APARC LEADER WORKING GROUP I:

DECADAL VARIABILITY OF THE STRATOSPHERE AND ITS CONNECTION TO SURFACE CLIMATE: A MODEL INTERCOMPARISON

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WORKING GROUP 1:

DECADAL VARIABILITY OF THE STRATOSPHERE AND ITS CONNECTION TO SURFACE CLIMATE

During eight consecutive winters in the 1990s, no Sudden Stratospheric Warmings (SSWs) occurred in the NH and the vortex was anomalously strong (Domeisen, 2019). It is not clear whether this was sampling variability or if it was externally forced.

Overarching scientific question: What are the origins and impacts of the strong decadal variability in the stratosphere?

The "SSW drought" in the 1990s coincides with the longest absence of NAO events since 1850

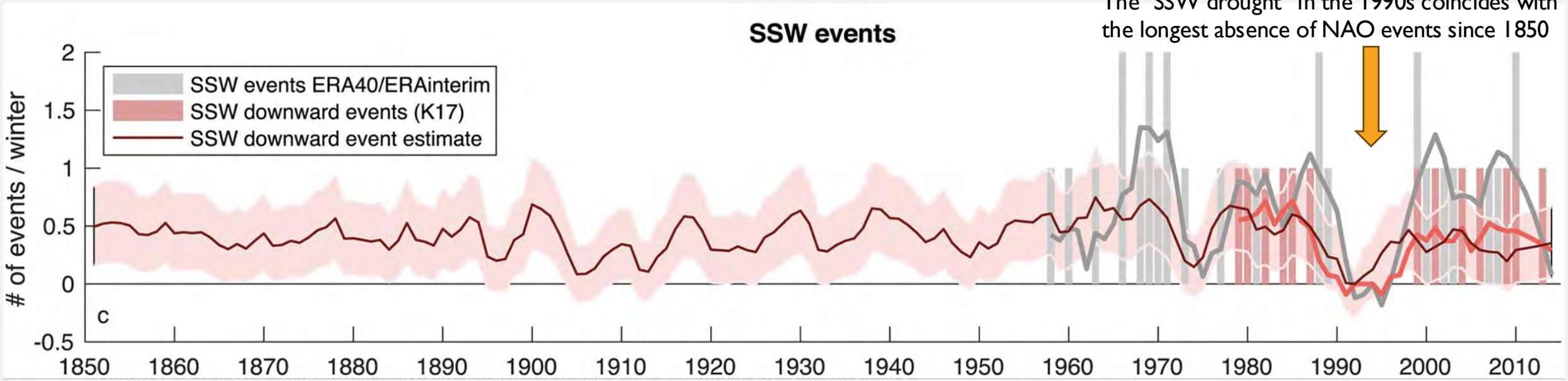

Figure: reconstructed SSW frequency based on surface NAO- events from observations and reanalysis. *From: Domeisen, 2019, JGR-Atmospheres*

WORKING GROUP 1:

DECADAL VARIABILITY OF THE STRATOSPHERE AND ITS CONNECTION TO SURFACE CLIMATE

WG goals:

The large ensembles available in LESFMIP allow us to determine the **role of internal variability versus external forcings for Sudden Stratospheric Warming (SSW) droughts and the associated downward impacts**. We will also consider the **role of decadal stratospheric variability for model biases in tropospheric circulation decadal variability**.

SELECTED RESEARCH QUESTIONS OF WORKING GROUP I:

DECADAL VARIABILITY OF THE STRATOSPHERE AND ITS CONNECTION TO SURFACE CLIMATE

Is decadal variability in the stratosphere present in the single forcing experiments?

- Is there a particular forcing (e.g. ozone, volcanic eruptions) that lead to more frequent SSW droughts?
- How often do decades with a strong or weak vortex occur?

What are the origins of (or the absence of) decadal variability in the single forcing experiments?

- What sea surface temperature and stationary wave patterns are associated with such decades?
- Is the inter-model spread in decadal variability related to e.g. mean-state biases in the polar vortex, biases in tropospheric stationary waves?

How well is the downward impact of the stratosphere on the troposphere captured?

- Do the models capture the downward surface impact accurately, including the impact on extreme events?
- Do they capture the regional patterns of the surface impacts? (e.g. cold in northern Eurasia, cold and dry in Australia)

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AVAILABLE MODELS AND LARGE ENSEMBLE MODEL RUNS

- historical → all forcings
- hist–X → forcing X is the only one varying,
  while all others are kept constant

- Daily data much more limited compared to monthly data,
- For daily data, 'large ensemble' could be down to only a few ensemble members for some models

Daily zonal wind data availability

	1.1 hist-GHG	1.2 hist-aer	1.3 hist-sol	1.4 hist-volc	1.5 hist-totalO3	1.6 hist-lu	3.1 historical
ACCESS-CM2	1	3					3
ACCESS-ESM 1-5	3	3					40
CESM2	3	2					9
CNRM-CM6-1	3	3					25
CanESM5	10	10	10	10	10		25
FGOALS-g3	3	3					1
GISS-E2-1-G	1	1					1
HadGEM3-GC 31-LL*	5	5					5
IPSL-CM6A-L R	9	9			9		31
MIROC6	3	3	3	3	3		9
MRI-ESM2-0	5	5	5	5	3		5

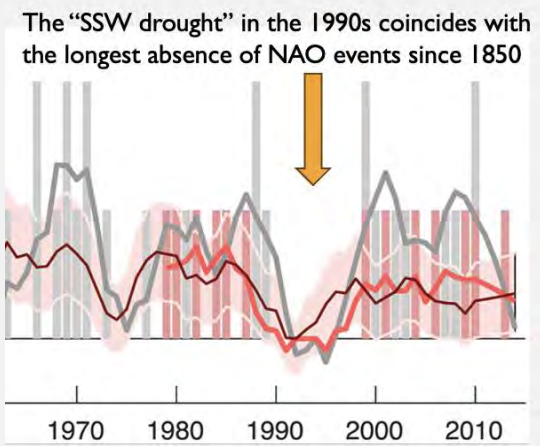
Numbers above indicate total number of ensemble members

* more ensemble members are available (to be downloaded)

DEFINING SSW DROUGHT INDEX AND NAM INDEX

- As a first step, we put together two indices to represent the decadal variability in the stratosphere:
  - SSW drought index (based on daily U10 data),
    - 0 < SSW drought index < 1, 1 = 'perfect' drought

$$p(drought\ periods) = \frac{\#SSWs_{10} \leq 2}{10}$$



Domeisen, 2019

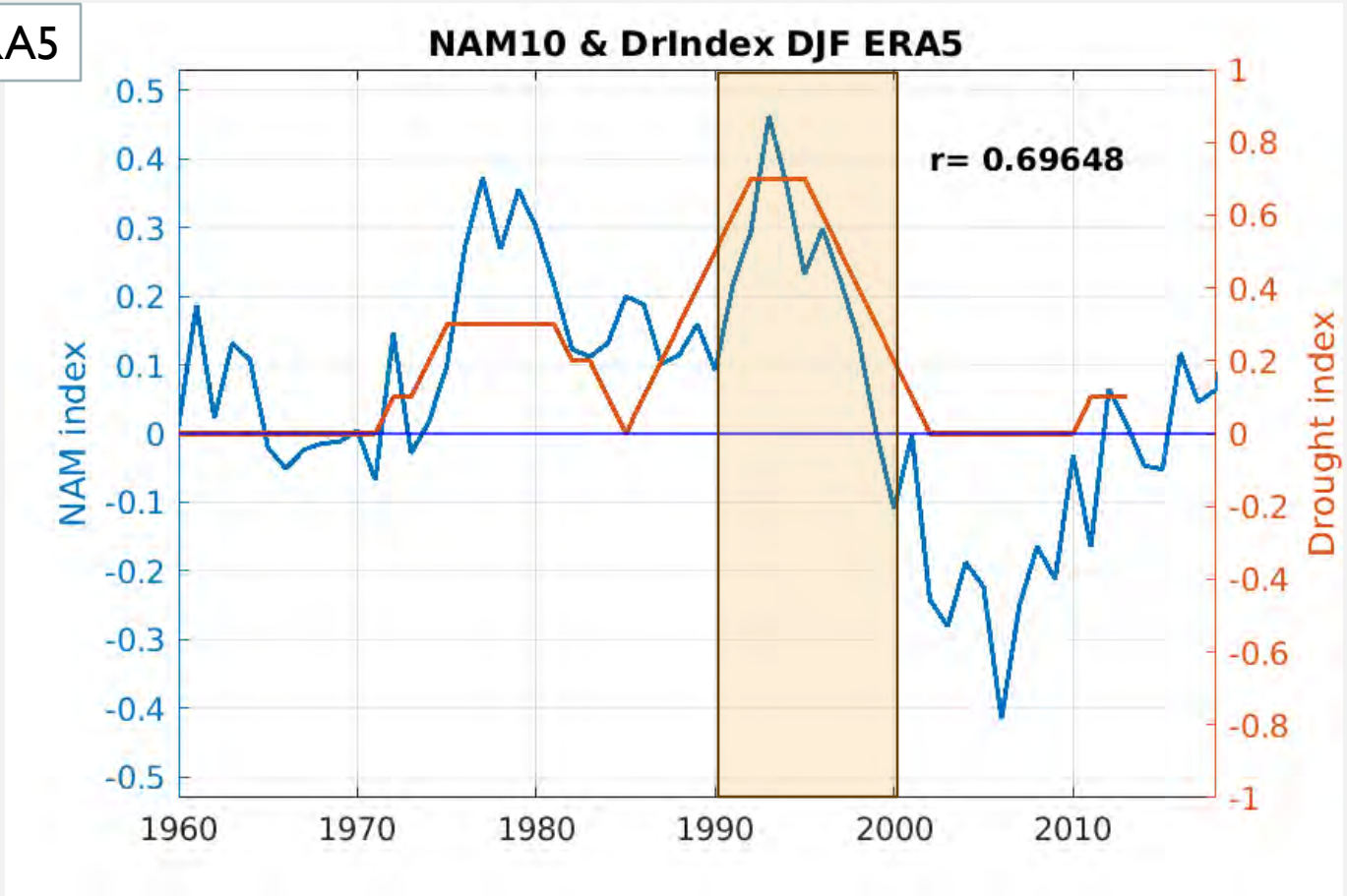
  - Northern Annular Mode index at 10hPa (NAM10) (based on monthly data)

    PC of the EOF of zonal mean geopotential height between 20 and 90°N at 10hPa
    Standarized with respect to each individual ensemble members

- 2 events during the observed "SSW drought" in 1990s

BOTH NAM10 AND SSW DROUGHT INDEX CAN CHARACTERIZE THE DECADAL VARIABILITY IN THE STRATOSPHERE

ERA5



NAM index also contains some information about decadal variability in SSWs

Both the NAM-10 and SSW drought index reproduce the "SSW drought" in the 90's.

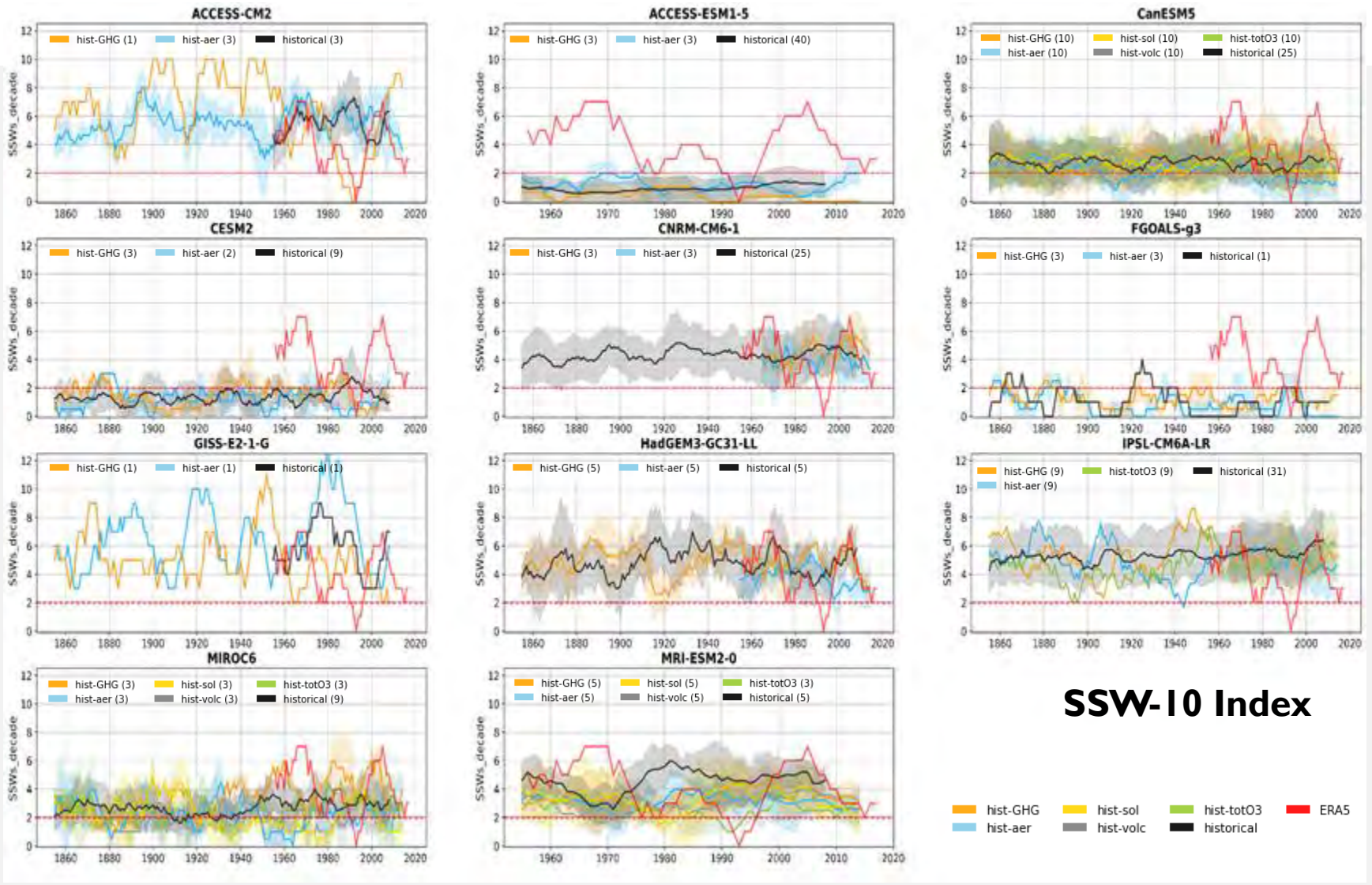
Figure by D. De Maeseneire and S. Benito-Barca

SSW FREQUENCY IN LESFMIP EXPERIMENTS

Biases in the SSW frequency: some models underestimate the SSW frequency, while a few overestimate it

- SSW defintion: U10hPa, 60°N < 0

Figure by D. De Maeseneire



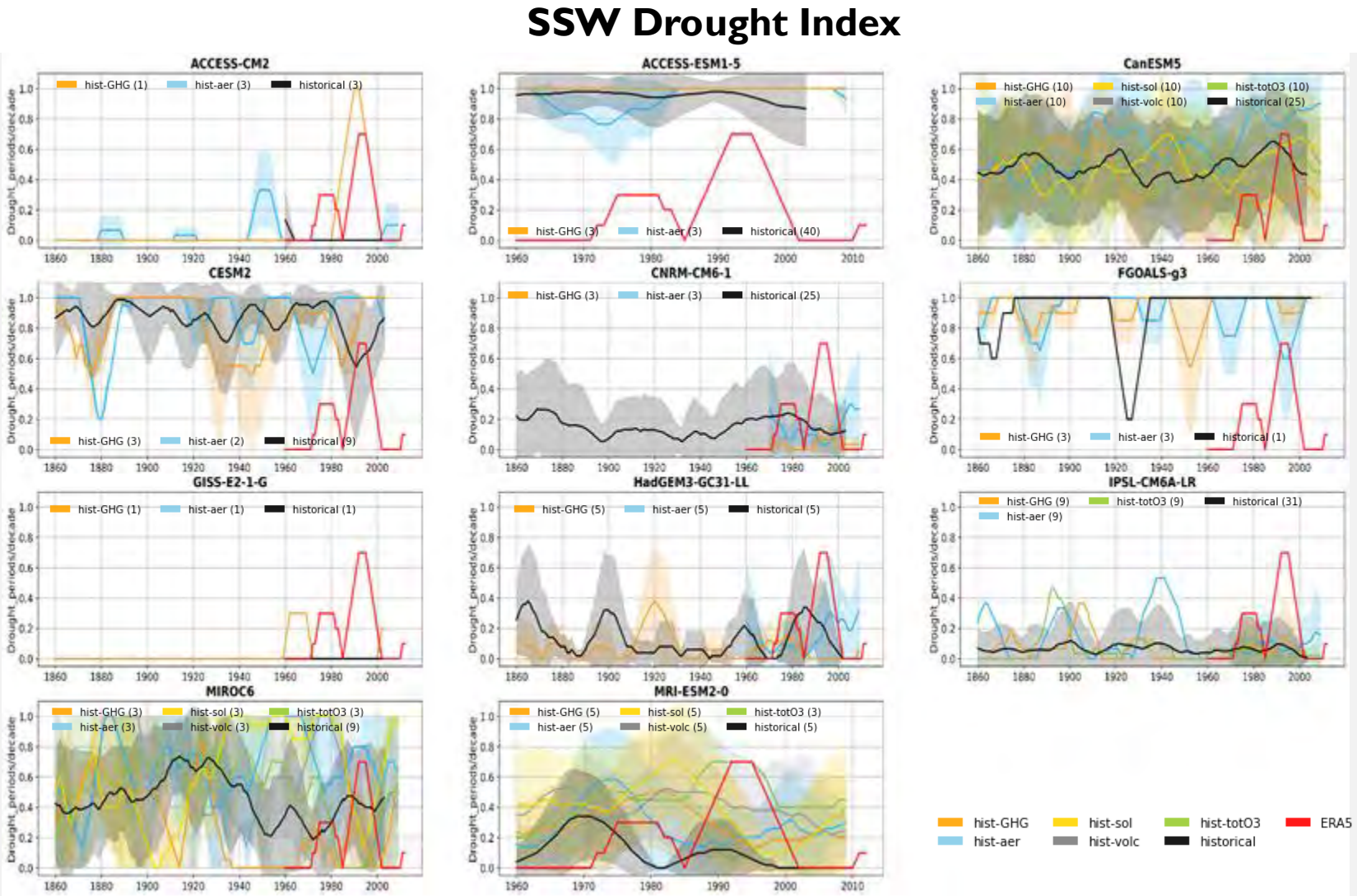
LARGE INTER-MODEL VARIABILITY IN SSW DROUGHT INDEX

The magnitude of the SSW-Drought index is highly model dependent: models differ due to biases in the SSW frequency.

There's no forcing dependency in the overall SSW droughts and/or frequency.

- 0 < SSW drought index < 1,
  1 = 'perfect' drought

Figure by D. De Maeseneire

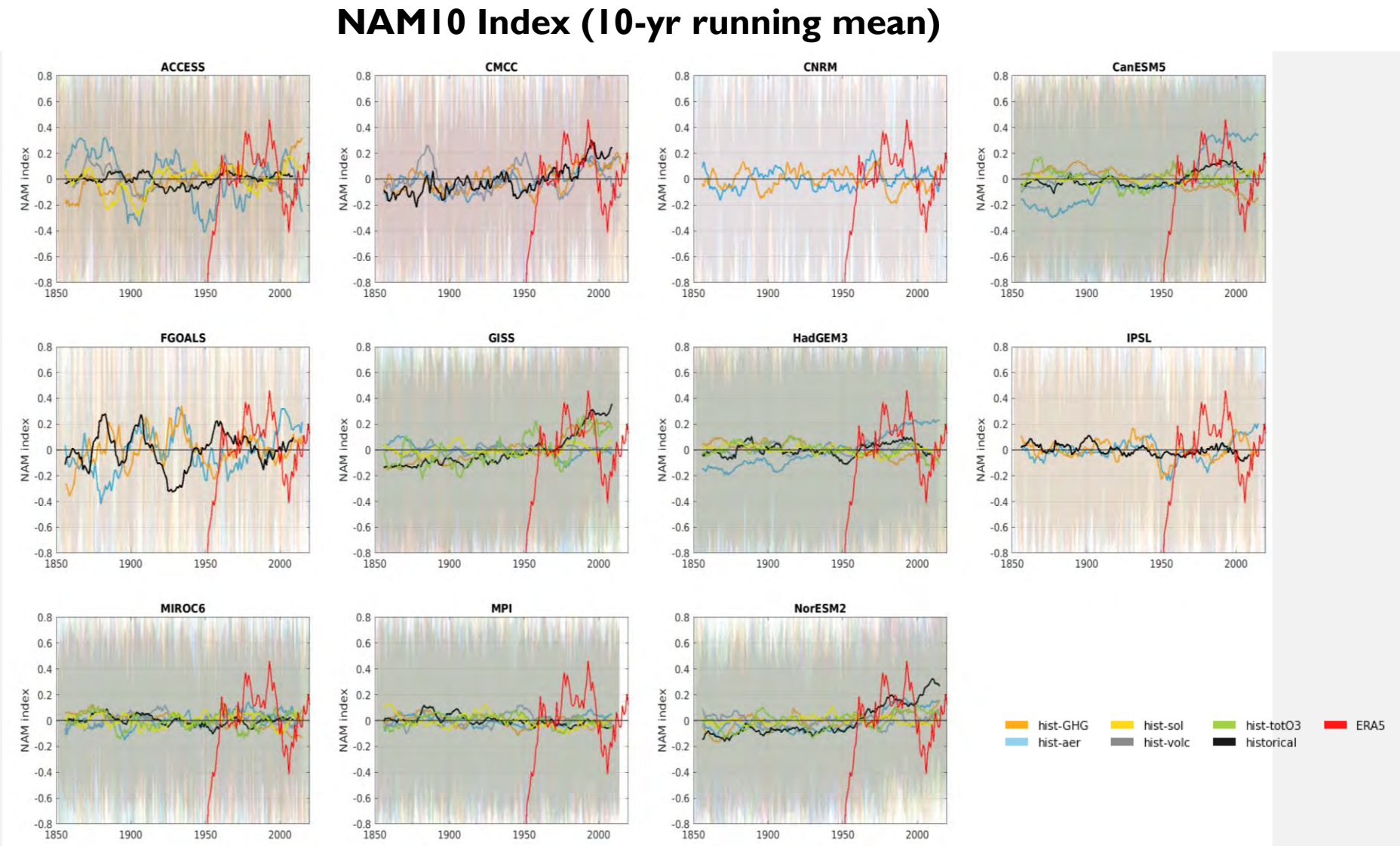


DECADAL VARIABILITY IN NAM INDEX

There's no clear decadal swings in the NAM10 in models, consistent with SSW-10 and drought index.

Decadal variability in the stratosphere, at least in terms of SSWs and NAM10, seems to be mostly driven by internal variability and not by a particular forcing.

Figure by S. Benito-Barca



UPWARD COUPLING: BIASES IN THE TROPOSPHERIC STATIONARY WAVE DISTRIBUTION

Figure: winter (DJF) climatology of the Z500 zonal anomaly averaged for the latitude range [40-60N] for CMIP6 models and ERA5 for the recent climatology (1984-2014) for the historical simulation.

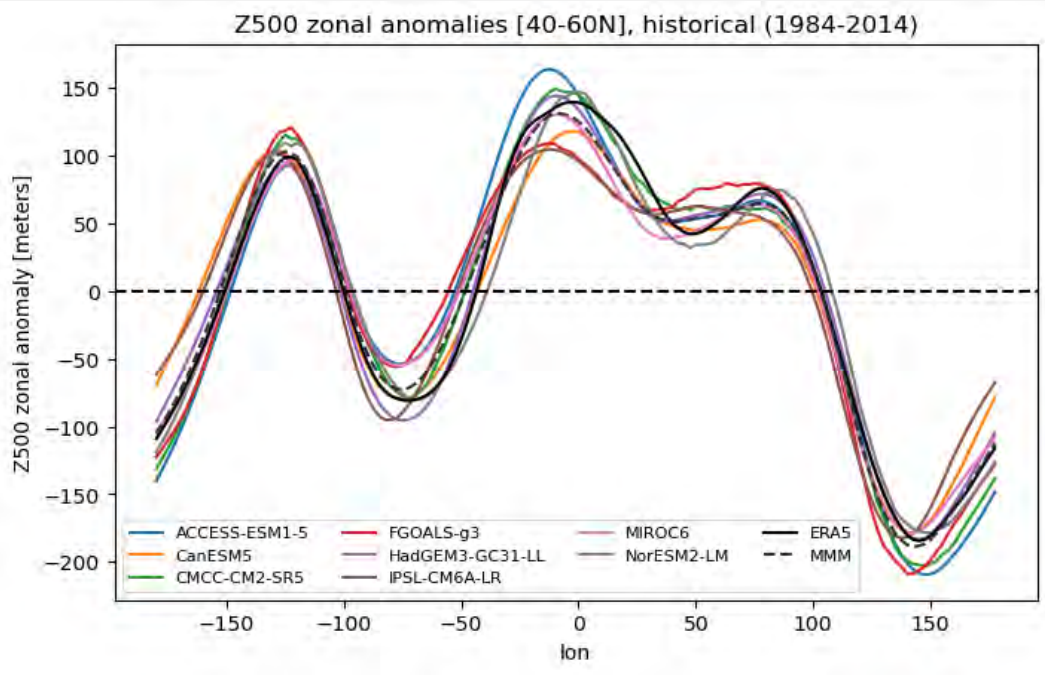
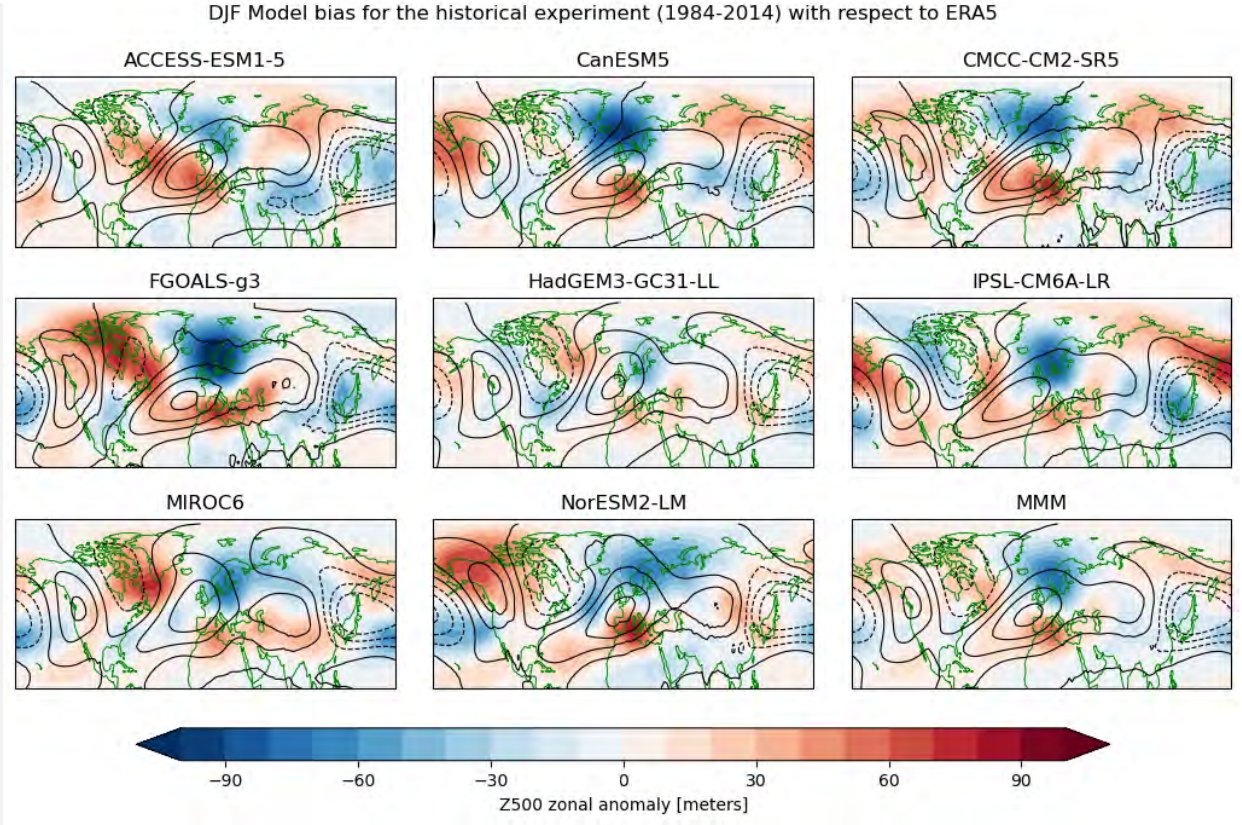


Figure by B. Jiménez-Esteve



Biases in the climatological stationary waves could be one of the contributing factors to the different SSWs climatology but other factors e.g. mean-state bias in the stratosphere can also play a role

DOWNWARD COUPLING OF NAM INDEX TO THE TROPOSPHERE

Most models show higher correlations (strat-trop coupling) than ERA5 for the period 1950-2012 (common period for all models and ERA5).

- **No differences between forcings**

- **Wide variety of correlations among models**

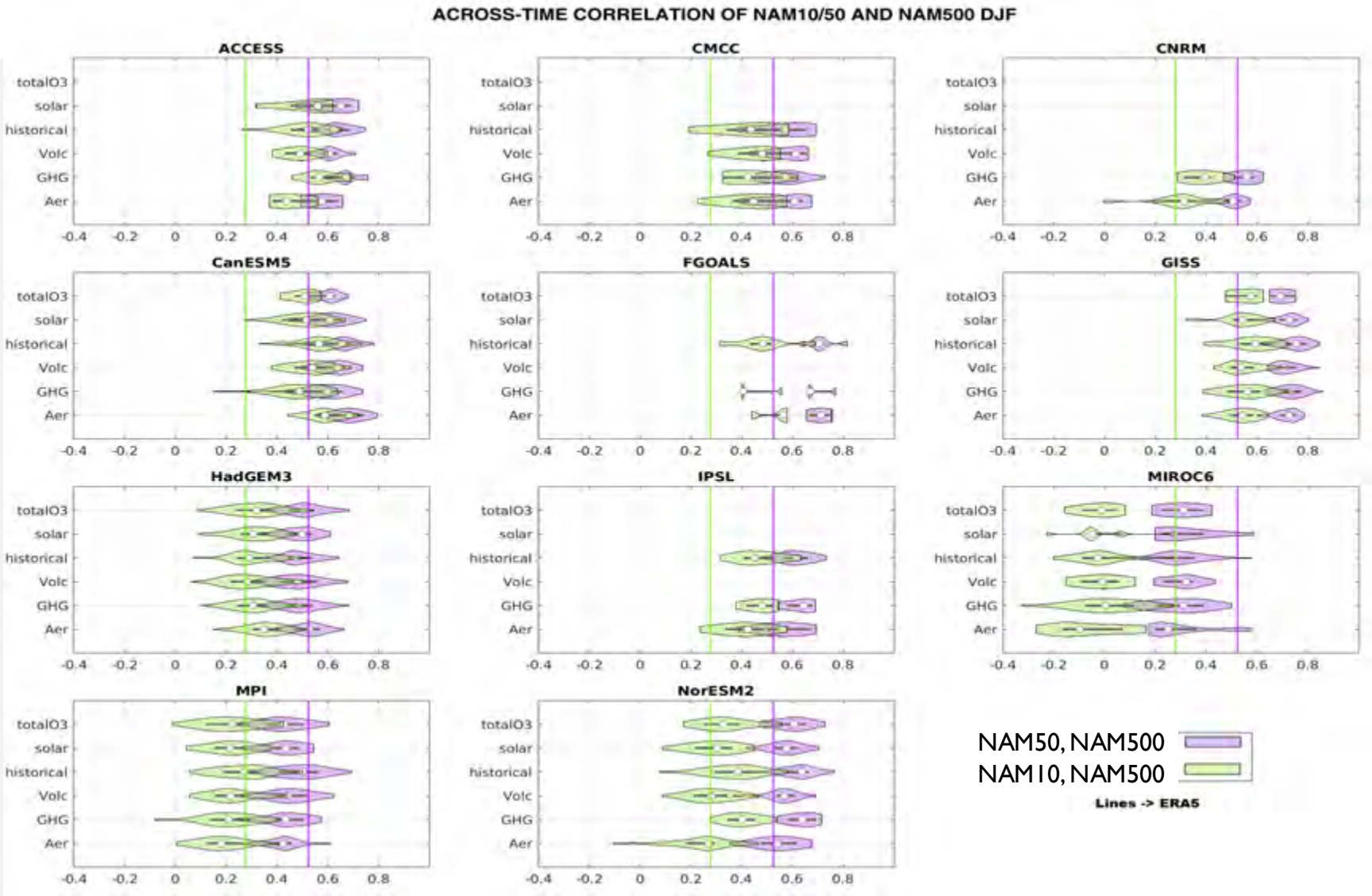
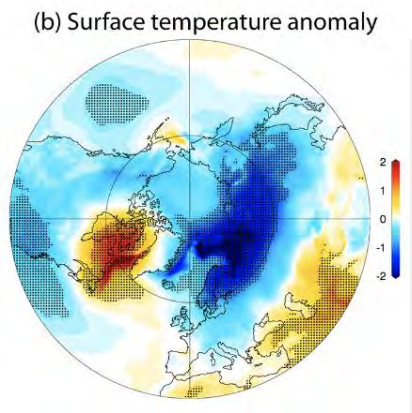


Figure by S. Benito-Barca

DOWNWARD IMPACT: SURFACE RESPONSE TO STRATOSPHERIC EVENTS



From: Butler et al, 2017

The model response to weak vs strong vortex events does not differs more strongly between different models than between different forcings.

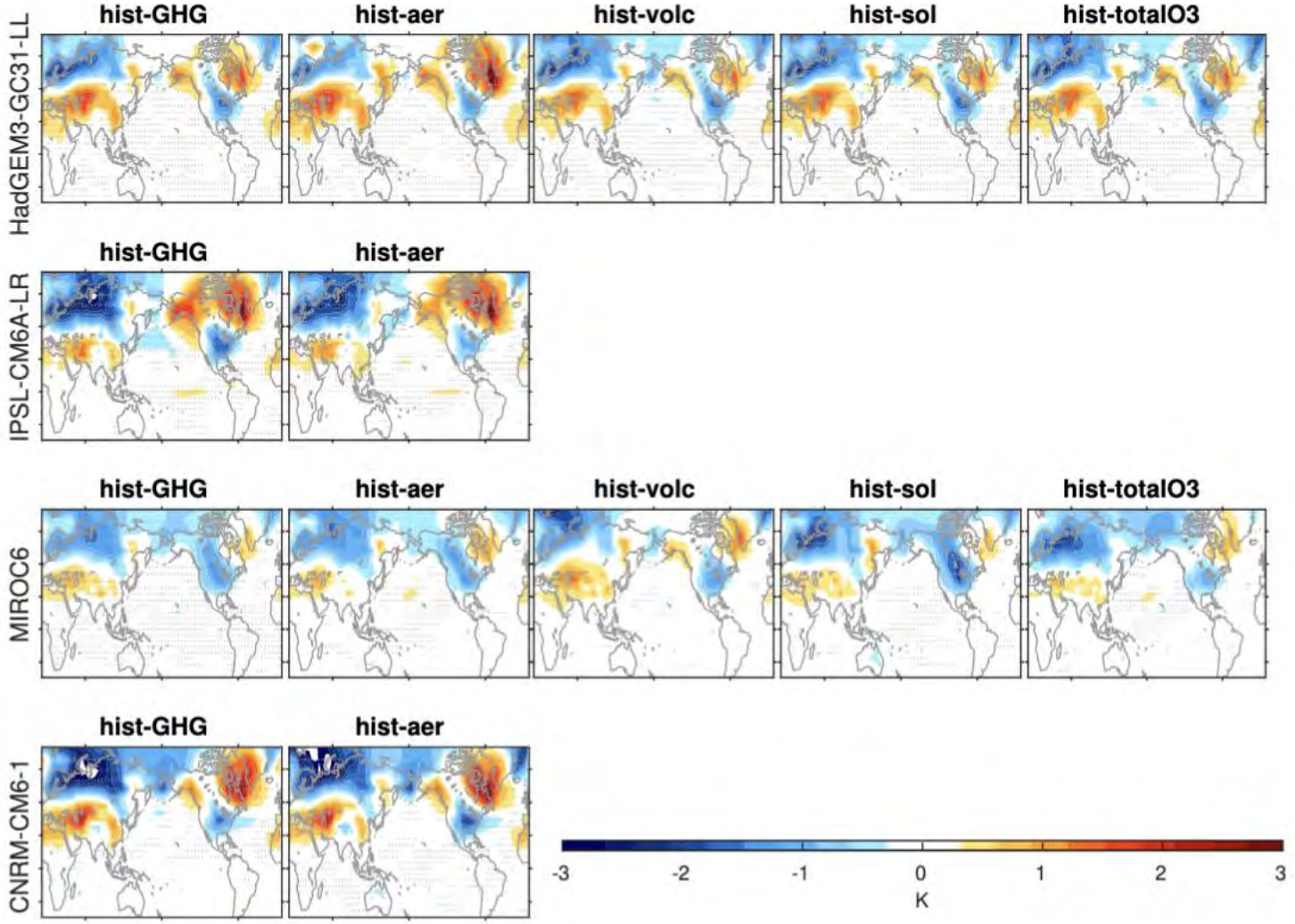


Figure: Surface temperature anomaly in the month after weak minus strong vortex events defined by the zonal wind at 10hPa / 60N.

Figure by C. Garfinkel

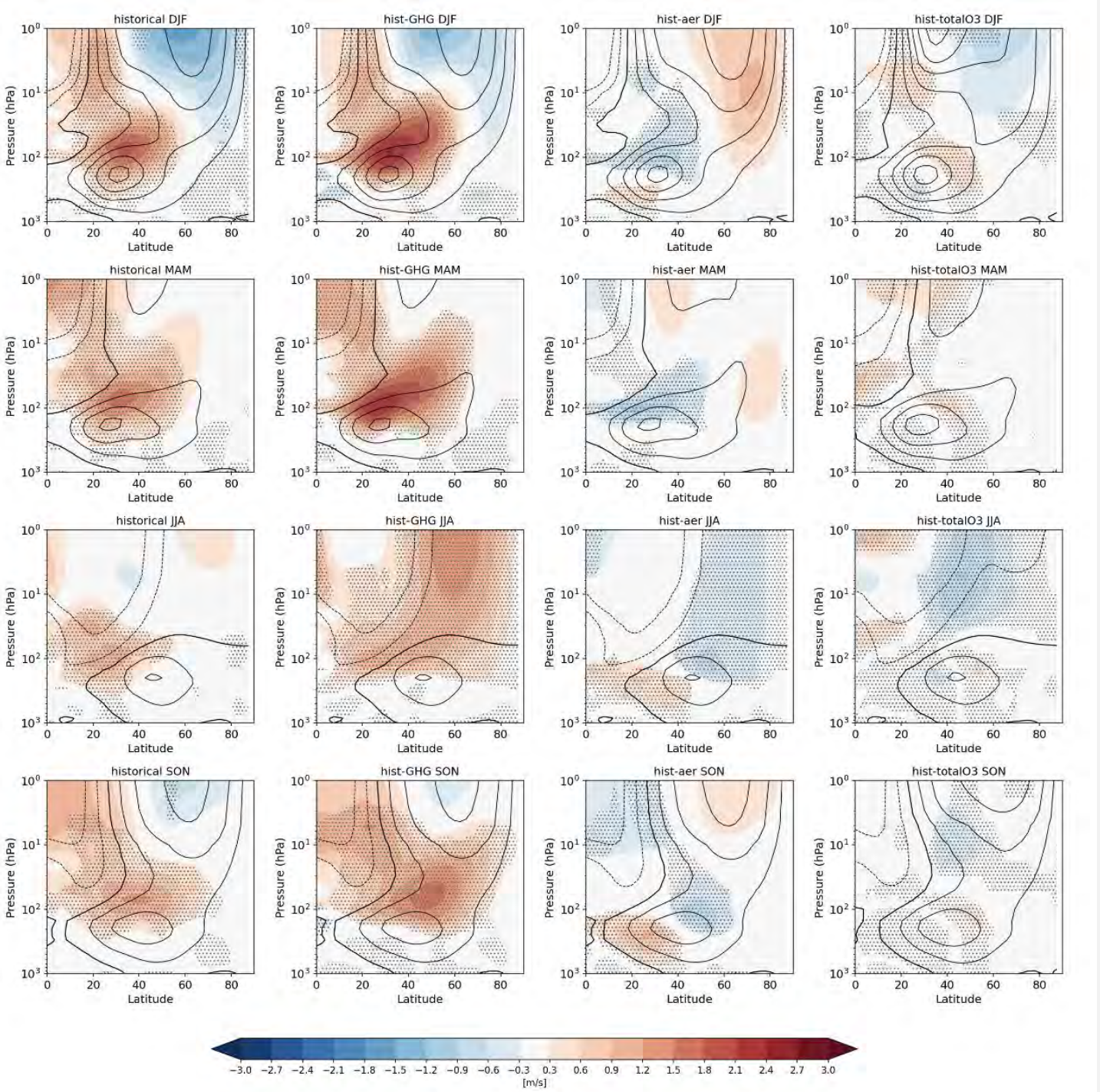
CONCLUSIONS

- All models can produce SSW and surface impact pattern comparable to reanalysis but there is a large inter-model spread
- Large inter-model spread might be related to biases in tropospheric stationary waves and in the mean-state of the stratosphere
- Difficult to conclude at this stage the role of internal versus external variability, as the inter-model spread is much larger than spread between forcing experiments
  - Consider a weighted MME? Sub-select models that better represent historical stratospheric variability to see if clearer signals emerge
- Indices and analyses developed in the project could be used to assess general model performance in capturing decadal stratospheric variability and its associated impacts on the surface

SSW DROUGHT INDEX

1. Calculate the number of SSWs that are in 10-year windows = SSW_10
2. Threshold: With these values then we calculate in windows of 10 years how many times we have values of SSW_10 ≤ 2 (drought periods)
3. The index is the probability to have these drought periods during the 10 year windows selected
4. We repeat these process for running windows of 10 years for all the period

$$p(drought\ periods) = \frac{\#SSWs_{10} \leq 2}{10}$$



Multi-model mean, zonal-mean NH zonal wind responses for LESFMIP models (difference from the end of the simulation compared to the start)

Figure by A. Butler