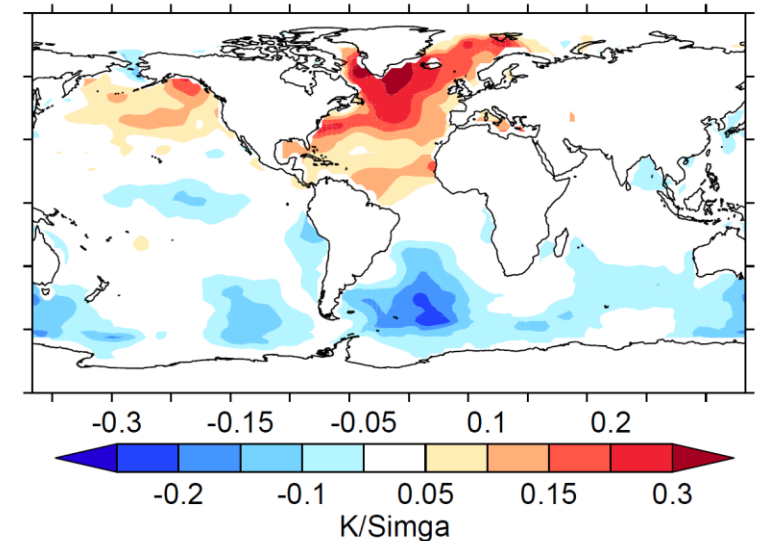# Contrasting the internal and external components of Atlantic Multidecadal Variability in CMIP6 historical simulations

Jon Robson, Rowan Sutton, Matt Menary, Michael Lai
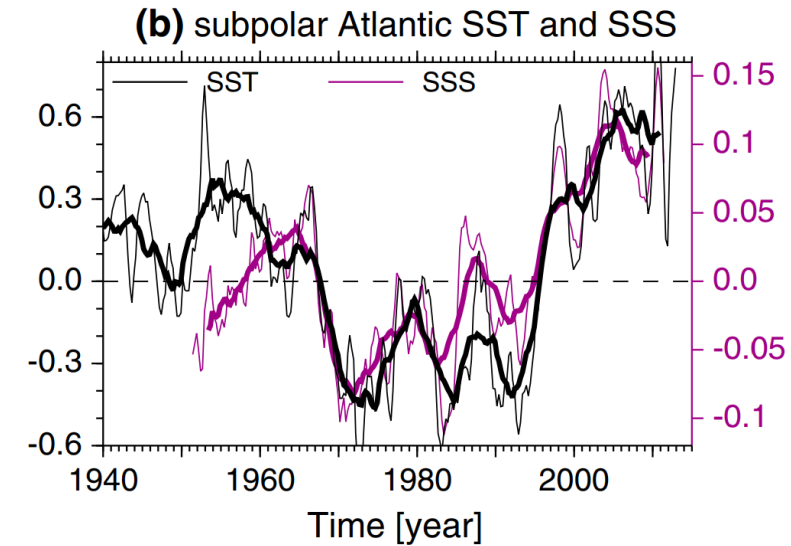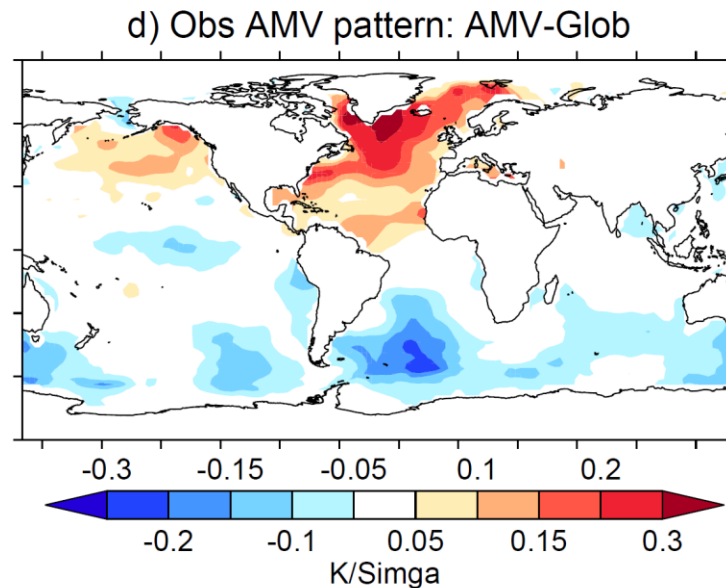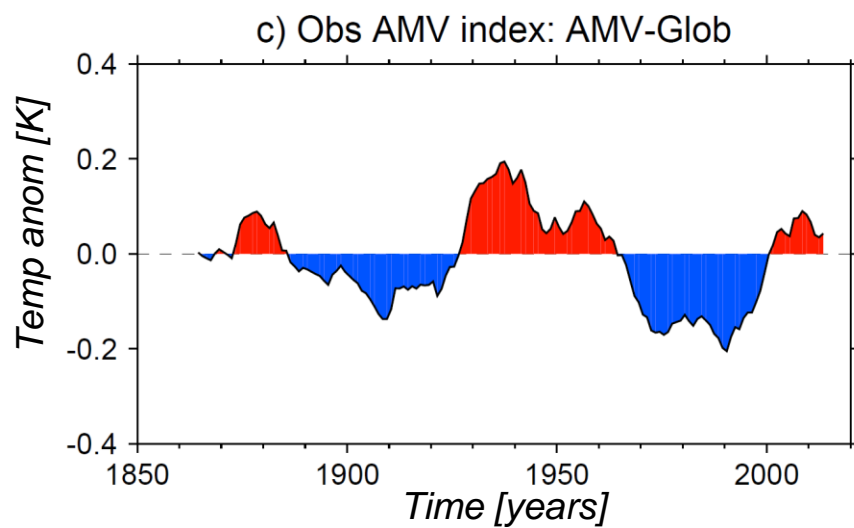
j.i.robson@reading.ac.uk

https://research.reading.ac.uk/meteorology/people/jon-robson/

d) Obs AMV pattern: AMV-Glob

Atlantic Multi-decadal Variability (AMV)

c) Obs AMV index: AMV-Glob

d) Obs AMV pattern: AMV-Glob

(b) subpolar Atlantic SST and SSS
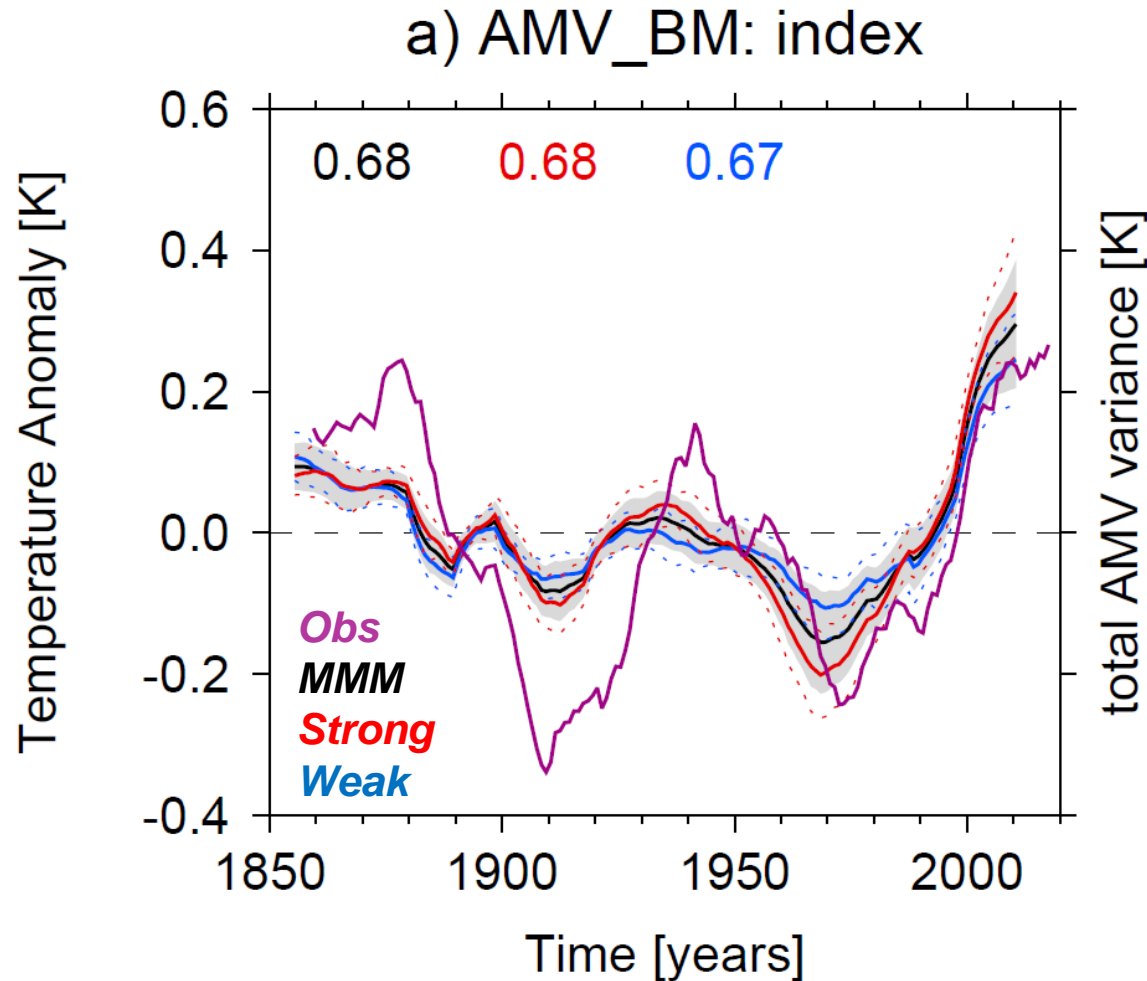
Robson et al., 2014

- **North Atlantic temperatures have varied significantly over the past 150 years**
  - Significant changes in other variables that vary in phase with AMV (e.g., Salinity, heat fluxes etc)
- **There is substantial uncertainty about the ultimate drivers of AMV**
  - Is AMV an expression of internally generated variability or, is it an expression of external forcings?
  - Is there a role for the ocean circulation, at all?

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

Focus of this study

- **Systematically explore the simulation of AMV in CMIP6 historical simulations**
  - Focus on **multi-model mean of 17 models**, and also on models which have a **strong** or **weak** sensitivity to Anthropogenic Aerosols *(c.f. Robson et al., 2022)*
  - Compare to **Observed AMV** computed from ERSSTv5

- **Explore the sensitivity of results to the choice of AMV index used**
  - **AMV_BM:** Linearly detrended basin-mean SST
  - **AMV-Glob:** Remove globally coherent signals through regression before making basin-mean SST

- **Decompose total AMV variability into the externally-forced and internally generated (e.g., residual) component**
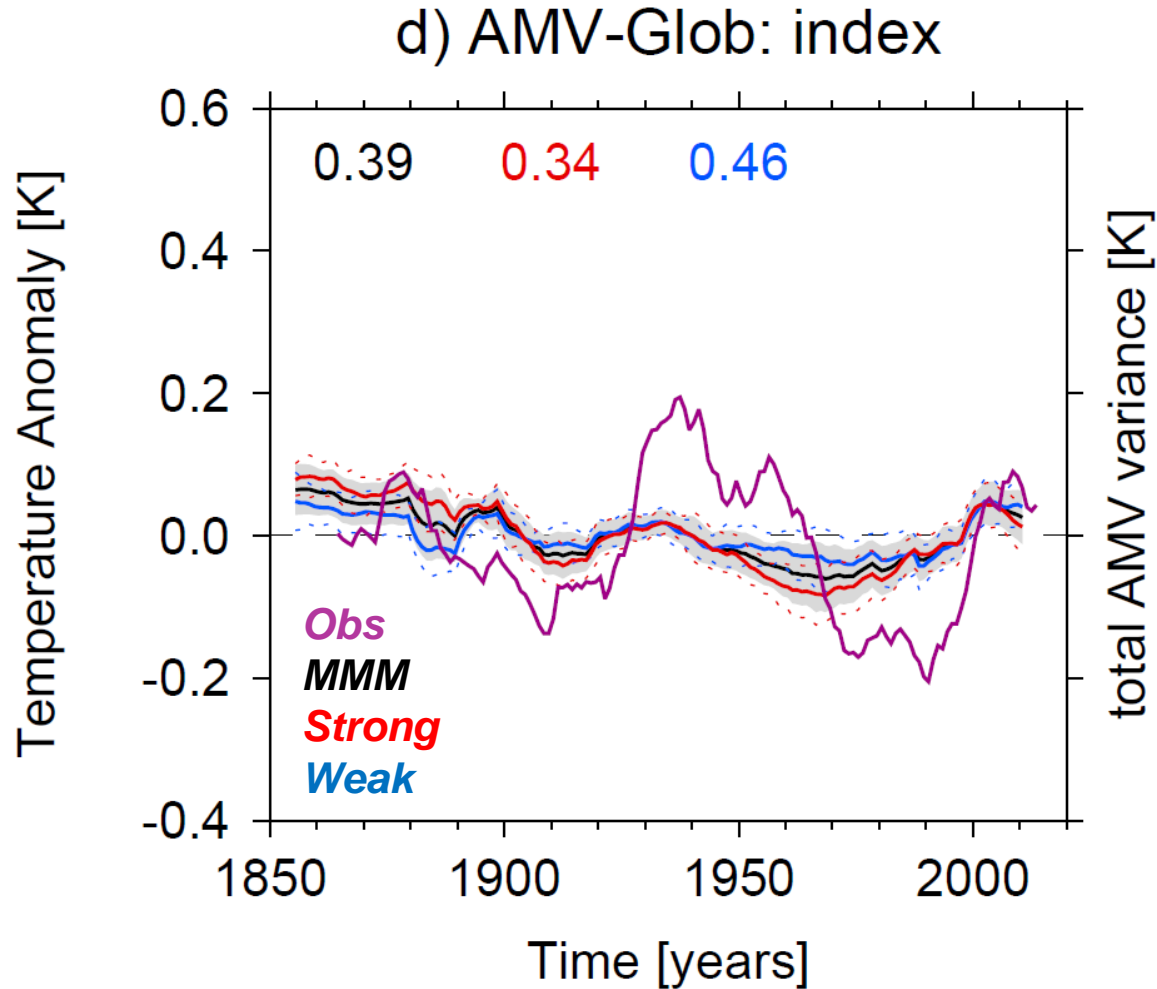 - Total AMV = iAMV + fAMV

National Centre for Atmospheric Science

NATURAL ENVIRONMENT RESEARCH COUNCIL

Impact of AMV index on statistics of externally-forced AMV (fAMV)

a) AMV_BM: index

- **Using the linearly detrended basin-mean AMV-index (AMV_BM) implies a significant role of external forcings in driving AMV**
  - Largely accounts for magnitude of anomalies after 1960
  - Large increase in total variance compared to iAMV (2x for MMM)
  - Longer time-scale variability compared to iAMV

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

Impact of AMV index on statistics of externally-forced AMV (fAMV)


d) AMV-Glob: index

- **But, the importance of externally forced AMV is substantially smaller after removing globally-forced signals first**
  - Does not account for magnitude of anomalies after 1960
  - Increased variance much smaller (1.25x for MMM)
  - Length of variability not significantly affected

National Centre for Atmospheric Science

NATURAL ENVIRONMENT RESEARCH COUNCIL

fAMV is part of a broader externally-forced signal

b) SST iAMV_BM   c) SST fAMV_BM

Stippling shows 80% of models disagree on pattern

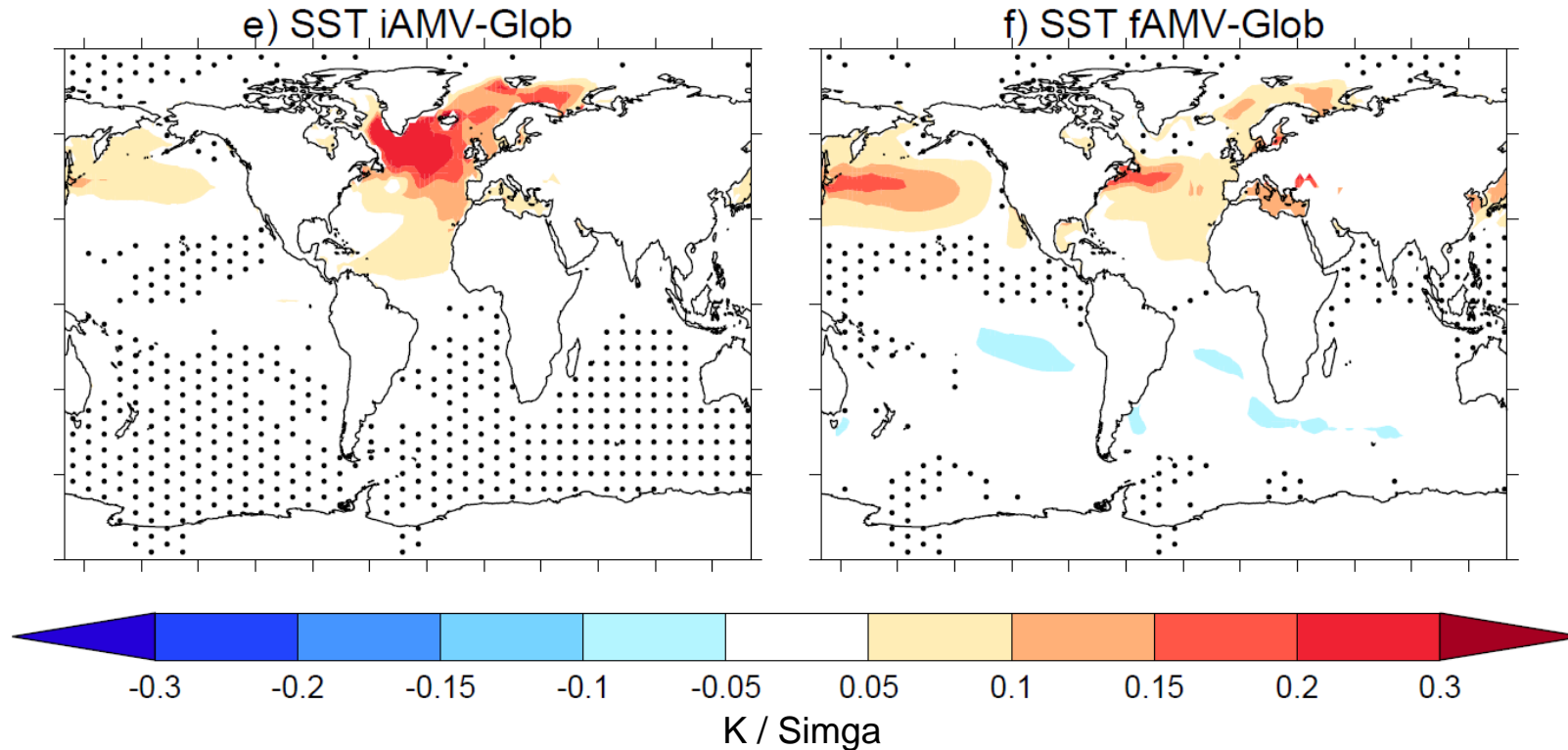-0.3   -0.2   -0.15   -0.1   -0.05   0.05   0.1   0.15   0.2   0.3

K / Simga
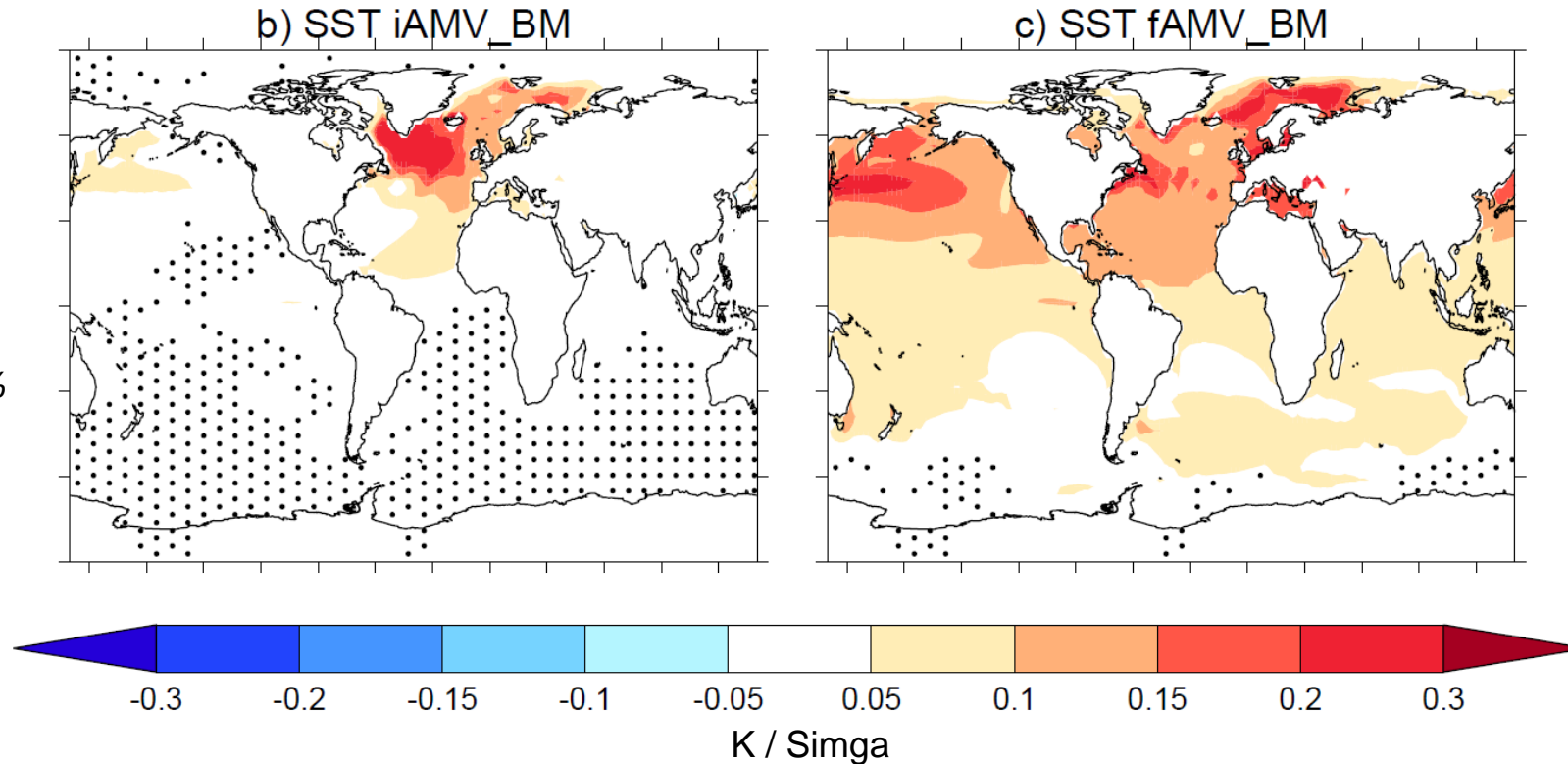
- **fAMV is part of a coherent northern hemisphere signal rather than the North Atlantic**, unlike internal AMV (or observations) – consistent with *Andrews et al, 2020 and Baek et al., 2022*

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

fAMV is part of a broader externally-forced signal

e) SST iAMV-Glob   f) SST fAMV-Glob

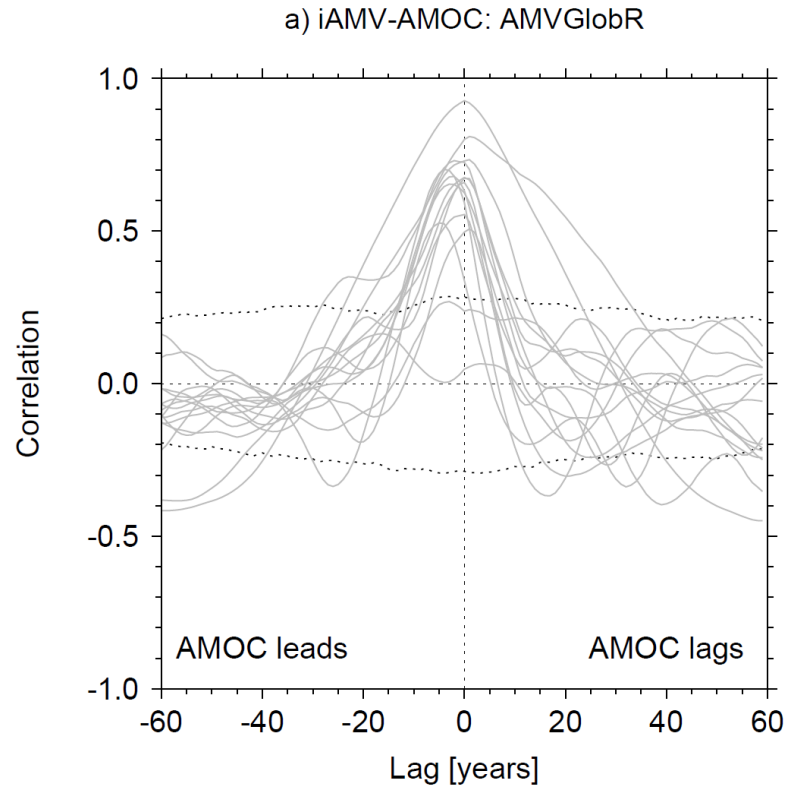*Stippling shows 80% of models disagree on pattern*

K / Simga

- After removing the globally-forced variability – we find significant differences in the North Atlantic AMV pattern.
  - in particular, **fAMV is a largely a subtropical signal** and not consistent with iAMV (or observations).

National Centre for Atmospheric Science
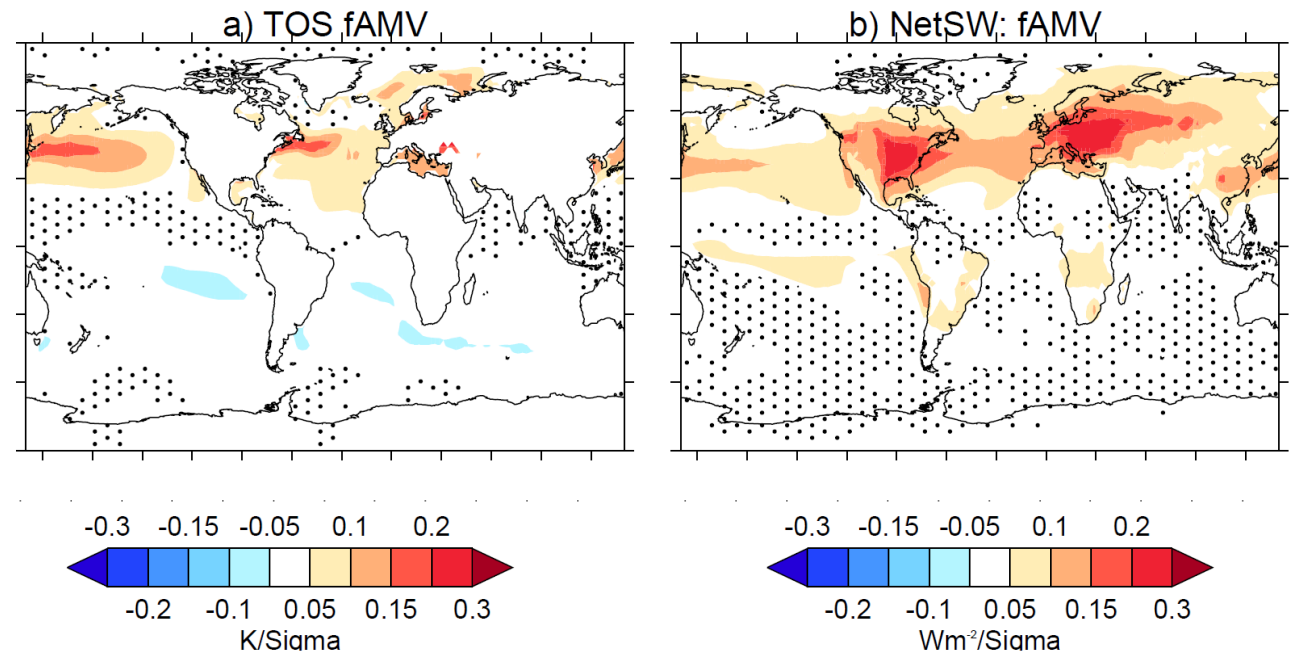NATURAL ENVIRONMENT RESEARCH COUNCIL

Drivers of internal and externally forced AMV variability

Ocean circulation plays key role in iAMV
(consistent with many previous studies)

Downwelling solar heat fluxes play key role in fAMV *(consistent with Booth et al, 2012)*

a) iAMV-AMOC: AMVGlobR

a) TOS fAMV

b) NetSW: fAMV

National Centre for Atmospheric Science
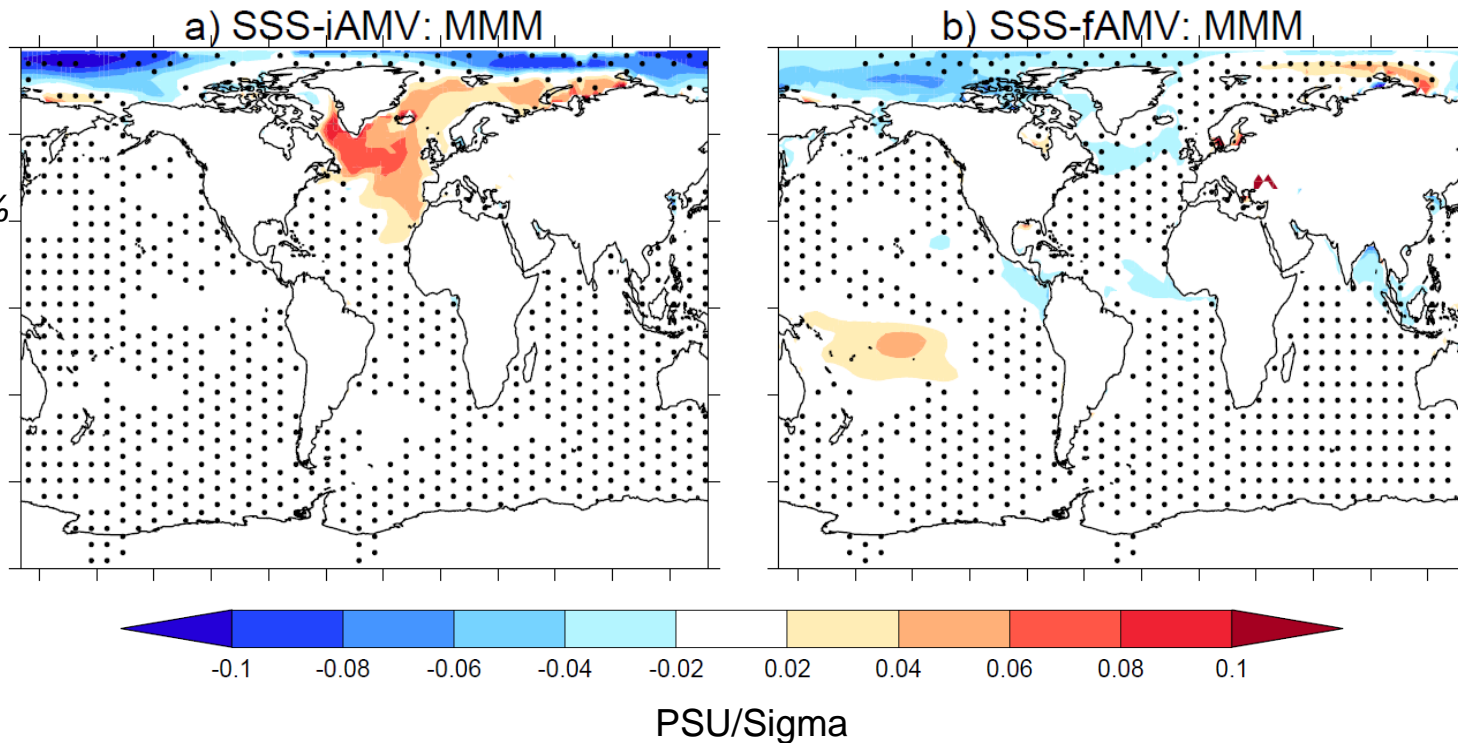NATURAL ENVIRONMENT RESEARCH COUNCIL

Multi-variate fingerprint of AMV variability

Different mechanisms lead to different multi-variate fingerprints of AMV
iAMV fingerprint consistent with observations.

Stippling shows 80% of models disagree on pattern

a) SSS-iAMV: MMM

b) SSS-fAMV: MMM

PSU/Sigma

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

Conclusions

- fAMV in CMIP6 is part of a broader (hemispheric) forced signal
  - **fAMV is very sensitive to the index used – please don't use only the basin-mean AMV index!**
- Once global signals are removed, the fAMV signal is small and focused on subtropics.

- The multi-variate fingerprint of AMV is crucial to separate mechanisms, and shows:
  - Ocean-circulation changes are an important part of iAMV across CMIP6 models
  - fAMV in CMIP6 is largely a passive-ocean surface fluxed forced phenomena – *dominated by models with* *strong* *sensitivity to aerosol forcing*

- Overall, CMIP6 simulations still support the hypothesis that changes in ocean circulation dominate the observed AMV, and that it is likely internally generated. However, external forcings still play a role.

- However, many issues with models including signal-to-noise problems in atmospheric variability (forced and internal)
  - Plausible that forced *dynamical* component is larger in reality than the models currently suggest.
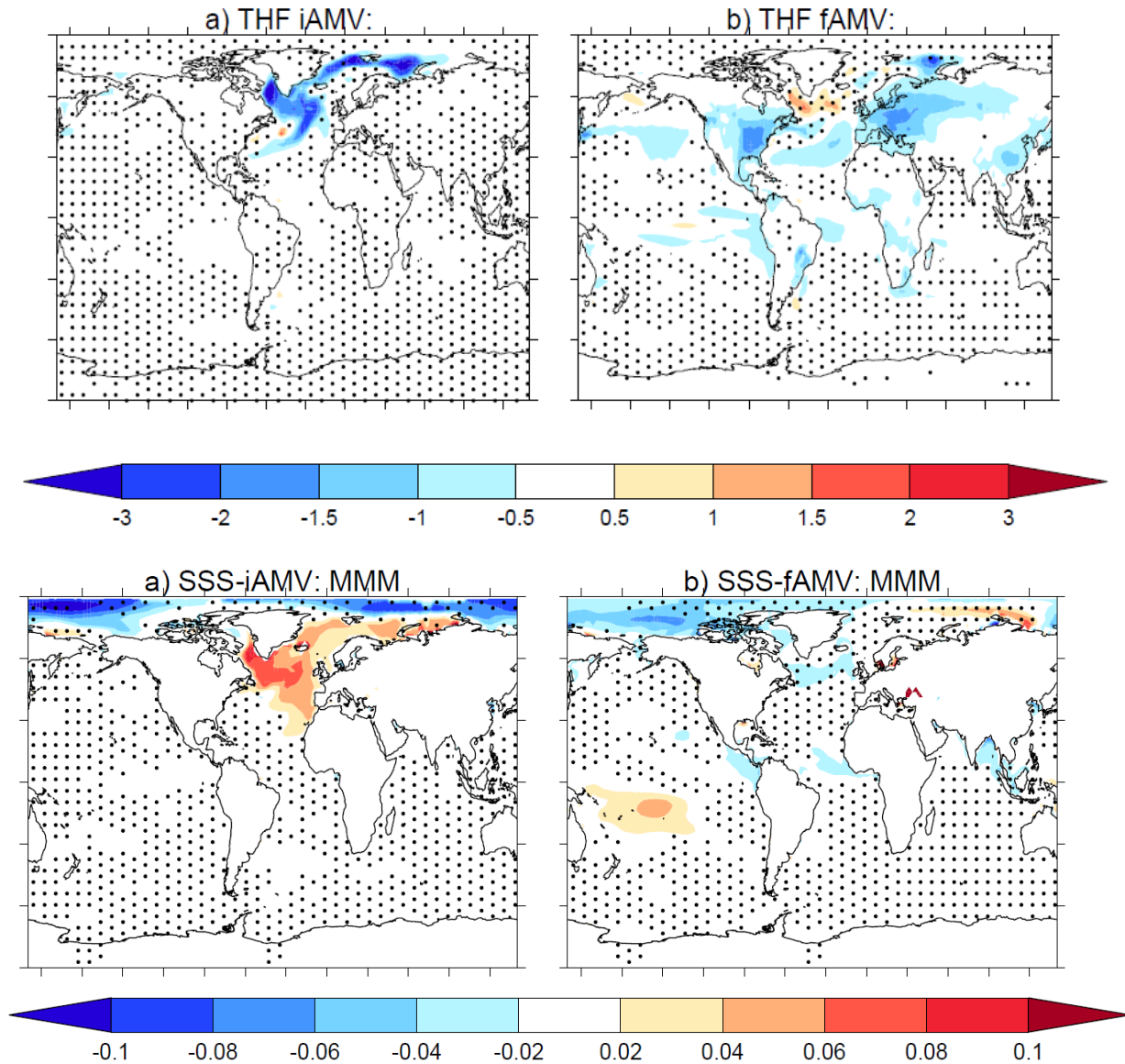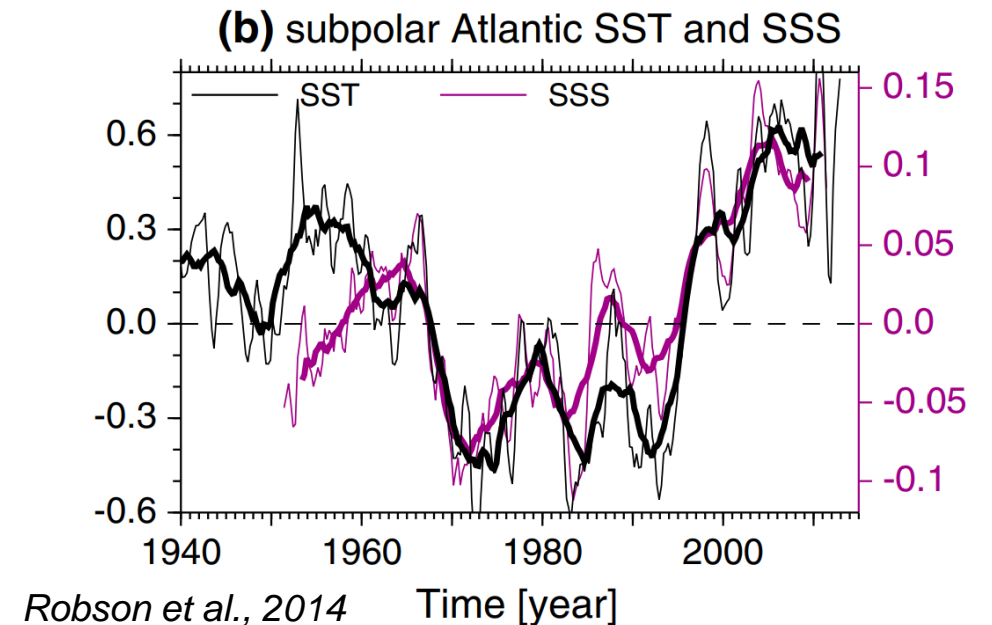
**National Centre for Atmospheric Science**
NATURAL ENVIRONMENT RESEARCH COUNCIL

Extra slides

Contrasting the multi-variate fingerprint of iAMV and fAMV

a) THF iAMV: b) THF fAMV:

a) SSS-iAMV: MMM   b) SSS-fAMV: MMM

(b) subpolar Atlantic SST and SSS

Robson et al., 2014

- iAMV multi-variate fingerprint is consistent with changes in ocean circulation
  - Opposite true for fAMV.
- iAMV fingerprint is similar to the observed (e.g., Gulev et al, 2013; Yan et al., 2017)
- Hence, further support for the hypothesis that ocean circulation is a key part of observed AMV
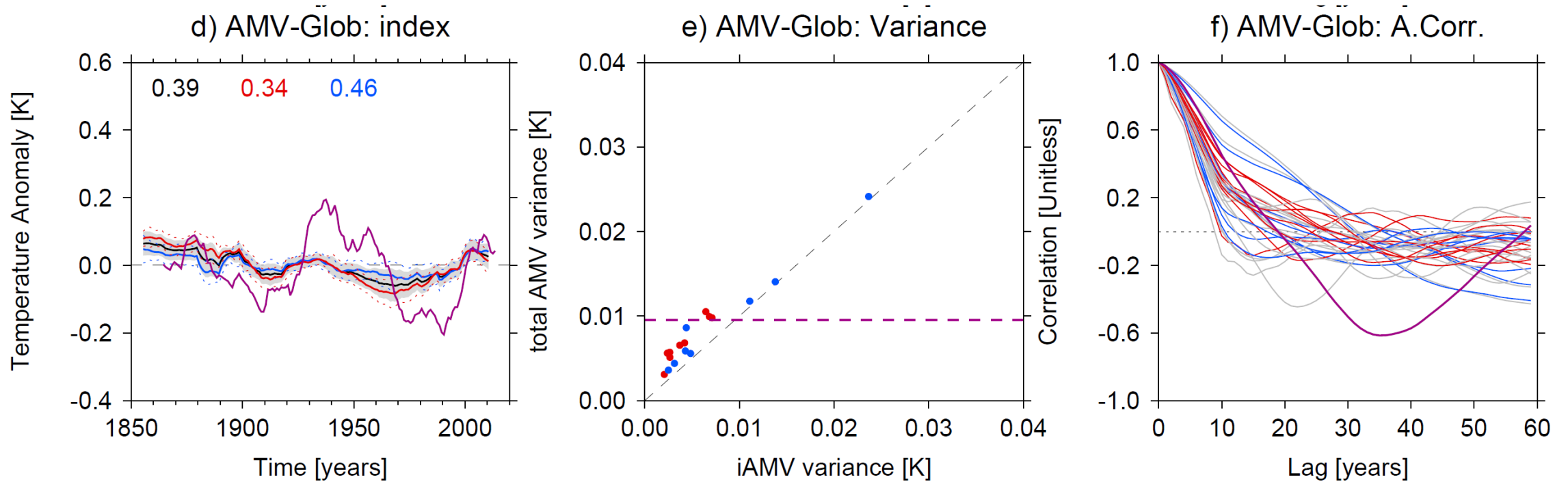
Impact of AMV index on statistics of externally-forced AMV (fAMV)

a) AMV_BM: index

b) AMV_BM: Variance

c) AMV_BM: A.Corr.
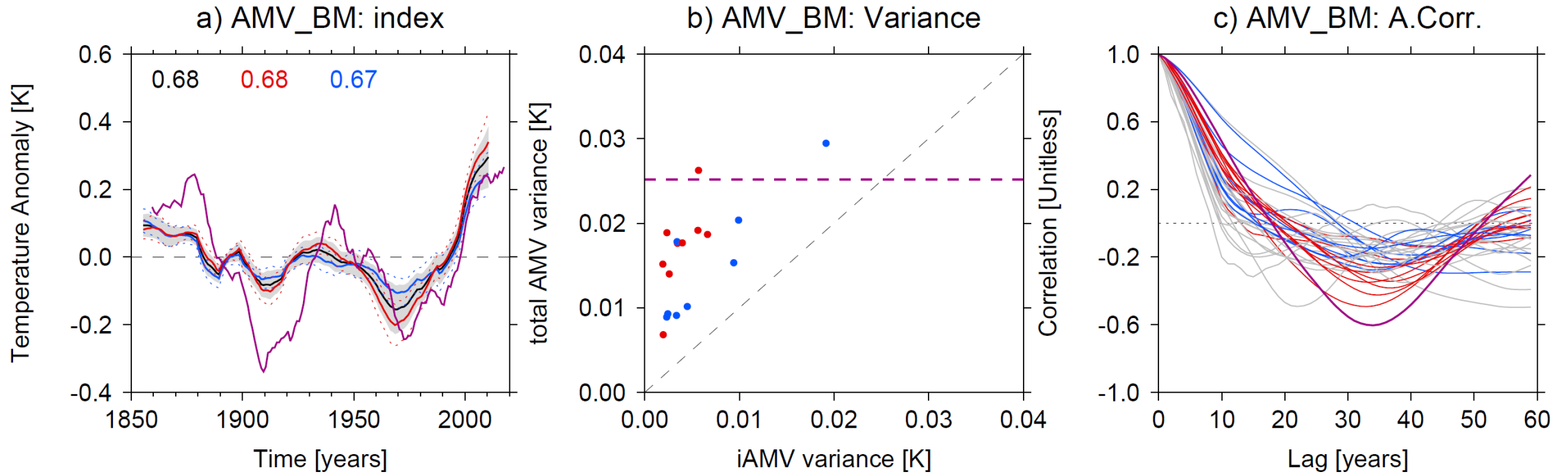
- **When using basin mean AMV-index (AMV_BM) external forcings appear to significantly affect AMV**
  - Largely accounts for magnitude of anomalies after 1960
 - Increased variance (2x for MMM)
  - Longer variability

National Centre for Atmospheric Science

NATURAL ENVIRONMENT RESEARCH COUNCIL

Impact of AMV index on statistics of fAMV

d) AMV-Glob: index

0.39 0.34 0.46

e) AMV-Glob: Variance

f) AMV-Glob: A.Corr.

- **But, the importance of externally forced AMV is substantially smaller if removing globally-forced signals**
  - Does not account for magnitude of anomalies after 1960
  - Increased variance much smaller (1.25x for MMM)
  - Length of variability not significantly affected

National Centre for Atmospheric Science
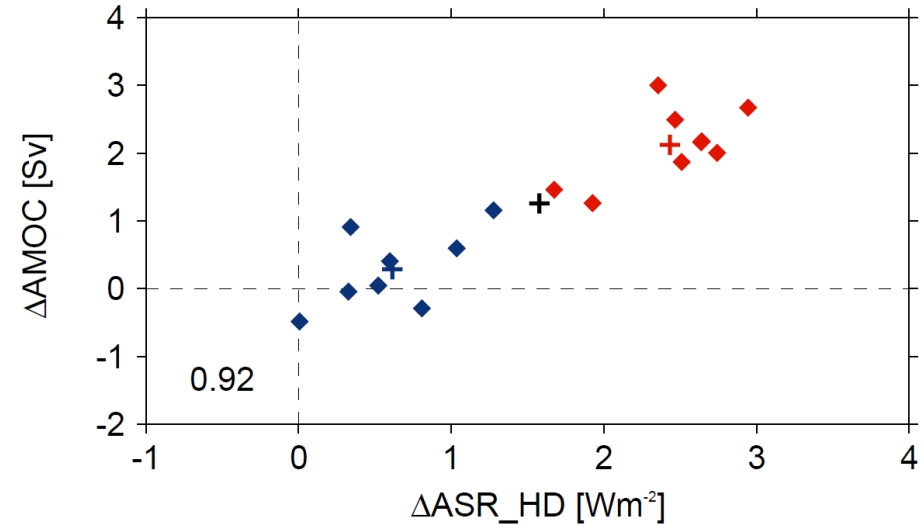NATURAL ENVIRONMENT RESEARCH COUNCIL

Stratify CMIP6 ensemble based on ASR_HD

a) ASR_HD index
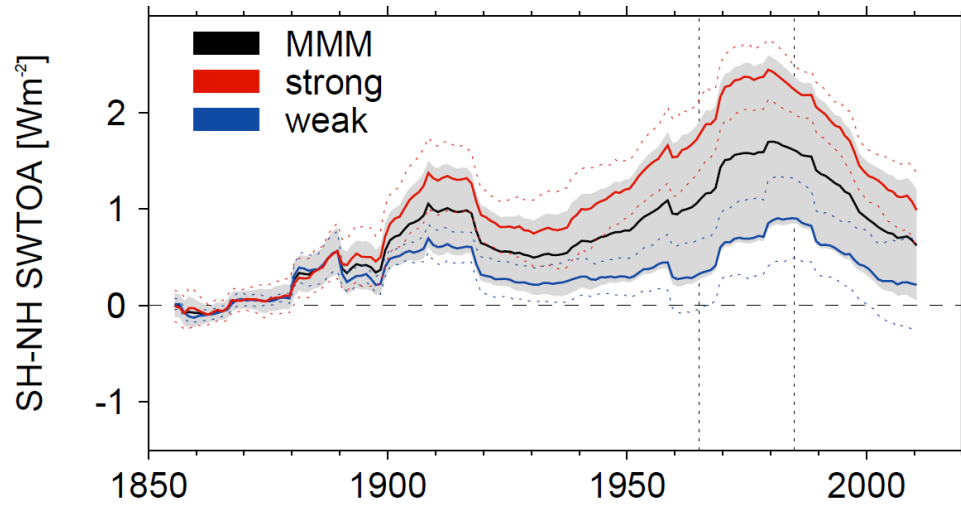
b) AMOC at 35°N
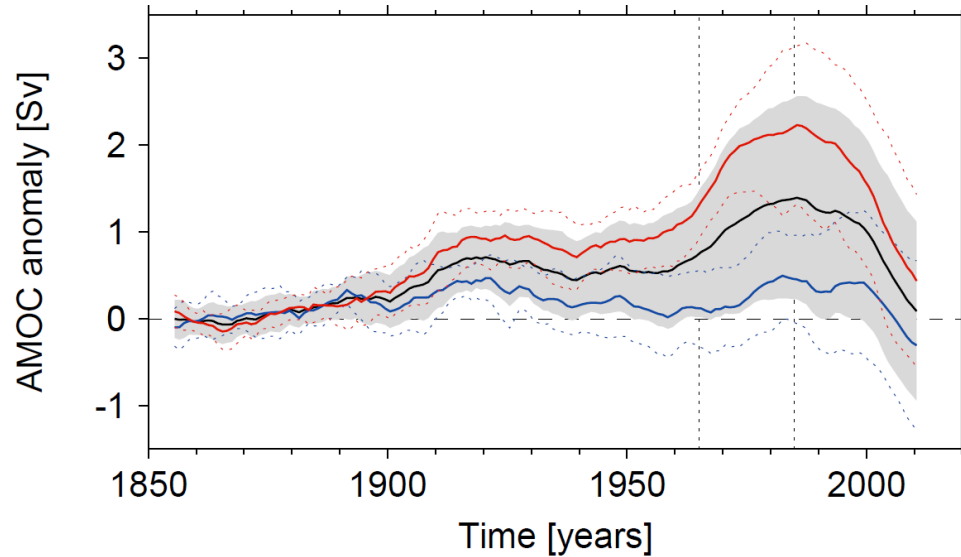
c) 1850-1985 ΔASR_HD vs ΔAMOC

- Increase in AMOC to 1985 is only seen in the strong models
- weak models have a much smaller change in ASR_HD and little change in AMOC

Differences between strong and weak models

c) TOS fAMV DIFF

d) NetSW fAMV DIFF

b) fAMV-AMOC: AMVGlobR

K/Sigma

Wm⁻²/Sigma

AMOC leads   AMOC lags

Lag [years]

a) AMV_BM: index

0.68   0.68   0.67

Temperature Anomaly [K]

d) SSS-fAMV: STRONG

e) SSS-fAMV: WEAK

f) SSS-fAMV DIFF: STRONG - WEAK