Disentangling Internal and External Contribution to Atlantic Multidecadal Variability over the Past Millennium

(Fang et al. 2021, GRL)

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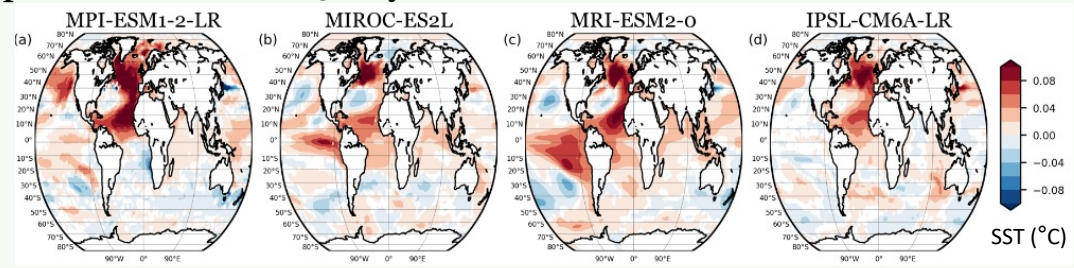
[3]University Ca' Foscari of Venice, Italy

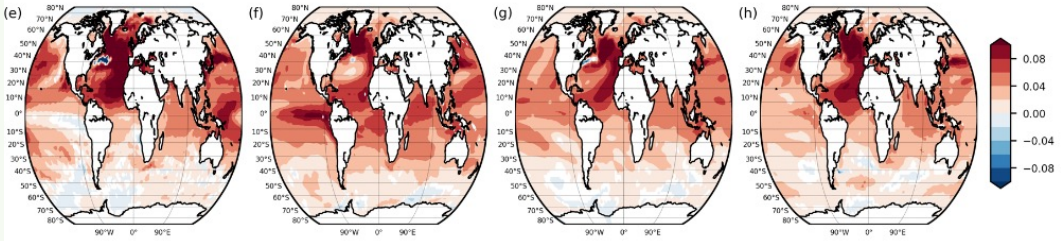
Max-Planck-Institut
für Meteorologie

Atlantic Multidecadal Variability: Internal and External Component

piControl-CMIP6 (500 years)



Past1000-PMIP4 (850-1849) (Jungclaus et al., 2017)



Typical AMV: SST averaged over North Atlantic (0°N–60°N, 80°W–0°W) with 10-year running mean
Internal variability -> triggered by internal processes (Sea Ice, ocean mixing, …)
External variability -> triggered by external processes (Volcano, Solar, Aerosol, GHG…)

Atlantic Multidecadal Variability: Internal and External Component

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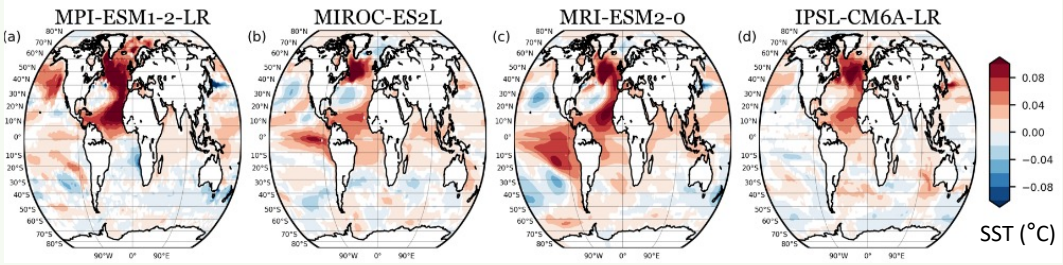

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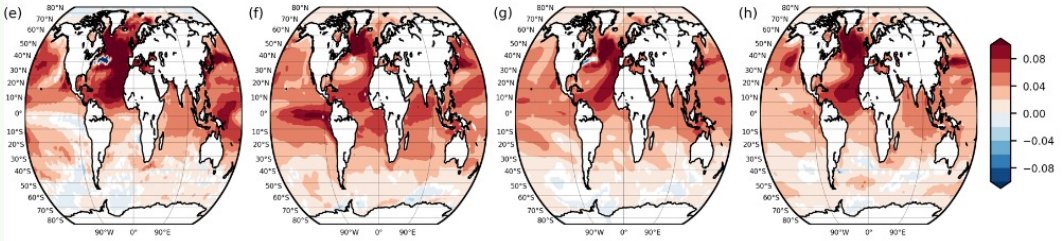

1. Why different patterns?
2. How do internal and external forcing impact AMV?
3. What is the relative contribution of internal and external forcing?

Typical AMV: SST averaged over North Atlantic (0°N–60°N, 80°W–0°W) with 10-year running mean
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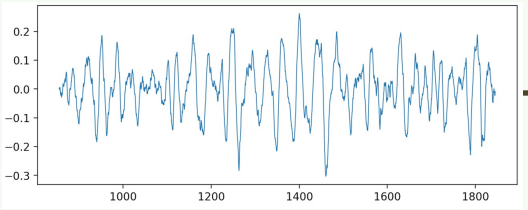
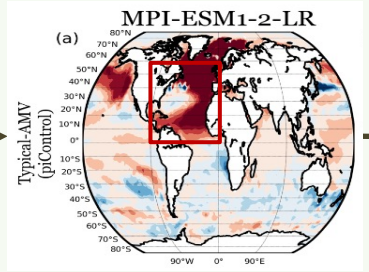
Extracting Internal AMV in past1000 Using piControl AMV pattern

Typical AMV Index
in piControl run
(SST averaged over North Atlantic
Ocean with 10 years running mean)



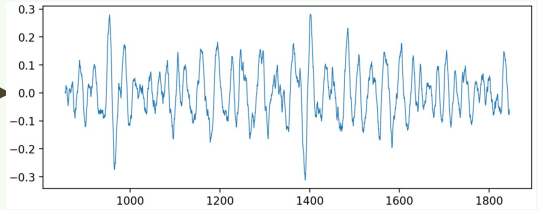
Regression
Onto North
Atlantic SST

Typical AMV pattern
of piControl run



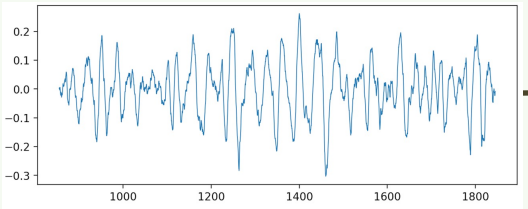
Regression
Onto past1000
North Atlantic

Pattern AMV
index of past1000
(10years running mean)



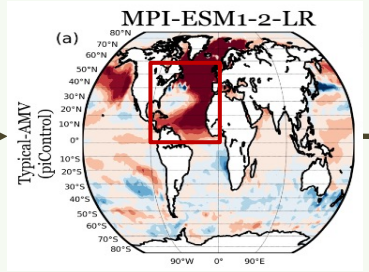
Extracting Internal AMV in past1000 Using piControl AMV pattern

Typical AMV Index
in piControl run
(SST averaged over North Atlantic
Ocean with 10 years running mean)



Regression
Onto North
Atlantic SST

Typical AMV pattern
of piControl run



Regression
Onto past1000
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Pattern AMV
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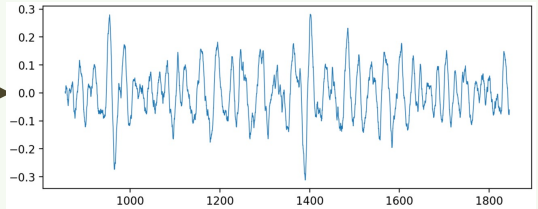
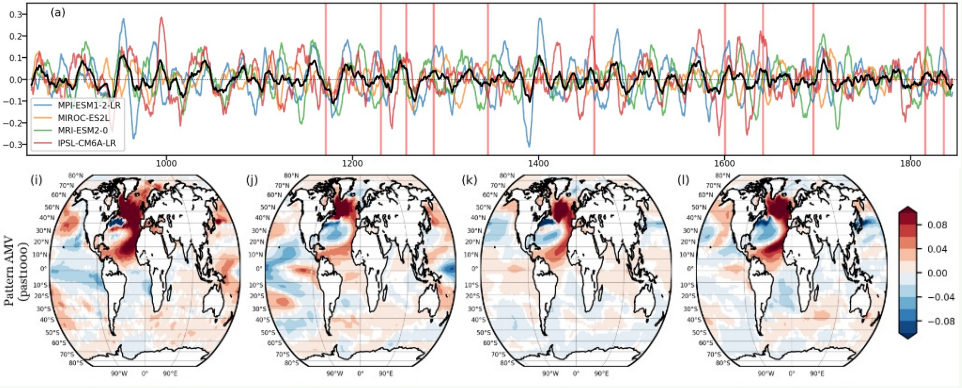


Pattern AMV: Using spatial signature to estimate internal forced AMV.
Other methods: Using temporal signature to estimate external forced AMV.

The Pattern AMV index has limited susceptibility from the external forcing.
The AMV residual index contains the oscillatory responses to volcanic forcing.

Pattern AMV, past1000



(Typical AMV – Pattern AMV) Residual AMV, past1000

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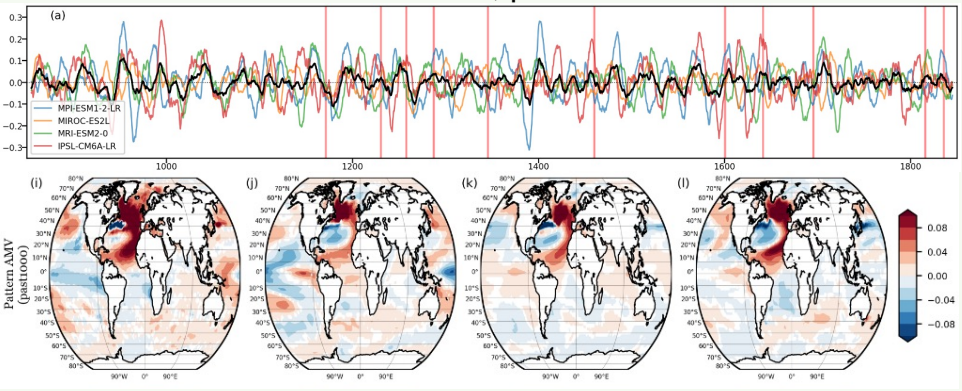
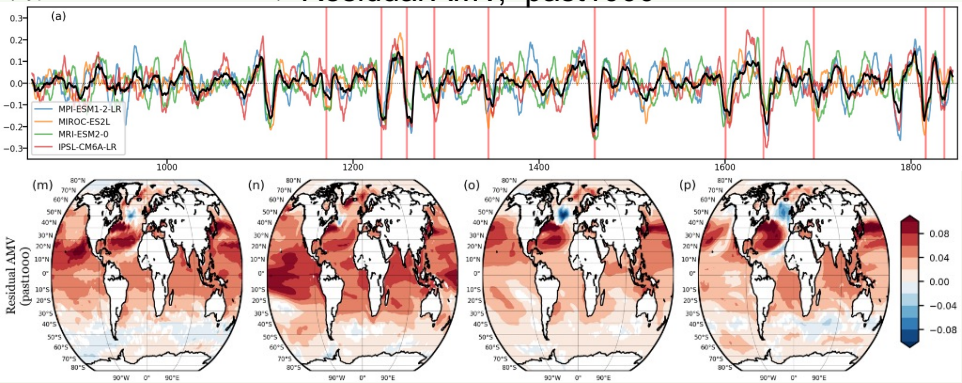
Pattern AMV, past1000



(Typical AMV – Pattern AMV) Residual AMV, past1000



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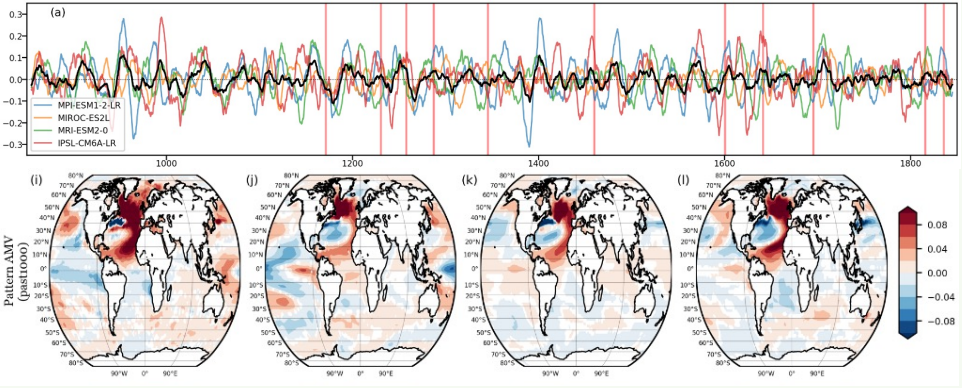
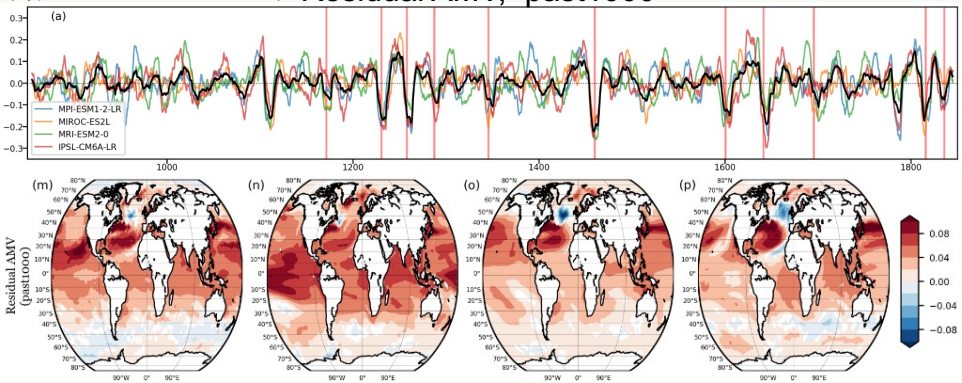
Pattern AMV, past1000

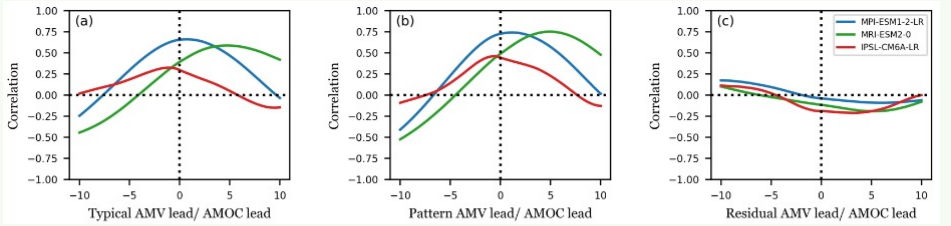


(Typical AMV – Pattern AMV) Residual AMV, past1000

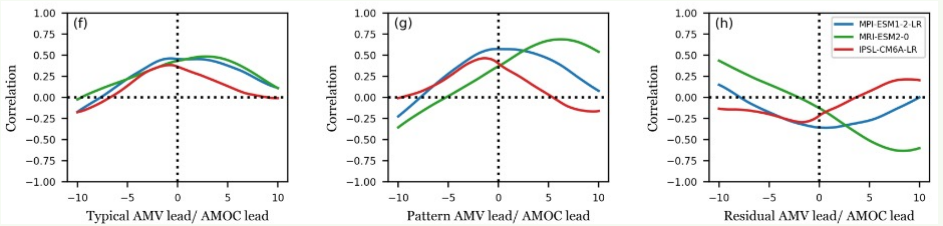


Cross Correlations between AMVs and AMOC

piControl

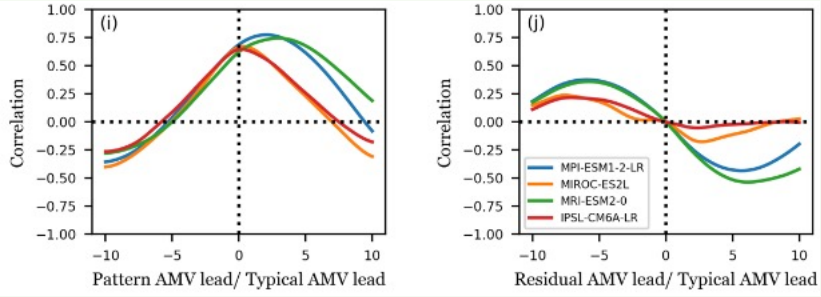


past1000

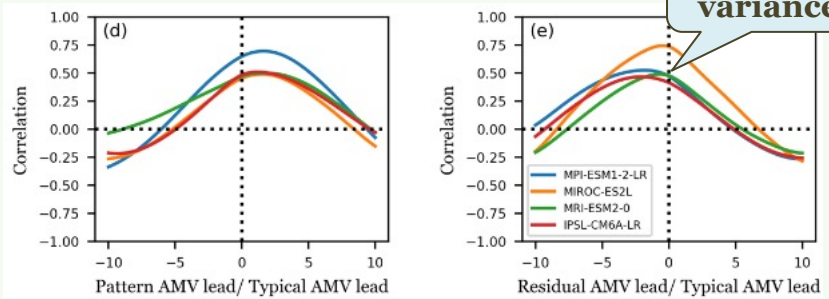


Relative Contribution from Internal and External Forcing

piControl



past1000



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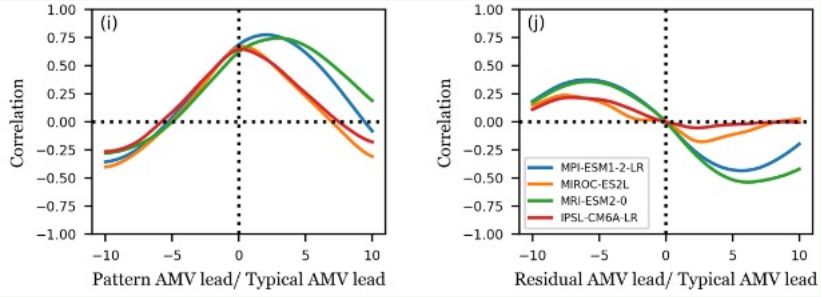
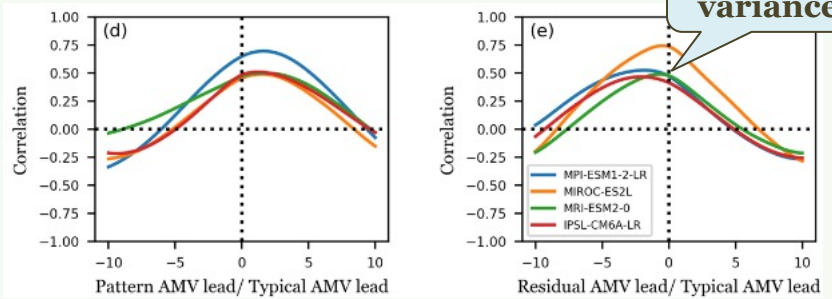


past1000



~25% variance

1. The internal and external contributions to AMV over the past millennium can be separated by a pattern-based calculation of AMV.
2. The internal/pattern AMV has a robust tripole pattern and dominates the relationship with meridional overturning circulation.
3. The external/residual AMV responds to post-eruption global cooling with an oscillatory behavior and account for ~25% of variance in the past millennium.

Thank you.

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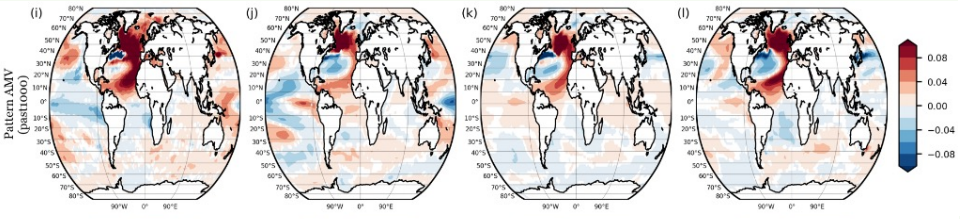
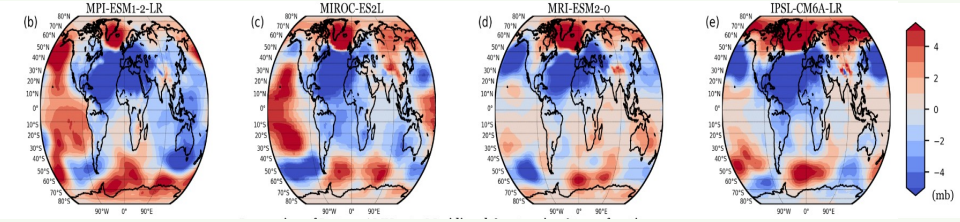
Pattern AMV (Internal Component of AMV)

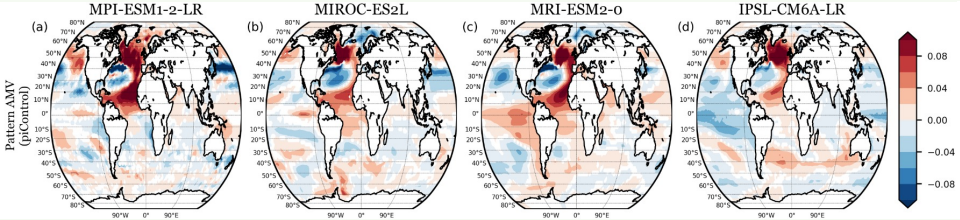
SST regression pattern in past1000



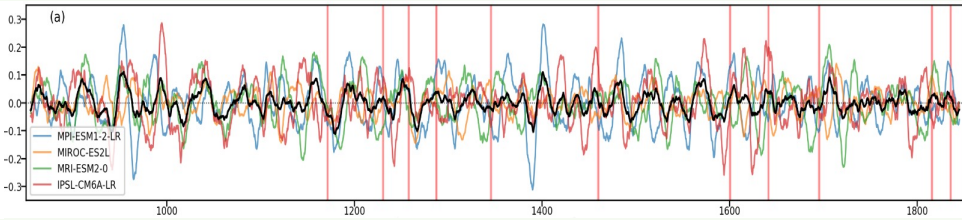
SLP regression pattern in past1000



SST regression pattern in piControl



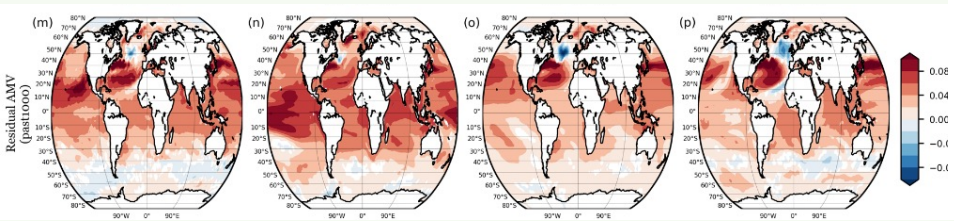
Pattern AMV time series in past1000



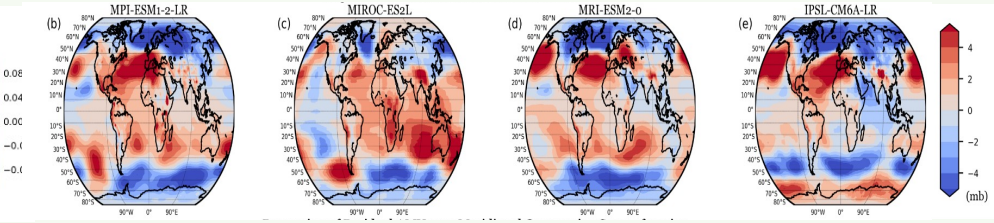
AMV Residual (External Component of AMV)

(Typical AMV – Pattern AMV)

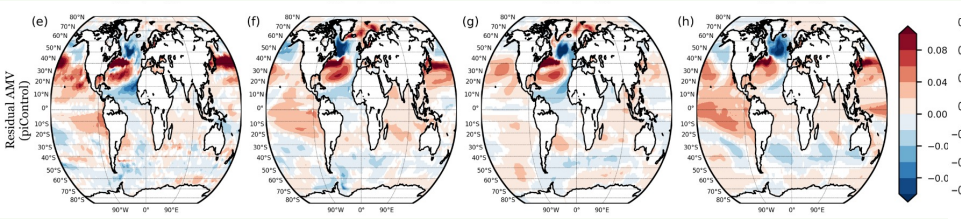
SST regression pattern in past1000



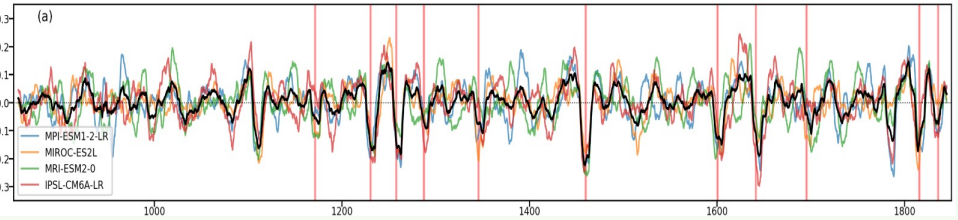
SLP regression pattern in past1000



SST regression pattern in piControl



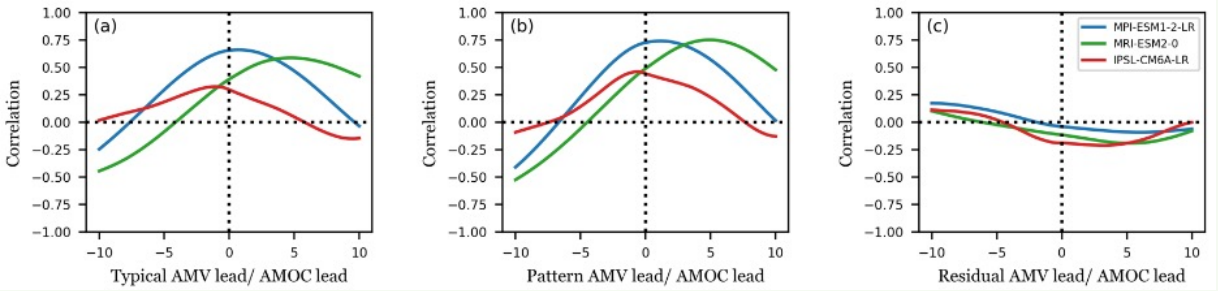
AMV Residual time series in past1000



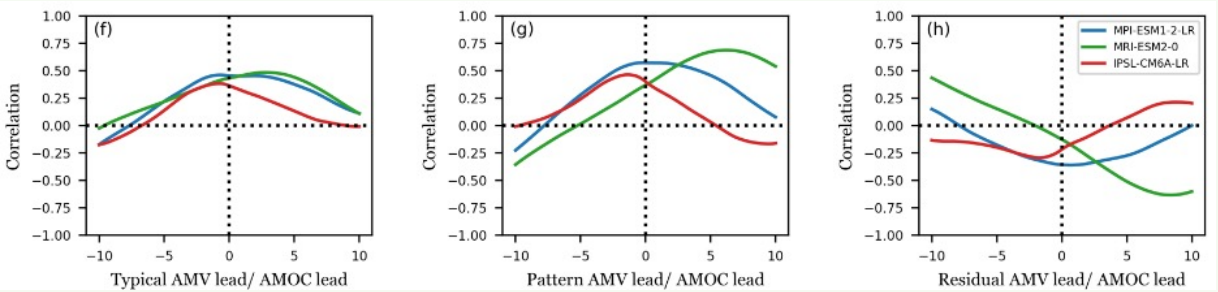
The Pattern AMV index has limited susceptibility from the external forcing.
The AMV residual index contains the responses to volcanic forcing.

Pattern (Internal) AMV dominates the relation with AMOC

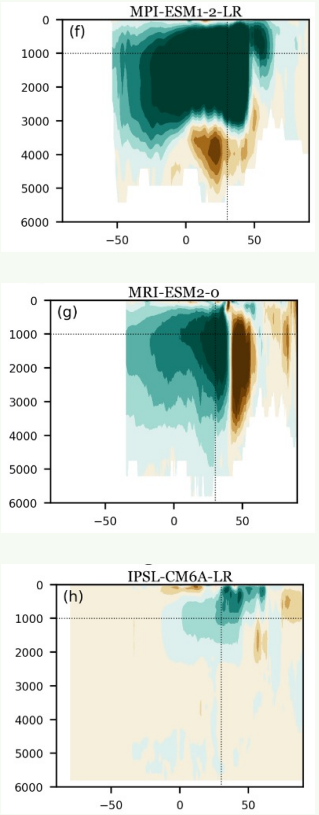
piControl



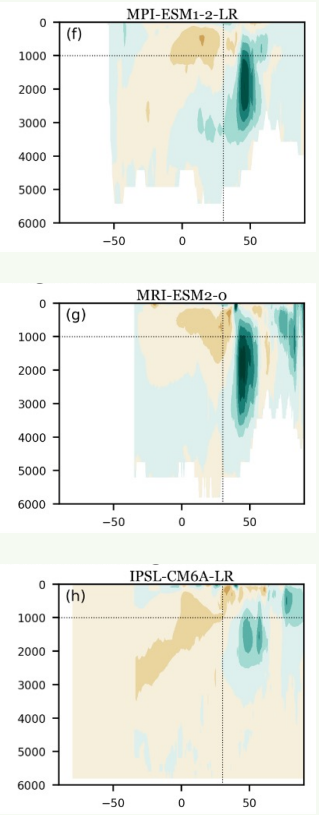
past1000



Pattern AMV (past1000)



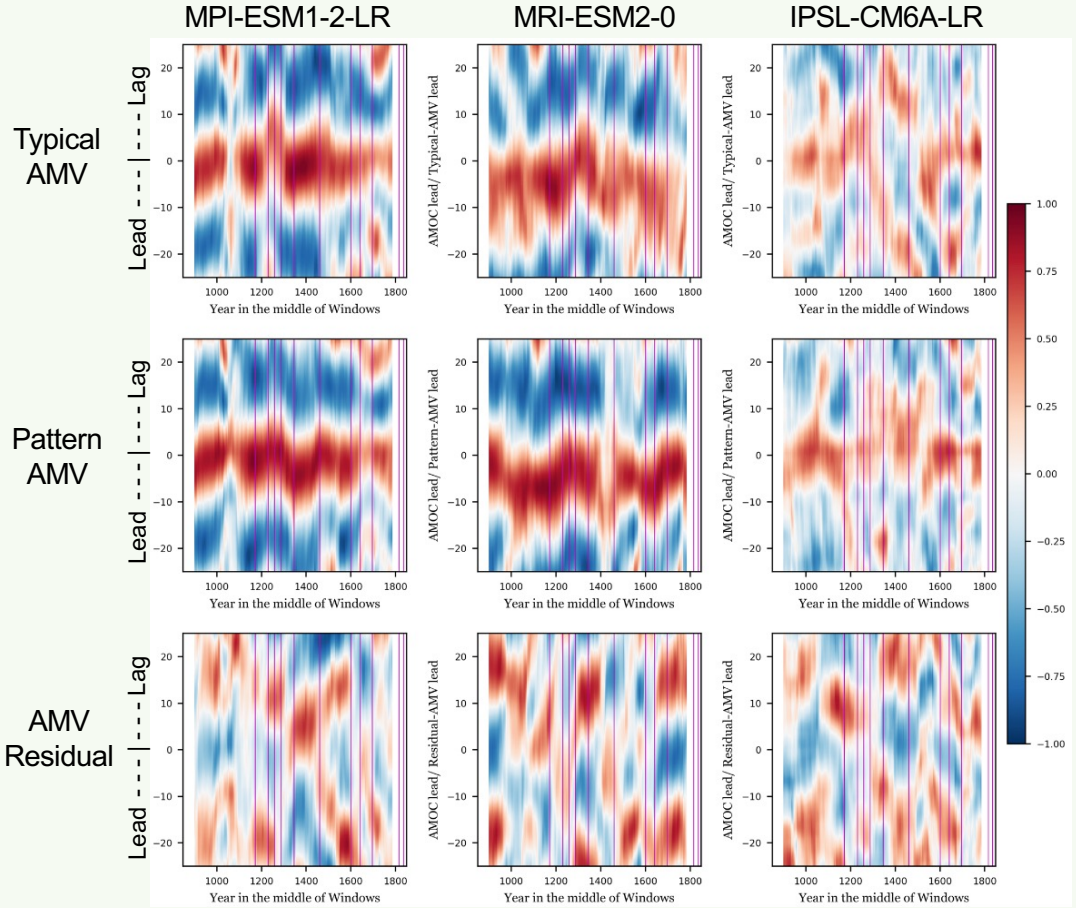
AMV Residual (past1000)



AMOC: Maximum meridional overturning streamfunction at 30°N below 1000m.

Each eruption may have a distinct impact on AMOC

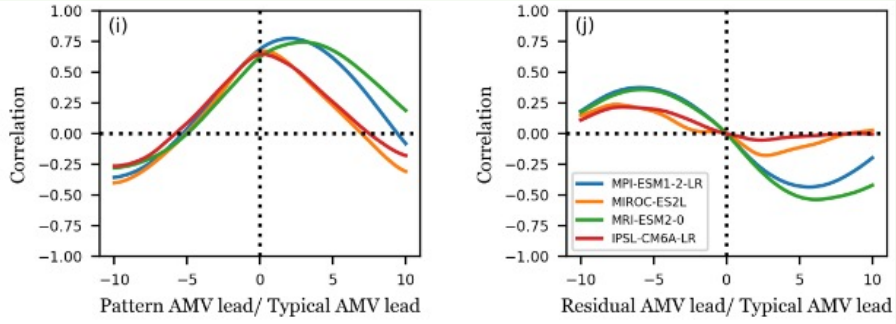
(Mignot et al., 2011)



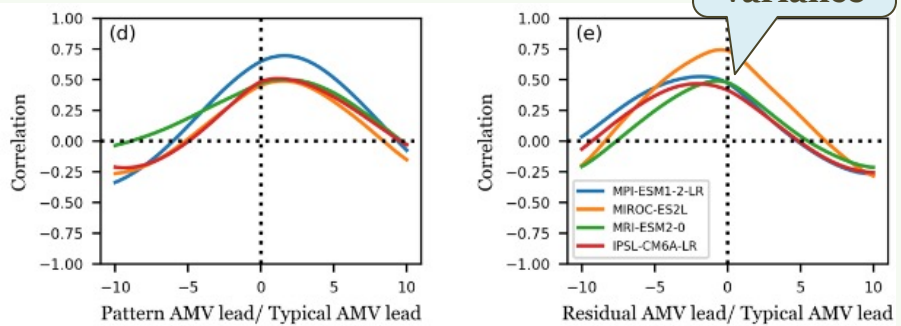
Running cross correlations with 100-year window

Relative Contribution from Internal and External Forcing

piControl



past1000



~25% variance

Summary

1. The internal and external contributions to AMV over the past millennium can be separated by a pattern-based calculation of AMV.

2. The internal/pattern AMV has a robust tripole pattern and dominates the relationship with meridional overturning circulation.

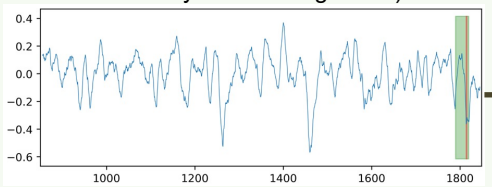
3. The external/residual AMV responds to post-eruption global cooling with an oscillatory behavior and account for ~25% of variance in the past millennium.

Discussion

1. The **natural** external forcing over past millennium may have less impacts on AMOC than the **anthropogenic** forcing in recent decades. (Caesar et al., 2018; Chemke et al., 2020)
2. How much the external-forced AMV can impact AMOC over the past millennium?
3. Mann et al. (2021) emphasizes the control of volcanic eruptions on the AMV spectrum. We found that this volcanic forced AMV may not involve the same dynamical relation with AMOC.

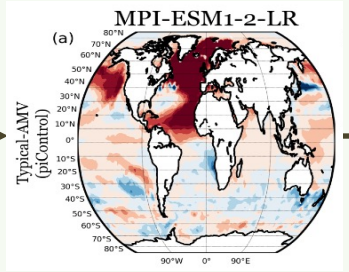
Procedure of Calculating Pattern AMV index

Typical AMV Index in piControl run
(SST averaged over North Atlantic Ocean with 10 years running mean)



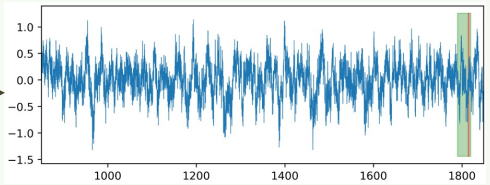
Regression Onto North Atlantic SST

Typical AMV pattern of piControl run



Regression Onto past1000 North Atlantic

Pattern AMV index of past1000
(10years running mean)



For t in each month in past1000:

$$SSTA_{t,NAlantic} = Slope_t * AMVPattern_{NAtlantic} + Intercept_t * I_{NAtlantic} + Noise_{t,Natlantic}$$

$$SSTA_{past1000,NAlantic} = Slopes * AMVPattern_{NAtlantic} + Intercepts * INAtlantic + Noise_{NAtlantic}$$

Typical-AMV := Spatial Average($SSTA_{past1000,NAlantic}$)

Pattern-AMV := Spatial Average($Slopes * AMVPattern_{NAtlantic}$)

Residual-AMV := Spatial Average($Intercepts * I_{NAtlantic} + Noise_{t,NAtlantic}$)

Figure 1

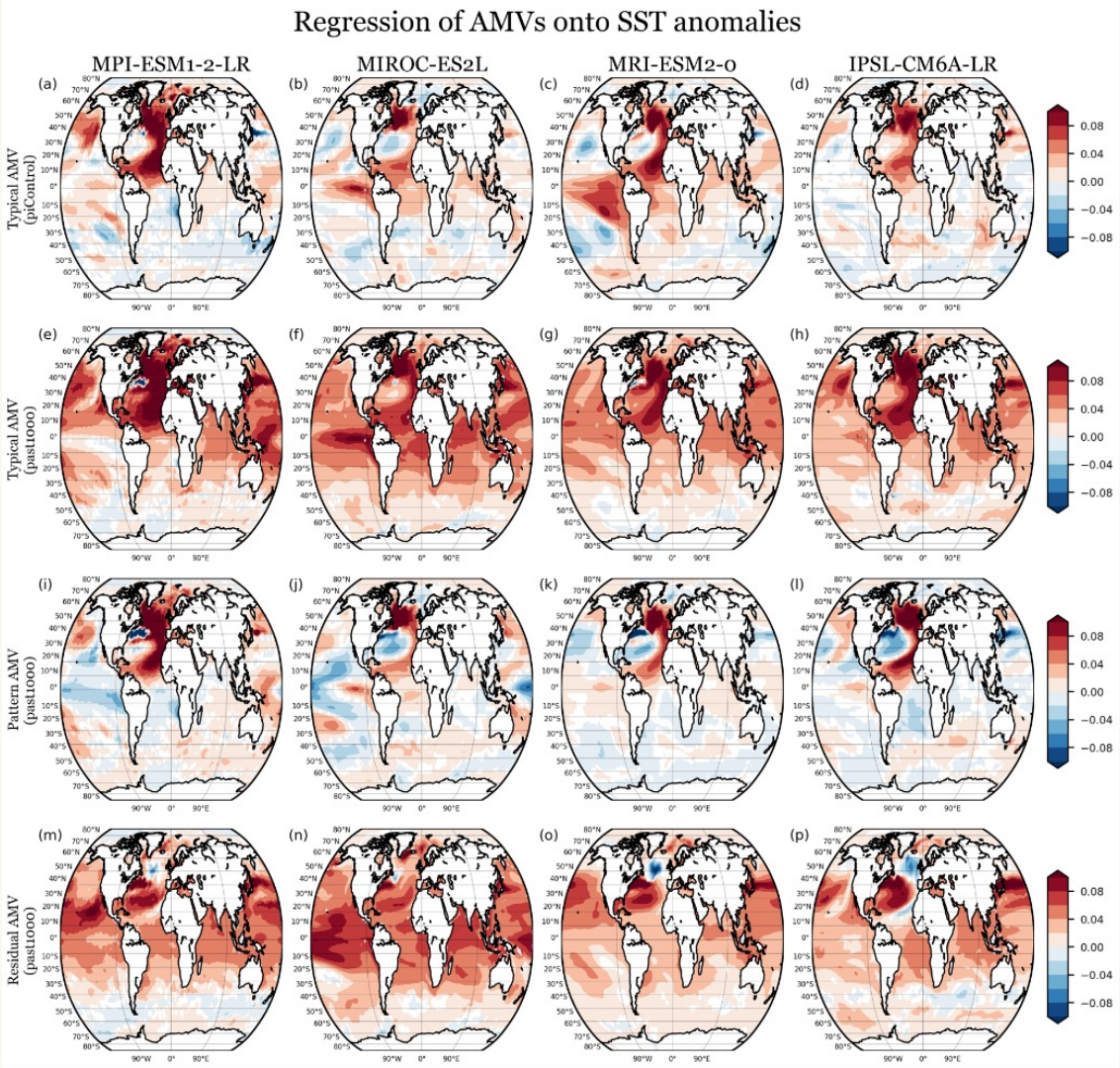

Regression of AMVs onto SST anomalies
MPI-ESM1-2-LR
MIROC-ES2L
MRI-ESM2-0
IPSL-CM6A-LR
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)
(k)
(l)
(m)
(n)
(o)
(p)
Typical AMV (piControl)
Typical AMV (past1000)
Pattern AMV (past1000)
Residual AMV (past1000)
0.08
0.04
0.00
−0.04
−0.08

Figure 2

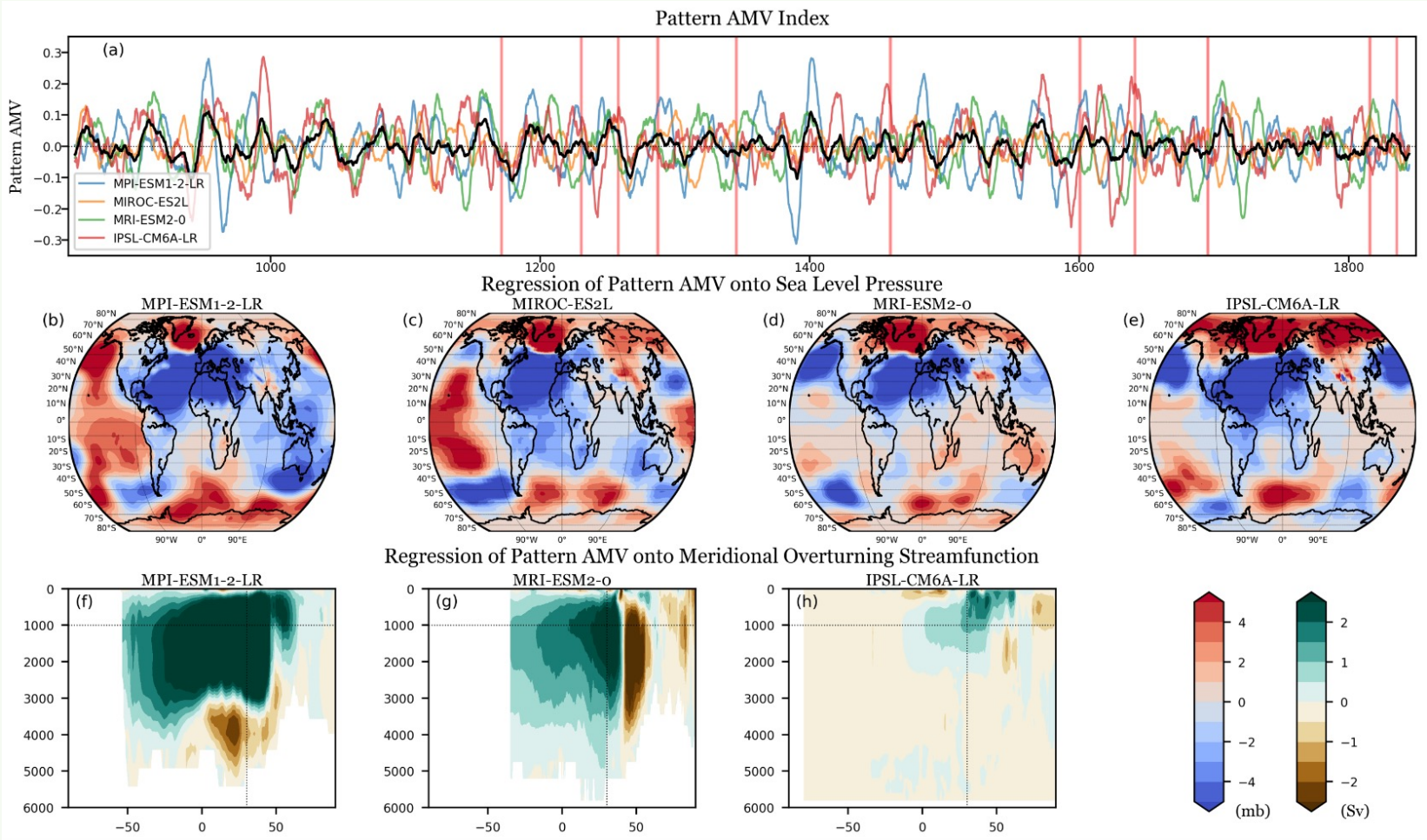

Pattern AMV Index
(a)
Pattern AMV
MPI-ESM1-2-LR
MIROC-ES2L
MRI-ESM2-0
IPSL-CM6A-LR
Regression of Pattern AMV onto Sea Level Pressure
(b) MPI-ESM1-2-LR
(c) MIROC-ES2L
(d) MRI-ESM2-0
(e) IPSL-CM6A-LR
Regression of Pattern AMV onto Meridional Overturning Streamfunction
(f) MPI-ESM1-2-LR
(g) MRI-ESM2-0
(h) IPSL-CM6A-LR
(mb)
(Sv)

Figure 3

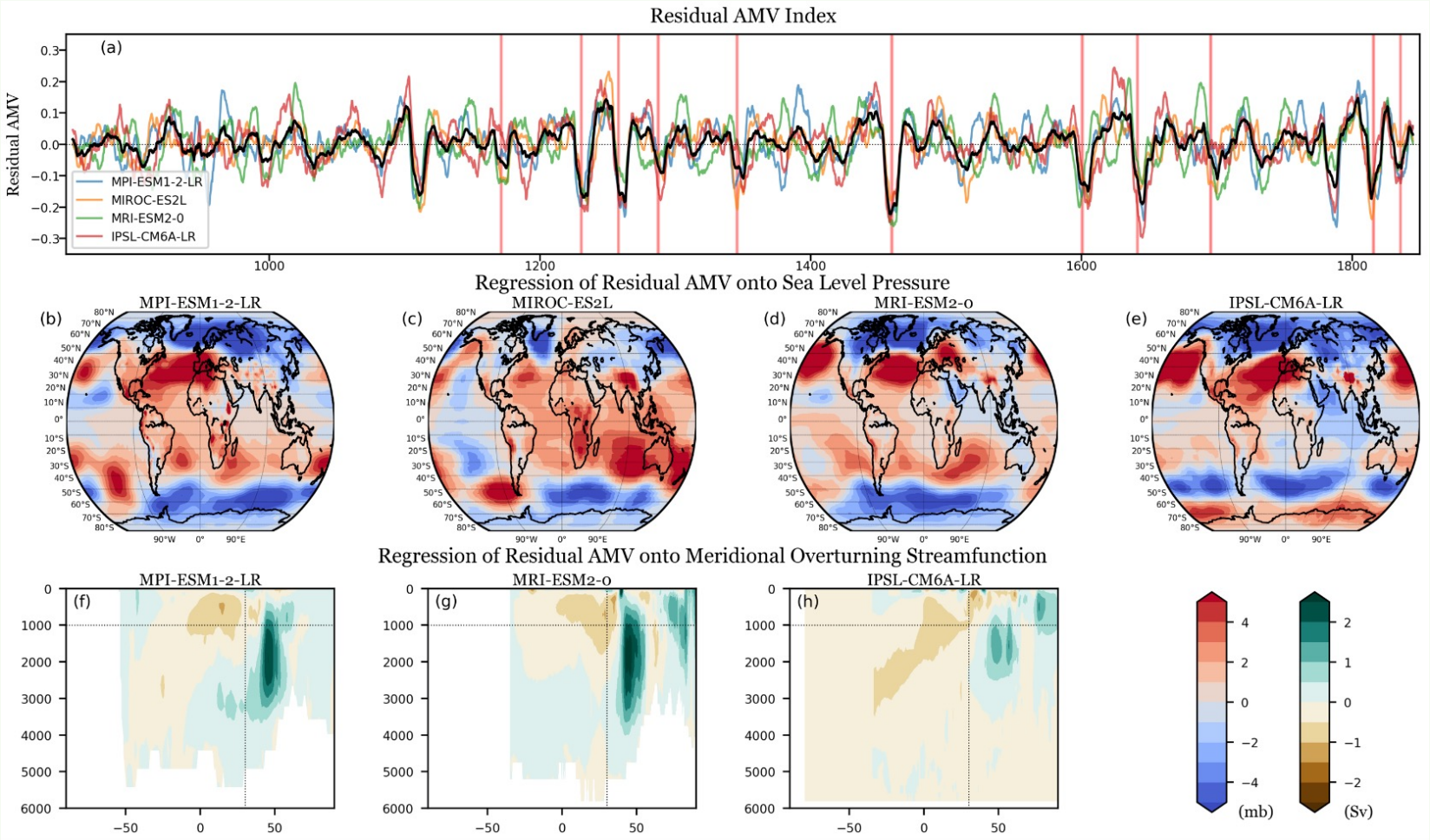

Residual AMV Index
(a)
Residual AMV
MPI-ESM1-2-LR
MIROC-ES2L
MRI-ESM2-0
IPSL-CM6A-LR
Regression of Residual AMV onto Sea Level Pressure
(b) MPI-ESM1-2-LR
(c) MIROC-ES2L
(d) MRI-ESM2-0
(e) IPSL-CM6A-LR
Regression of Residual AMV onto Meridional Overturning Streamfunction
(f) MPI-ESM1-2-LR
(g) MRI-ESM2-0
(h) IPSL-CM6A-LR
(mb)
(Sv)

Figure 4

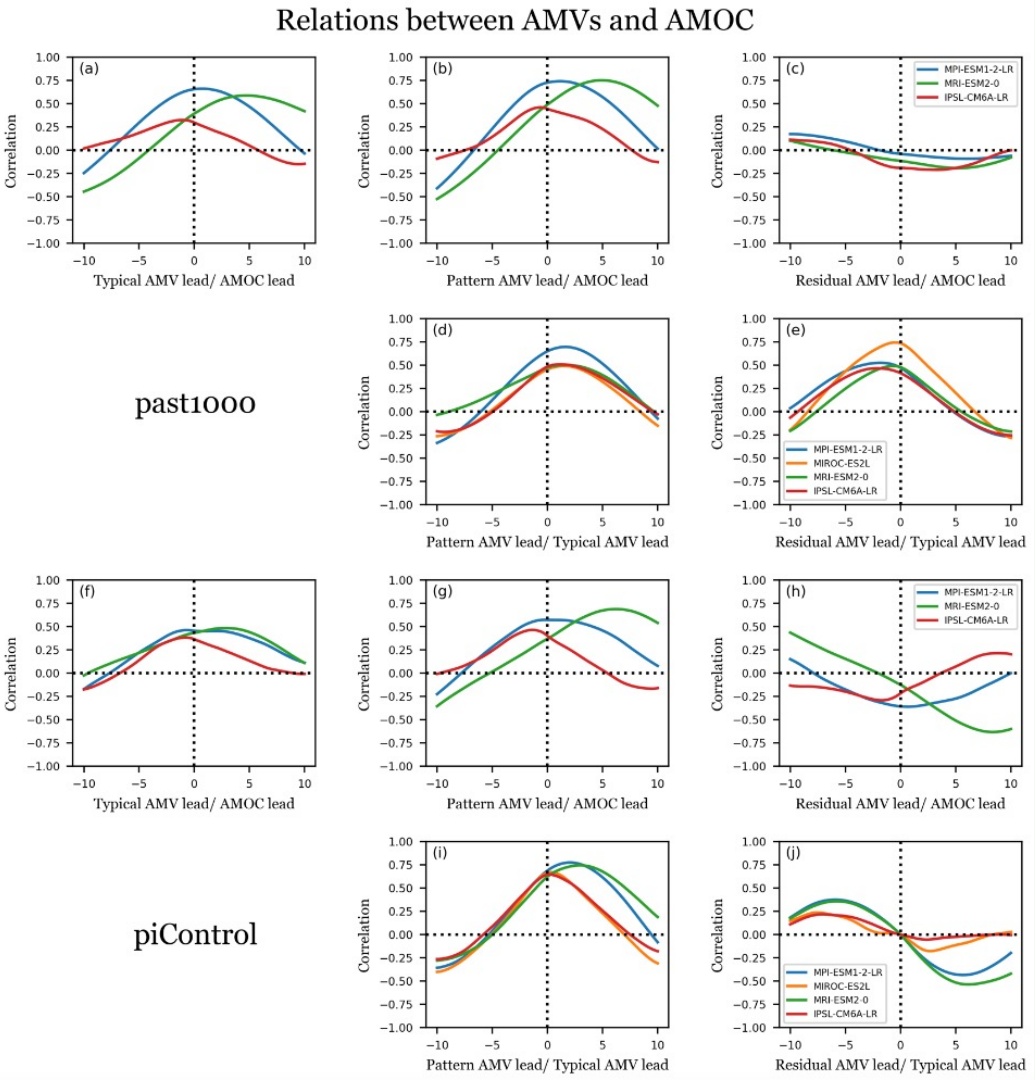

Relations between AMVs and AMOC
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)
Correlation
Typical AMV lead/ AMOC lead
Pattern AMV lead/ AMOC lead
Residual AMV lead/ AMOC lead
Pattern AMV lead/ Typical AMV lead
Residual AMV lead/ Typical AMV lead
past1000
piControl
MPI-ESM1-2-LR
MIROC-ES2L
MRI-ESM2-0
IPSL-CM6A-LR

Figure S1

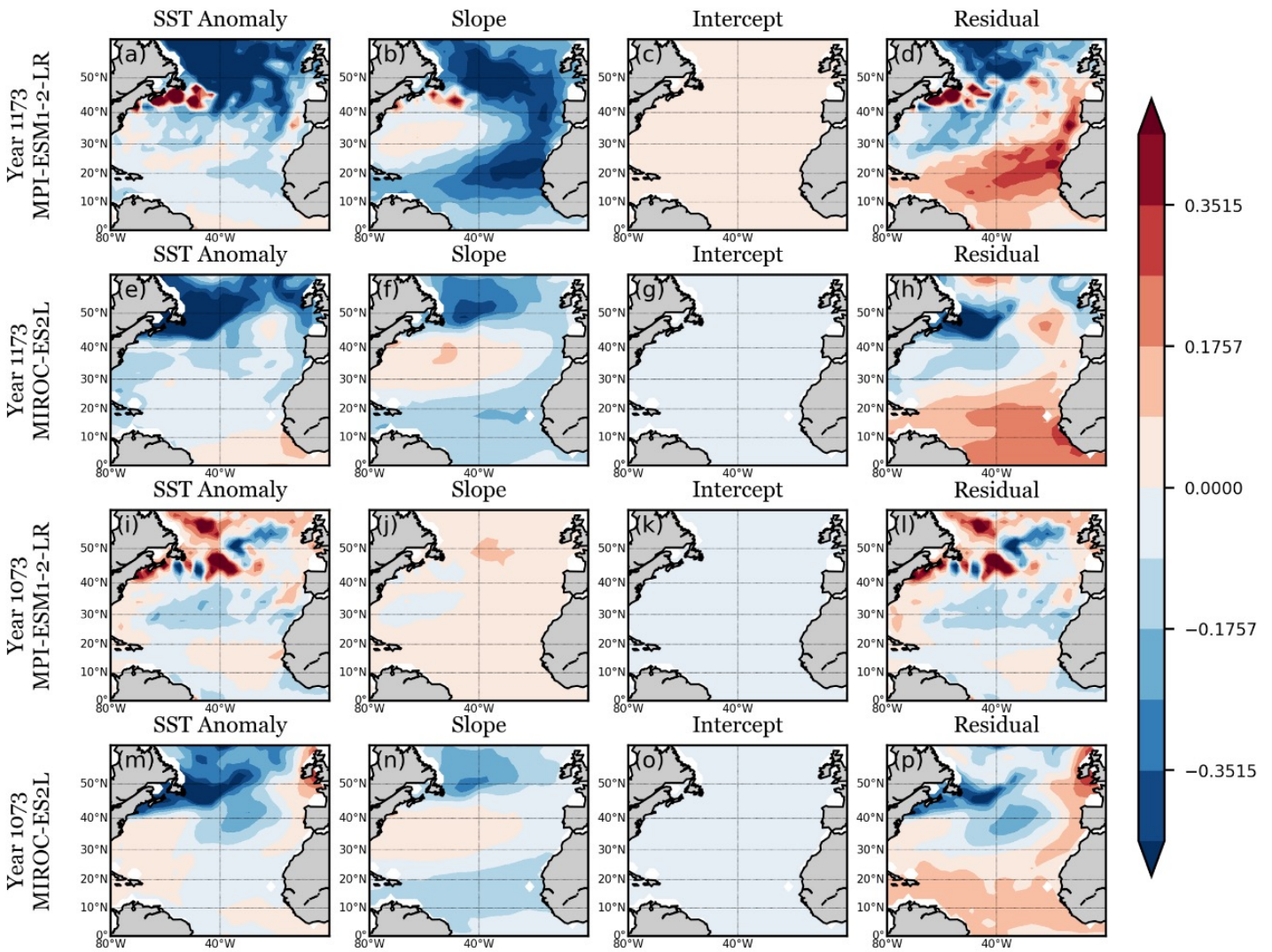

SST Anomaly
Slope
Intercept
Residual
Year 1173
MPI-ESM1-2-LR
Year 1173
MIROC-ES2L
Year 1073
MPI-ESM1-2-LR
Year 1073
MIROC-ES2L
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)
(k)
(l)
(m)
(n)
(o)
(p)
50°N
40°N
30°N
20°N
10°N
0°
80°W
40°W
0.3515
0.1757
0.0000
−0.1757
−0.3515

Figure S2

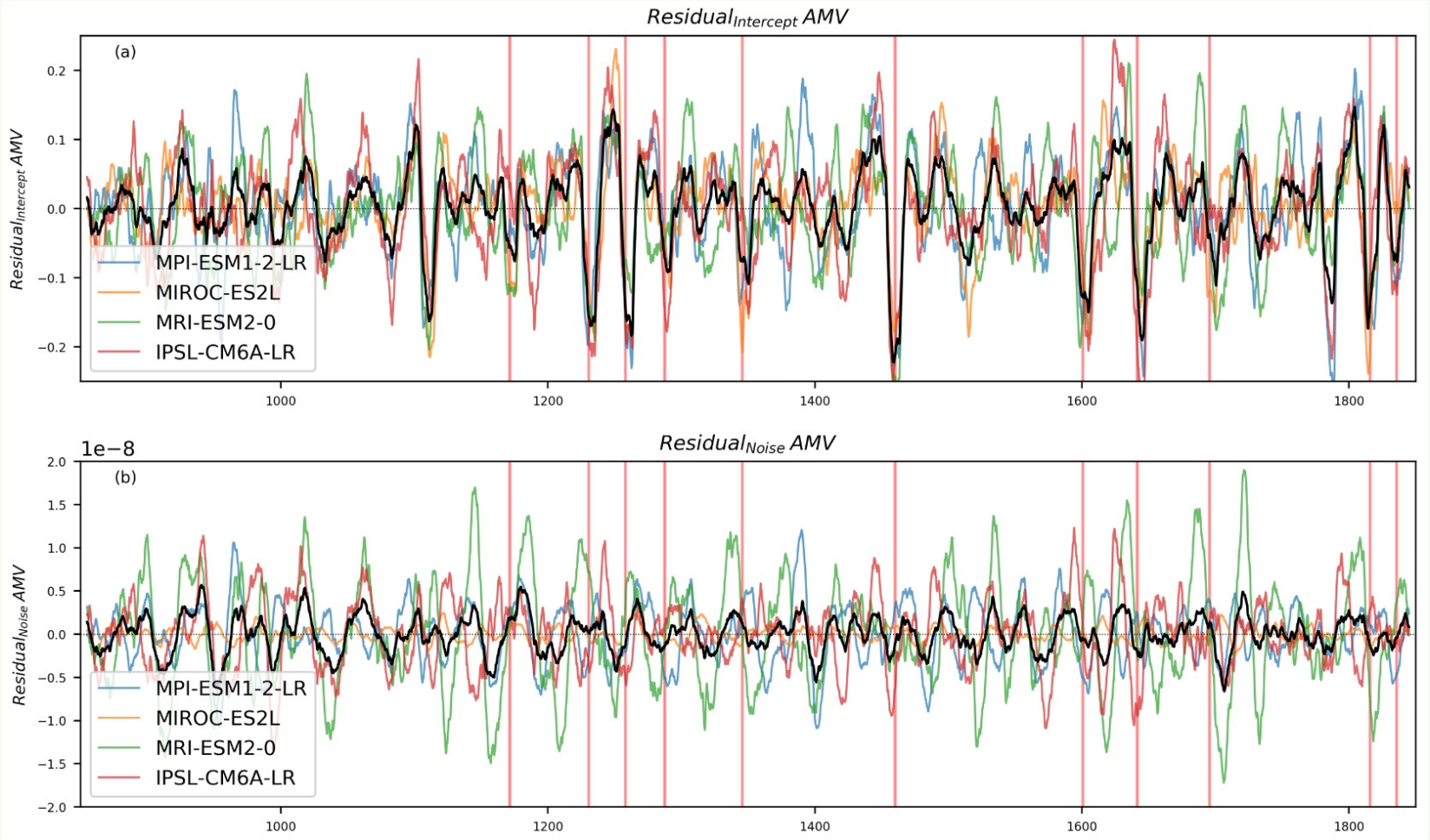

Residual$_{Intercept}$ AMV
(a)
Residual$_{Intercept}$ AMV
MPI-ESM1-2-LR
MIROC-ES2L
MRI-ESM2-0
IPSL-CM6A-LR
Residual$_{Noise}$ AMV
1e−8
(b)
Residual$_{Noise}$ AMV
MPI-ESM1-2-LR
MIROC-ES2L
MRI-ESM2-0
IPSL-CM6A-LR

Figure S3

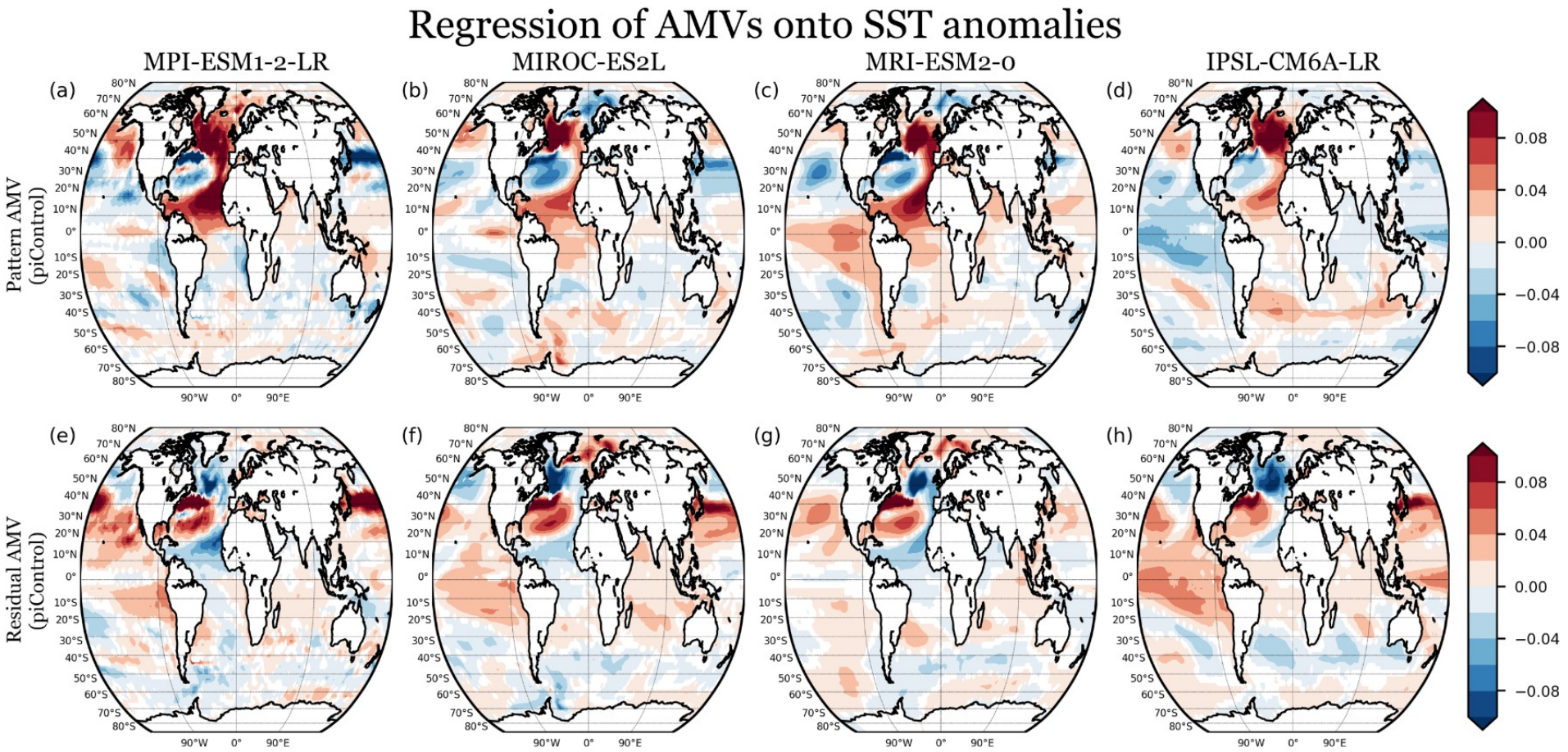

Regression of AMVs onto SST anomalies
MPI-ESM1-2-LR
MIROC-ES2L
MRI-ESM2-0
IPSL-CM6A-LR
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
Pattern AMV (piControl)
Residual AMV (piControl)
0.08
0.04
0.00
−0.04
−0.08

Figure S4

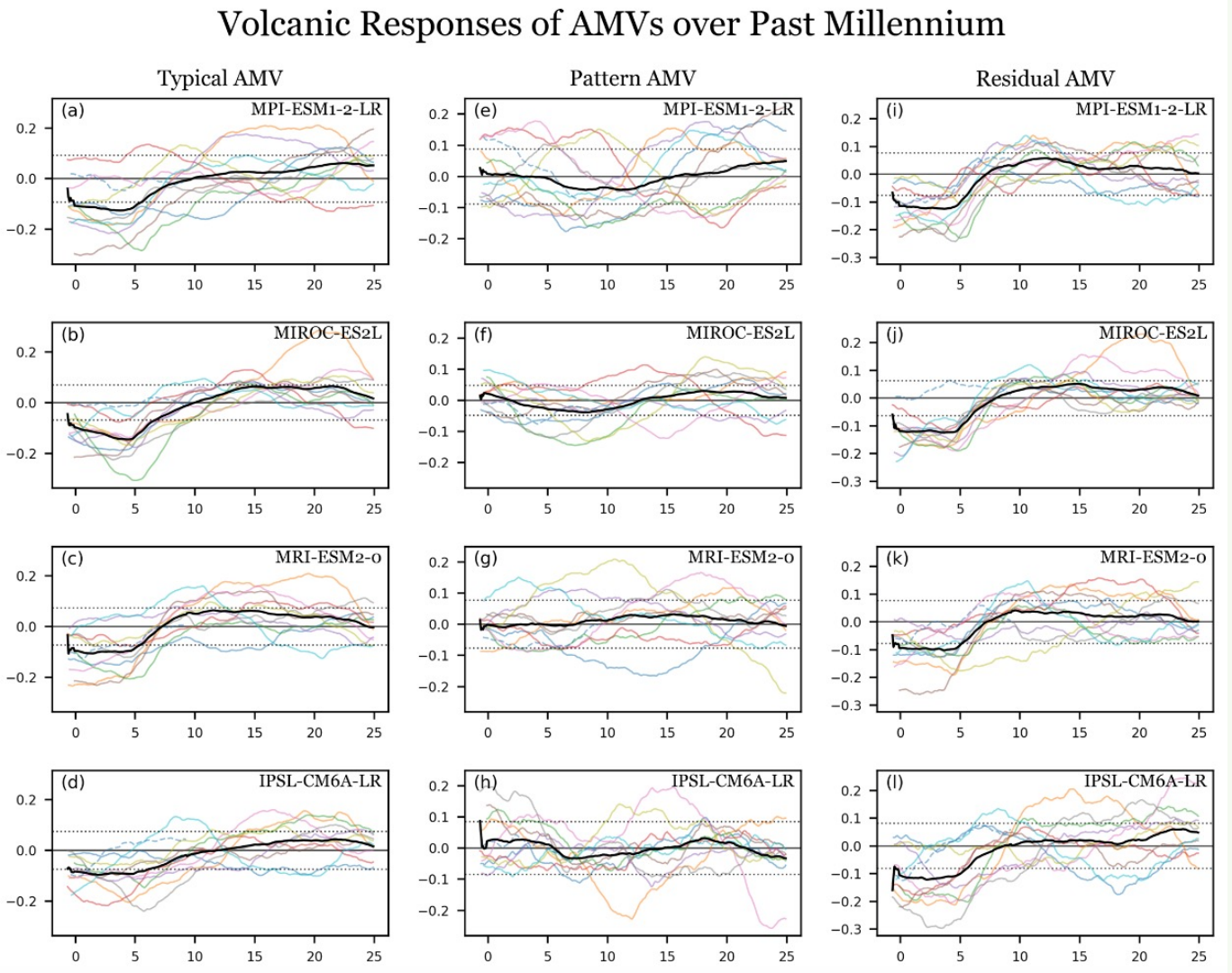

Volcanic Responses of AMVs over Past Millennium
Typical AMV
Pattern AMV
Residual AMV
(a) MPI-ESM1-2-LR
(e) MPI-ESM1-2-LR
(i) MPI-ESM1-2-LR
(b) MIROC-ES2L
(f) MIROC-ES2L
(j) MIROC-ES2L
(c) MRI-ESM2-0
(g) MRI-ESM2-0
(k) MRI-ESM2-0
(d) IPSL-CM6A-LR
(h) IPSL-CM6A-LR
(l) IPSL-CM6A-LR

Figure S5

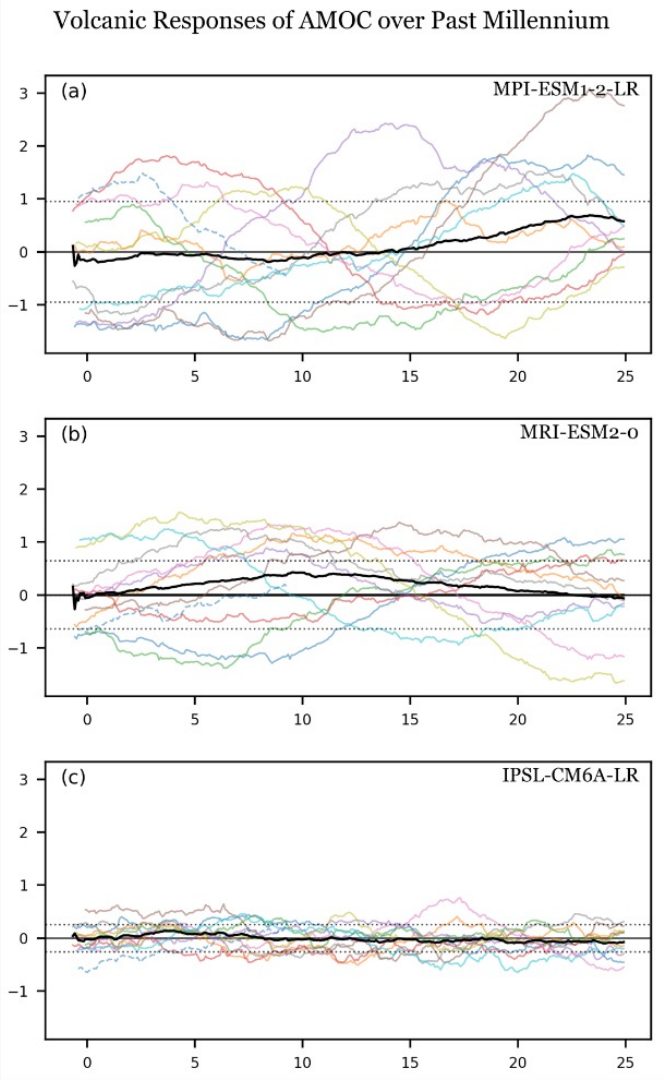

Volcanic Responses of AMOC over Past Millennium
(a)
MPI-ESM1-2-LR
(b)
MRI-ESM2-0
(c)
IPSL-CM6A-LR
3
2
1
0
−1
0
5
10
15
20
25

Figure S6

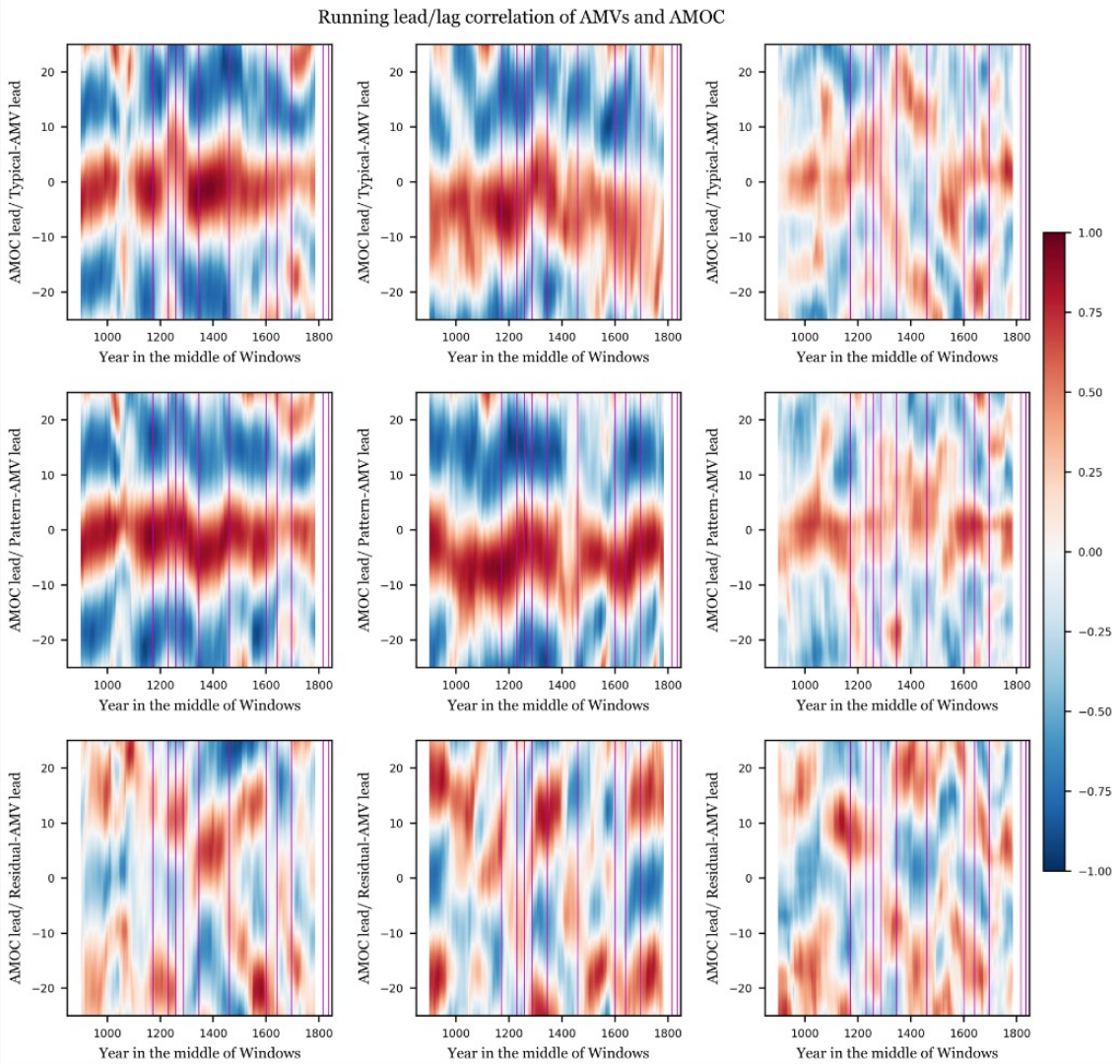

Running lead/lag correlation of AMVs and AMOC
AMOC lead/ Typical-AMV lead
AMOC lead/ Pattern-AMV lead
AMOC lead/ Residual-AMV lead
Year in the middle of Windows
20
10
0
−10
−20
1000
1200
1400
1600
1800
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00

Table S1

Models	MPI-ESM1-2-LR	MIROC-ES2L	MRI-ESM2-0	IPSL-CM6A-LR
Reference	Wieners et al. 2019 Mauritsen et al. 2019	Ohgaito et al. 2021 Hajima et al. 2021	Yukimoto et al. 2019 Yukimoto et al. 2020	Boucher et al. 2018 Lurton et al. 2020
Aerosol	evolv2k	evolv2k	MASINGAR	evolv2k
Solar	SATIRE-M 14C	SATIRE-M 14C	SATIRE-M 14C?	SATIRE-M 14C
QBO	No	Yes	Yes	Yes
Res. Atm.	1.875 X1.875 (250 km)	Horizontal resolution of the atmosphere is set to T42 spectral truncation. Vertical resolution is 40 levels up to 3 hPa.	100 km	250 km
Res.Ocean	22 to 220 km	100 km	100 km	100 km

Table S2

Name	Geographical location	Year	Month	W/m² changes (MPI/MIROC/MRI/IPSL)
Unidentified	-	**1171**	**February**	**12.45/ 12.55/ 10.06/ 6.65**
Unidentified	_	**1230**	**February**	**15.00/ 15.17/ 12.40/ 7.65**
Rinjani (Samalas)	8°S, 116°E |	**1257**	**August**	**24.86/ 14.91/ 22.78/ 14.15**
Unidentified		**1287**	**January**	**9.39/ 7.28/ 6.14/ 6.52**
Unidentified		**1345**	**March**	**12.16/ 10.20/ 14.79/ 7.16**
Unidentified		**1459**	**August**	**8.63/ 6.47/ 7.04/ 5.60**
Huaynaputina	16°S, 70°W	**1600**	**March**	**14.25/ 12.37/ 8.85/ 7.34**
Parker	6°N, 124°E |	**1641**	**January**	**13.45/ 11.38/ 7.19/ 7.28**
Unidentified		**1695**	**March**	**15.42/ 8.97/ 13.10/ 8.74**
Tambora	8°S, 118°E	**1815**	**May**	**16.04/ 13.37/ 10.56/ 11.01**
Cosigüina	12°N, 87°W	**1835**	**April**	**10.11/ 6.94/ 6.61/ 7.98**