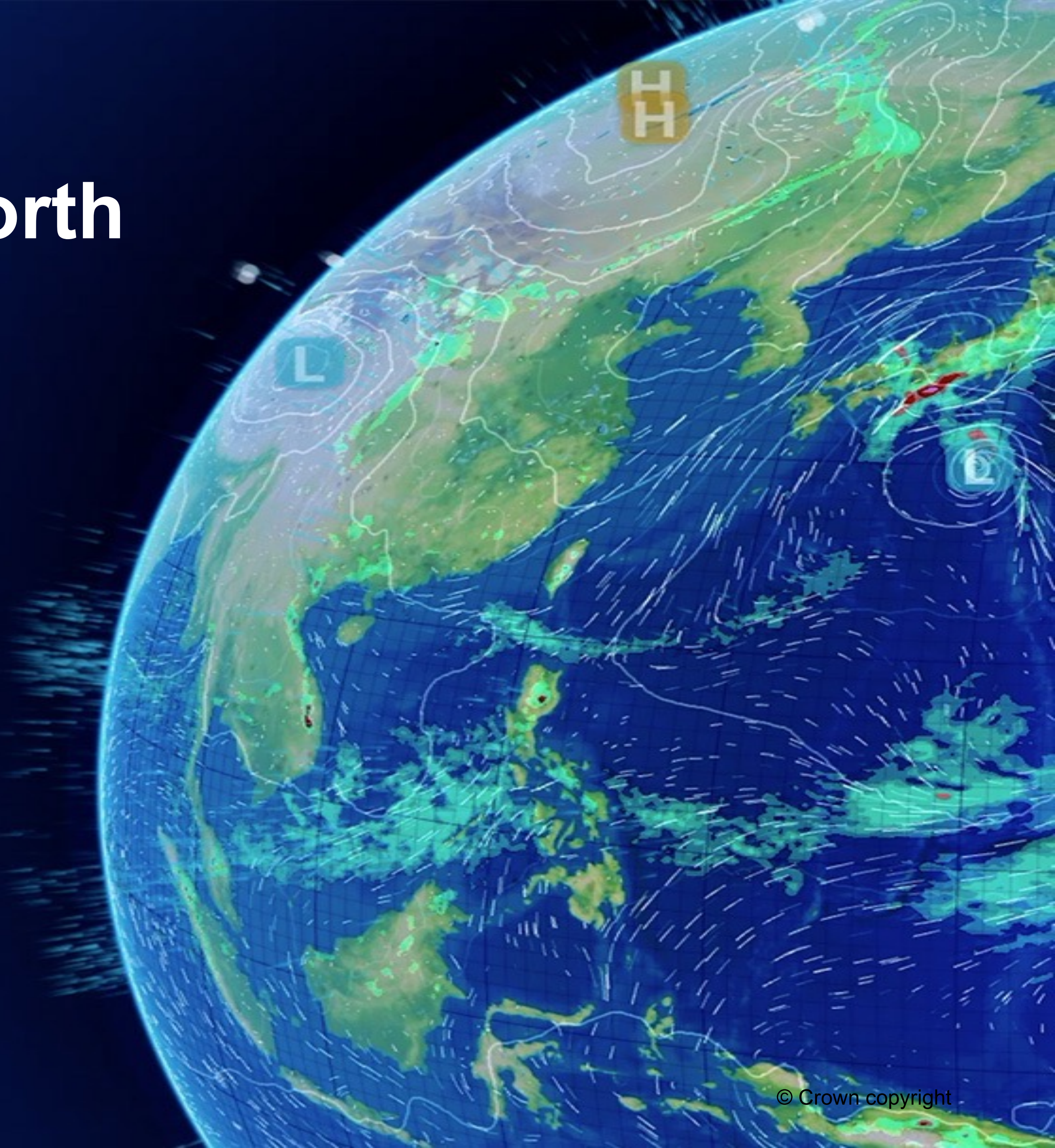
Met Office

External forcing of the North Atlantic Oscillation



Doug Smith, Nick Dunstone, Rosie Eade, Steven Hardiman, Leon Hermanson, Adam Scaife, Melissa Seabrook

Climate models fail to capture NAO trends

Trends 1951-2020

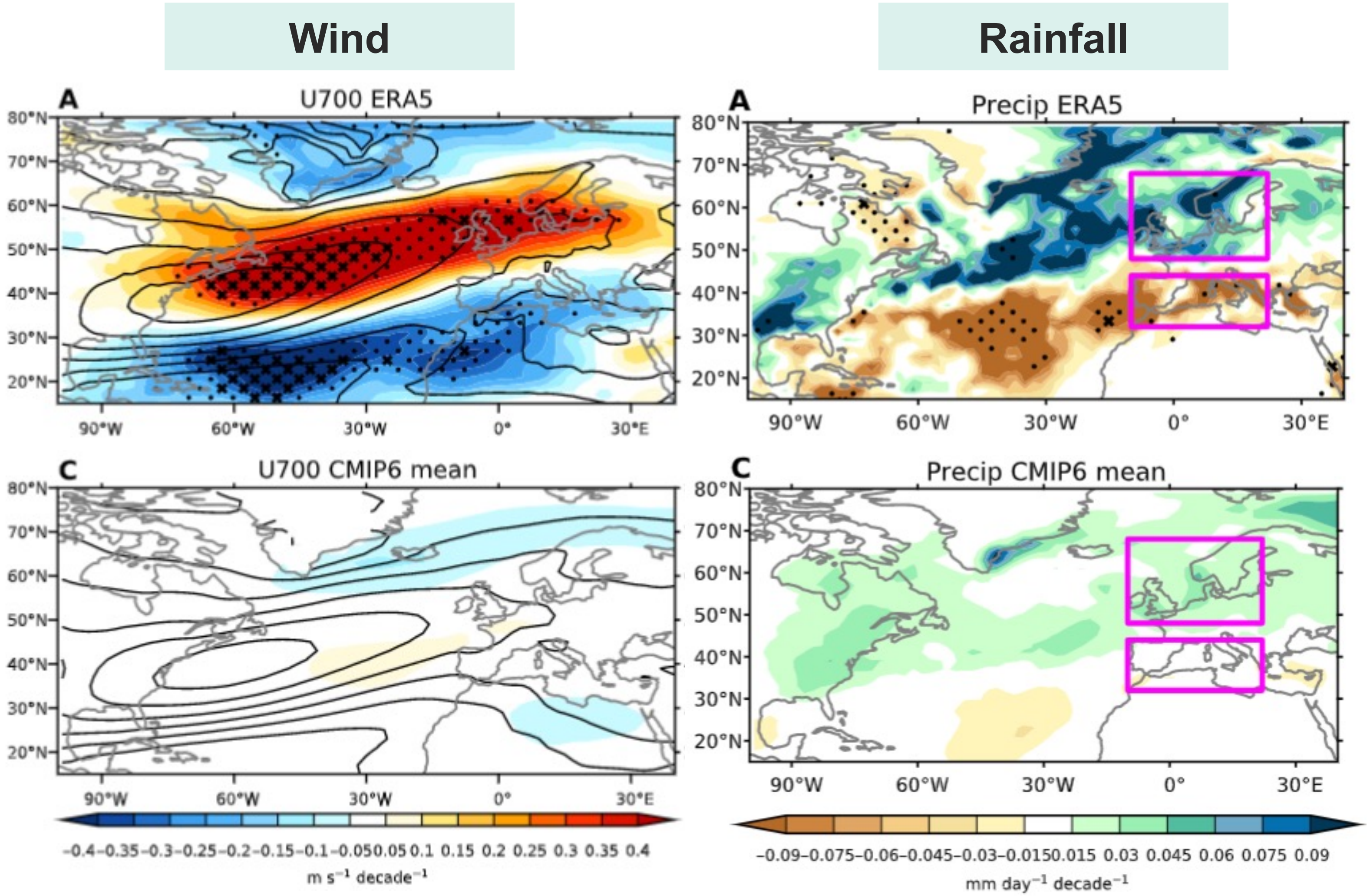
Observations (upper panels)

Climate models (lower panels)

Crosses show where obs outside model range, dots where outside 2.5% to 97.5%

Similar patterns but obs much stronger

→ possible underestimation of forced response?



NAO response to natural forcings (solar + volcanic)

31-year rolling means

> 50 members CanESM5, HadGEM3, MIROC6

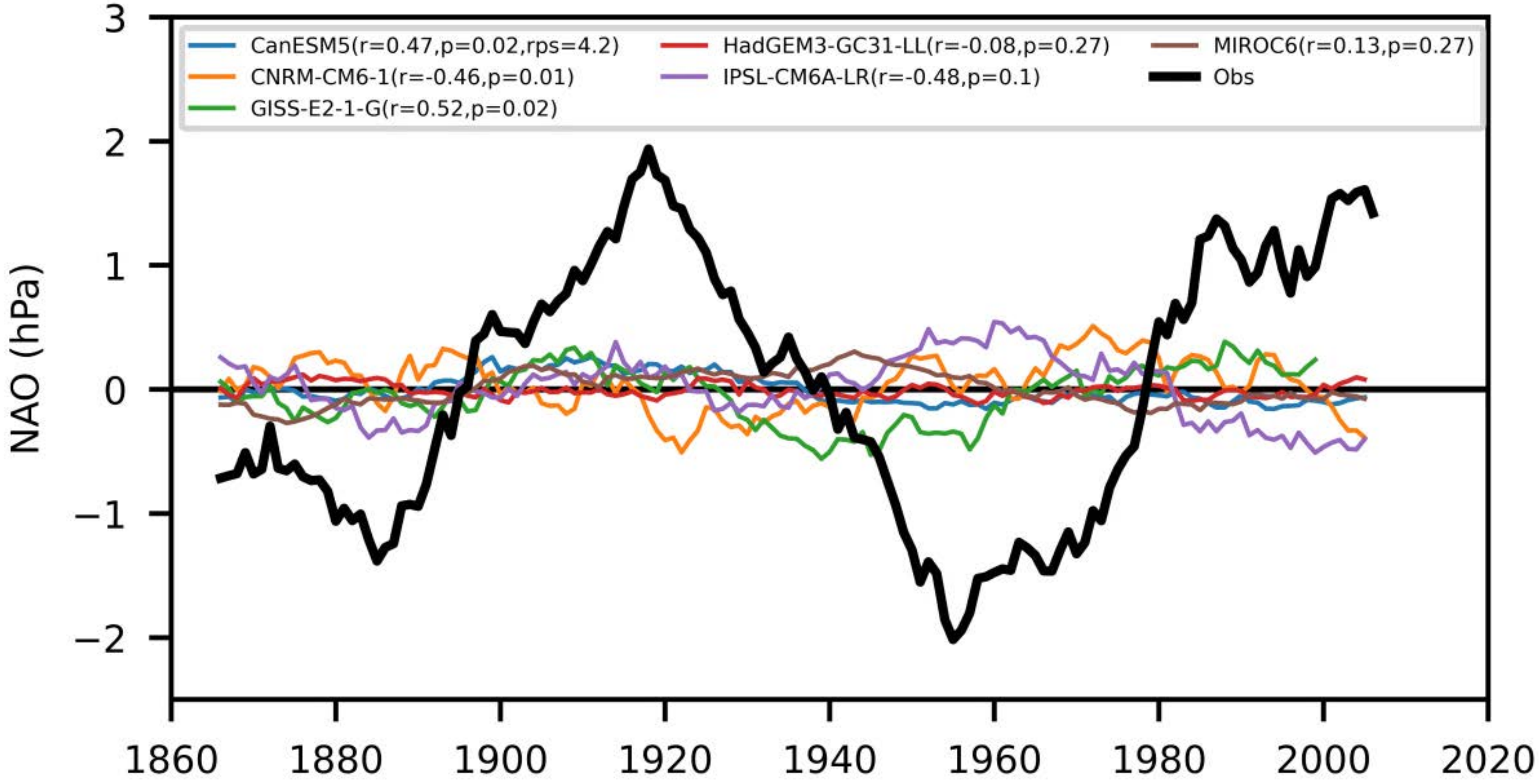
Some significant correlations with observations

→ potential role for solar and volcanic forcings

BUT opposite responses for some models:

CanESM5 r = 0.47 p = 0.02

CNRM-CM6-1 r = -0.46 p = 0.01



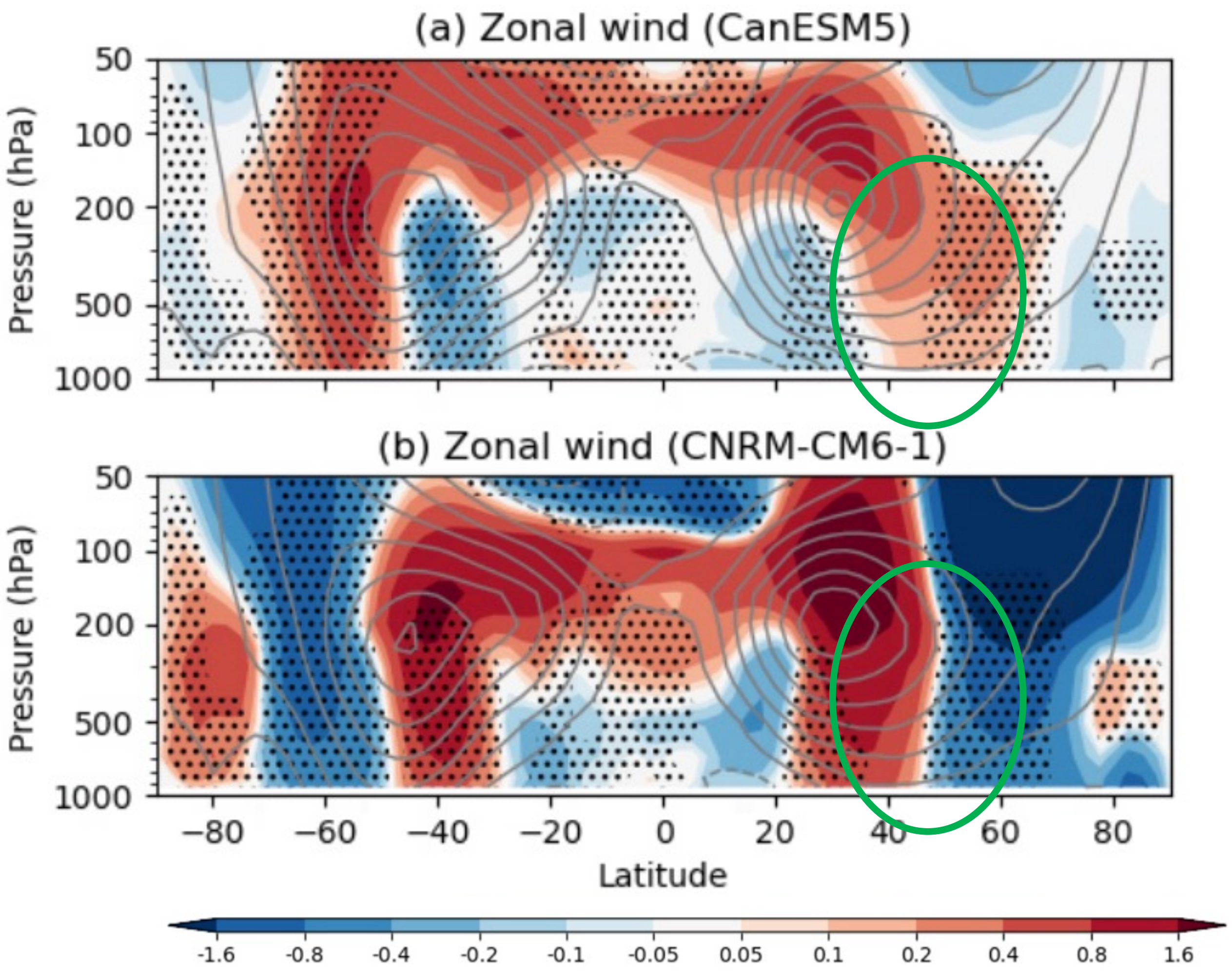
Regression between EEI and U (31 year)

Similar pattern (“n” shape increase)

Stippled where significantly opposite

CanESM5 → poleward shift

CNRM-CM6-1 → equatorward shift



Regression between EEI and T (31 year)

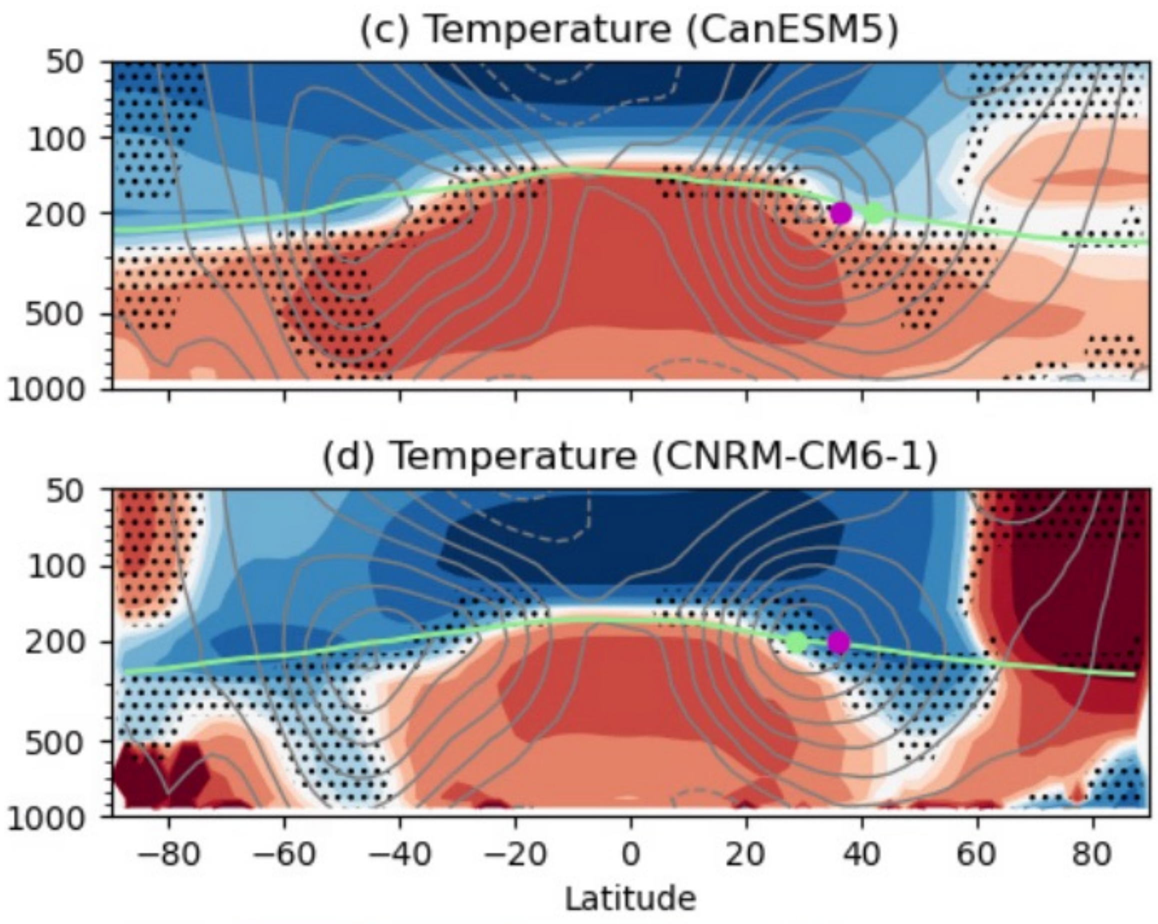
Positive energy imbalance → troposphere warming, thermal gradient at 200 hPa

● Magenta dot = jet centroid at 200 hPa

● Green dot = hygropause latitude at 200 hPa (diagnosed by water vapour contour)

CanESM5 → hygropause latitude poleward of jet → poleward shift

CNRM-CM6-1 → hygropause latitude equatorward of jet → equatorward shift



Explaining model differences

16 hist-nat models (with at least 3 ensemble members)

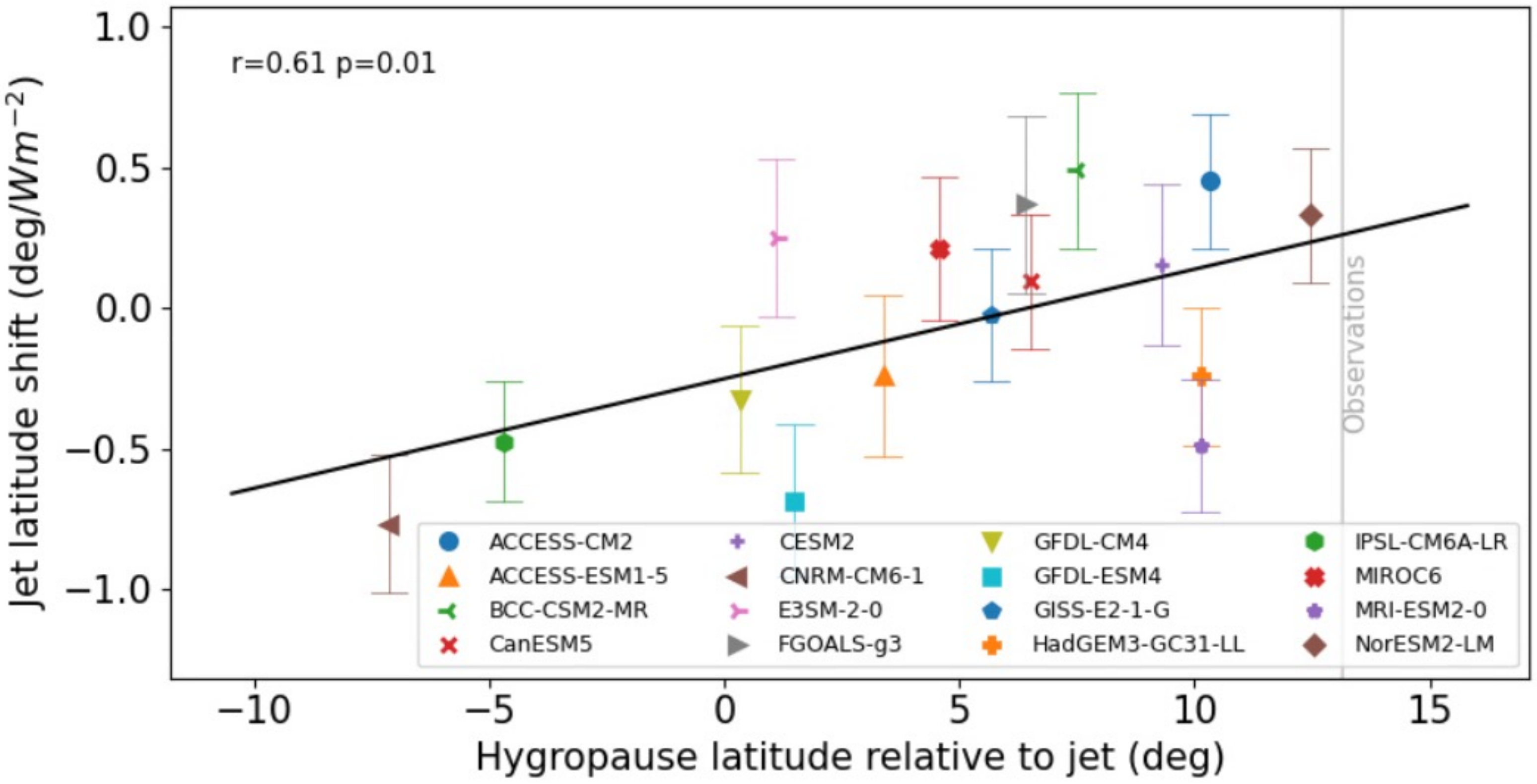
Jet shift at 200 hPa related to EEI

Significant correlation across models with hygropause latitude relative to jet (r = 0.61 p = 0.01)

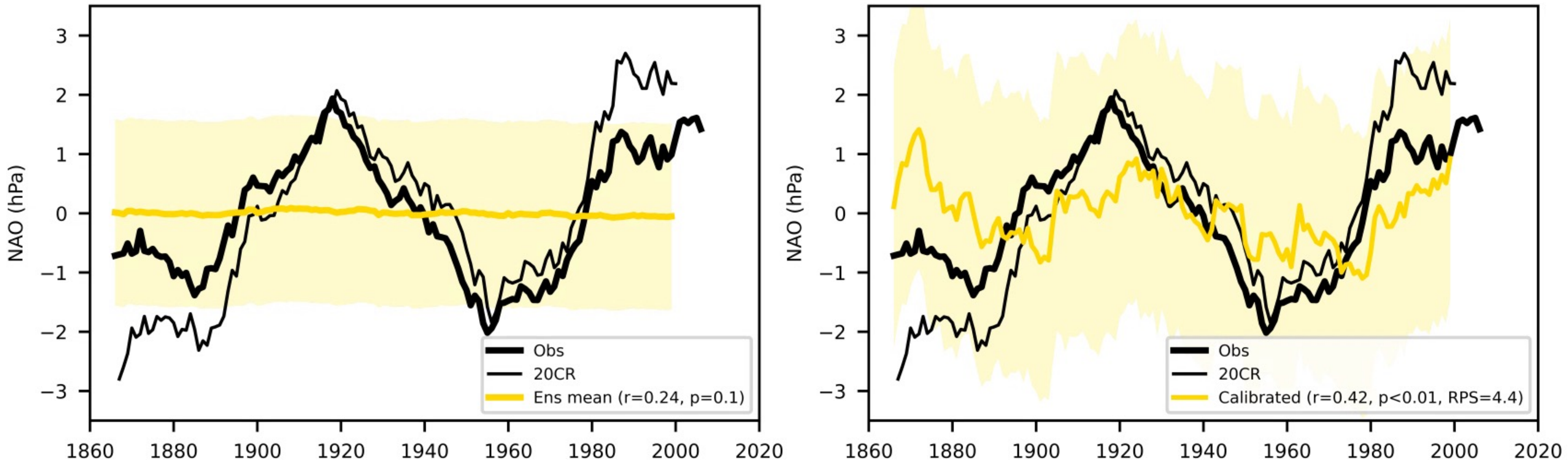
Models underestimate hygropause latitude relative to jet

→ real world poleward shift

→ greater than any model



Exploiting model differences



hygropause latitude relative to jet provides weights for each model

High weights for models close to obs

Negative weights for models that shift the jet the wrong way

Raw multi-model mean shows virtually no variability

Constrained estimate significantly correlated with obs

Variability scaled by ratio of predictable signals (RPS~4)

Role for natural forcings but minimum (~1980) later than obs

Ensemble regression, Bracegirdle and Stephenson 2012

NAO response to all forcings (historical + SSP245)

Some significant correlations with observations

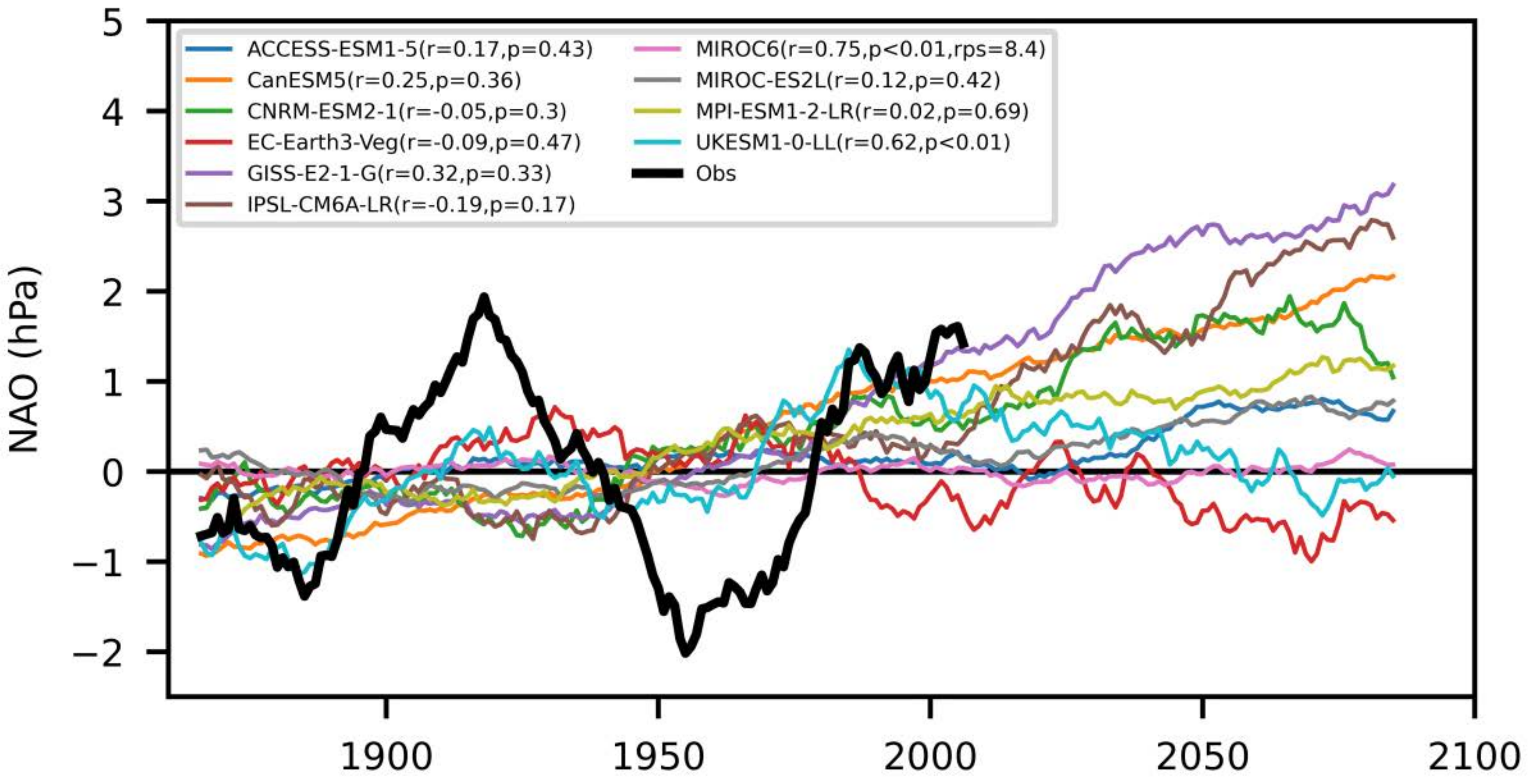
→ potential role for external forcings

BUT huge uncertainty in future trends:

MIROC6 – no trend
r = 0.75 p < 0.01

UKESM1-0-LL – negative trend
r = 0.62 p < 0.01

GISS-E2-1-G – positive trend
r = 0.32 p = 0.33



Explaining model differences

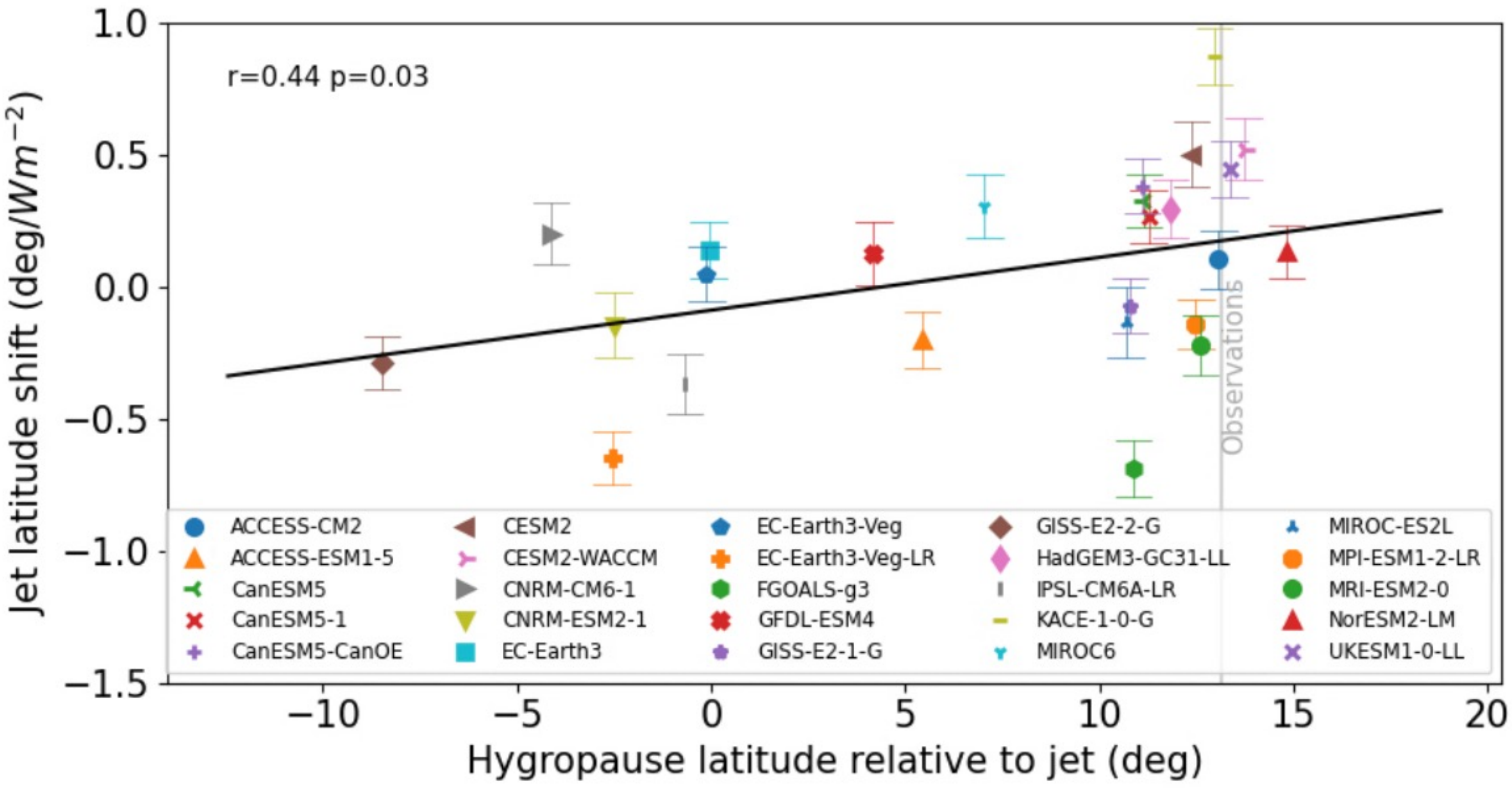
25 models (with at least 3 ensemble members for historical + SSP245)

Jet shift at 200 hPa related to EEI

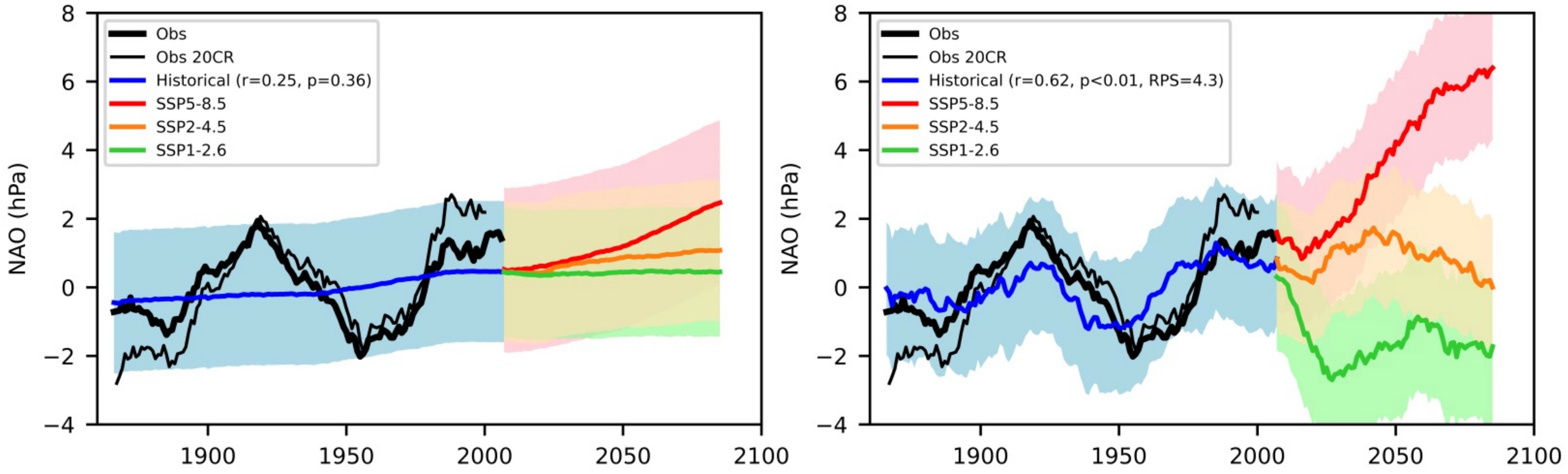
Significant correlation across models with hygropause latitude relative to jet ($r = 0.44$ $p = 0.03$)

Most models underestimate hygropause latitude relative to jet

Provides an out of sample test of emergent constraint



Exploiting model differences



Raw multi-model mean shows little variability and low correlation

Constrained estimate significantly correlated with obs

Variability scaled by ratio of predictable signals (RPS~4)

Projected to increase to unprecedented levels under SSP5-8.5

But can be avoided with mitigation

Mechanism

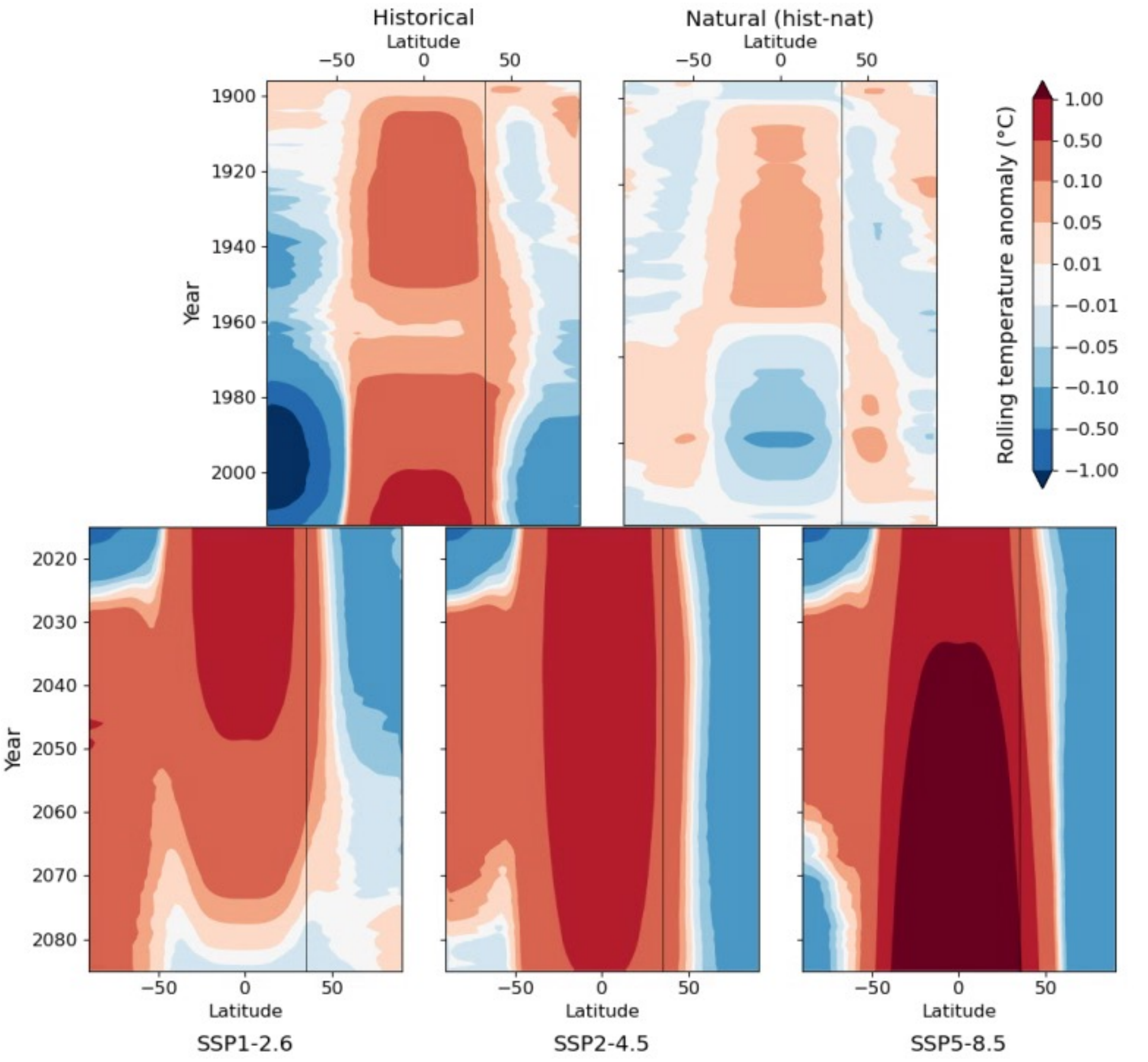
Hovmuller plots of rolling temperature at 200hPa anomalies from preceding 30-year mean (multi-model mean)

Tropical cooling following volcanic eruptions
→ minimum ~1990 (Agung+El Chichon+Pinatubo)

Greenhouse gas warming
→ minimum ~1960

$\frac{\partial \overline{T}}{\partial \emptyset}$ at jet latitude (35N) increases under SSP5-8.5

But reduces with mitigation

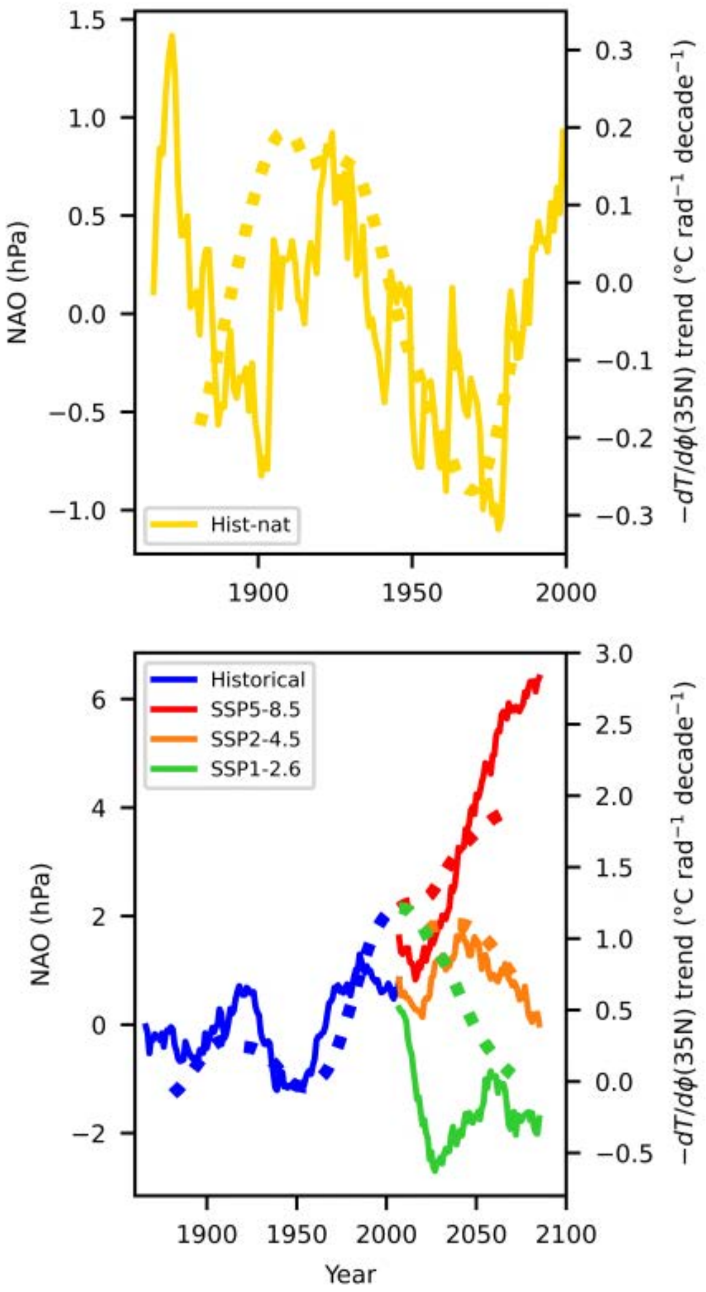


Mechanism

Constrained timeseries are largely explained by trends in $\frac{\partial \overline{T}}{\partial \emptyset}$

→ suggests climate will equilibrate to a given level of forcing

→ will respond to further changes in forcings



Summary

Models can have very different responses → they can't all be right!

Some of the differences can be explained by background water vapour → controls latitude of heating

Resulting constraint reveals externally forced NAO
→ volcanoes cool the tropical upper troposphere → equatorward shift, negative NAO
→ greenhouse gases warm the tropical upper troposphere → poleward shift, positive NAO

NAO projected to increase to unprecedented values under SSP5-8.5

But can be avoided with mitigation

Taking model projections at face value and seeking consensus could leave society unprepared for impending extremes