The response of the North Atlantic atmospheric and oceanic circulation to external forcings:

understanding intermodel spread and model-observations discrepancies

Chaim I. Garfinkel, Isla Simpson, David Avisar
+20 others

Conclusions

- >100,000 years of model output contributed by three modeling centers to the Large Ensemble Single Forcing Model Intercomparison Project (LESFMIP).
- Pronounced model vs. observations discrepancies in historical changes over the subpolar North Atlantic. Discrepancies evident in several fields (SLP, U 700hPa).
- Some sensitivity to start date – do we trust observations before 1979?
- From 1979-2014, discrepancies in winter go away, but a discrepancy in jet latitude become evident in summer.
- The total U700 and SLP responses are non-additive (at least in winter), so difficult to ascertain whether a too-weak response to a specific forcing is responsible for discrepancies. (In summer, some evidence for aerosols being responsible).
- **Implications and discussion: how best can we use decadal predictions from these models to predict future changes?**

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)
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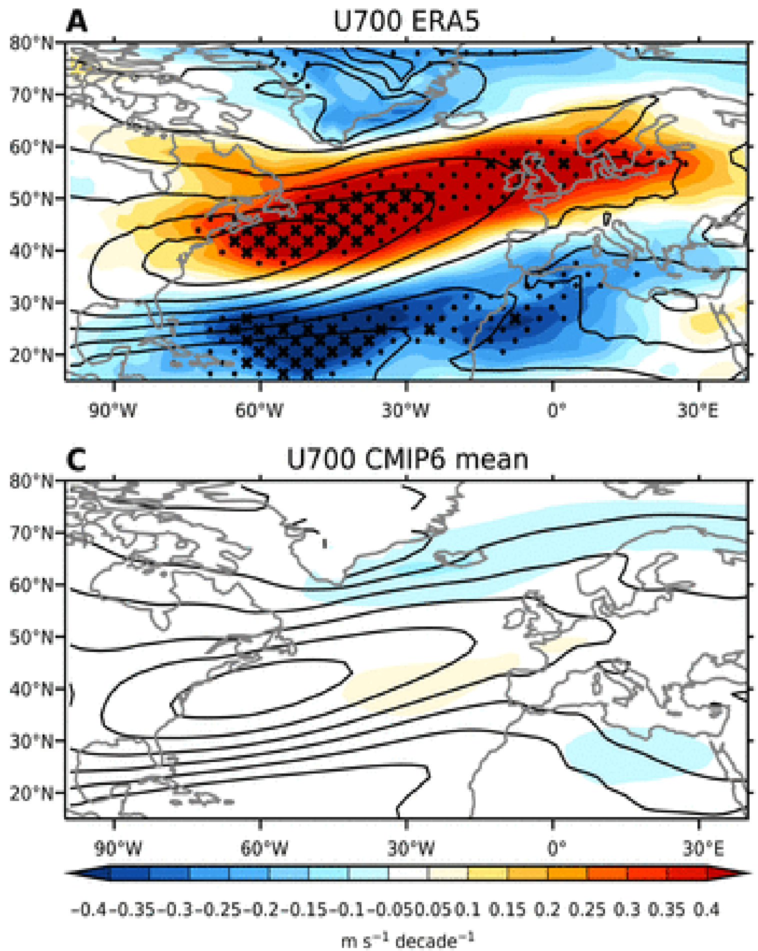
hist-lu	Historical simulations with only land use changes

- Mainly DAMIP simulations but >10 ensemble members from 1850-2020
- Additional runs to assess non-linearity and sensitivity to background state
- ~12 modeling centers. Nearly all of the data is on ESGF, and much of it easily accessible on JASMIN.

	ACC	Can	CMCC	FG	GISS	Had	IPSL	MIROC	MPI	Nor	CNRM	CESM2
hist-GHG	10	50	10	3	45	55	10	50	30	23	10(9psl)	15
hist-aer	10	30	10	3	45	55	10	10	30	23	10	15***
hist-volc	10	50	10or9	-	40	50	-	10	30	20	-	-
hist-solar	9	50	-	-	40	50	-	10	30	20	-	-
hist-totalO3	-	10	-	-	5	50	-	10	30	20	-	-
historical	40	65	11	6	46	55	33	50	51	44	-	-

Models miss DJF historical trends in North Atlantic



Blackport and Fyfe 2022
1951-2020 trend
Large ‘x’ indicate obs outside the range of all 303 simulations examined.

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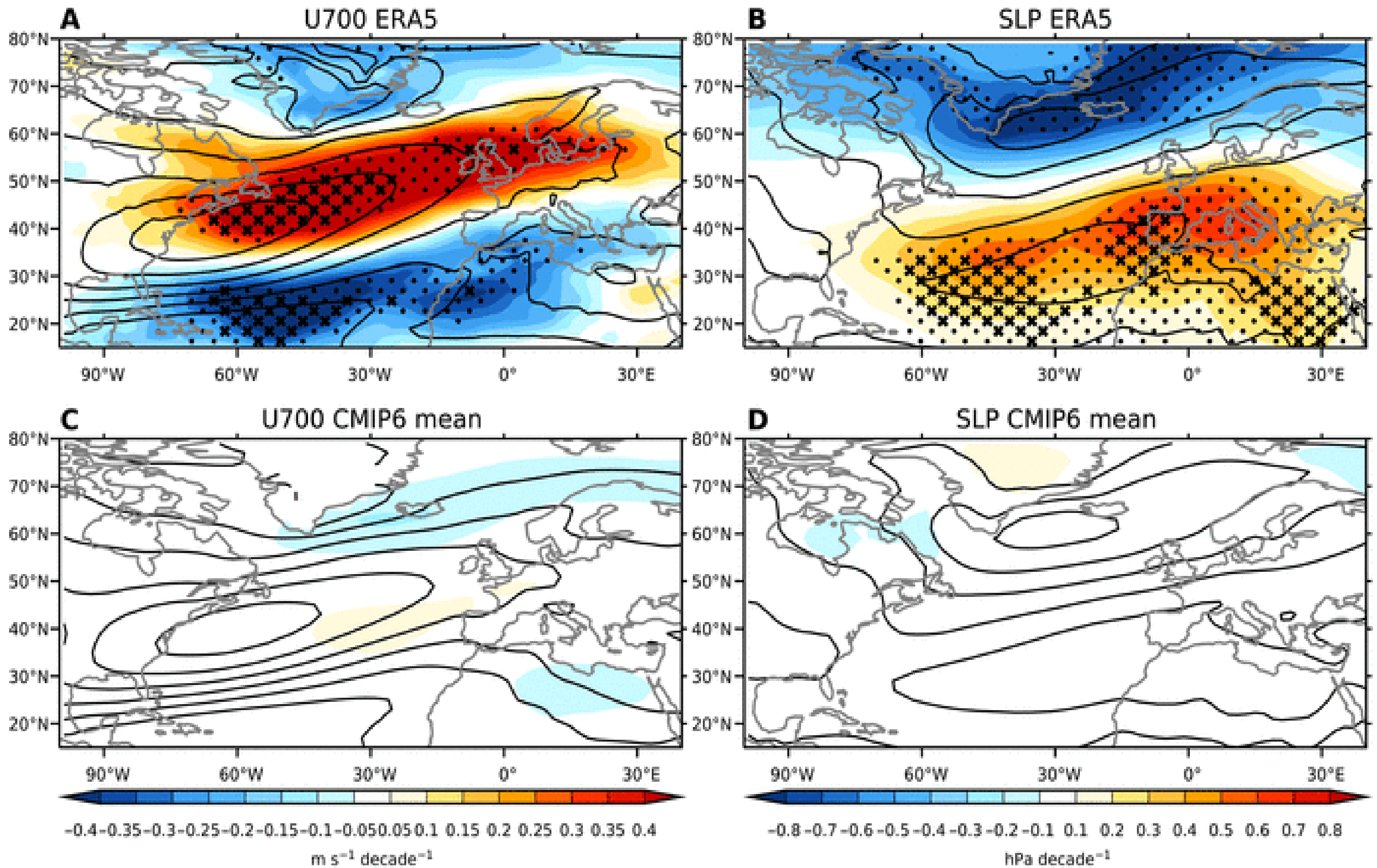

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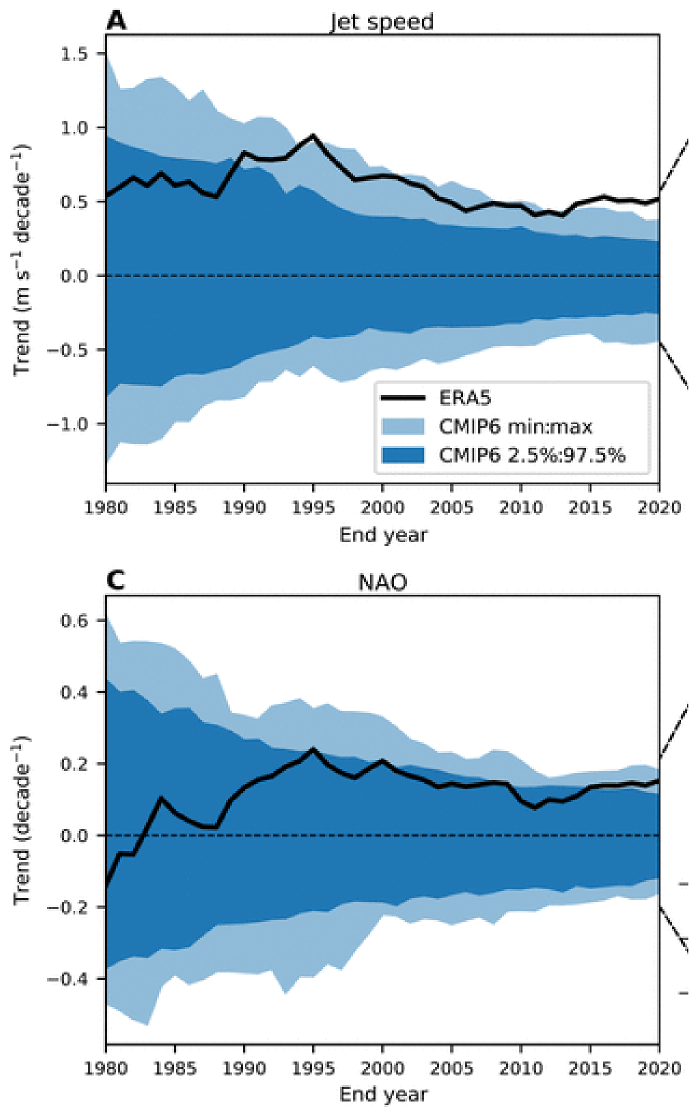

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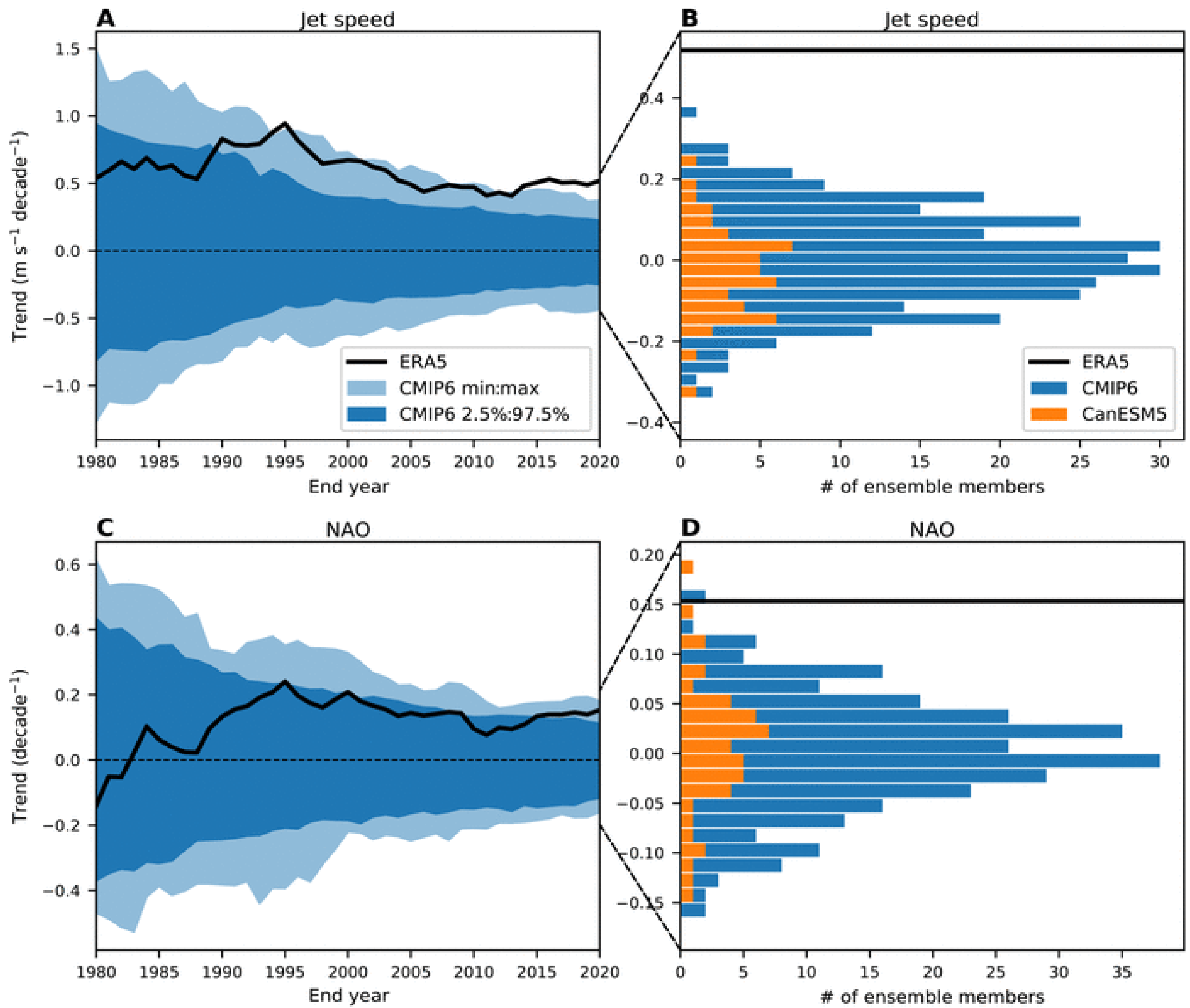

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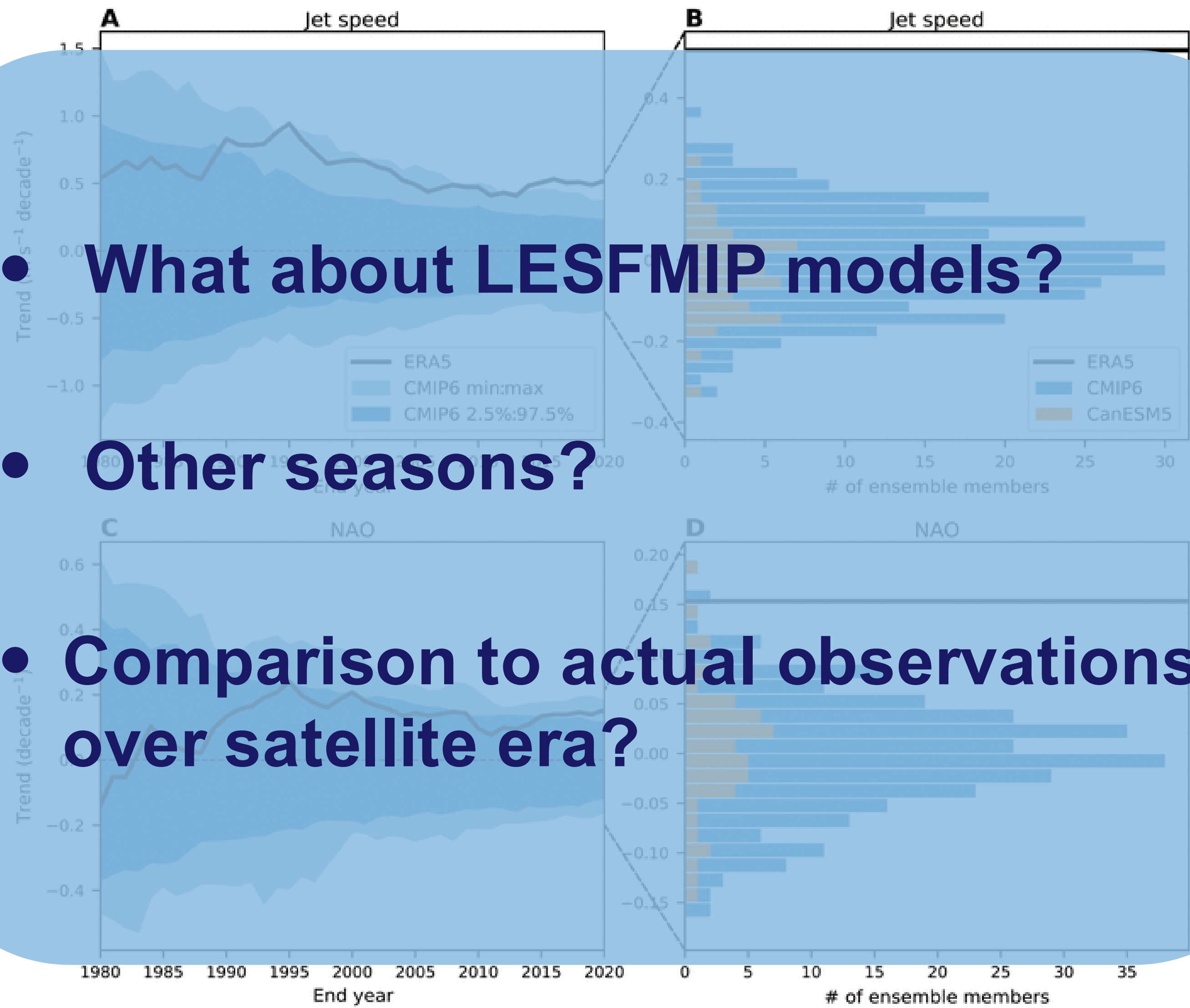
- Comparison to actual observations over satellite era?



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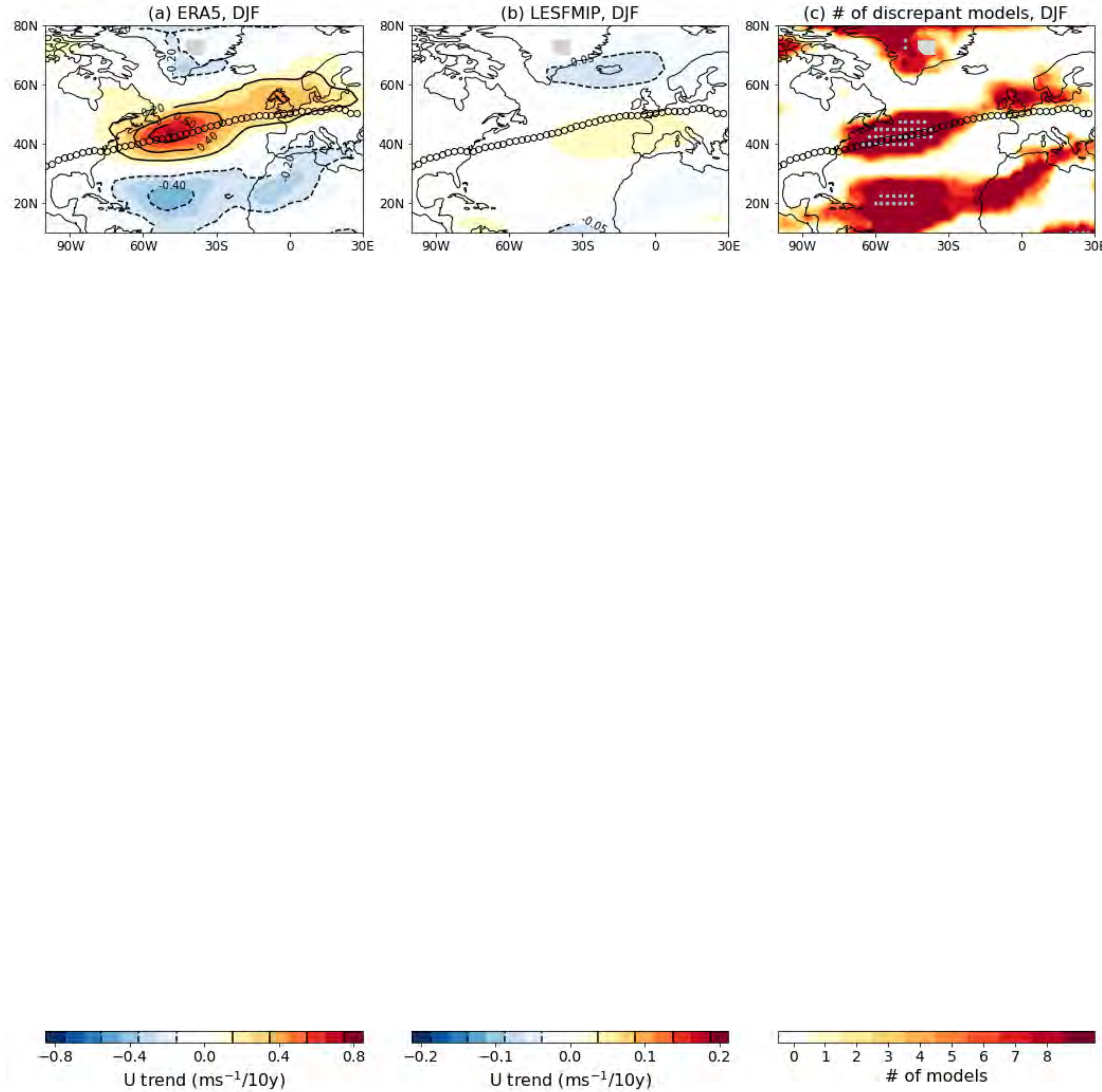

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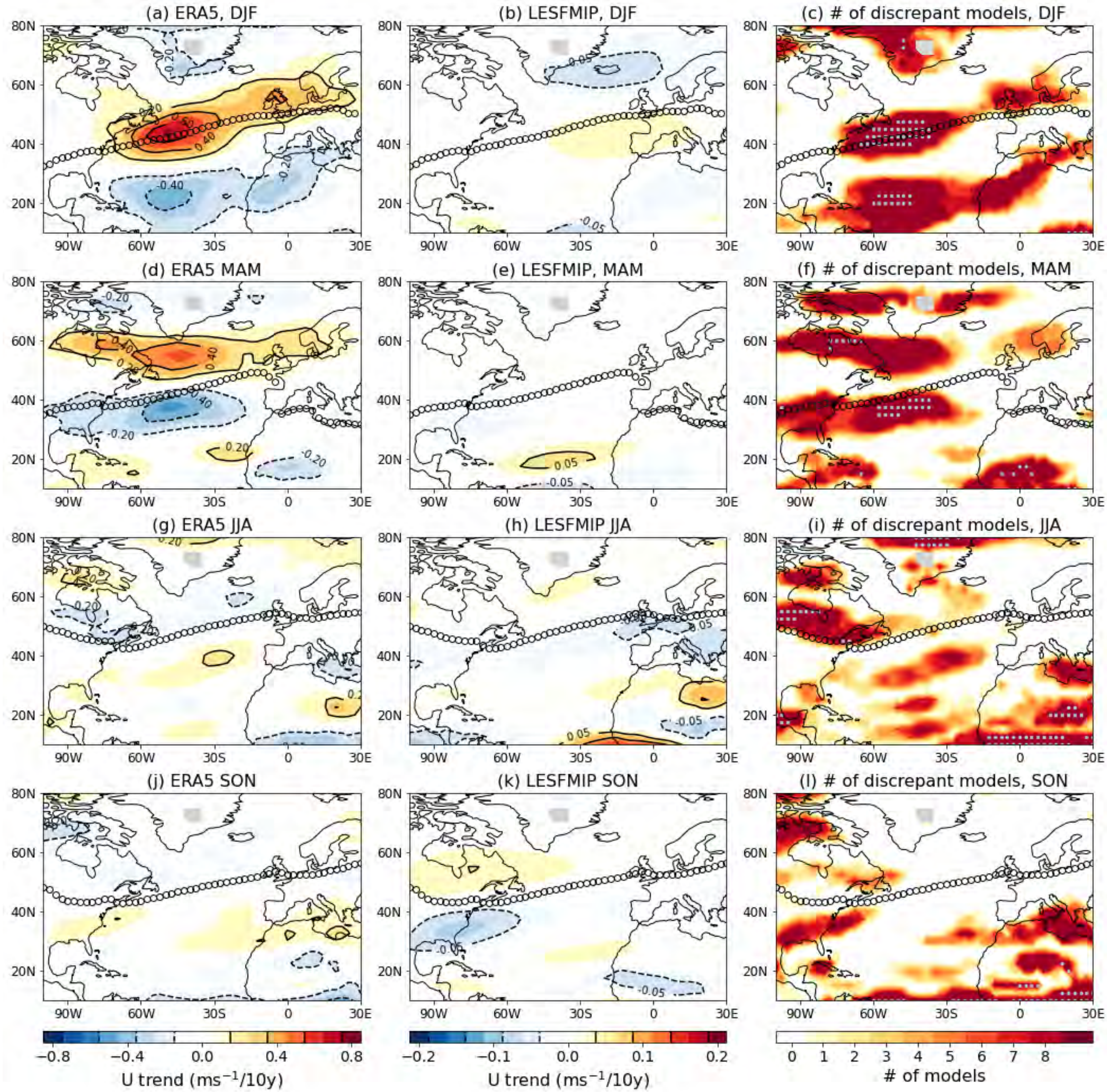

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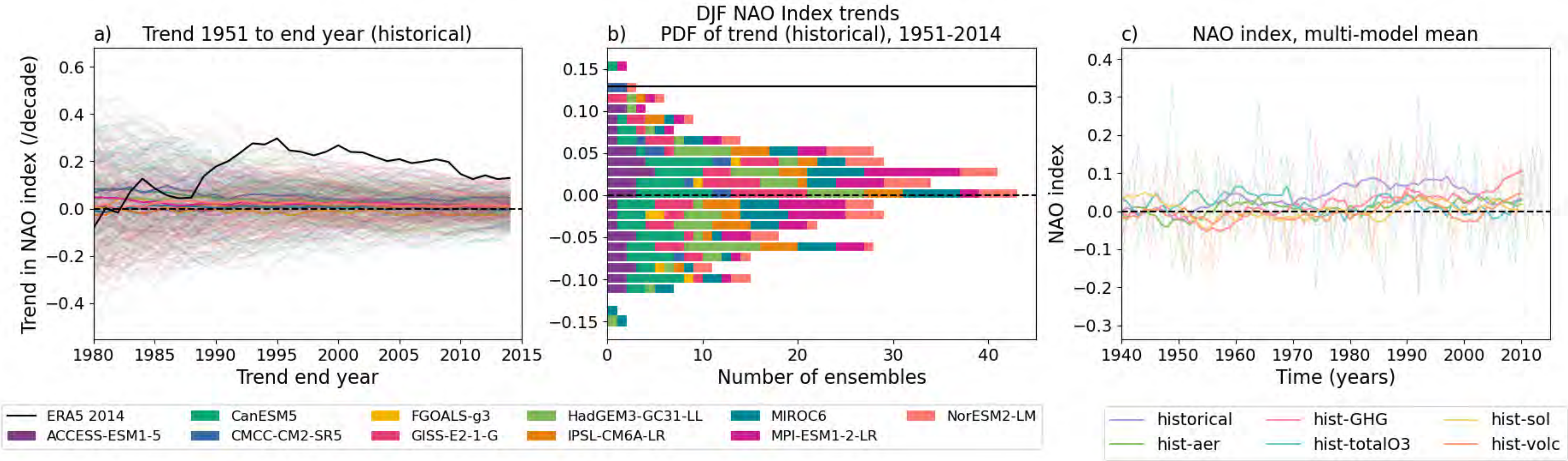

Figure courtesy of Sara Bennie

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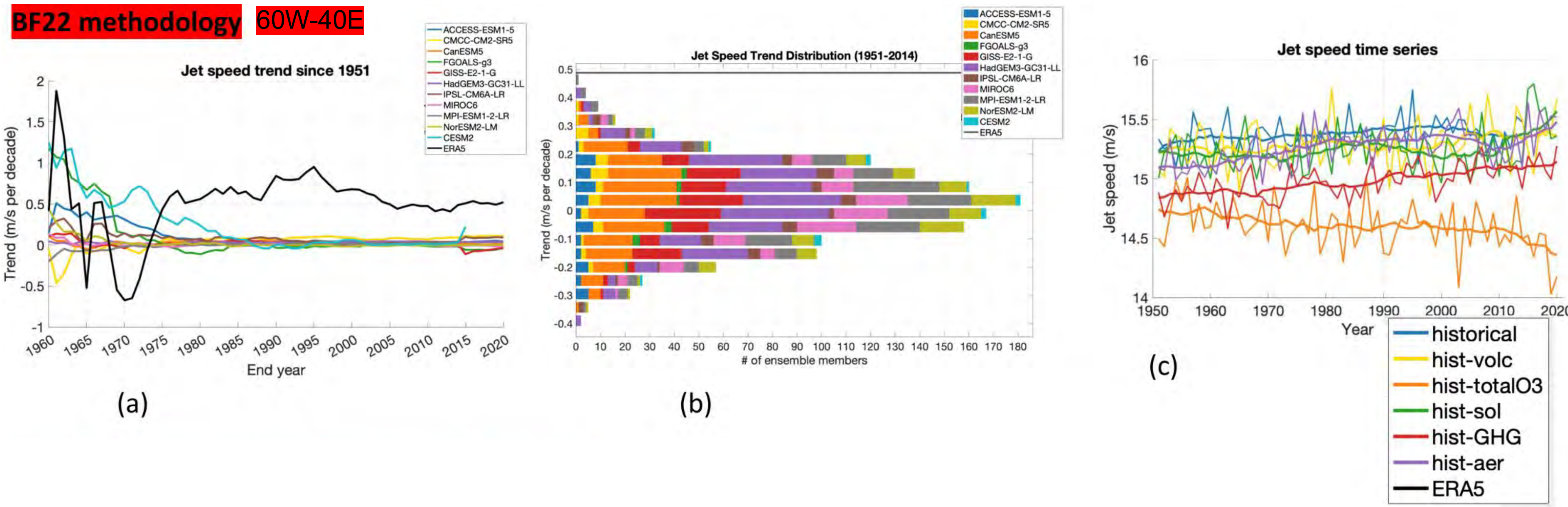
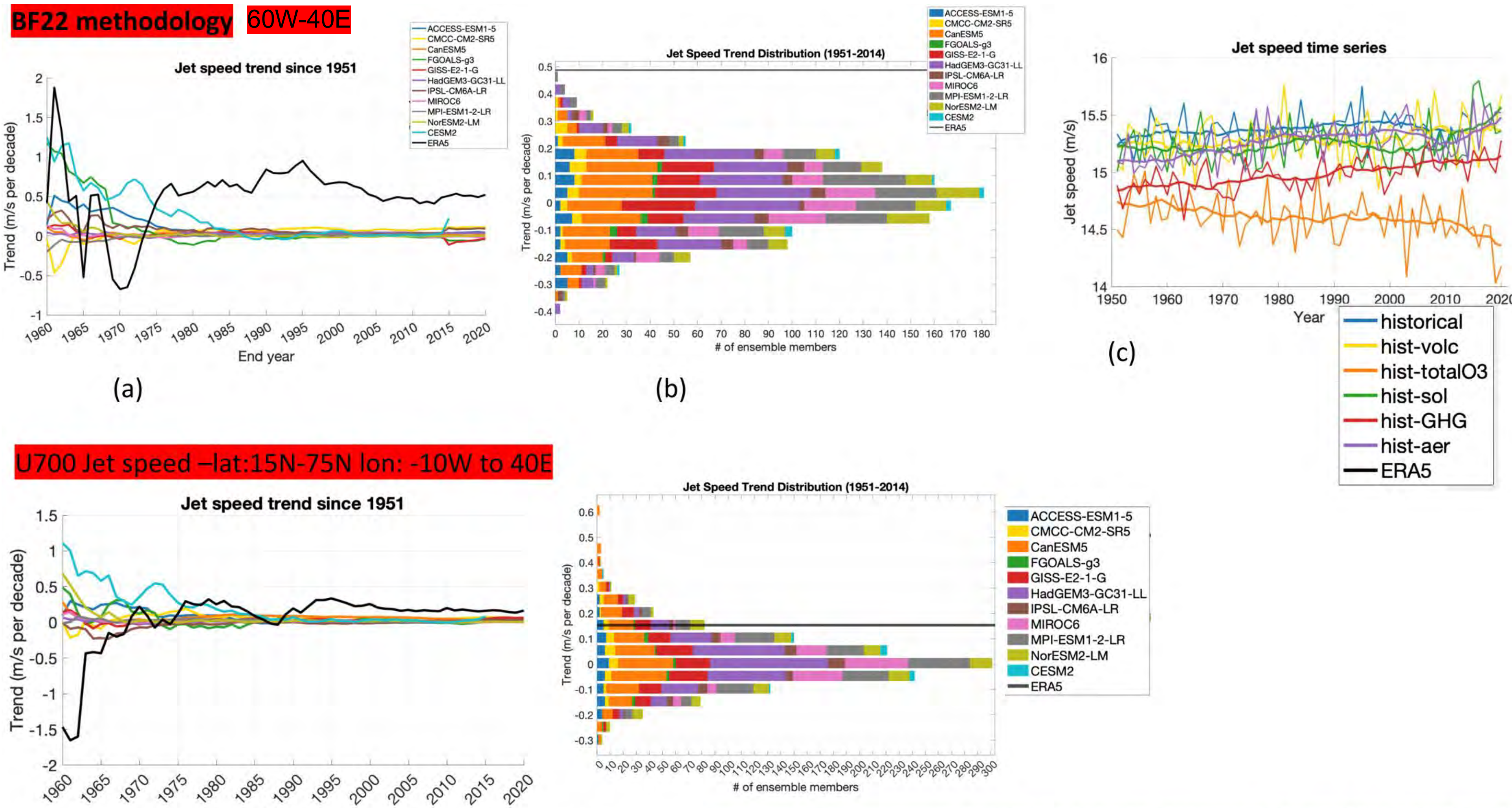


Forcing	'historical'	'hist-volc'	'hist-totalO3'	'hist-sol'	'hist-GHG'	'hist-aer'
No. of ensemble members	367	180	125	175	288	219

Figure courtesy of Sohan Suresan

Models miss historical trends in North Atlantic



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(d) (e)

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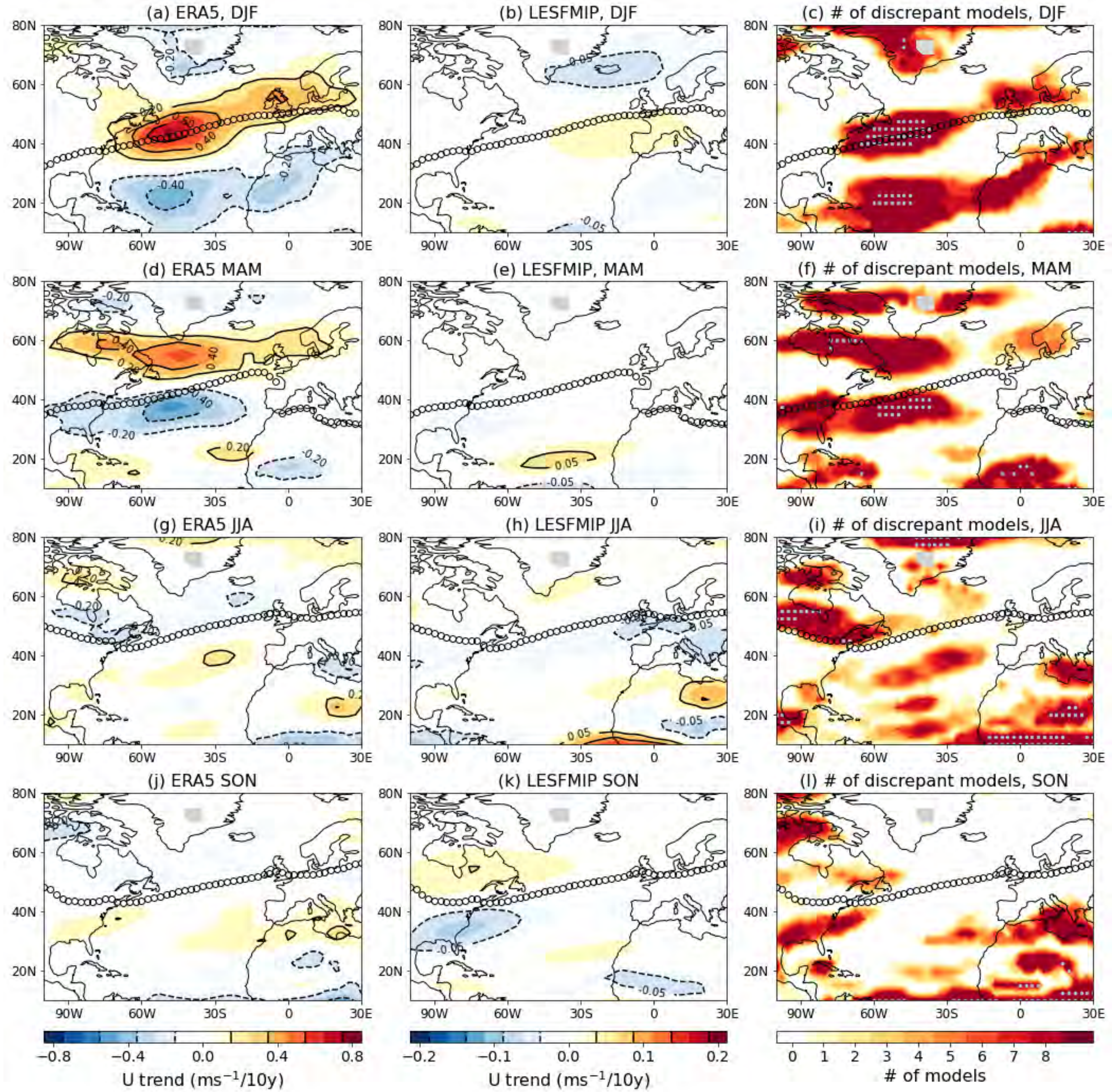

Hist-GHG trends looks like ERA5, but historical response non-additive

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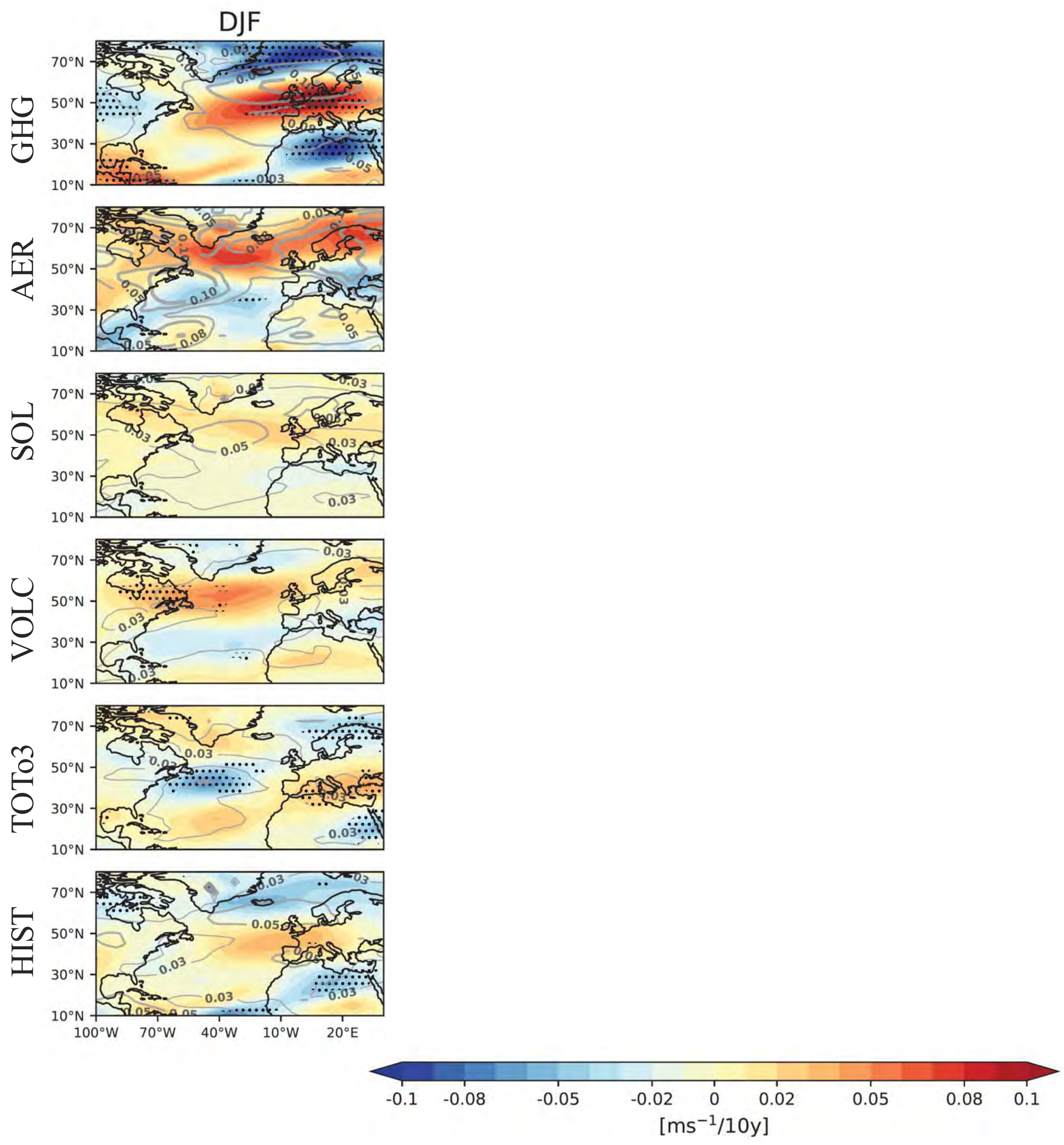
Figure courtesy of David Avisar

Simpson et al 2023 found non-additivity in CESM2 as well



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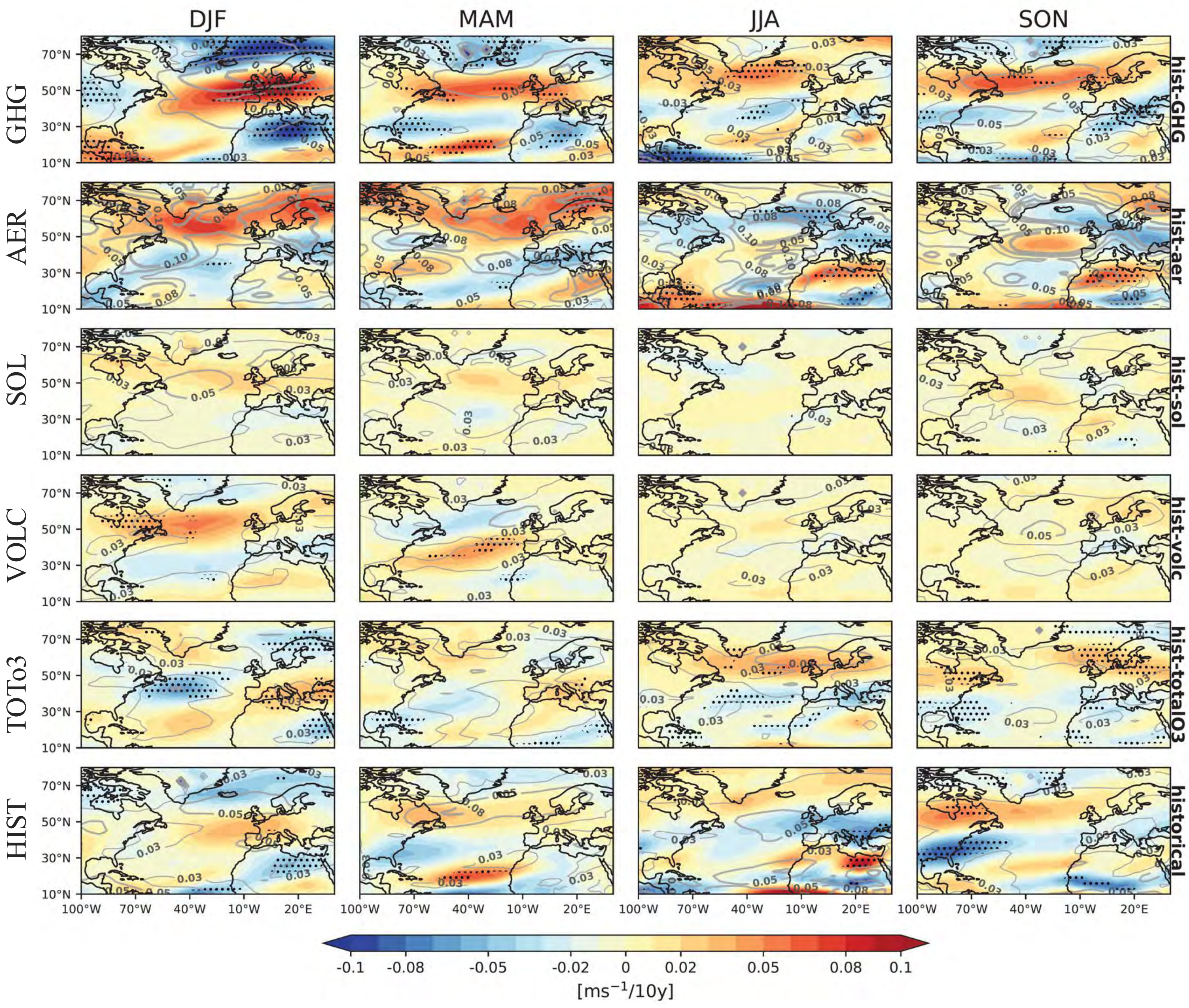

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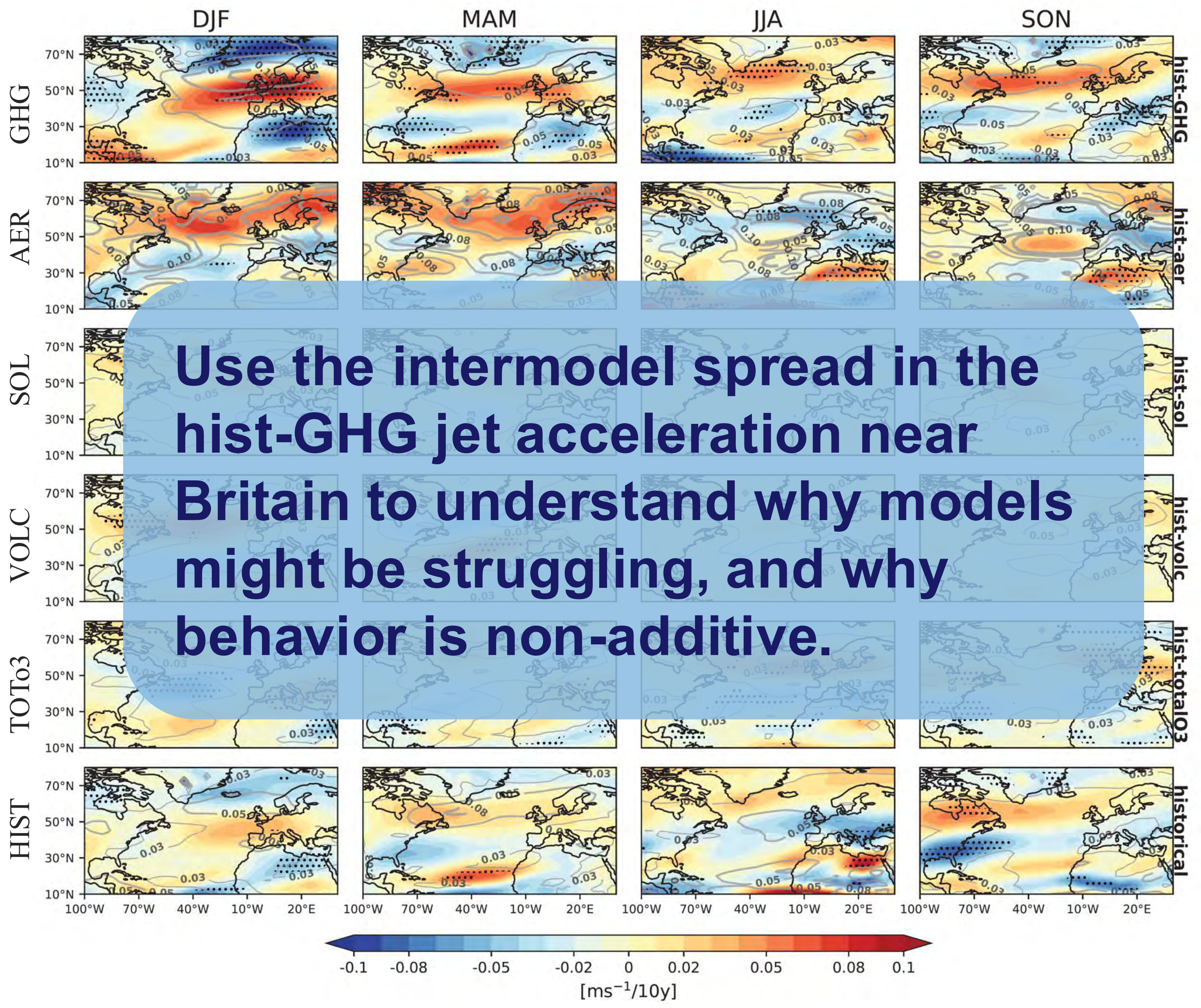

Use the intermodel spread in the hist-GHG jet acceleration near Britain to understand why models might be struggling, and why behavior is non-additive.

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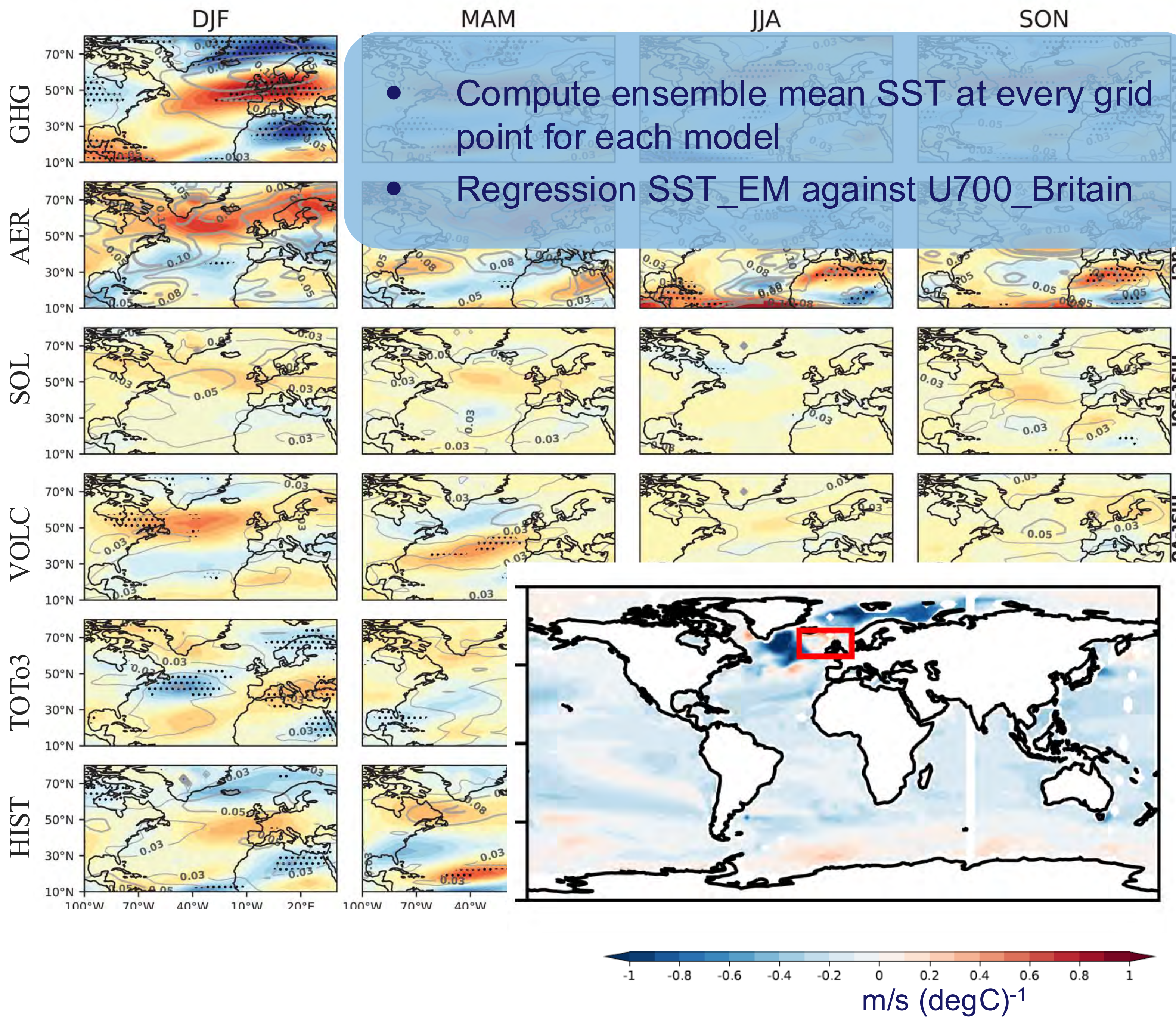
- Compute ensemble mean SST at every grid point for each model
- Regression SST_EM against U700_Britain



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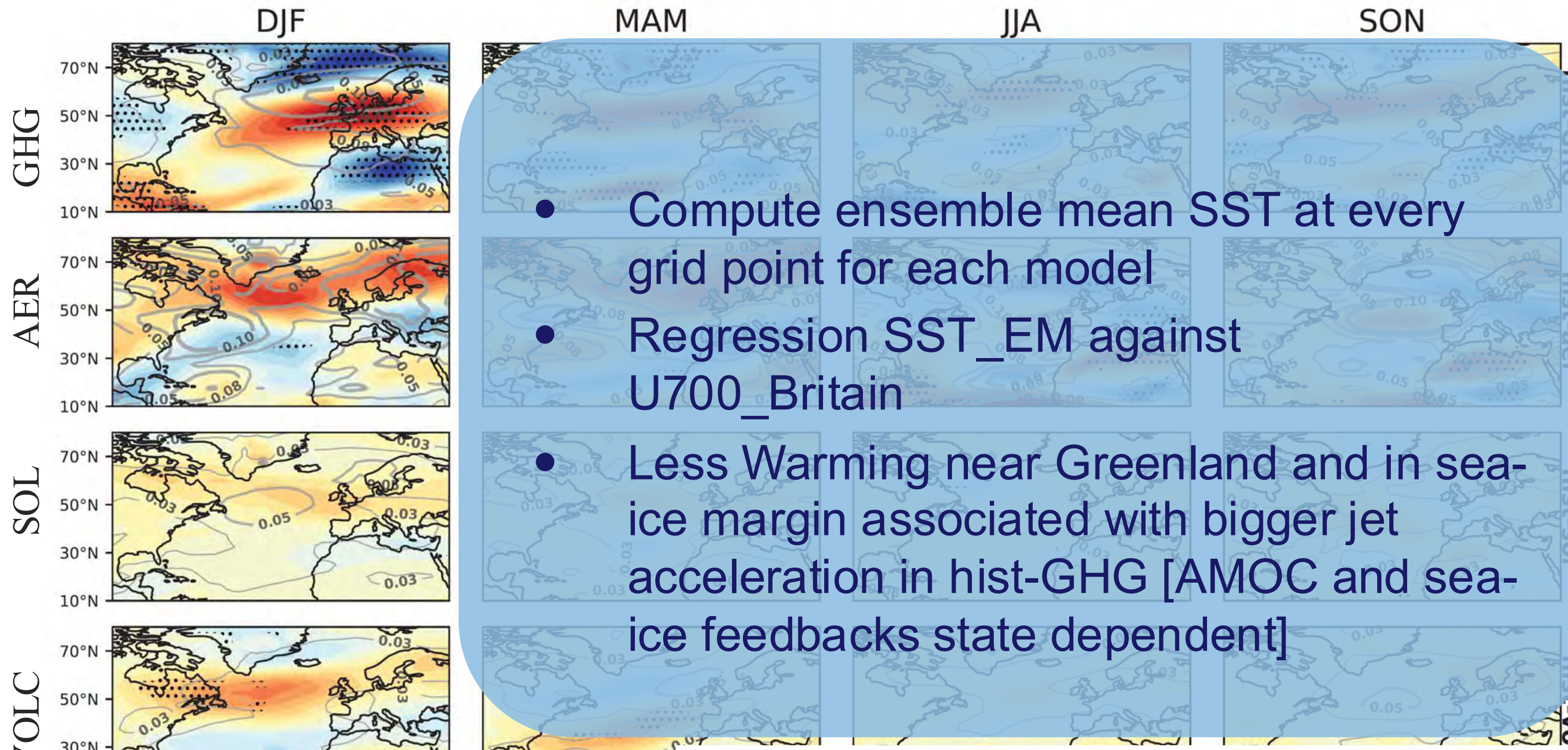
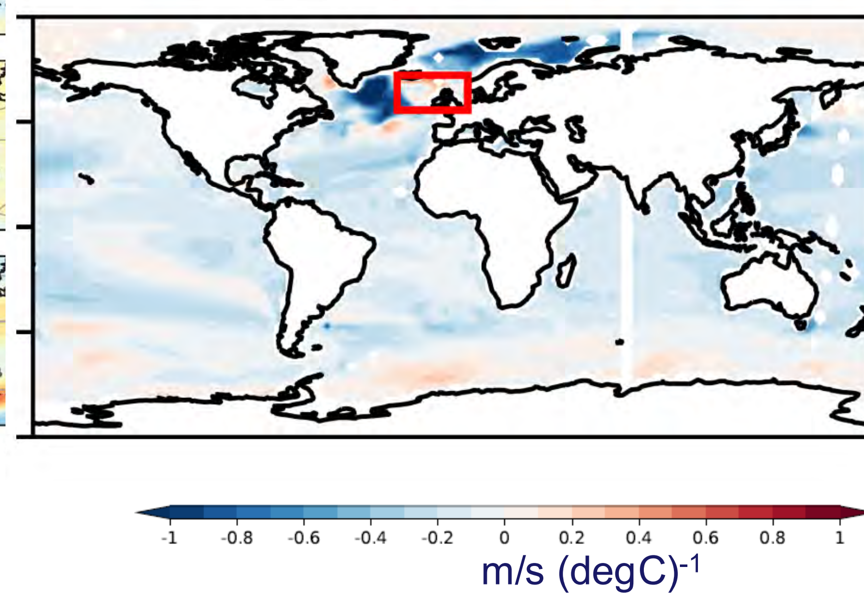


- Compute ensemble mean SST at every grid point for each model
- Regression SST_EM against U700_Britain
- Less Warming near Greenland and in sea-ice margin associated with bigger jet acceleration in hist-GHG [AMOC and sea-ice feedbacks state dependent]



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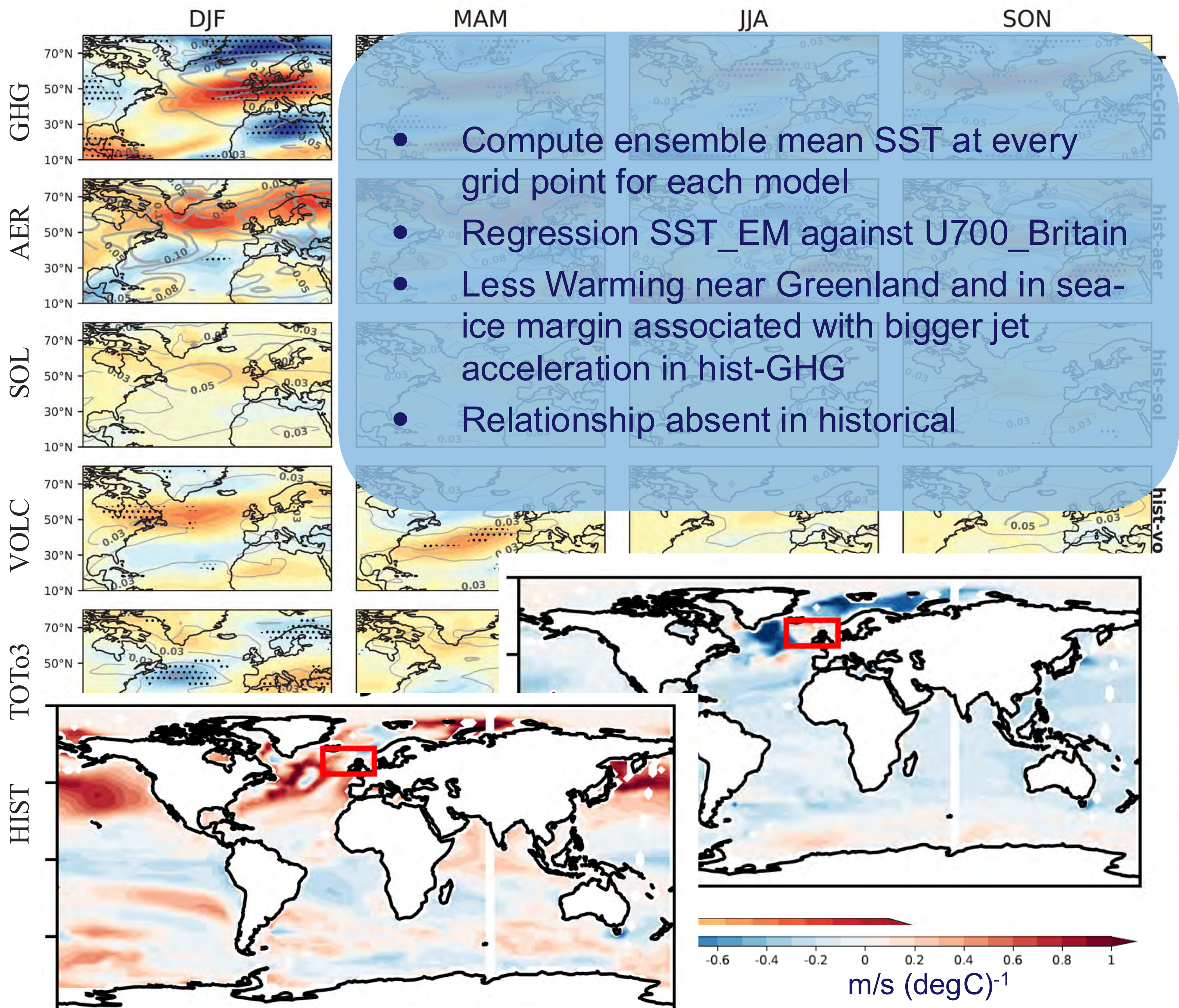

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- Relationship absent in historical

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AMOC at 35N

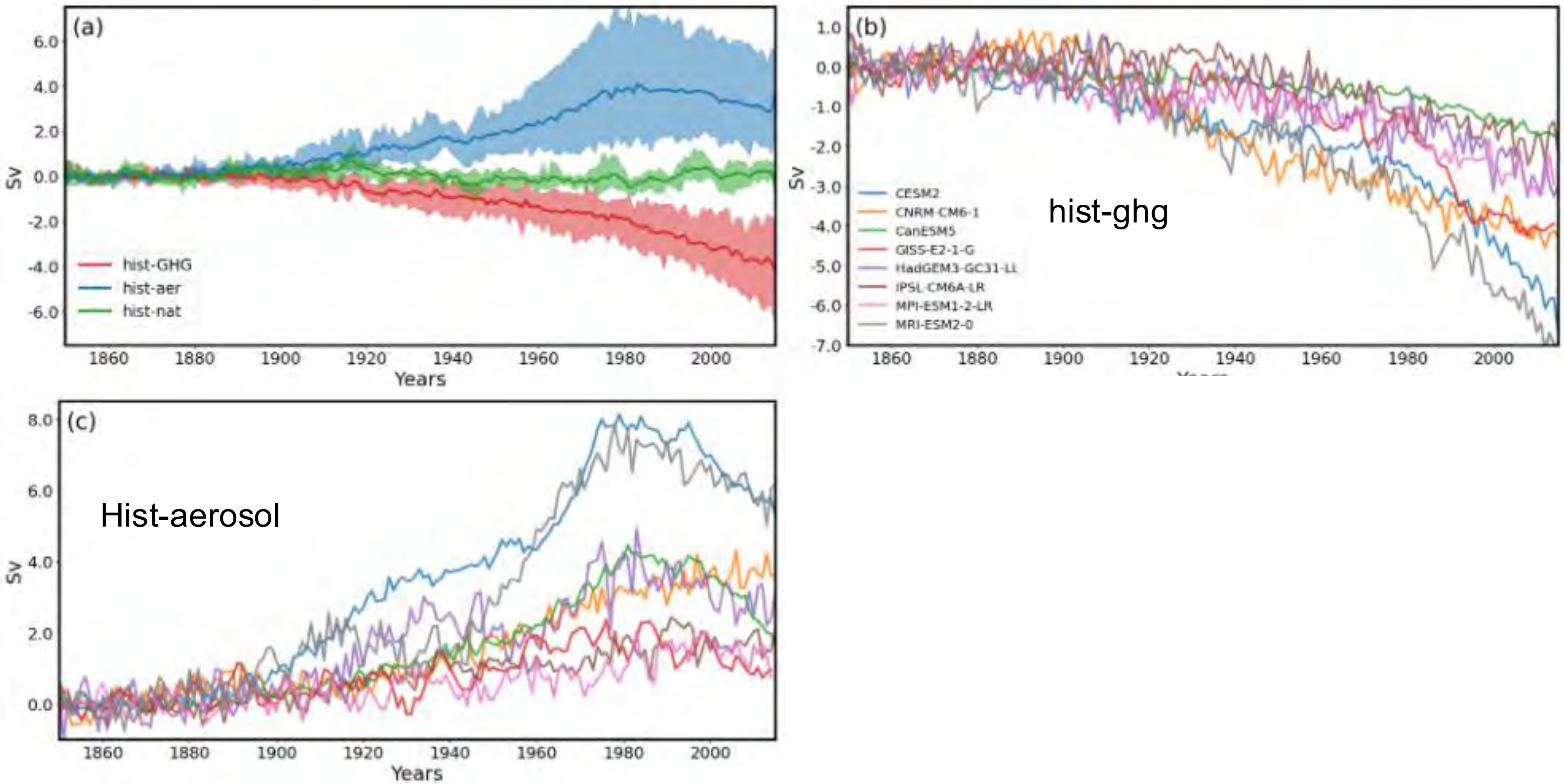

Figure courtesy of
Gaurav Madan

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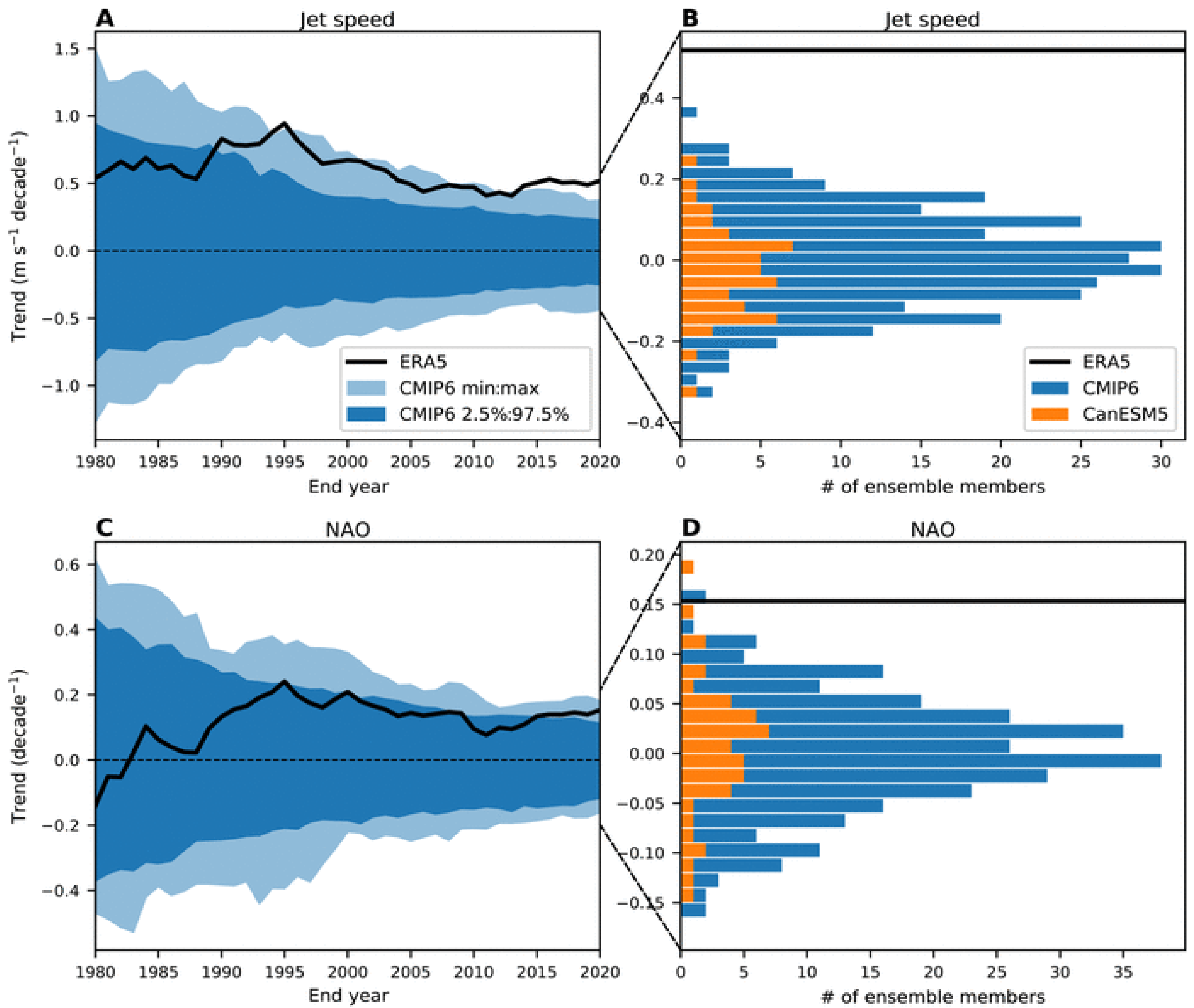
- Other seasons?
- **Comparison to actual observations over satellite era?**



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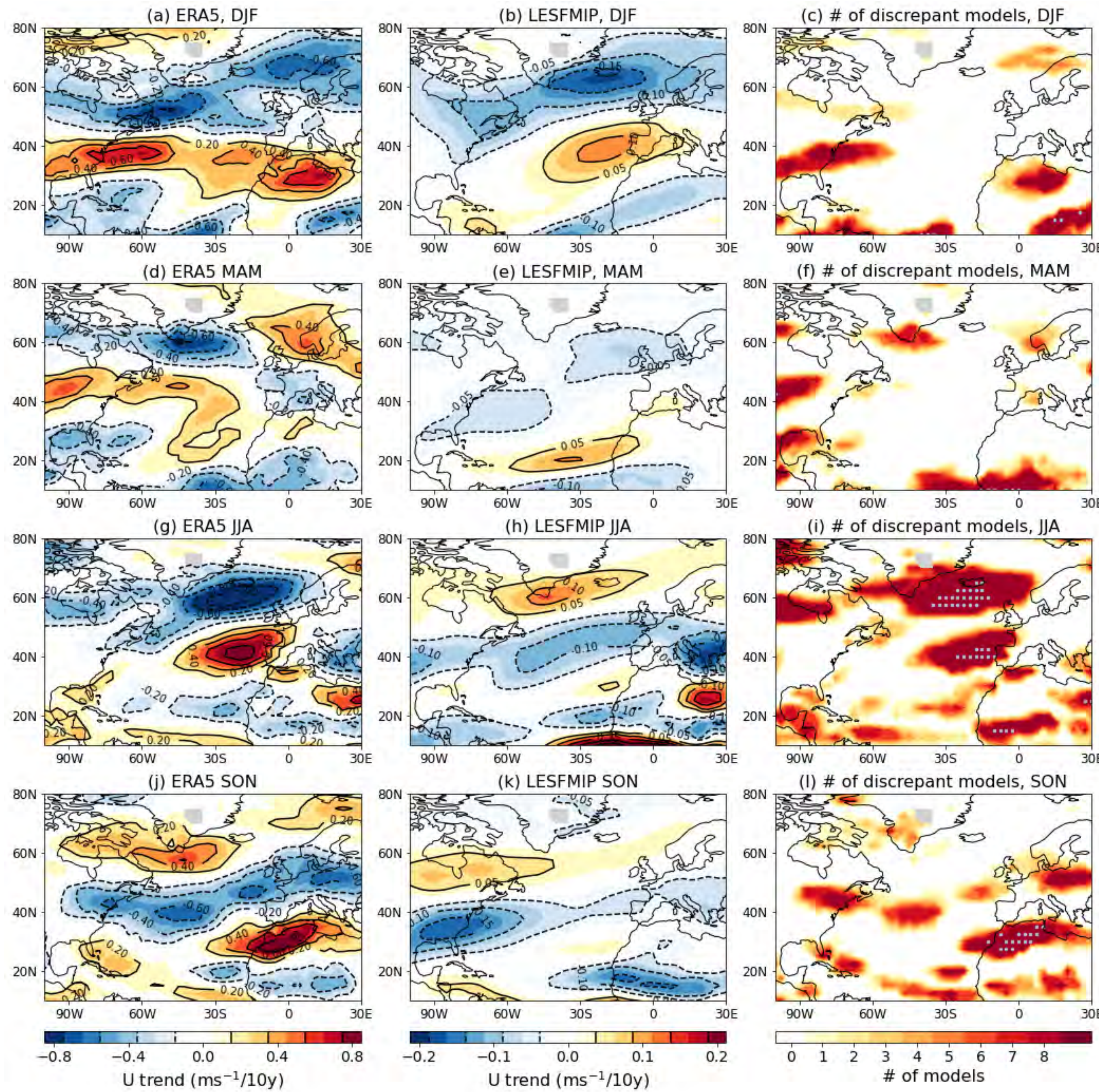
Over satellite era, models are ok in DJF but not in JJA in North Atlantic

1979-2014 trend

U700

Figure courtesy of Isla Simpson



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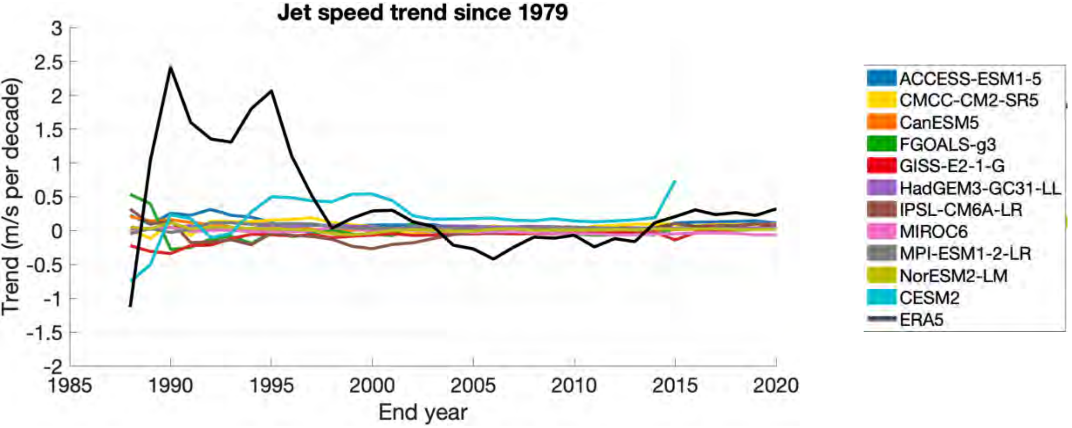
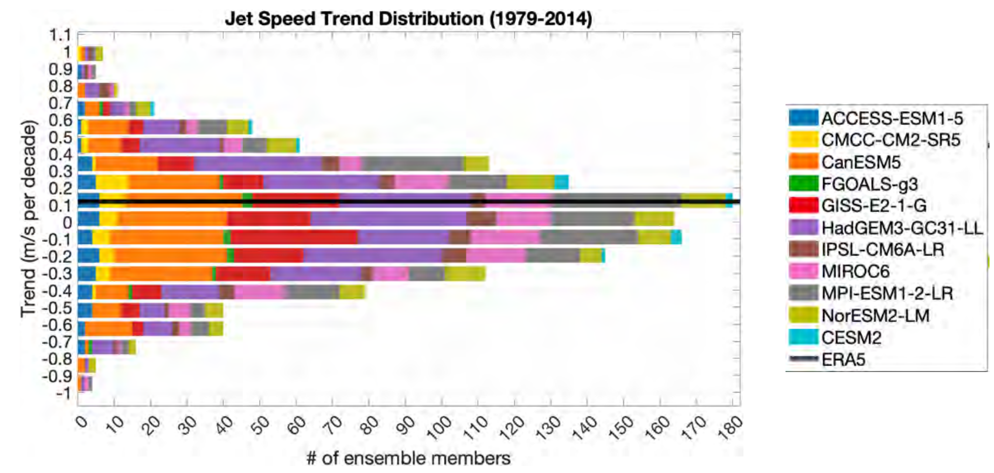
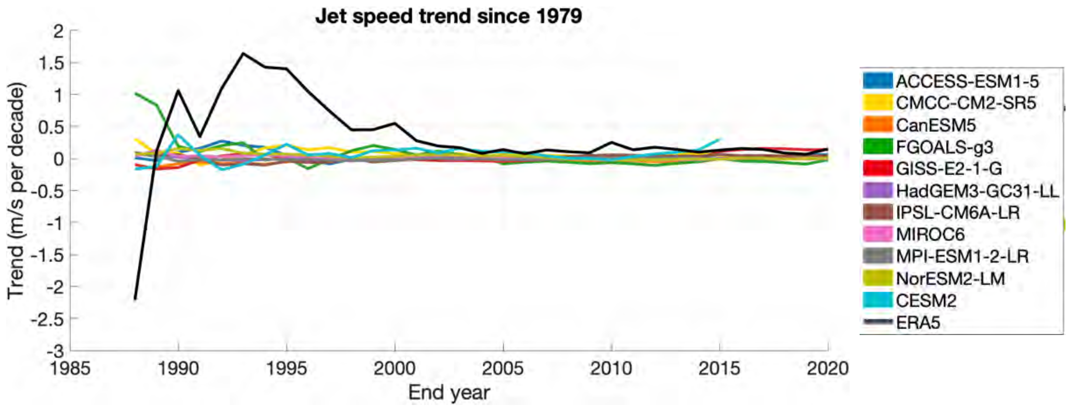
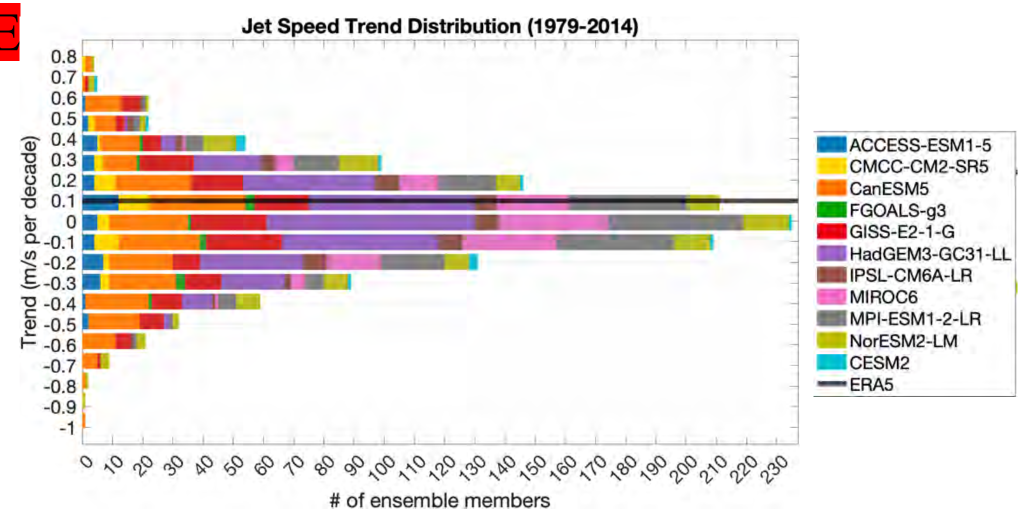
U700 Jet speed –BF22 methodology





U700 Jet speed –lat: 15N to 75N lon: -10W to 40E





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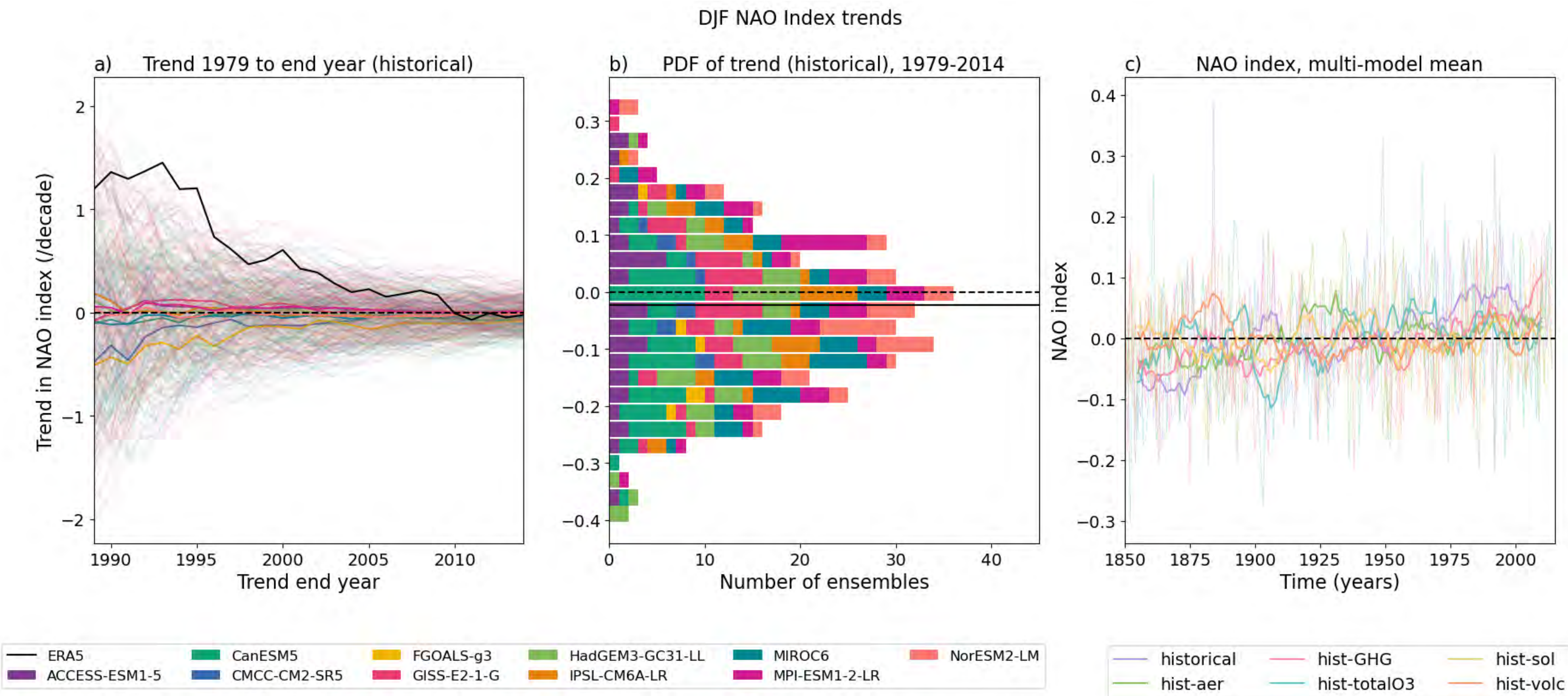

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Conclusions

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- **Implications and discussion: how best can we use decadal predictions from these models to predict future changes?**

Items for discussion

Implications and discussion: given the discrepancies between models and obs, how best can we use decadal predictions from these models to predict future changes? [Can the initialization help save us for short timescales?]

- If signals are non-additive, then how to relate changes in historical to individual forcings? (Simpson et al 2023 found non-additivity in CESM2 as well)
- Do these model have the correct amount of decadal and multi-decadal variability? Probably no …
- How much of the AMOC variability that is missing is forced vs. naturally occurring?

LEADER

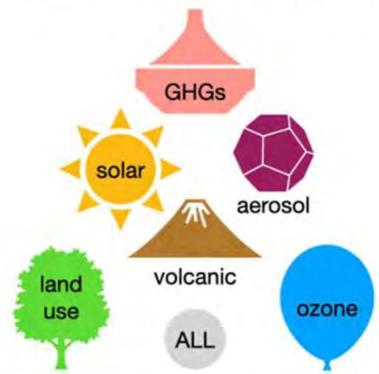
Large Ensembles for Attribution of Dynamically-driven ExtRemes

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?

To sign up, or for more information, **contact**:

chaim.garfinkel@mail.huji.ac.il
scott.ospray@physics.ox.ac.uk

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

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- Phase 2 (2026) will include operational decadal forecasts

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**

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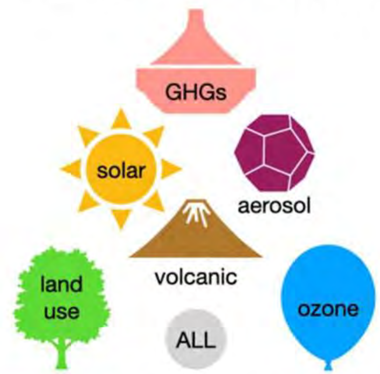

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Large Ensemble | Single Forcing | MIP

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

chaim.garfinkel@mail.huji.ac.il

scott.ospray@physics.ox.ac.uk

of internal variability? | different forcings? | climate models doing?

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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.**
- **To do: impact of these external forcings on QBO teleconnections**