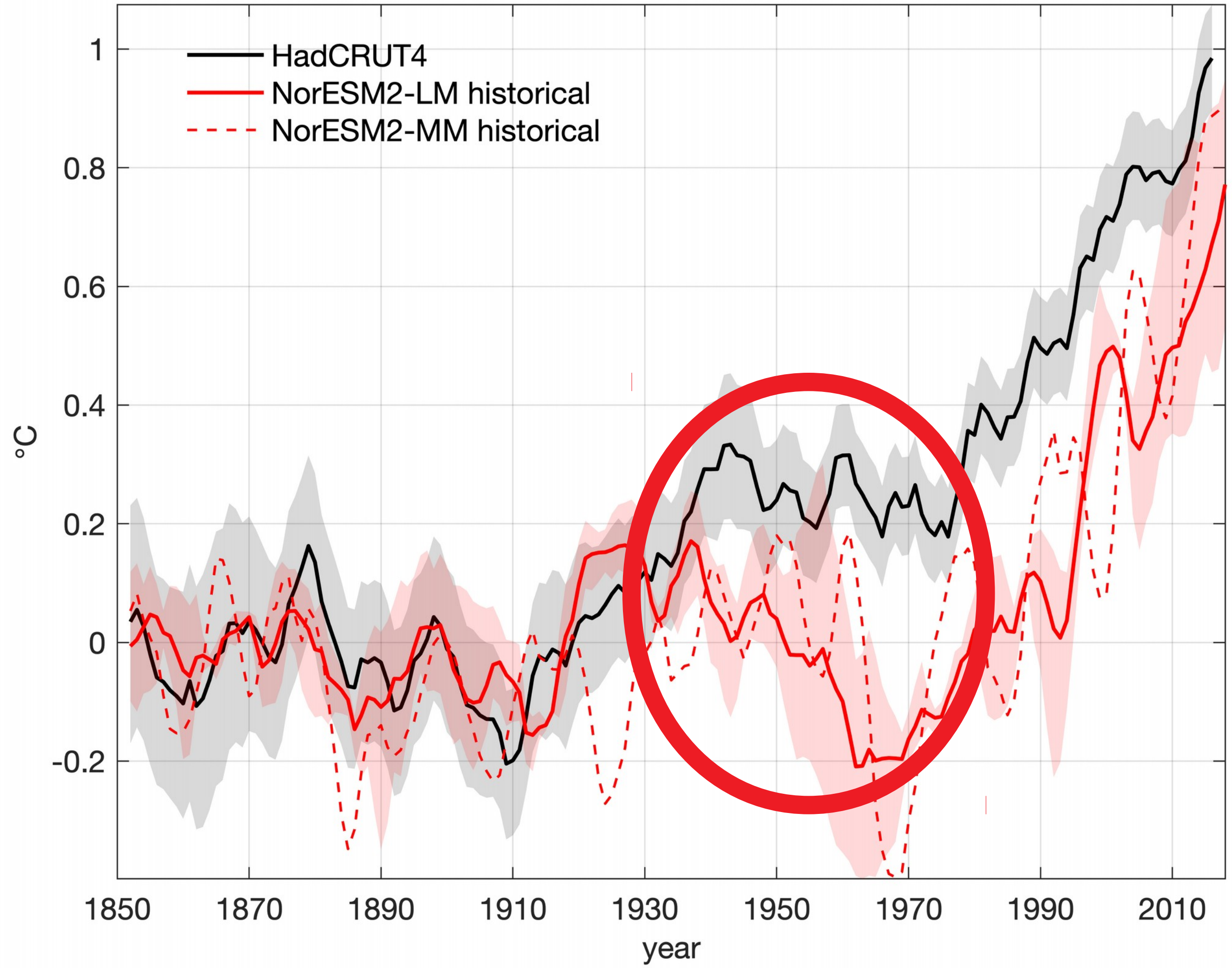
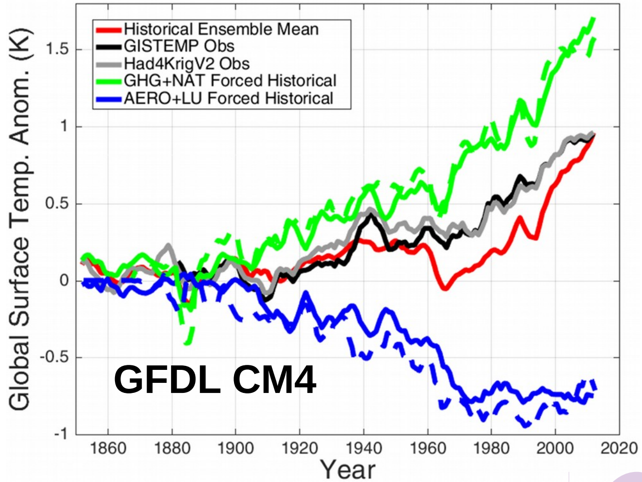
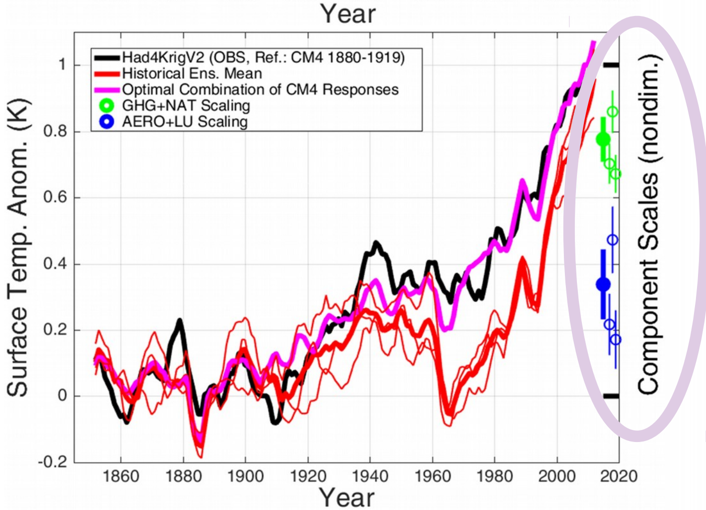


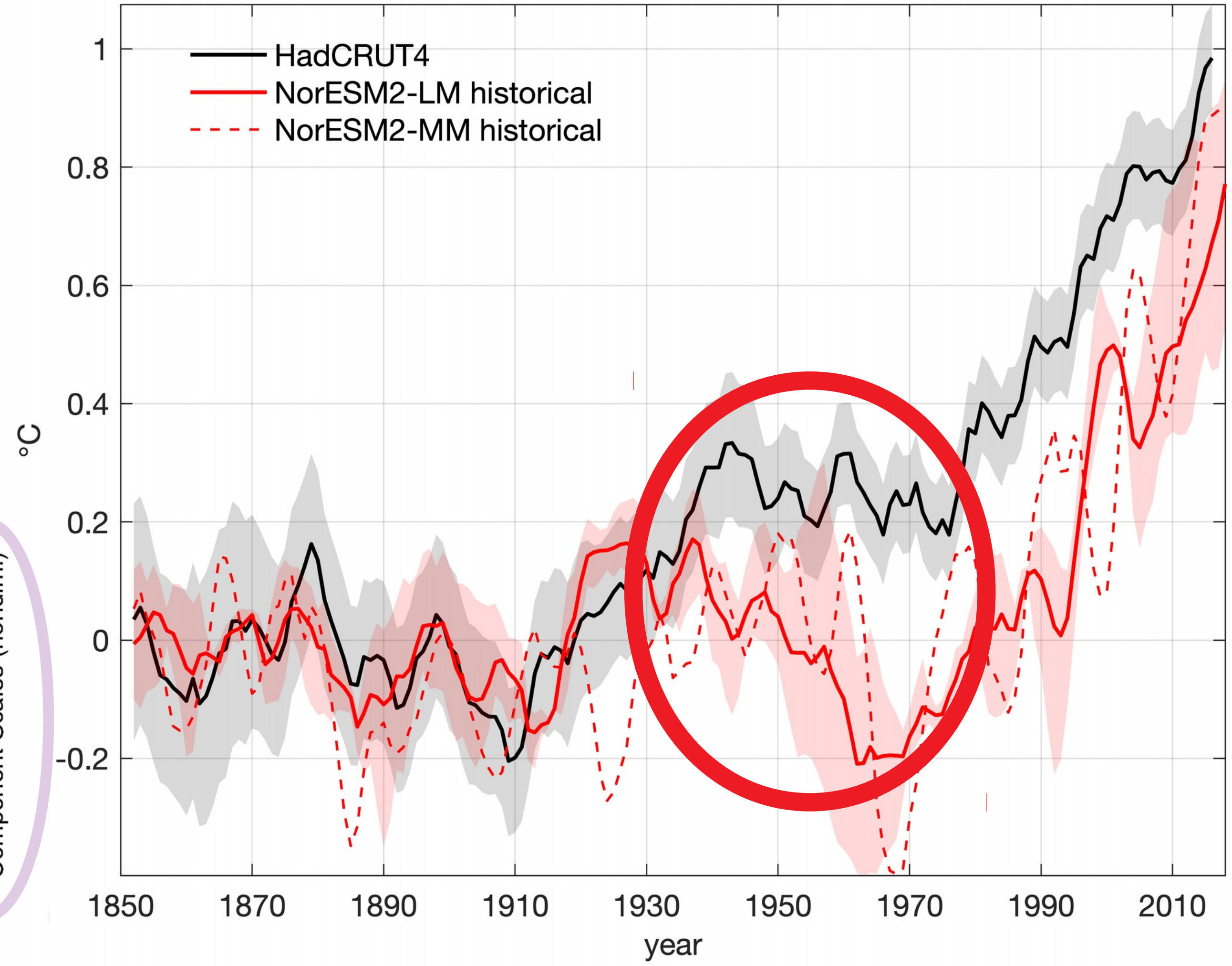


Simulated evolution of historical global-average near-surface temperature

Winton et al. 2019 (JAMES)







Summary: DECK evaluation

- **Paper in GMD discussions (Seland et al. 2020, https://doi.org/10.5194/gmd-2019-378) – comments welcome!**
- **CESM and NorESM development has resulted in better validation of NorESM2 simulation wrt observations**
- **ENSO OK-ish, but SSTa too large, and notable lack of dry anomalies of MC**
- **Climatology improves with higher atm. resolution, but variability does not**
- **Excessive cooling in post-WWII period**

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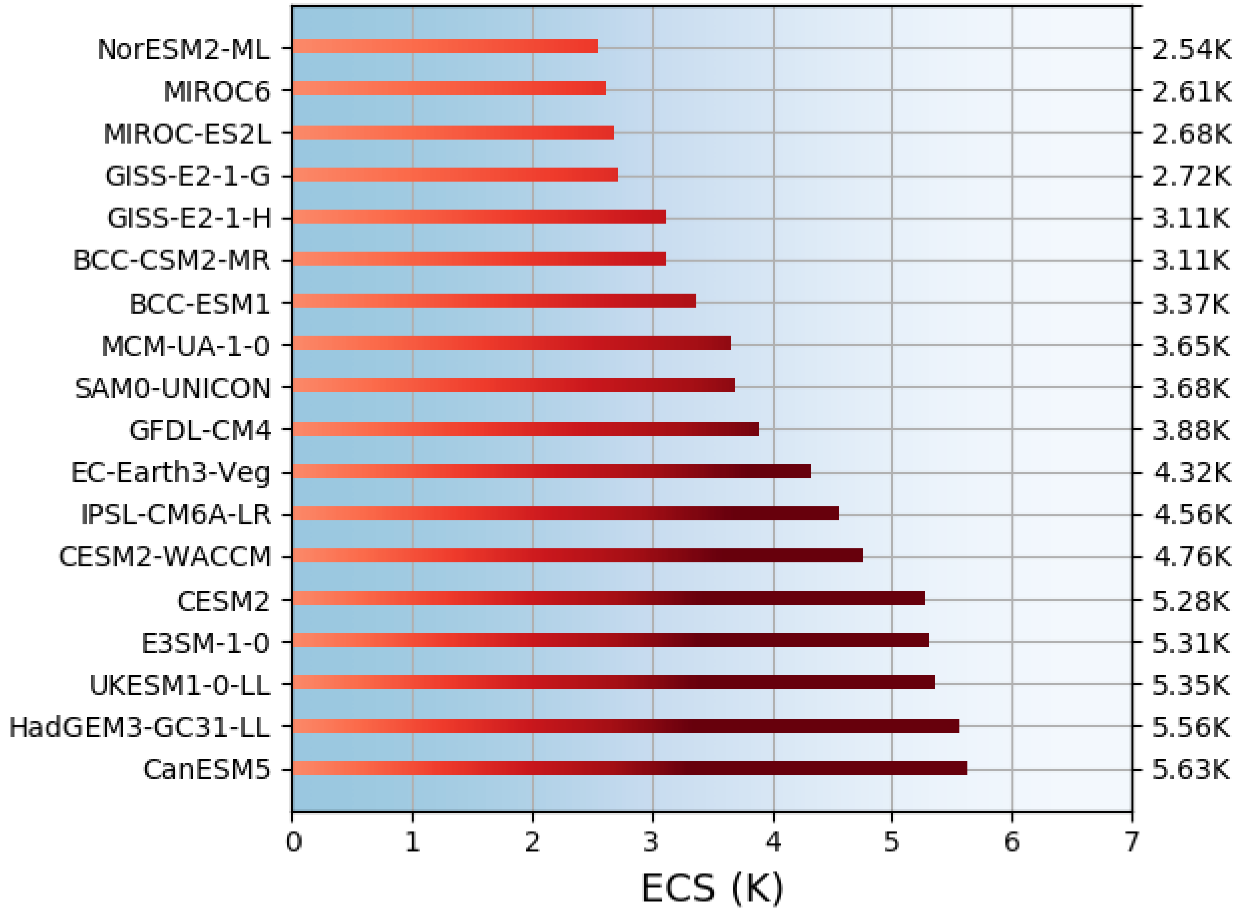
II. Analysis of NorESM2's different (transient) climate sensitivity compared to CESM2 (Gjermundsen et al., in preparation)

Gregory Climate Sensitivity in CMIP6



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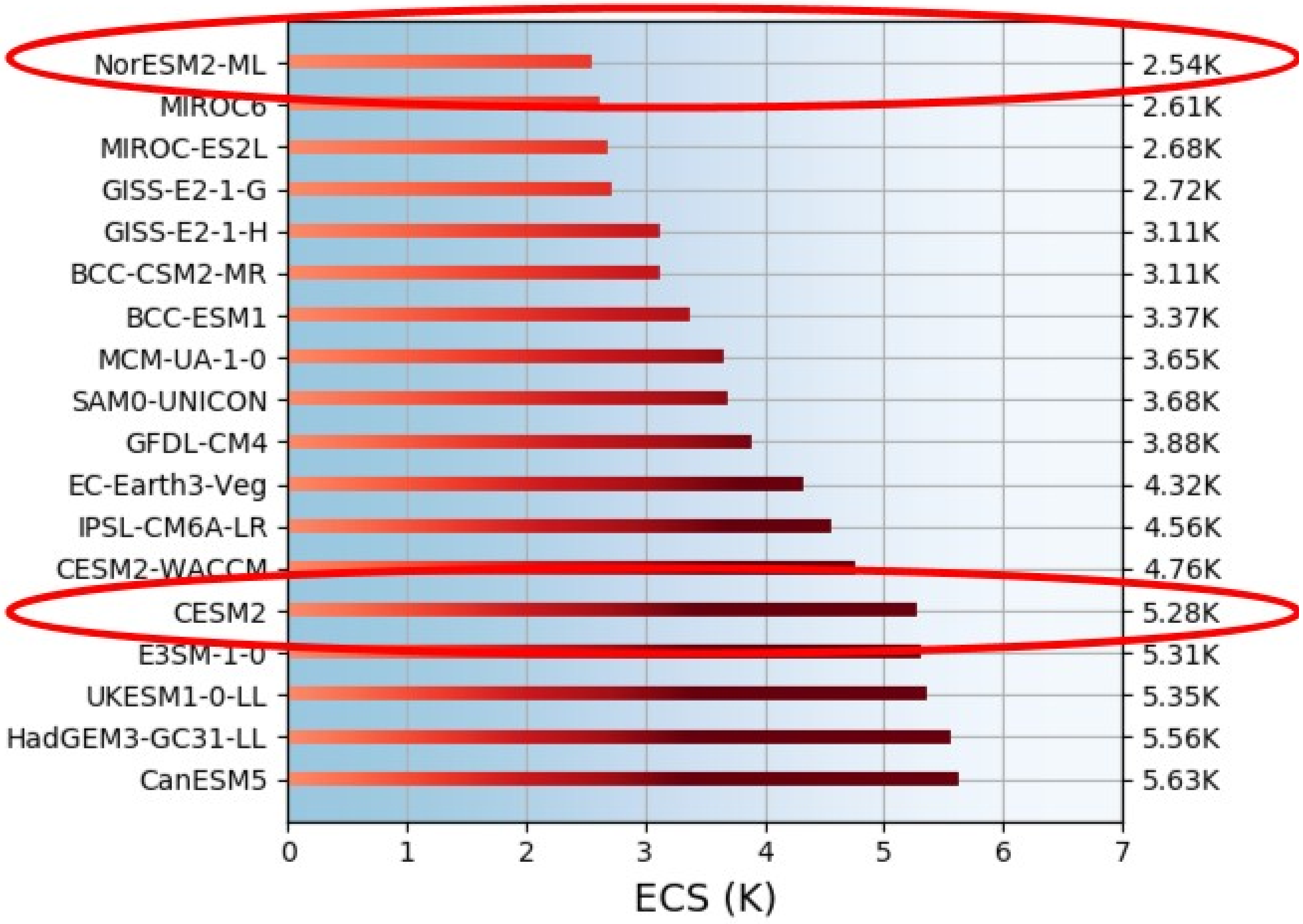
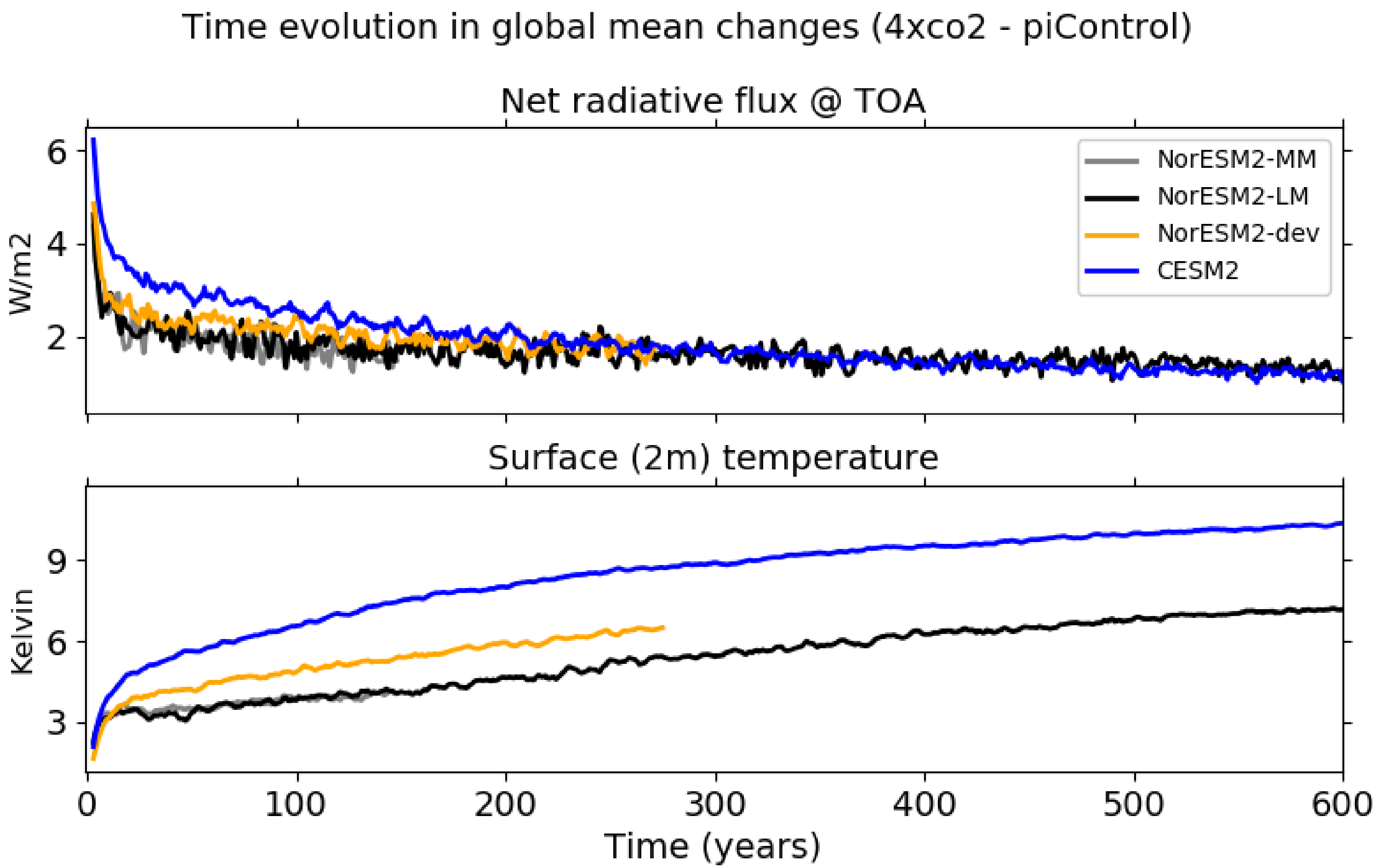
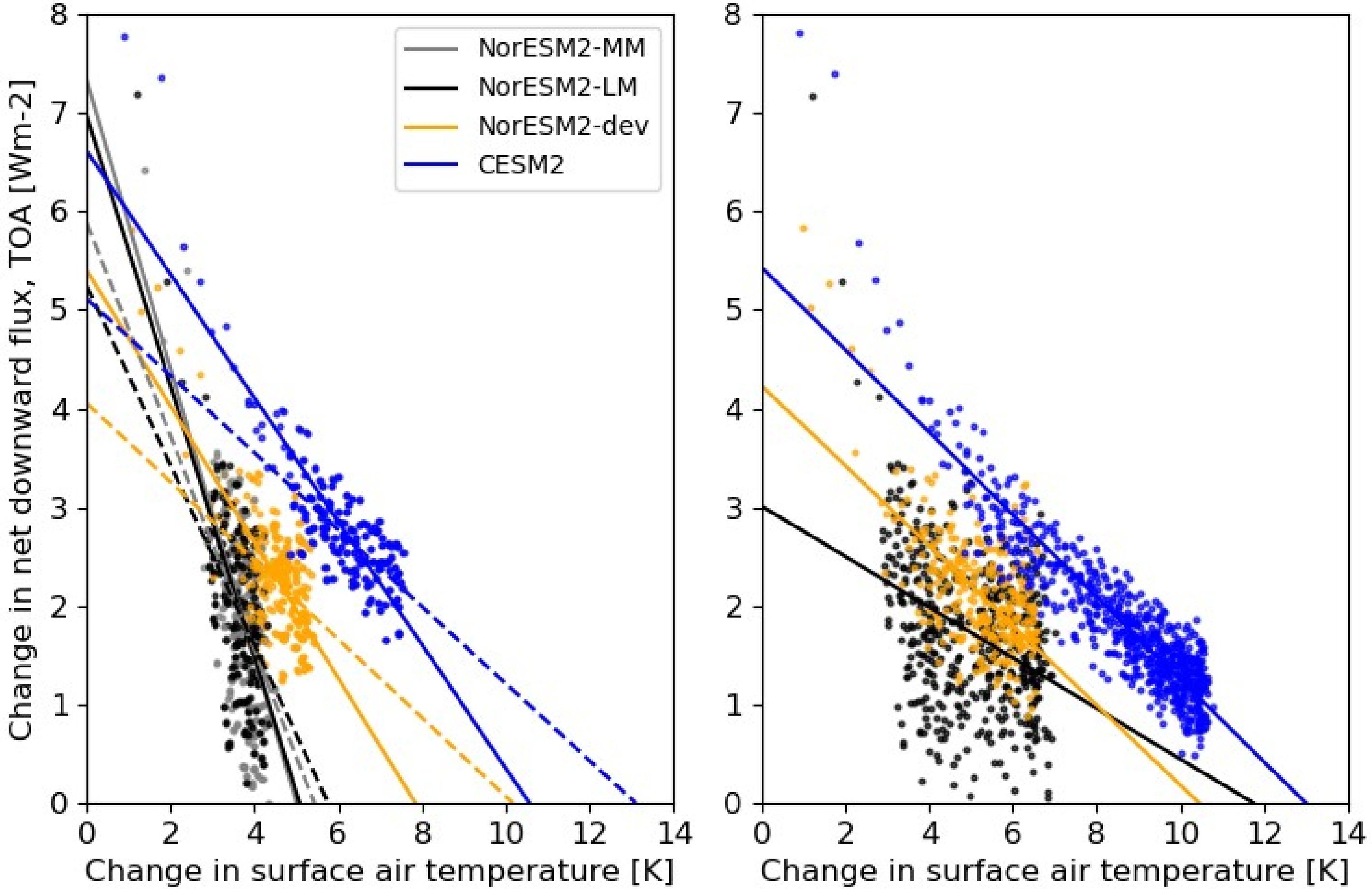


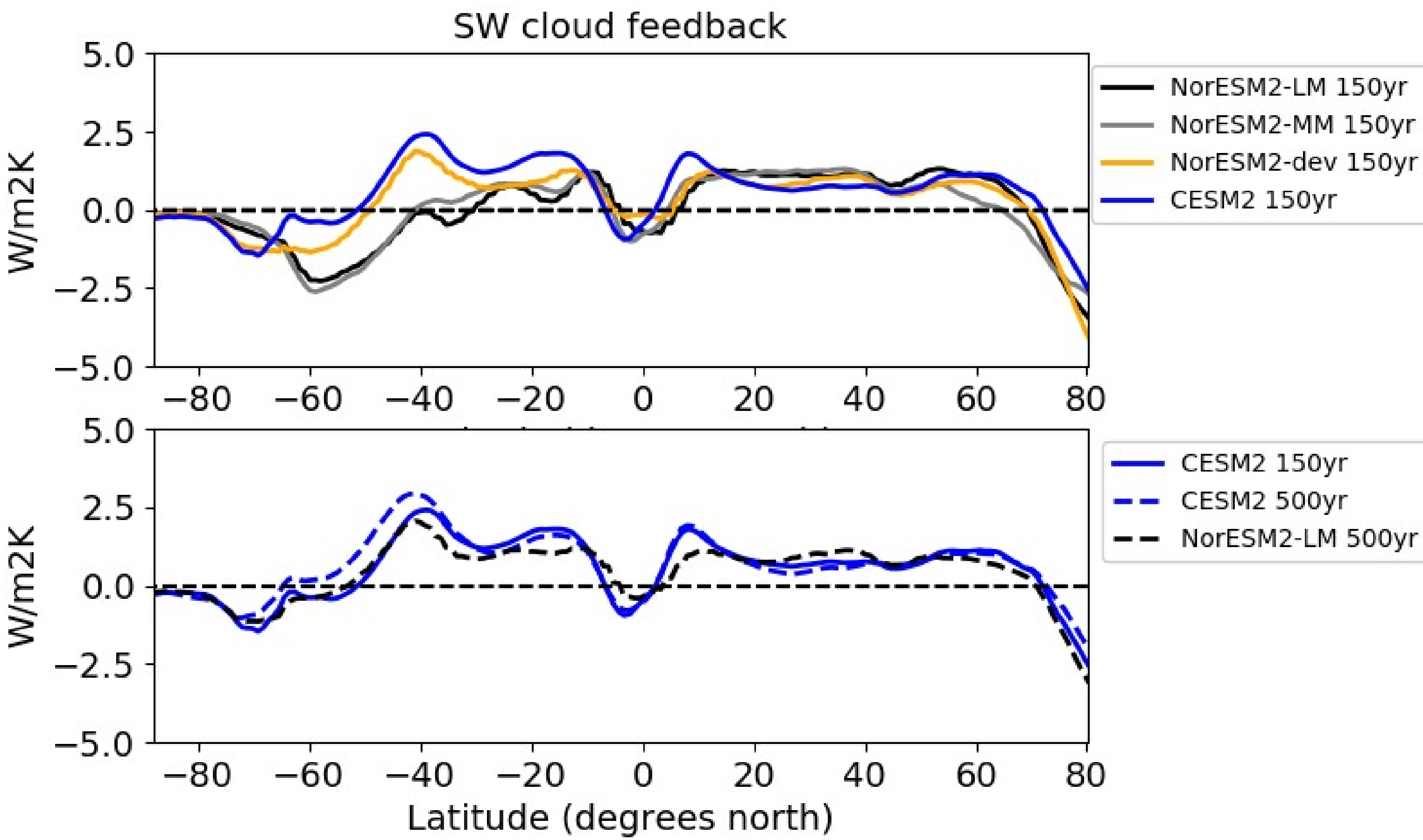
Comparison of NorESM2 and CESM2



“Equilibrium” vs “effective” CS



Similar equilibrium feedback(s)...



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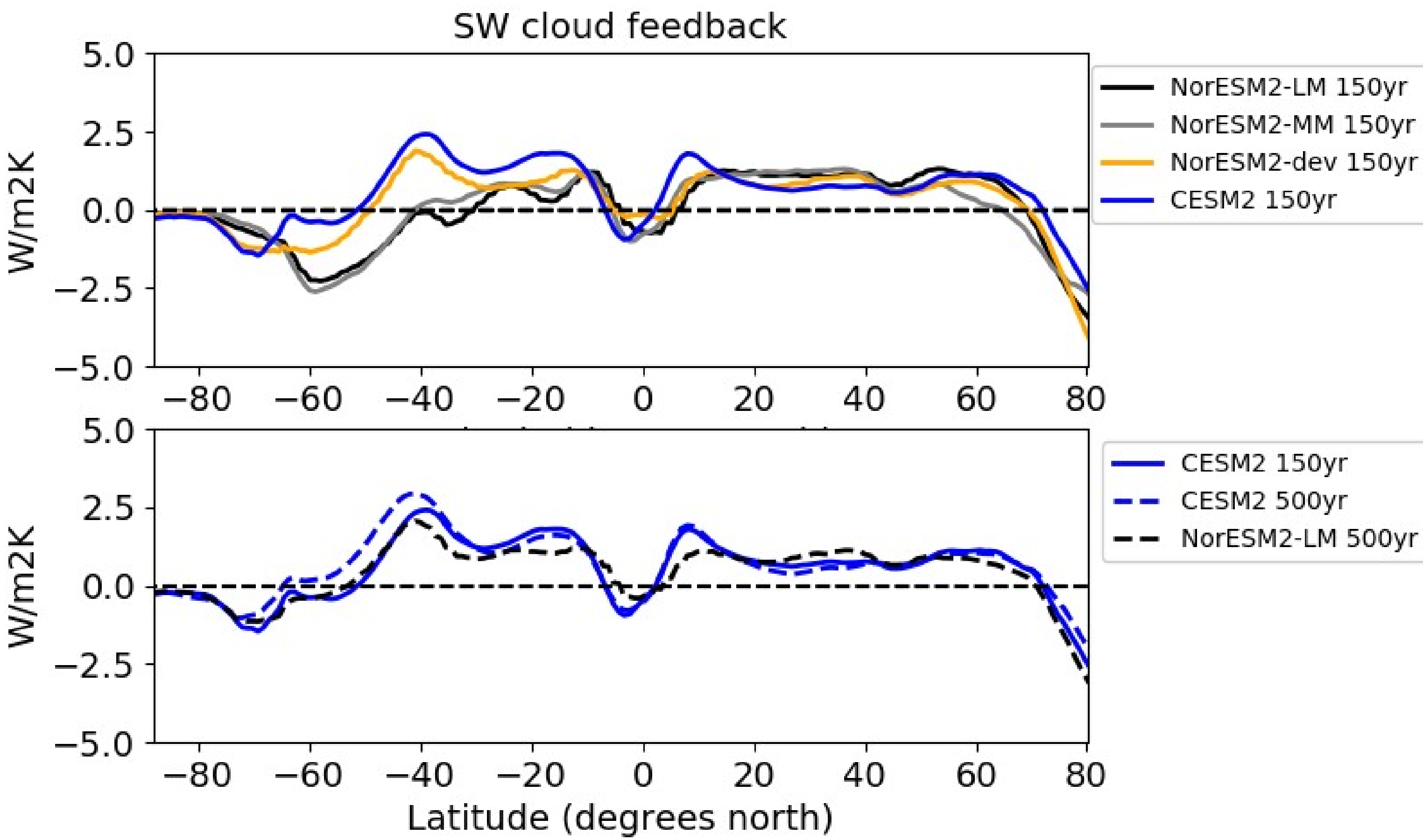
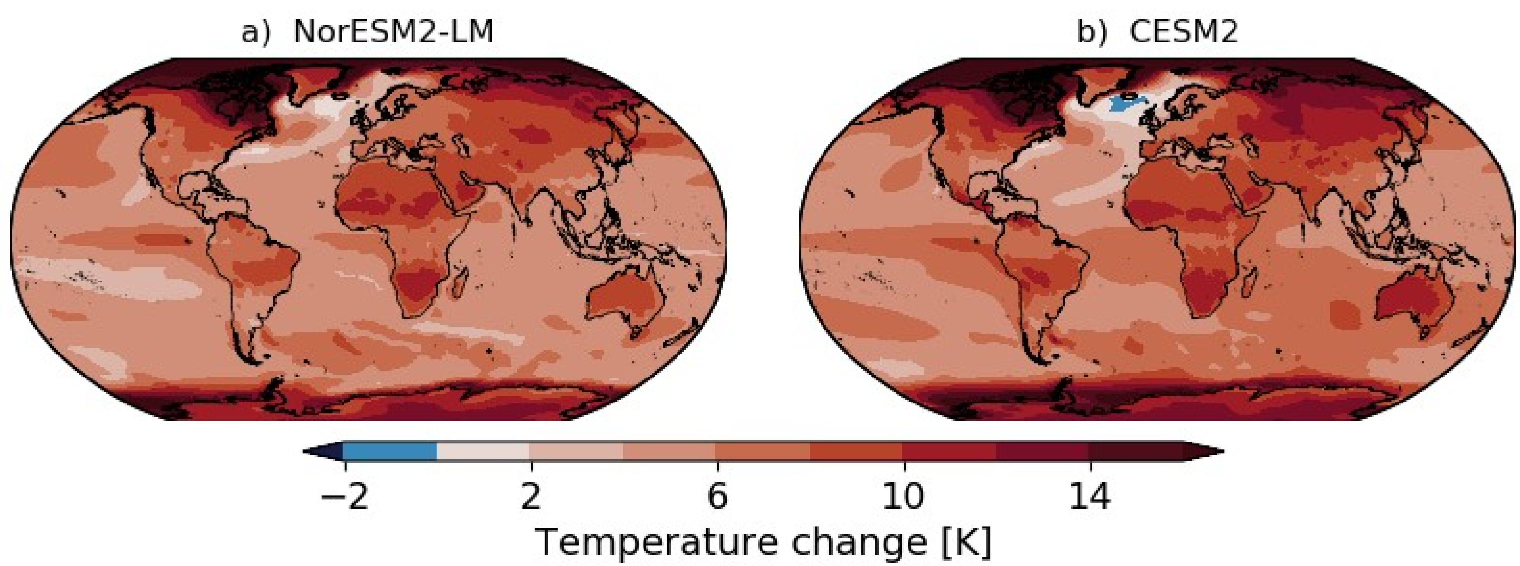
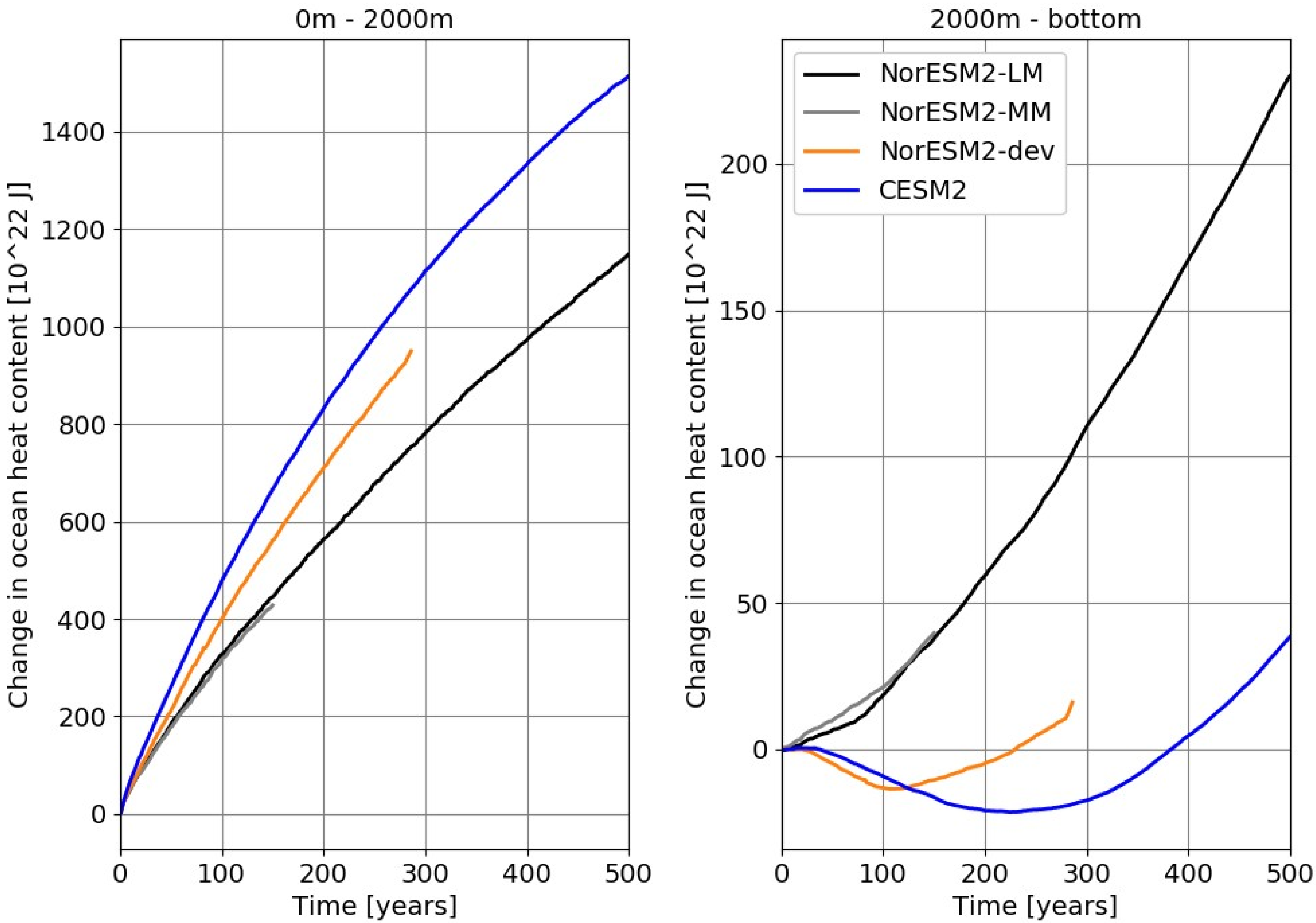


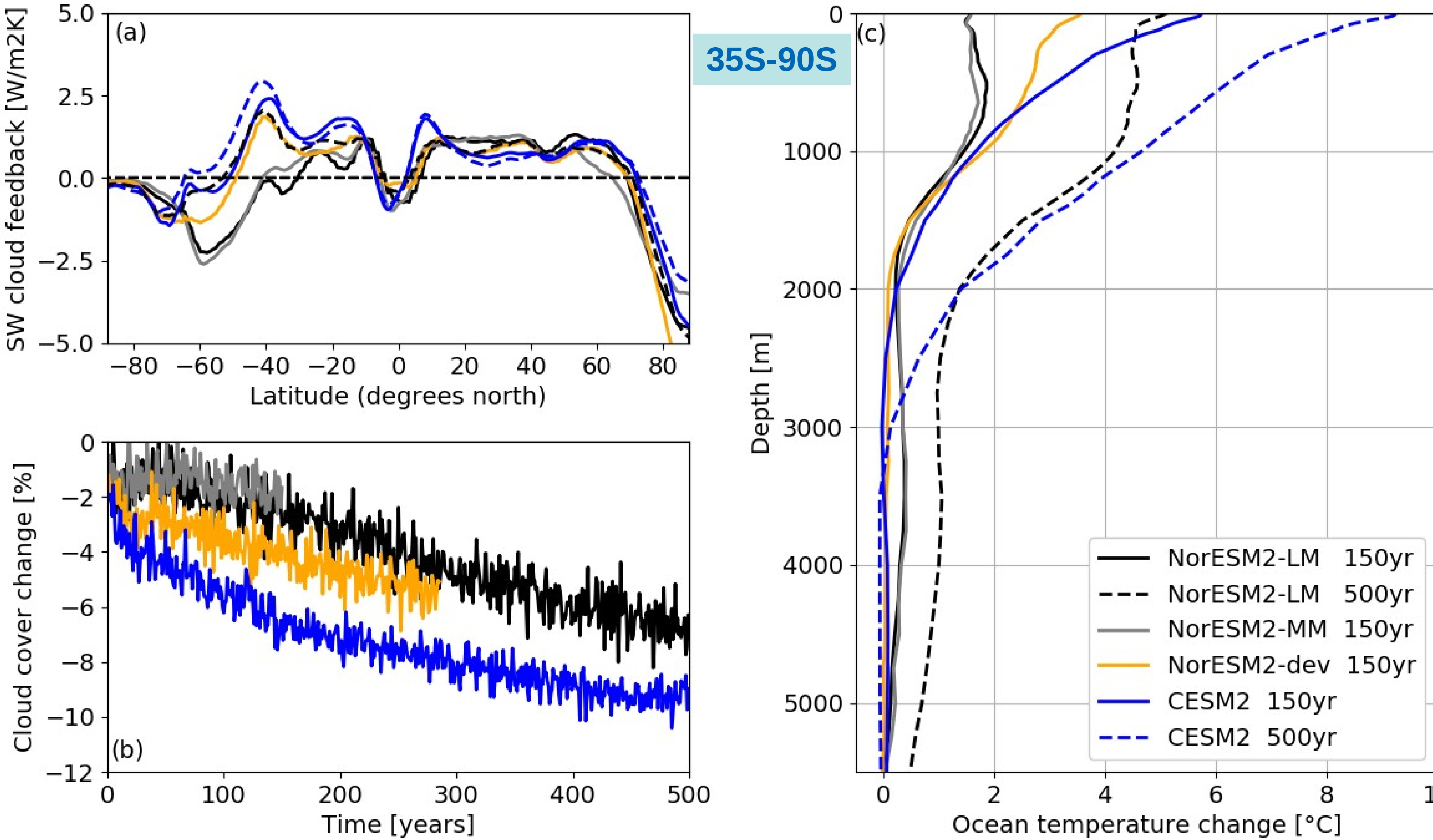
and response



Different ocean heat storage



Summary of phenomenology (35S-90S)



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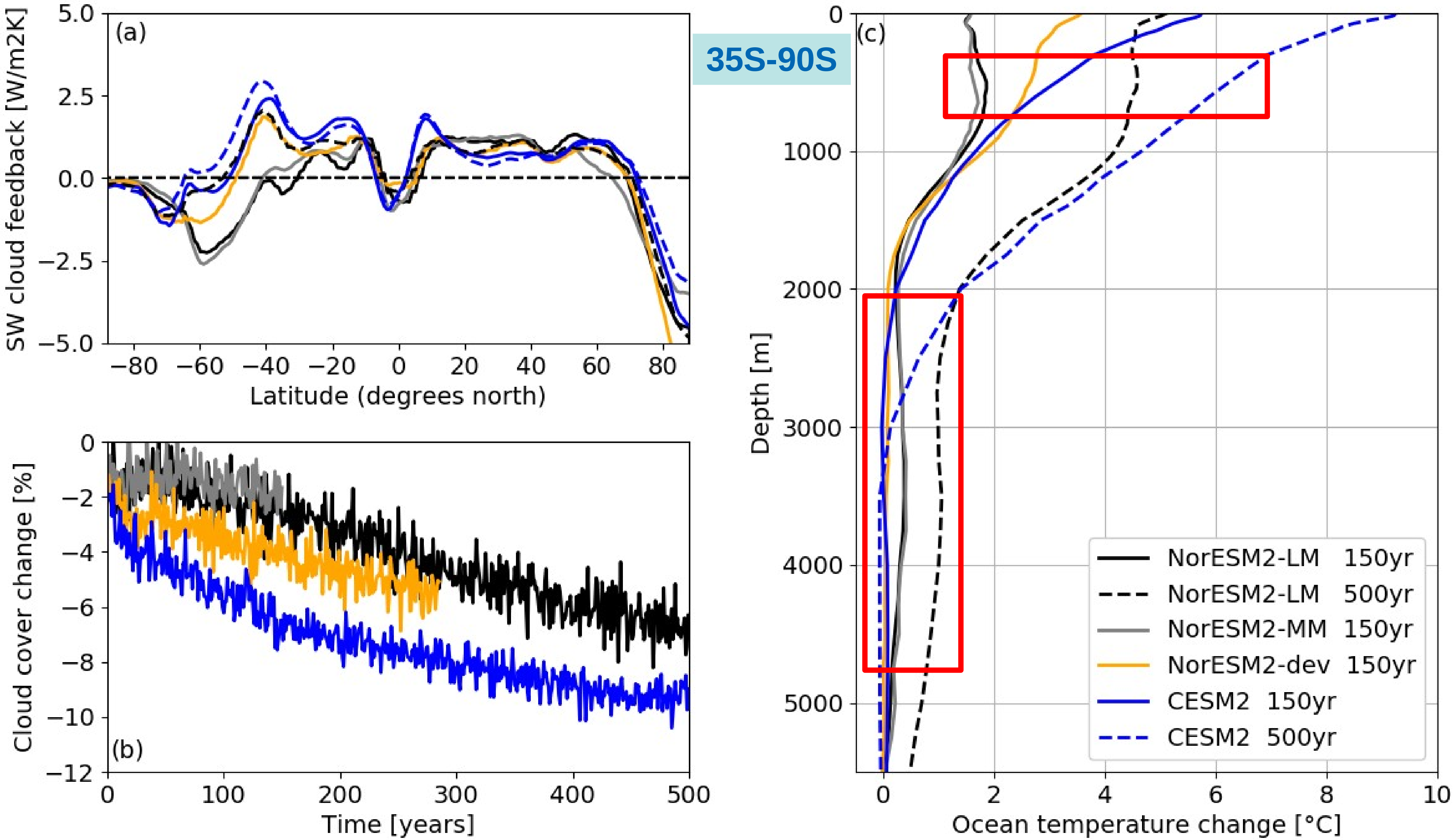
35S-90S



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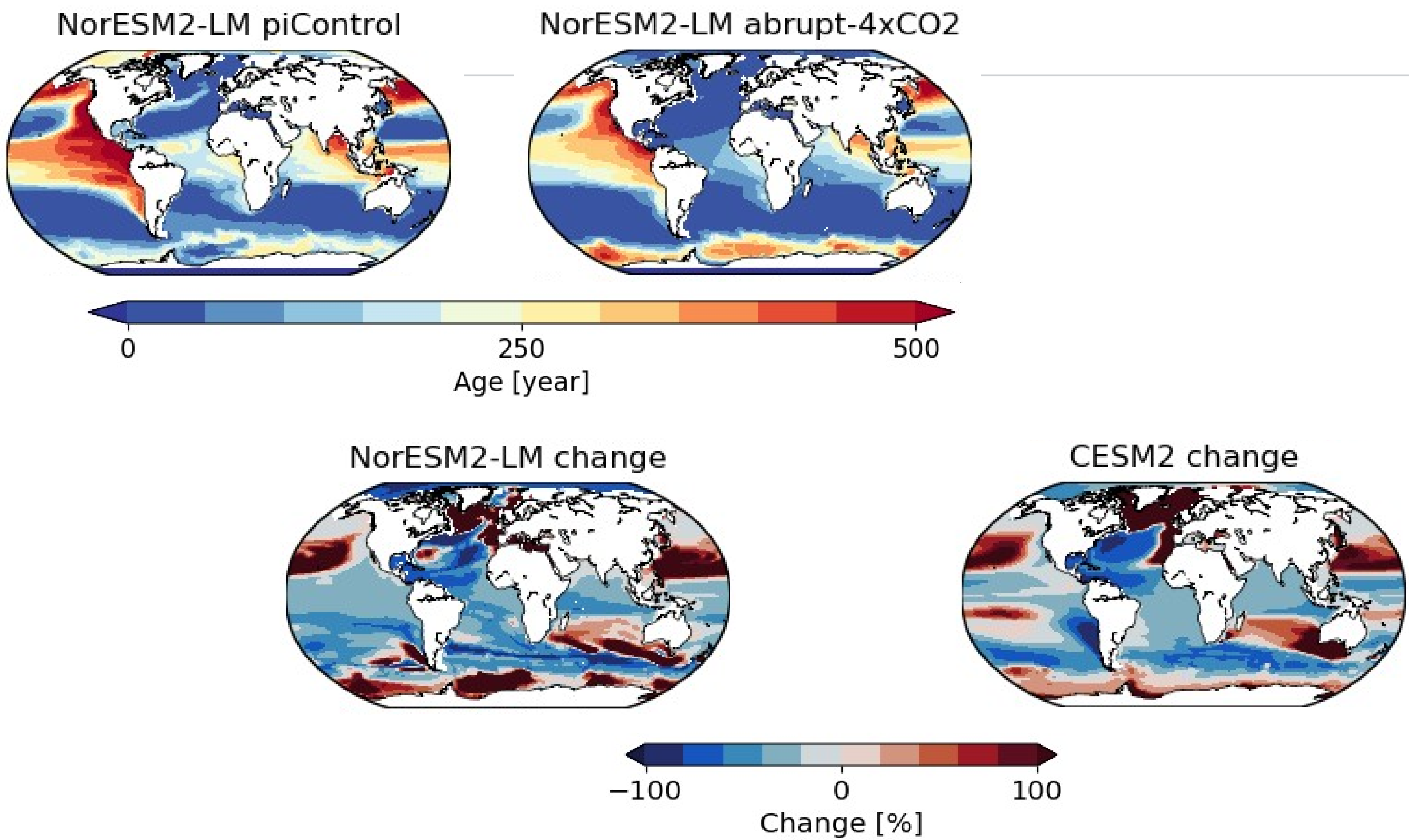
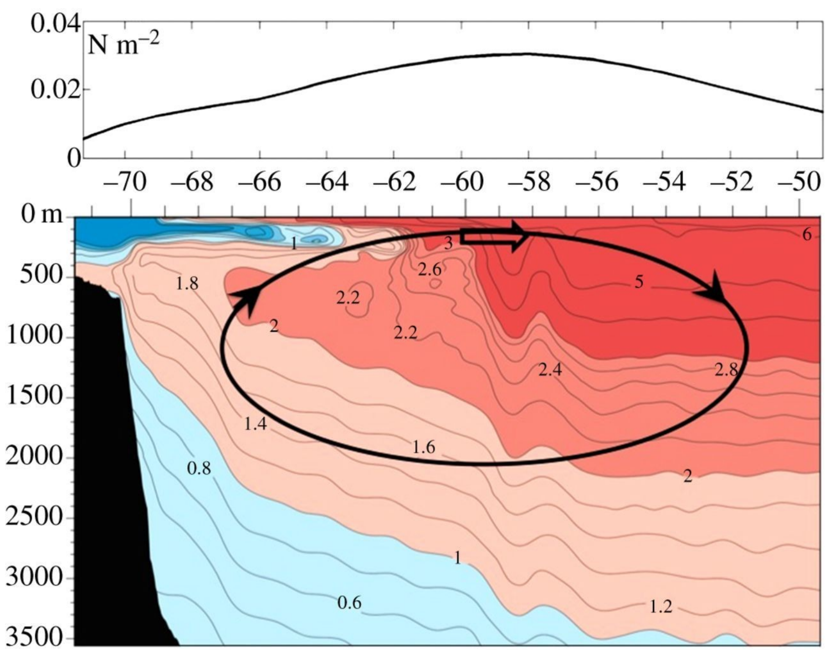
Reduced deep mixing in SO

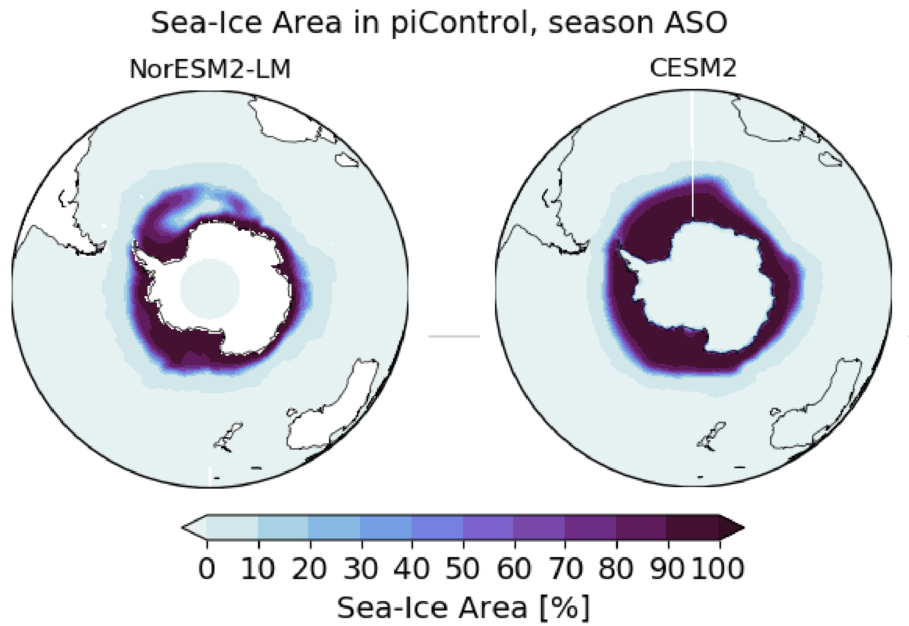
Age of sea water @300m

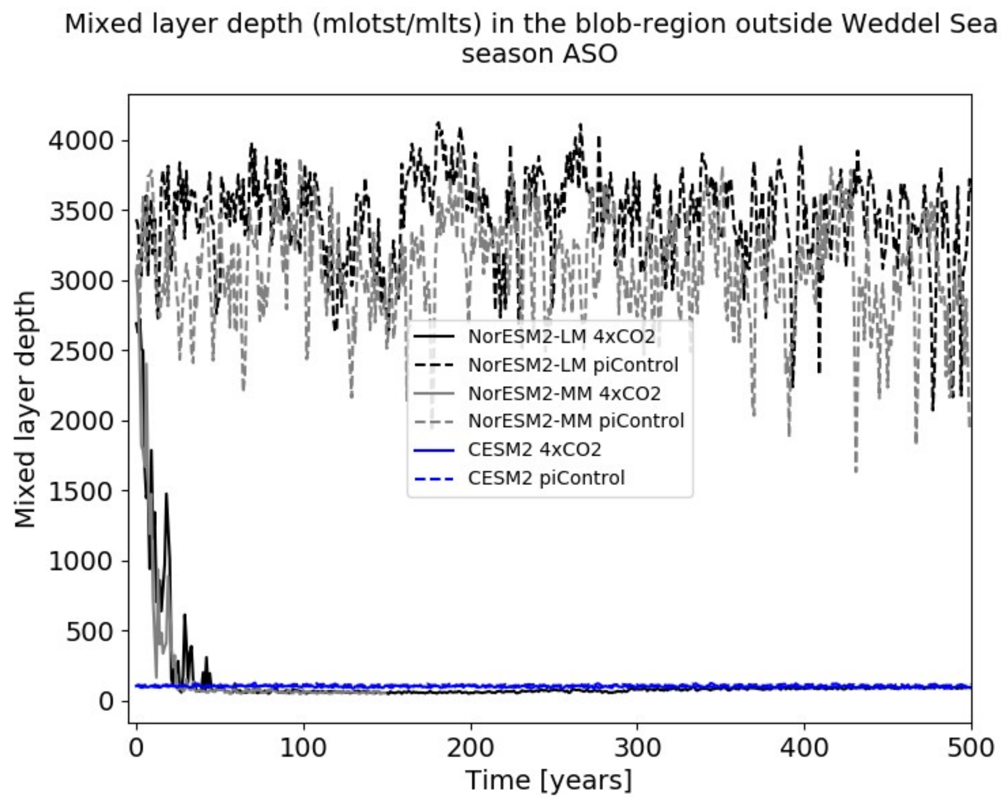


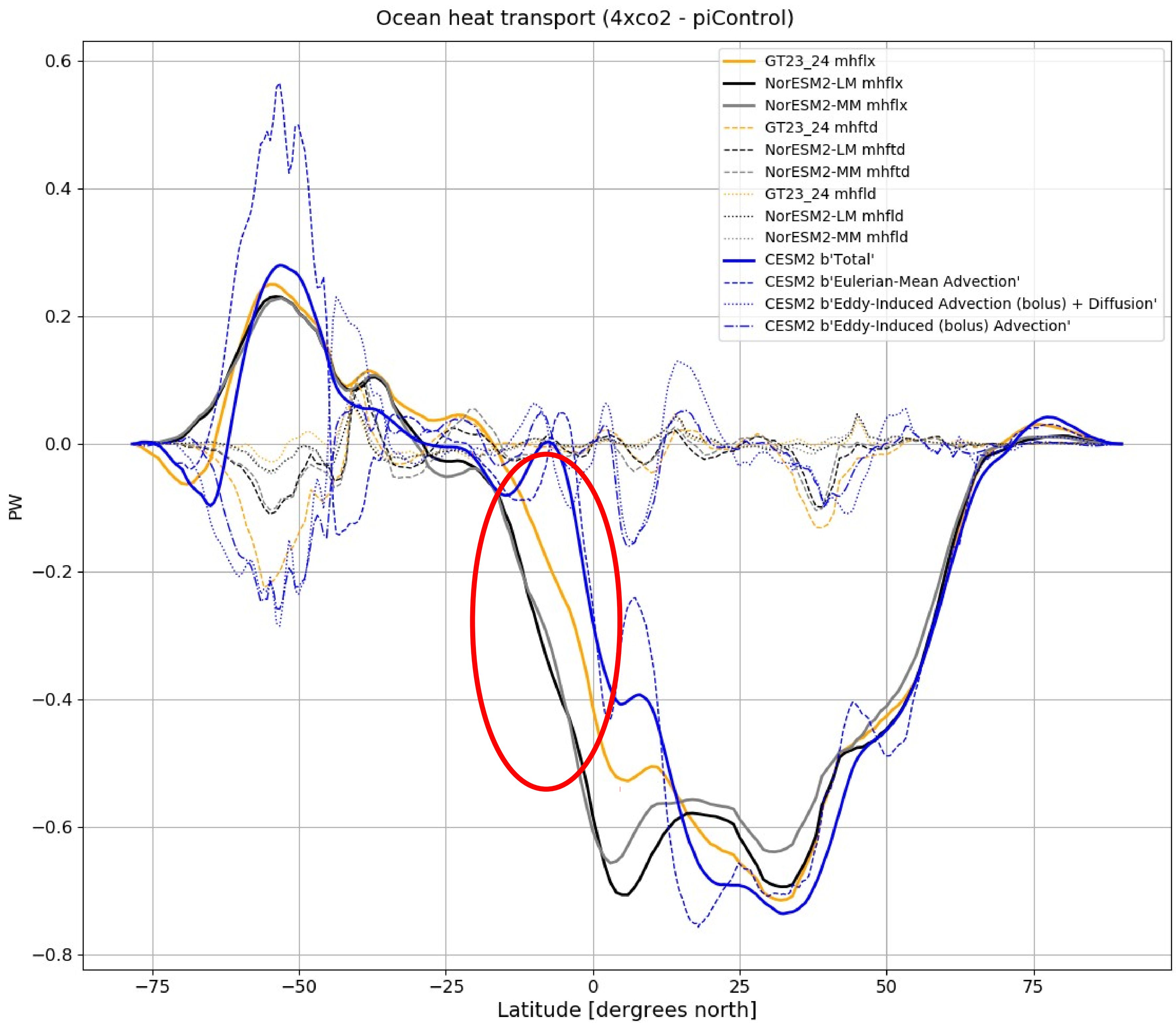
A special polynya in the NorESM2 control climate



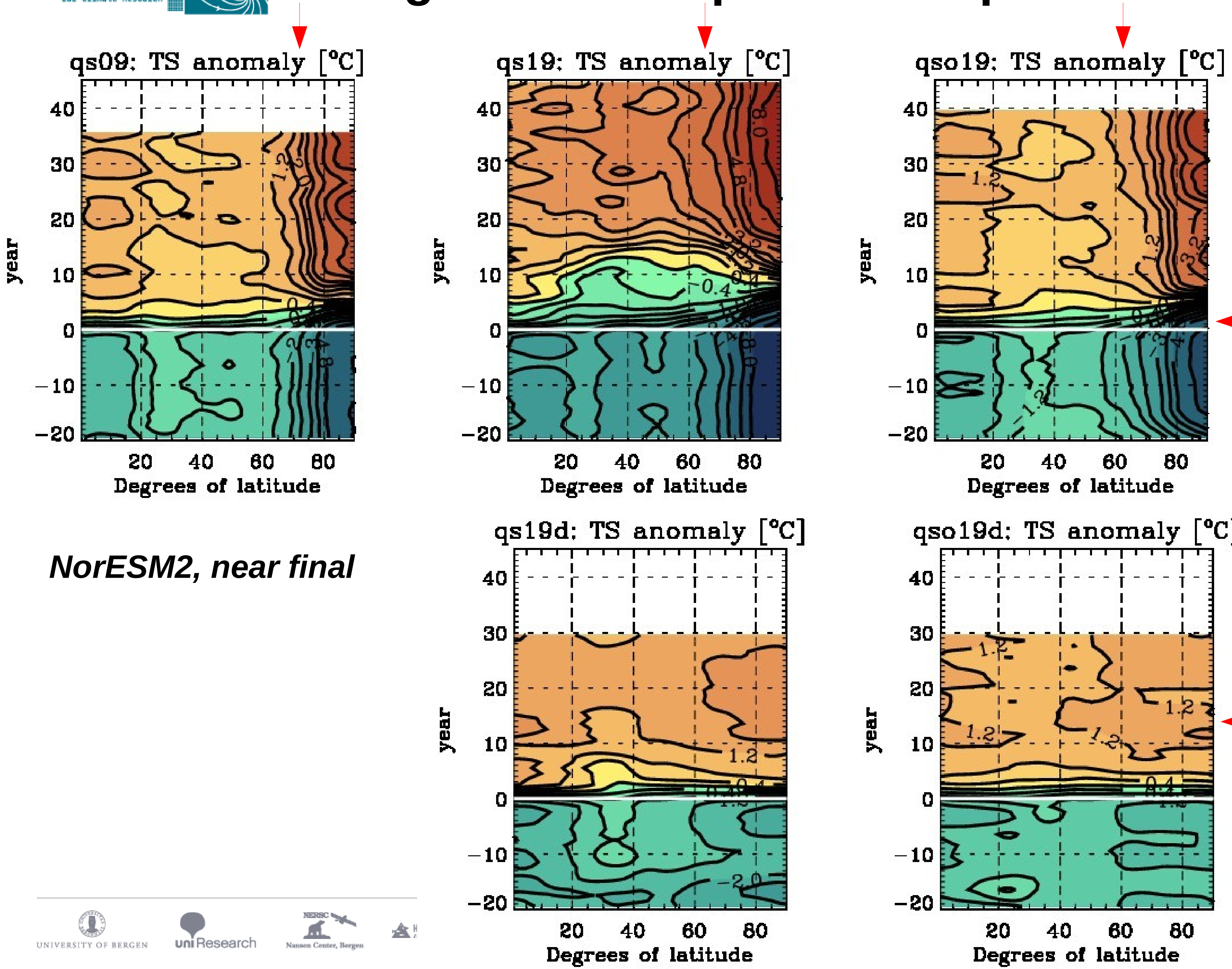
Marshall et al. 2019 (PTRS-A)






Ocean heat transport (4xco2 - piControl)
PW
Latitude [dergrees north]
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−75
−50
−25
0
25
50
75
GT23_24 mhflx
NorESM2-LM mhflx
NorESM2-MM mhflx
GT23_24 mhftd
NorESM2-LM mhftd
NorESM2-MM mhftd
GT23_24 mhfld
NorESM2-LM mhfld
NorESM2-MM mhfld
CESM2 b'Total'
CESM2 b'Eulerian-Mean Advection'
CESM2 b'Eddy-Induced Advection (bolus) + Diffusion'
CESM2 b'Eddy-Induced (bolus) Advection'

Changes in atmospheric component



NorESM2, near final

Changes in ocean heat transport *(prescribed)*

Summary: climate sensitivity

- For a given amount of warming, NorESM2 has similar feedbacks as CESM2
- But contrary to CESM2 and most models, the NorESM2 warming pattern after 150 years under 4xCO2is not representative of its equilibrium warming
- The reason appears to be that BLOM is storing heat at depth, mainly in the SO
- The crucial difference is the control state, where a large permanent polynya causes warm subtropical subsurface water to be exposed to the atmosphere
- The polynia rapidly disappears with warming, along with that mechanism
- Physically, there is a sharp increase in southward ocean heat advection
- Slab simulations qualitatively reproduce the relation between oceanic heat advection and climate sensitivity with both CAM6 and CAM6-Nor

III. Impact of changes in CAM6-Nor moist physics

Précis

- CAM6(-Nor) is a “cool” and “wet” model: positive RESTOM due to cool troposphere, and often-active, efficient convection
- The RESTOM imbalance is a clearsky problem: cloud forcing already biased positive in SW, negative in LW
- Dominant tropical pattern of wet land with excessive OLR, and dry ocean with too little OLR
- We surmised that this could be addressed with changes in the deep convection scheme aimed at:

1. Reducing overall efficiency, i.e. achieving less convective drying for a given convective heating rate
2. Re-balance efficiency between land and sea, favoring the former

- This attempt was fairly successful, achieving the intended aims, but with two drawbacks:

1. CRE got worse (which we realised and accepted)
2. We lost the MJO (which we discovered too late!)

Summary of non-Oslo physics in CAM6-Nor

1. COARE formulation of air-sea turbulent fluxes **(NorESM1.2; avail. in CESM2)**
2. Local conservation of enthalpy **(NorESM1.2)**
3. Global conservation of angular momentum **(NorESM2; avail. in CESM2)**

Geosci. Model Dev., 13, 1–21, 2020. https://doi.org/10.5194/gmd-13-1-2020

4. Convection **(NorESM2)**

Summary of non-Oslo physics in CAM6-Nor

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Geosci. Model Dev., 13, 1–21, 2020. https://doi.org/10.5194/gmd-13-1-2020

4. Convection **(NorESM2)**

Changes in ZM convection scheme to:

1. **reduce convective drying for a given convective heating rate**
2. **increase efficiency over land, reduce it over ocean**

How:

- Parametric tuning:

  1) Reduce autoconversion rate over ocean, increase it over land (→ equal values)

  2) Increase Tiedke parameter (cumulus-ensemble plume buoyancy) over land

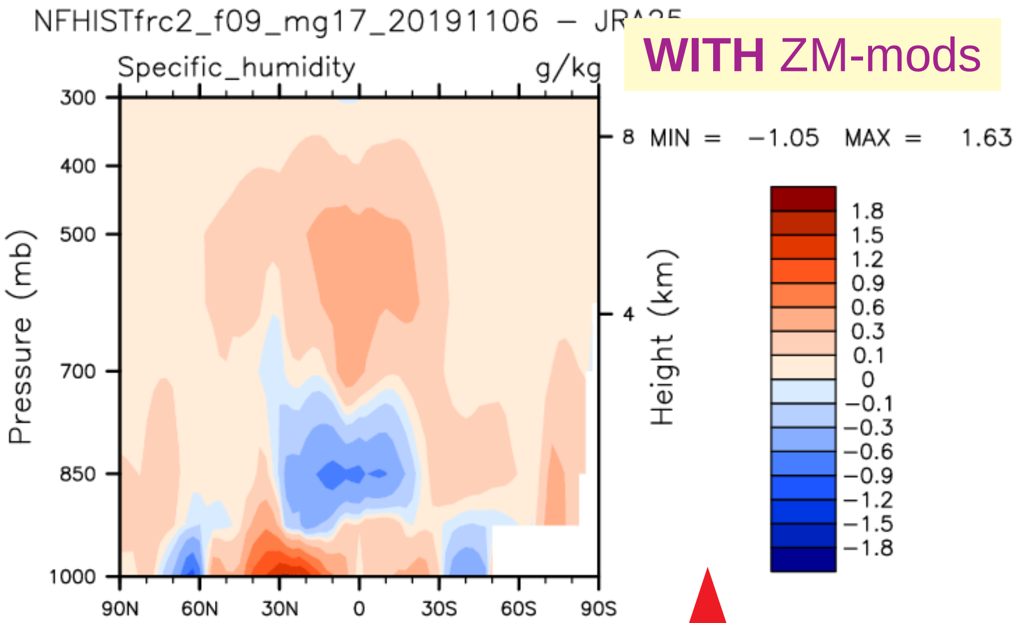
- Modifications of the scheme:

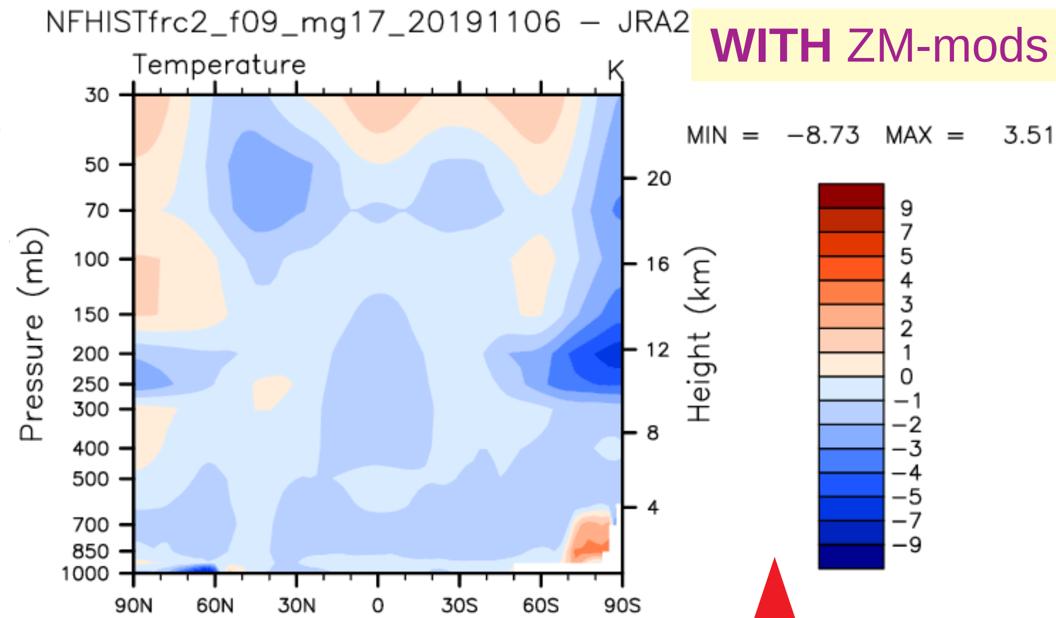
  1) Increase base mass flux (launching level)

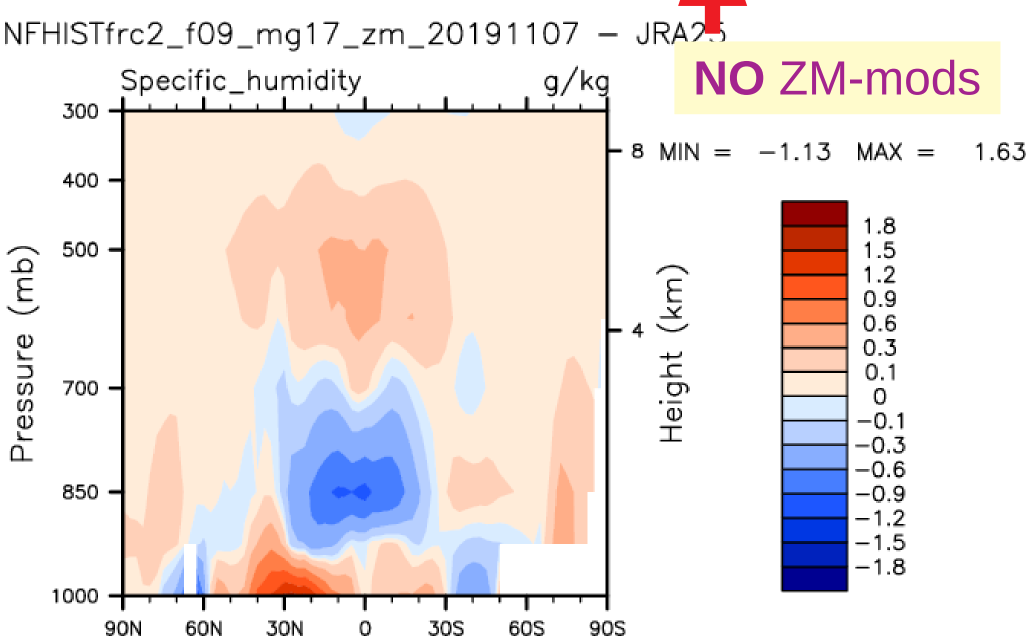
  2) Harden trigger function (CIN + iterative entrainment rate)

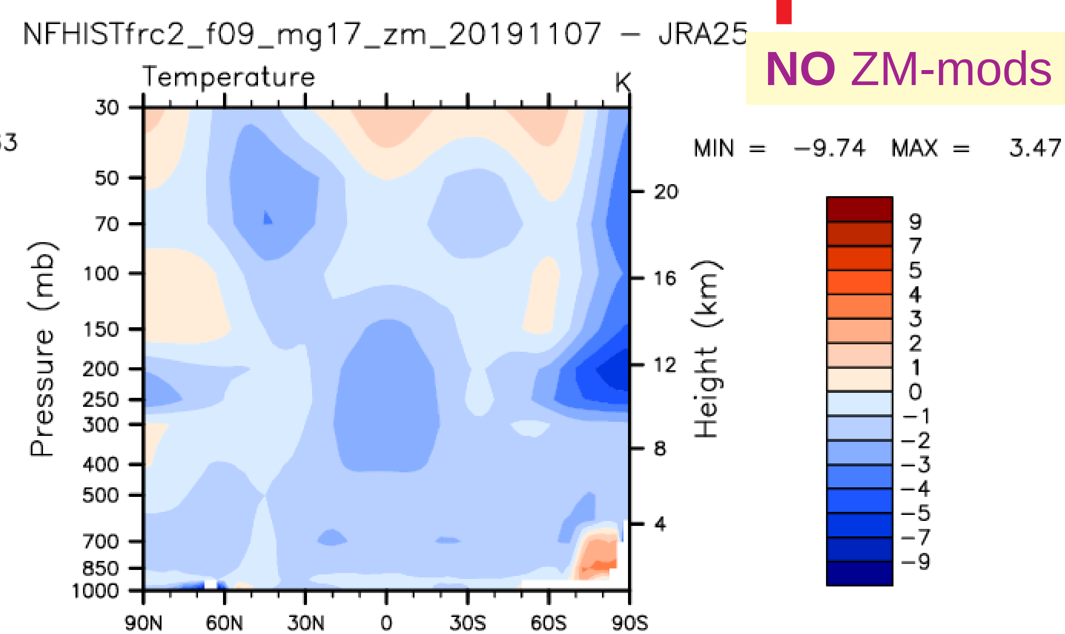
  3) Increase latent heating rate (T-dependence of L)

- Added a new parameter (CIN threshold), effectively removed two


NFHISTfrc2_f09_mg17_20191106 − JRA25
WITH ZM-mods
Specific_humidity
g/kg
MIN = −1.05 MAX = 1.63
Pressure (mb)
Height (km)
300
400
500
700
850
1000
8
4
1.8
1.5
1.2
0.9
0.6
0.3
0.1
0
−0.1
−0.3
−0.6
−0.9
−1.2
−1.5
−1.8
90N 60N 30N 0 30S 60S 90S


NFHISTfrc2_f09_mg17_20191106 − JRA25
WITH ZM-mods
Temperature
K
MIN = −8.73 MAX = 3.51
Pressure (mb)
Height (km)
30
50
70
100
150
200
250
300
400
500
700
850
1000
20
16
12
8
4
9
7
5
4
3
2
1
0
−1
−2
−3
−4
−5
−7
−9
90N 60N 30N 0 30S 60S 90S


NFHISTfrc2_f09_mg17_zm_20191107 − JRA25
NO ZM-mods
Specific_humidity
g/kg
MIN = −1.13 MAX = 1.63
Pressure (mb)
Height (km)
300
400
500
700
850
1000
8
4
1.8
1.5
1.2
0.9
0.6
0.3
0.1
0
−0.1
−0.3
−0.6
−0.9
−1.2
−1.5
−1.8
90N 60N 30N 0 30S 60S 90S


NFHISTfrc2_f09_mg17_zm_20191107 − JRA25
NO ZM-mods
Temperature
K
MIN = −9.74 MAX = 3.47
Pressure (mb)
Height (km)
30
50
70
100
150
200
250
300
400
500
700
850
1000
20
16
12
8
4
9
7
5
4
3
2
1
0
−1
−2
−3
−4
−5
−7
−9
90N 60N 30N 0 30S 60S 90S

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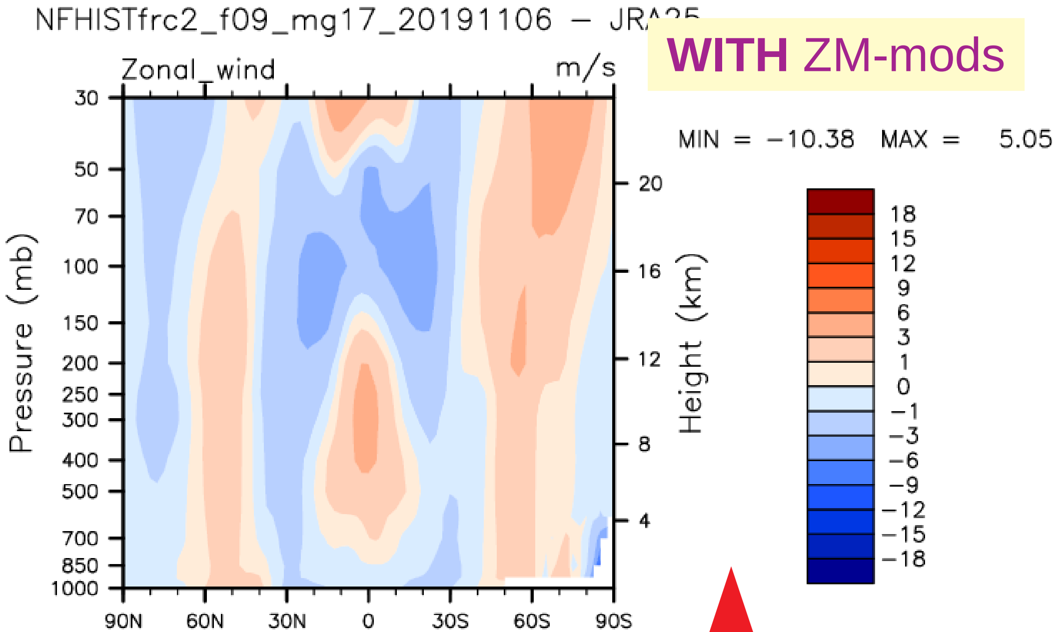
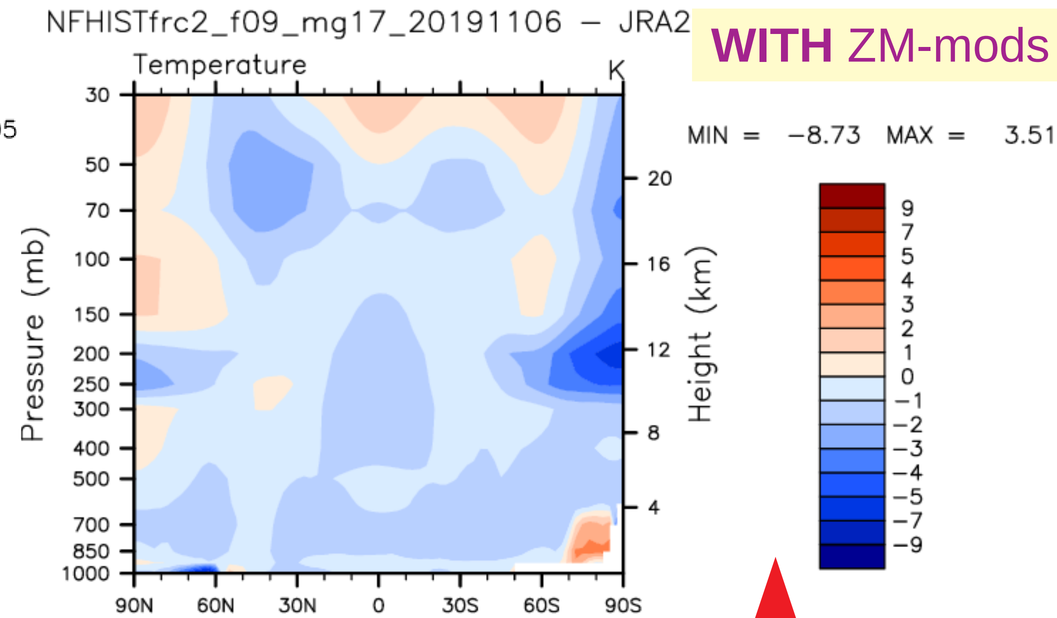
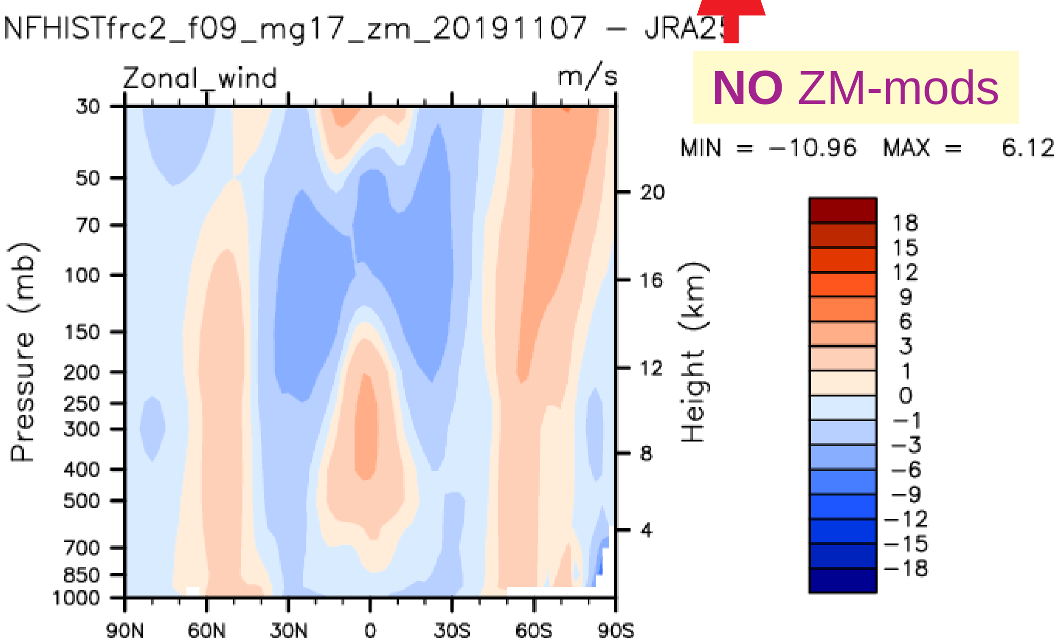
WITH ZM-mods



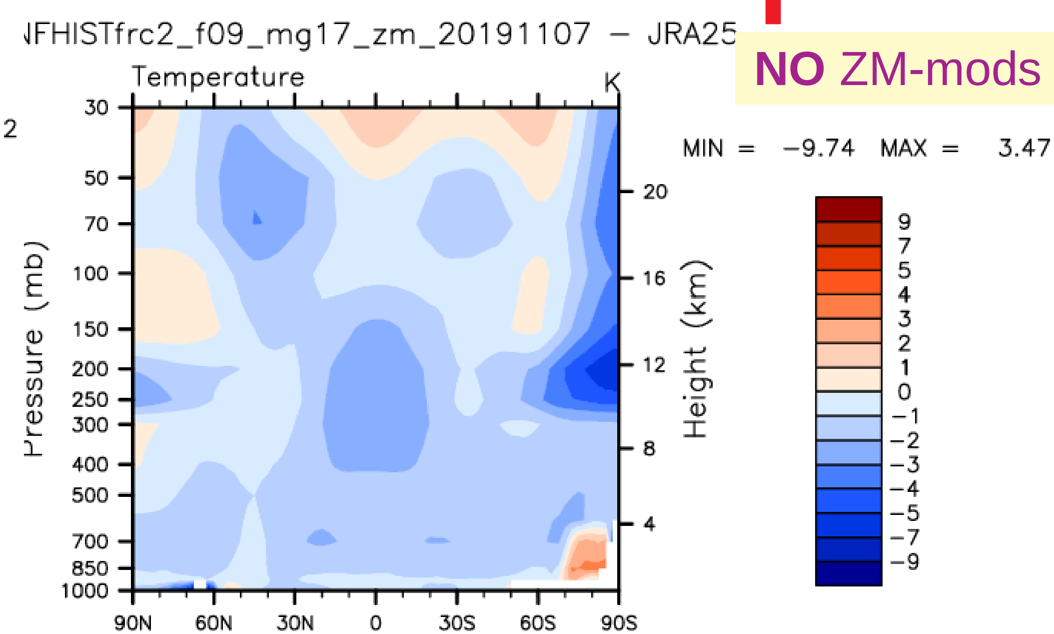
WITH ZM-mods



NO ZM-mods



NO ZM-mods



cor coef: Space−Time	NFHISTfrc2_f09_mg17_201911		NFHISTfrc2_f09_mg17_zm_201911
	ANN		ANN
Sea Level Pressure (ERAI)	0.978	=	0.976
SW Cloud Forcing (CERES−EBAF)	0.914	V	0.903
LW Cloud Forcing (CERES−EBAF)	0.843	V	0.816
Land Rainfall (30N−30S, GPCP)	0.900	=	0.899
Ocean Rainfall (30N−30S, GPCP)	0.854	=	0.851
Land 2−m Temperature (Willmott)	0.990	=	0.990
Pacific Surface Stress (5N−5S,ERS)	0.916	V	0.911
Zonal Wind (300mb, ERAI)	0.965	=	0.963
Relative Humidity (ERAI)	0.935	=	0.934
Temperature (ERAI)	0.989	=	0.987

bias [%]: Space−Time	NFHISTfrc2_f09_mg17_201911		NFHISTfrc2_f09_mg17_zm_201911
	ANN		ANN
Sea Level Pressure (ERAI)	0.008	V	0.012
SW Cloud Forcing (CERES−EBAF)	2.446	=	2.413
LW Cloud Forcing (CERES−EBAF)	7.940	X	5.857
Land Rainfall (30N−30S, GPCP)	8.523	V	10.100
Ocean Rainfall (30N−30S, GPCP)	13.734	X	11.753
Land 2−m Temperature (Willmott)	0.034	V	0.050
Pacific Surface Stress (5N−5S,ERS)	15.958	X	12.526
Zonal Wind (300mb, ERAI)	1.499	V	2.703
Relative Humidity (ERAI)	7.895	=	7.872
Temperature (ERAI)	0.576	V	0.713

Modifications of ZM scheme:

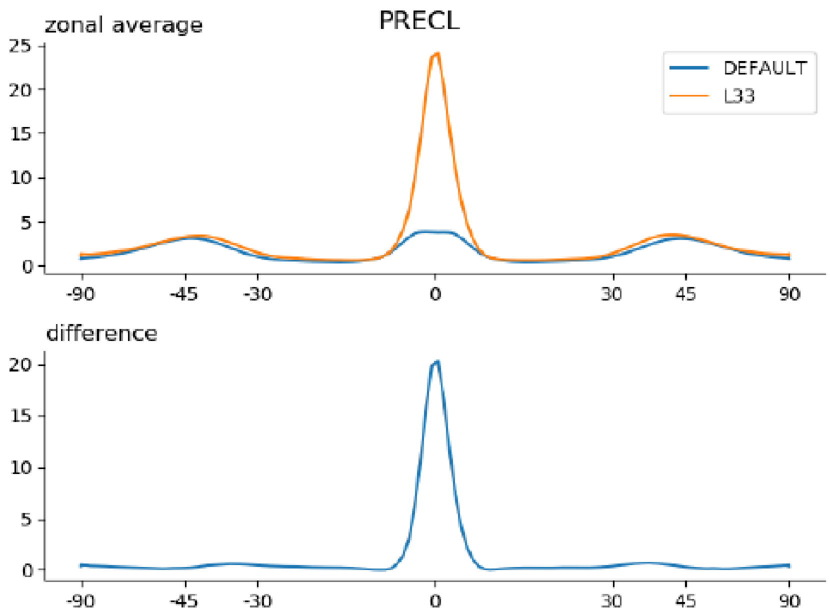
ZM1. Increase base mass flux (launching level)

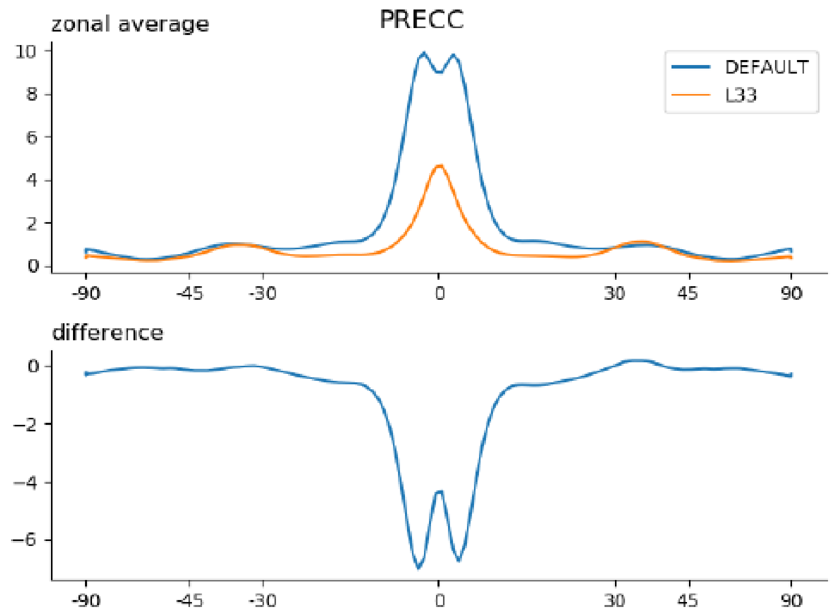
ZM2. Harden trigger function (CIN + iterative entrainment rate)

ZM3. Increase latent heating rate (T-dependence of L)

ZM1: sub-cloud layer

L33: Standard L32 grid with one extra level at ~8m.
2-year aquaplanet test with CAM6 by Brain M





http://www.cesm.ucar.edu/events/workshops/ws.2018/presentations/amwg/discussion.pdf

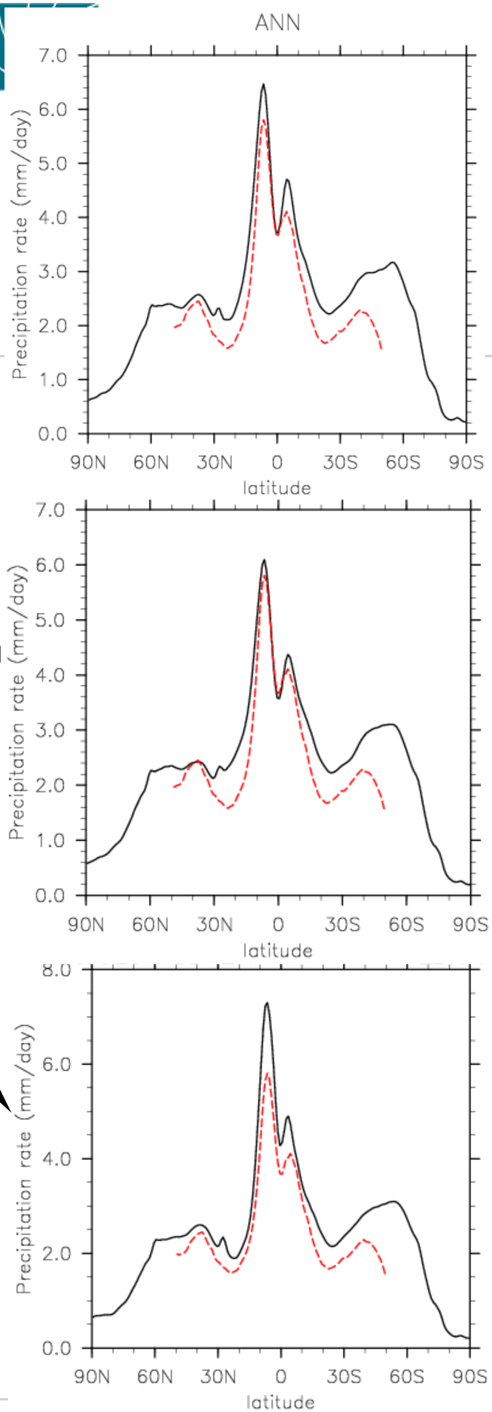
Split-ITCZ merges to single ITCZ.
Rain changes from dominated by convection to dominated by large-scale.
(Likely due to triggering of deep convection scheme)

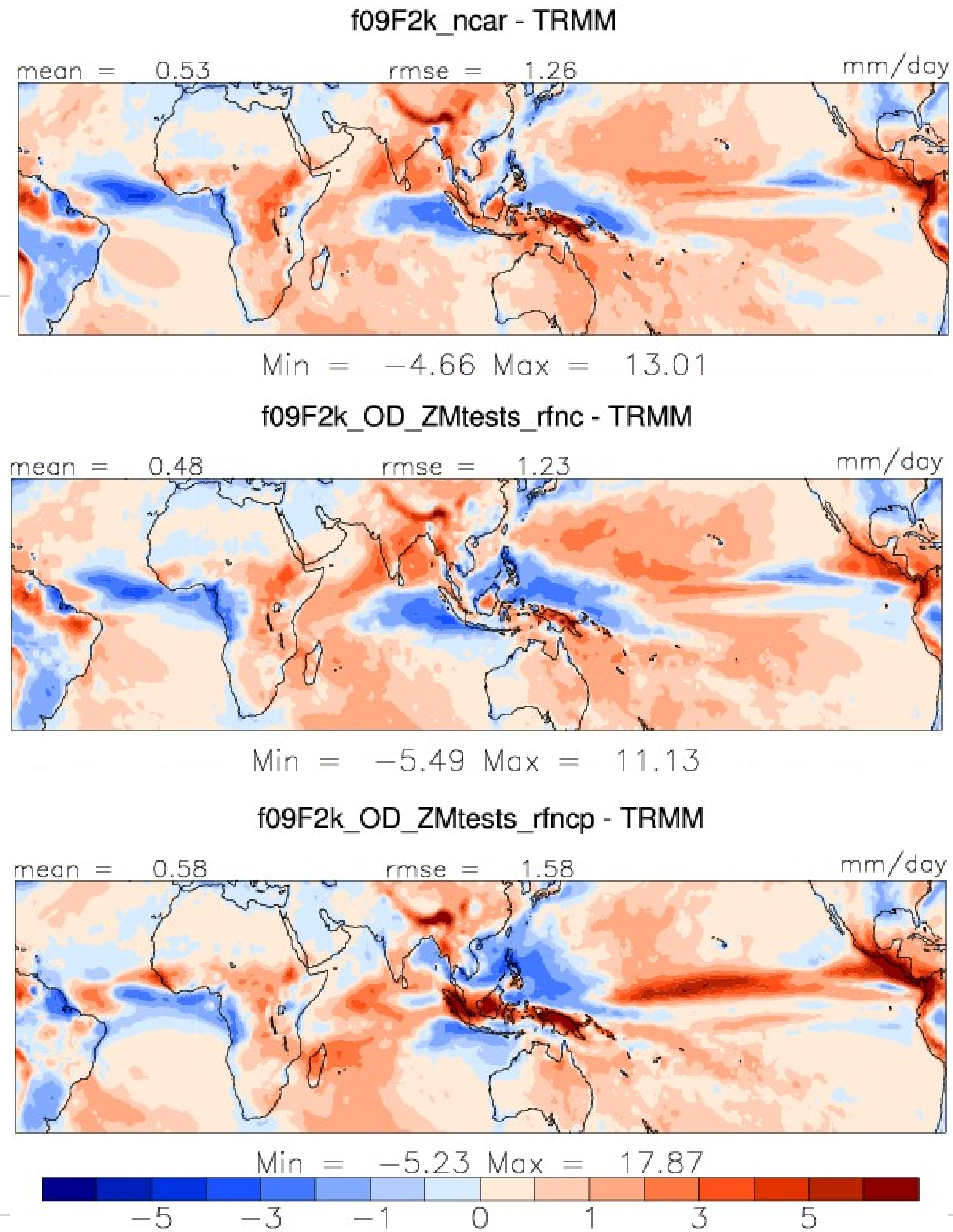
Precipitation

annual mean

- Oslo
- Non-Oslo
- gamma

- **ZM1**



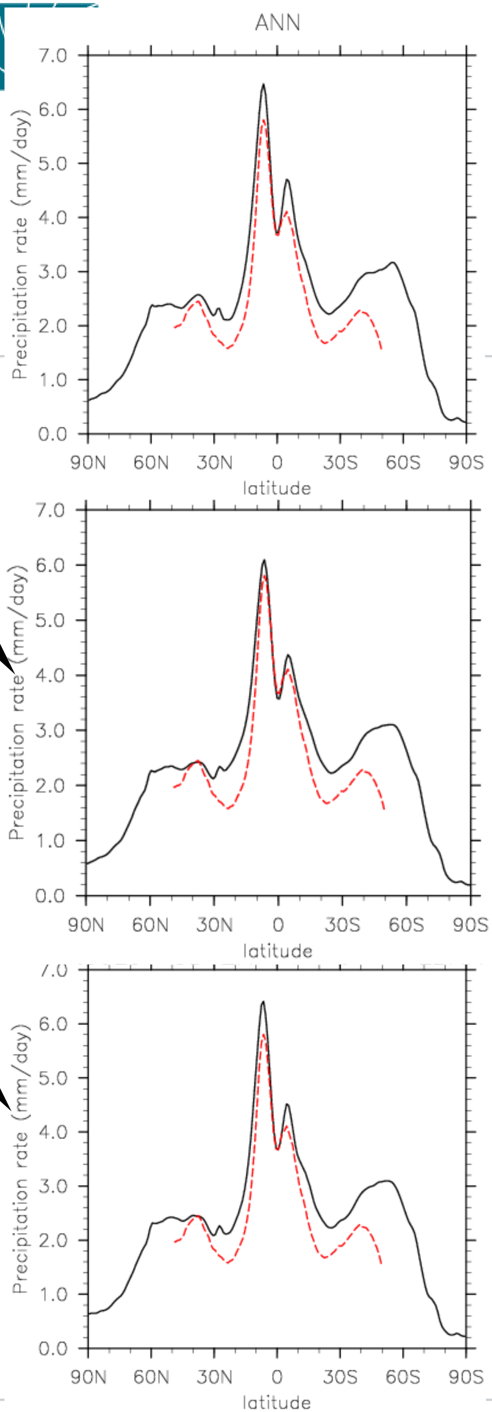


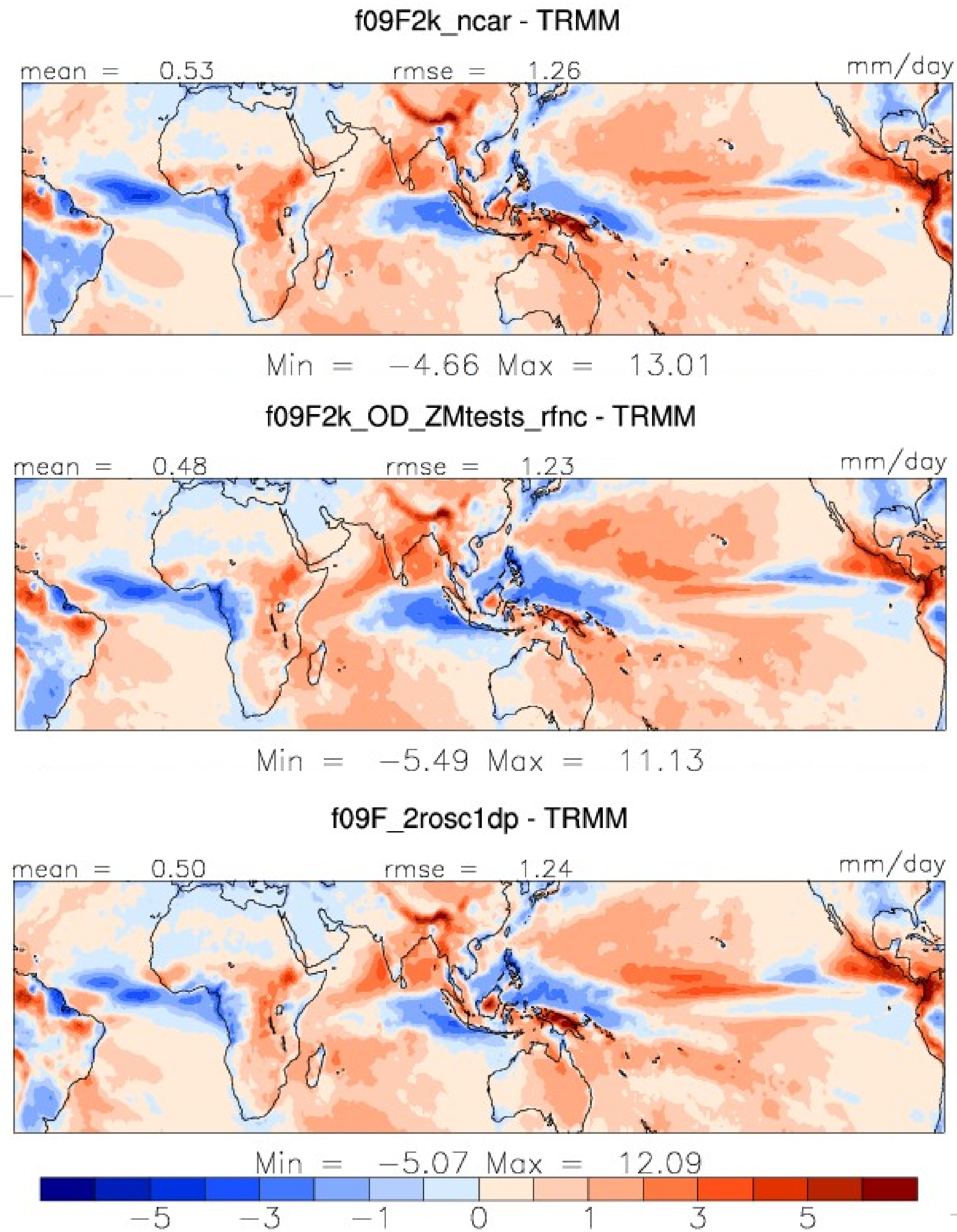
Precipitation

annual mean

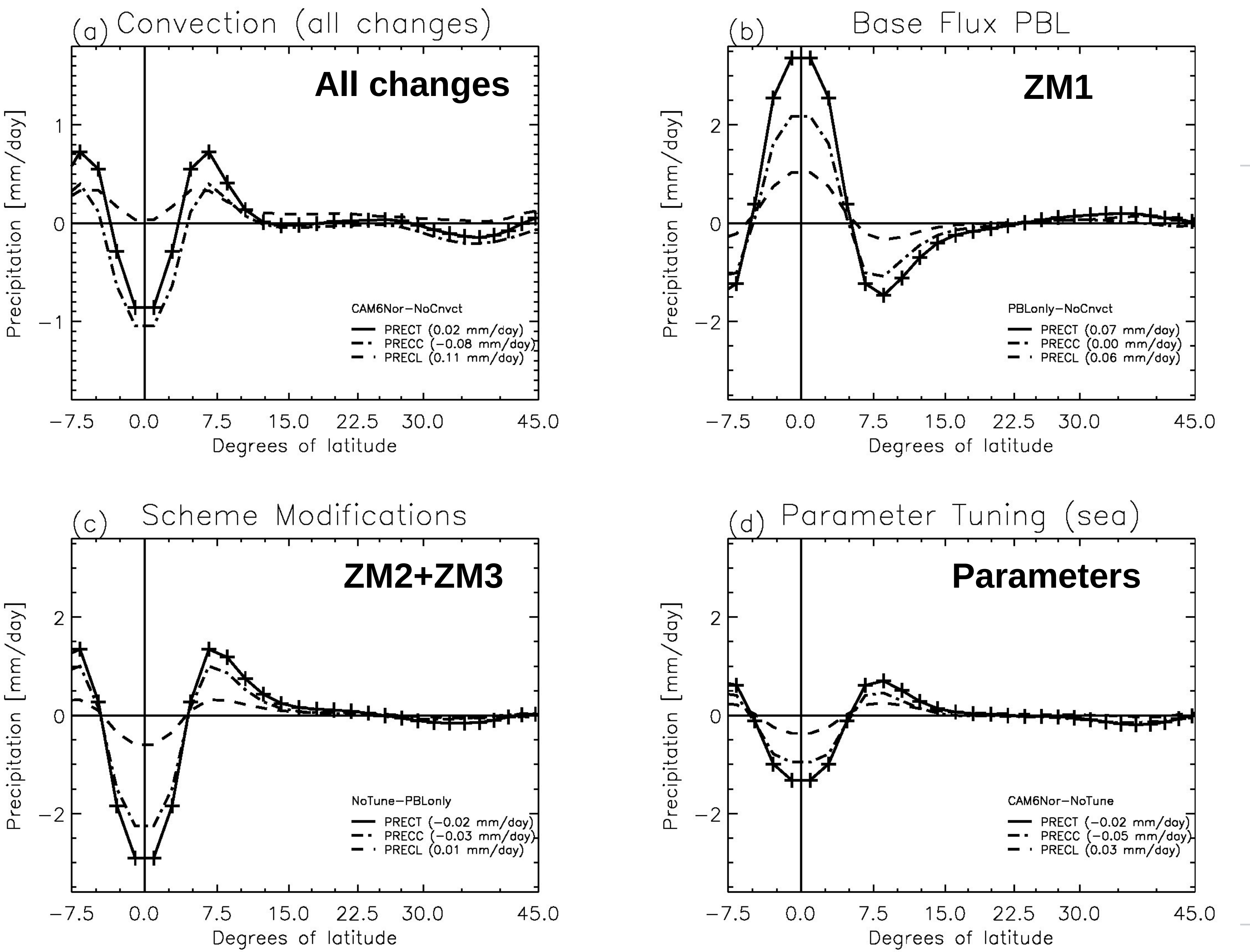
- Oslo
- Non-Oslo
- gamma

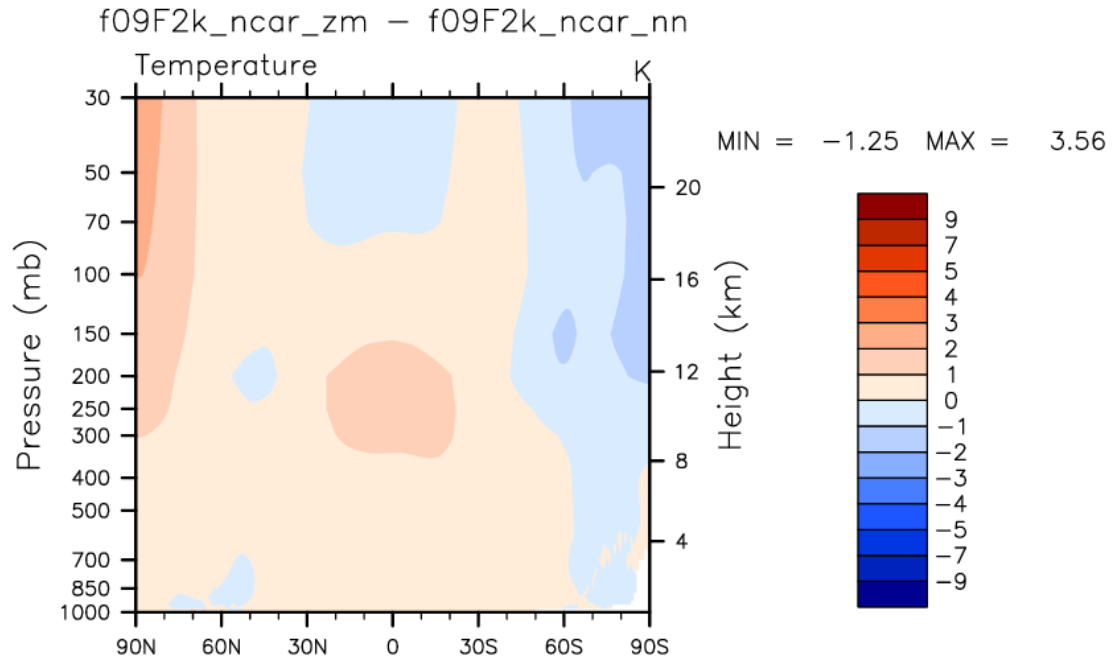
- **ZM1**
- **+ZM2**
- **+ZM3**
- **+params**





Impact in QP (FV19) experiments





f09F2k_ncar_zm – f09F2k_ncar_nn
Temperature
K
MIN = –1.25 MAX = 3.56
Pressure (mb)
Height (km)
30
50
70
100
150
200
250
300
400
500
700
850
1000
20
16
12
8
4
90N
60N
30N
0
30S
60S
90S
9
7
5
4
3
2
1
0
–1
–2
–3
–4
–5
–7
–9

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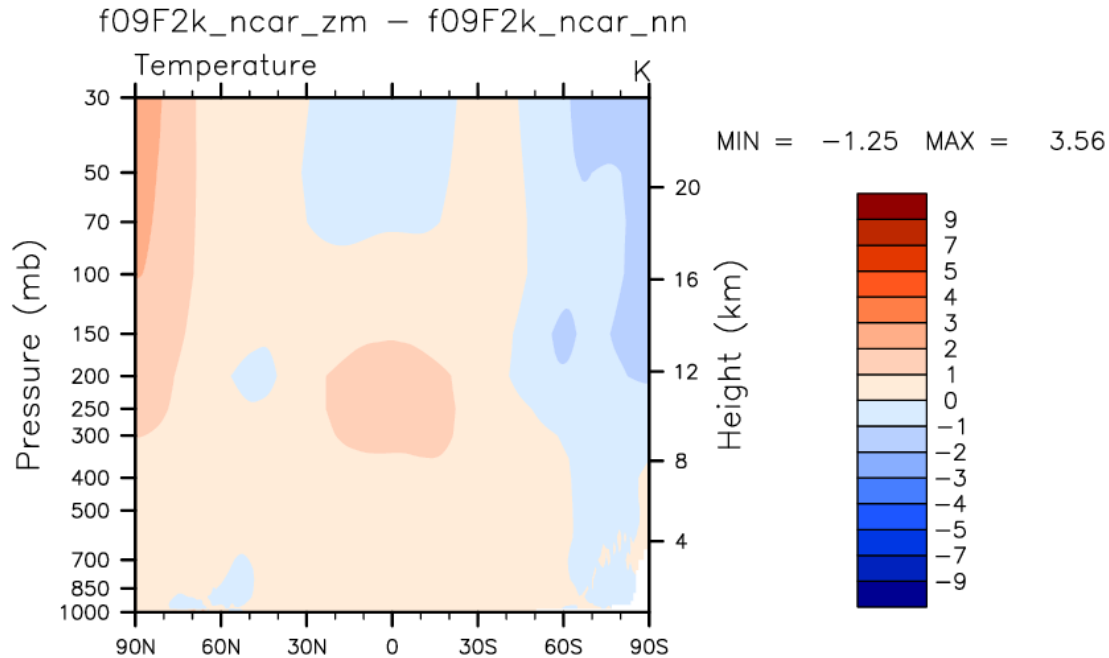
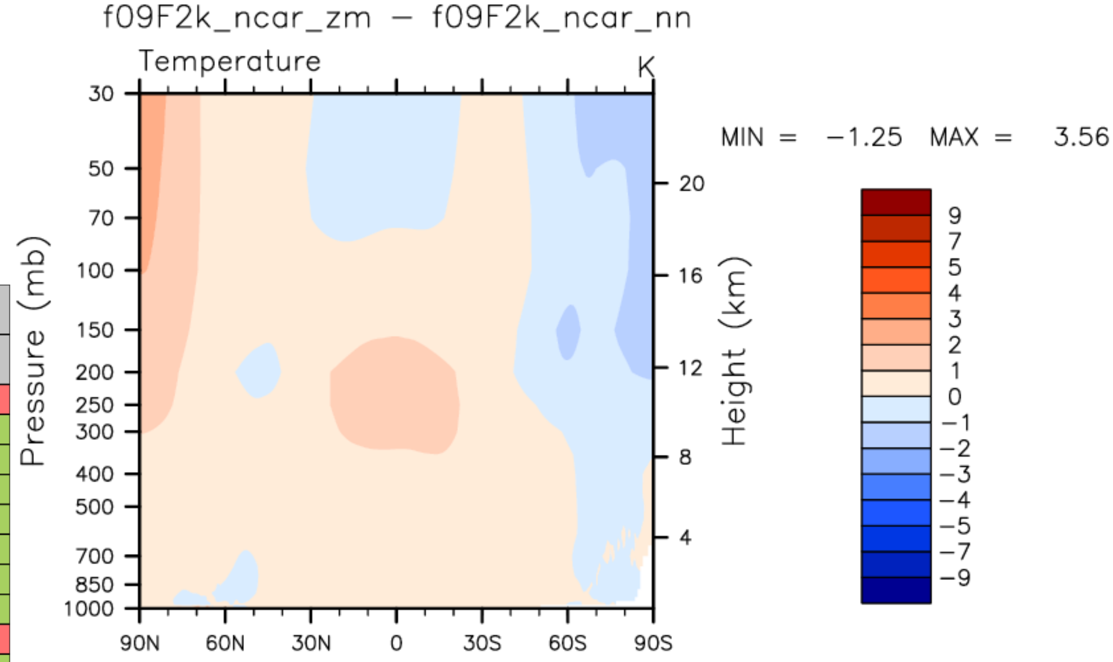


cor coef: Space–Time	f09F2k_ncar_nn	f09F2k_ncar_zm	
	ANN	ANN	
Sea Level Pressure (ERAI)	0.969	0.967	=
SW Cloud Forcing (CERES–EBAF)	0.892	0.896	=
LW Cloud Forcing (CERES–EBAF)	0.842	0.844	=
Land Rainfall (30N–30S, GPCP)	0.865	0.873	=
Ocean Rainfall (30N–30S, GPCP)	0.813	0.819	=
Land 2–m Temperature (Willmott)	0.990	0.990	=
Pacific Surface Stress (5N–5S,ERS)	0.883	0.895	V
Zonal Wind (300mb, ERAI)	0.956	0.956	=
Relative Humidity (ERAI)	0.922	0.922	=
Temperature (ERAI)	0.987	0.988	=



cor coef: Space–Time	f09F2k_ncar_nn	f09F2k_ncar_zm
	ANN	ANN
Sea Level Pressure (ERAI)	0.969	0.967
SW Cloud Forcing (CERES–EBAF)	0.892	0.896
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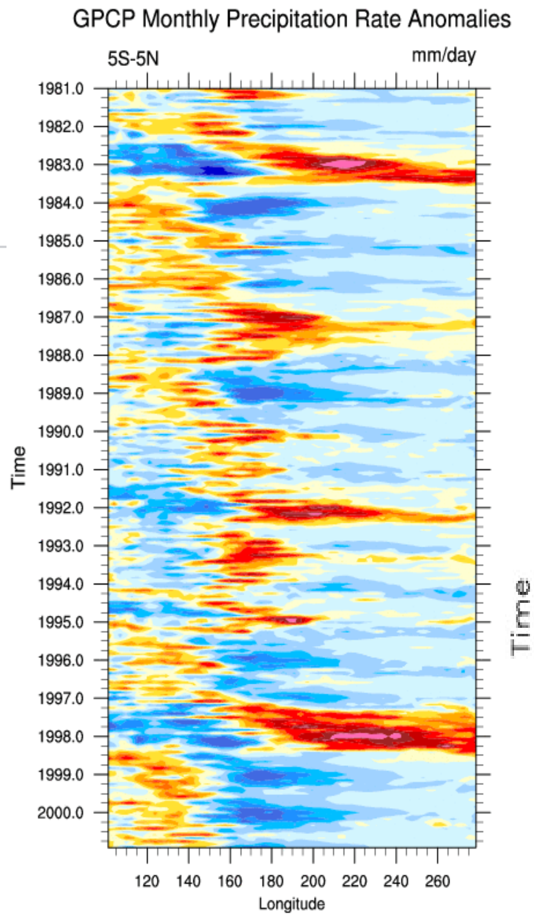
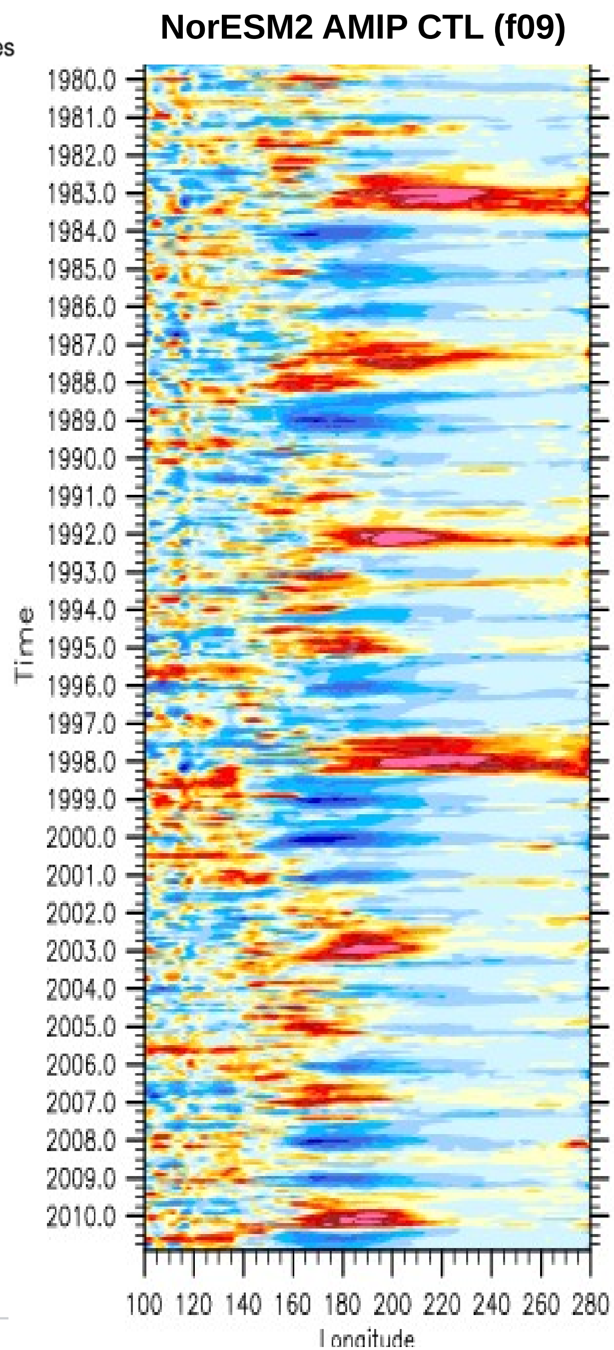
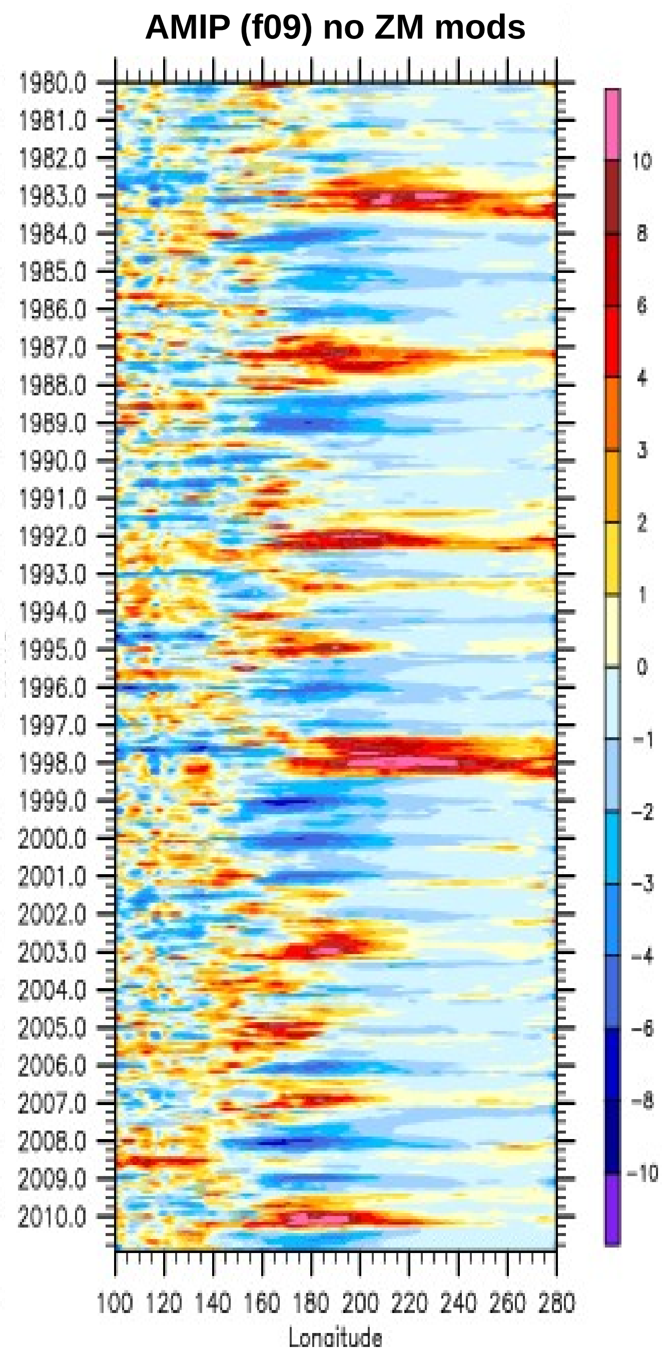
Relative Humidity (ERAI)	0.922	0.922
Temperature (ERAI)	0.987	0.988

bias [%]: Space–Time	f09F2k_ncar_nn	f09F2k_ncar_zm
	ANN	ANN
Sea Level Pressure (ERAI)	0.007 X	0.004
SW Cloud Forcing (CERES–EBAF)	0.977 V	0.643
LW Cloud Forcing (CERES–EBAF)	10.093 =	10.069
Land Rainfall (30N–30S, GPCP)	20.066 X	21.507
Ocean Rainfall (30N–30S, GPCP)	11.702 X	13.907
Land 2–m Temperature (Willmott)	0.179 X	0.246
Pacific Surface Stress (5N–5S,ERS)	16.293 X	22.120
Zonal Wind (300mb, ERAI)	6.272 V	5.467
Relative Humidity (ERAI)	7.970 X	8.138
Temperature (ERAI)	0.508 V	0.378







While tuning we checked for possible negative impacts on ENSO...

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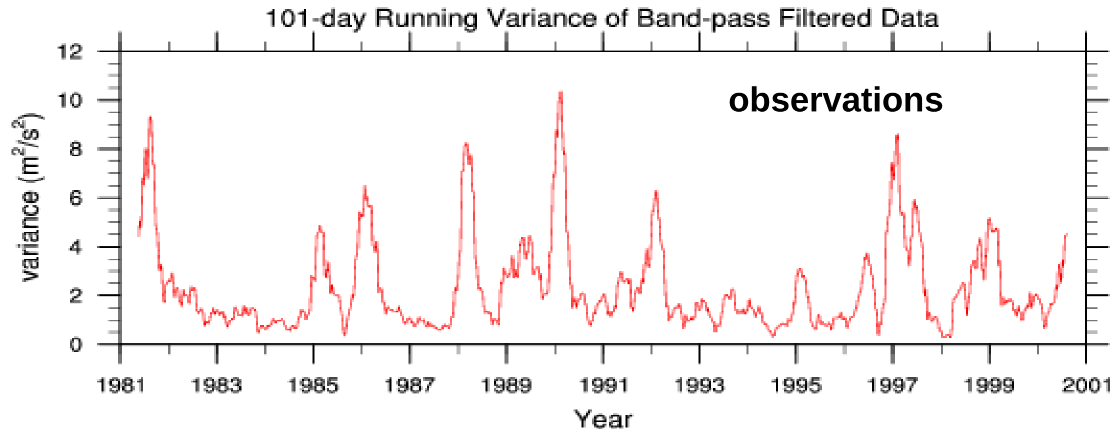
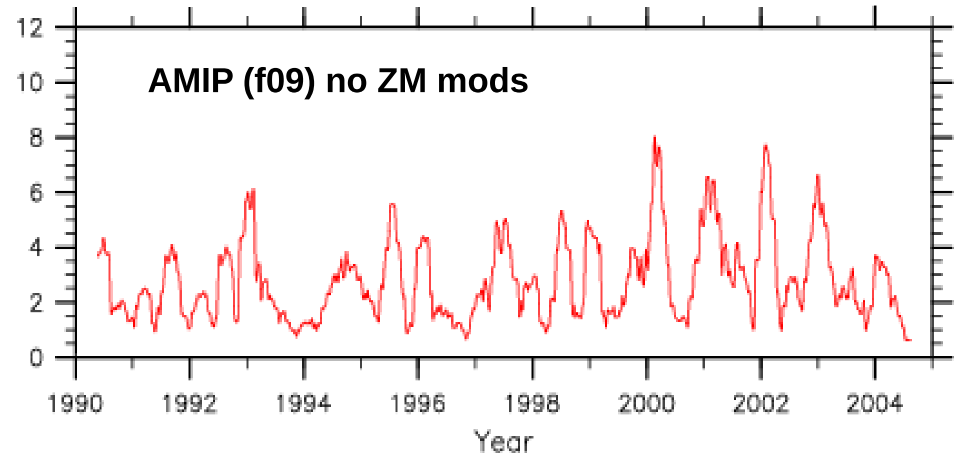
...but not on the MJO





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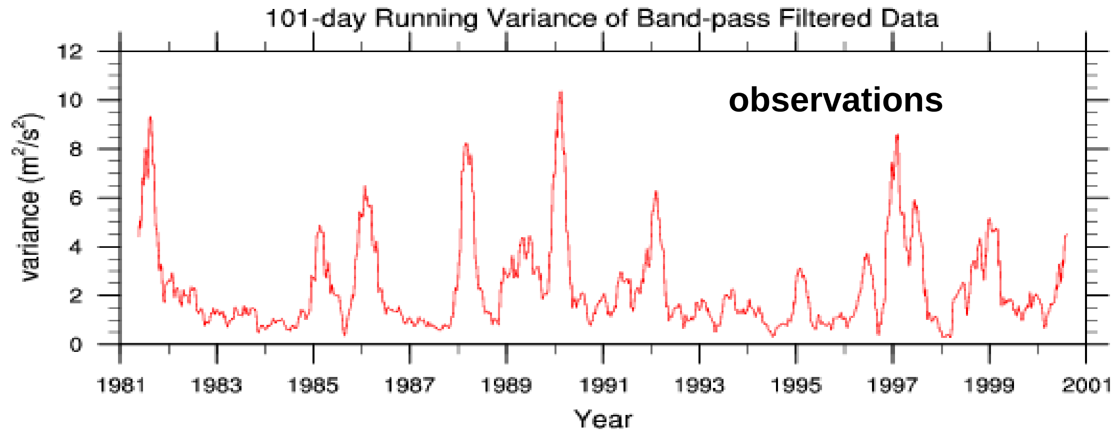
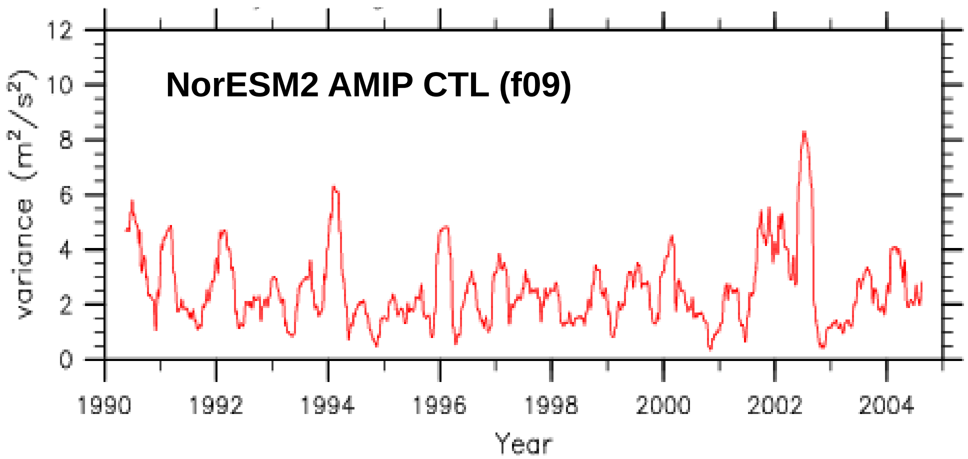
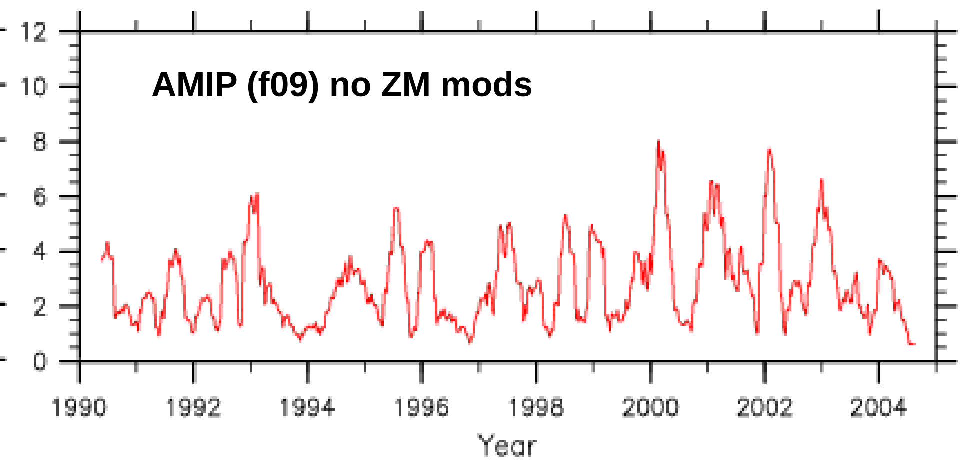
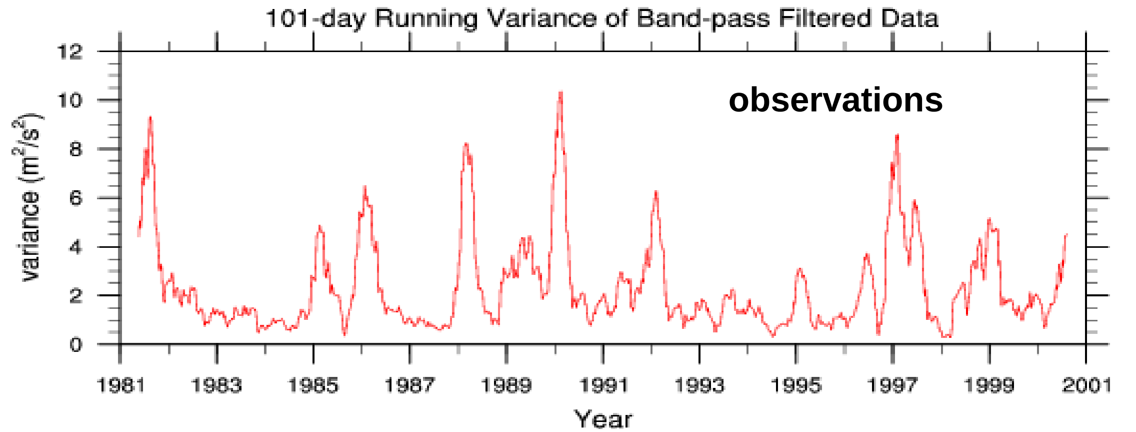
...but not on the MJO

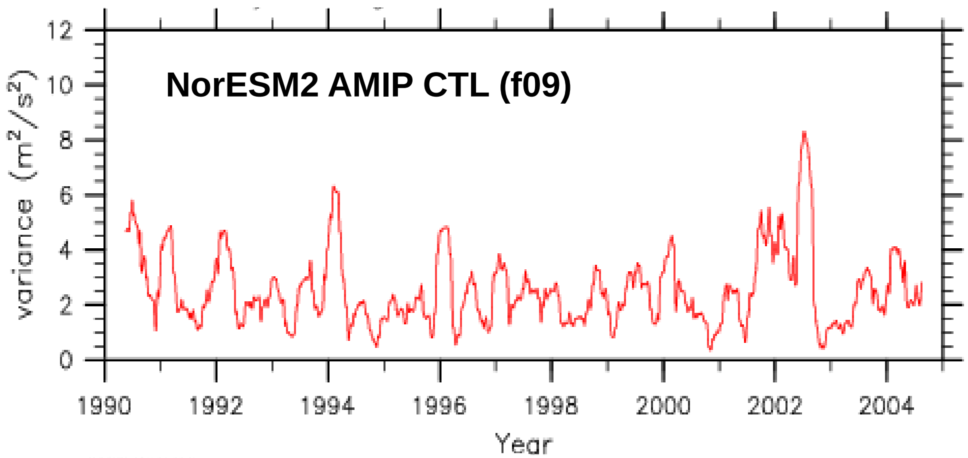


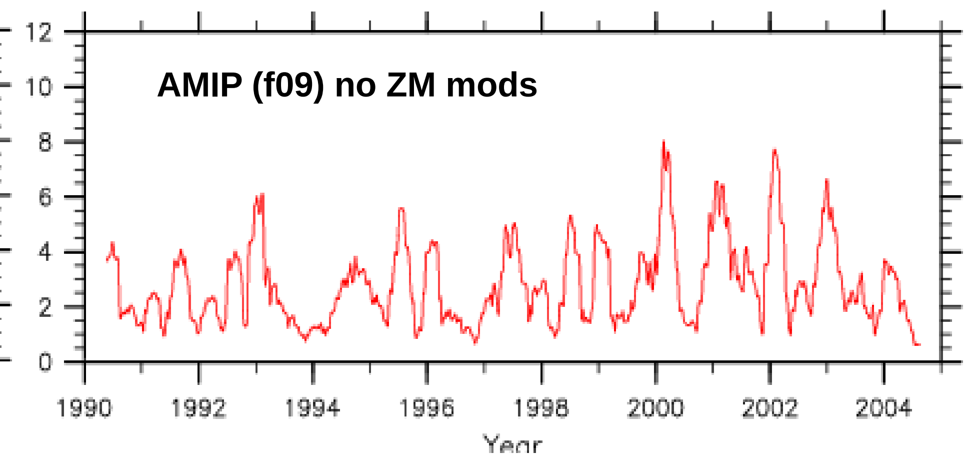


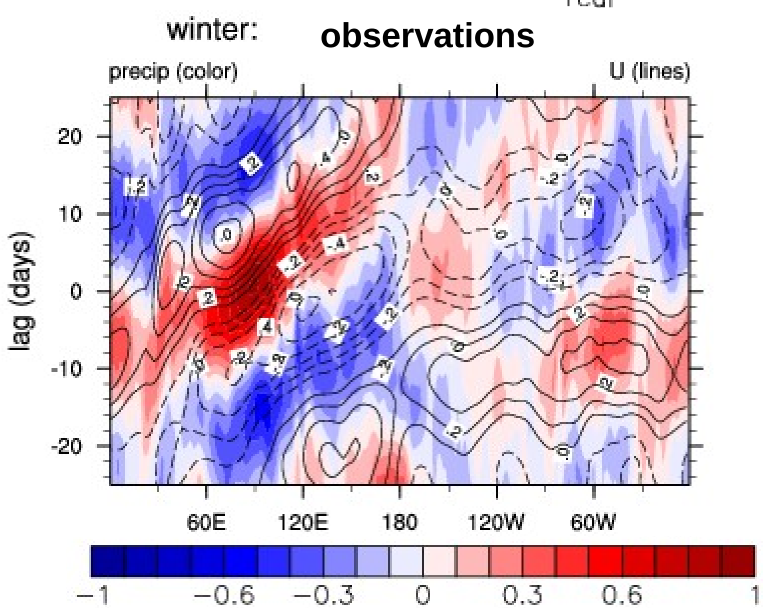


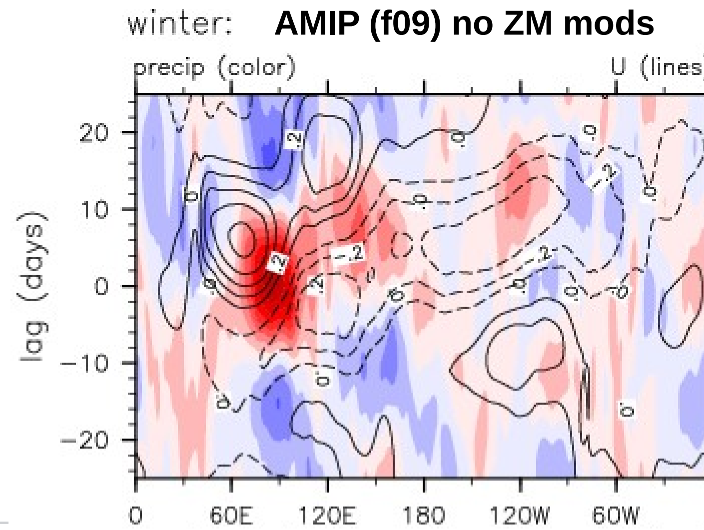
...but not on the MJO



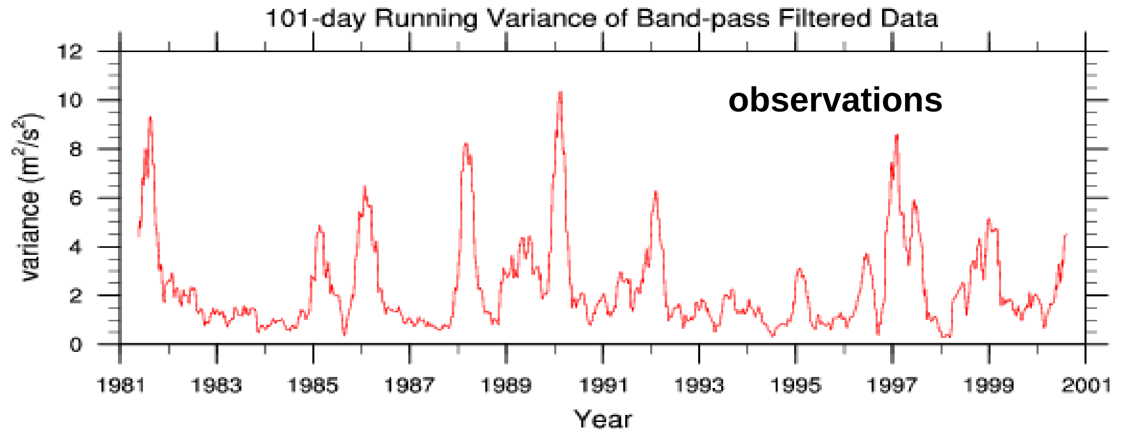


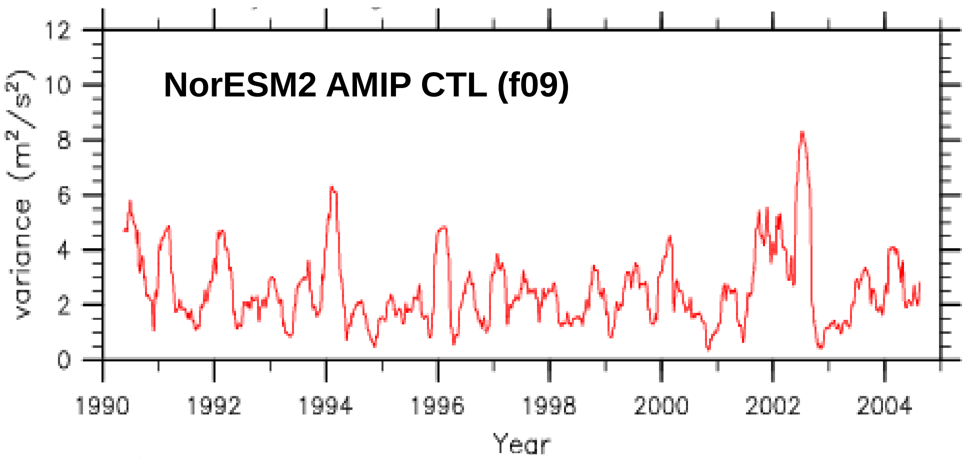


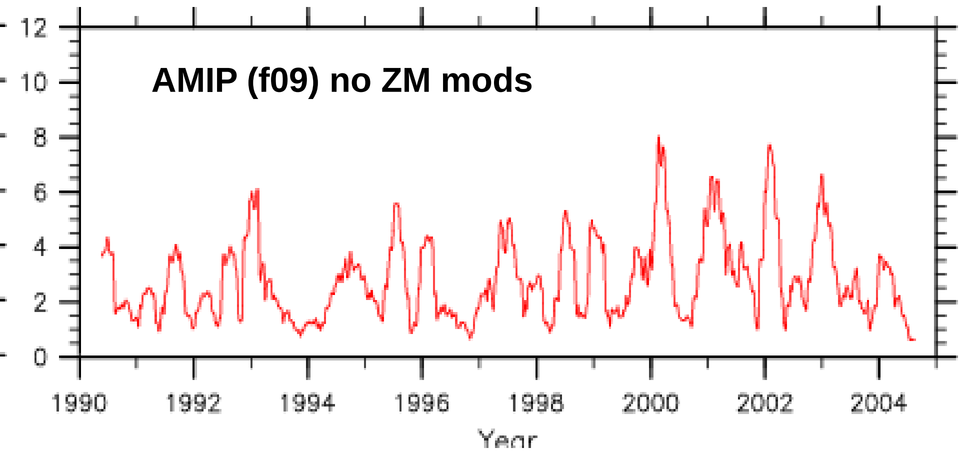


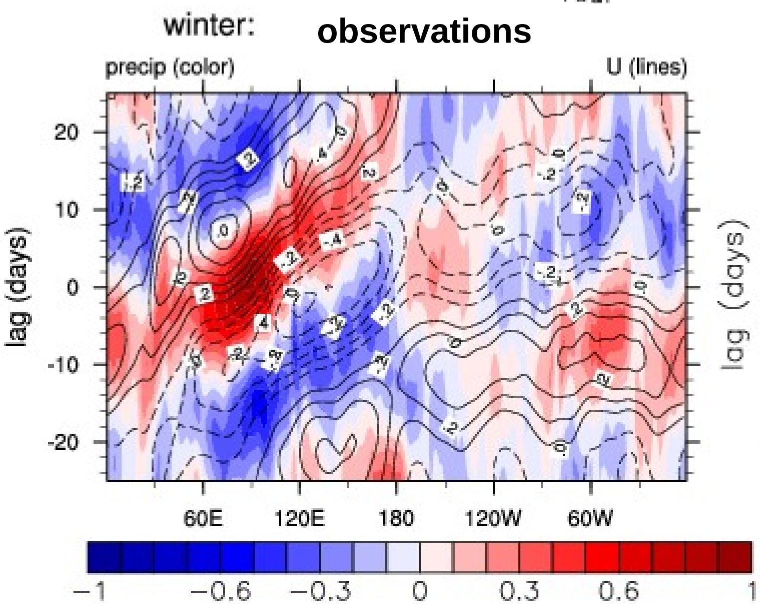


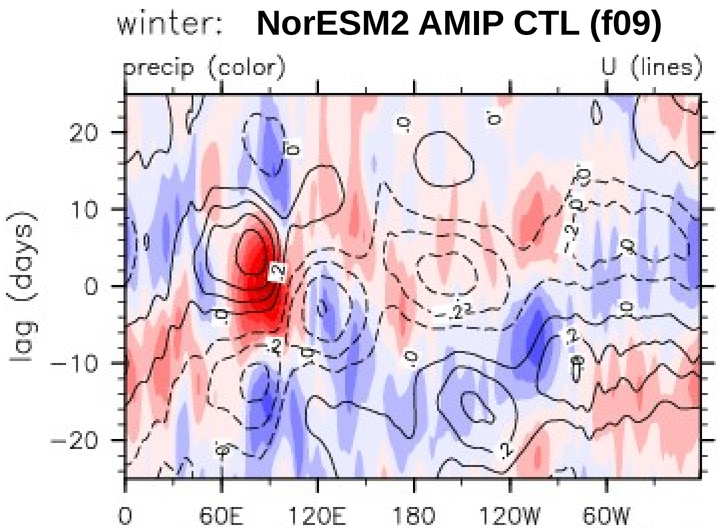
...but not on the MJO

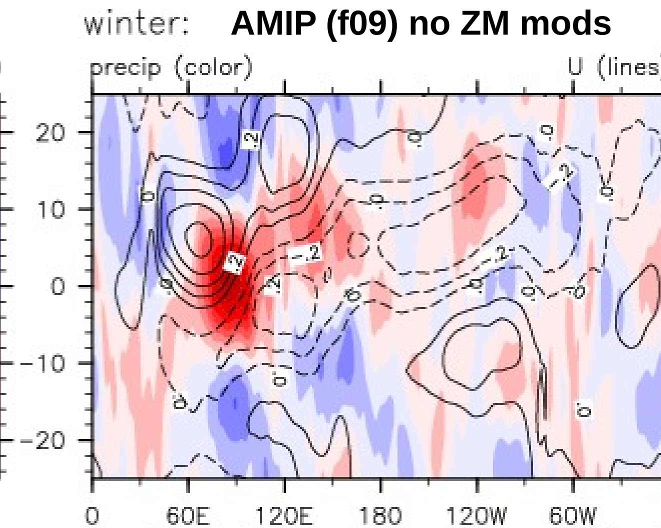












Summary: convection tuning

- We targeted the ZM scheme to warm the troposphere and reduce RESTOM
- Changing the base mass layer definition is necessary and has the largest effect, but results in large RMSE
- This was repaired by hardening the trigger and reducing drying efficiency
- The climatology and seasonal cycle were thus improved
- However these changes also lead to equatorial drying
- The effects are negative but acceptable for ENSO, but bad for the MJO

Thanks for listening!

Questions?