The response of the QBO to external forcings: implications for disruption events

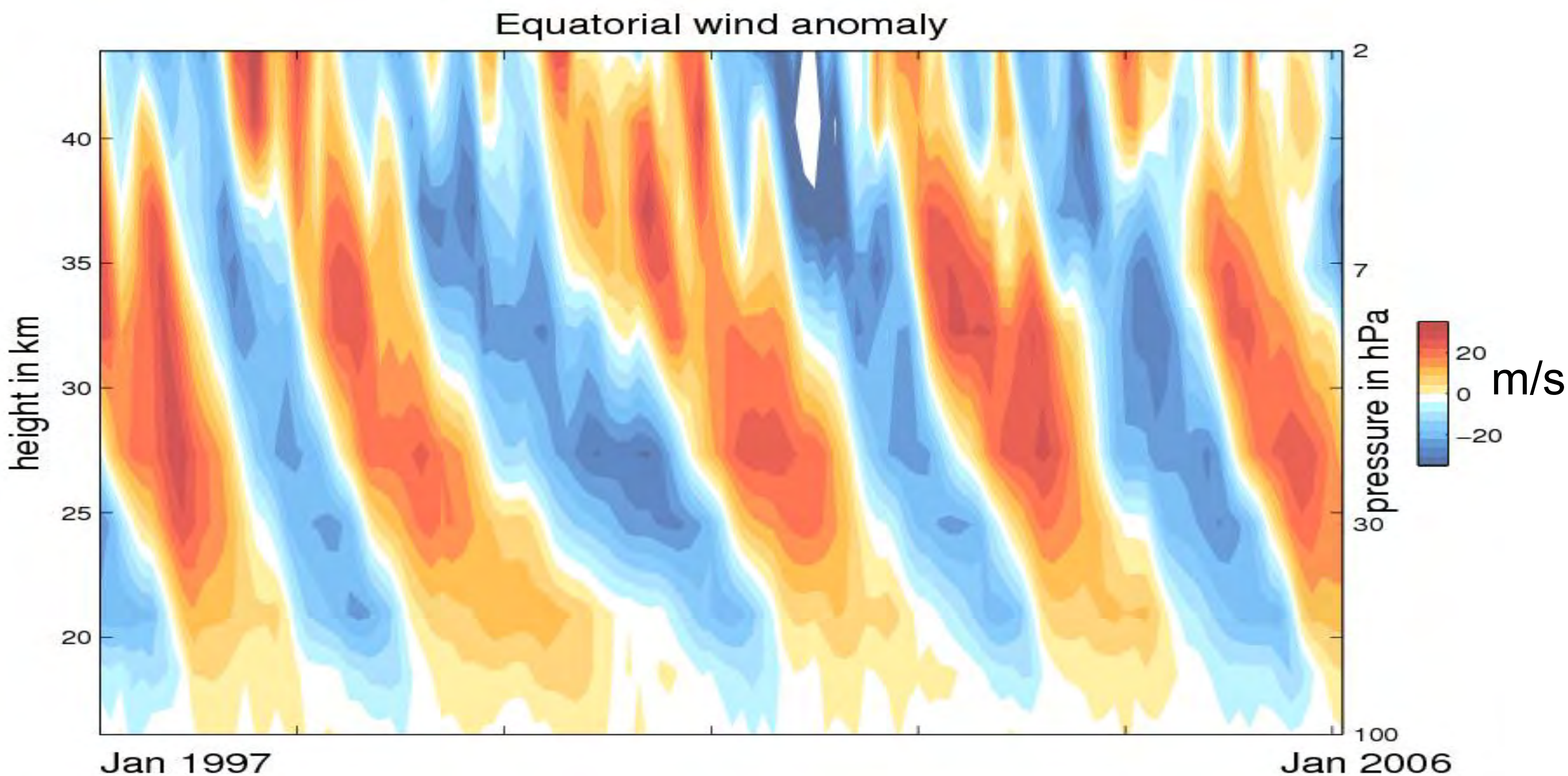
Chaim I. Garfinkel, David Avisar
Doug Smith, Scott Osprey

The surface response to the QBO in the LESFMIP simulations: model vs. obs discrepancies in teleconnection strength

Chaim I. Garfinkel, David Avisar
Doug Smith, Scott Osprey

Quasi Biennial Oscillation (QBO)

1. Alternating zonally symmetric westerlies and easterlies in tropical stratosphere
2. Weakens poleward of 10N and 10S
3. Period of ~28 months



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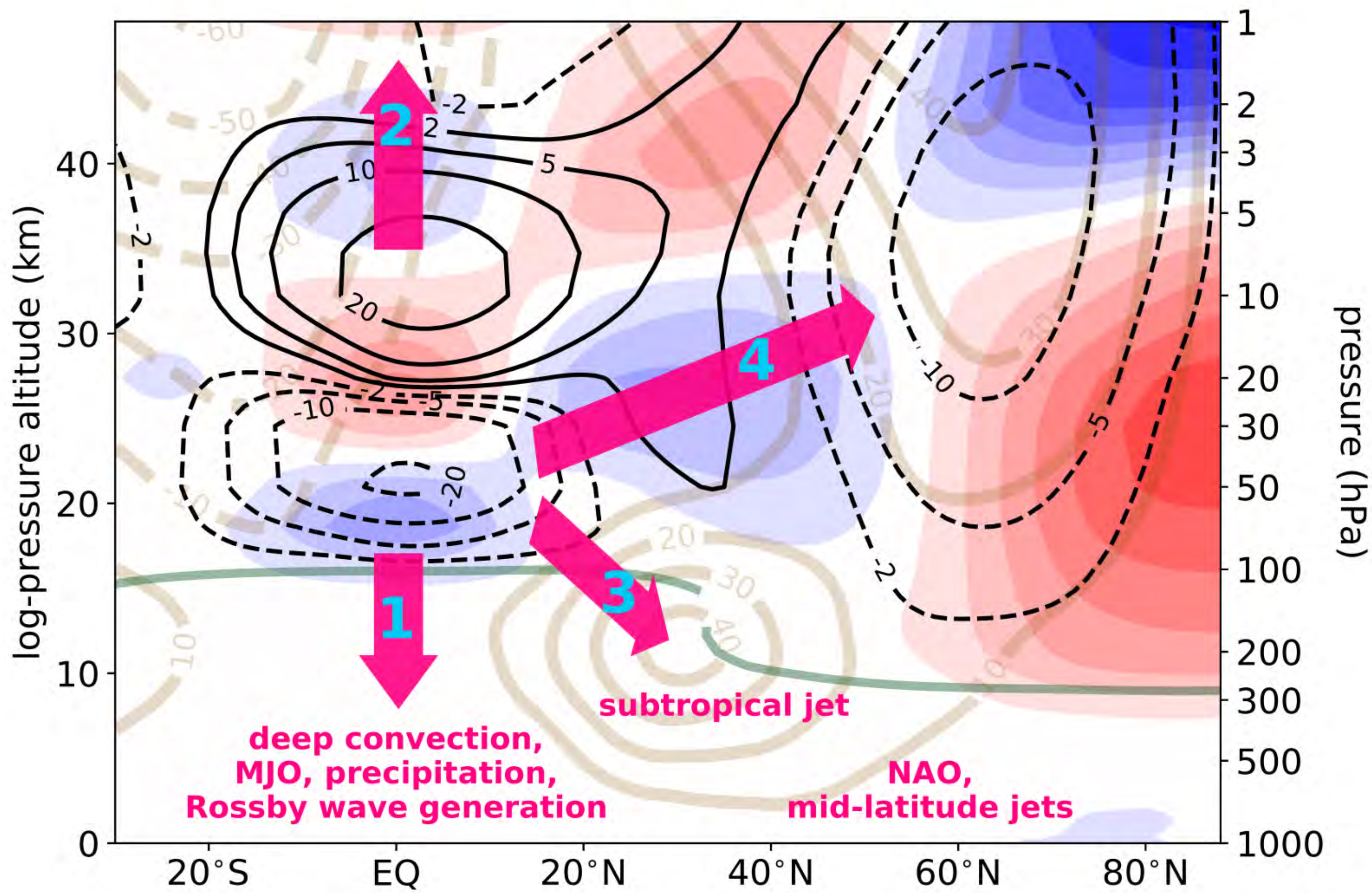
Chaim I. Garfinkel

QBO pathways to surface climate



Anstey et al 2022

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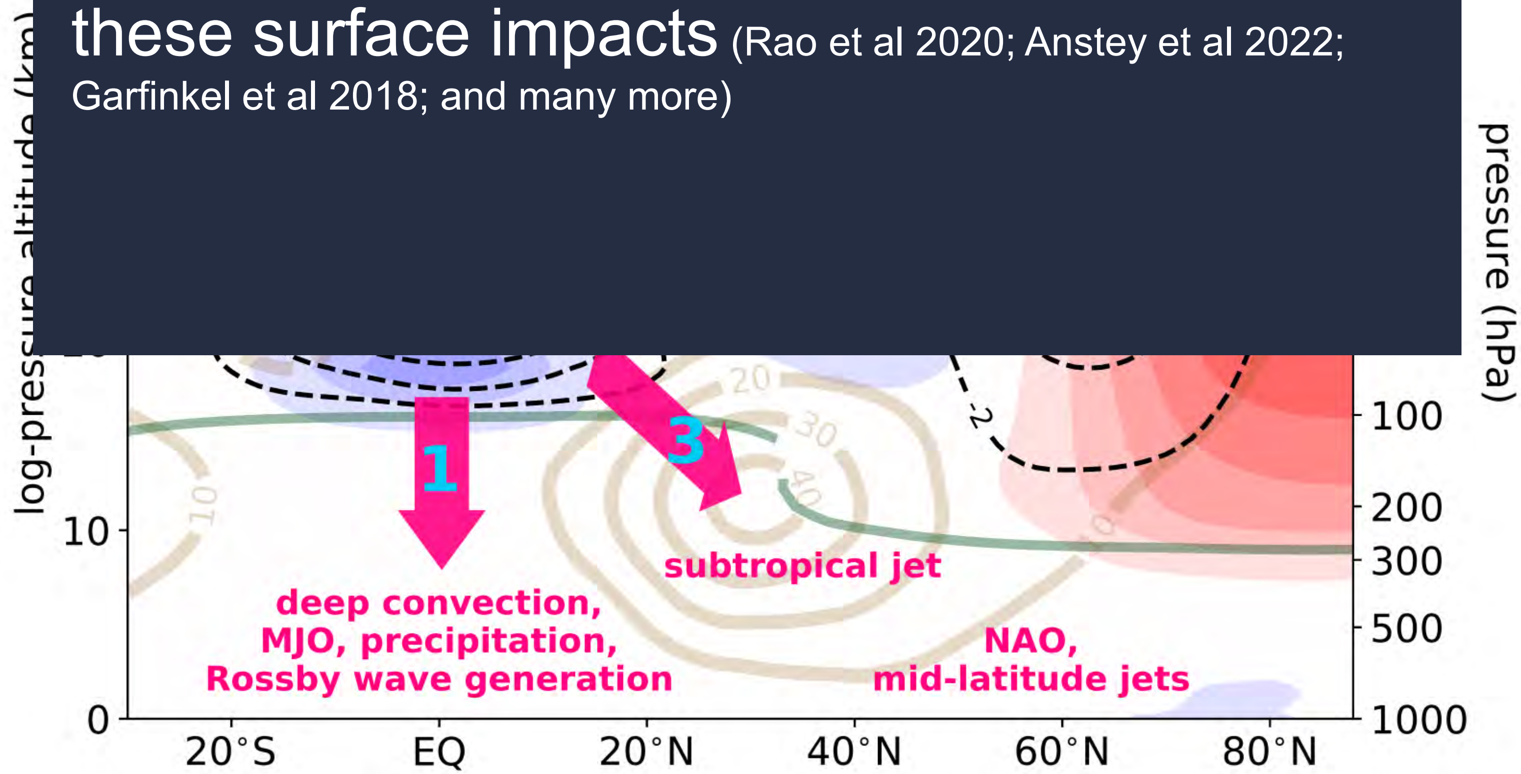
Chaim I. Garfinkel

QBO pathways to surface climate

CMIP, QBOi, and S2S models underestimate these surface impacts (Rao et al 2020; Anstey et al 2022; Garfinkel et al 2018; and many more)



Anstey et al 2022

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Chaim I. Garfinkel

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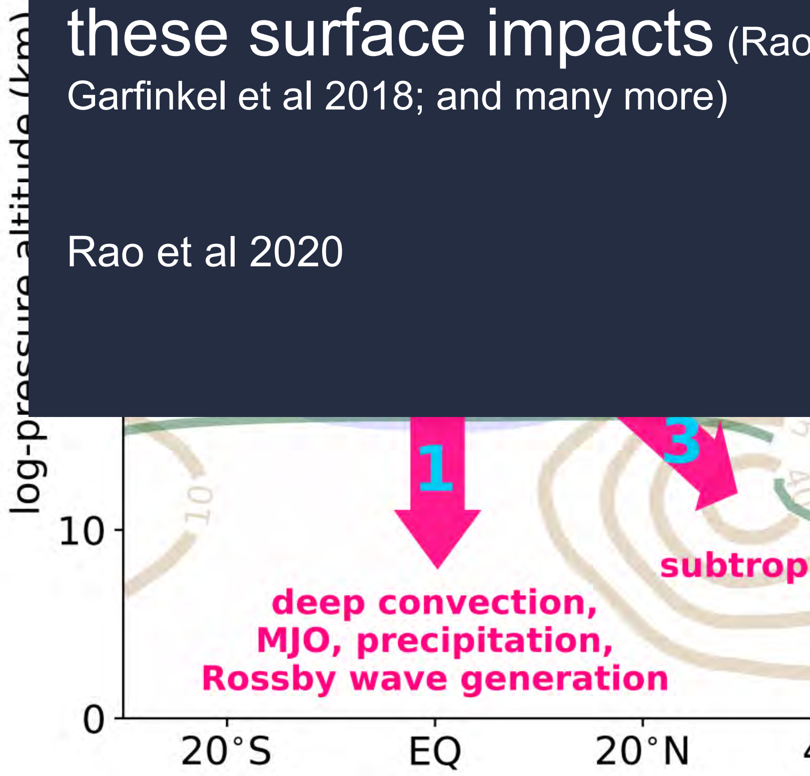
Rao et al 2020



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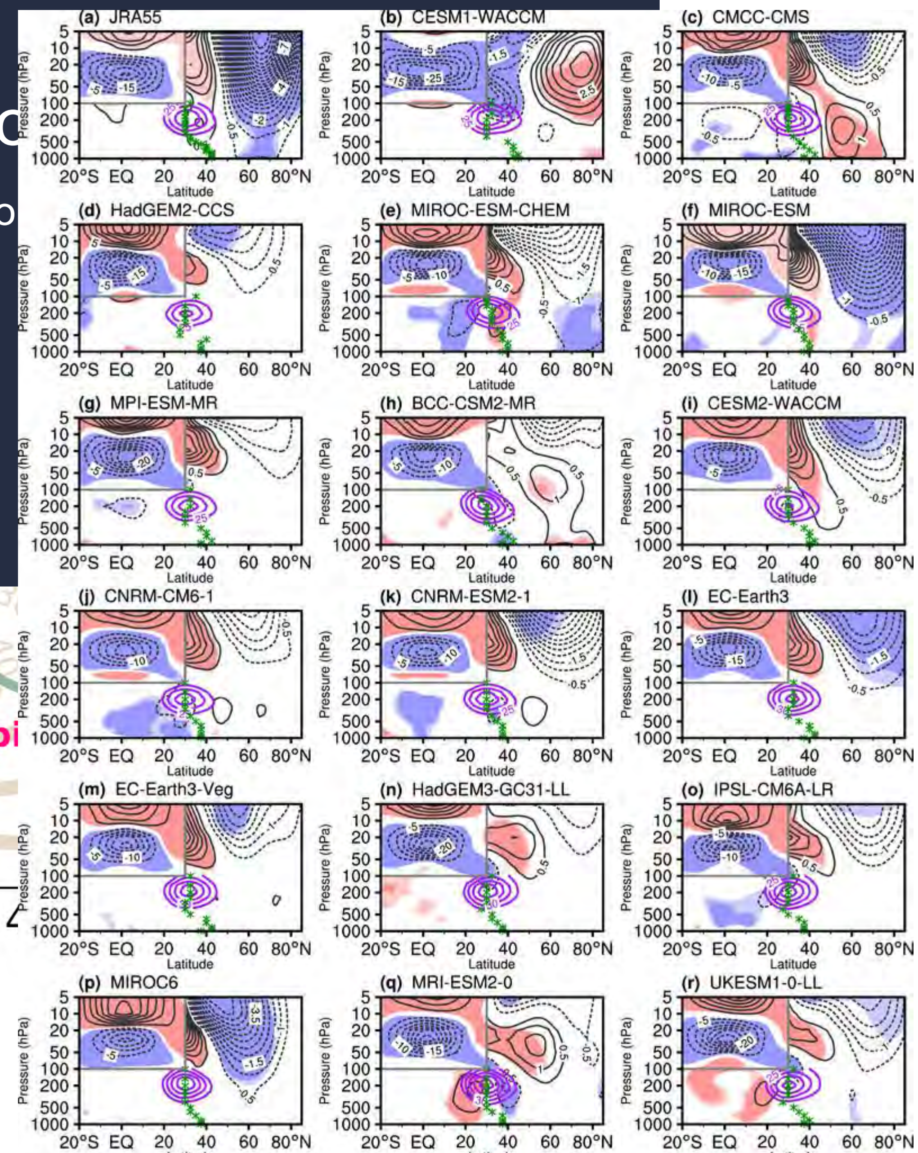

Large Ensemble Single Forcing MIP (LESFMIP)

Experiment name	Description
hist-GHG	Well-mixed greenhouse-gas-only historical simulations (WMGHGs)
hist-aer	Anthropogenic-aerosol-only historical simulations (BC, OC, SO2, SO4, NOx, NH3, CO, NMVOC)
hist-sol	Solar-only historical simulations (solar irradiance)
hist-volc	Volcanic-only historical simulations (stratospheric aerosol)
hist-totalO3	Ozone-only historical simulations (stratospheric and tropospheric ozone)
hist-lu	Historical simulations with only land use changes

- Mainly DAMIP simulations but >10 ensemble members from 1850-2020
- Additional runs to assess non-linearity and sensitivity to background state
- ~12 modeling centers. Data from eleven is on ESGF and in a JASMIN workspace. 4 models represent the QBO.

Smith et al 2022; Gillett et al 2016; Findell et al. 2023

Eight working groups

1) Role of **annual to decadal variability** of the **polar vortex** for surface climate

2) Identifying the forced response of the **Southern Hemispheric atmospheric circulation** to greenhouse gases, aerosols, and ozone, and associated surface impacts on extremes

3) Identifying the forced response of the **Northern Hemispheric atmospheric circulation** to greenhouse gases, aerosols, and ozone, and associated surface impacts on extremes

4) Surface response to **solar** variability

5) Surface response to **Pinatubo** and other large **eruptions**

6) QBO influences on surface climate (4 models spontaneously simulate a QBO)

7) Identifying the forced response of the **Asian monsoon** to greenhouse gases, aerosols, and ozone, and associated surface impacts on extremes

8) Role of external forcings and internal variability for **atmospheric temperature trends**:

Methodology – four models with a QBO

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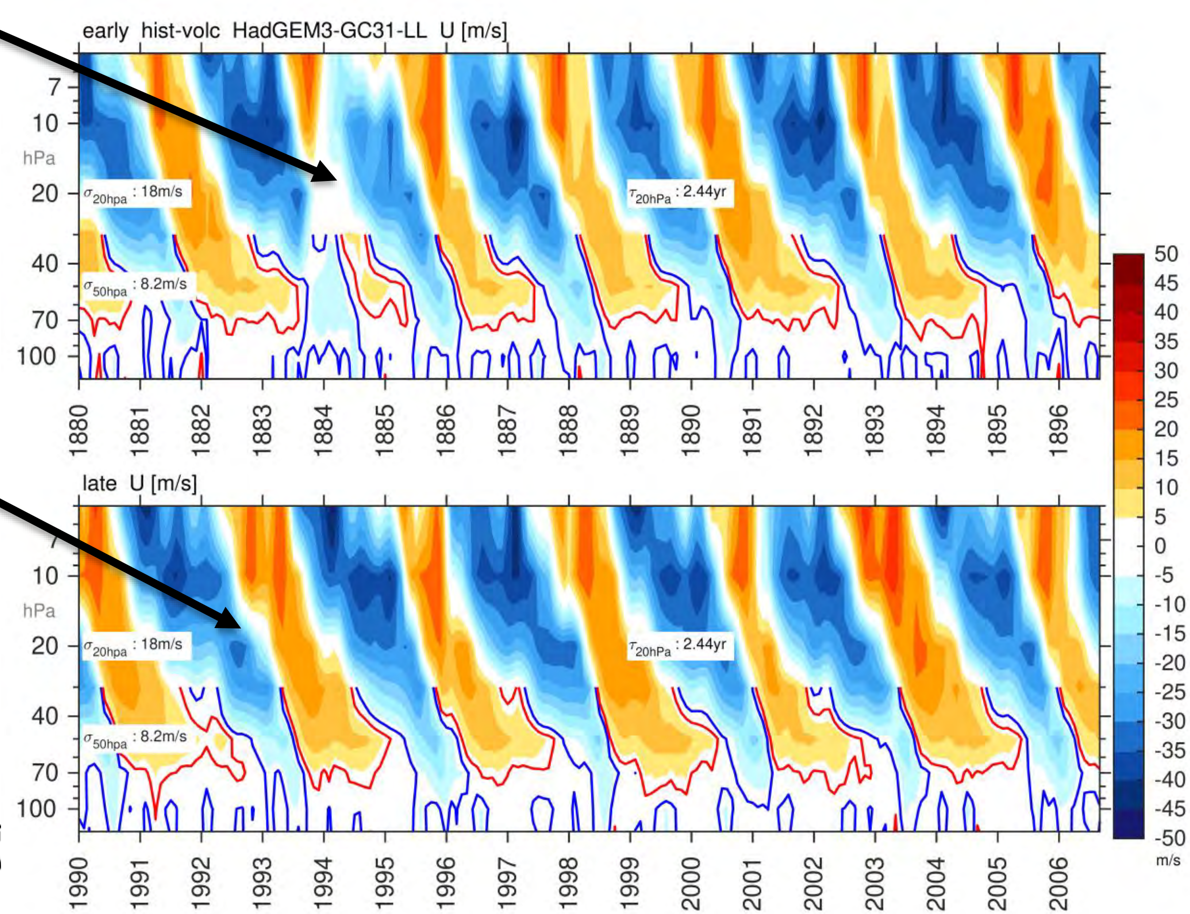

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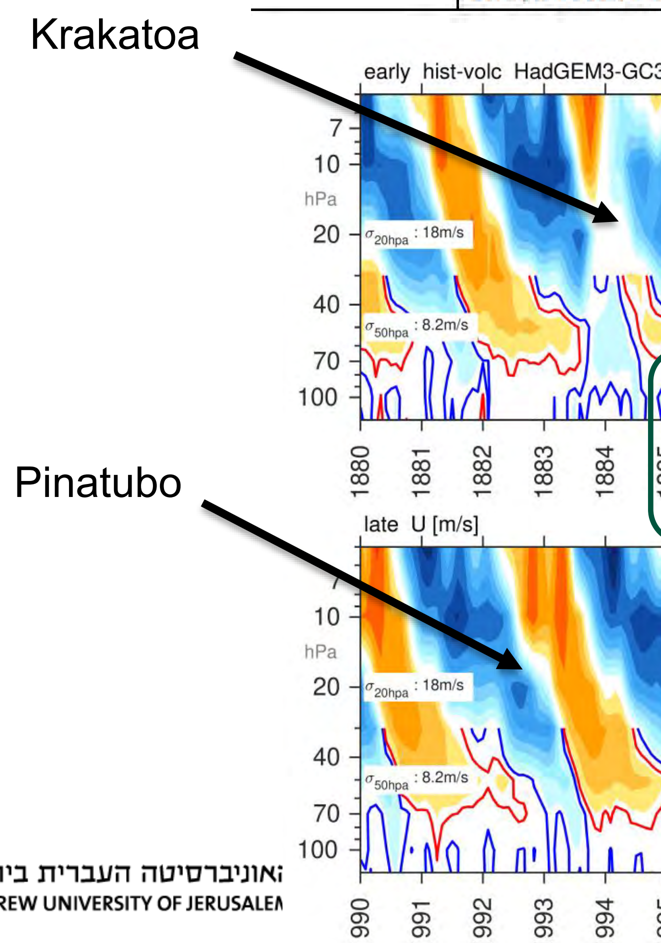

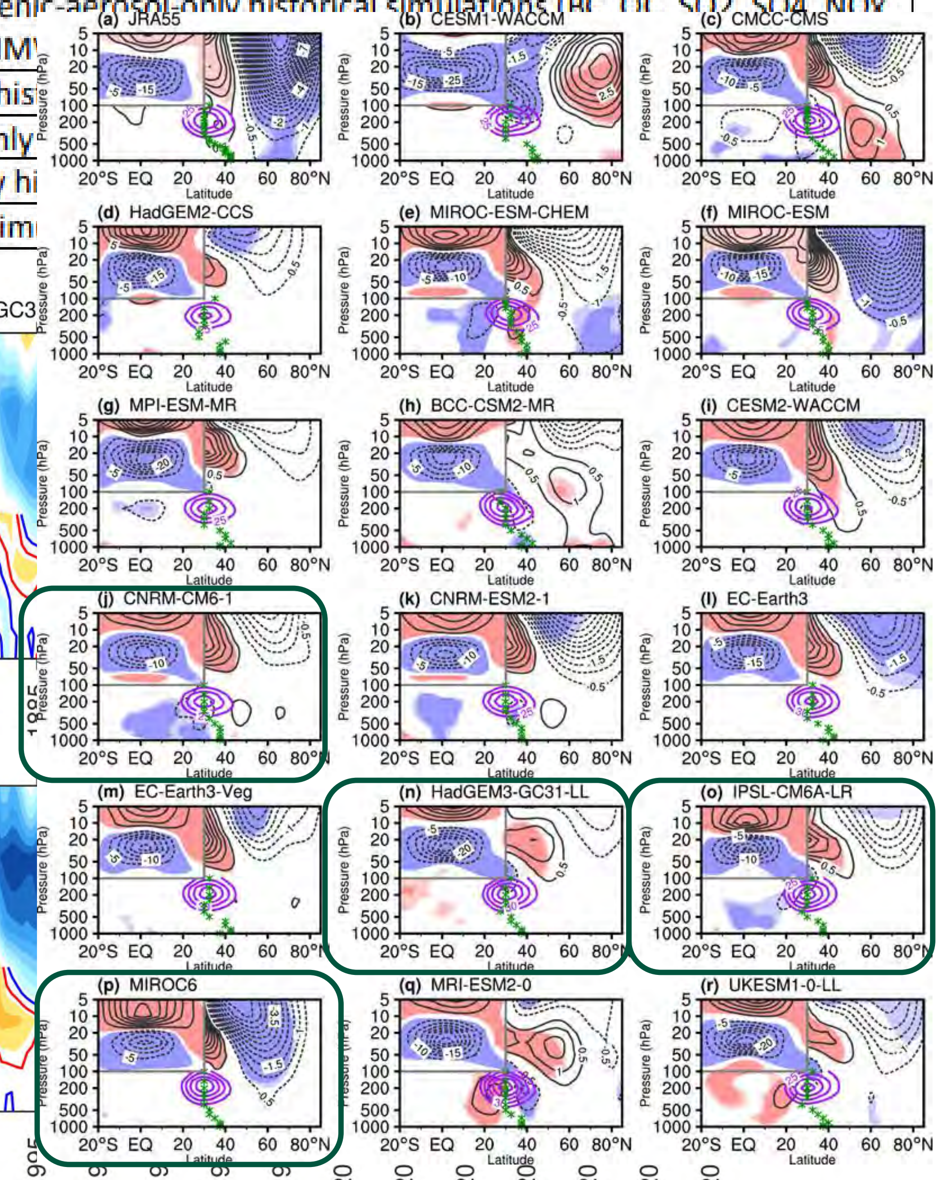

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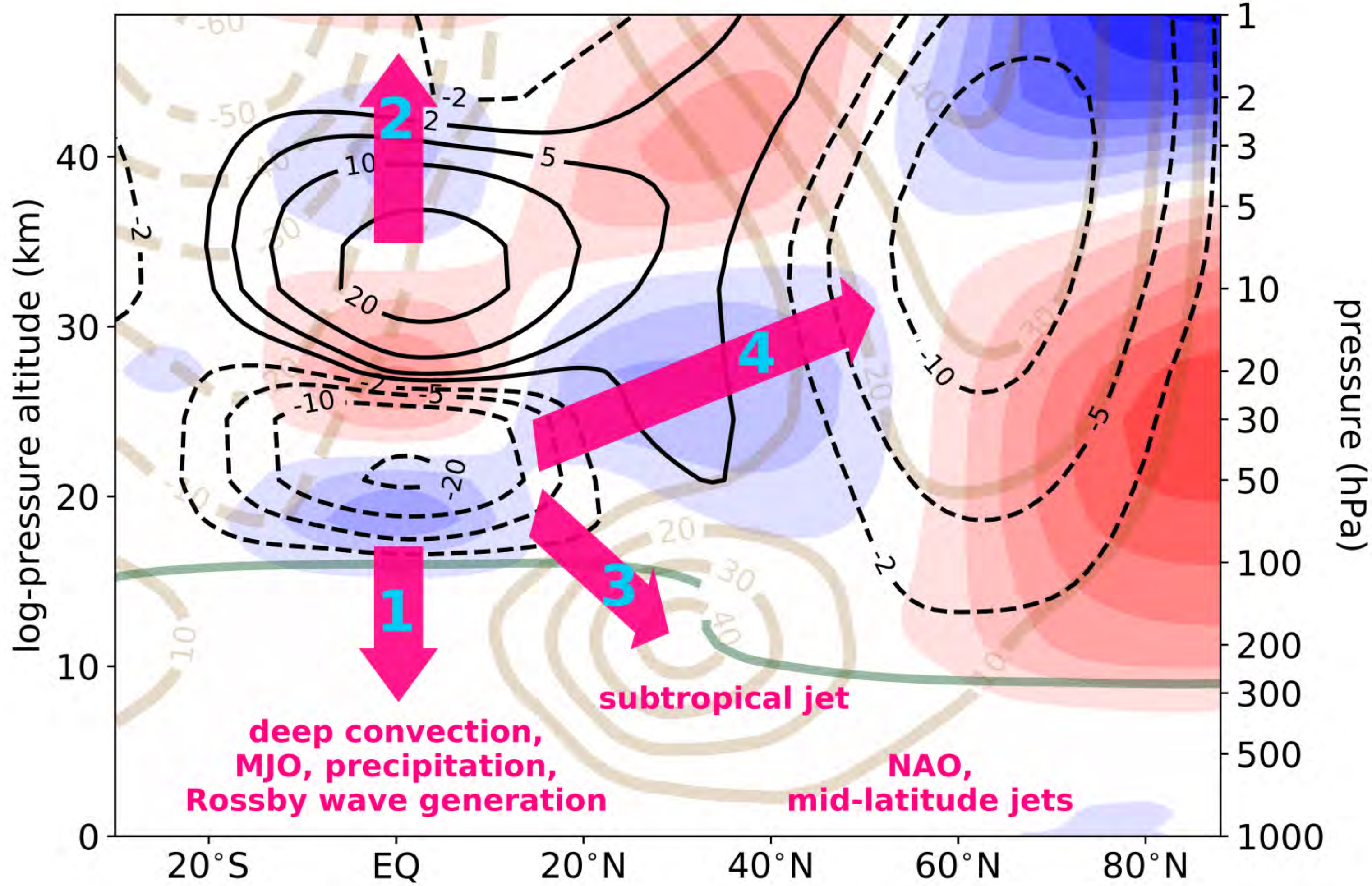
QBO pathways to surface climate



Anstey et al 2022

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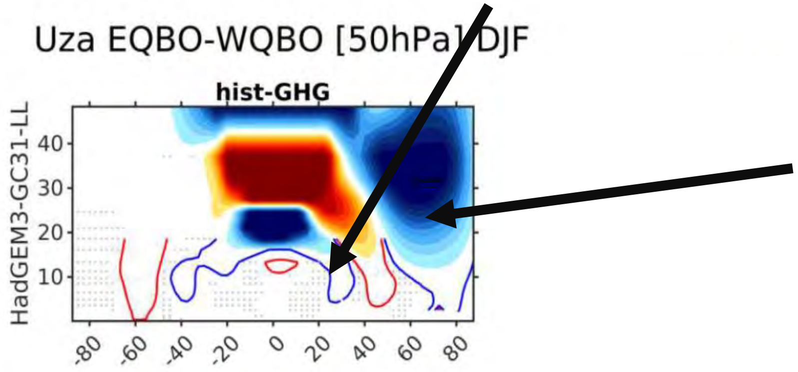

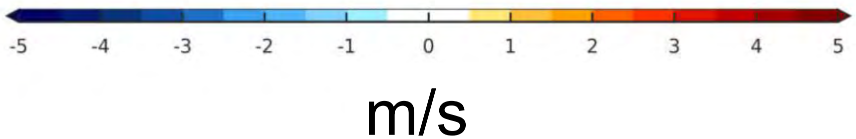

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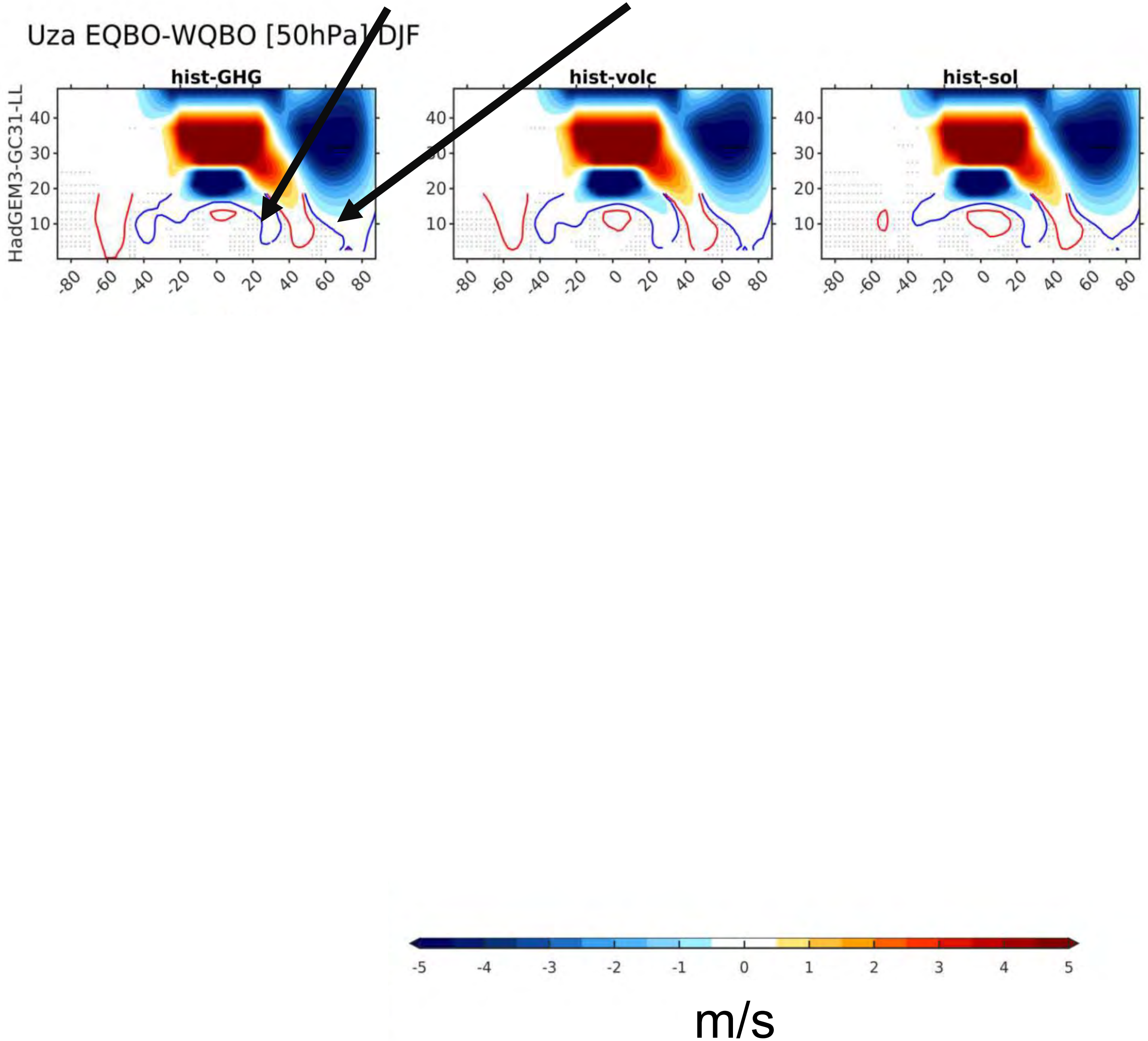

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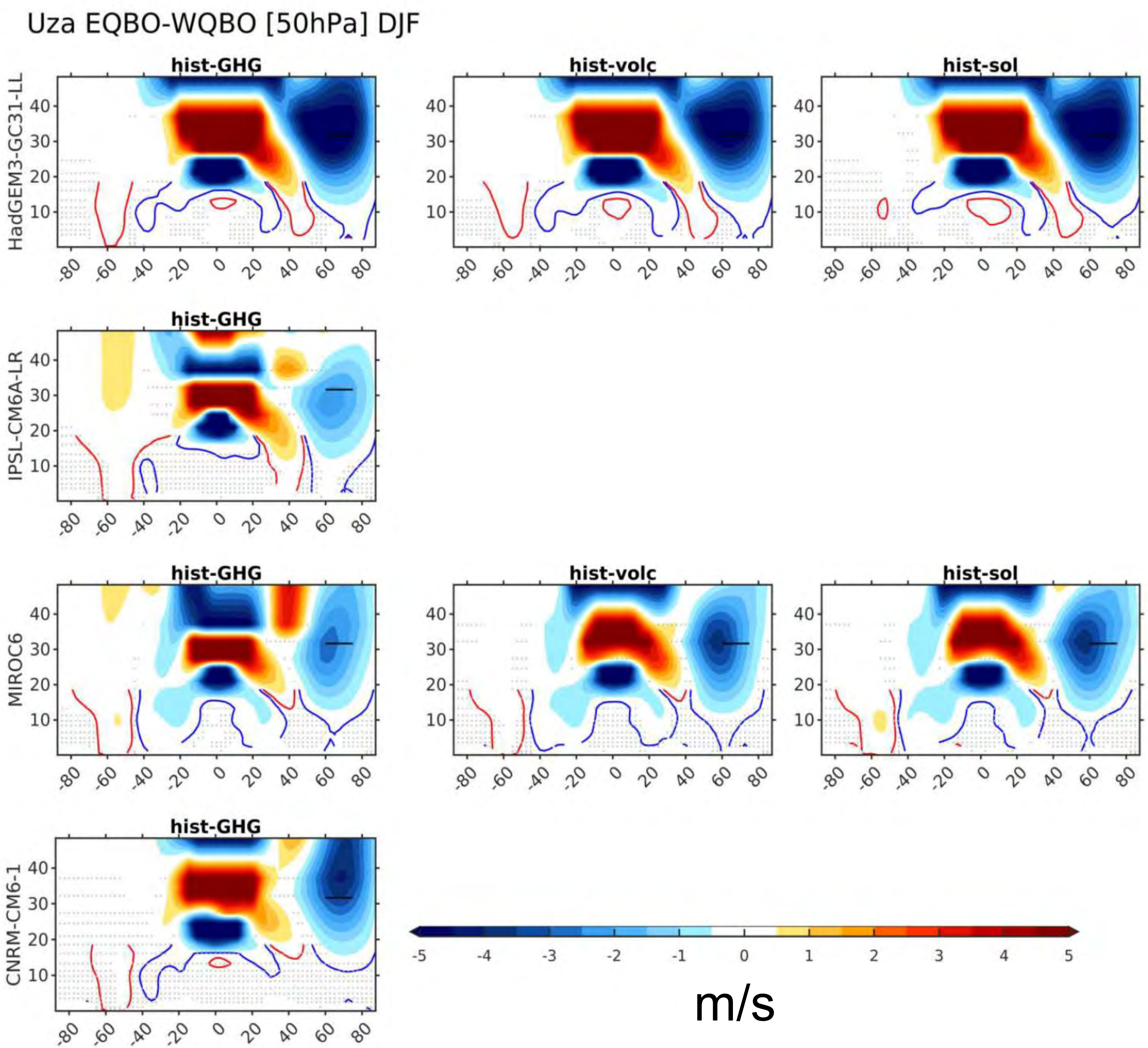
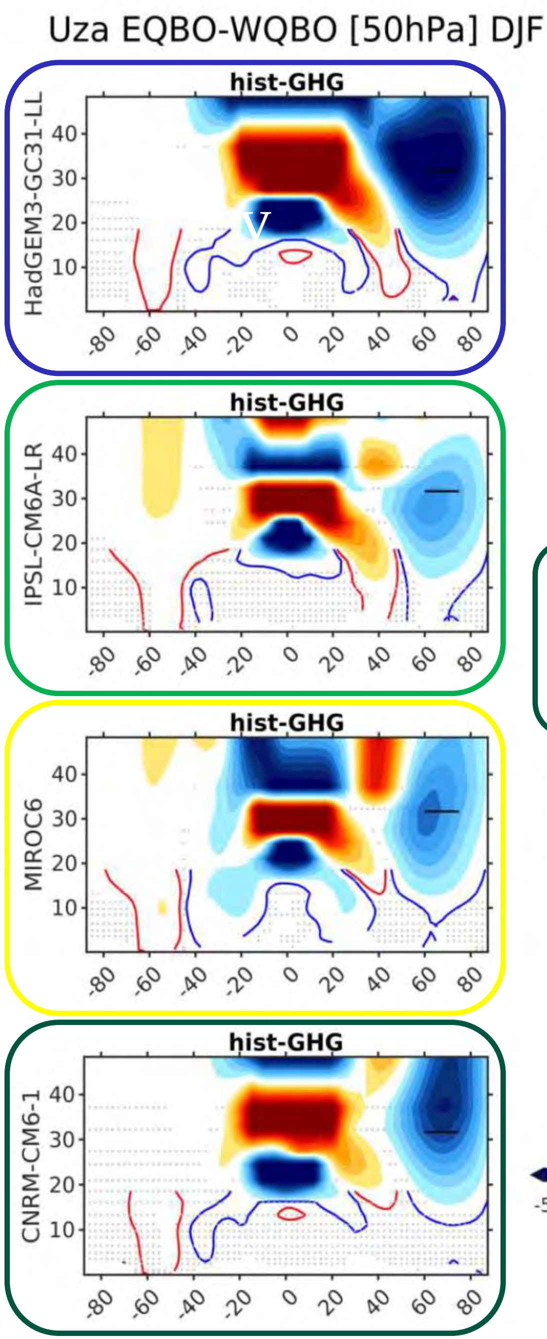
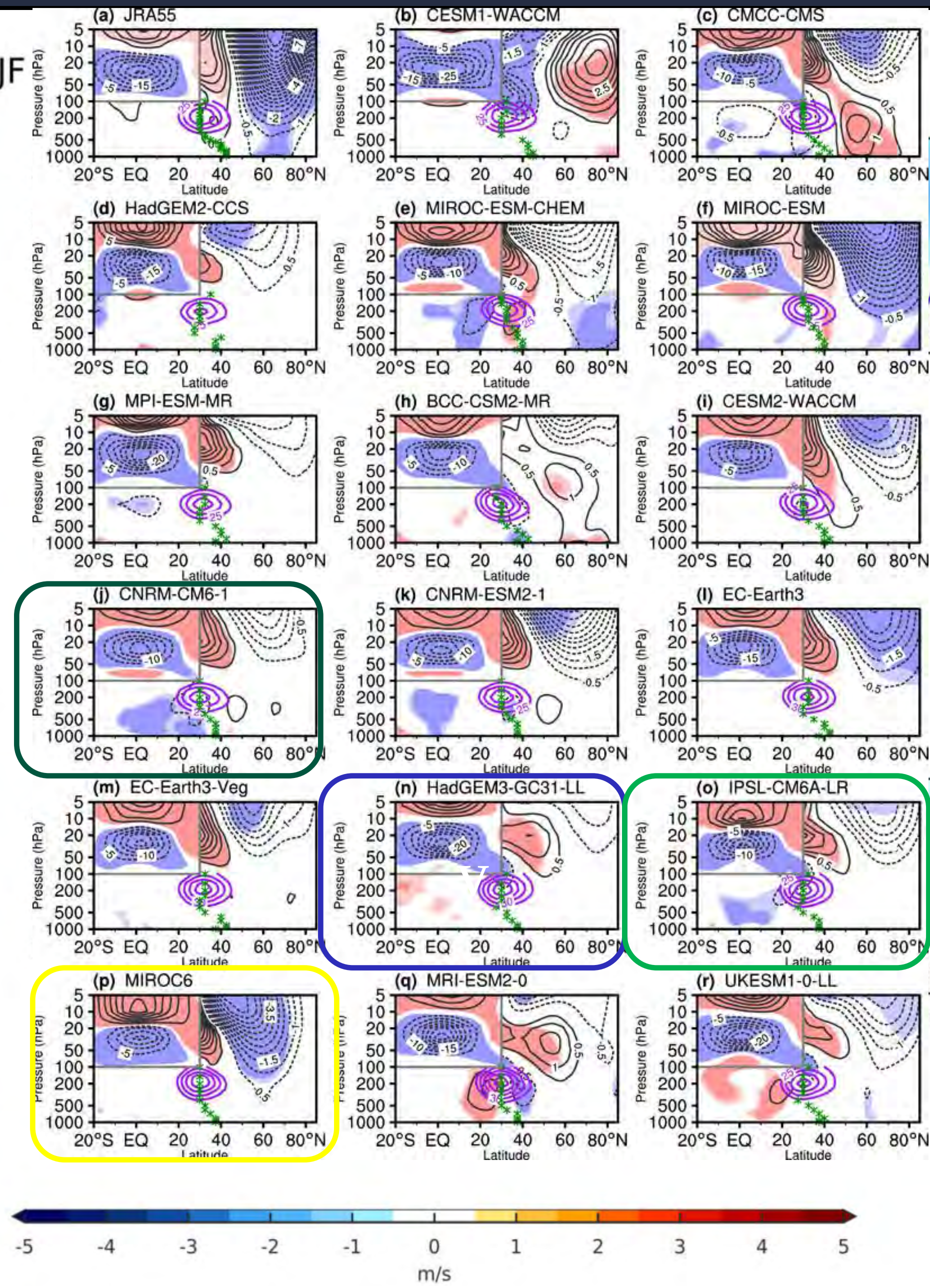


More robust response for the four models with a QBO in LESFMIP than CMIP

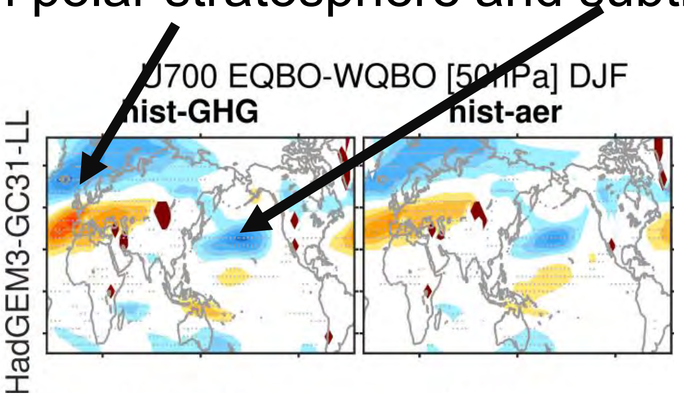


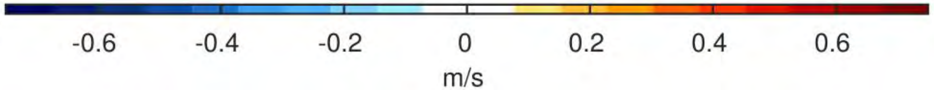


Chaim I. Garfinkel

U700 response to QBO

- Both polar stratosphere and subtropical routes evident





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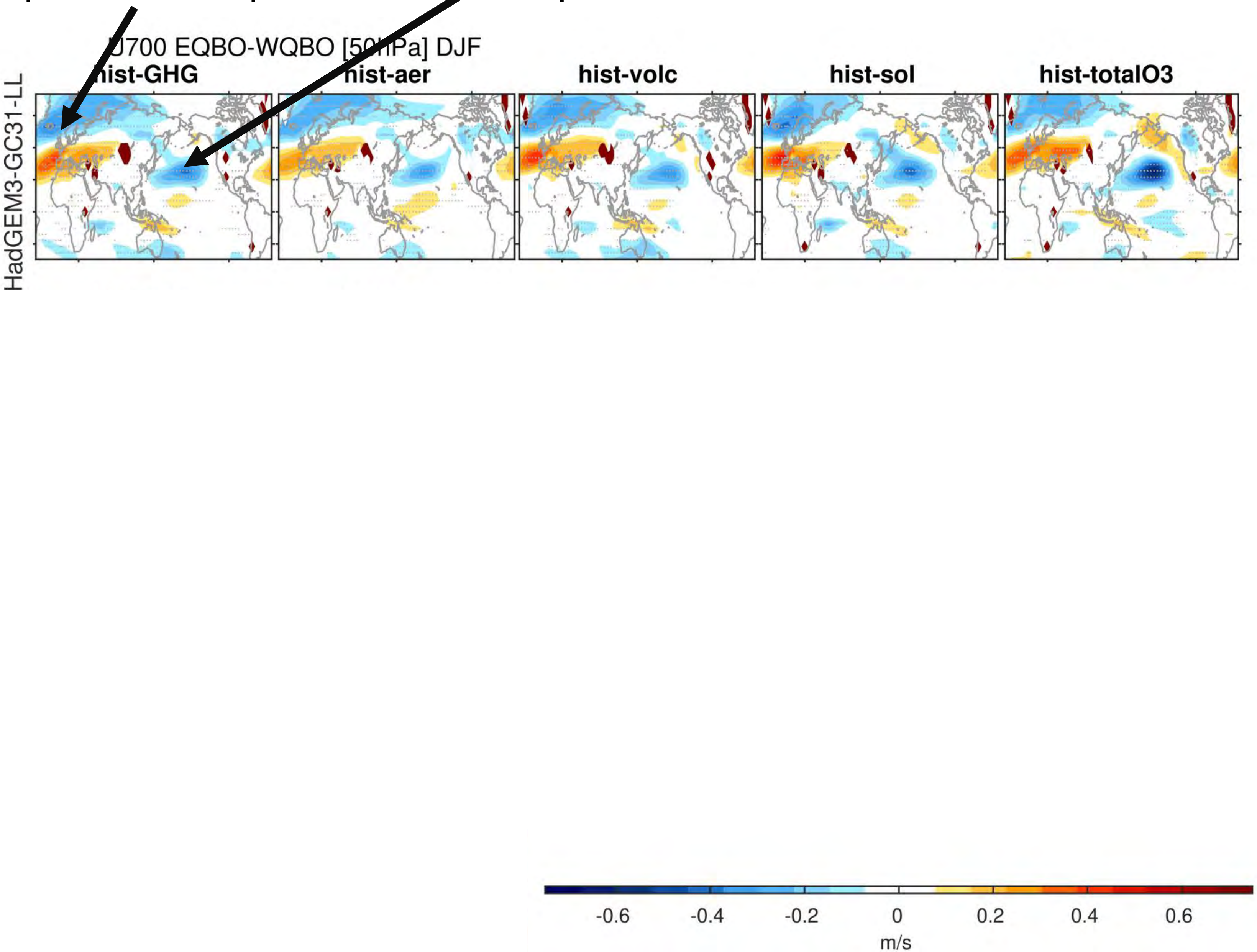

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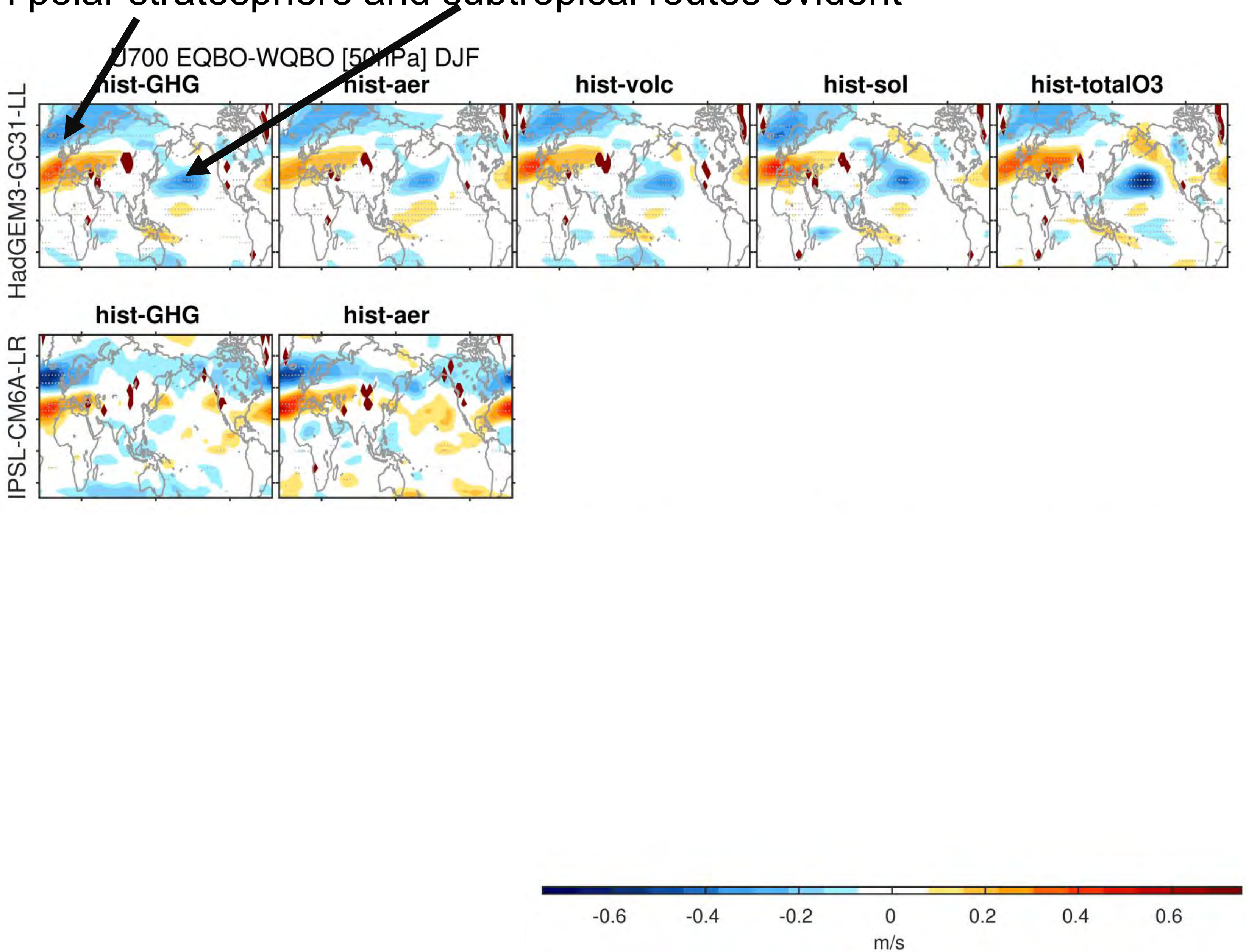

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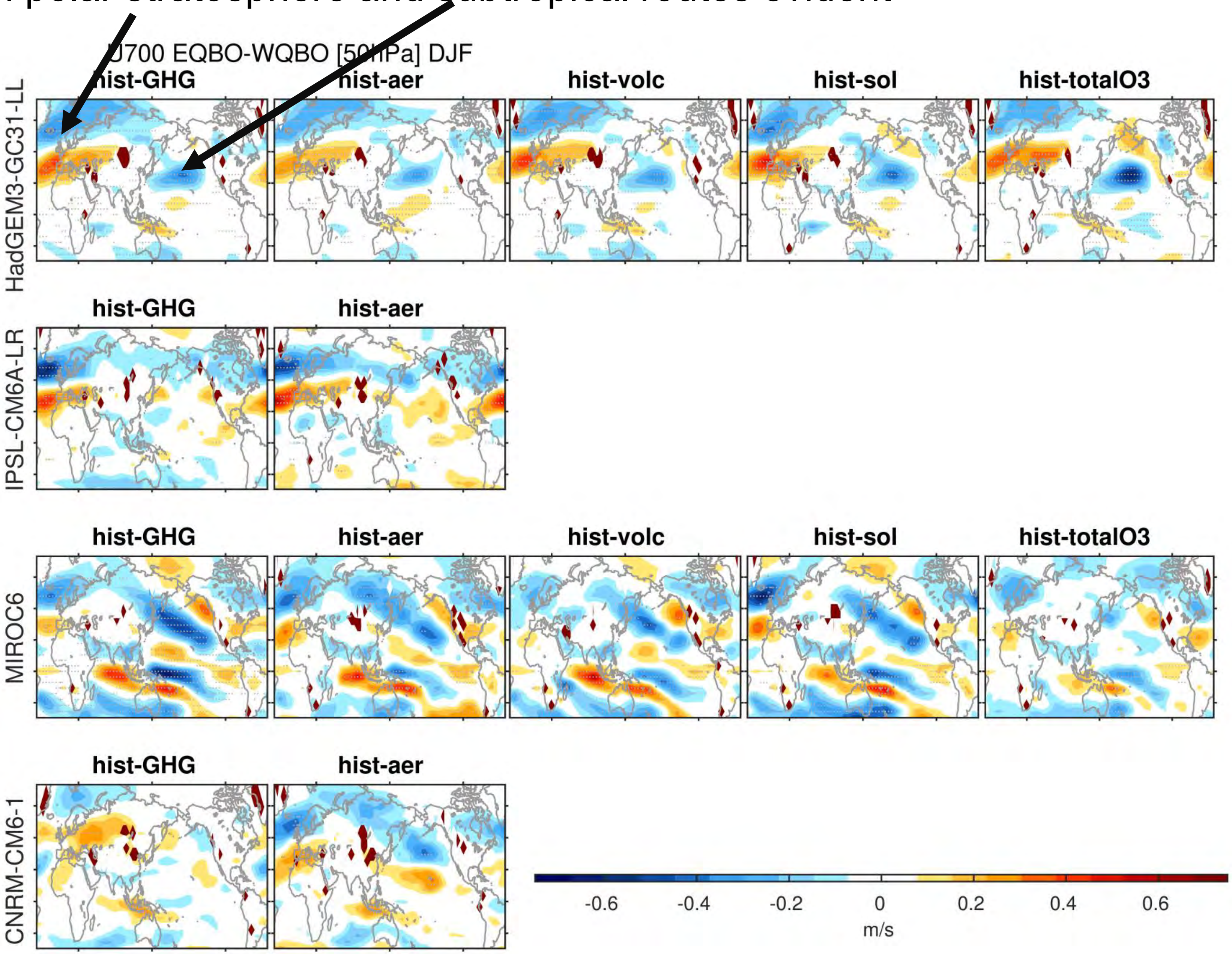

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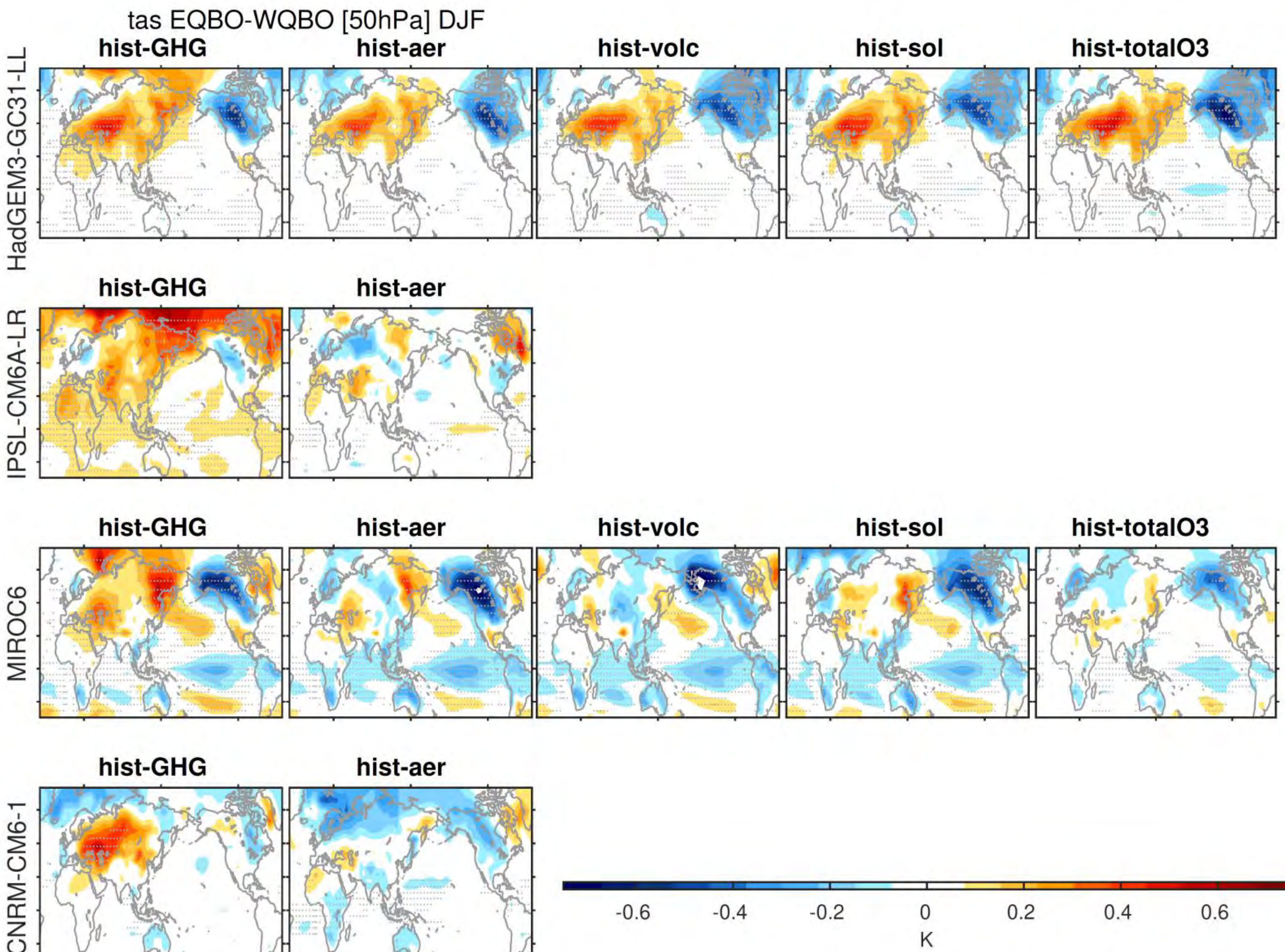
surface T response to QBO

- Eurasian warmer consistent with the increased wind speed. North American cooling.



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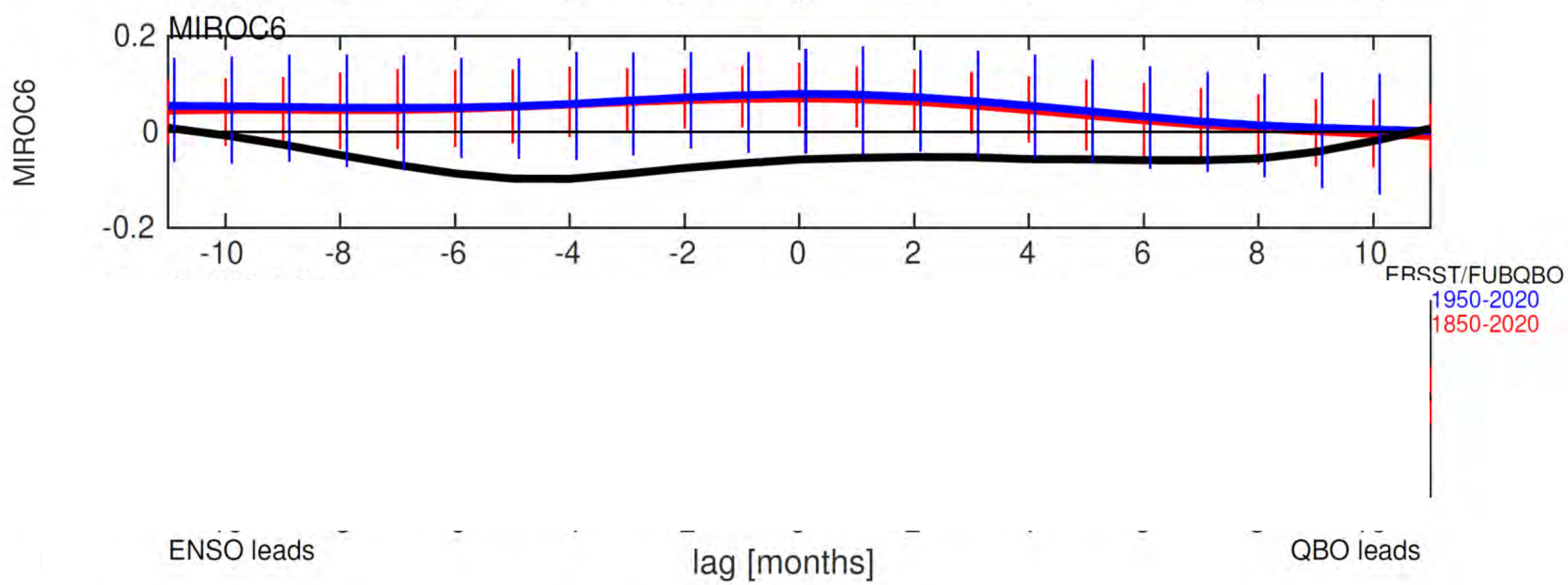
Correlation of QBO50 with Nino3.4

- MIROC6 has a La Nina response for eQBO, El Nino for wQBO. Inconsistent with obs



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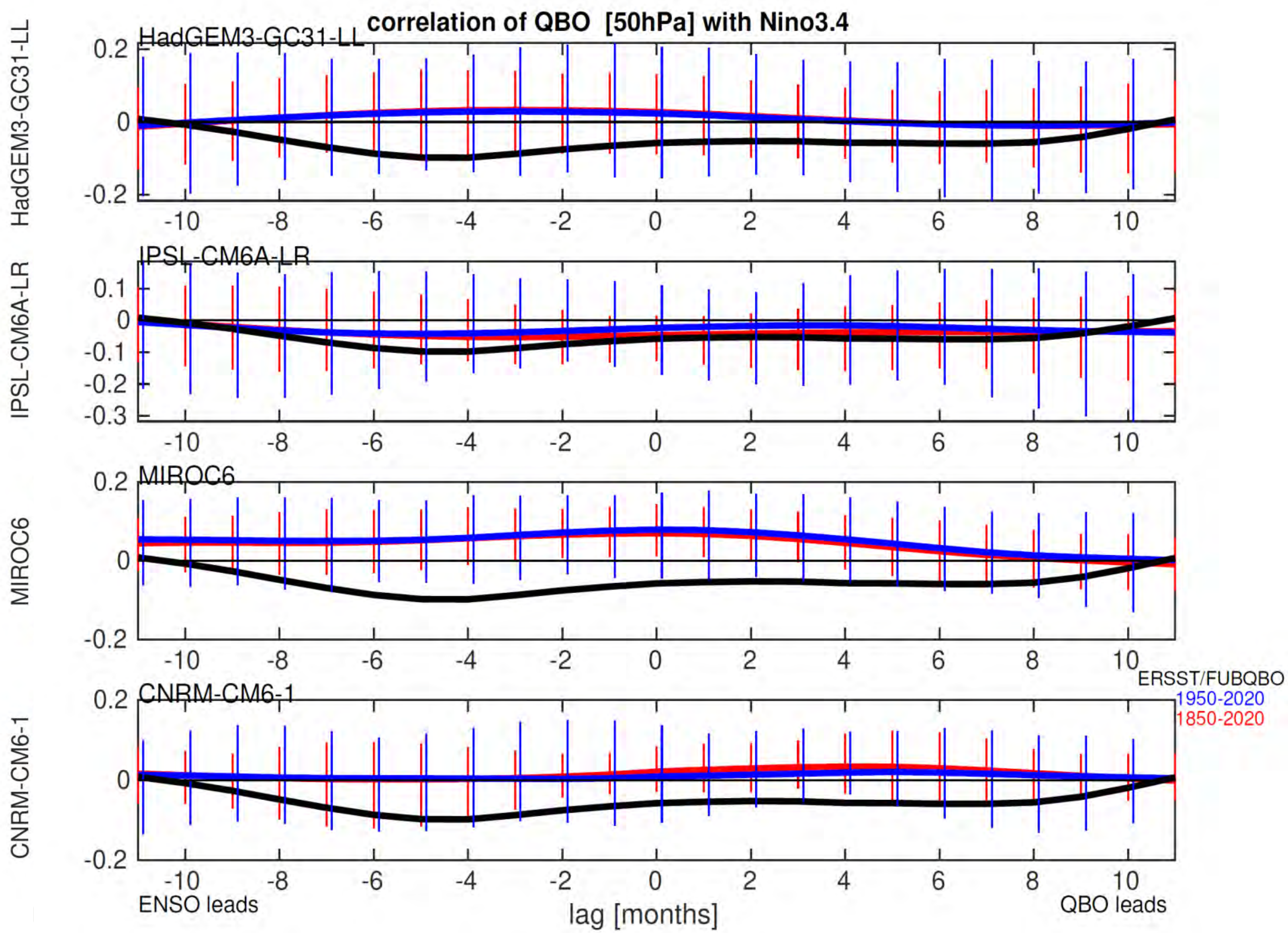
surface T response to QBO

- MIROC6 has a La Nina response for eQBO, but IPSL has the opposite!



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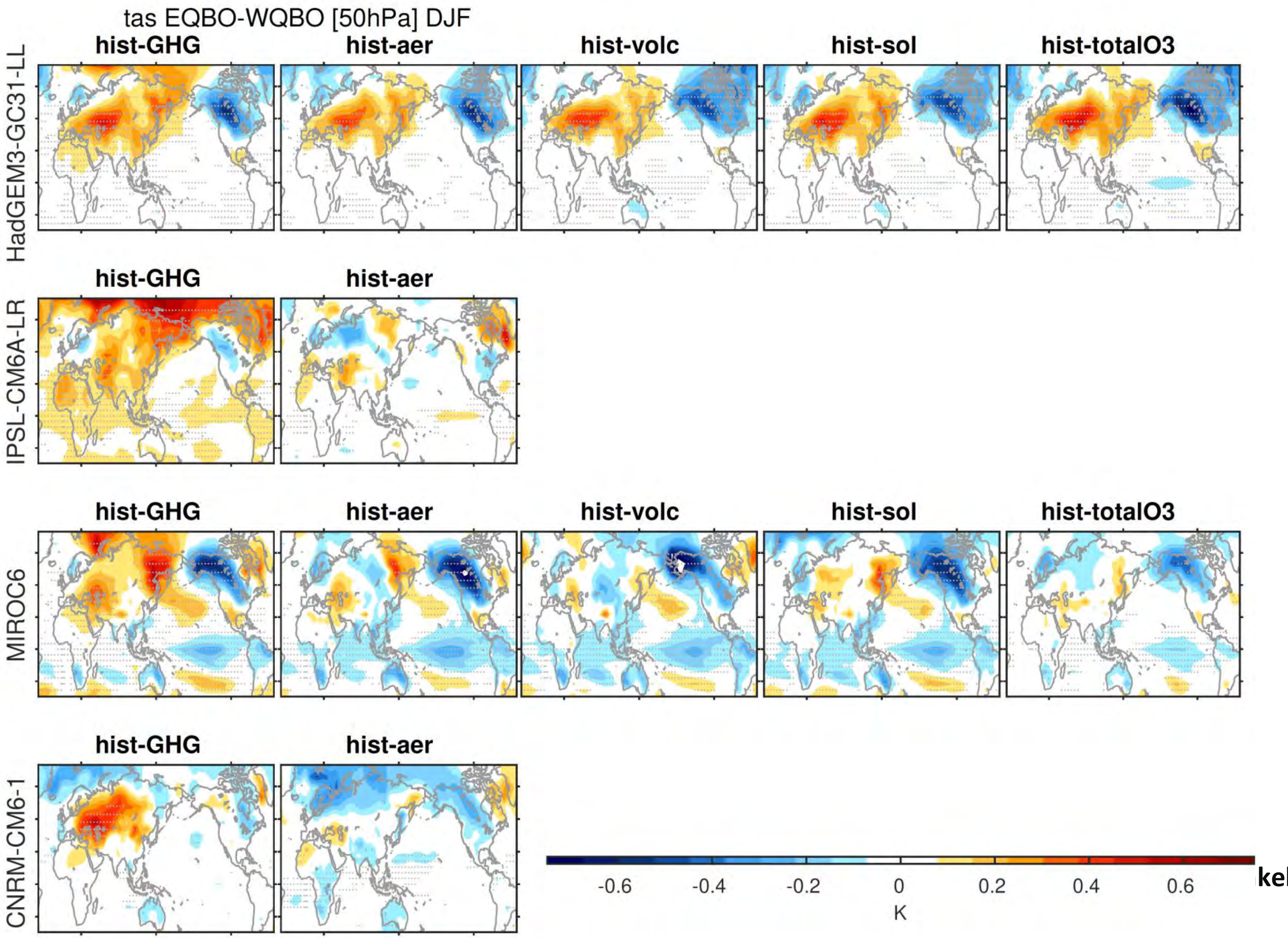
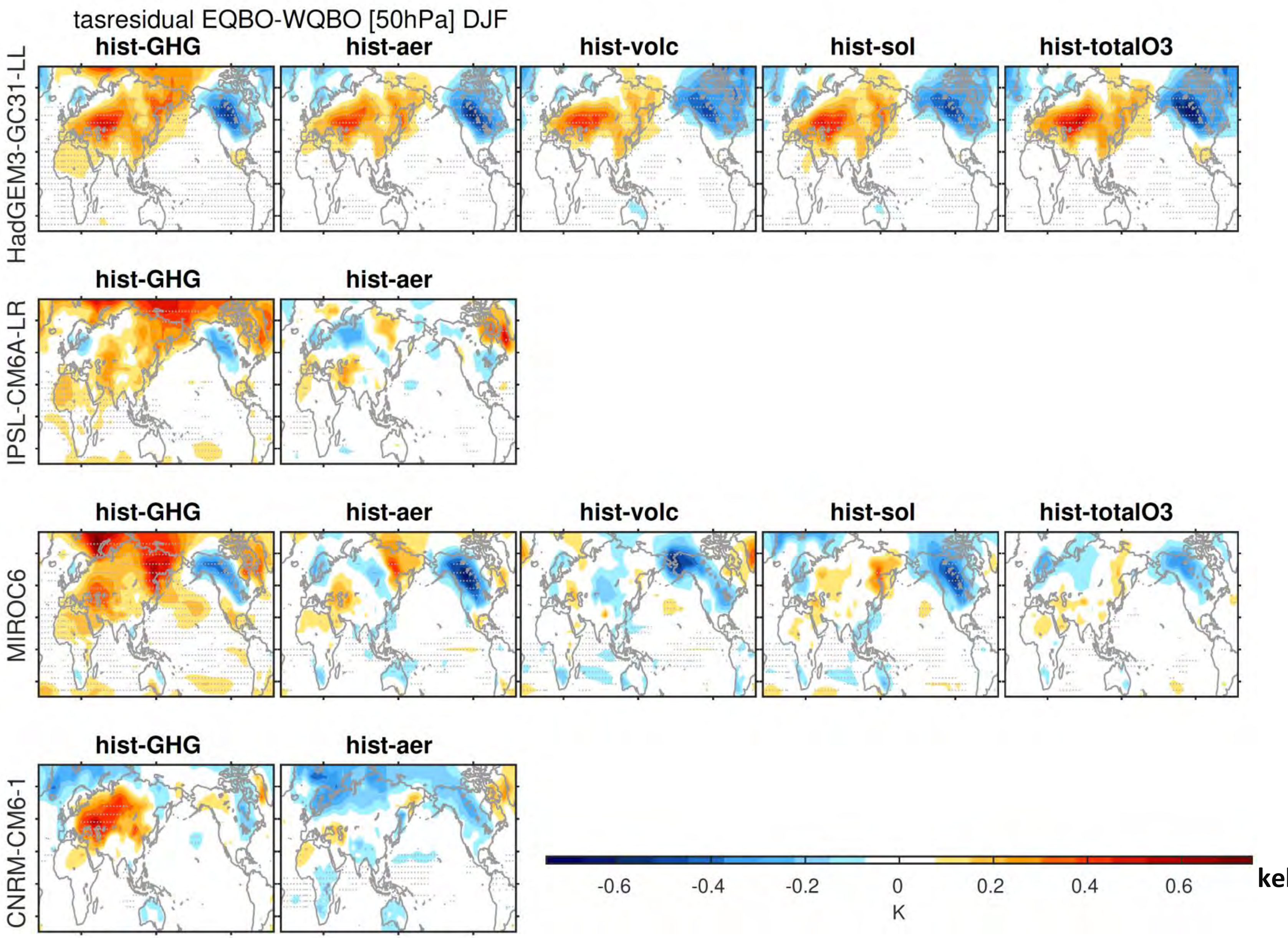
surface T response to QBO

- Are these signals aliased from ENSO?

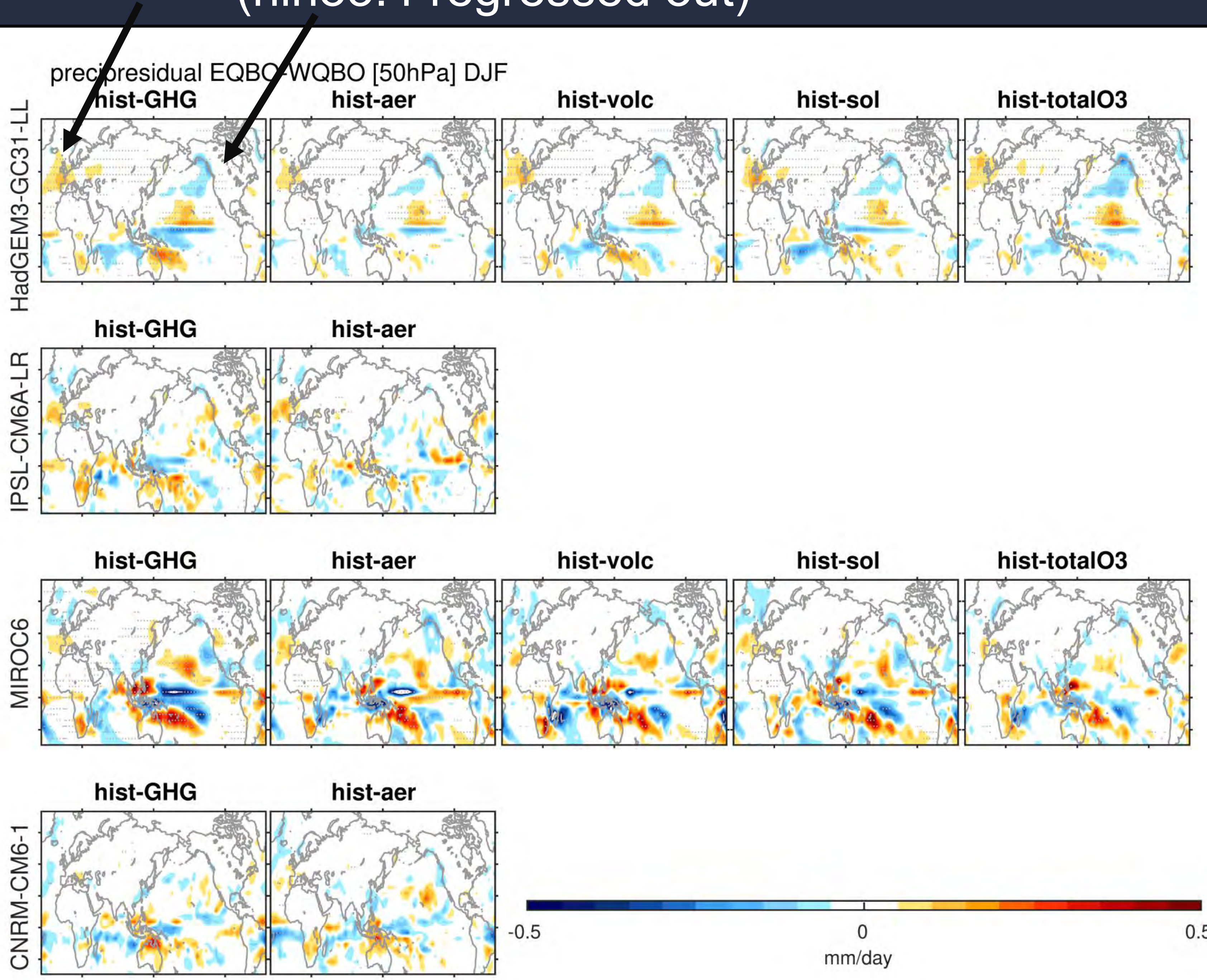


Surface T response after regressing out ENSO

- Generally similar signal, more model agreement but CNRM still outlier



precip response to QBO, DJF
(nino3.4 regressed out)



precip response to QBO, JJA

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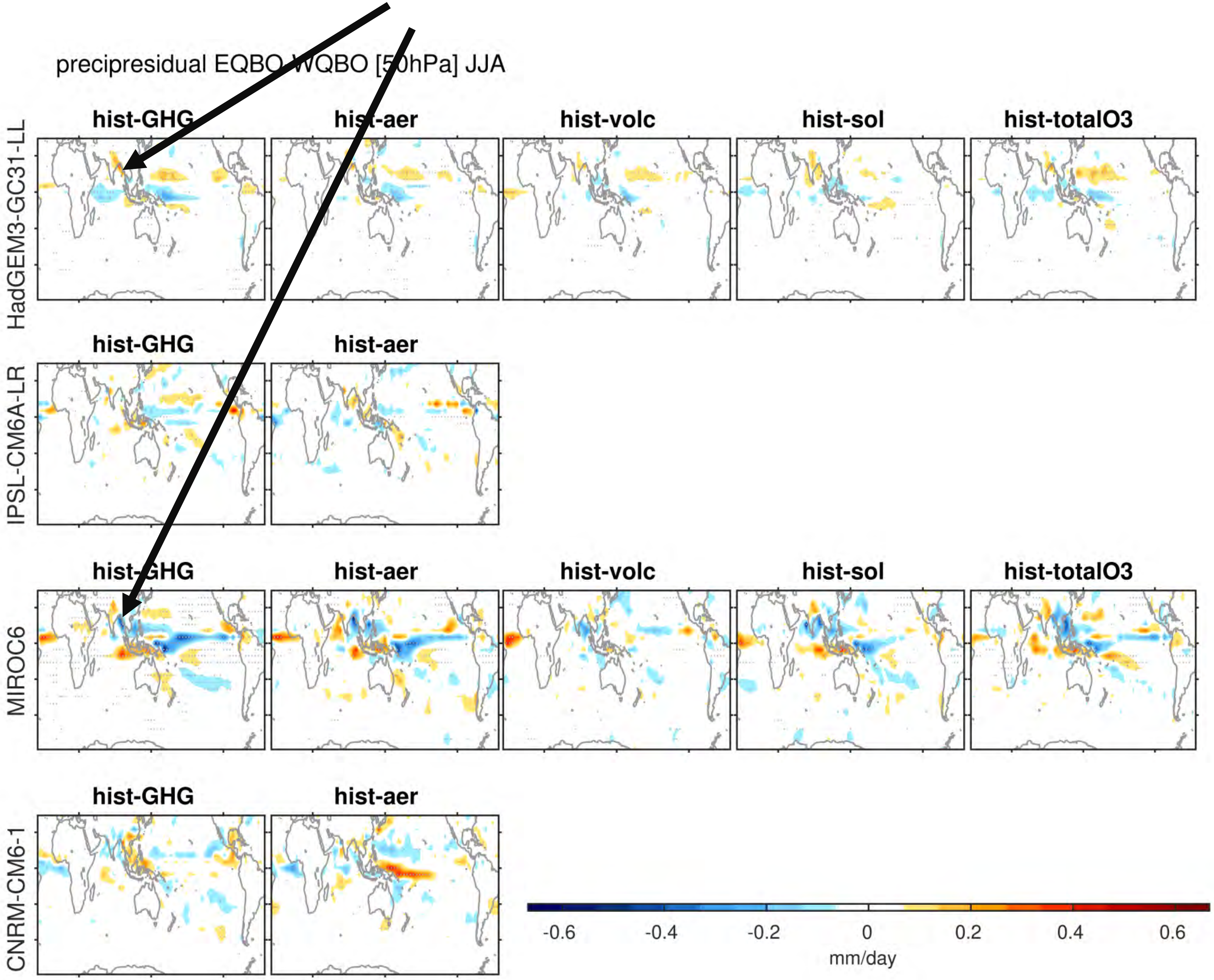
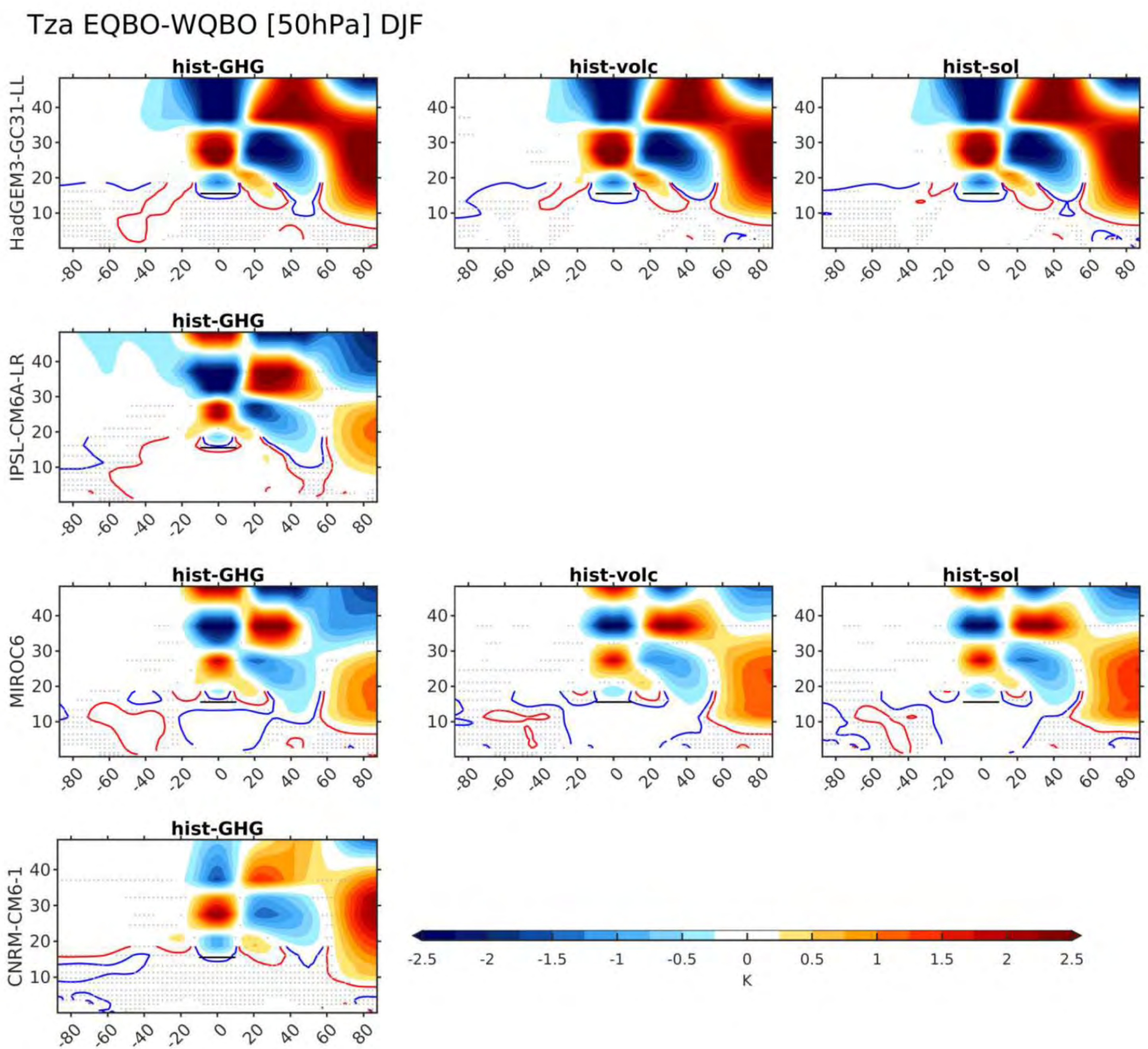


QBO pathways to surface climate



Conclusions

~62,000 years of model output contributed by four modeling centers to the Large Ensemble Single Forcing Model Intercomparison Project (LESFMIP).

QBO has a significant impact on surface T and precipitation over much of Eurasia and North America in DJF. Also over monsoons in JJA.

To do: i) analyze ensemble spread to consider whether the model response is consistent with obs, or is too weak; ii) seasonality of response; iii) do teleconnections strengthen in time?

Discussion: how best to isolate QBO signal from ENSO? Is the linear regression approach enough?

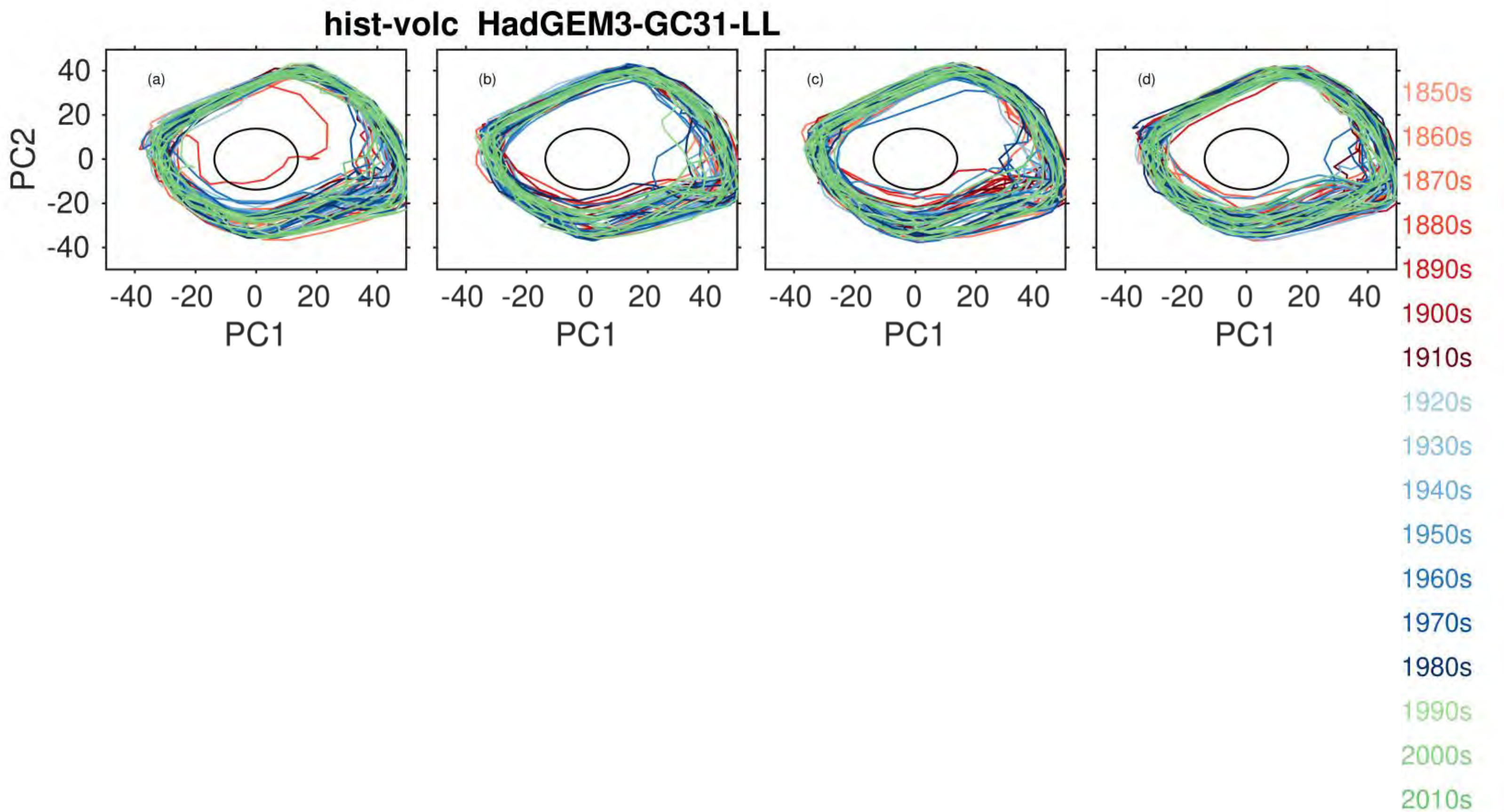
Conclusions from paper 1 [submitted]:
Increasing greenhouse gas concentrations and explosive volcanic eruptions lead to weakening of the QBO and an increased likelihood of a disruption event.

Increasing aerosols leads to a strengthening of the QBO.

The ozone forcing used for LESFMIP helps synchronize the QBO phase regime across ensemble members, and also increases the strength of the QBO.

Transition to EOF phase space

- Disruptions occur preferentially in the 1880s and 1990s in hist-vol



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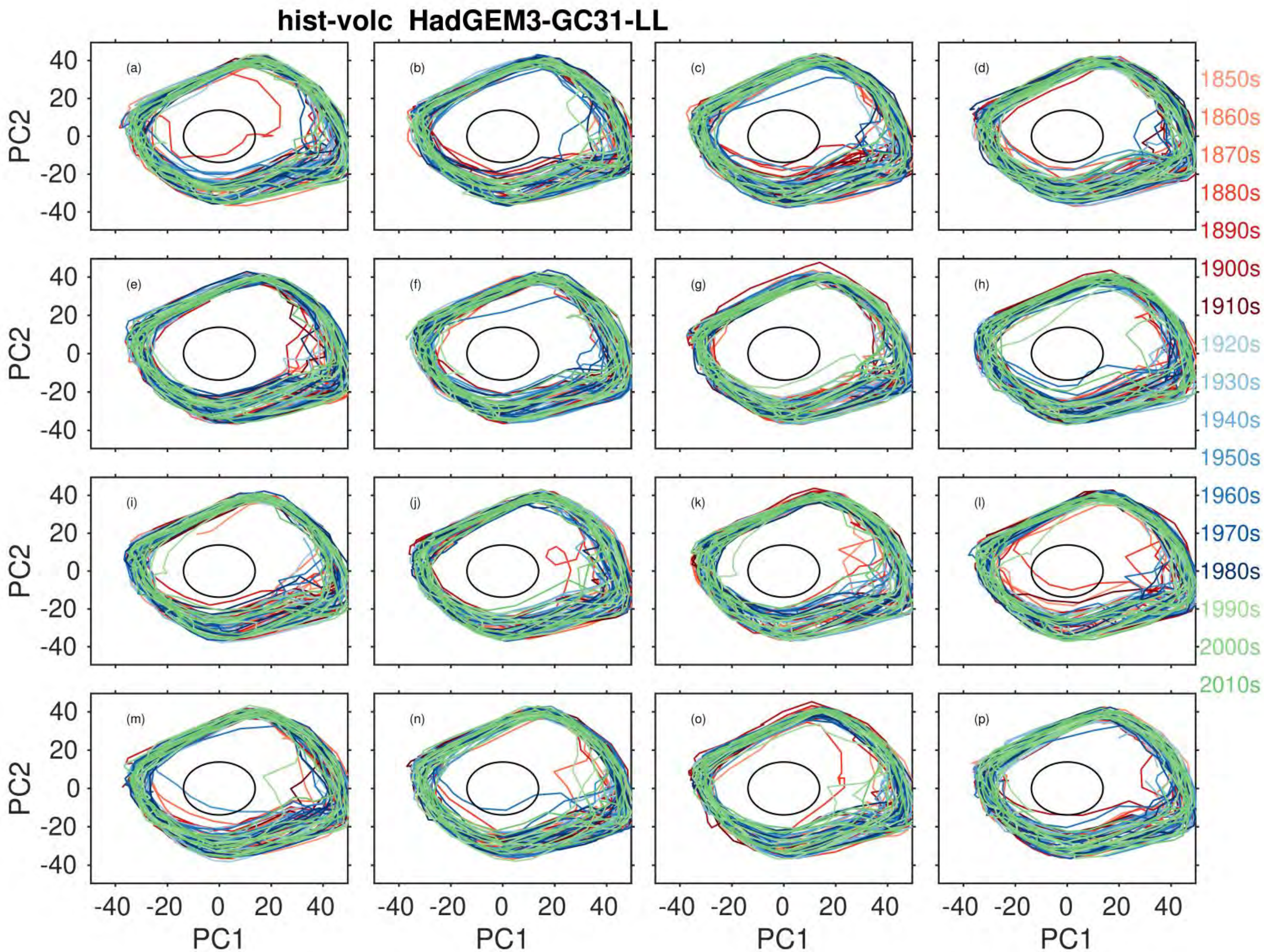

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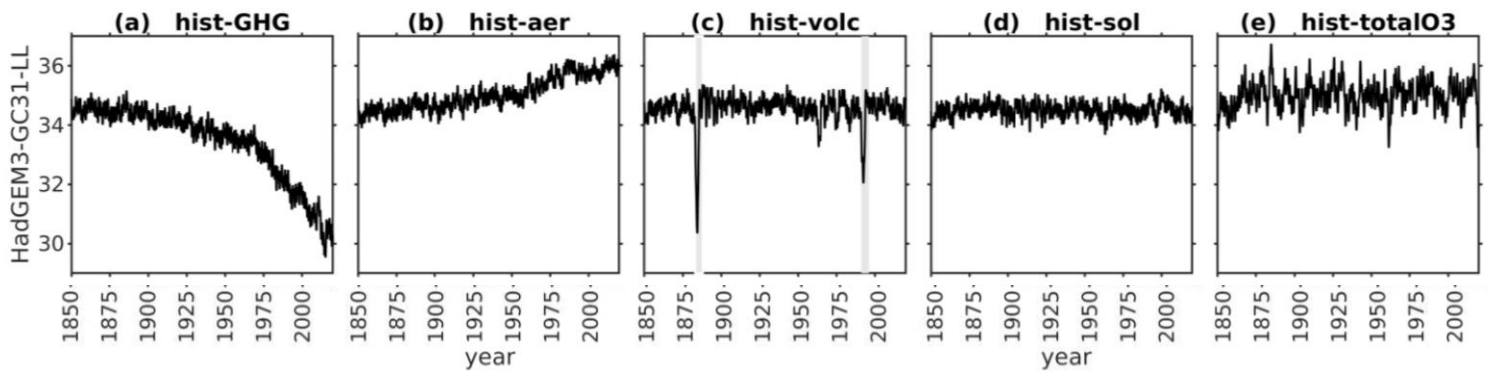
QBO amplitude

- GHG, aerosols, and volcanos all have notable influence on QBO amplitude



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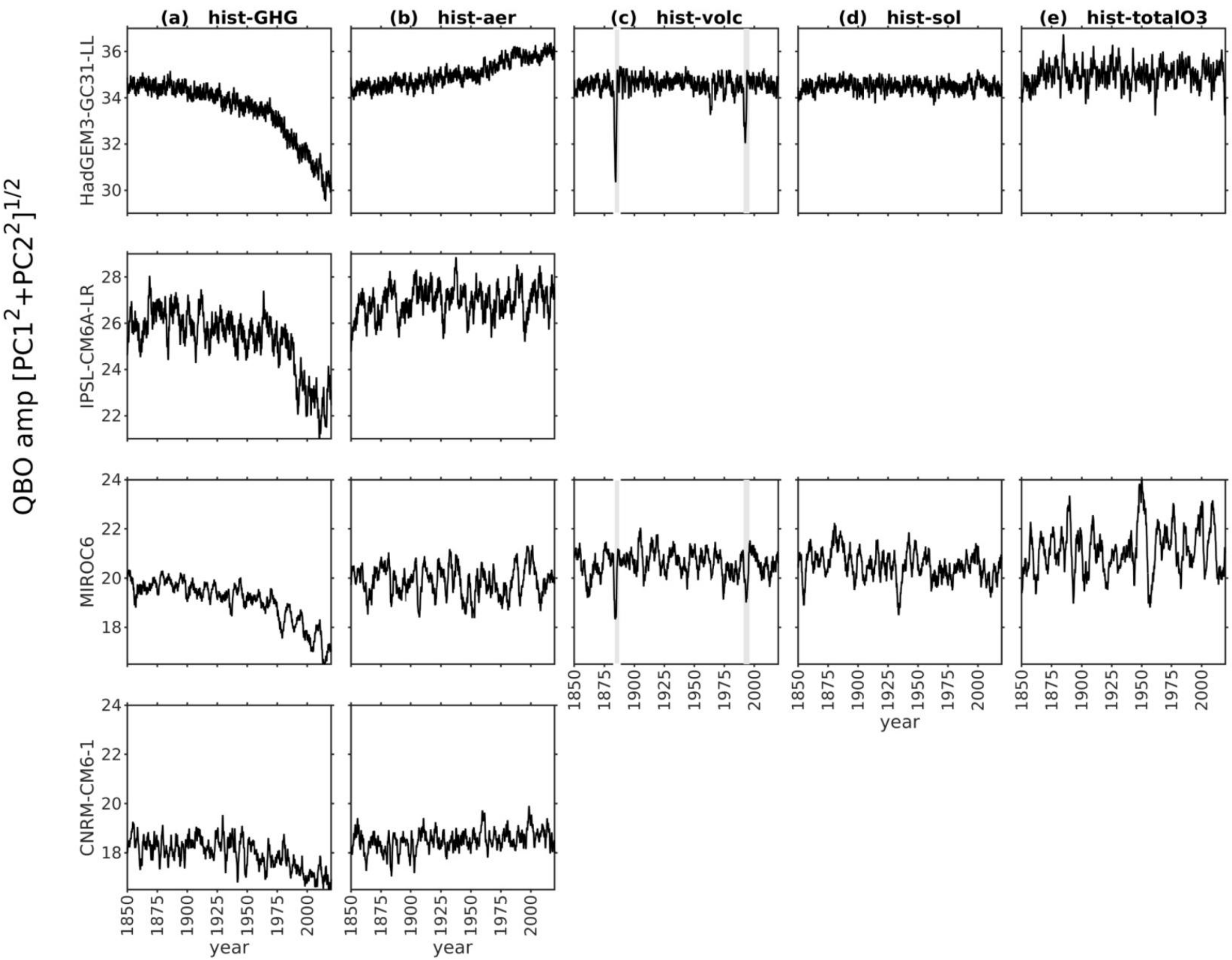

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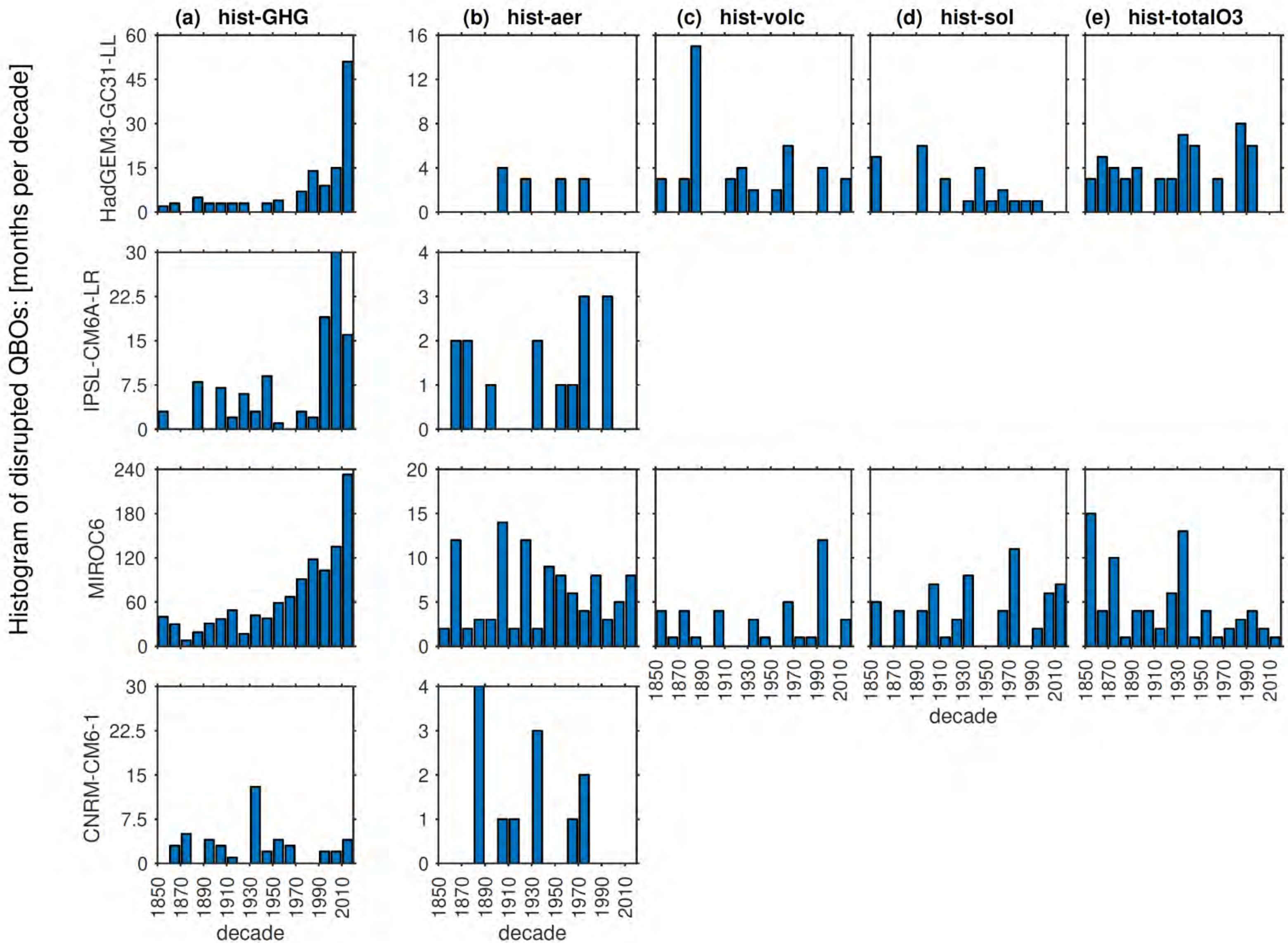
Impact of external forcings on disruptions

- GHG, aerosols, and volcanos all have notable influence on QBO amplitude with implications for disruptions



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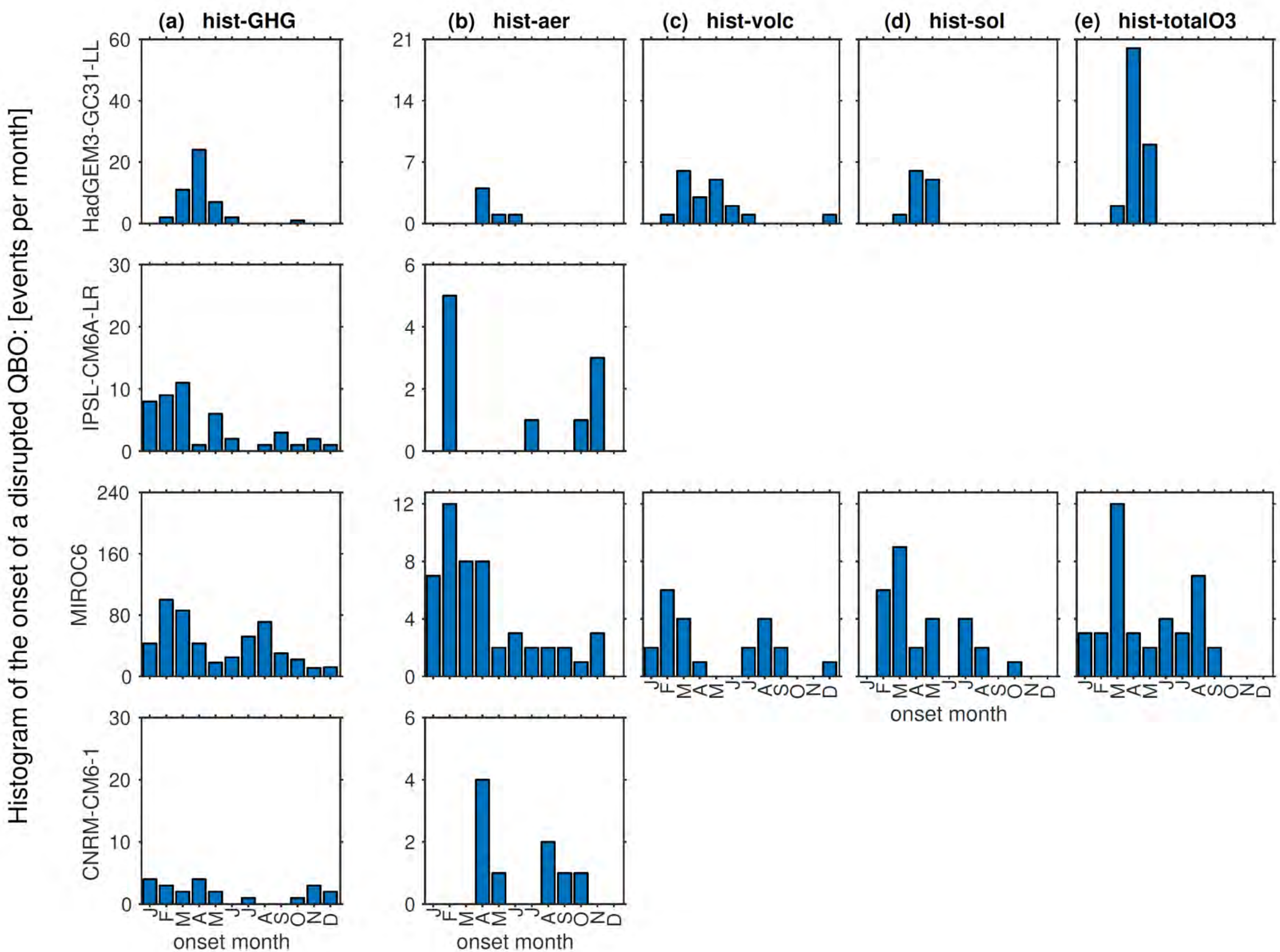
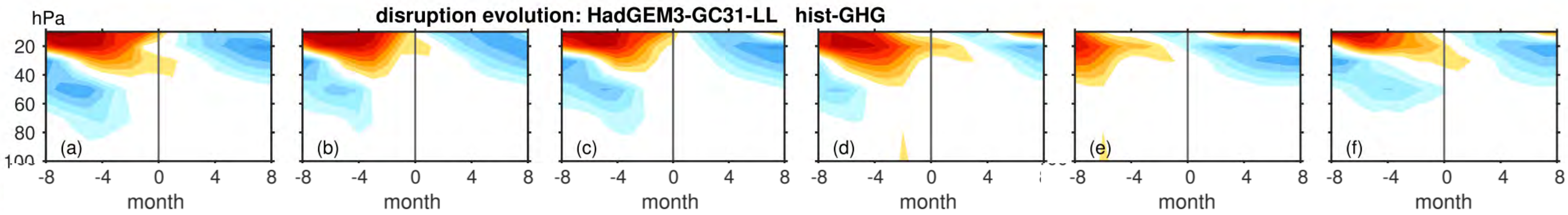
Disruptions onset in late boreal winter (as observed)



disruptions predominantly occur following the QBO regime with lower strat easterlies

- Matches one of the observed disruption events, though not the other



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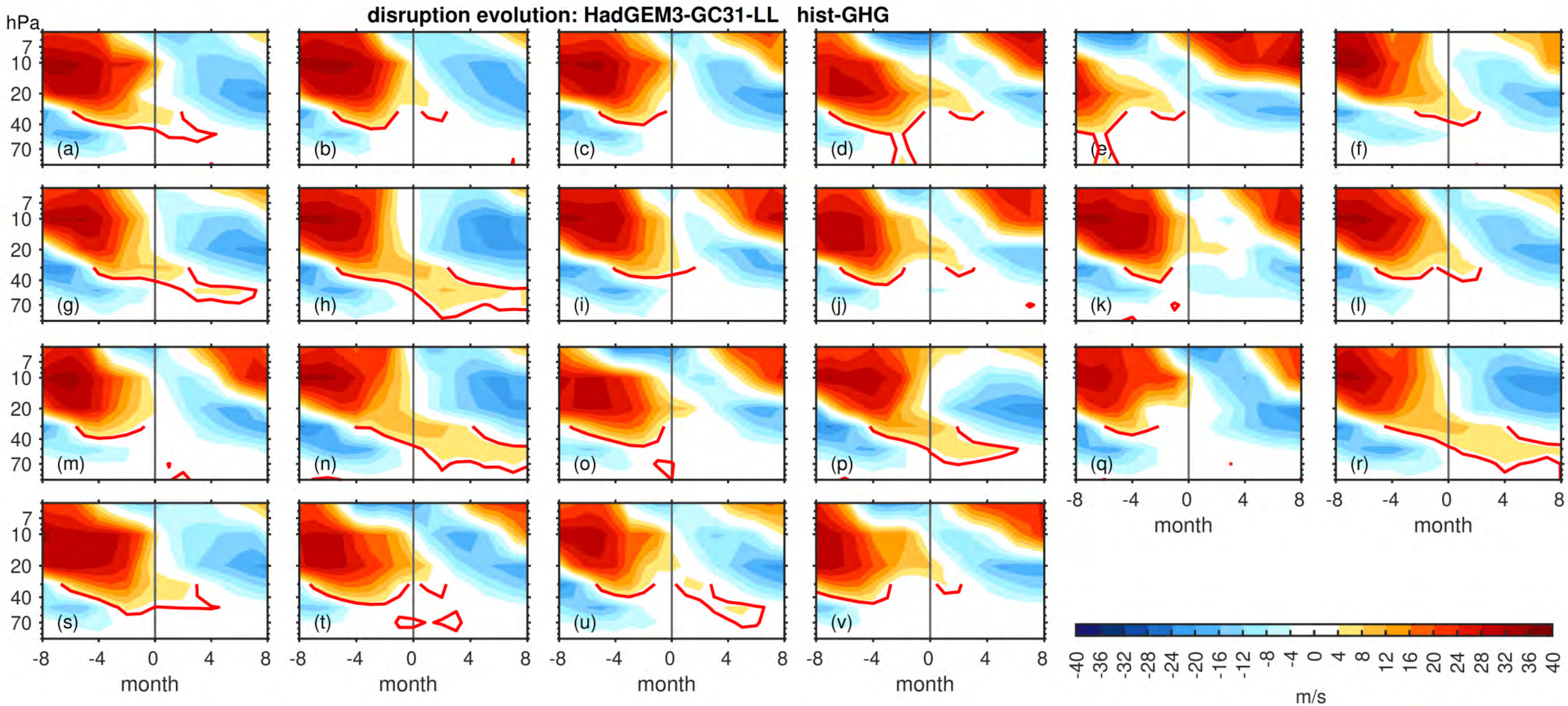

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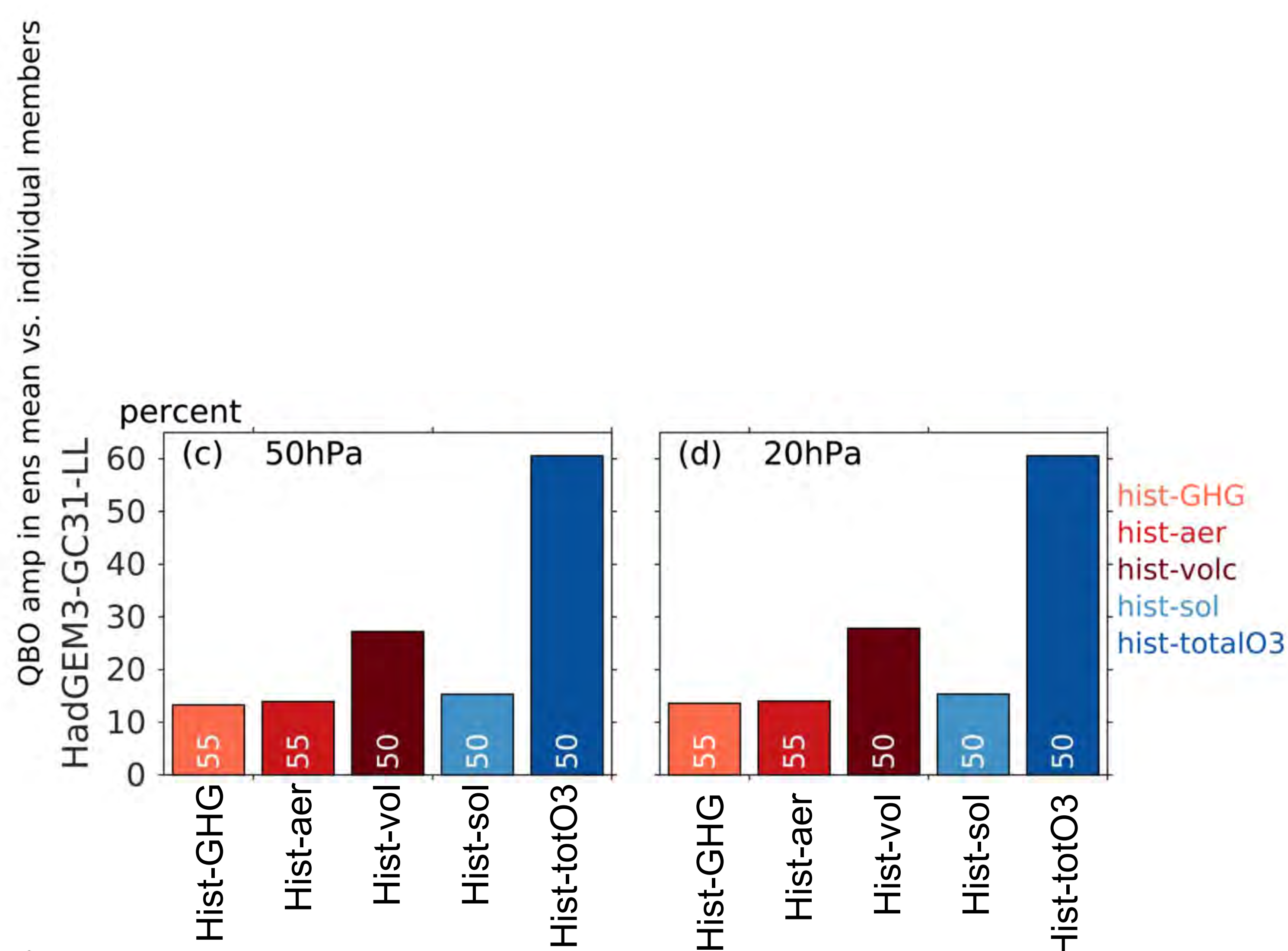
hist-ozone leads to phase synchronization

- consistent with Butchart et al 2023, but we have proper single forcings



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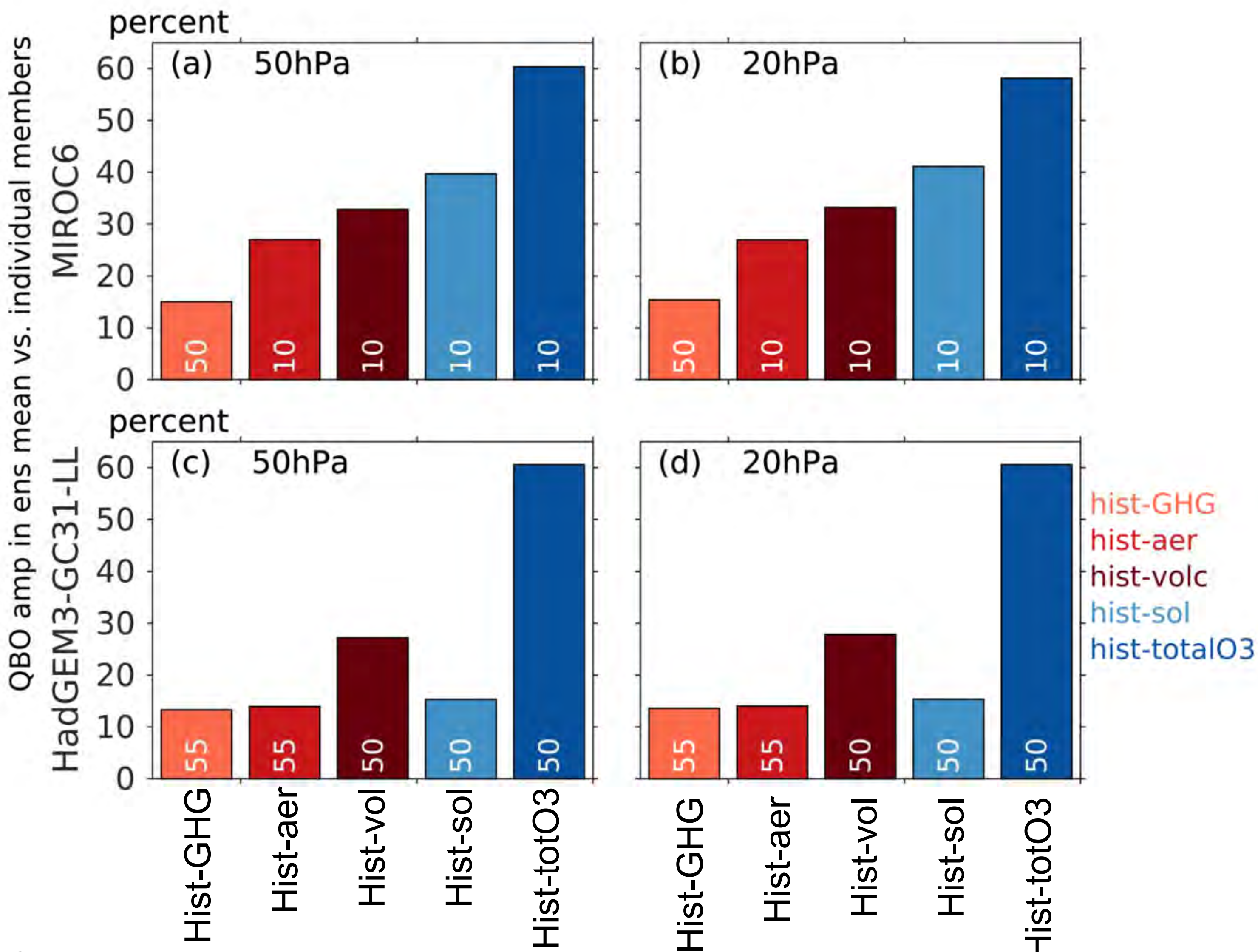

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Conclusions

~62,000 years of model output contributed by three modeling centers to the Large Ensemble Single Forcing Model Intercomparison Project (LESFMIP).

Increasing greenhouse gas concentrations leads to weakening of the QBO and an increased likelihood of a disruption event, with the effect most pronounced in the lower stratosphere.

Increasing aerosols leads to a strengthening of the QBO.

Explosive volcanic eruptions lead to a weakening of the QBO and can help trigger a QBO disruption.

The ozone forcing used for LESFMIP helps synchronize the QBO phase regime across ensemble members, and also increases the strength of the QBO.

Solar forcing has the smallest impact on the QBO of the five forcings.

Disruption events preferentially onset in late boreal winter, and follow the QBO regime with upper stratospheric westerlies.

LEADER

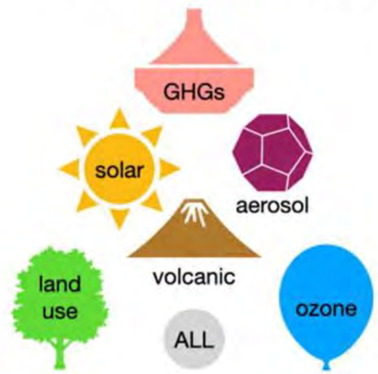
Large Ensembles for Attribution of Dynamically-driven ExtRemes

LEADER is a limited-term activity from 2024–2026 focused on analyzing the outputs of the Large Ensemble Single Forcing Model Intercomparison Project (LESFMIP), an ongoing extension of the Detection & Attribution MIP (DAMIP) protocol to more forcing agents and larger ensembles:

Large Ensemble

What are the characteristics of internal variability?

Single Forcing



What is the response to different forcings?

MIP

How well are current climate models doing?

Objectives of the LEADER activity:

- Provide a **process-based understanding** of recent annual to decadal climate changes
- Quantify the roles of **internal variability** and **external drivers**
- Assess predictability, sources of skill, drivers and mechanisms to increase **confidence in predictions and projections**
- Contribute to **IPCC** and **WMO Climate Update** and **State of Climate** reports

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To sign up, or for more information, contact:

Chaim Garfinkel (chaim.garfinkel@mail.huji.ac.il)
Scott Osprey (scott.osprey@physics.ox.ac.uk)

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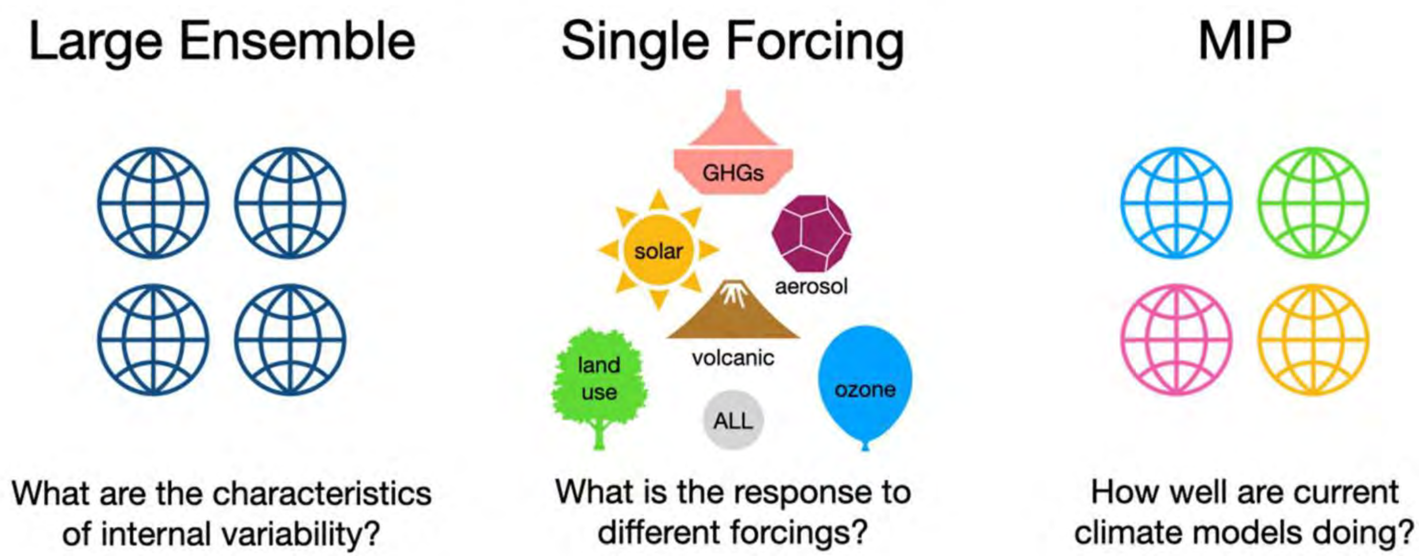

Please let Scott and I know if you are interested in joining this effort!

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To do: impact of these external forcings on QBO teleconnections

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