Climate model trend errors are evident in short-lead seasonal forecasts

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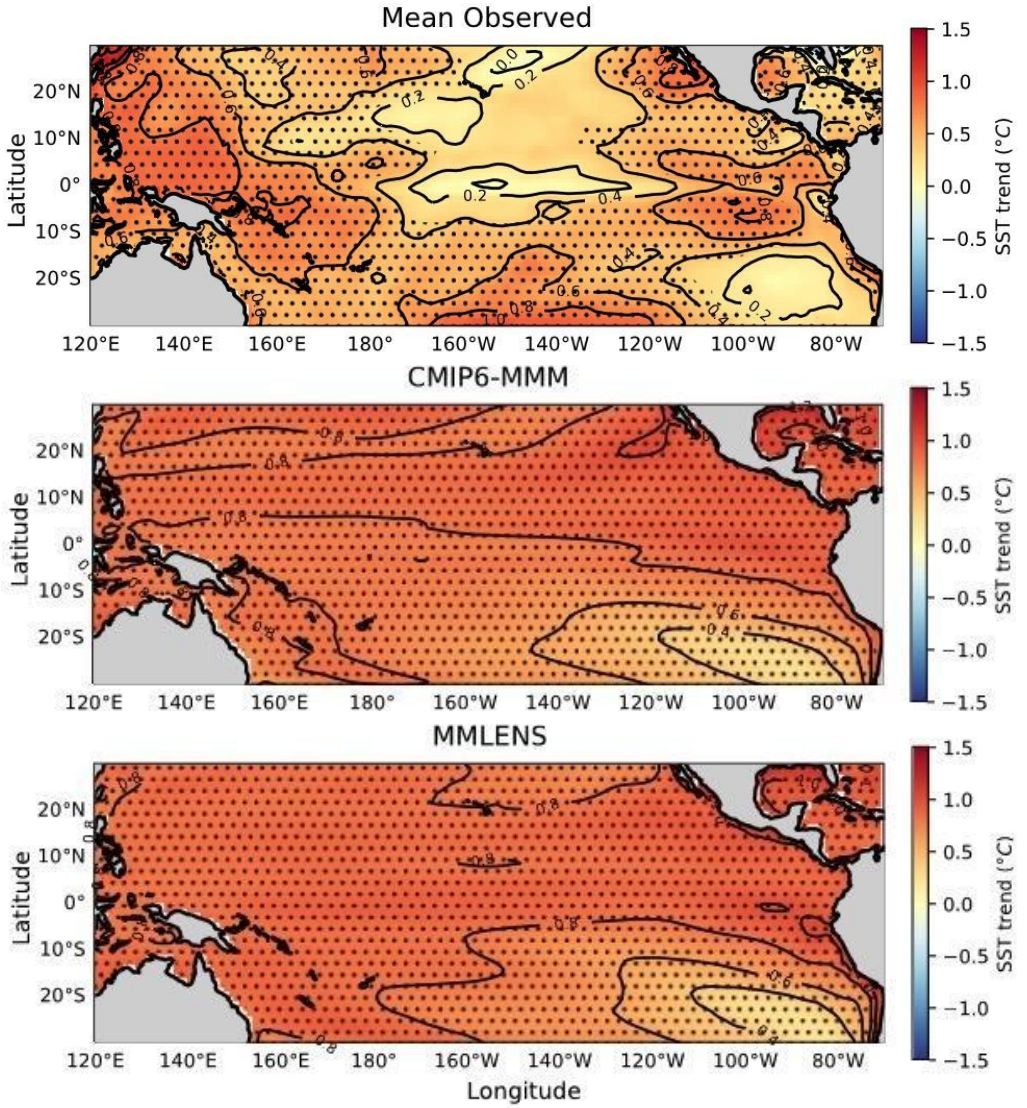
How can we diagnose climate model trend errors?

- Climate models have exhibited historical trend errors for many years
- Proposed reasons for these discrepancies include:
  - Sampling issues/model error in internal variability
  - The errors are transient
  - Errors are teleconnected from other regions (e.g. Southern Ocean)
  - Errors in forcing fields (CO_2/aerosols etc)
  - **Or the models are wrong**
- These are hard to test in free-running historical simulations
- BUT: we also use same/similar models for seasonal hindcasts, where they suffer from known mean biases



From Seager et al. 2022

Key points

Today, we will show that:

- Seasonal forecast models exhibit systematic global trend errors which are very similar to climate model trend errors
- These errors develop rapidly, at forecast leads of months
- The trend errors likely reflect *sensitivity of model mean biases* to changing initial condition radiative forcing (e.g. CO_2, aerosols)
    - That is: **Mean model biases change as the imposed external forcing changes, which produces an apparent trend error**

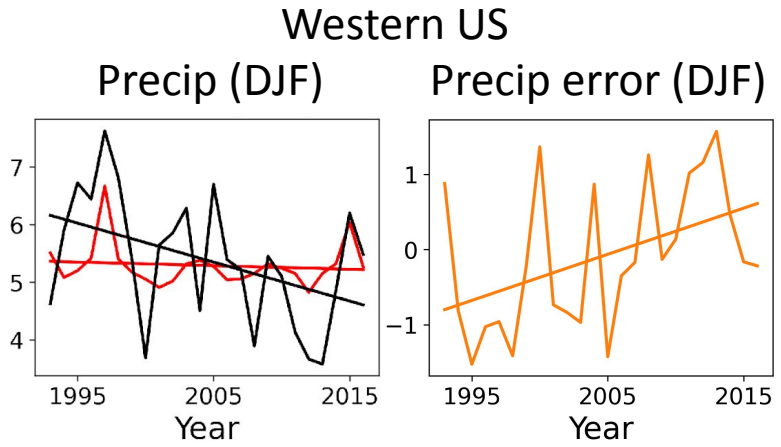
Models and data

- We analyse seasonal hindcasts over their common period (1993—2016):
  - ECMWF SEAS5
  - DWD GCFS2.1
  - CMCC SPS3.5
  - UKMO GloSea6-GC3.2
  - MeteoFrance System 8
  - JMA CPS3
  - ECCC CanCM4i
  - ECCC GEM5-NEMO
  - NCEP CFSv2
  - GFDL SPEAR
  - NASA GEOS-S2S
- We look at four different initialisations (1st Mar, 1st Jun, 1st Sep, 1st Dec)
- We compare these to historical (1993—2014) + SSP-245 (2015—2016) simulations from 38 CMIP6 models
- The seasonal forecast models are not identical to CMIP6 models, but **use the same radiative forcings as CMIP5 or CMIP6 models**

Methods

- "Trend error" is the slope of the linear line of best fit of the model error time series (model minus observations) at a given lead time; same as taking the difference between model and observed regression slopes

Black = observations
Red = MMM
Orange = MMM error



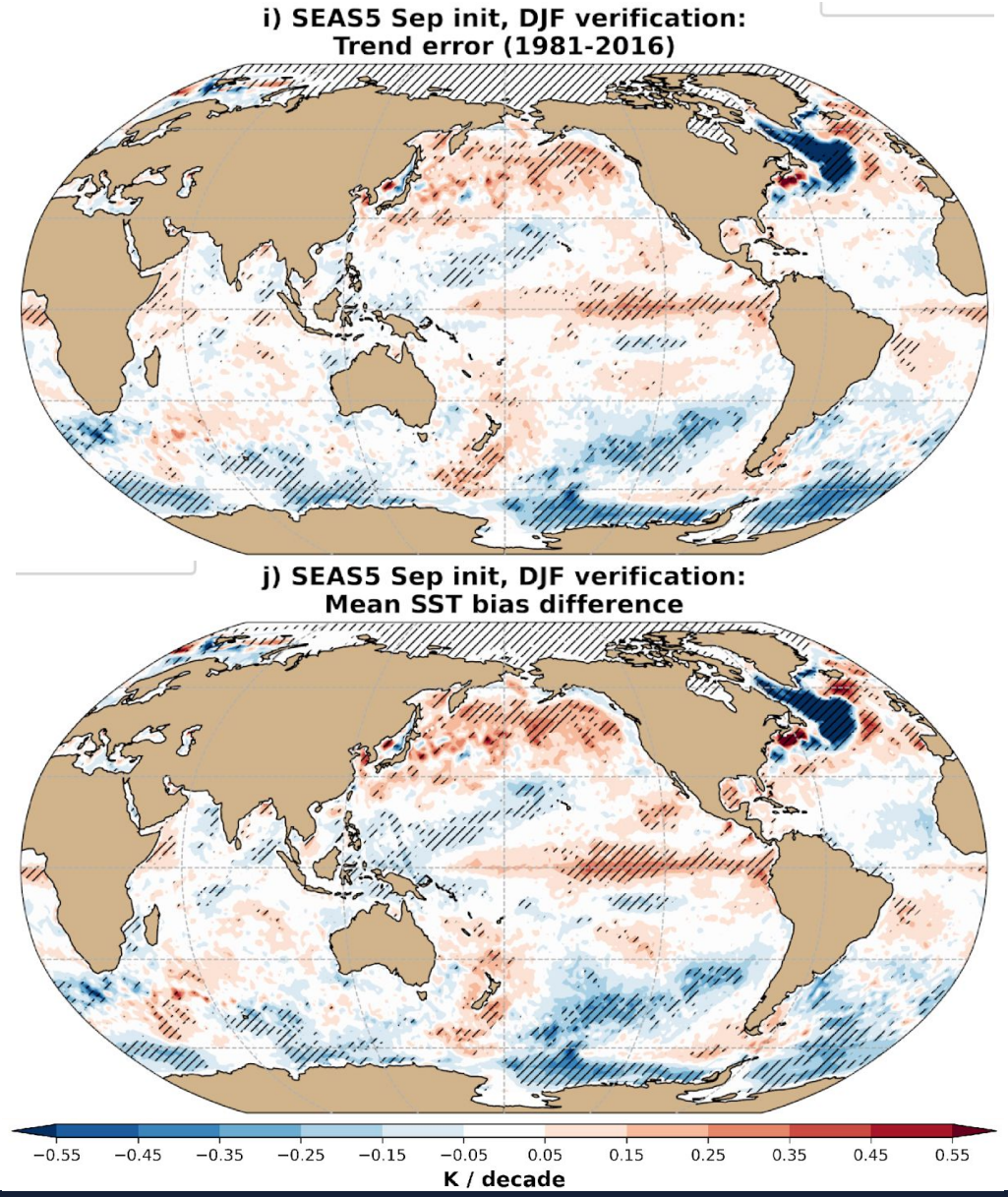
- We look at seasonal mean trend errors at **two seasons lead** (i.e., averaged over leads of 4-6 months)
- Significance is computed using the Hamed and Rao modification to the Mann-Kendall trend test to account for serial autocorrelation

Trend error represents a long-term change to the model mean bias:

- **Difference in mean bias** between early (1981—1998) and late (1999—2016) periods is **very similar to the trend error** over the whole period
- Suggests that **trend errors represent (roughly) linear change in mean bias**, due to time-evolving radiative conditions in each hindcast run – which are the same as in CMIP6 simulations

SEAS5 SST trend error (full hindcast period)

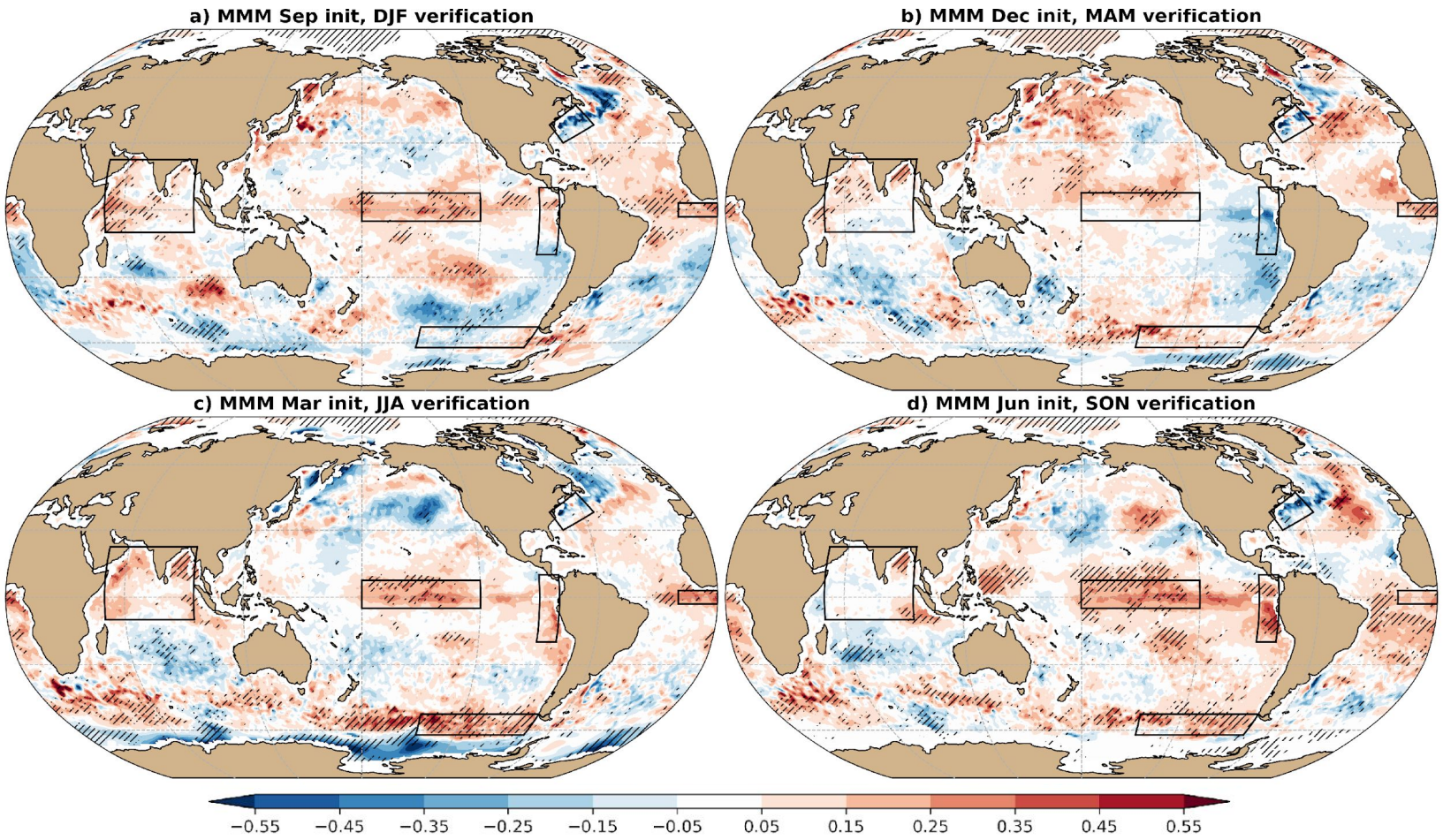
SEAS5 mean bias difference (late minus early)



Seasonal forecasts exhibit significant and systematic SST trend errors:

- **Significant SST trend errors** are present in all seasons
- In the tropical Pacific, **these resemble the CMIP6 historical El Niño-like trend error**
- The **pattern of trend error** across different seasonal forecast models is also **very similar**

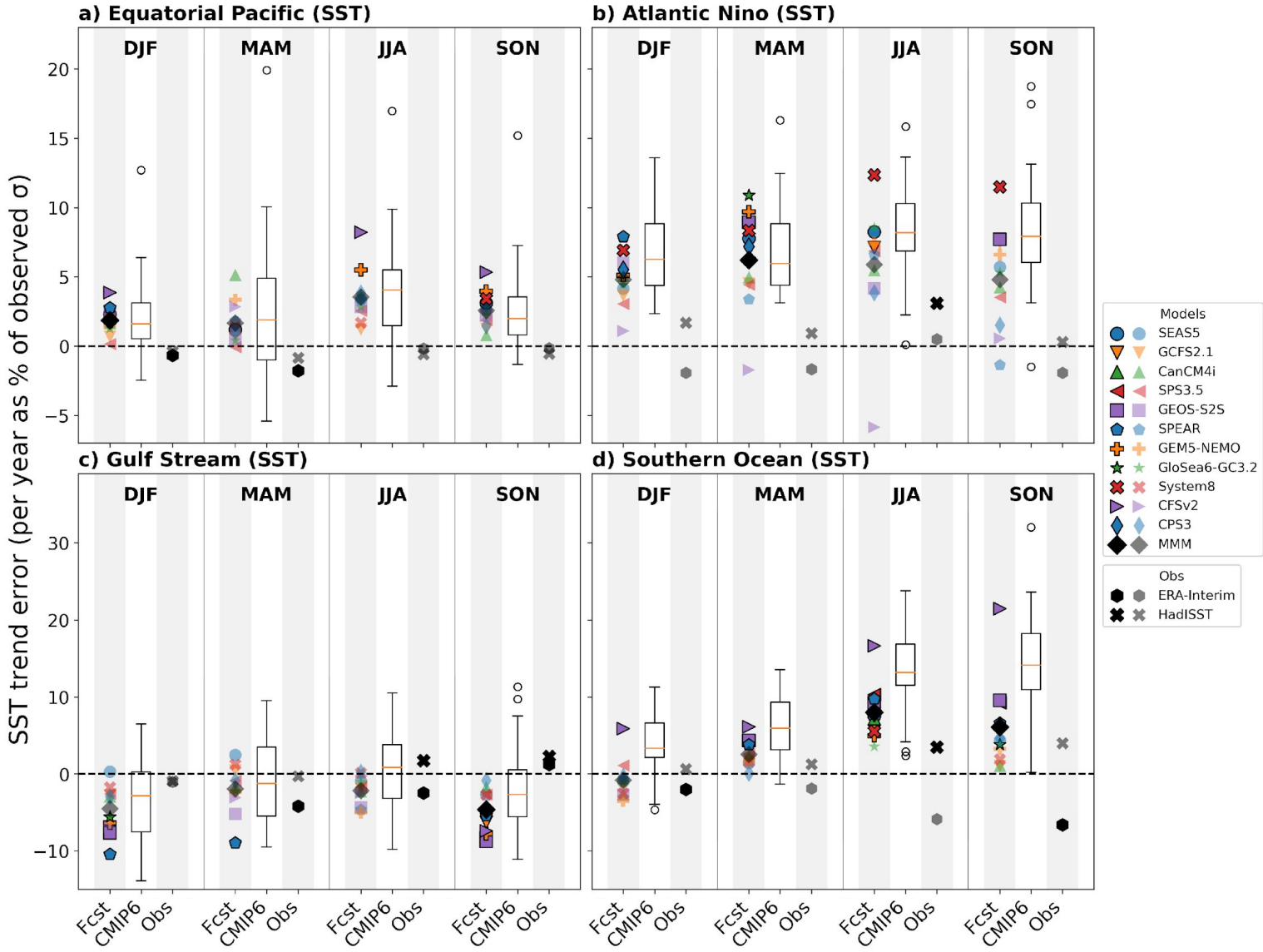
- **Shown are multi-model mean (MMM) errors, across 11 different operational forecast models**



Shading = Seasonal forecast MMM SST trend error (unit: K / decade)
Hatching = Significance at 5% level

These two-season lead trend errors closely match climate model errors:

- For different indices, **hindcast model spread closely matches CMIP6**
- **Agreement in sign**, if not always magnitude, is also evident for **most regions and seasons**



Coloured symbols = seasonal forecast models
Box plots = CMIP6 models

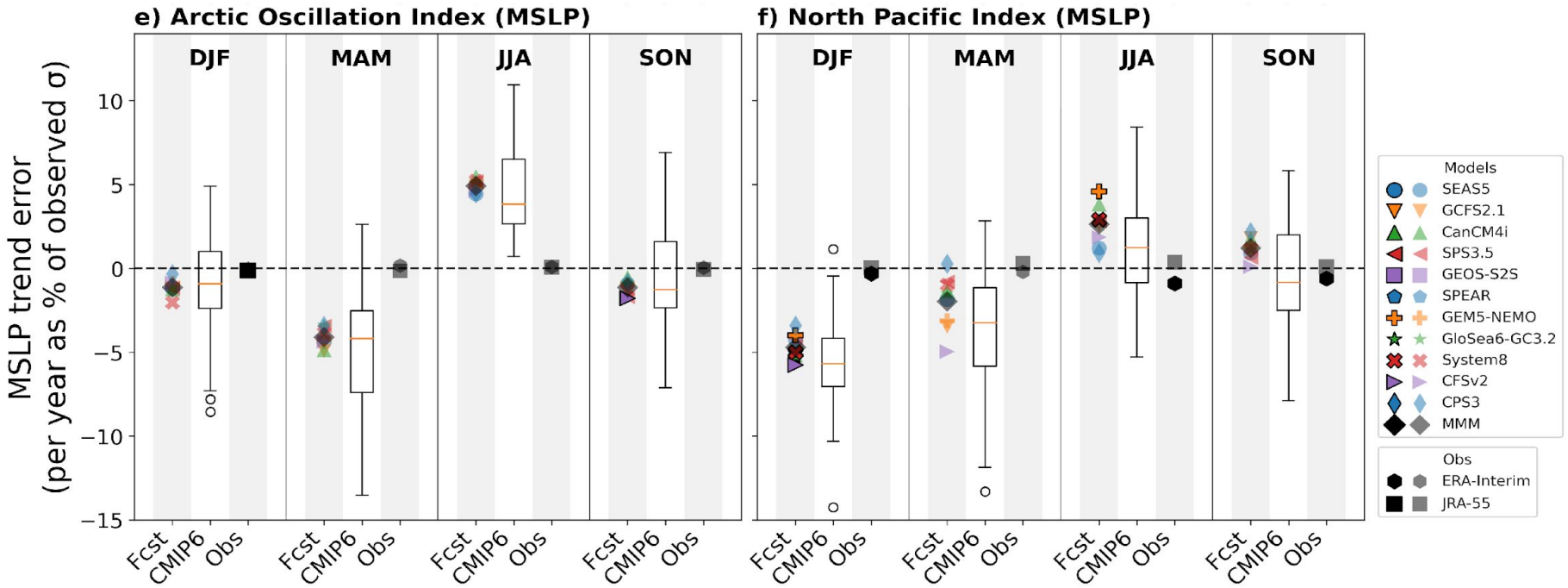
y-axis = trend error per year as a percentage of observed (ERA5) standard deviation

These two-season lead trend errors closely match climate model errors:

- **Similar levels of agreement for MSLP**, with similar seasonal evolutions
- Changes in sign (e.g. AO Index) also consistent

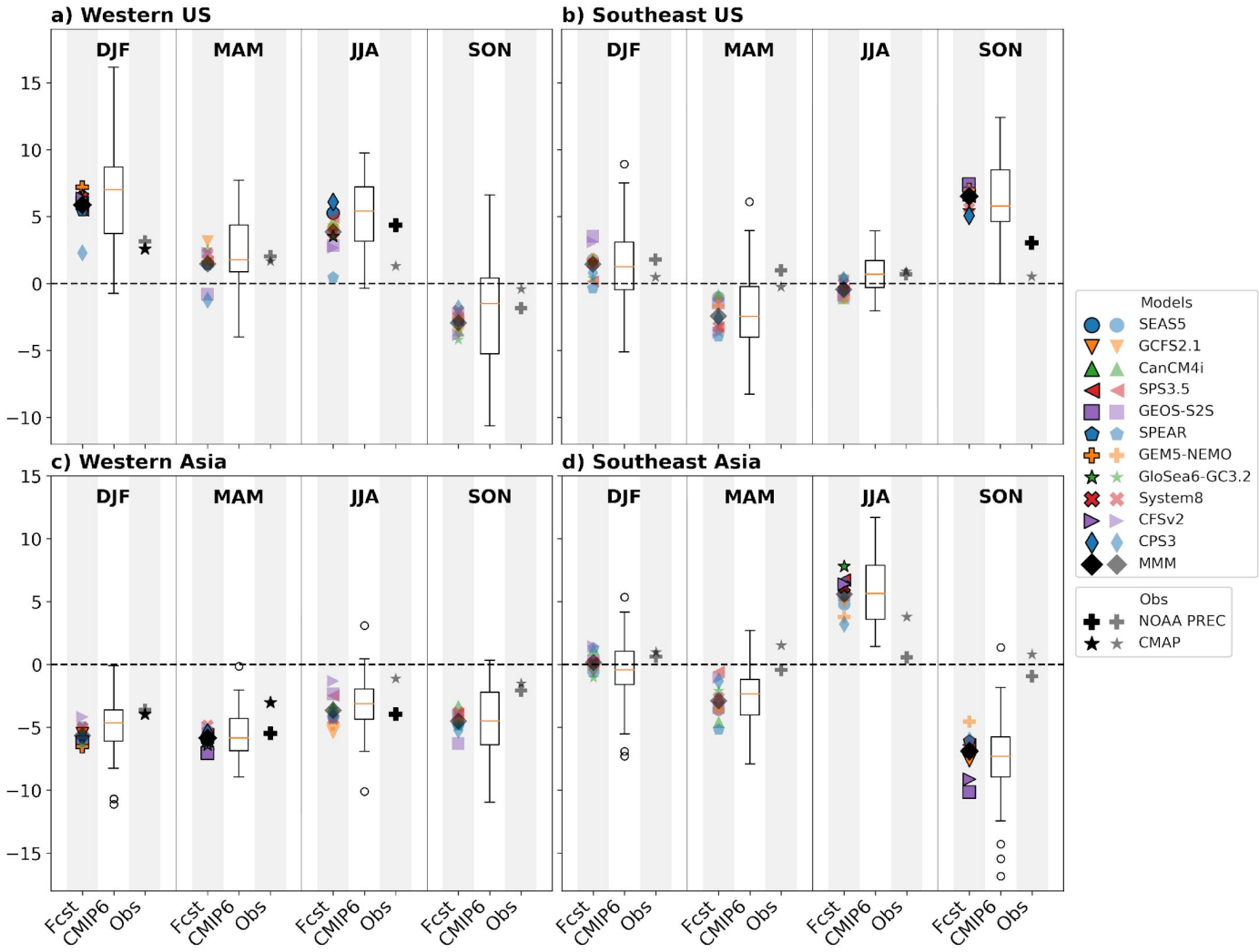
Coloured symbols = seasonal forecast models
Box plots = CMIP6 models

y-axis = trend error per year as a percentage of observed (ERA5) standard deviation



There are also associated significant precipitation trend errors:

- Hindcast/CMIP6 agreement is **even stronger for precipitation**
- Median CMIP6 errors often **align with hindcast ensemble means**
- **Changes in sign** from season-to-season **are also similar** (e.g. southeast Asia)



Coloured symbols = seasonal forecast models
Box plots = CMIP6 models

y-axis = trend error per year as a percentage of observed (GPCP) standard deviation

Summary

- Seasonal forecasts at 1-2 seasons lead have rapidly-developing trend errors that are **very similar to climate model trend errors**

- As the forecasts are initialised from observations, this suggests that **the errors are not due to unrepresented internal variability or that they are transient**, but that they are **fundamentally model errors**

- Trend errors reflect **sensitivity of model mean biases to changing radiative forcings** – both initialised and uninitialised models contain the same historical external forcings

- Diagnosis of climate model trend errors would therefore benefit from **analysis of the early development of errors in seasonal hindcasts, which should be done for every CMIP7 model**

- **No reason to think that the incorrect historical trends will not continue into the projections**
  - Model trends in historical and projected simulations should be considered in the context of potentially changing model biases

Trend errors manifest as changes to the model mean bias:

- **Trend errors are related to changes to the model mean bias** over the hindcast period
- This could be an **increase, decrease, or change of sign** of the mean bias between start and end of hindcast period

Index time series, 1993-2016, lead 4-6 months average