AMOC early warning signals in CMIP6 models?

Lana Blaschke, Maya Ben-Yami, Niklas Boers, Da Nian

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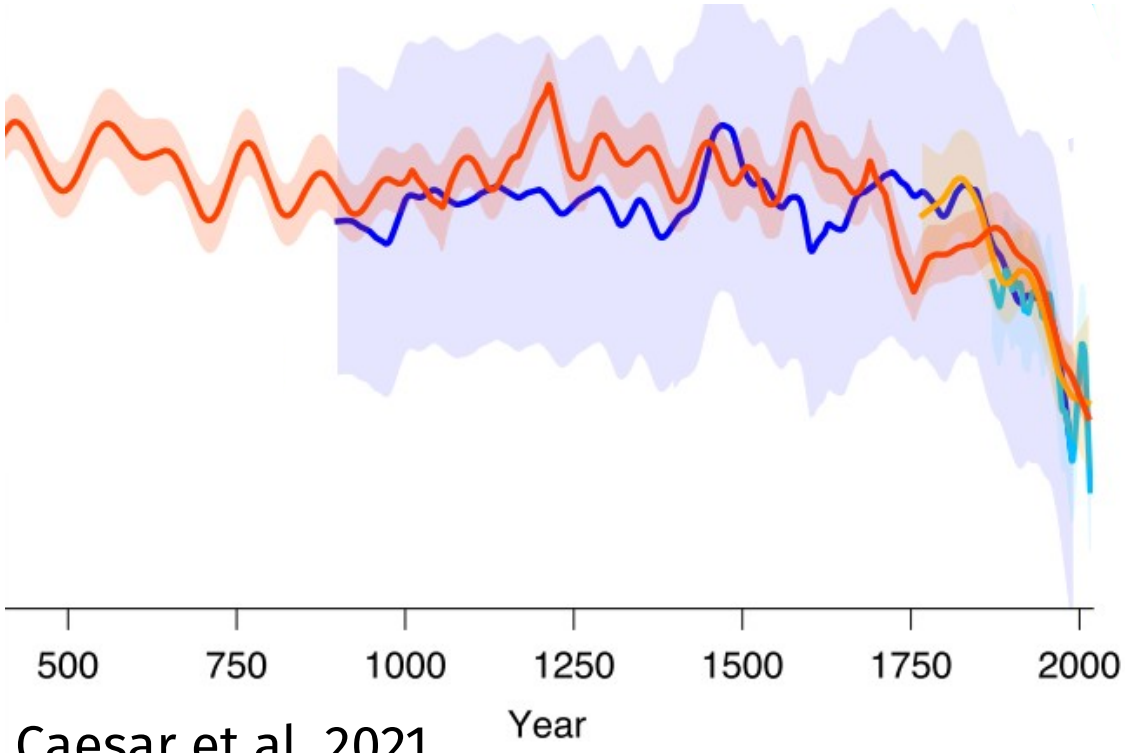
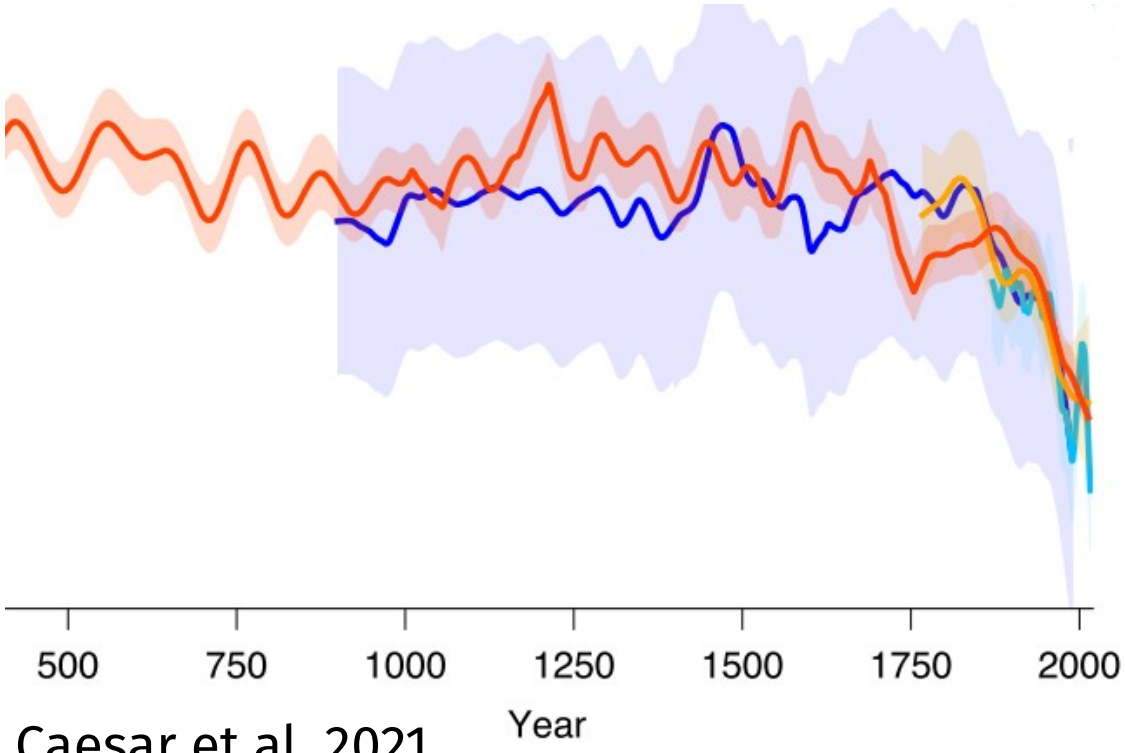
AMOC decline



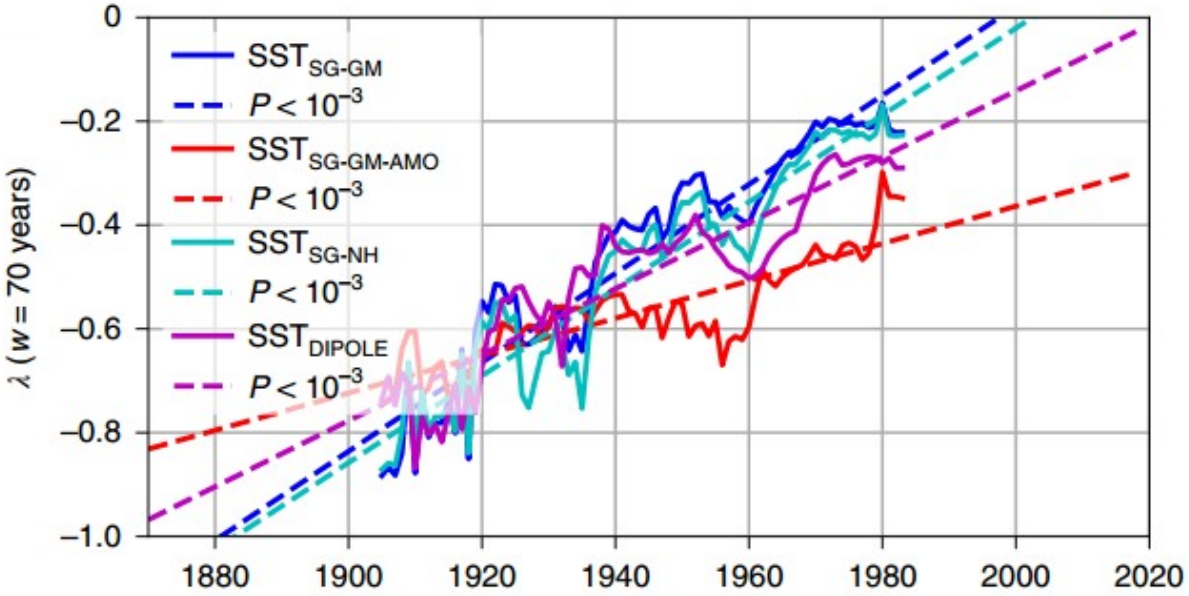
Caesar et al. 2021

AMOC decline



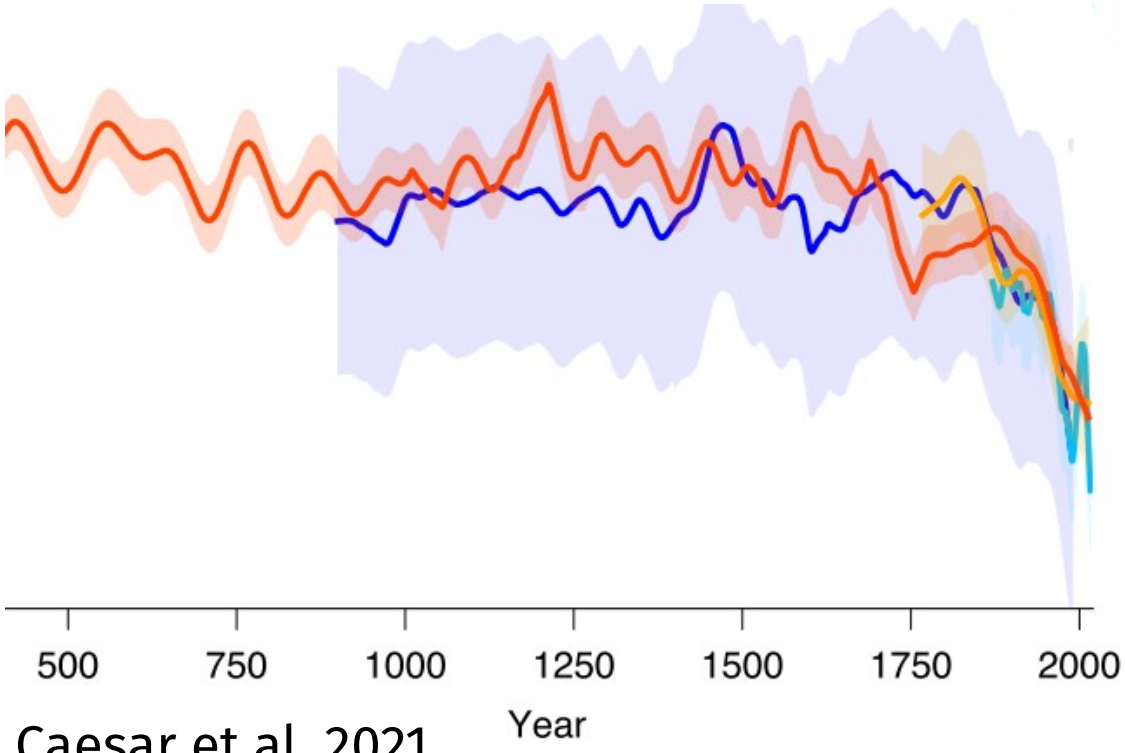
Caesar et al. 2021

early warning signals



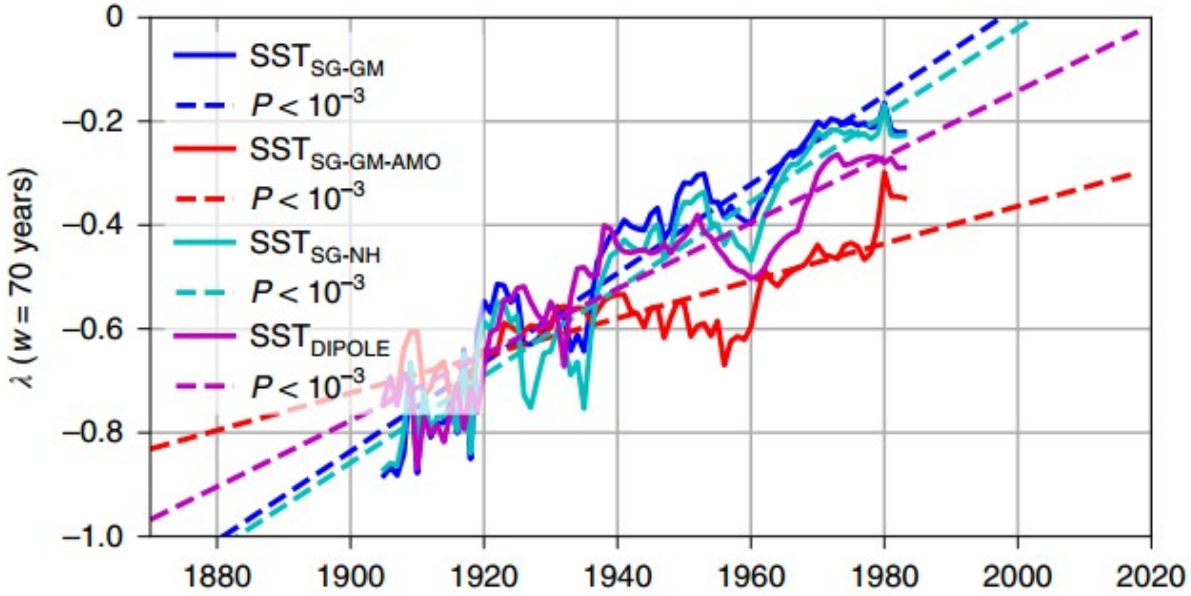
Boers 2021

AMOC decline



Caesar et al. 2021

early warning signals

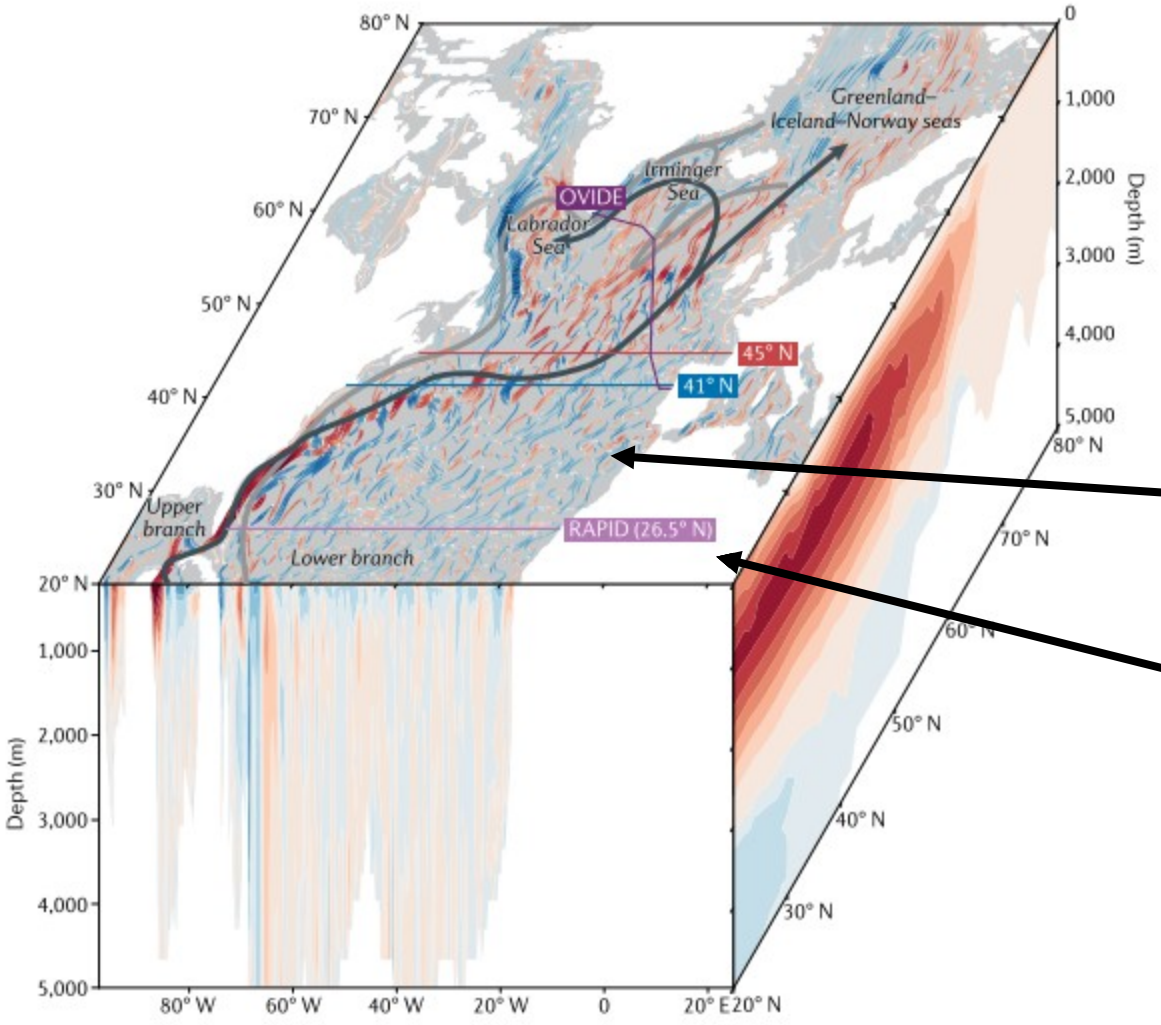


Boers 2021

BUT the decline is still controversial!

Latif et al. 2022

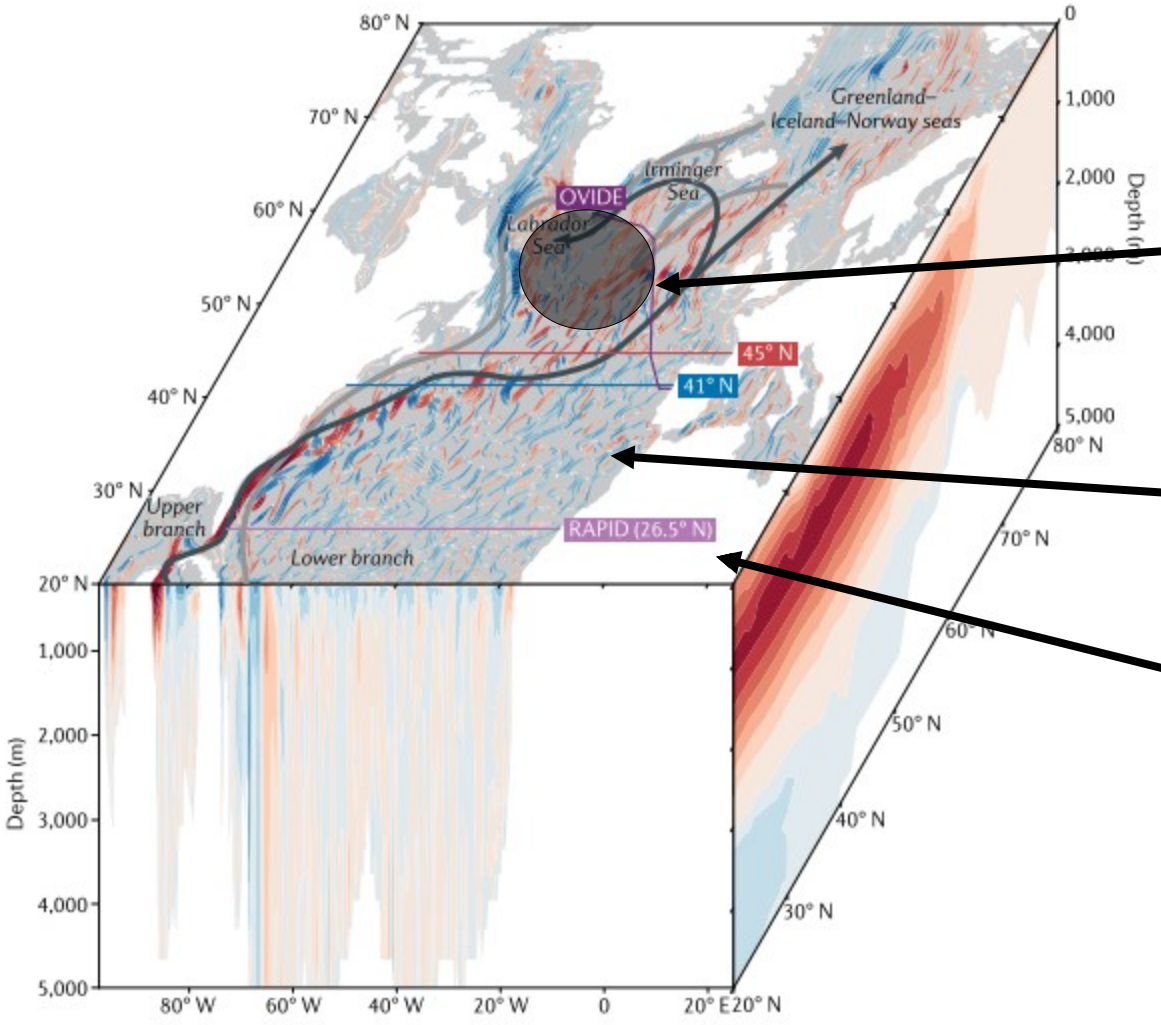
Kilbourne et al. 2022



Strength at 35° N

Strength at 26.5° N

Jackson et al. 2022



SST Index

Subpolar gyre SSTs
- global mean SSTs

Strength at 35° N

Strength at 26.5° N

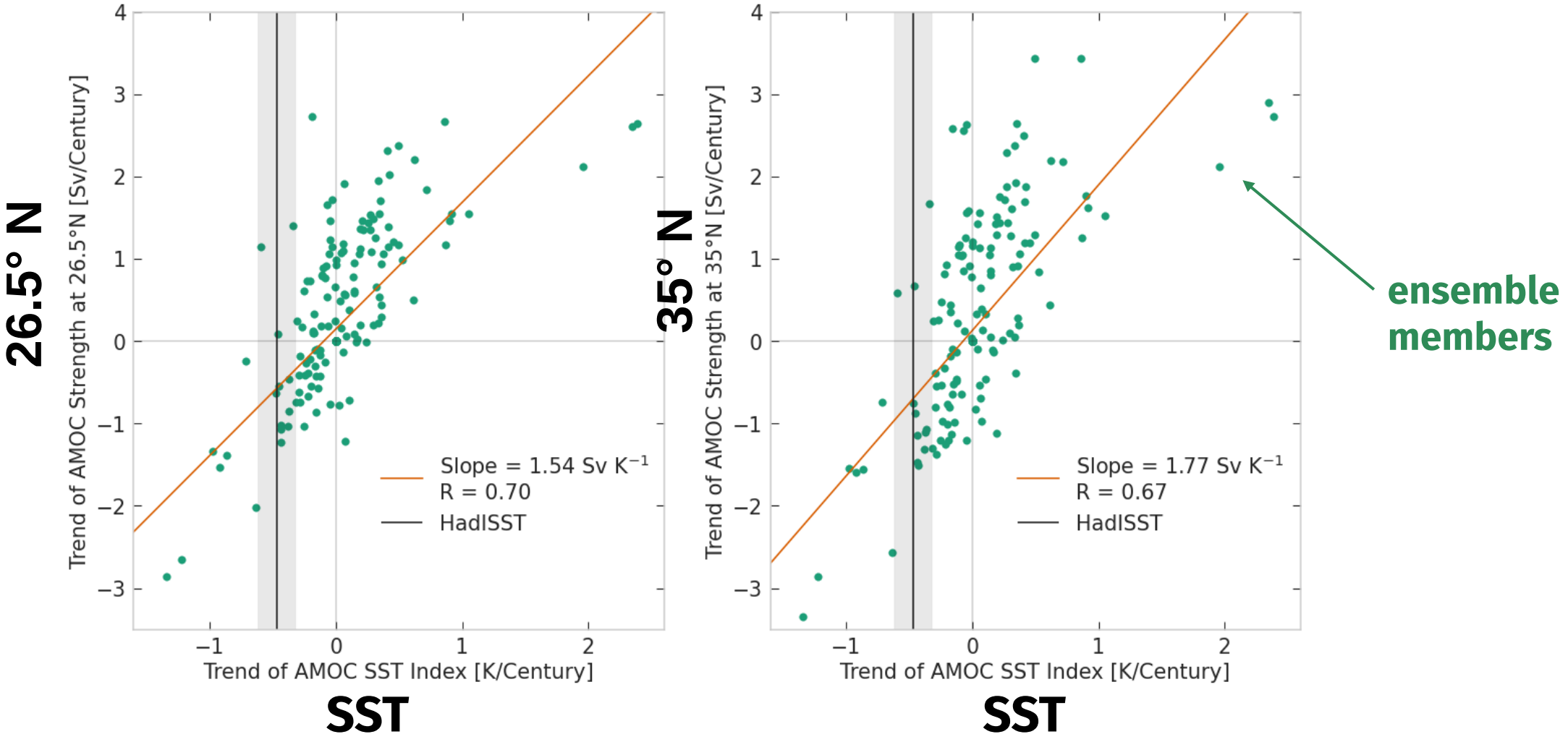
Jackson et al. 2022

Early warning signals (EWS)

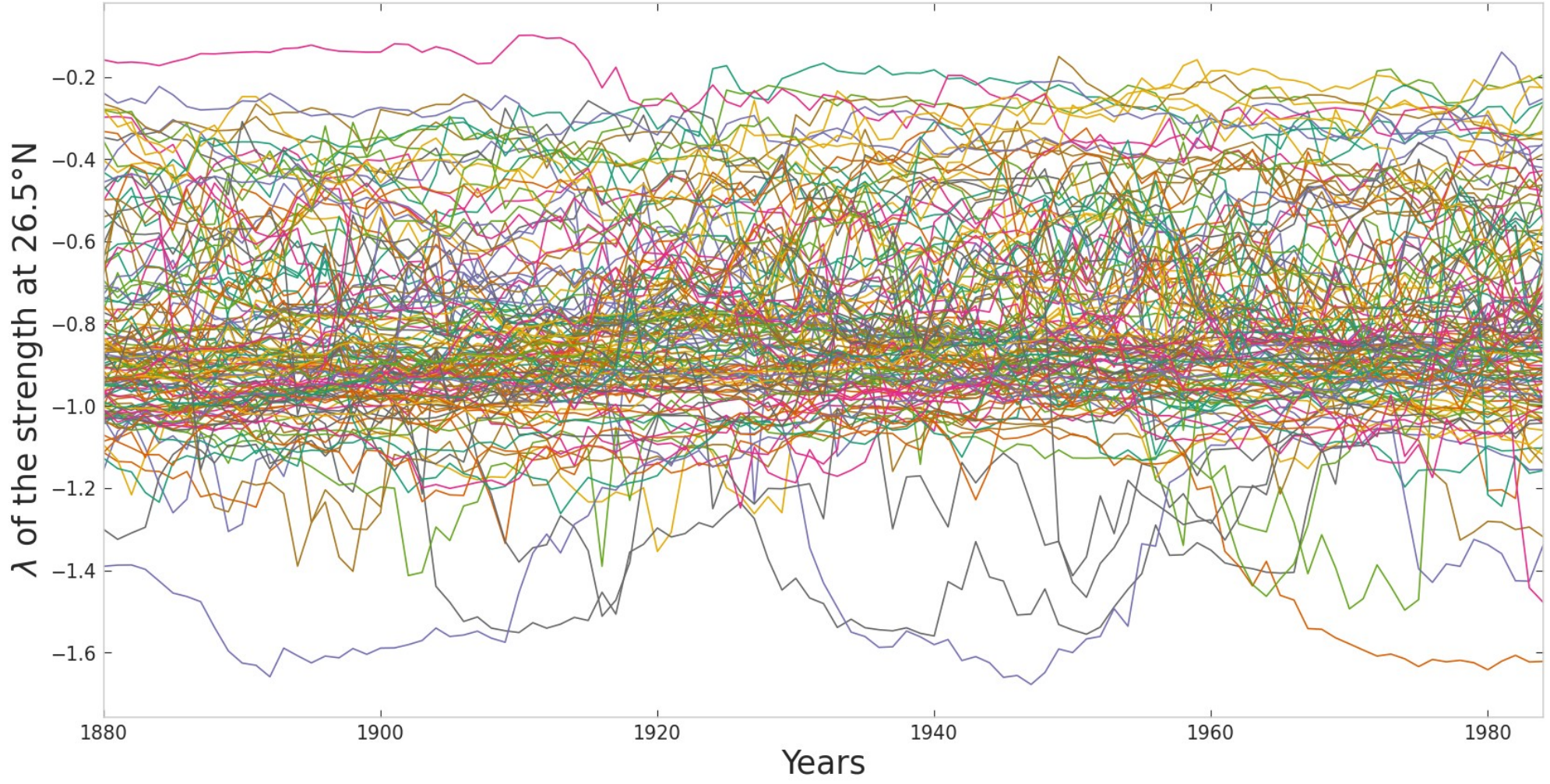
$$\frac{\mathrm{d}\Delta x}{\mathrm{d}t} \approx \lambda \Delta x + \eta(t)$$

1) Trends

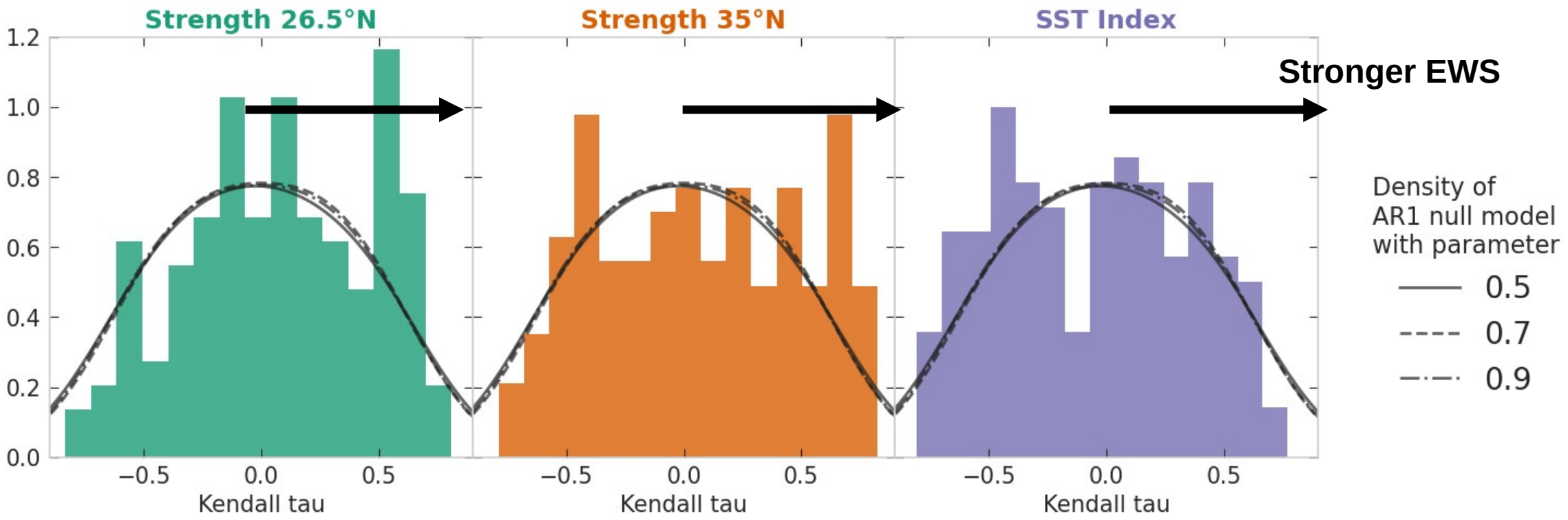
- good correlation
- many models outside observational range



2) Early warning signals



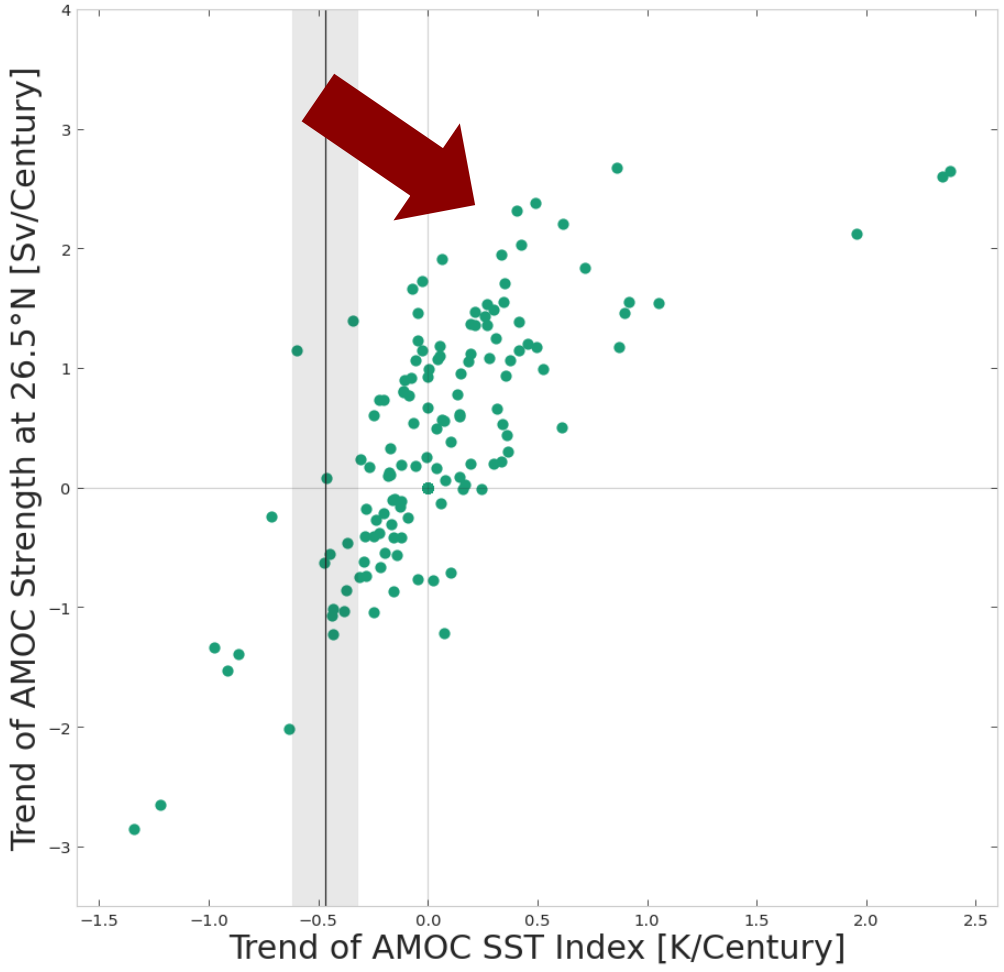
2) Early warning signals



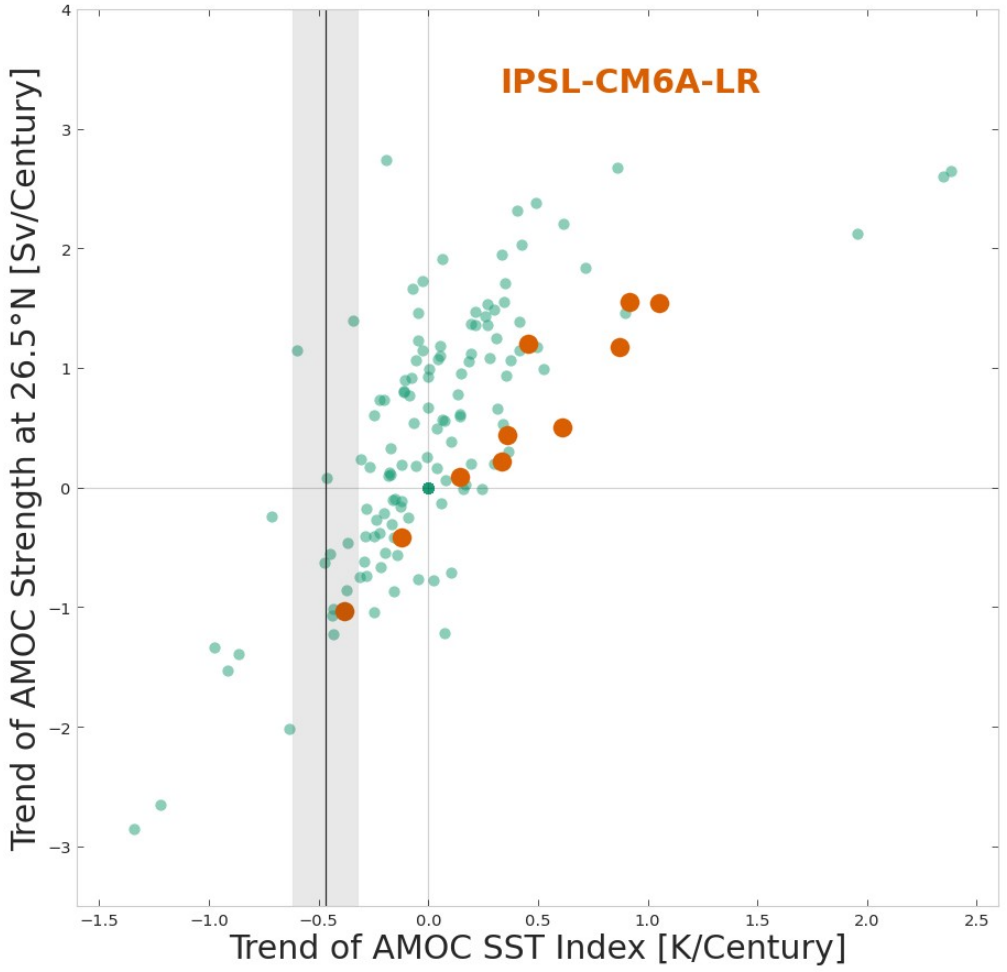
1) AMOC trend does not match observations for most models
2) No coherence for early warning signals

Why?

1) AMOC trend does not match observations for many models

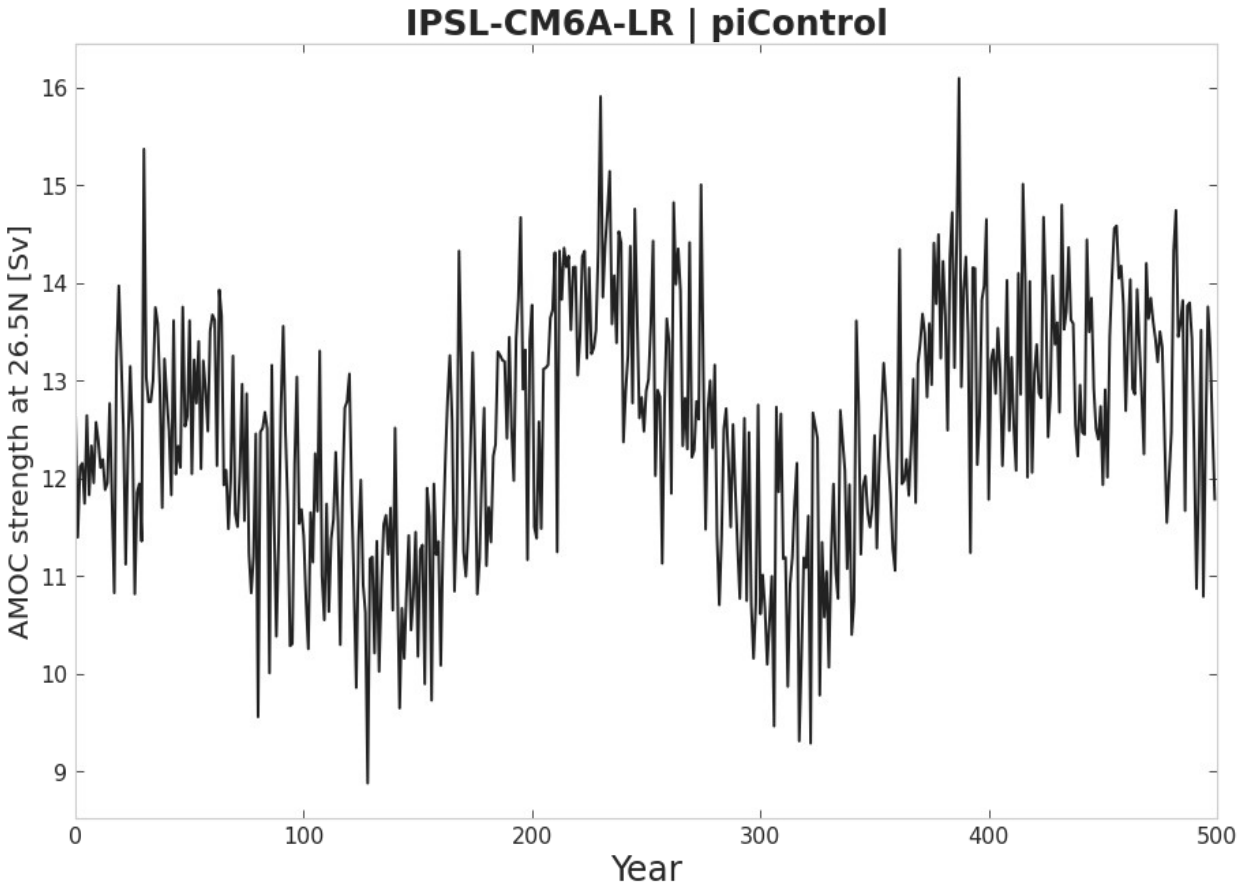


1) AMOC trend does not match observations for many models



1) AMOC trend does not match observations for many models

—> centennial oscillations of the AMOC?

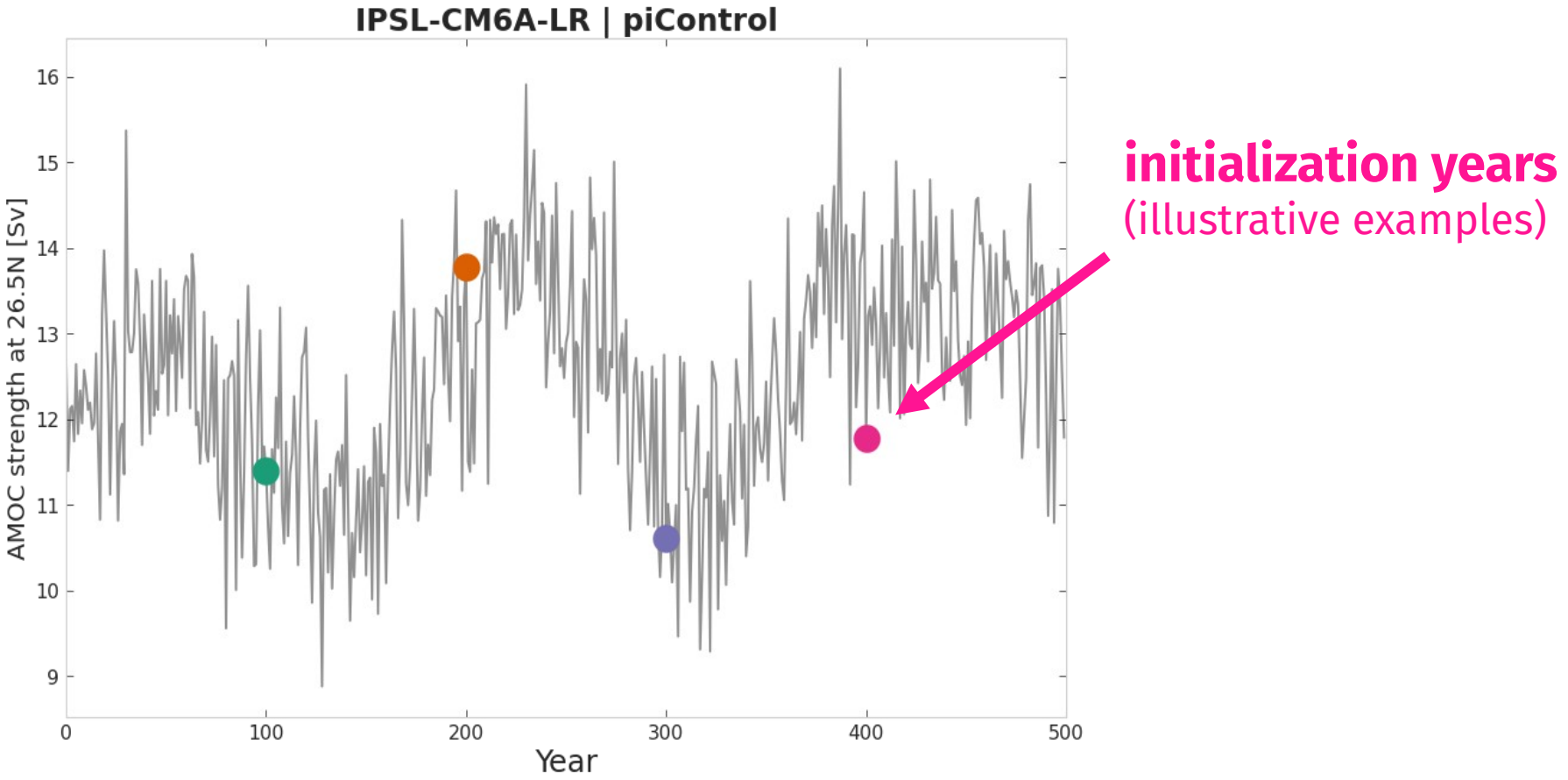


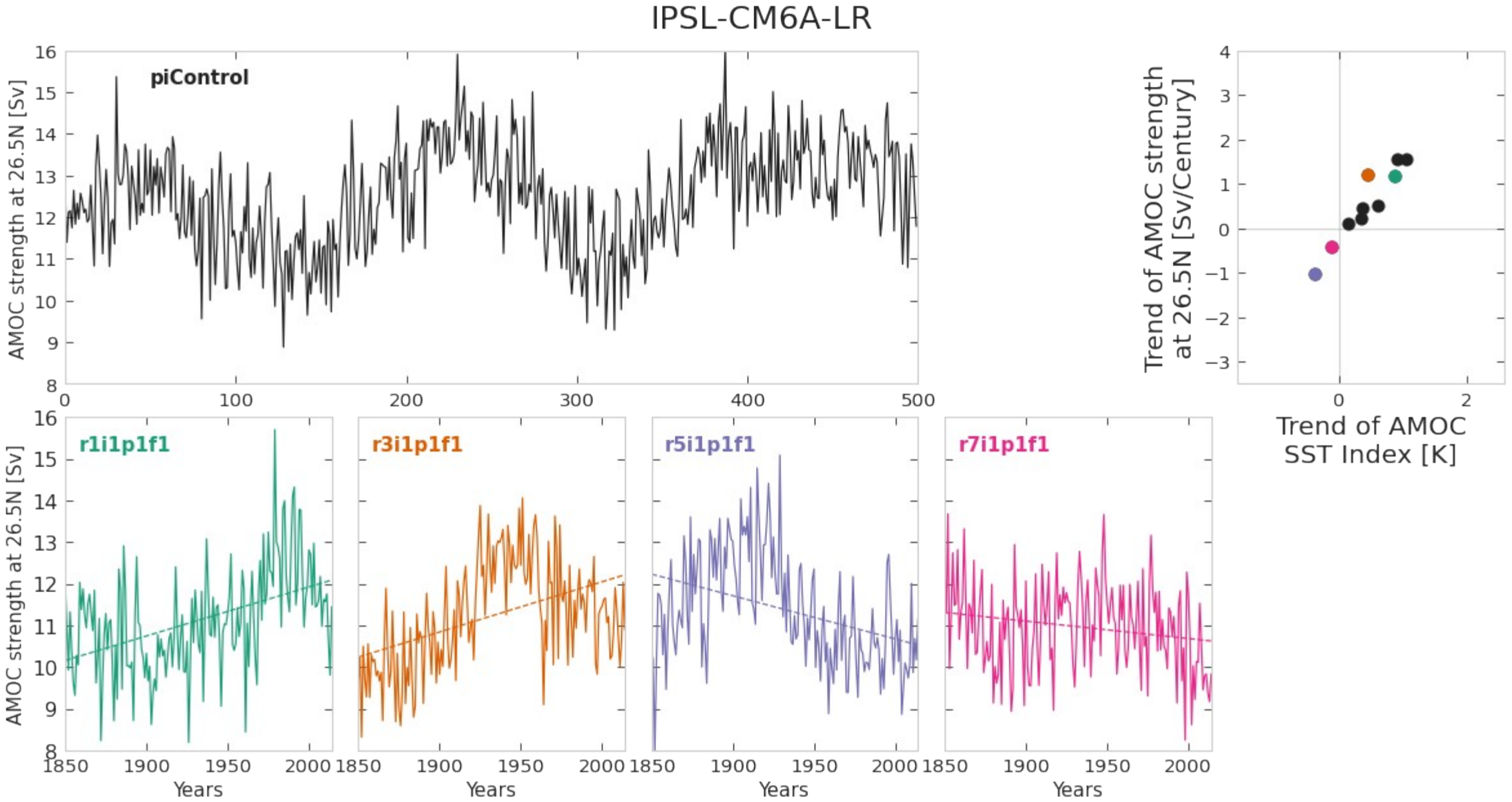
Also see:

- Bonnet, R., Boucher, O., Deshayes, J., Gastineau, G., Hourdin, F., Mignot, J., et al. (2021)
- Bonnet, R., Swingedouw, D., Gastineau, G. et al. (2021)
- Jiang, W., Gastineau, G., & Codron, F. (2021)

1) AMOC trend does not match observations for many models

—> centennial oscillations of the AMOC?




IPSL-CM6A-LR
piControl
AMOC strength at 26.5N [Sv]
r1i1p1f1
r3i1p1f1
r5i1p1f1
r7i1p1f1
Years
Trend of AMOC strength at 26.5N [Sv/Century]
Trend of AMOC SST Index [K]

What about the early warning signals?

Not more than null model, no coherence in indices or ensemble members

- Model **representation** of the AMOC?
- AMOC subsystems **destabilize separately**?
- Decline part of an **oscillation** and not a destabilization?
- EWS analysis **problematic for a 1D fingerprint** of an extended system?

Questions?

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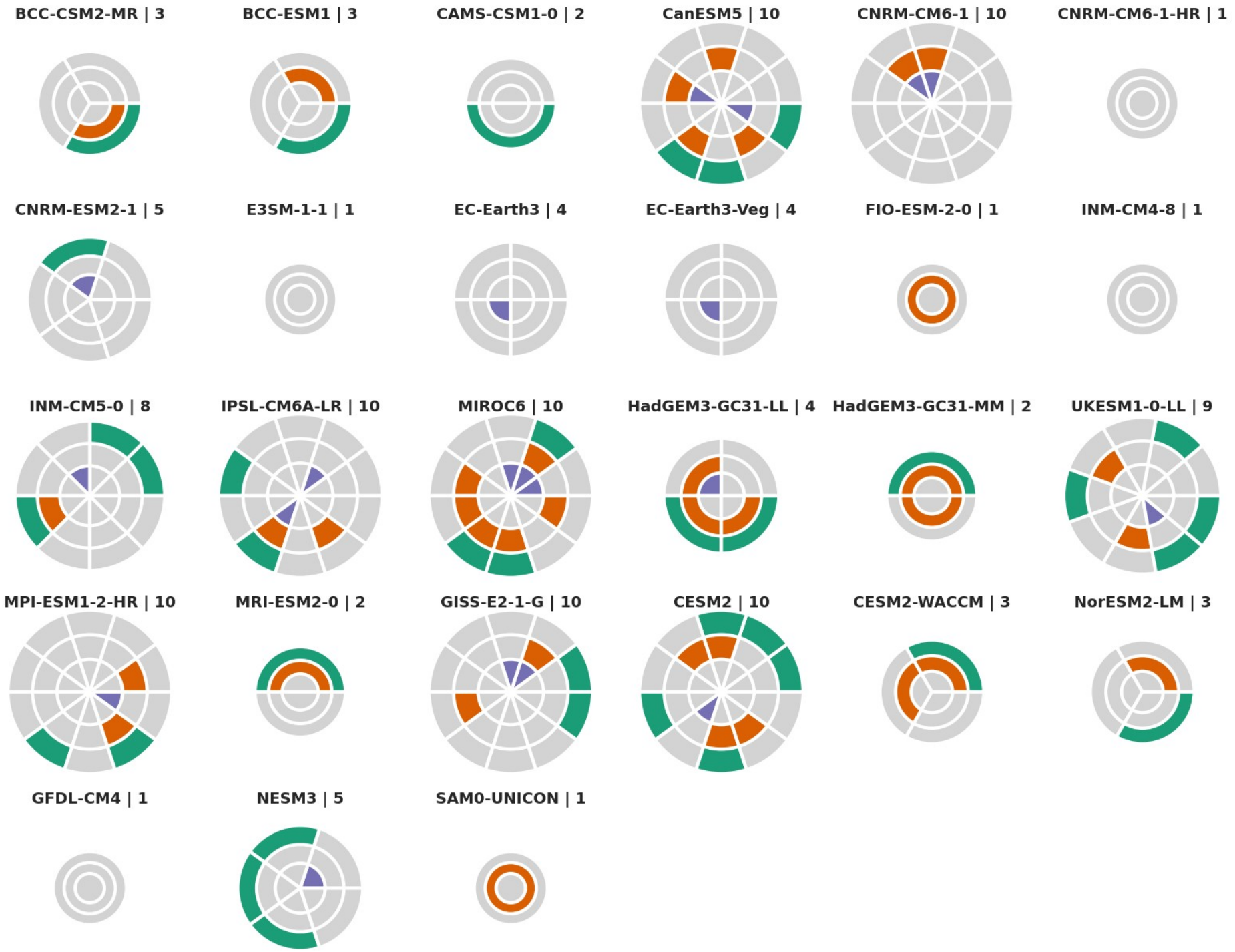
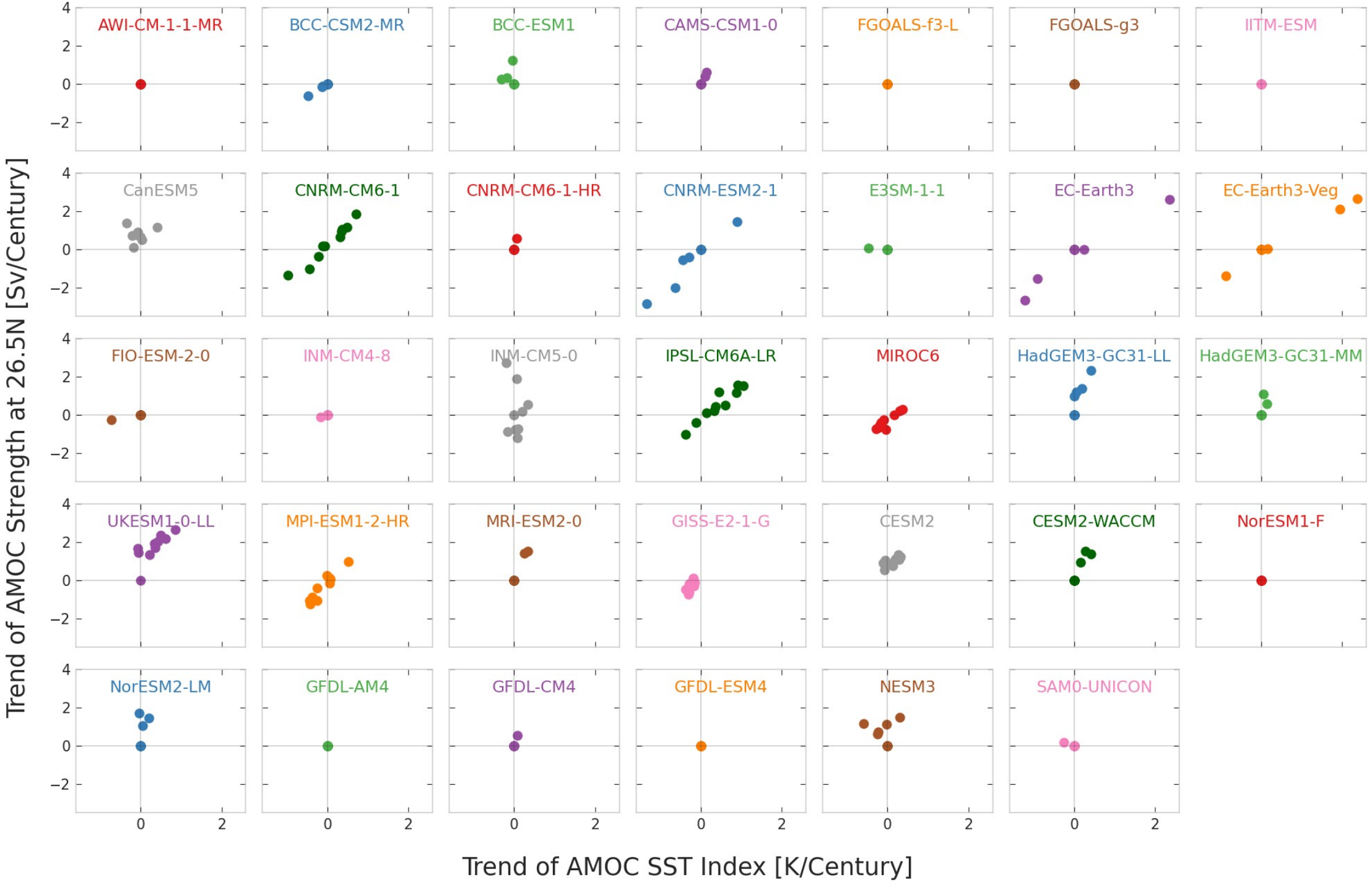
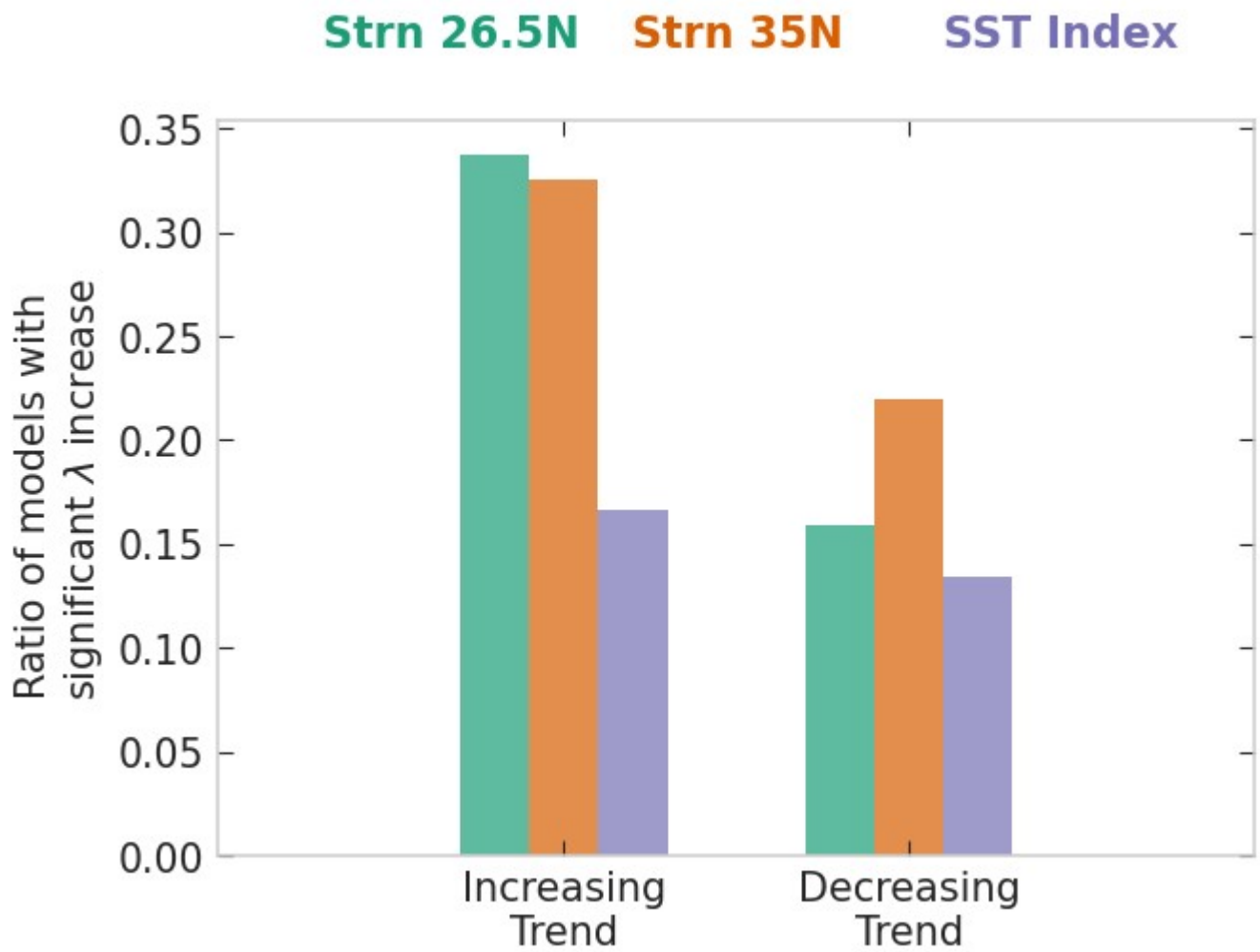
2) Early Warning Signals

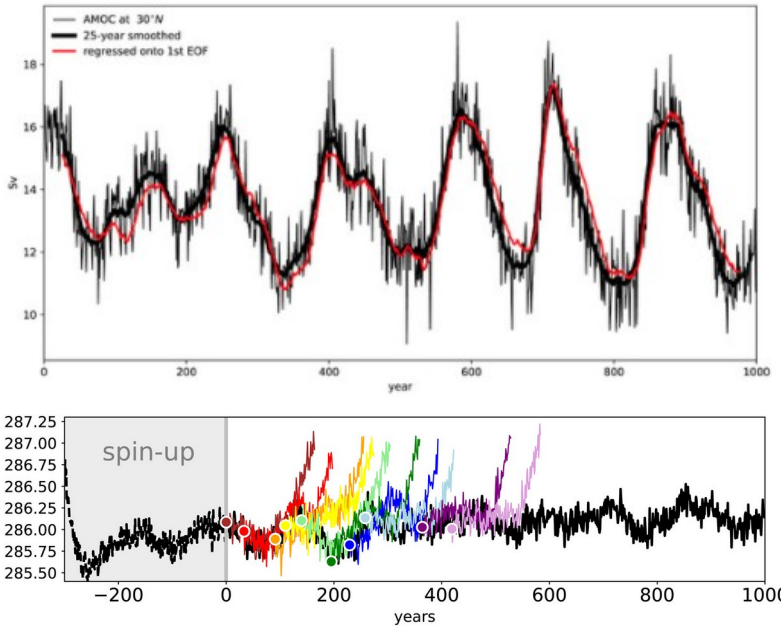
Significantly increasing λ in:

Strength 26.5°N
Strength 35°N
SST Index

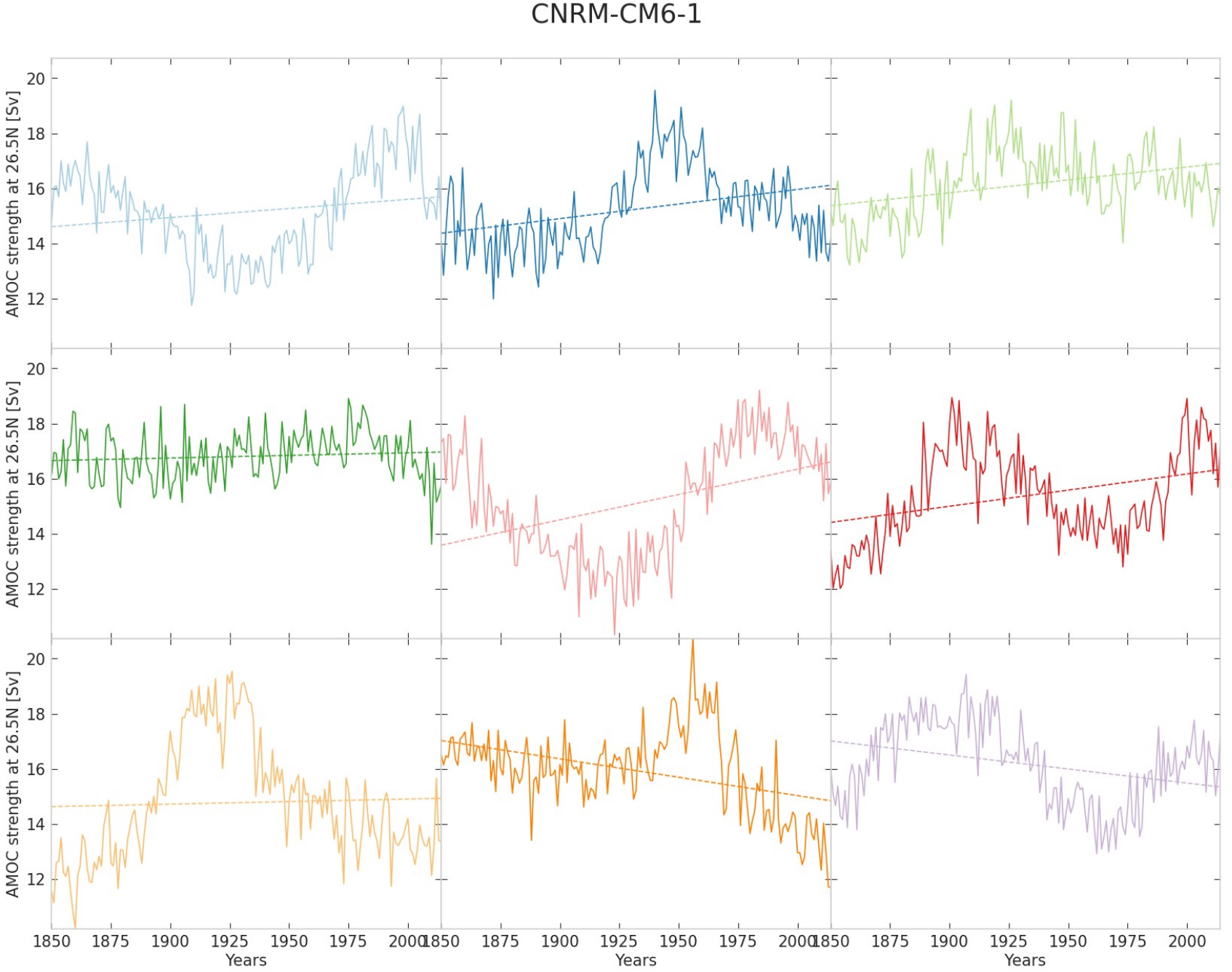


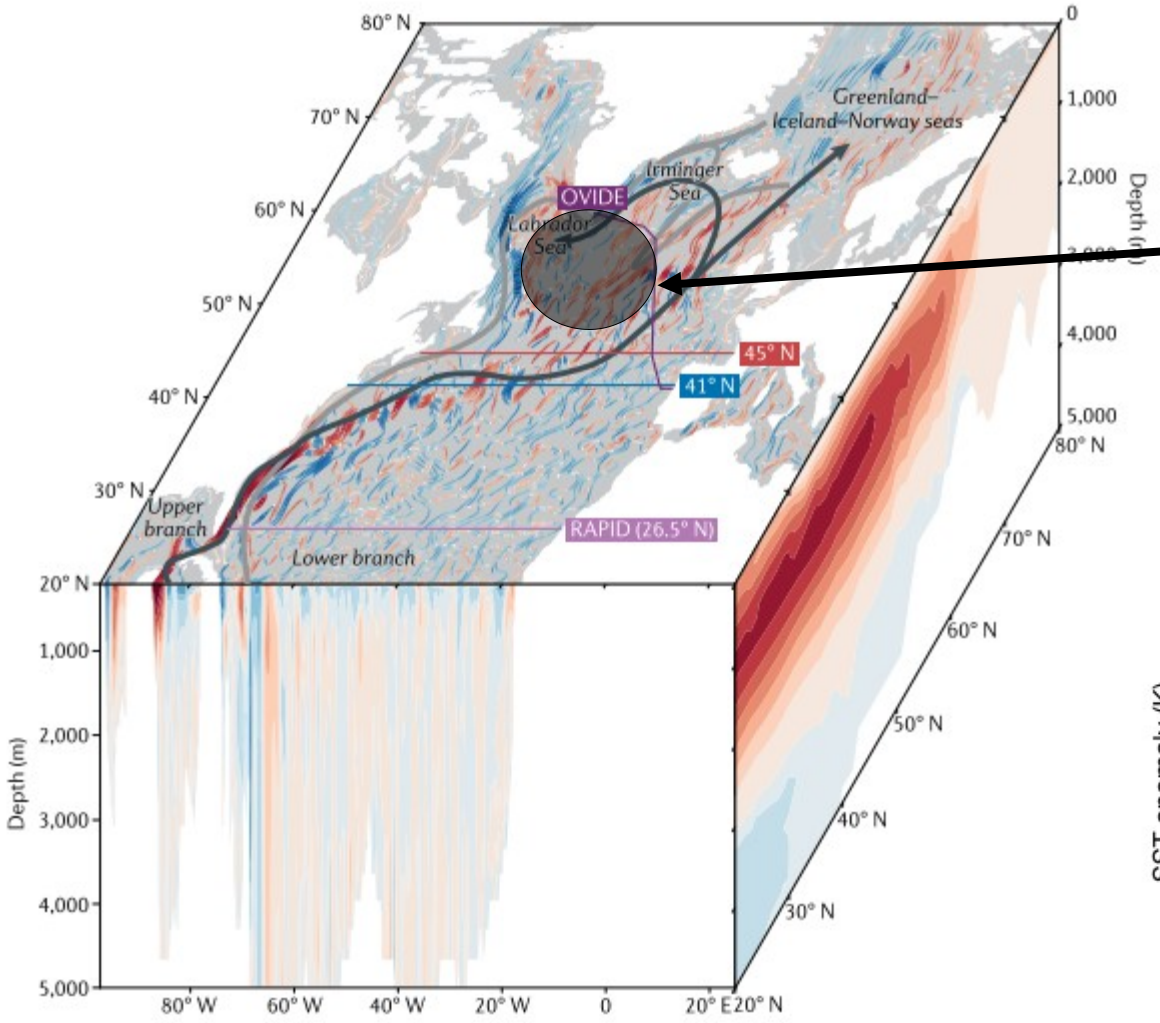

AWI-CM-1-1-MR
BCC-CSM2-MR
BCC-ESM1
CAMS-CSM1-0
FGOALS-f3-L
FGOALS-g3
IITM-ESM
CanESM5
CNRM-CM6-1
CNRM-CM6-1-HR
CNRM-ESM2-1
E3SM-1-1
EC-Earth3
EC-Earth3-Veg
FIO-ESM-2-0
INM-CM4-8
INM-CM5-0
IPSL-CM6A-LR
MIROC6
HadGEM3-GC31-LL
HadGEM3-GC31-MM
UKESM1-0-LL
MPI-ESM1-2-HR
MRI-ESM2-0
GISS-E2-1-G
CESM2
CESM2-WACCM
NorESM1-F
NorESM2-LM
GFDL-AM4
GFDL-CM4
GFDL-ESM4
NESM3
SAM0-UNICON
Trend of AMOC Strength at 26.5N [Sv/Century]
Trend of AMOC SST Index [K/Century]


Strn 26.5N
Strn 35N
SST Index
Ratio of models with significant λ increase
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Increasing Trend
Decreasing Trend



Voldoire et al. 2019
Waldman et al. 2020

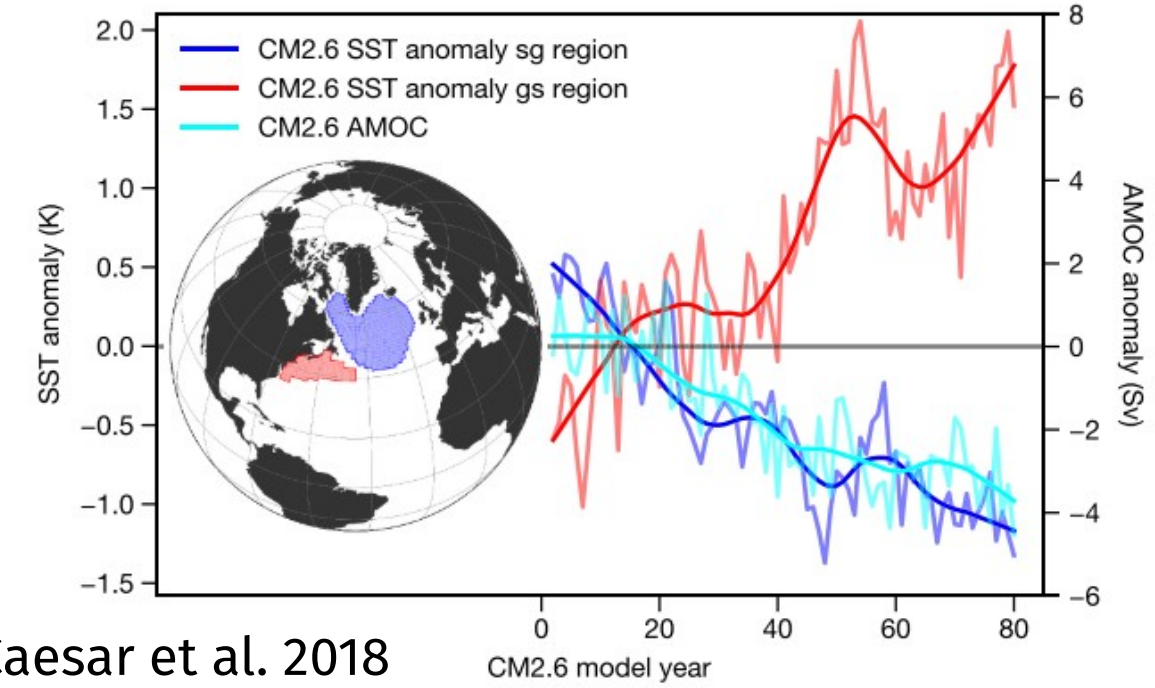




Jackson et al.
2022

SST Index

Subpolar gyre SSTs -
global mean SSTs



Caesar et al. 2018

	Control	1PC	Hosing	Recovery	N:$p < 0.05$
RAPID	**0.99**	**1.00**	**0.99**	**0.98**	21
RAPID_FC	**0.52**	**0.97**	**0.96**	**0.87**	21
RAPID_UMO	0.25	−0.44	−0.21	0.32	11
OSNAP	**0.86**	**0.98**	**0.96**	**0.87**	19
SST_dipole	0.37	**−0.82**	**0.91**	0.52	15
SST_caesar	0.18	**0.87**	**0.90**	0.49	13
SST_spg	**0.53**	**0.96**	**0.87**	0.64	16
amv1	**0.65**	0.50	**0.98**	**0.77**	17
amv2	**0.56**	**0.95**	**0.94**	0.70	18
Tsub	0.32	**0.95**	0.22	0.57	11
uohc	0.09	**0.67**	−0.61	0.29	8
LS_mid	0.30	**0.96**	**0.87**	0.40	12
LS_dipole	0.37	**0.99**	**0.98**	0.66	16
m_dipole	**0.74**	**0.96**	**0.98**	**0.80**	18
z_dipole	−0.40	**0.96**	**0.94**	0.57	15
26N_dipole	0.22	**−0.91**	−0.16	−0.26	8
pintg	**0.56**	**0.98**	**0.94**	0.66	15
LS_mld	0.39	**0.97**	**0.87**	**0.83**	19
SPG_mld	0.44	**0.97**	**0.95**	**0.84**	19
sl0	−0.15	**0.66**	0.32	0.04	4
sl1	0.12	**0.92**	0.74	0.45	10

Fingerprints for Early Detection of Changes in the AMOC

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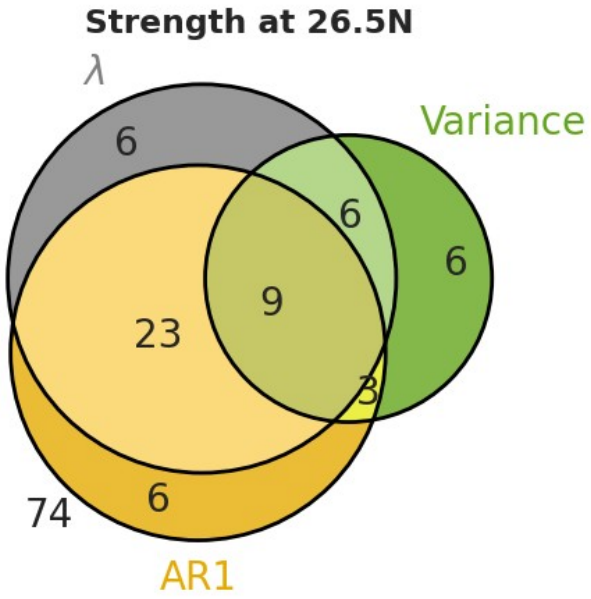
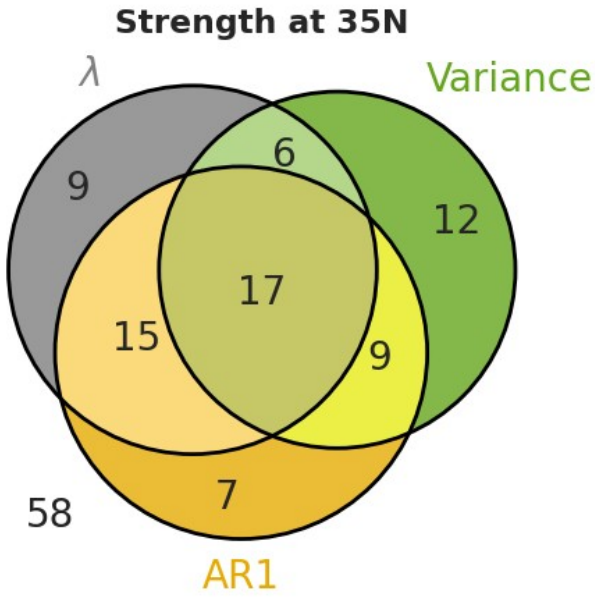
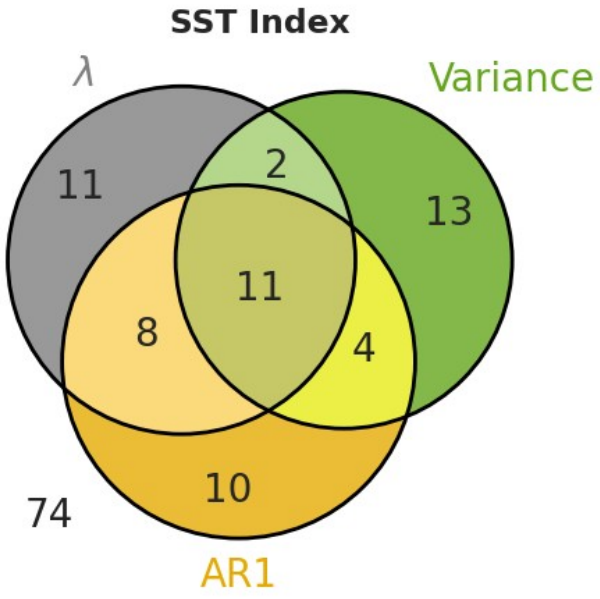
Hadley Centre, Met Office, Exeter, United Kingdom

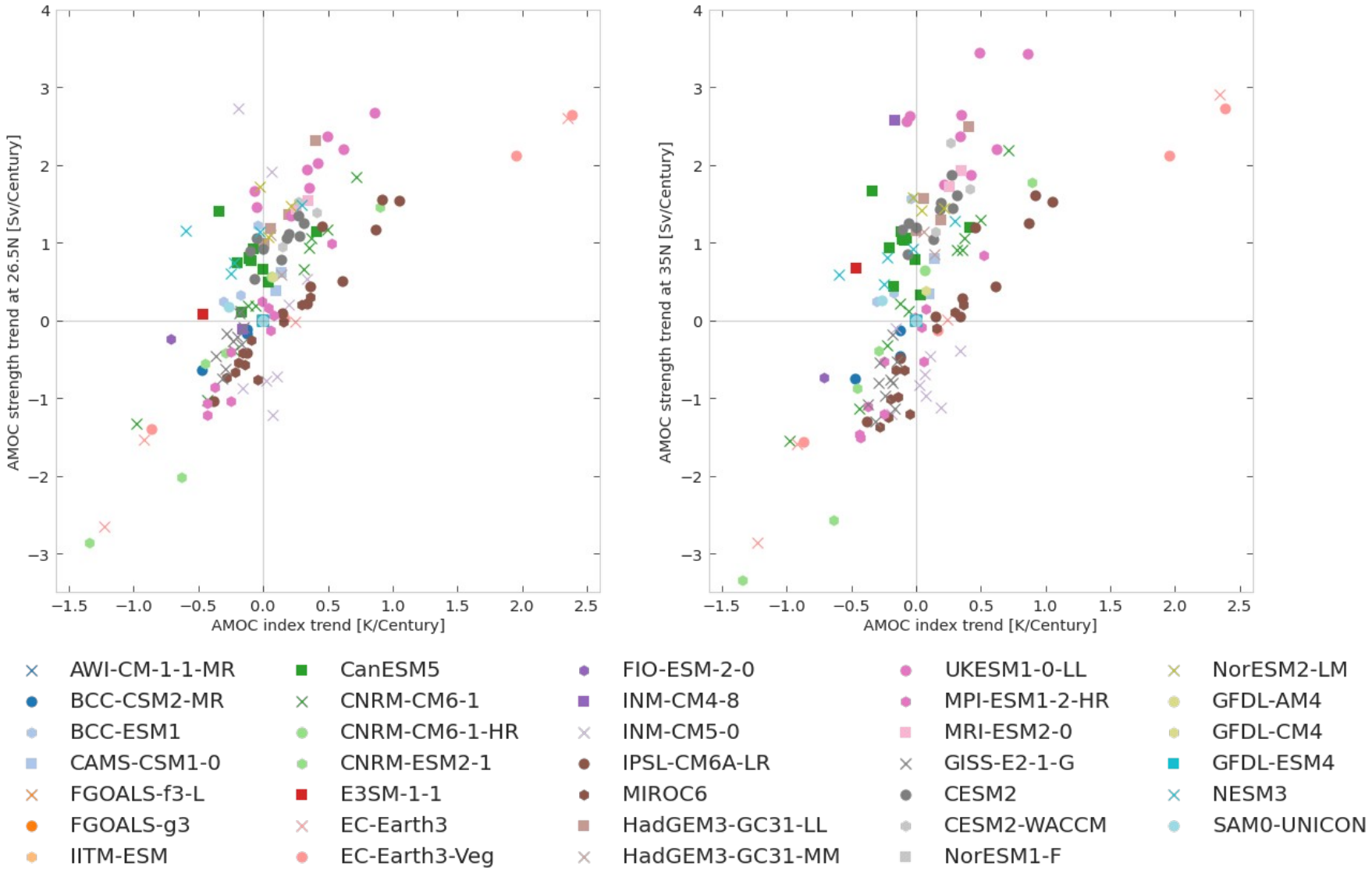
(Manuscript received 20 January 2020, in final form 15 May 2020)

There is evidence these fingerprints work to detect changes in the AMOC


Strength at 26.5N
λ
Variance
6
6
6
9
23
3
74
6
AR1


Strength at 35N
λ
Variance
9
6
12
17
15
9
58
7
AR1


SST Index
λ
Variance
11
2
13
11
8
4
74
10
AR1


AMOC strength trend at 26.5N [Sv/Century]
AMOC index trend [K/Century]
AMOC strength trend at 35N [Sv/Century]
AMOC index trend [K/Century]
AWI-CM-1-1-MR
BCC-CSM2-MR
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CNRM-CM6-1-HR
CNRM-ESM2-1
E3SM-1-1
EC-Earth3
EC-Earth3-Veg
FIO-ESM-2-0
INM-CM4-8
INM-CM5-0
IPSL-CM6A-LR
MIROC6
HadGEM3-GC31-LL
HadGEM3-GC31-MM
UKESM1-0-LL
MPI-ESM1-2-HR
MRI-ESM2-0
GISS-E2-1-G
CESM2
CESM2-WACCM
NorESM1-F
NorESM2-LM
GFDL-AM4
GFDL-CM4
GFDL-ESM4
NESM3
SAM0-UNICON