

Forced versus Internal Drivers of Storm Track Trends: Attribution with Large-Ensemble Single-Forcing Simulations

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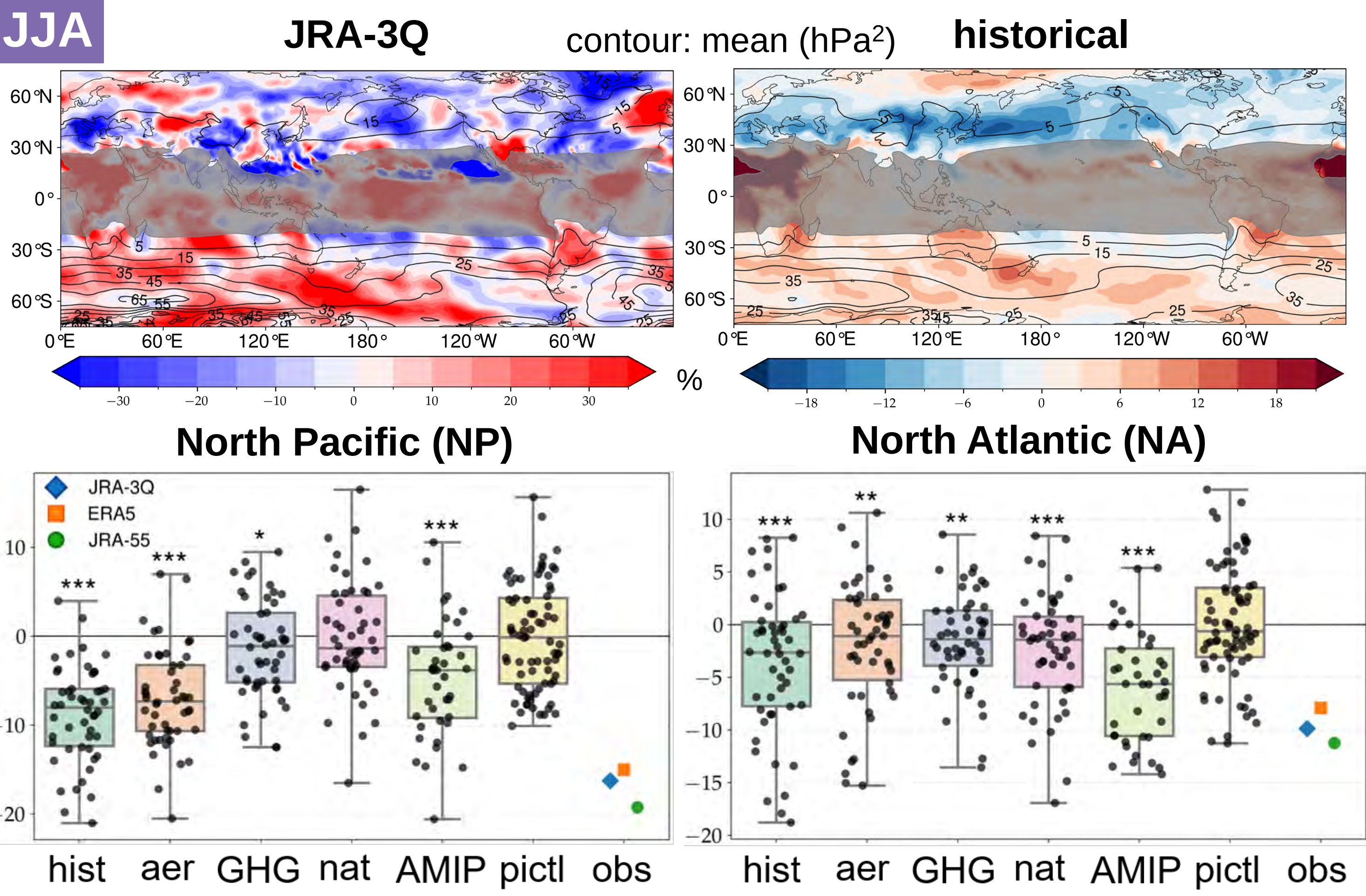
Introduction

Storm tracks directly shape midlatitude weather variability and extremes. Their regional multidecadal trends reflect responses to individual external forcings as well as internally generated climate variability.

Previous multi-model attribution studies identify forcing-specific responses (mostly in hemispheric-scale average), but limited ensemble sizes make it difficult to distinguish regional forced signals from internal variability and to identify the internal modes producing the spread.

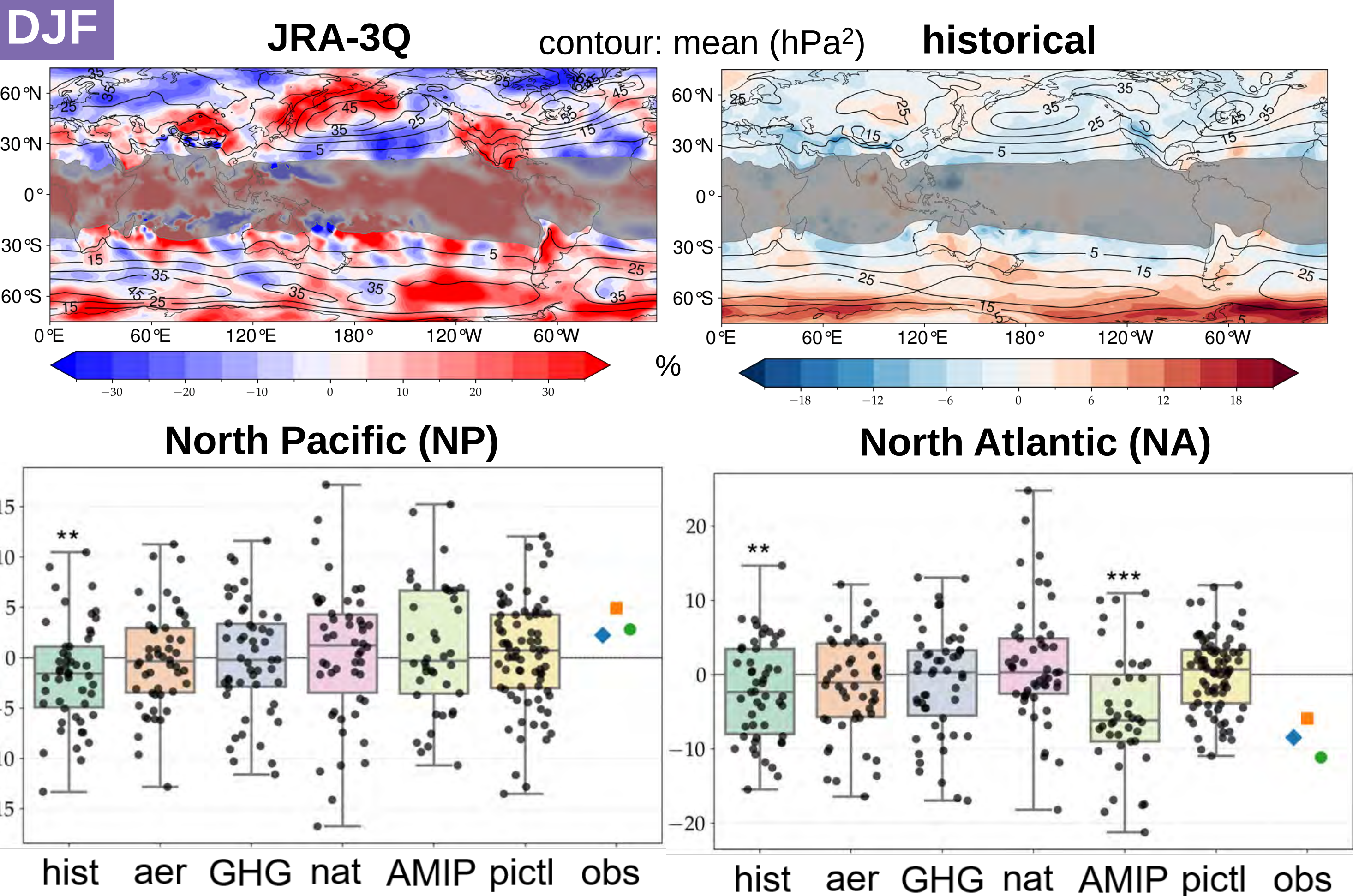
Here, we use large-ensemble single-forcing simulations to quantify the relative roles of individual forcings and internal SST variability in regional storm track trends during the satellite period.

Storm track trends (1980/81-2019/20)



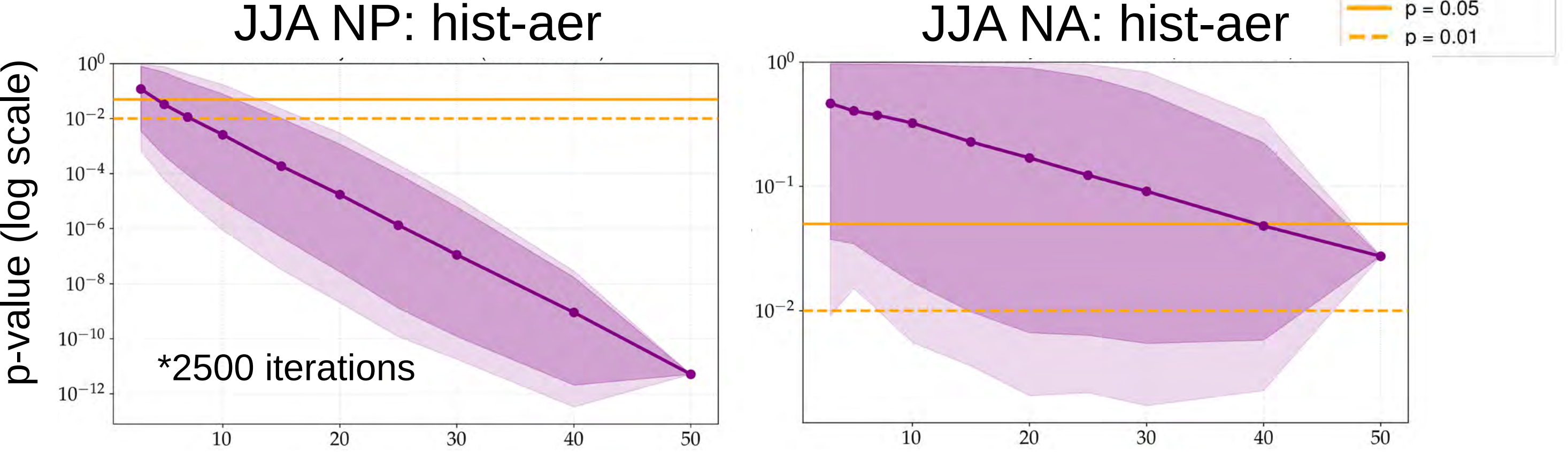
Aerosol forcing is important for the NP & NA weakening with a comparable GHG contribution in the NA. The weakening is accompanied by reduced baroclinicity and baroclinic energy conversion (not shown).

AMIP captures the obs trends; NP weakening is outside of trends in piControl.



NP & NA forced responses are much weaker than internal climate variability. GHG forcing is important for the SO strengthening (not shown).

Dependence on ensemble size



Even for the very robust NP storm track weakening, we need 5-10 members.

For the NA weakening by aerosol forcing, we need a large ensemble size to obtain a statistically significant signal, although MIROC6-LE might underestimate forced responses.

Data & Methods

MIROC6-LE (part of LESFMP; *Shiogama+2023*)

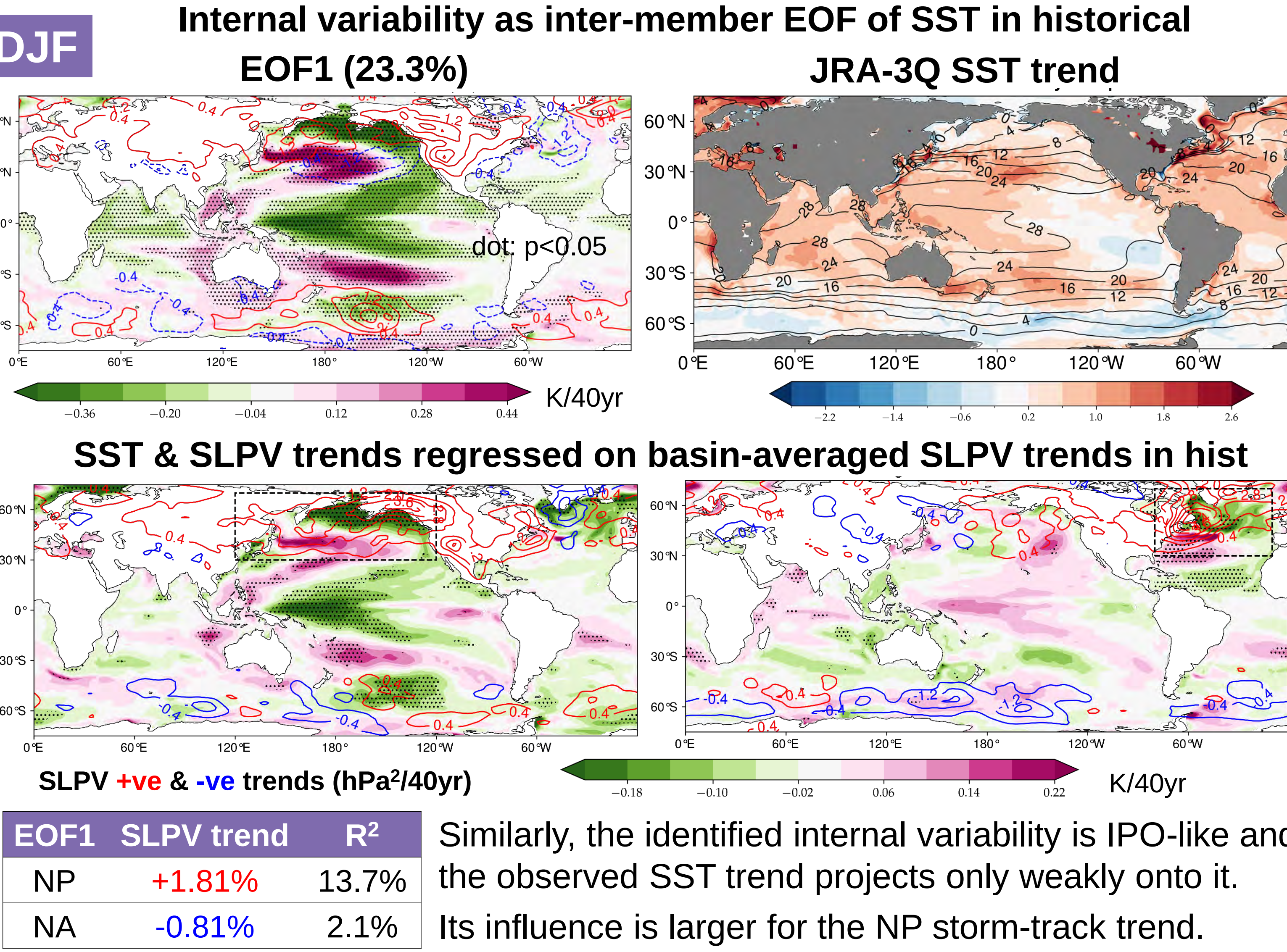
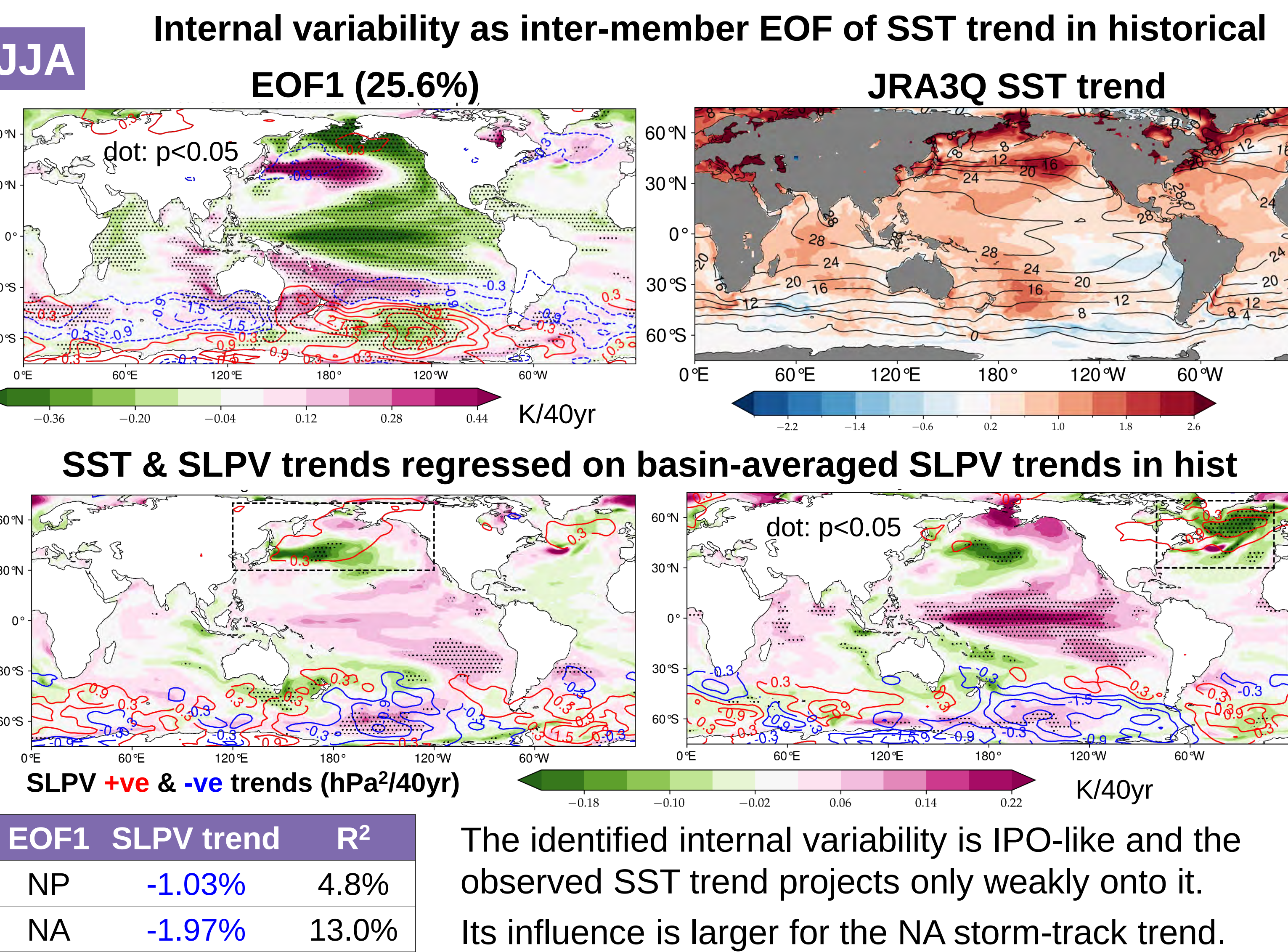
1850-2020 (historical + ssp245 forcing)

+ AMIP (1979-2021) & single-member piControl

historical	50 members
hist-aer	50 members
hist-GHG	50 members
hist-nat	50 members
AMIP	40 members
piControl	800 years

- We also analyze JRA-3Q, ERA5, and JRA-55
- JJA/DJF in 1980/81-2019/20
- Storm track activity: variance of 8-day-highpass-filtered daily-mean SLP (SLPV)
- Time series and trends are normalized by the 1980/81-1989/90 mean
- Key conclusions are qualitatively the same for HadGEM3-GC31-LL (not shown)

Internal climate variability



Summary

- Using **single-model, large-ensemble simulations (MIROC6-LE)**, we show
- Aerosol forcing drives much of the summertime North Pacific weakening and contributes to the North Atlantic response, whereas wintertime forced responses are small relative to internal variability.
 - Large ensembles are essential to obtain a robust signal of individual forcing. The ensemble size required for attribution is region dependent.
 - A leading IPO-like SST trend mode explains 14% of DJF North Pacific and 13% of JJA North Atlantic inter-member storm-track trend variance.

Large-ensemble single-forcing simulations enable regional attribution by separating individual forced responses from internal variability and identifying a specific coupled mode of internal variability.