Rapid development of systematic trend errors in seasonal forecasts and their connection to climate model errors

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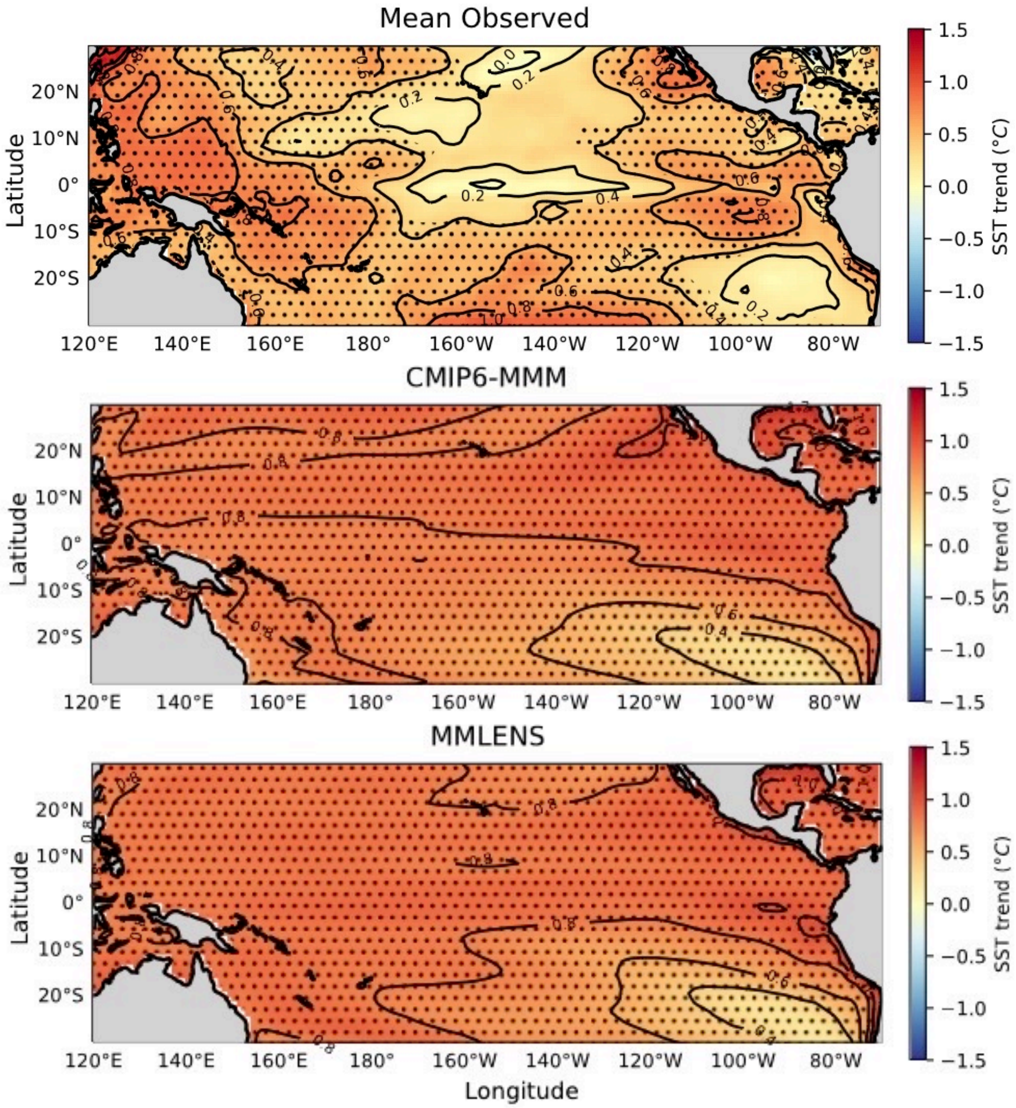
Beverley J. D., M. Newman and A. Hoell, 2024: Historical climate model trend errors evident in short-lead seasonal forecasts. *In Prep.*

How can we diagnose climate model trend errors?

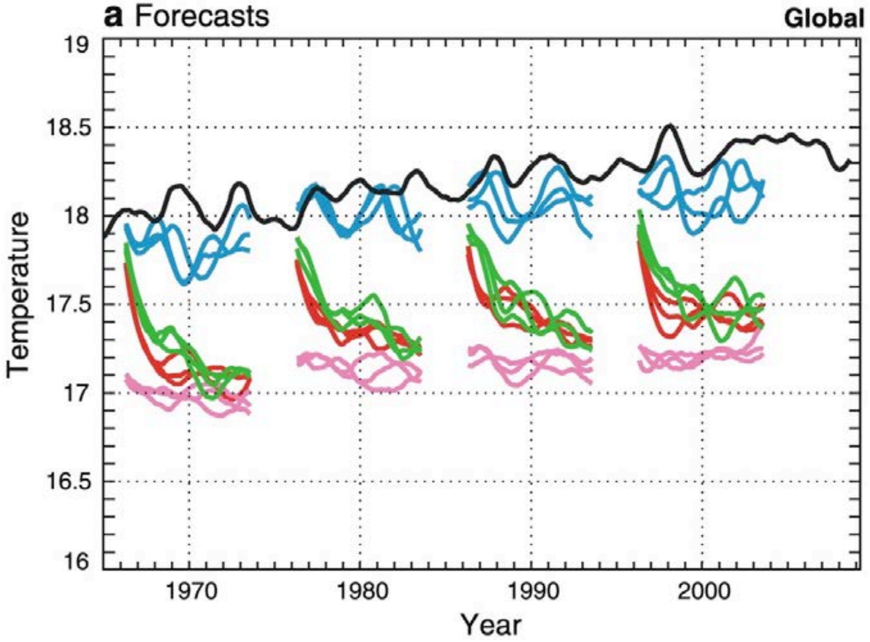
- Climate models have exhibited historical trend errors for many years
- Proposed reasons for these discrepancies include:
  - Sampling issues/model error in internal variability
  - The errors are transient
  - Errors are teleconnected from other regions (e.g. Southern Ocean)
  - Errors in forcing fields (CO_2/aerosols etc)
  - Or the models are wrong
- These are hard to test in free-running simulations



From Seager et al. 2022

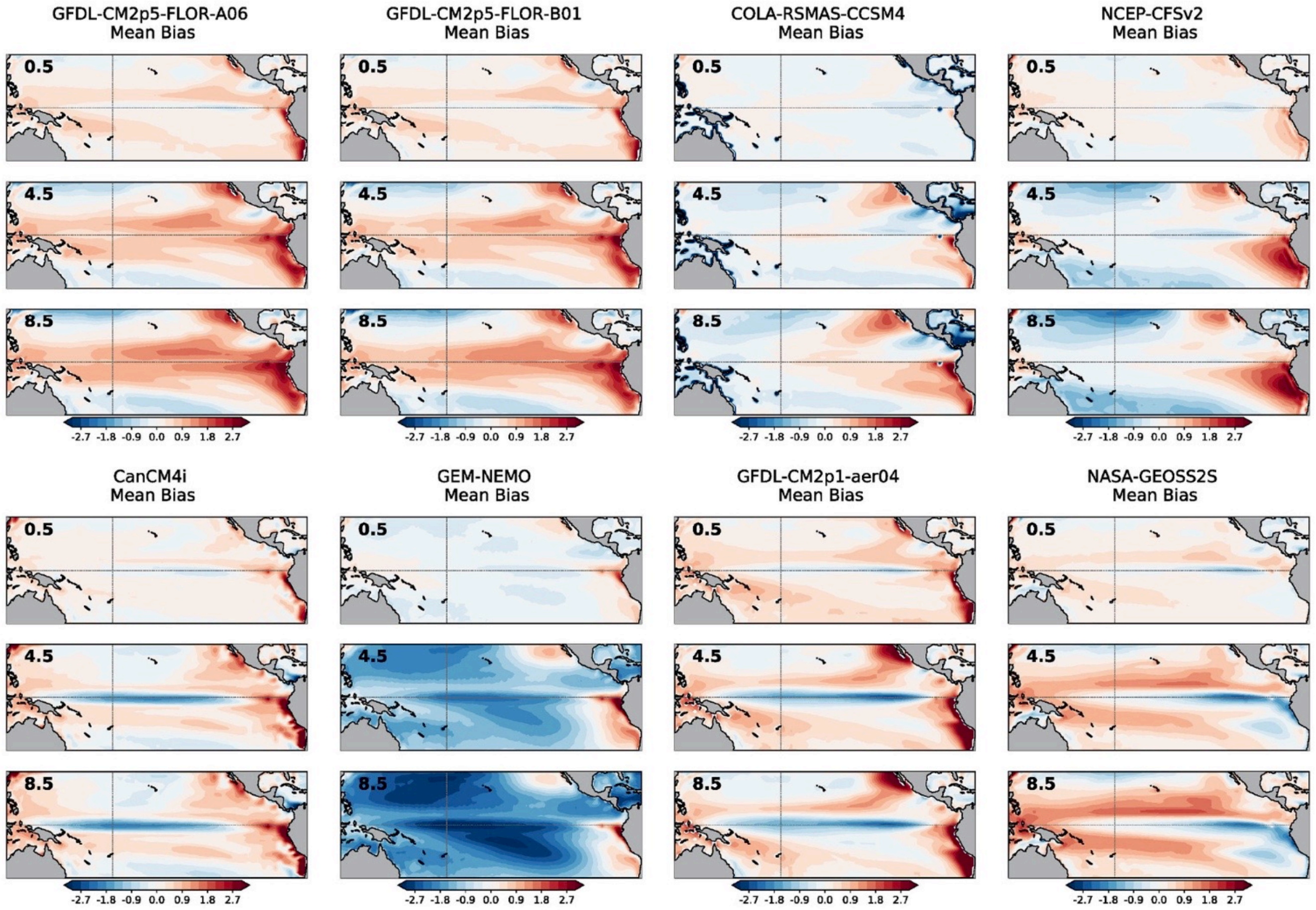
Seasonal forecast models are also known to have mean biases that develop rapidly and saturate:

- Fast development of surface biases have been linked to radiation imbalance at the top of the atmosphere (e.g. Magnusson et al. 2012)



From Magnusson et al. 2012

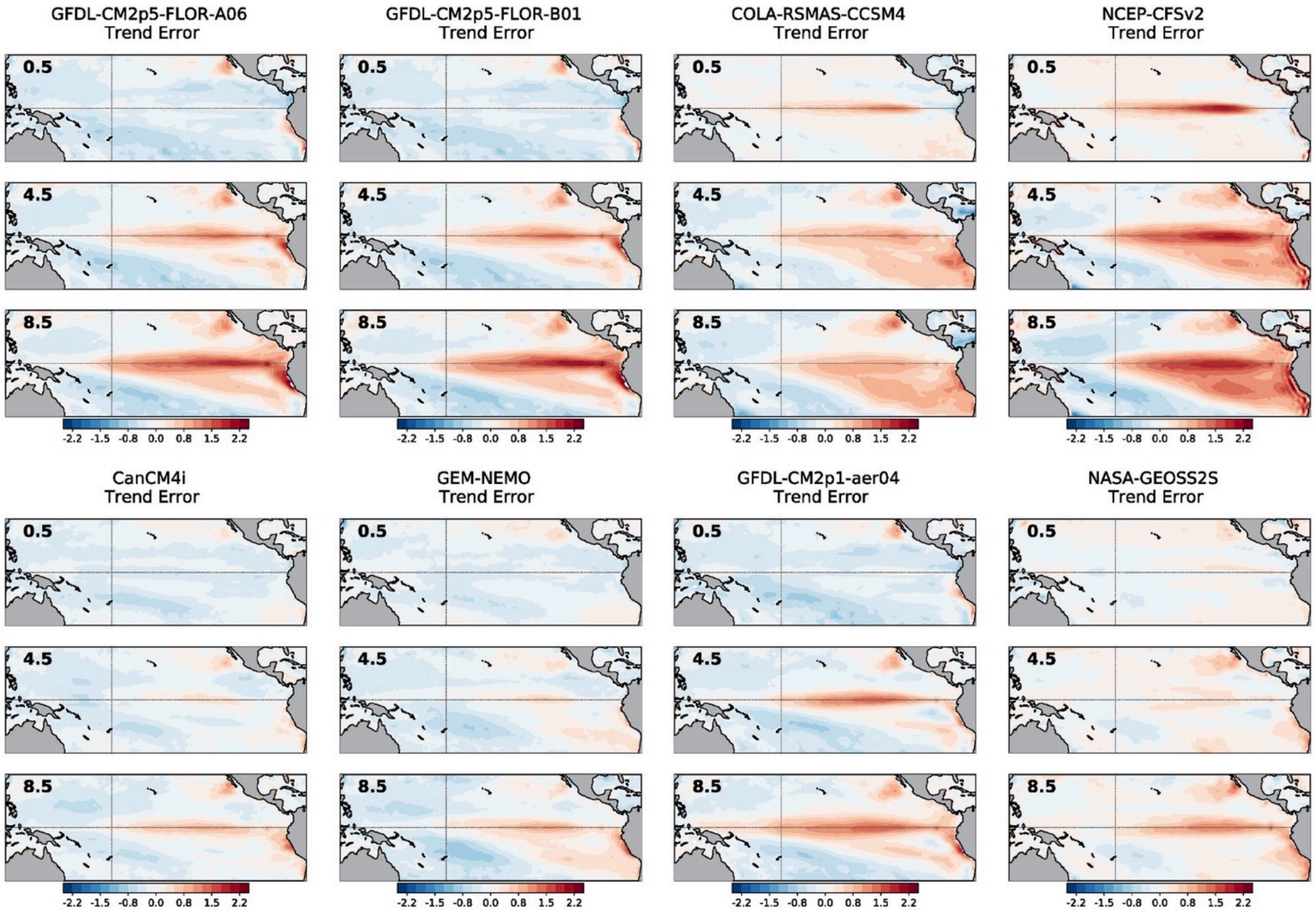
Red lines = full initialisation



From L'Heureux et al 2022

These models have also been shown to exhibit trend errors:

- Seasonal forecast models also have an El Niño-like SST trend error in the tropical Pacific
- Focus of this paper was on the impact of these errors on tropical Pacific forecast skill, however



From L'Heureux 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
  - The trend errors reflect sensitivity of model mean biases to changing initial condition radiative forcing (e.g. CO_2, aerosols)
    - i.e. Mean model biases change as the radiative forcing changes, which produces an apparent trend error

Models and data

- We analyse seasonal hindcasts from eleven models over their common period (1993—2016):
  - ECMWF SEAS5
  - DWD GCFS2.1
  - CMCC SPS3.5
  - UKMO GloSea6-GC3.2
  - MeteoFrance System 8
  - JMA CPS3

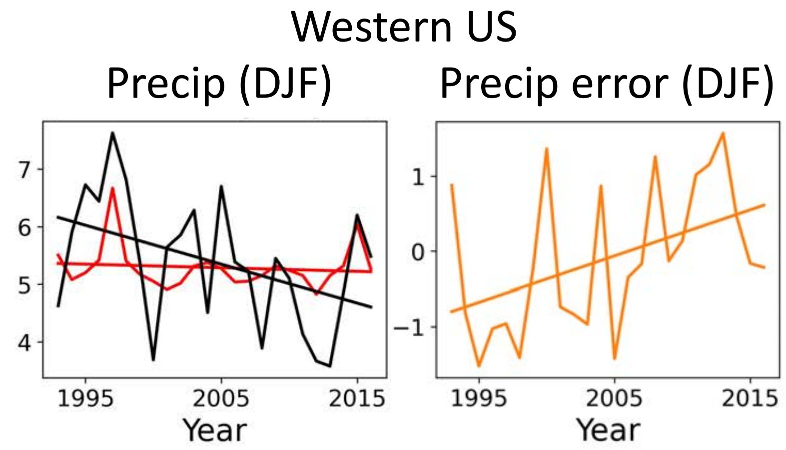
  - ECCC CanCM4i
  - ECCC GEM5-NEMO
  - NCEP CFSv2
  - GFDL-SPEAR
  - NASA GEOS-S2S

- We look at four different initialisations (Mar, Jun, Sep, 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

- We define the "trend error" as the slope of the linear line of best fit of the model error time series (model minus observations); this is the same as taking the difference between model and observed regression slopes

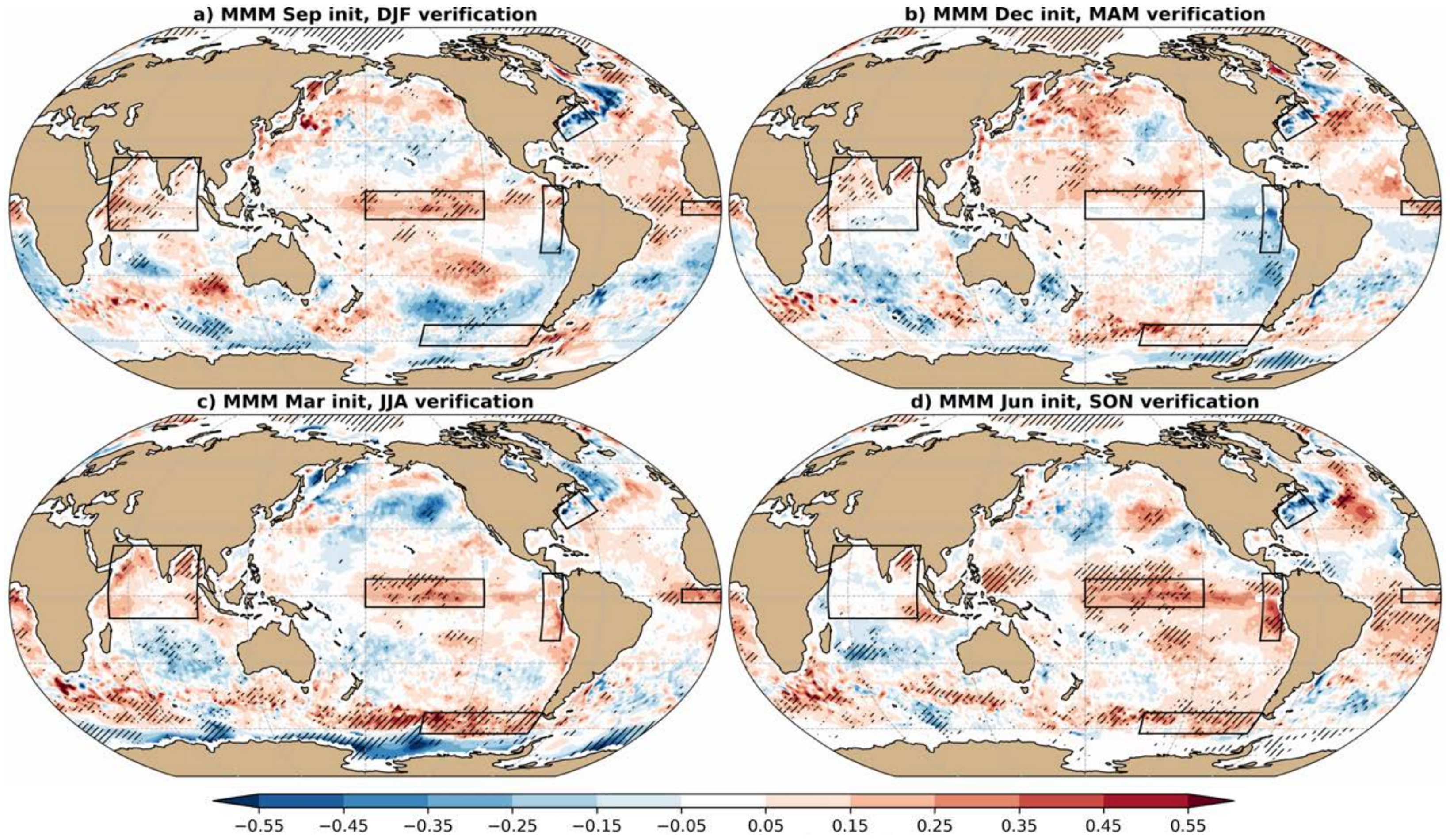
Black = observations
Red = MMM
Orange = MMM error



- We look at seasonal mean trend errors 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

Seasonal forecast models exhibit significant 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**



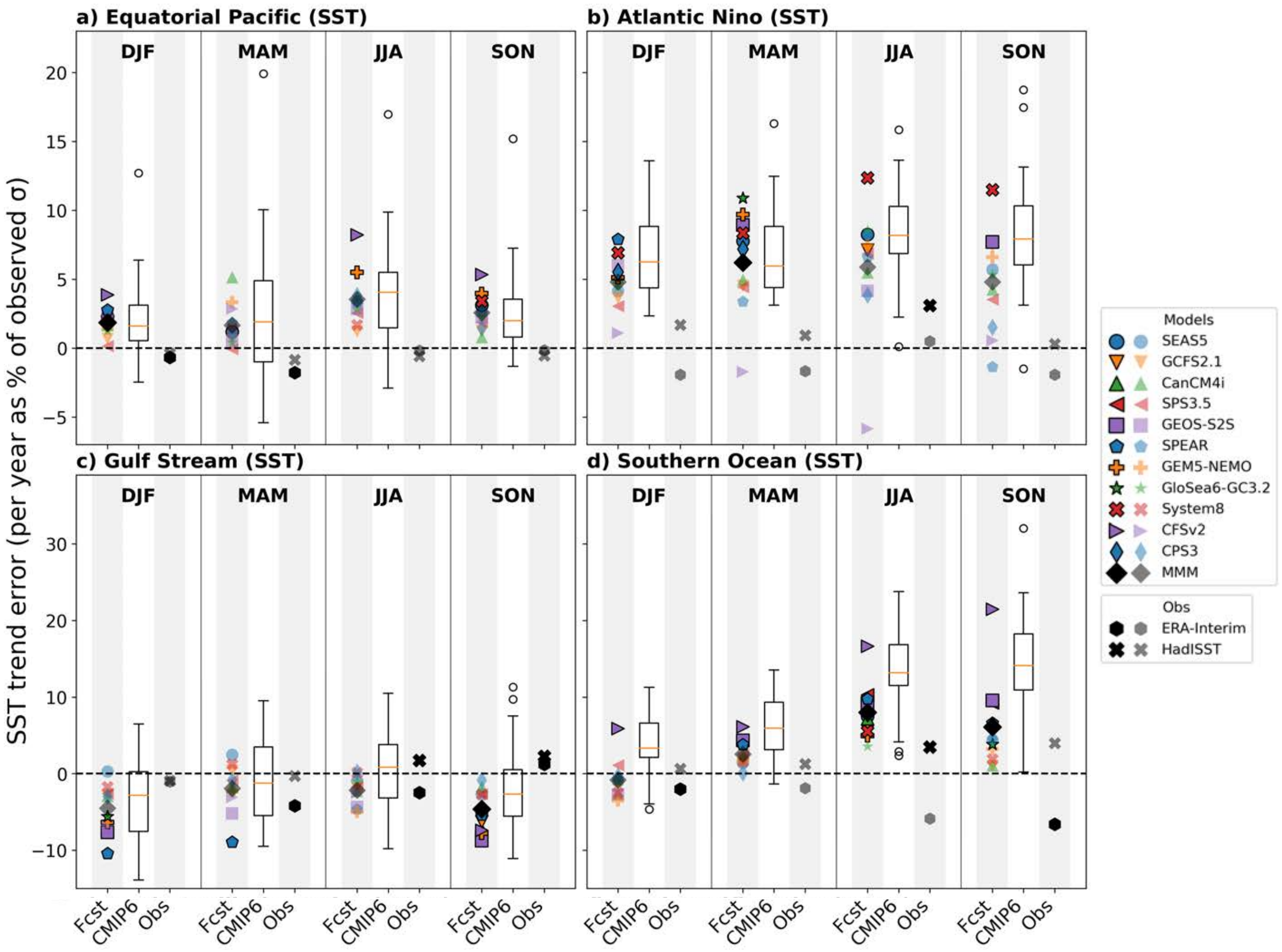
Shading = Seasonal forecast MMM SST trend error (unit: K / decade)
Hatching = Significance at 5% level

These 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**

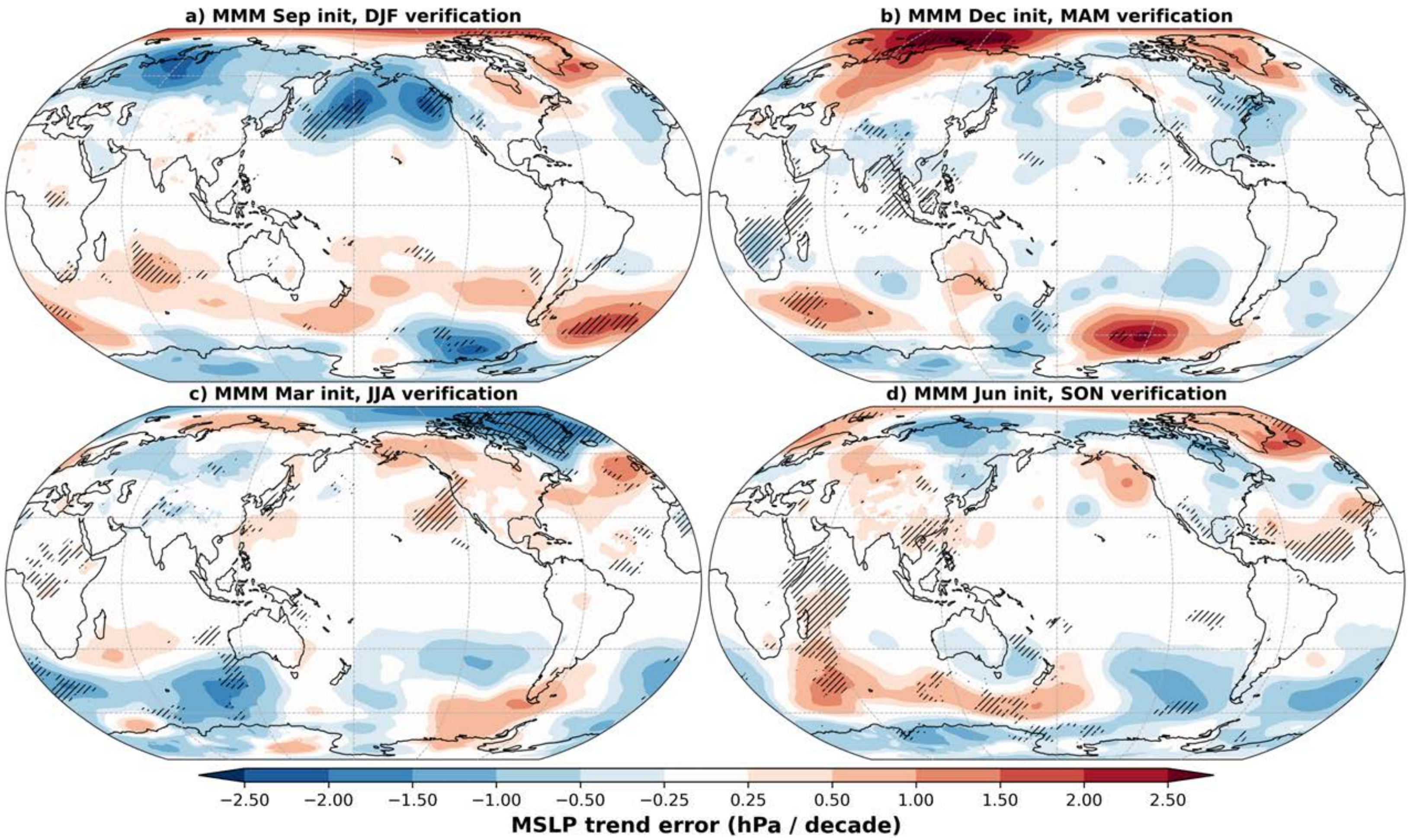
Coloured symbols = seasonal forecast models
Box plots = CMIP6 models

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



These trend errors closely match climate model errors:

- MSLP errors include an **anomalous deepening of the Aleutian Low** in DJF, and patterns that **project onto the Arctic Oscillation Index/NAO**



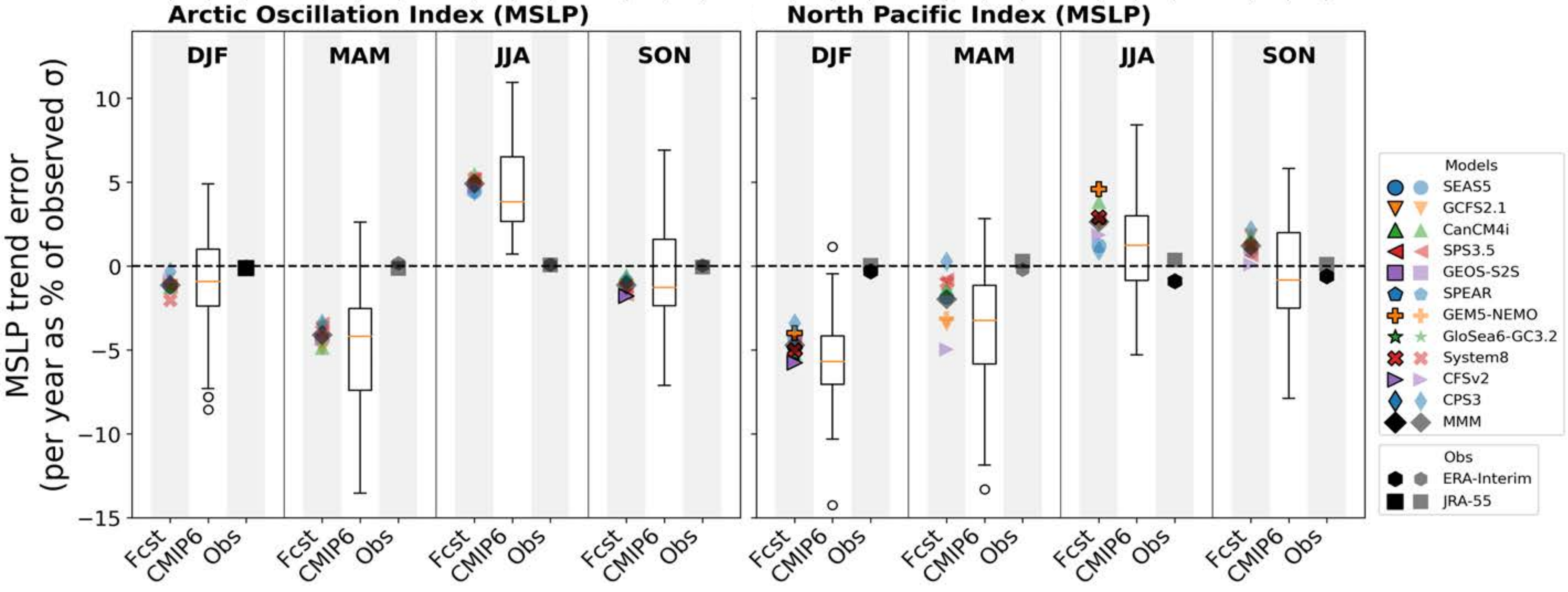
Shading = Seasonal forecast MMM MSLP trend error (unit: hPa / decade)
Hatching = Significance at 5% level

These 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

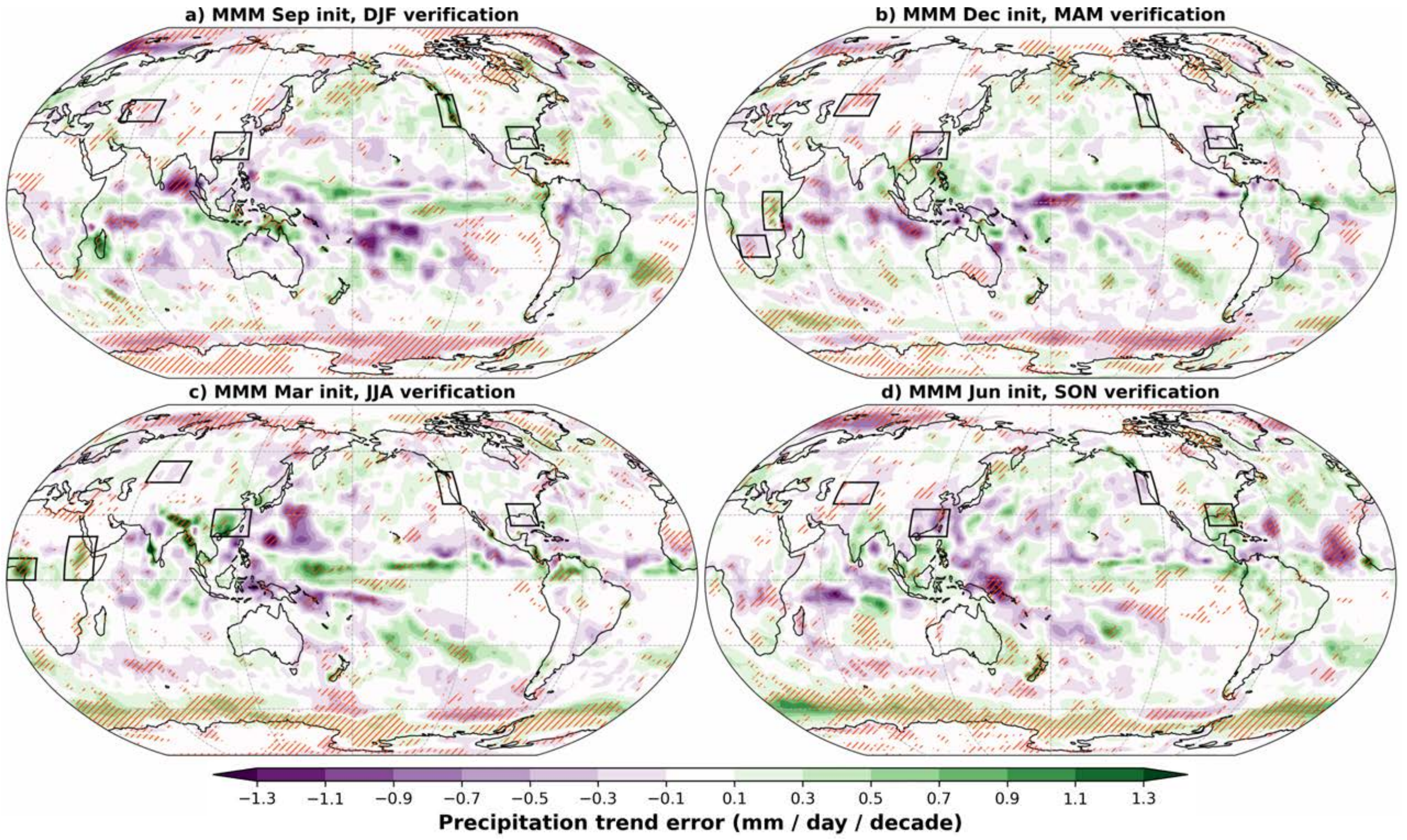
Coloured symbols = seasonal forecast models
Box plots = CMIP6 models

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



There are also associated significant precipitation trend errors:

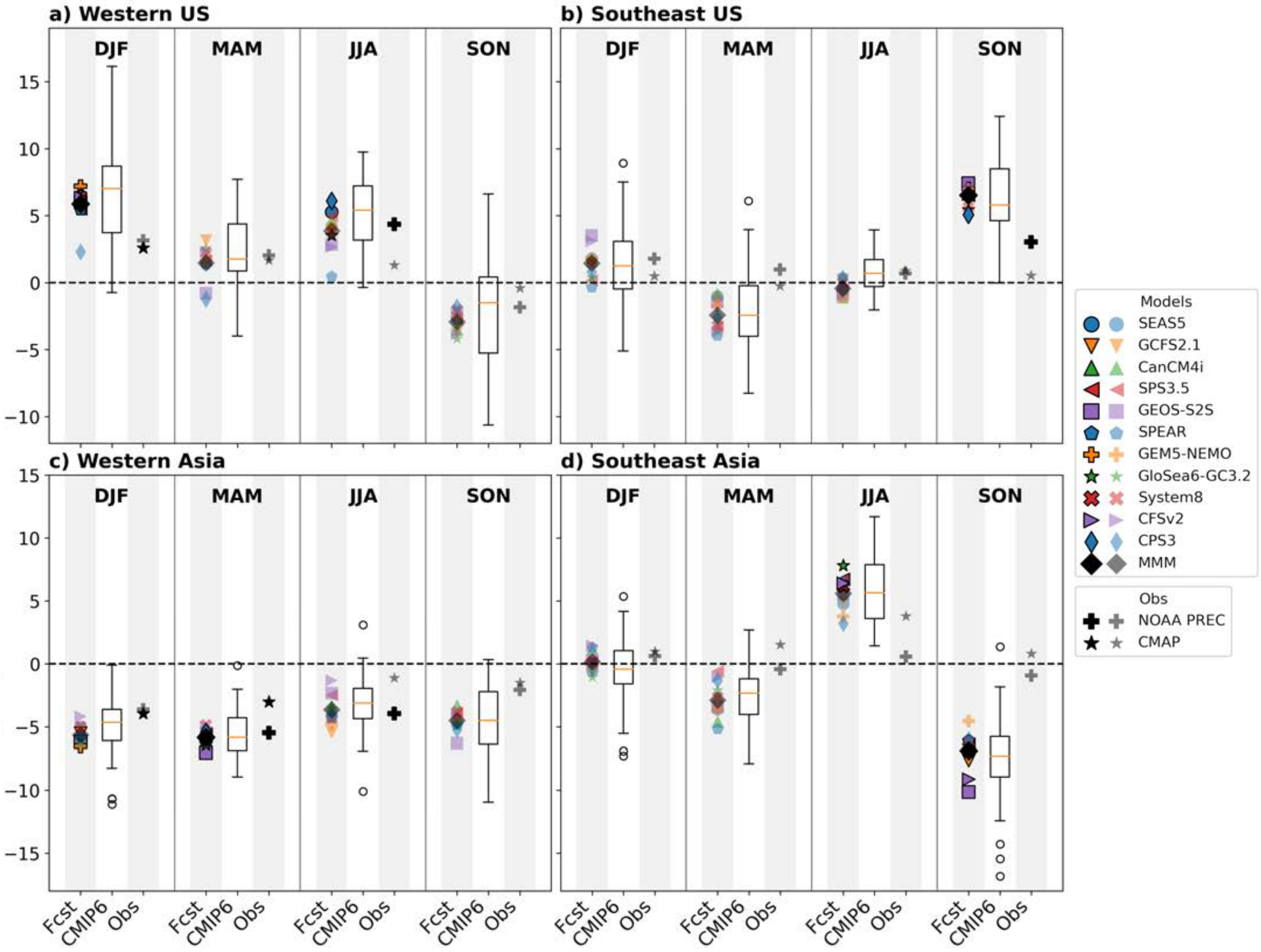
- Precipitation trend errors are **largely in agreement with the SST and MSLP errors**
- These often look like the **canonical El Niño signal** (e.g. Western US) or **align with the climatological wet season** (e.g. Western Equatorial Africa)
- Again, the **pattern of trend error** across different models is **very similar**



Shading = Seasonal forecast MMM precipitation trend error (unit: mm / day / decade)
Hatching = Significance at 5% level

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)

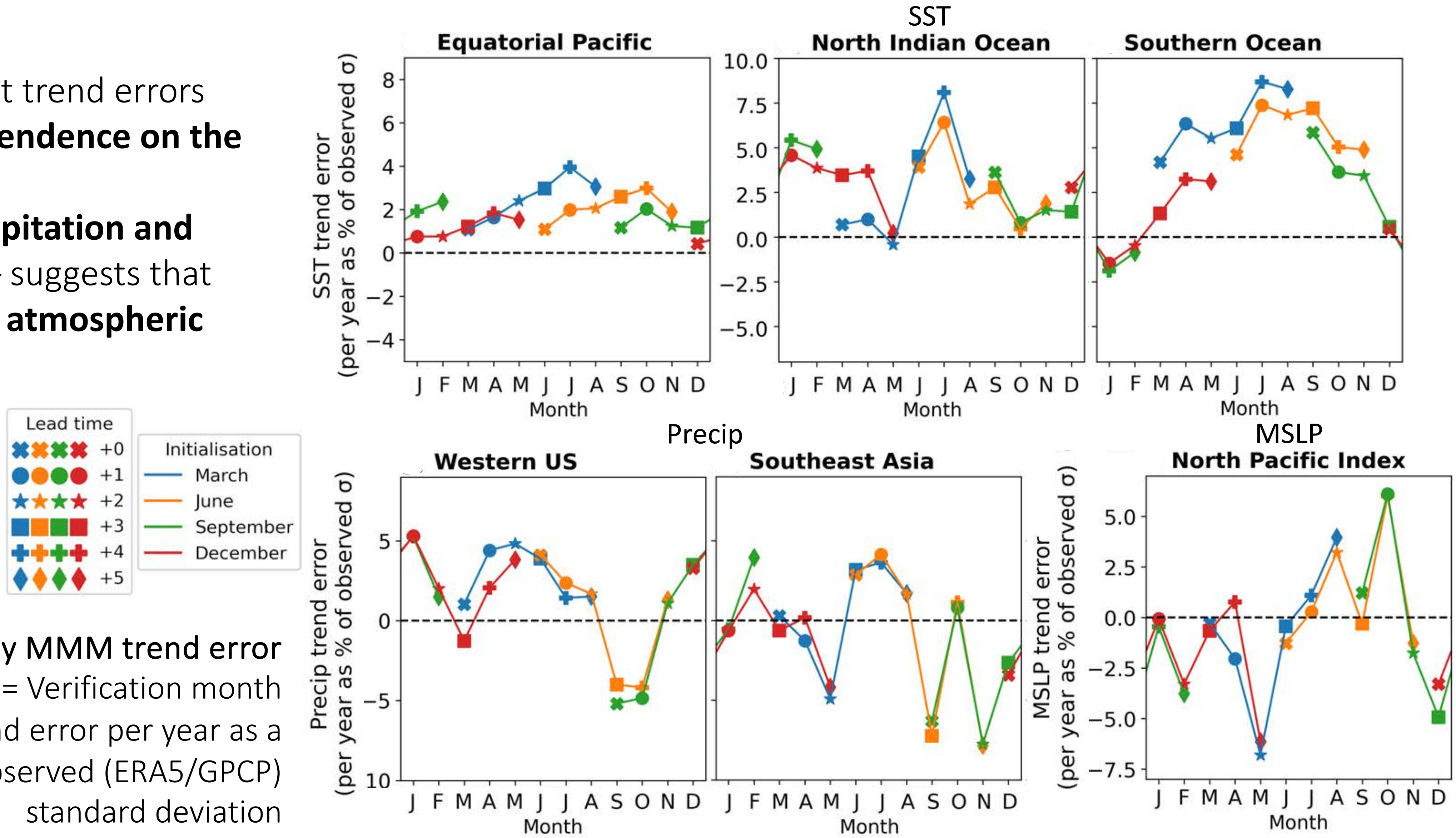


Coloured symbols = seasonal forecast models
Box plots = CMIP6 models

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

Hindcast trend errors are often well-developed at short lead times:

- Regional hindcast trend errors have **strong dependence on the seasonal cycle**
- **Clearer for precipitation and MSLP** than SST – suggests that errors **may have atmospheric origin**



Monthly MMM trend error

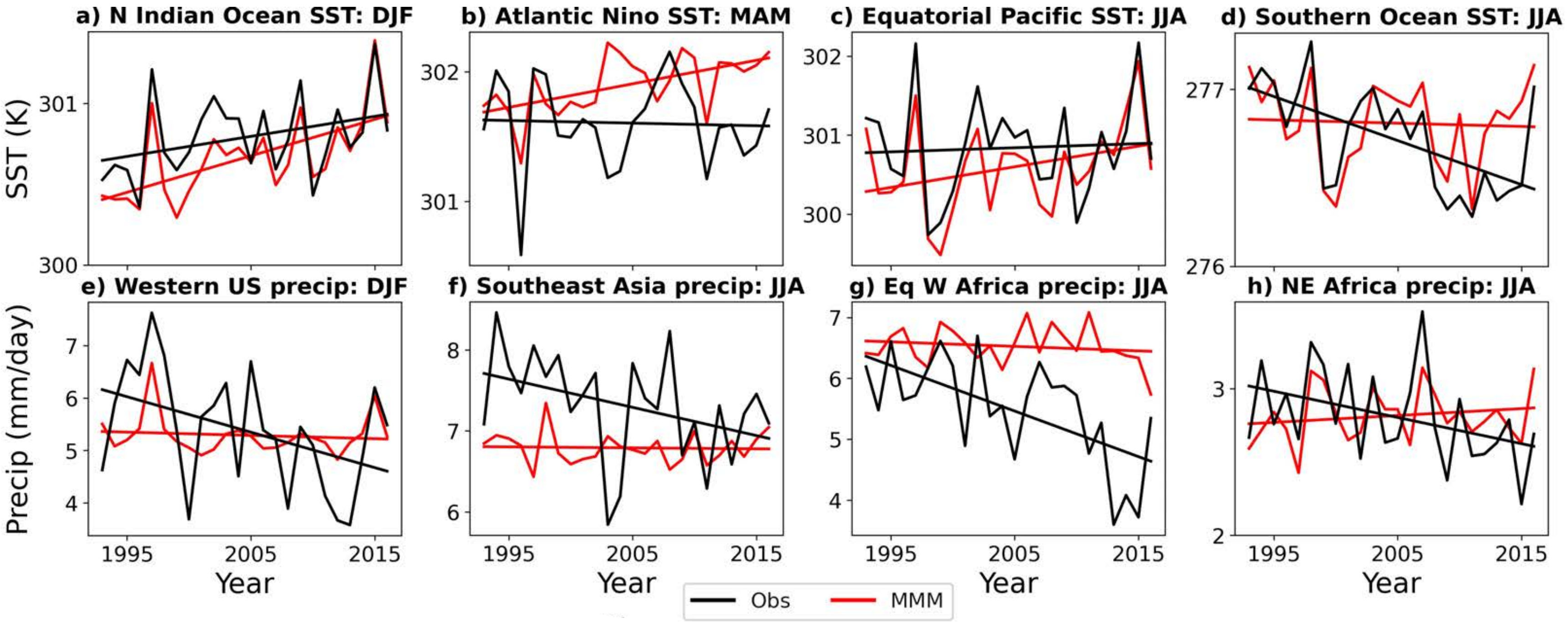
x-axis = Verification month

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

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

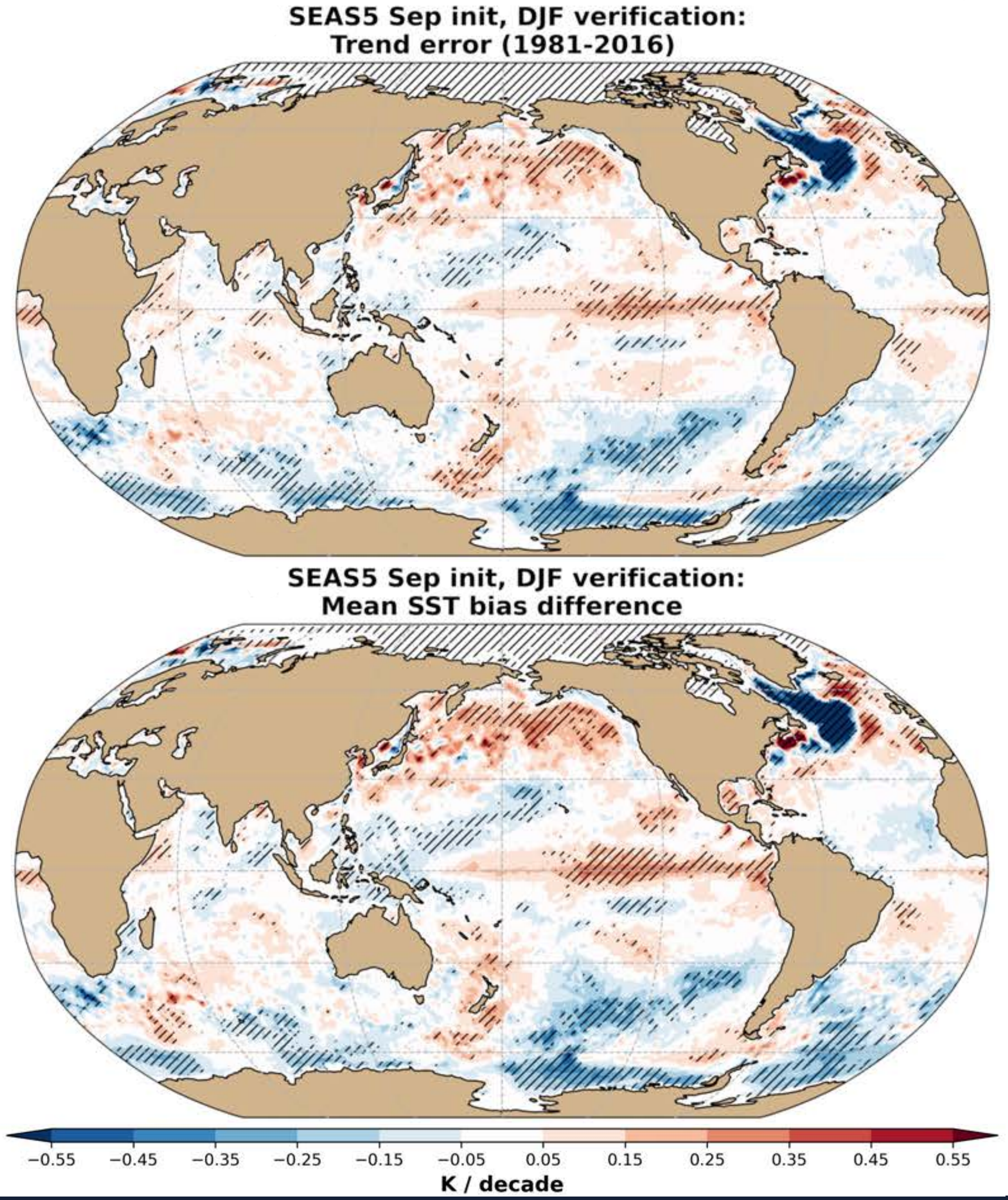


Trend errors manifest as changes to the model mean bias:

- **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)



Summary

- Seasonal forecasts have trend errors that are **very similar to climate model trend errors**
- These **develop rapidly and are tied to the seasonal cycle** – models transition from nature's attractor to the climate model attractor
- 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 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

Conclusions

- Diagnosis of climate model trend errors would therefore benefit from **analysis of the early development of errors in seasonal hindcasts**
- **Longer hindcast periods** would be beneficial
- Climate models used for projections **should also be run as seasonal forecast models:**
  - Shorter model runs required – reduces computing cost, speeds up production cycle
  - Can have larger ensembles
  - Evaluation of changes to model physics and parameterisations would be more efficient
- **No reason to suggest that the incorrect historical trends will not continue into the future**
  - Model trends in historical and projected sense should be examined with great care