Understanding historical changes in the Northern Hemisphere stratospheric polar vortex:

insights from the **L**arge **E**nsemble **S**ingle **F**orcing **M**odel **I**ntercomparison **P**roject

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et al

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האוניברסיטה העברית בירושלים
THE HEBREW UNIVERSITY OF JERUSALEM

NCAR

APARC
Atmospheric Processes And their Role in Climate

WCRP
World Climate Research Programme

LEADER

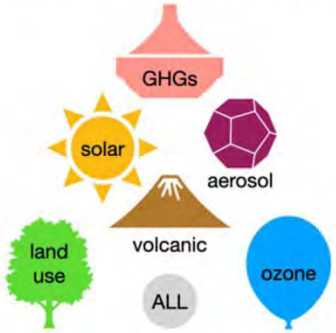
Large Ensembles for Attribution of Dynamically-driven ExtRemes

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?

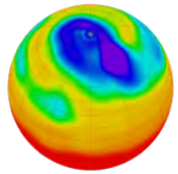
Single Forcing



What is the response to different forcings?

MIP

How well are current climate models doing?



Centre for Environmental Data Analysis

SCIENCE AND TECHNOLOGY FACILITIES COUNCIL
NATURAL ENVIRONMENT RESEARCH COUNCIL

JASMIN

INTAKE

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

To sign up, or for more information, contact:

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

LEADER: 8 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

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4) Surface response to **solar** variability

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

6) QBO influences on surface climate (3 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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Dataset

LESFMIP models

Large Ensemble Single Forcing MIP (LESFMIP)

- Mainly DAMIP simulations but >10 ensemble members from 1850-2020
- Additional runs to assess non-linearity and sensitivity to background state
- ~13 modeling centers. Data from ten is already on ESGF. Three of the models spontaneously simulate a QBO.
- Phase 2 (2026) will include operational decadal forecasts

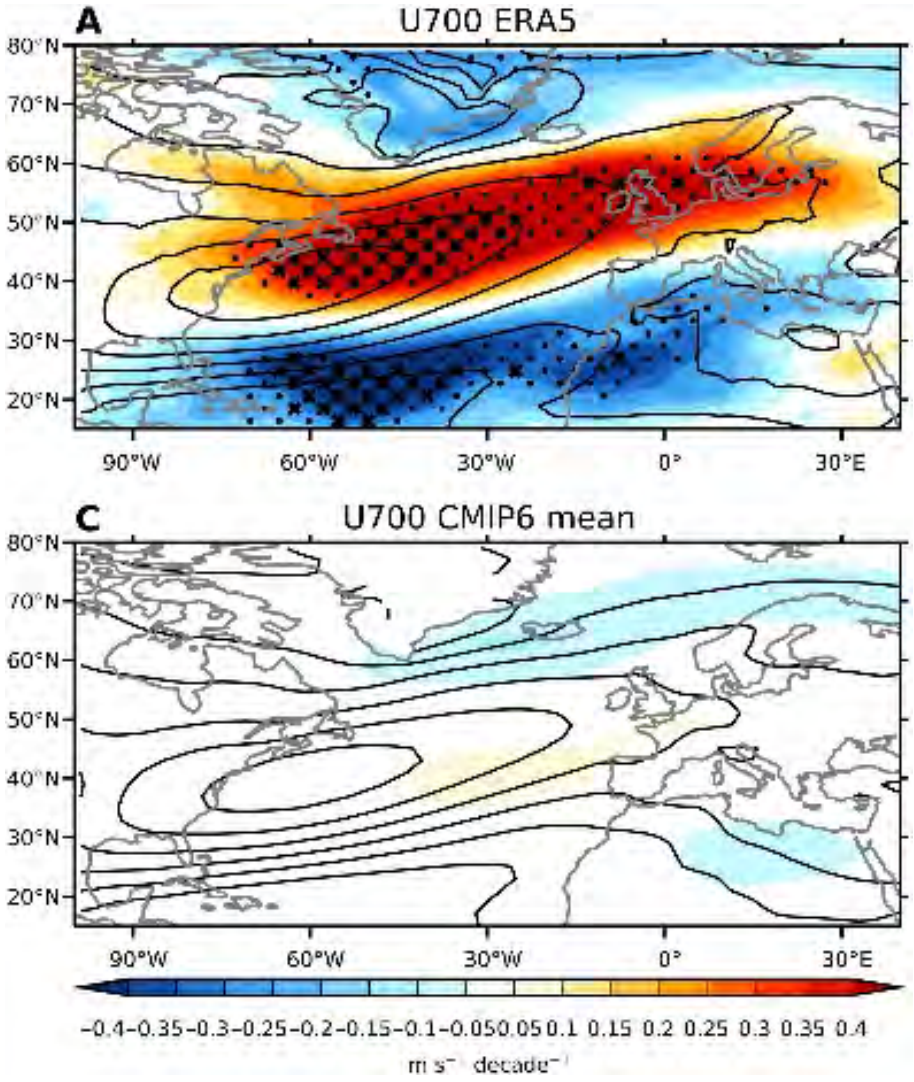
Experiment name	Description
hist-GHG	Well-mixed greenhouse-gas-only historical simulations (WMGHGs)
hist-aer	Anthropogenic-aerosol-only historical simulations (BC, OC, SO2, SO4, NOx, NH3, CO, NMVOC)
hist-sol	Solar-only historical simulations (solar irradiance)
hist-volc	Volcanic-only historical simulations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

Dataset

Number of ensemble members

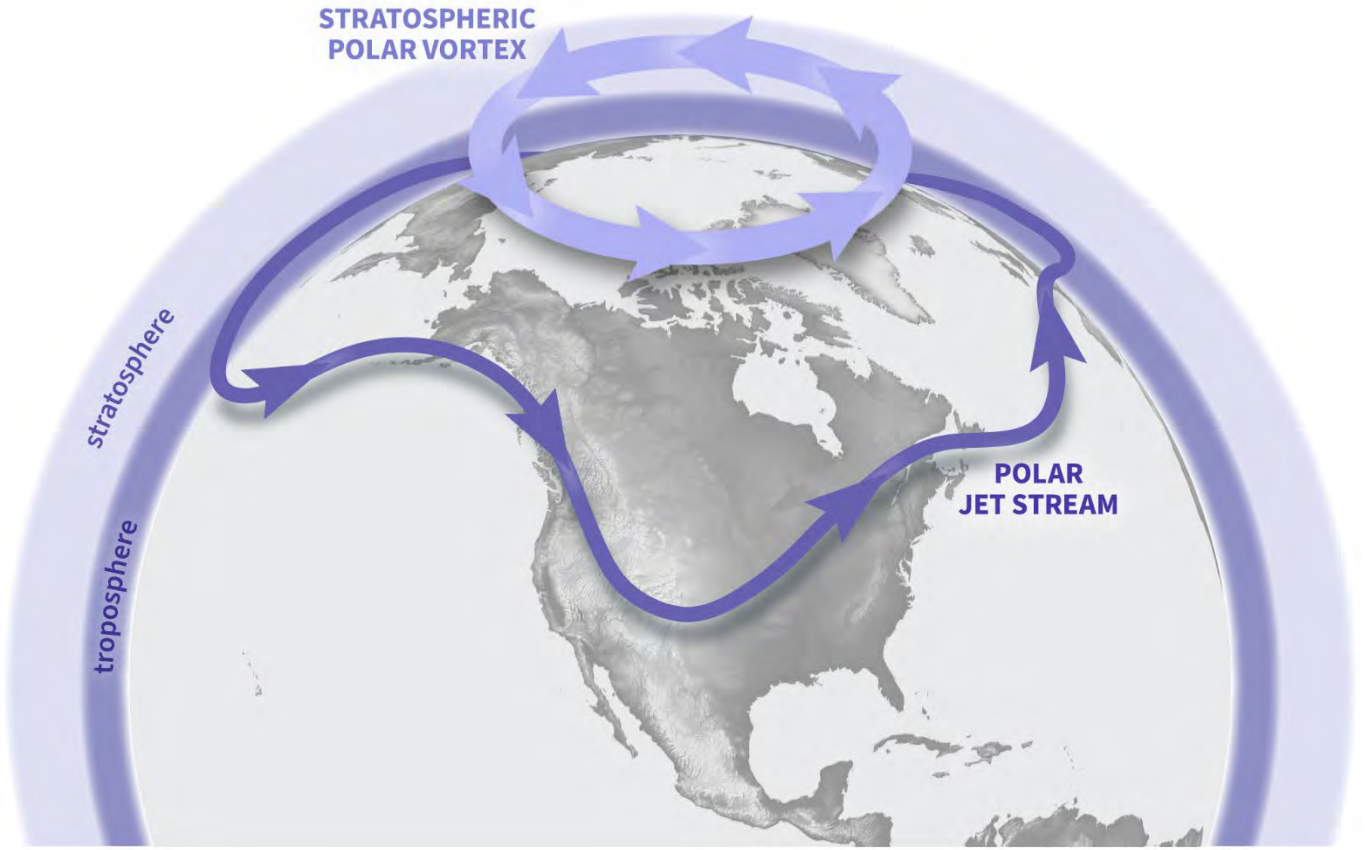
Model	Experiments				
	hist-GHG	hist-aer	hist-sol	hist-volc	hist-totalO3
ACCESS-ESM1-5	10	3	9	10	
CanESM5	50	30	50	50	10
CESM2	15	15			
CMCC-CM2-SR5	10	10		10	
FGOALS-g3	3	3			
GISS-E2-1-G	45	45	40	40	5
HadGEM3GC31-LL	55	55	50	50	50
IPSL-CM6A-LR	10	10			
MIROC6	50	10	10	10	10
MPI-ESM1-2-LR	30	30	30	30	30
NorESM2-LM	23	23	20	20	20

Models fail to capture strengthening wintertime NA jet



Blackport & Fyfe (2022)

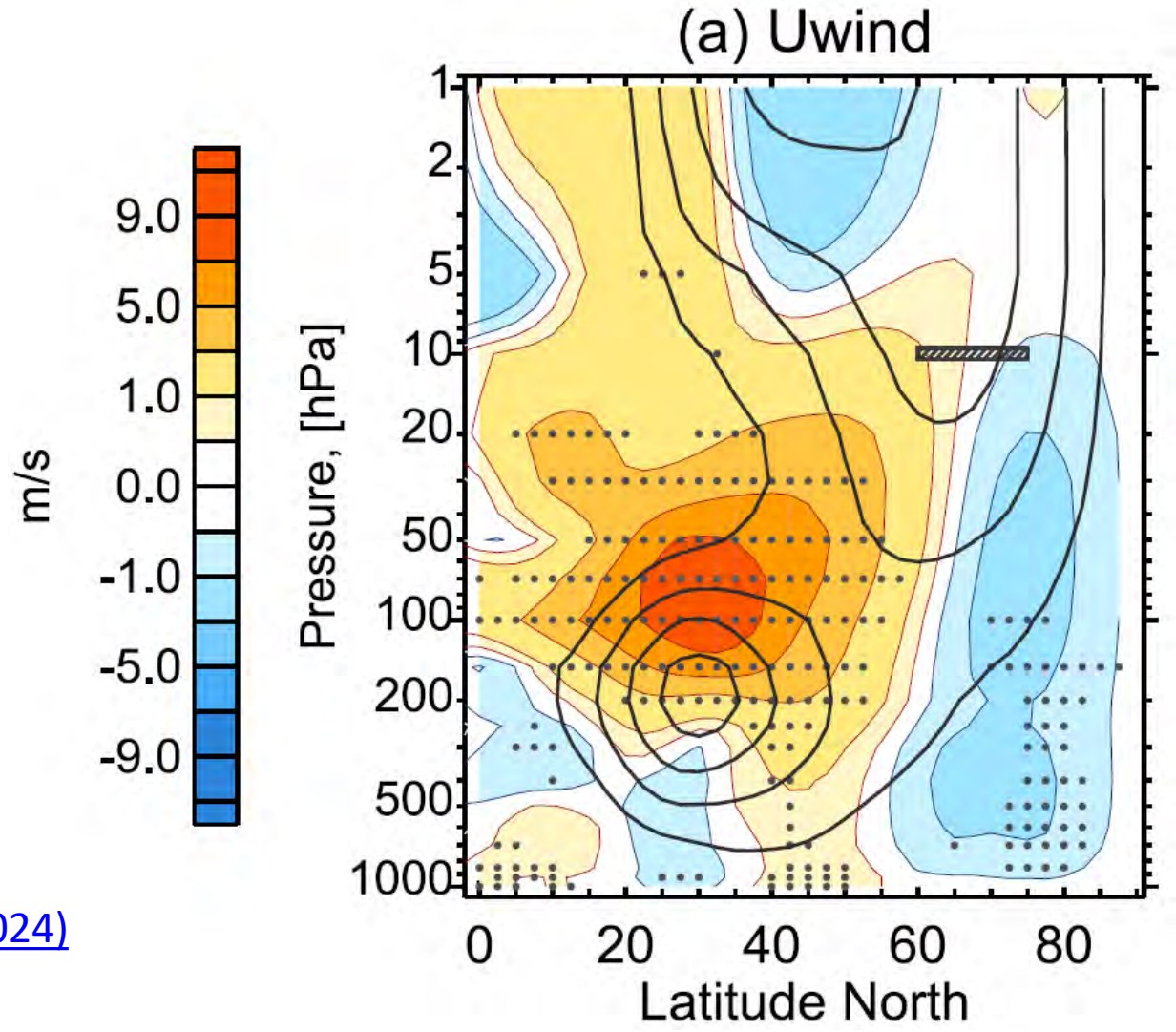
Motivation



NOAA Climate.gov
Data: Waugh et al., 2017

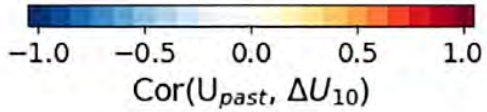
To constrain the projected response of the North Atlantic winter circulation with the strength of the winter stratospheric polar vortex

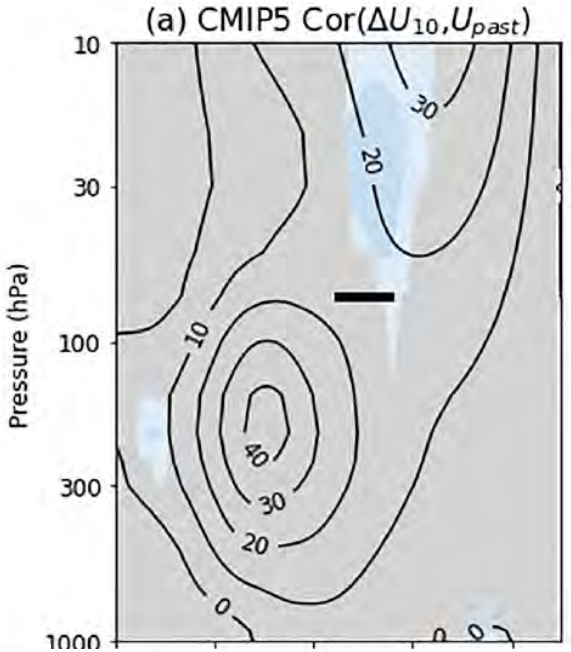
Large uncertainty in the projected winter Arctic stratospheric polar vortex response

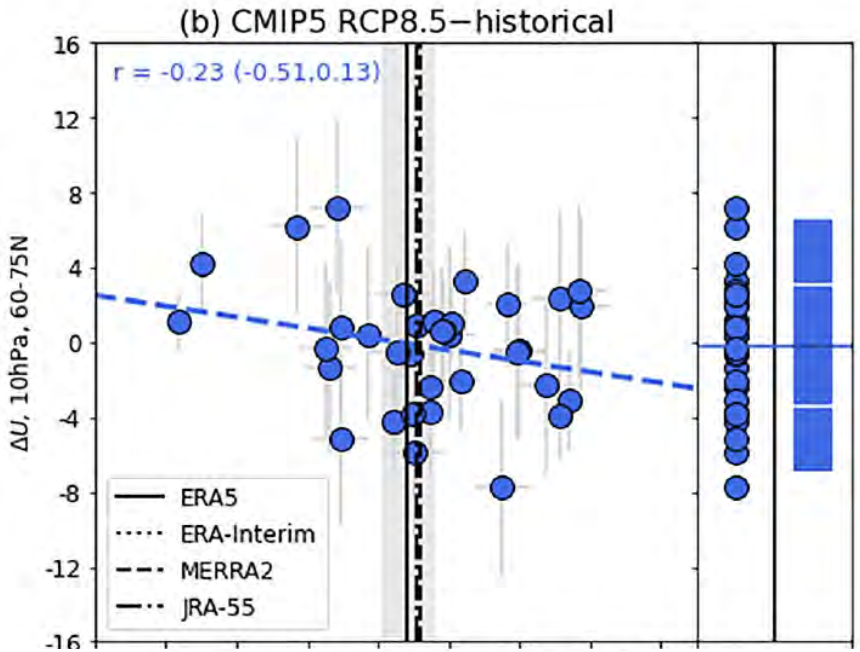


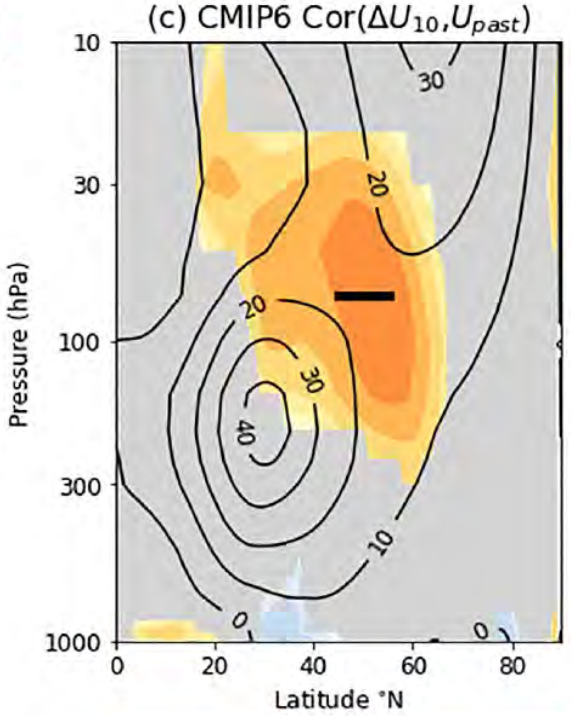
Karpechko et al (2024)

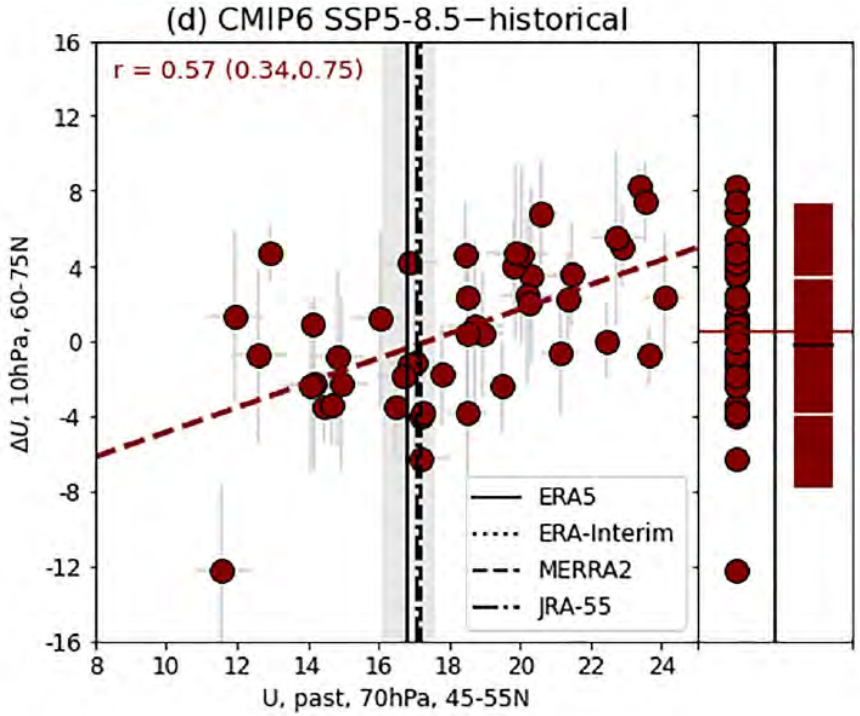
CMIP5 vs CMIP6





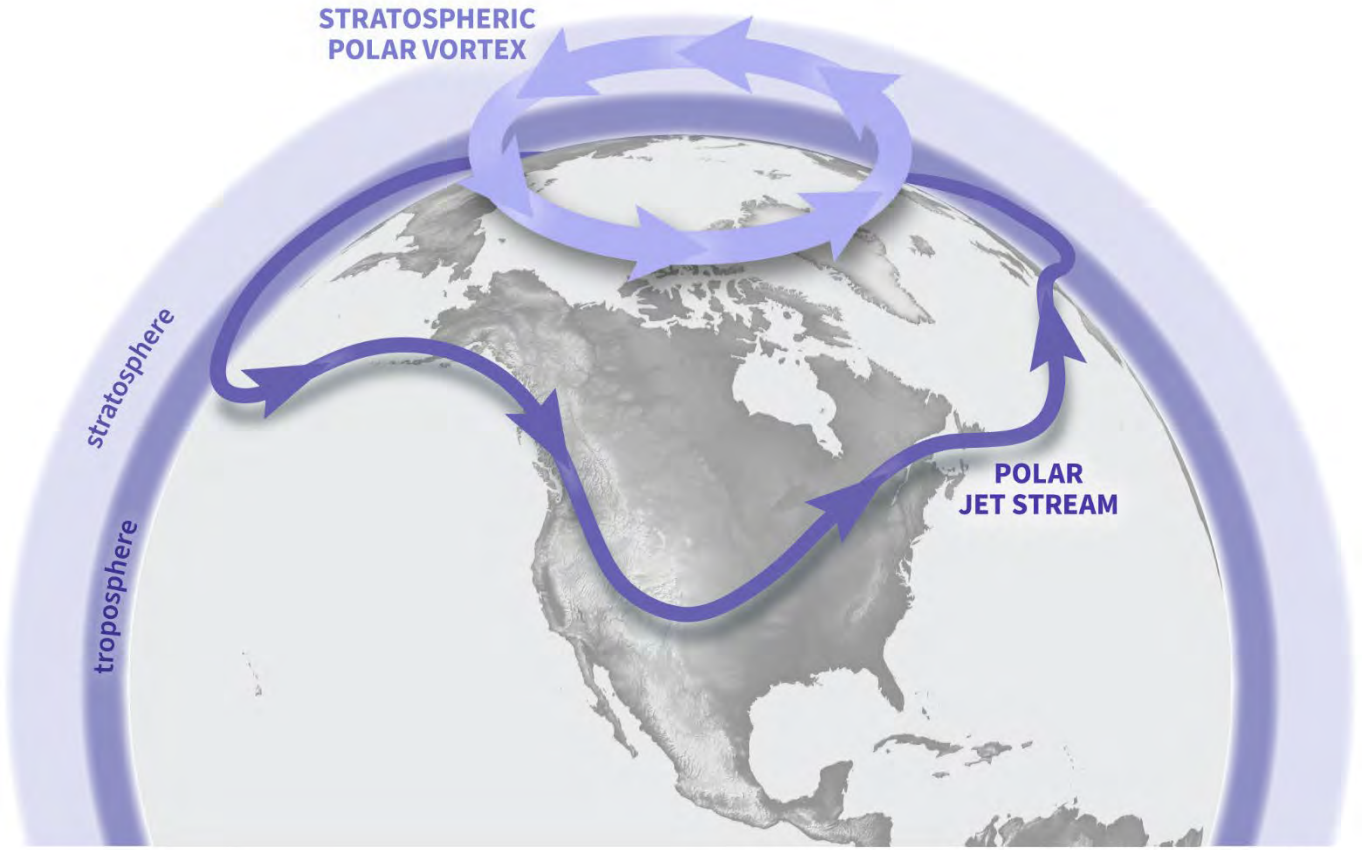






[Karpechko et al (2024)]

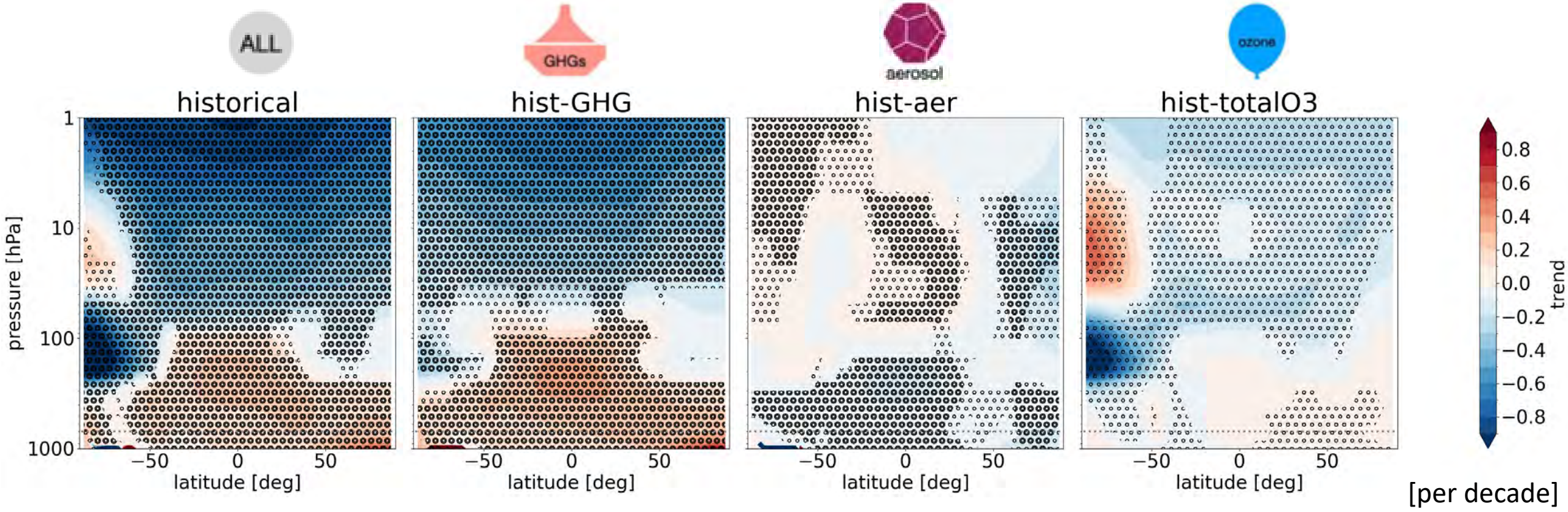
Results



NOAA Climate.gov
Data: Waugh et al., 2017

Wintertime **zonal wind**, **temperature** & **Northern Annular Mode (NAM)** trends for the period 1951-2014

Trends in **temperature** (DJF)

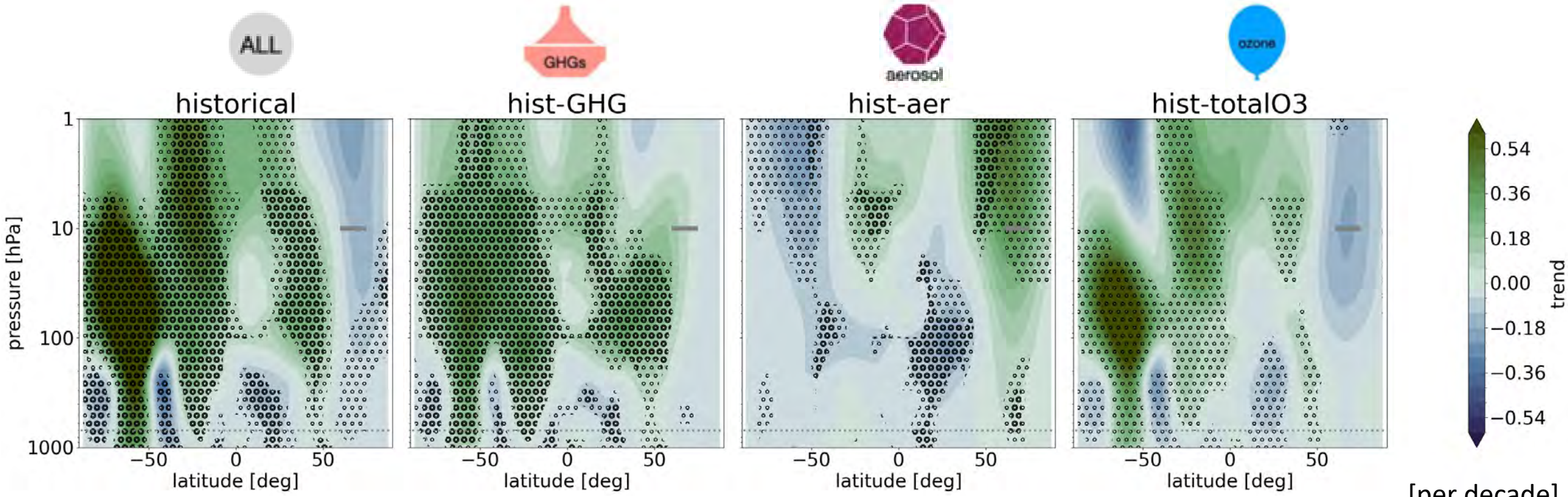


Sign test

o … p-values < 0.05

o … p-values < 0.01

Trends in **zonal wind** (DJF)



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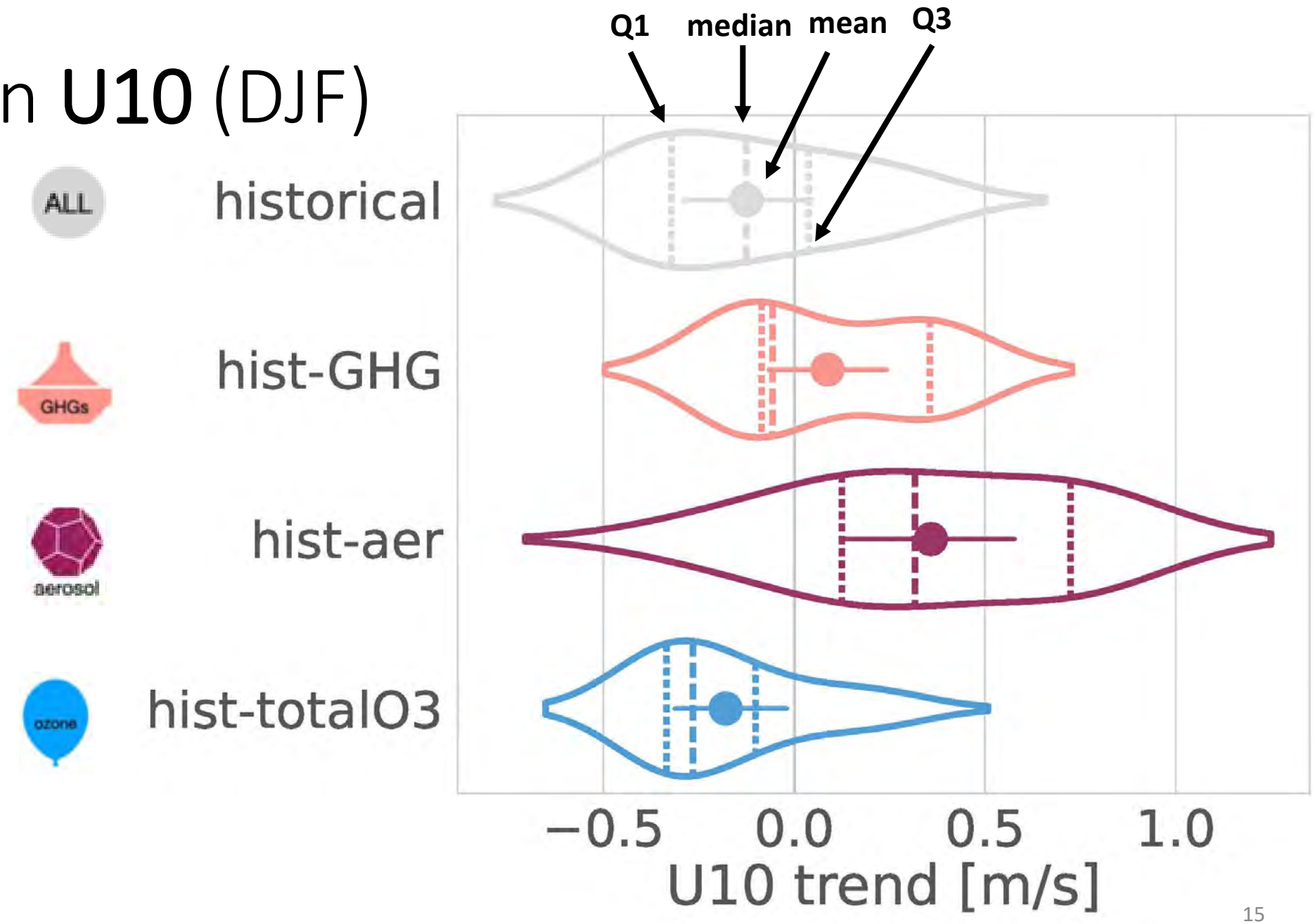
Issues:

1) model disagreement in high latitudes

Trends in **U10** (DJF)



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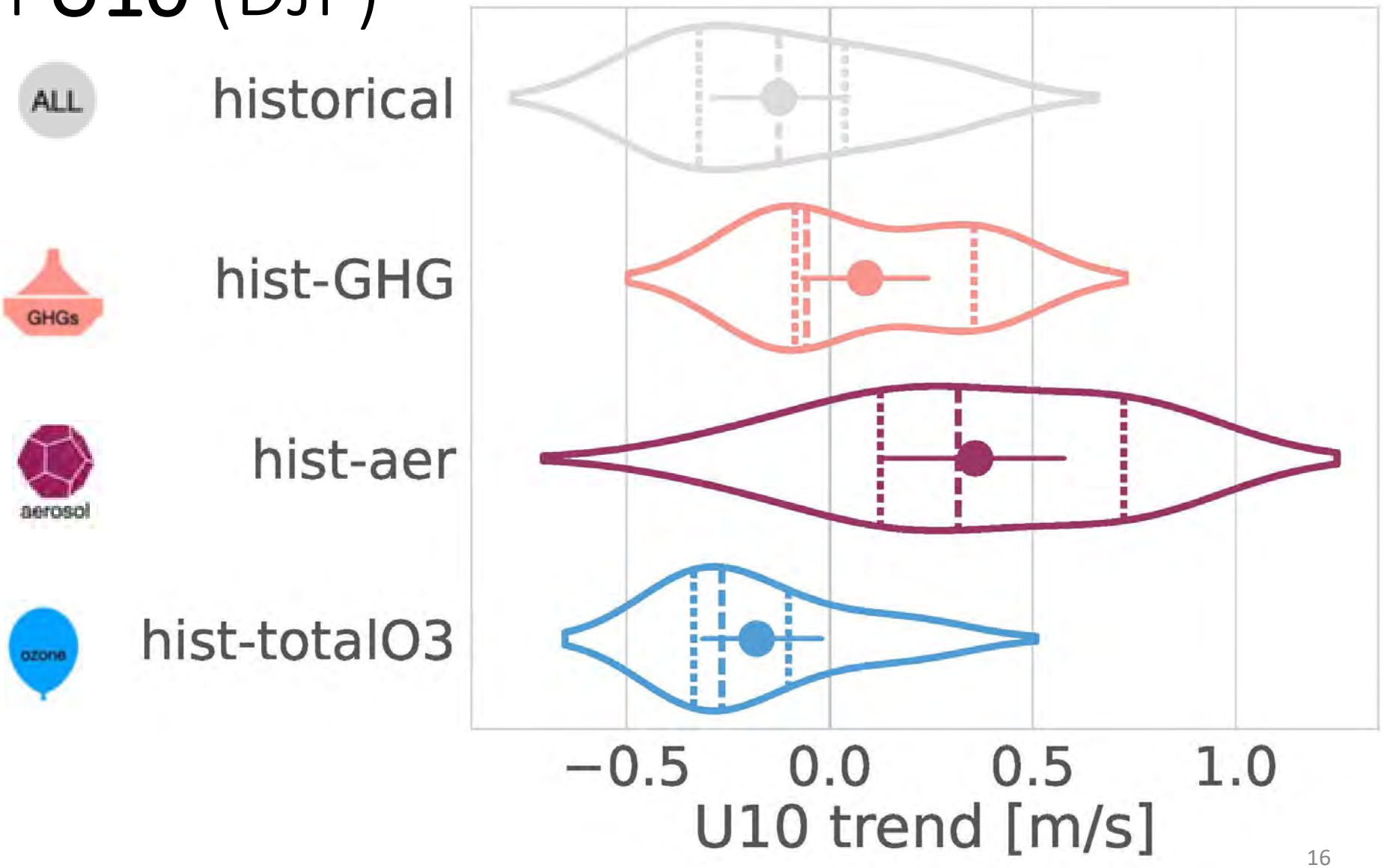
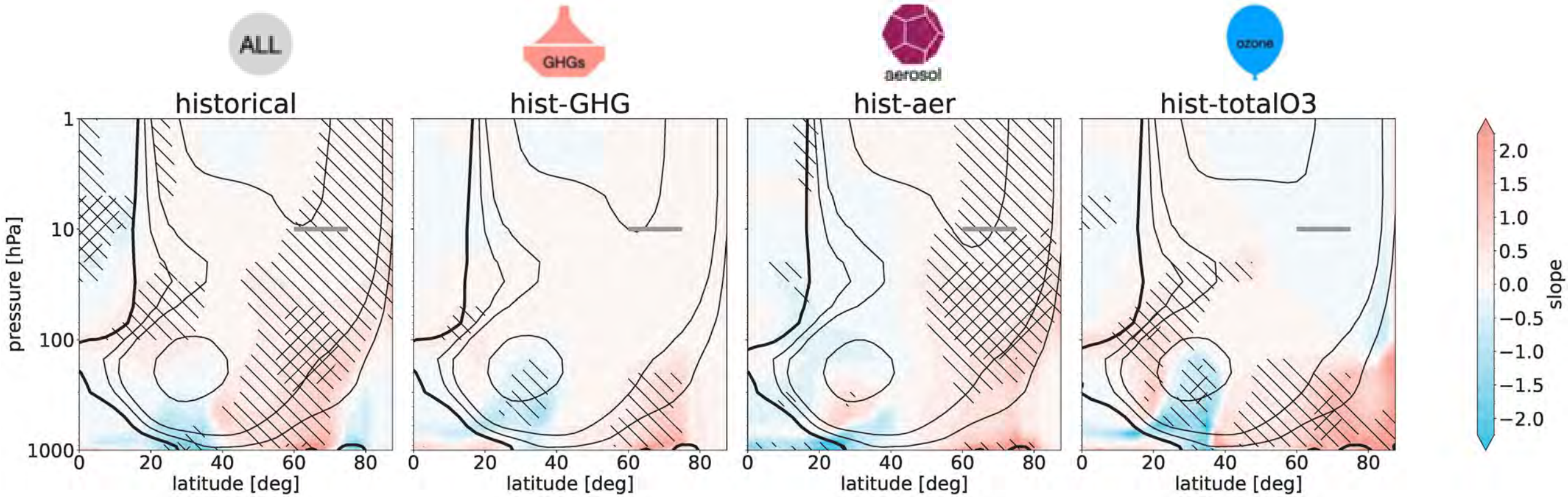


Possible emergent constraint?



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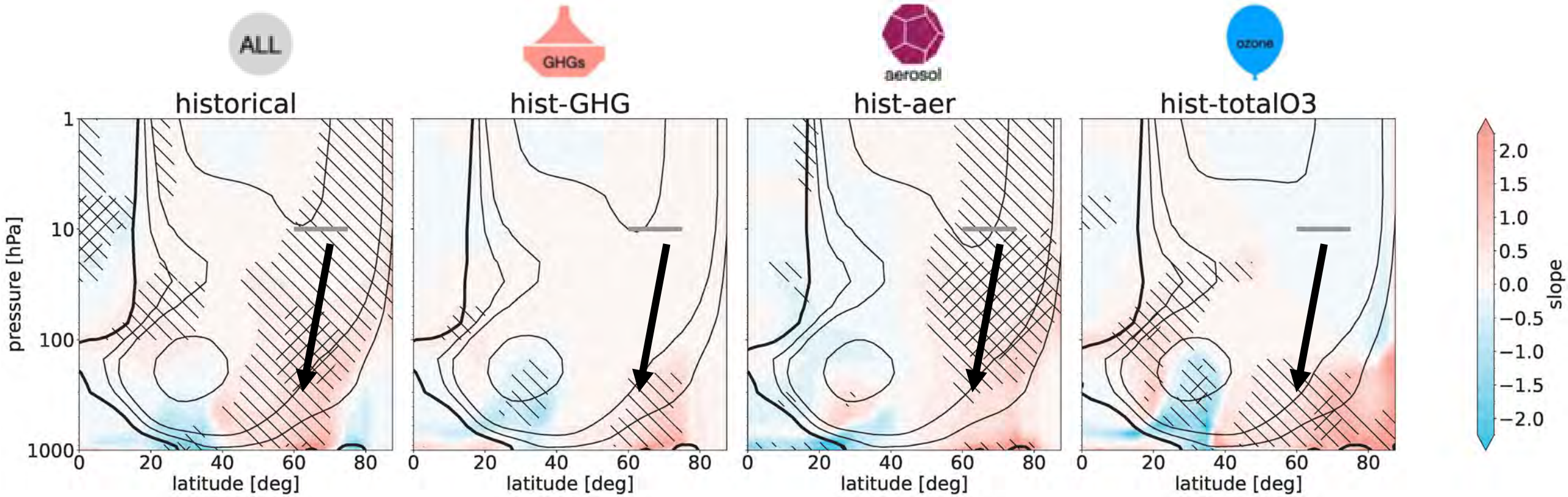

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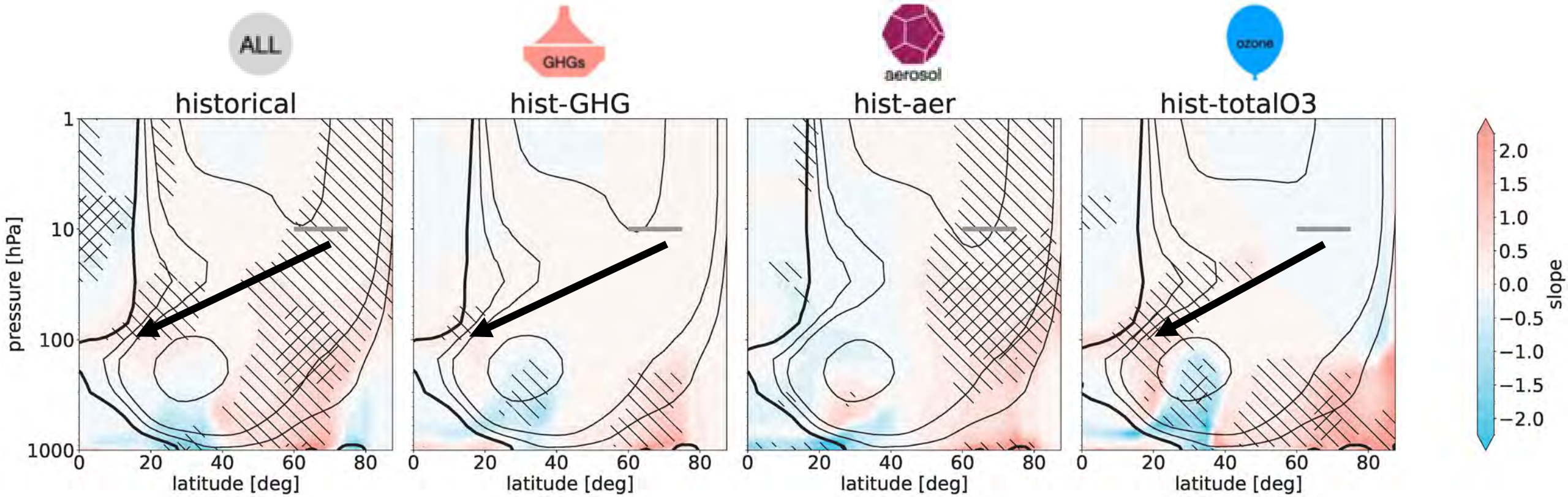
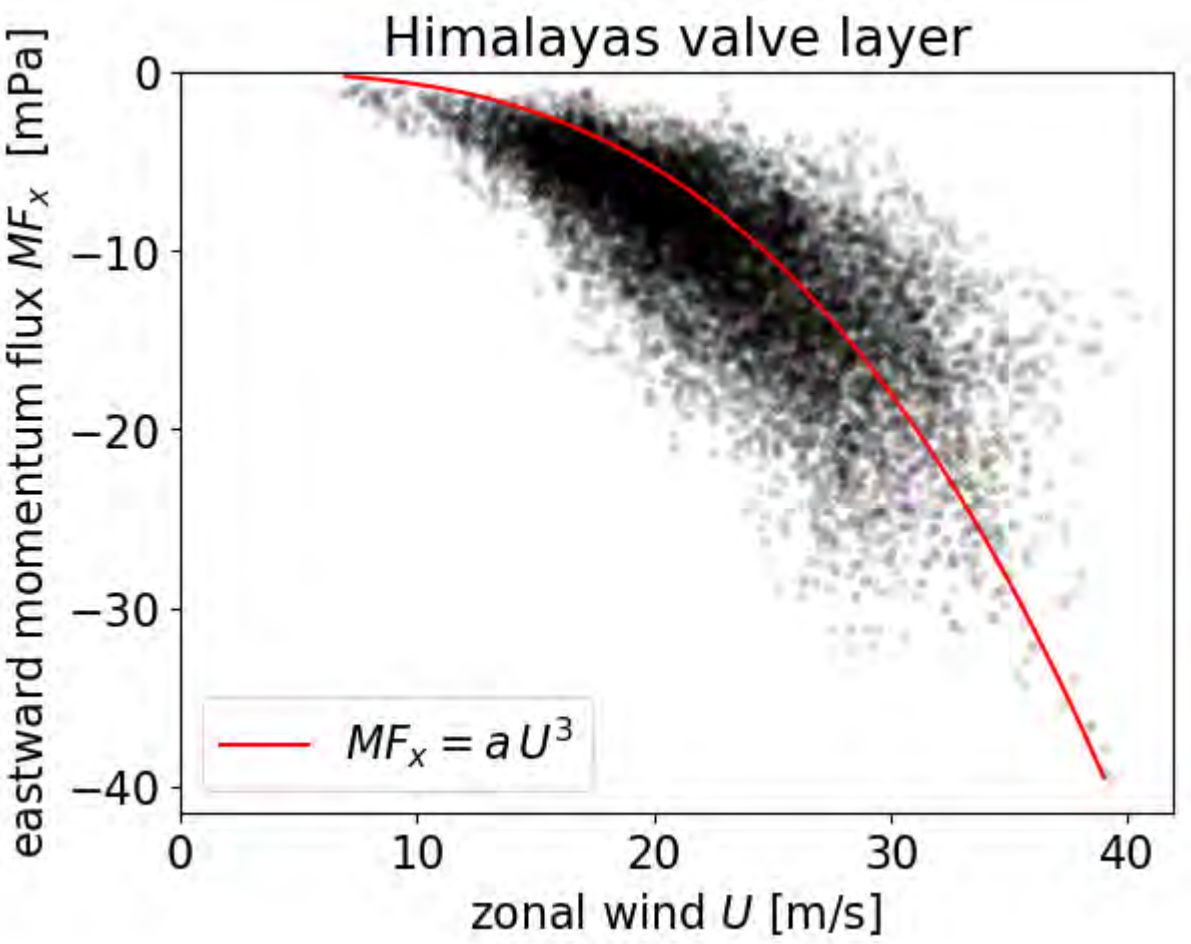
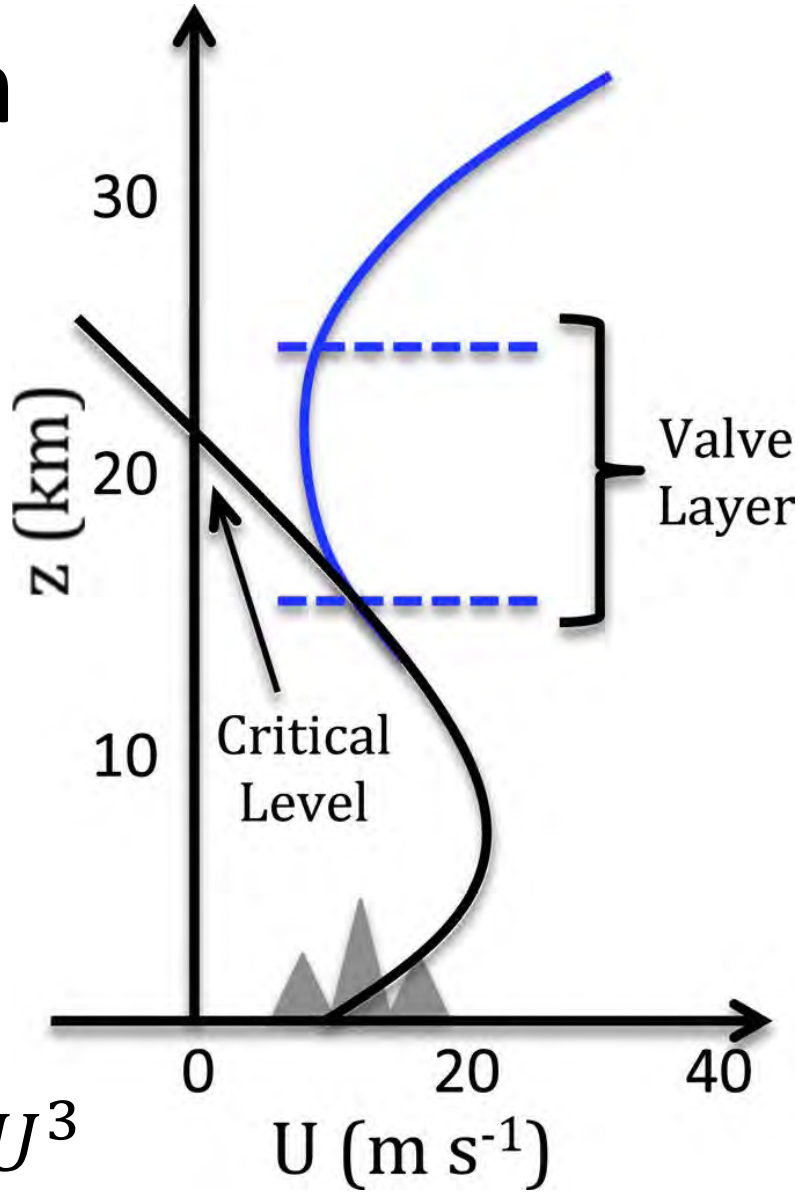


Mechanism of wave attenuation



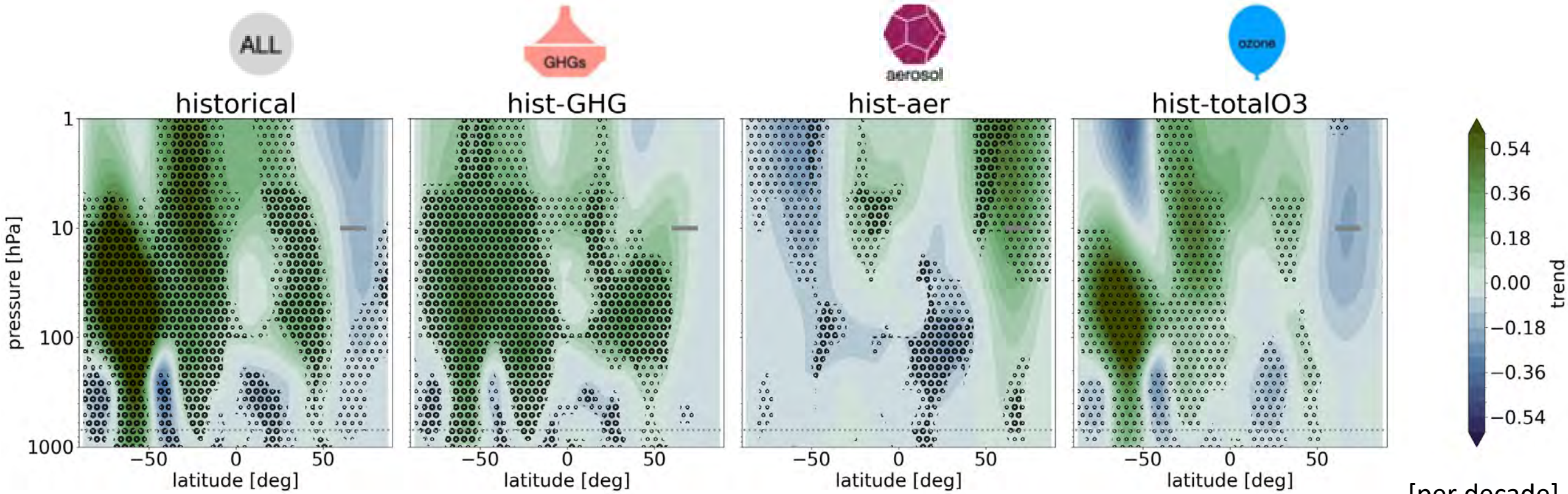


Parameterized saturated zonal momentum flux:

$$MF_{x_{sat}} = -\frac{F_c^2 \varepsilon k}{2}\frac{\bar{\rho} U^3}{N}$$

Kruse et al (2016) in JAS

Trends in **zonal wind** (DJF)



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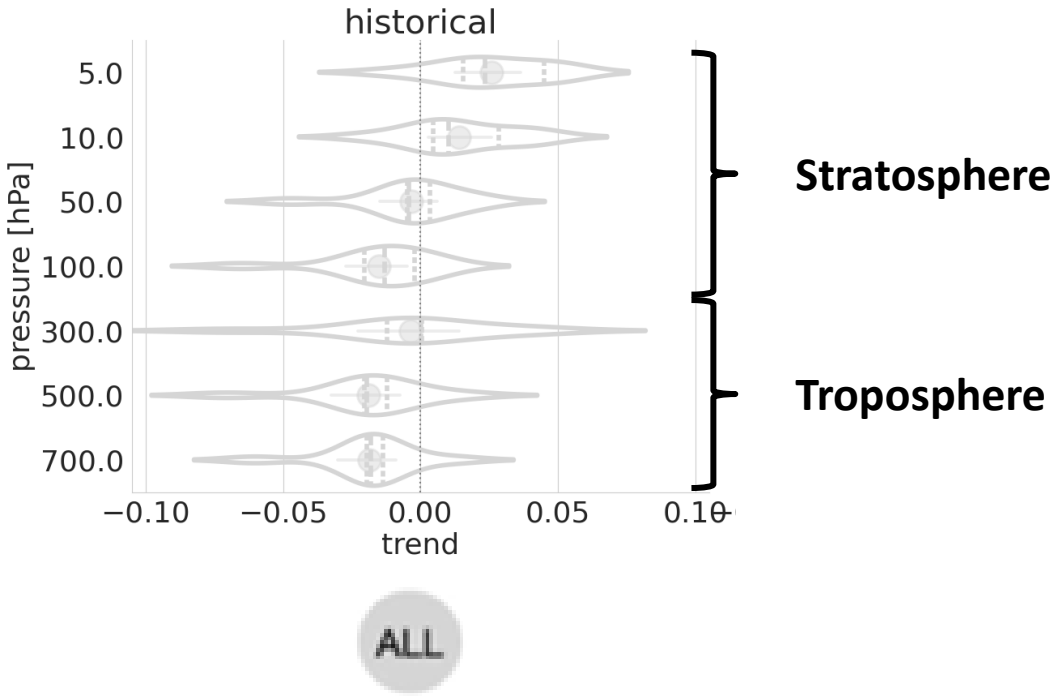
Issues:

1) model disagreement in high latitudes
2) region selection

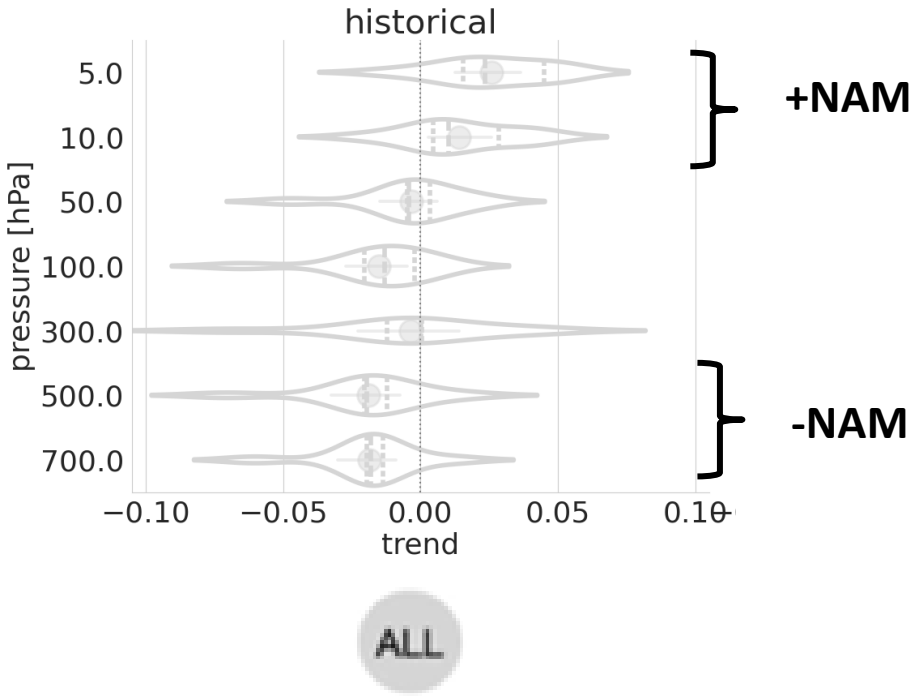
Trends in **NAM** (DJF) for 1951-2014



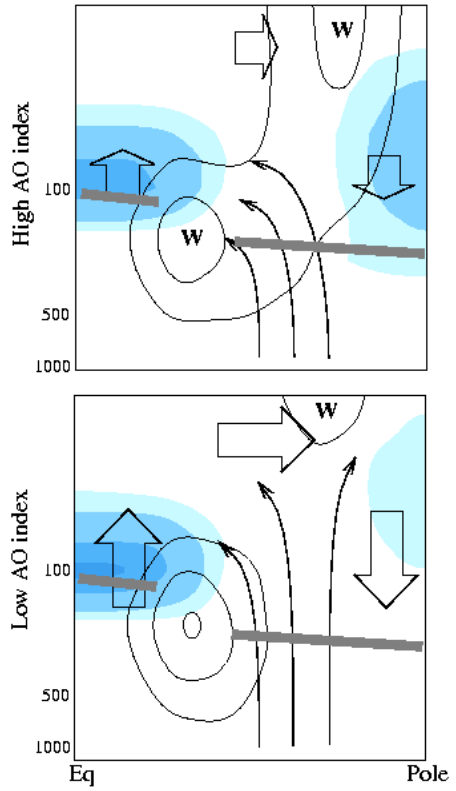
[per decade]

Courtesy of Gabriel Chiodo & Samuel Benito-Barca

Trends in **NAM** (DJF) for 1951-2014

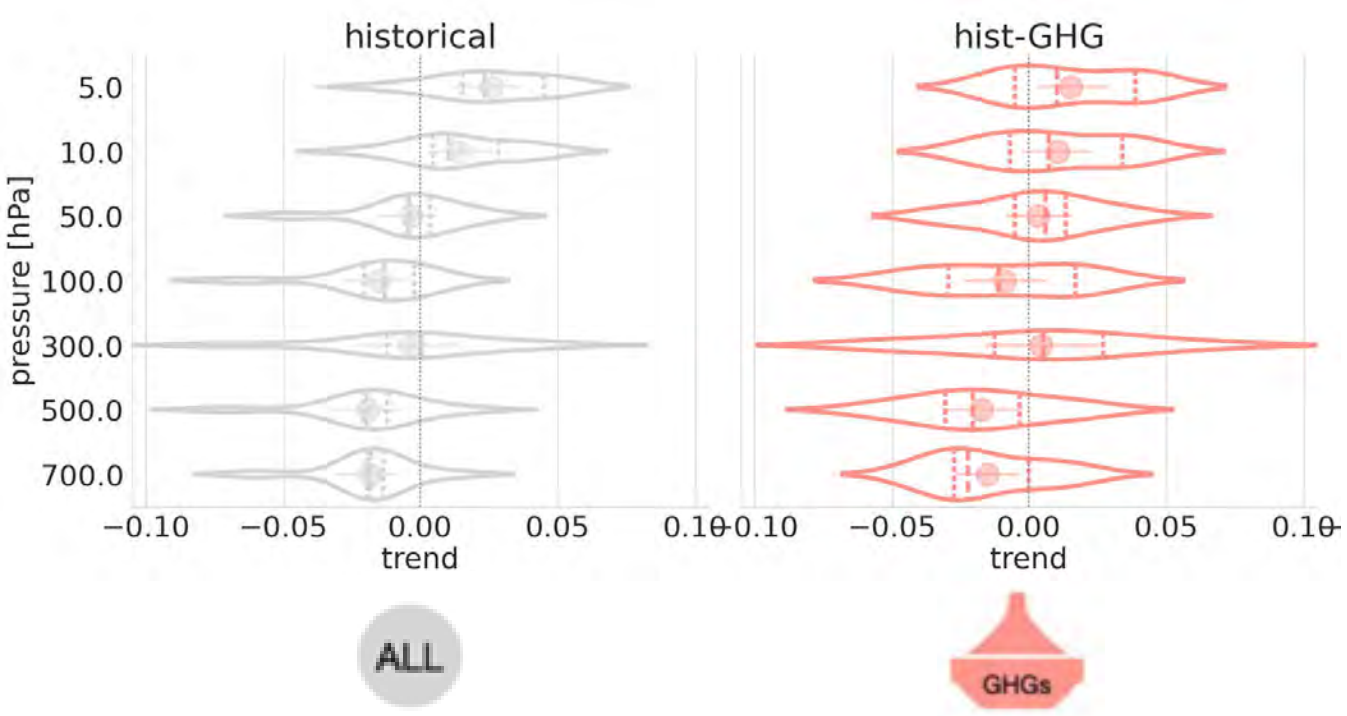


[per decade]



Courtesy of J. M. Wallace

Trends in **NAM** (DJF) for 1951-2014



[per decade]

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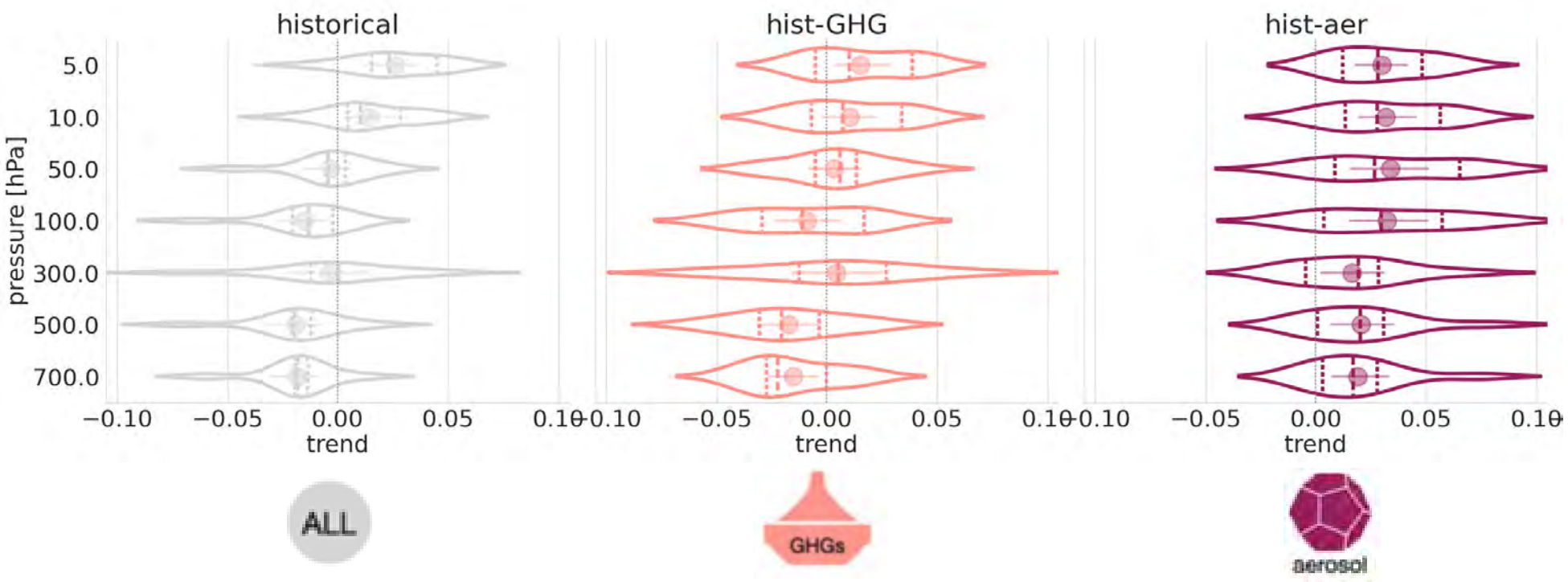
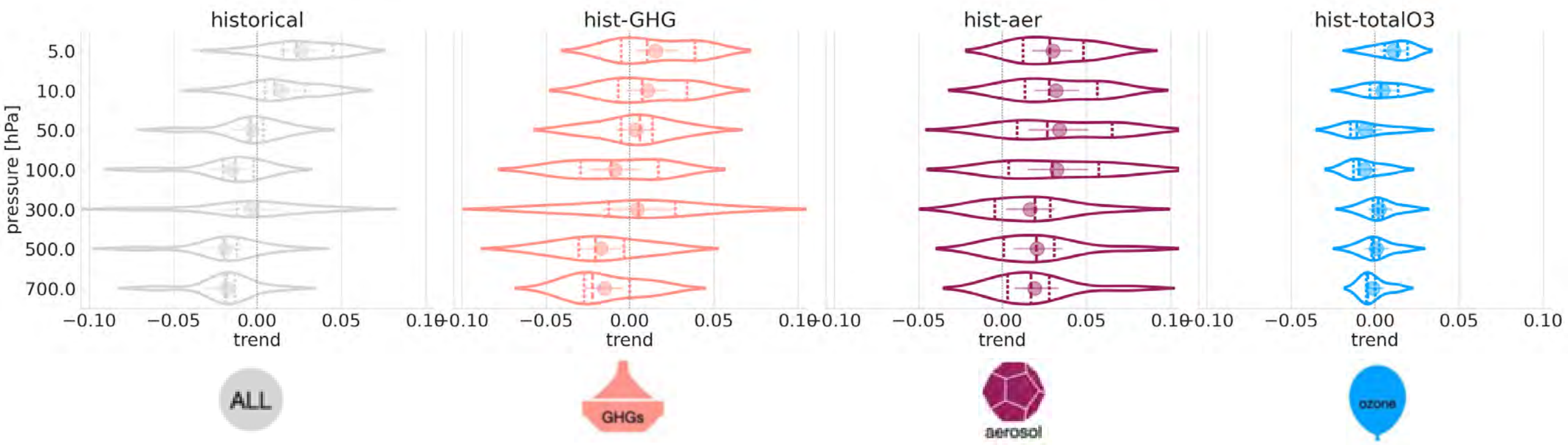


[per decade]

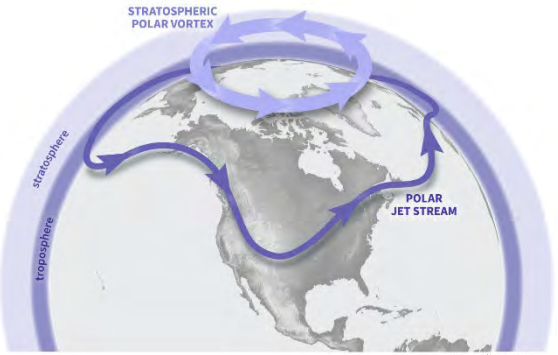
Trends in **NAM** (DJF) for 1951-2014



[per decade]

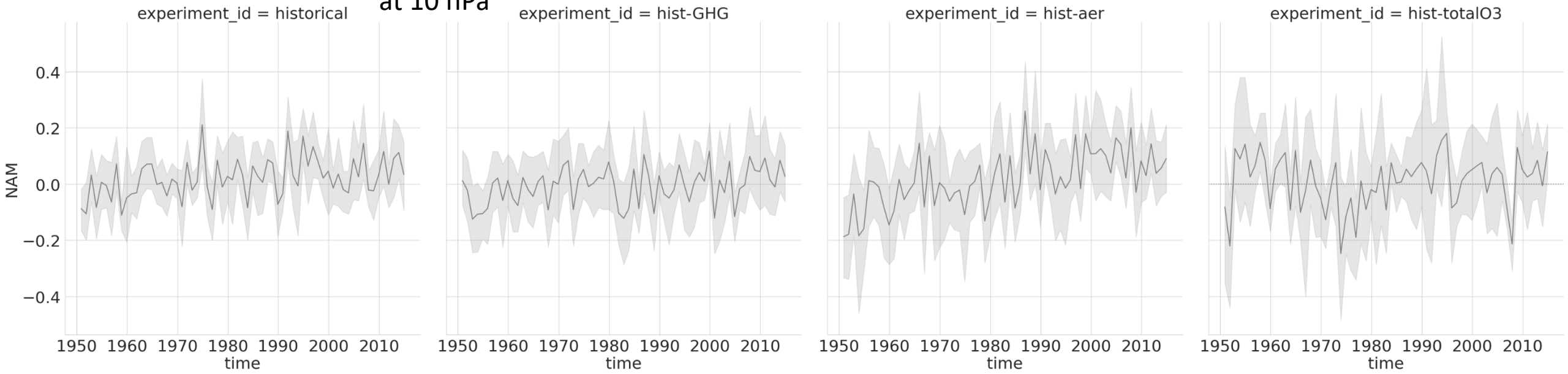
Preliminary conclusions

- community effort from the WCRP's APARC LEADER and EPESC projects
- the inter-model spread in the NH stratospheric polar vortex responses as one of dominating for surface
- tug of war between high- (AA) and low-latitude (UTTW) forcing
- ongoing work aims at
  - understanding the model responses with respect to observations
  - possible emerging constraint
  - aerosol forcing

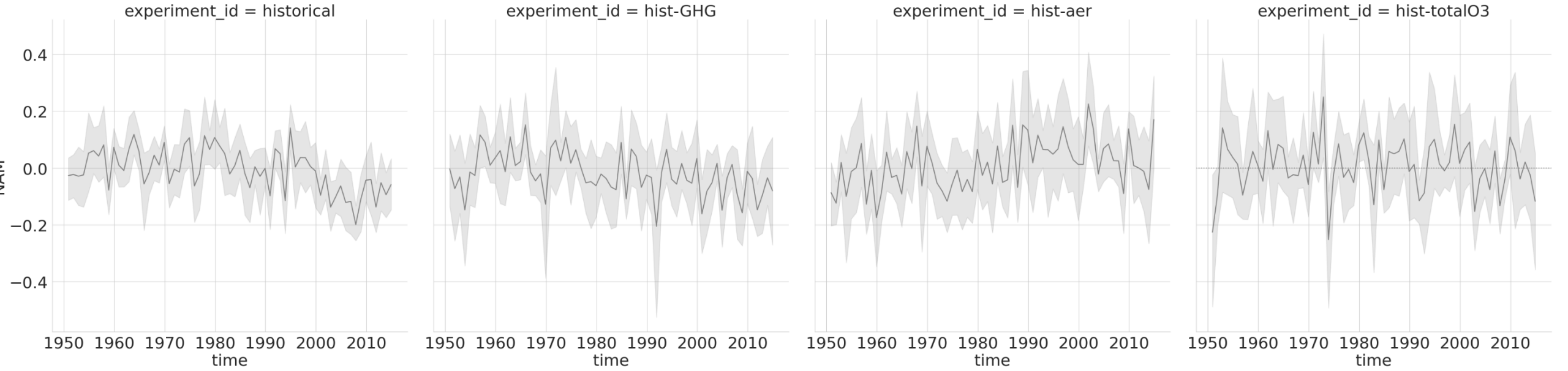


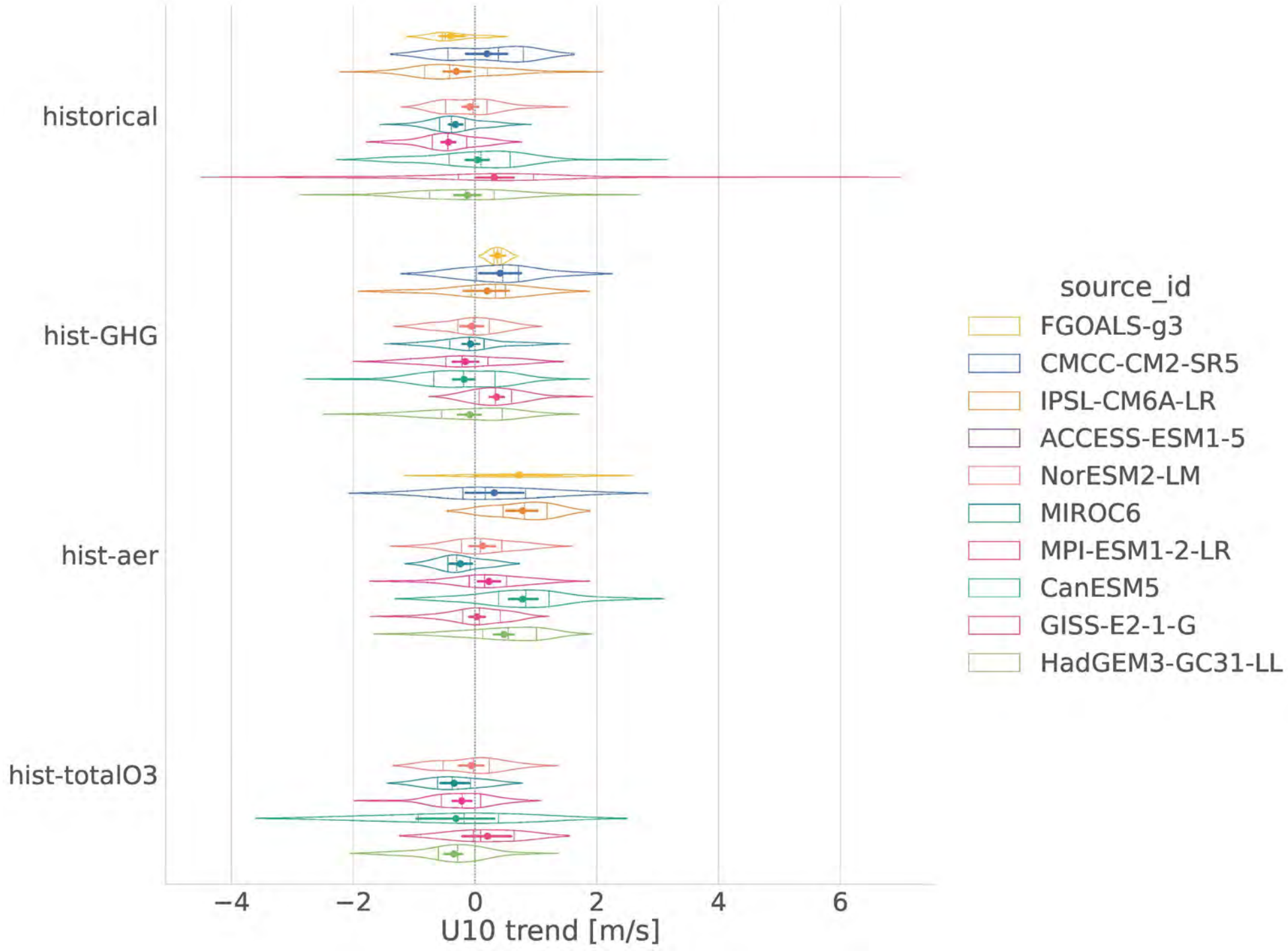
BACKUP

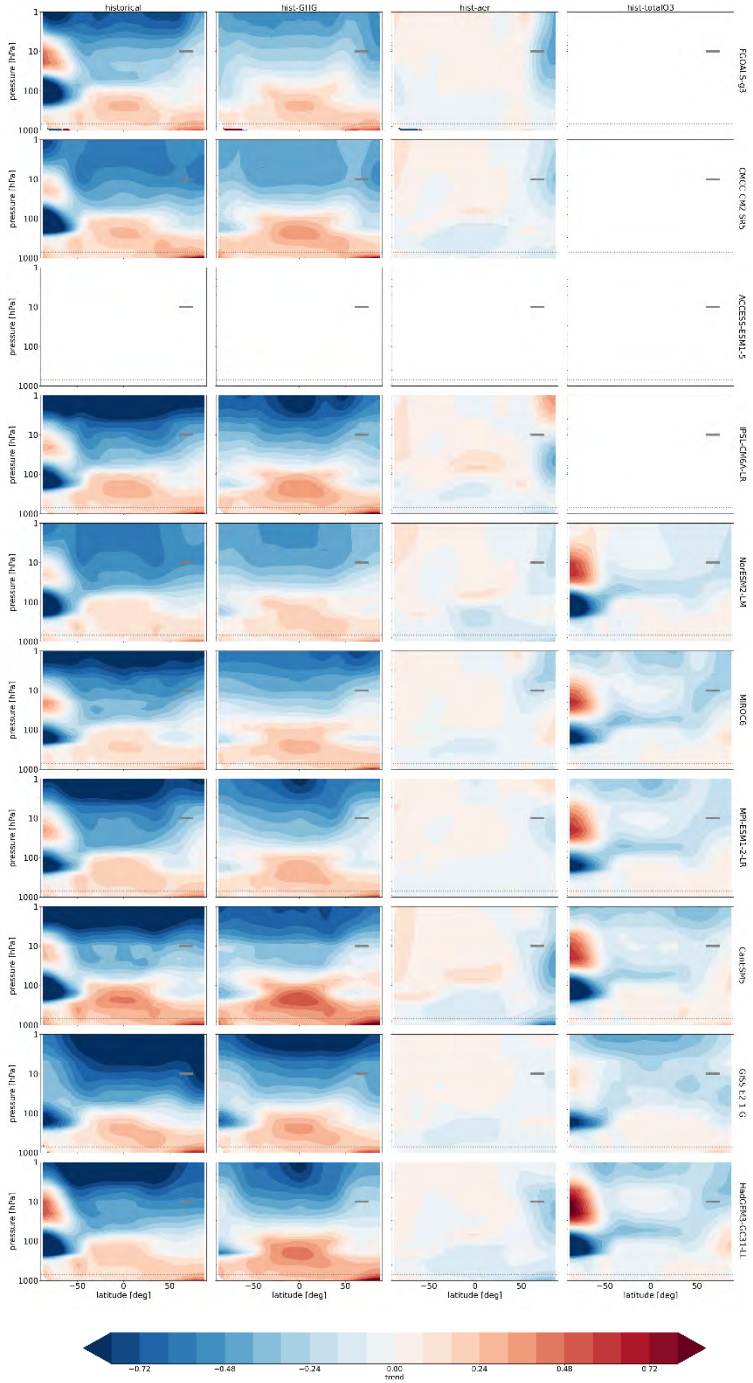
at 10 hPa



at 700 hPa




historical
hist-GHG
hist-aer
hist-totalO3
−4
−2
0
2
4
6
U10 trend [m/s]
source_id
FGOALS-g3
CMCC-CM2-SR5
IPSL-CM6A-LR
ACCESS-ESM1-5
NorESM2-LM
MIROC6
MPI-ESM1-2-LR
CanESM5
GISS-E2-1-G
HadGEM3-GC31-LL


historical
hist-GHG
hist-aer
hist-totalO3
pressure [hPa]
latitude [deg]
FGOALS-g3
CMCC-CM2-SR5
ACCESS-ESM1-5
IPSL-CM6A-LR
NorESM2-LM
MRI-ESM2-0
MPI-ESM1-2-LR
CanESM5
GISS-E2-1-G
HadGEM3-GC31-LL
trend