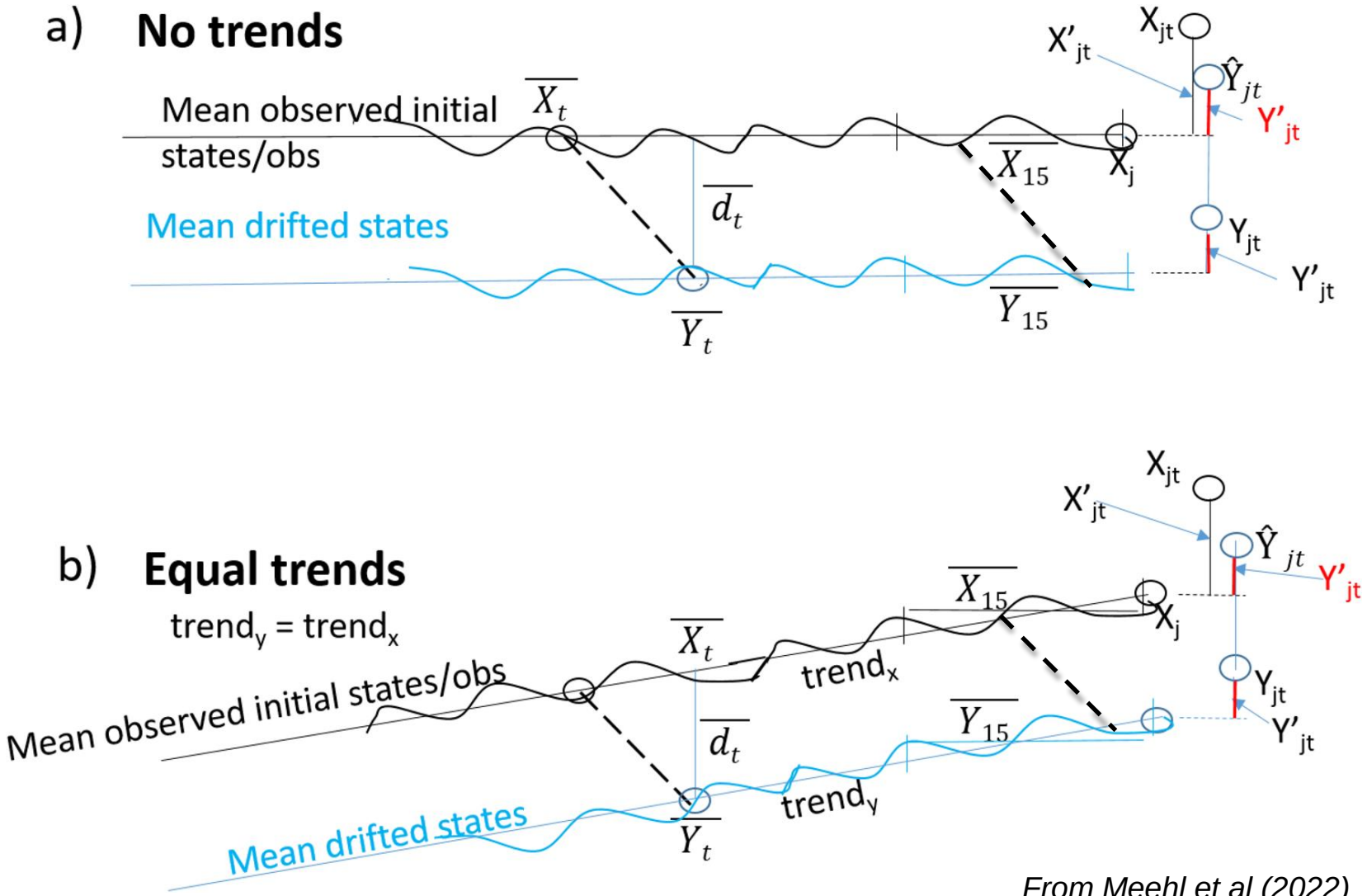
# Tropical Pacific trends in ECMWF seasonal forecasts

Michael Mayer, Magdalena Balmaseda, Frederic Vitart, Steffen Tietsche

ECMWF EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS

# Motivation I: Forecast calibration

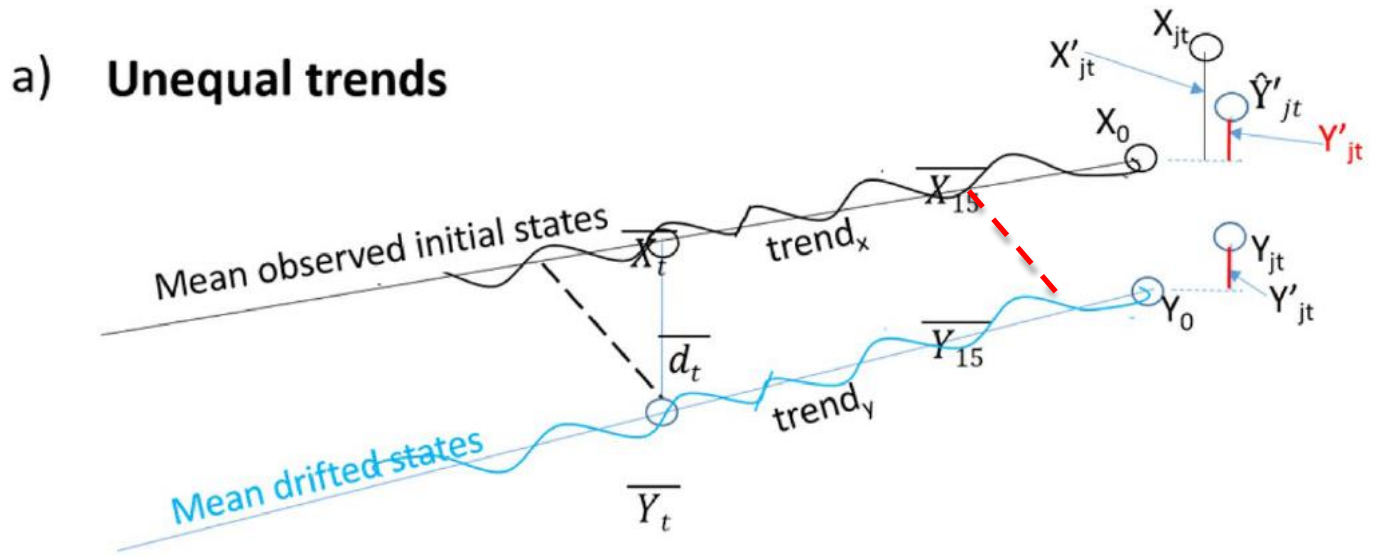
- The standard approach to present seasonal forecast anomalies is to remove the forecast bias computed for a reference period




*From Meehl et al (2022)*

# Motivation I: Forecast calibration

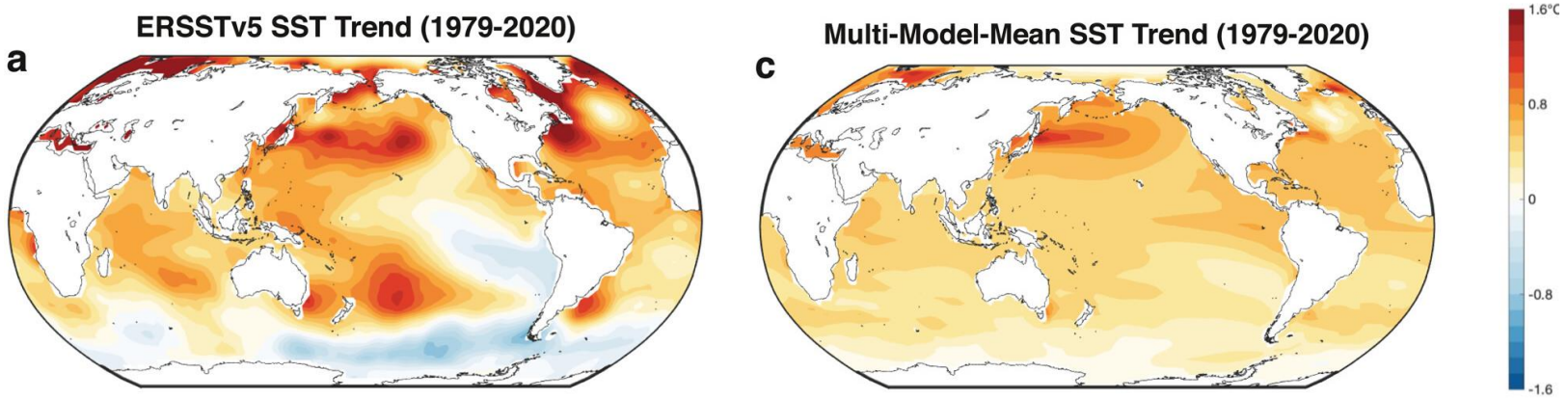
- This approach breakes down if the hindcast trends are different from the observed trends




→ Drift is different in early and late period of the hindcast, i.e. inadequate to remove constant bias

# Motivation II: Help understand trend errors in free-running models

- Observed zonal SST gradient in Pacific has been strengthening in recent decades, consistent with strengthening easterly winds
- Most climate models predict a weakening of the SST gradient, i.e. trends towards a persistent El Nino – like state (e.g. Wills et al. 2022)



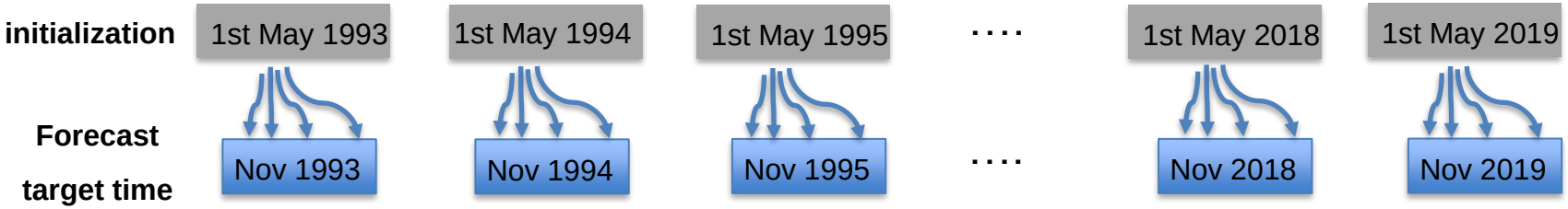

- Free-running CMIP-type simulations follow their own trajectory of natural (decadal) variability which hampers understanding of trend errors
- Initialized seasonal forecasts are much closer to the real evolution of the system (compared to free-running models) → could be a useful testbed for understanding model (trend) errors

# In this talk

- Characterize errors in tropical Pacific hindcast from ECMWF's SEAS5
- Diagnostics and experiments to identify contributors to trend errors
- Evaluate the role of trend errors in recent ENSO forecasts

# Concept of trends in seasonal hindcasts

- Example: November trends 1993-2019 for May initializations



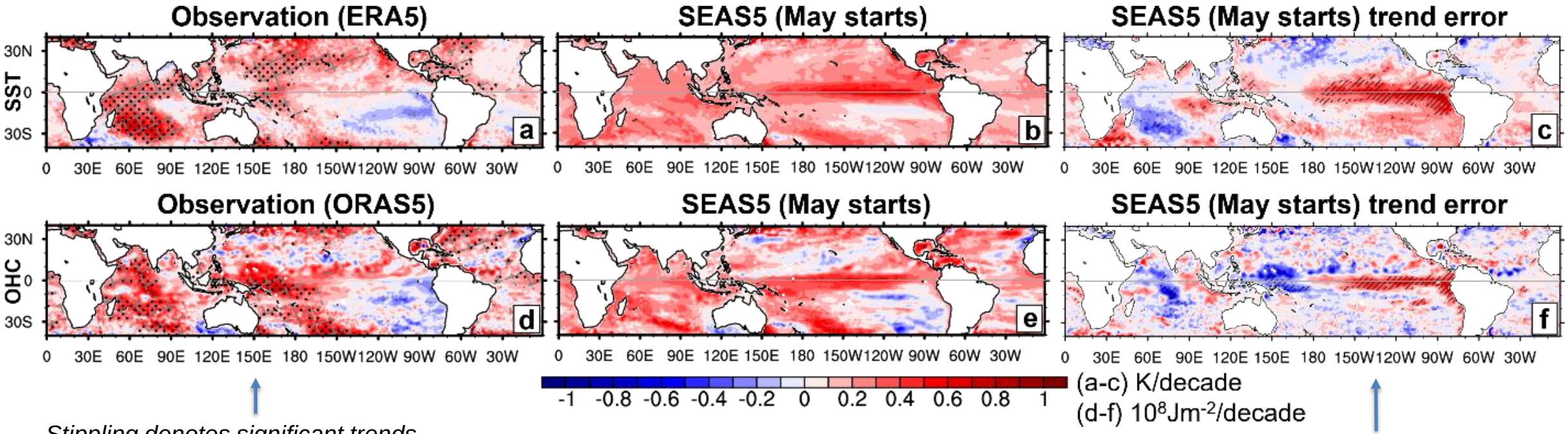

- We can look at trends in the ensemble mean, but each ensemble member represents an equally plausible realization

→ there are n_ens^n_years possible hindcast trends, from which we can sample. Can check consistency with observed trend

# Characterization of trend errors 1993-2019

# Hindcast trends in November 1993-2019: SST & OHC

- ECMWF‘s seasonal forecasting system SEAS5 overestimates positive SST trends in equatorial Pacific
- Observed SST and OHC trends in equatorial Pacific are outside distribution estimated from 1000 permutations of ensemble members



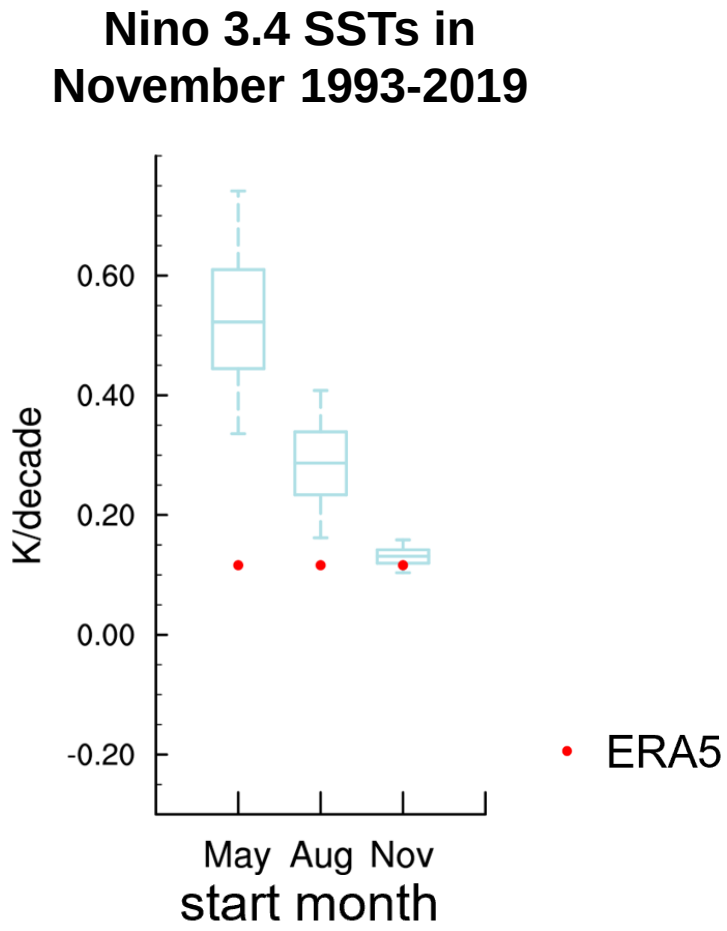

*Stippling denotes significant trends on 90% level*

*Hatching denotes where observed trends are outside distribution of 1000 randomly sampled hindcast trends*

# Nino 3.4 trends 1993-2019 for different start dates

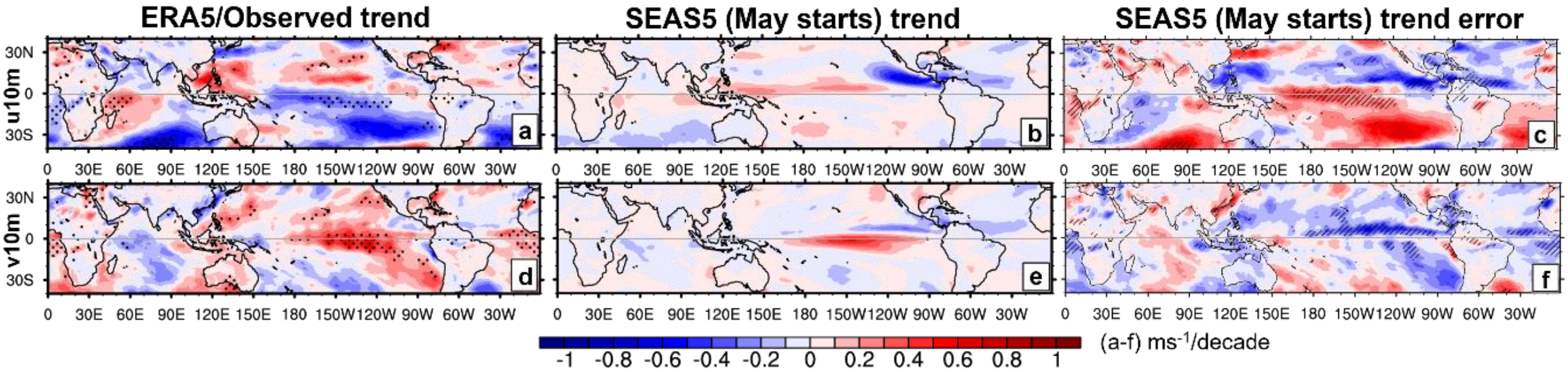
- SEAS5 trends on the warm side even for lead month 1

*Range of model trends derived from 1000 randomly sampled time series using 25 ensemble members*



# Hindcast trends in JJA 1993-2019: winds

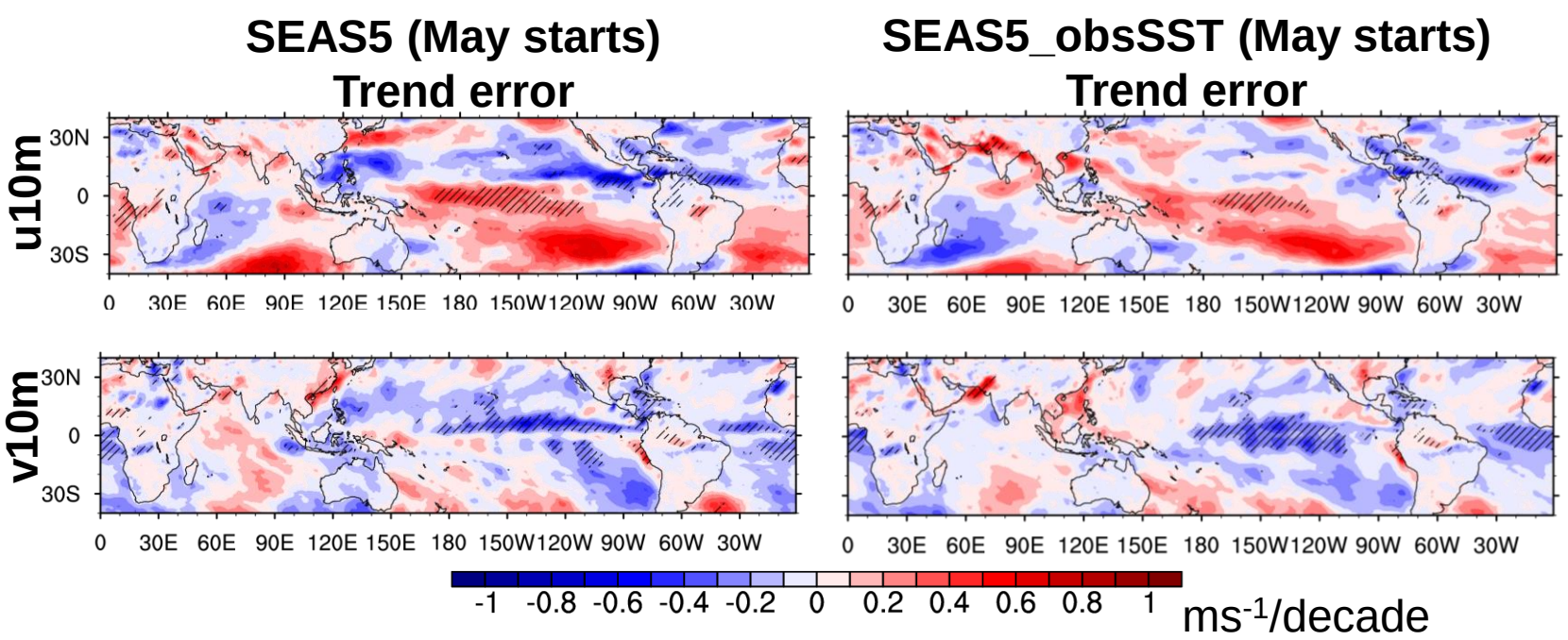
- Observed wind trends reminiscent of WES feedback
- SEAS5 underestimates easterly and southerly wind trends in equatorial Pacific



# Role of atmospheric model

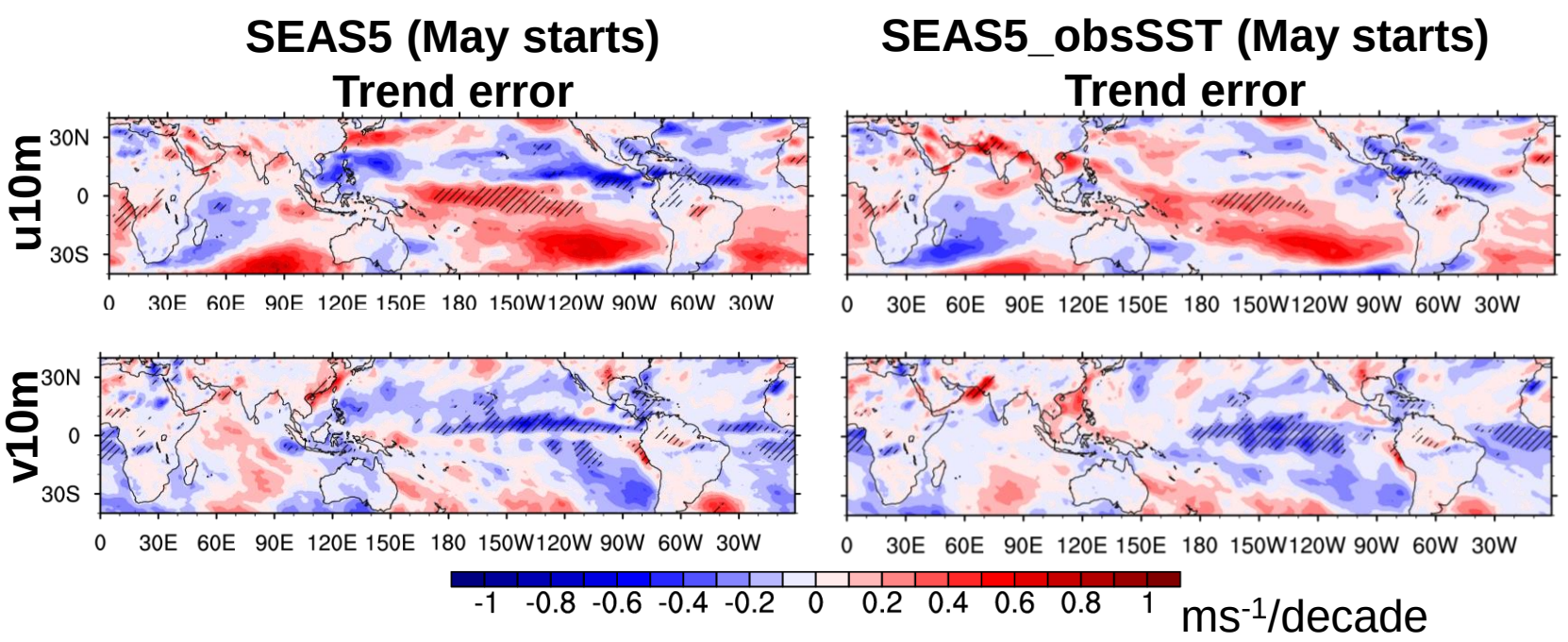
# Hindcast trends in JJA 1993-2019: role of atmosphere model

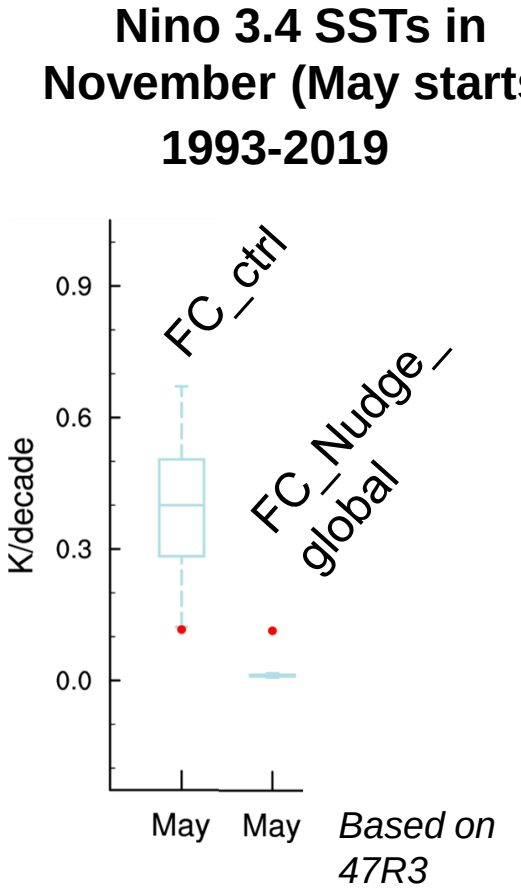
- Wind trend errors of uncoupled forecasts with observed SSTs similar to those of SEAS5



# Hindcast trends in JJA 1993-2019: role of atmosphere model

- Wind trend errors of uncoupled forecasts with observed SSTs similar to those of SEAS5
- Nudging T/Q/U/V to ERA5 in coupled hindcast experiment removes SST trend error

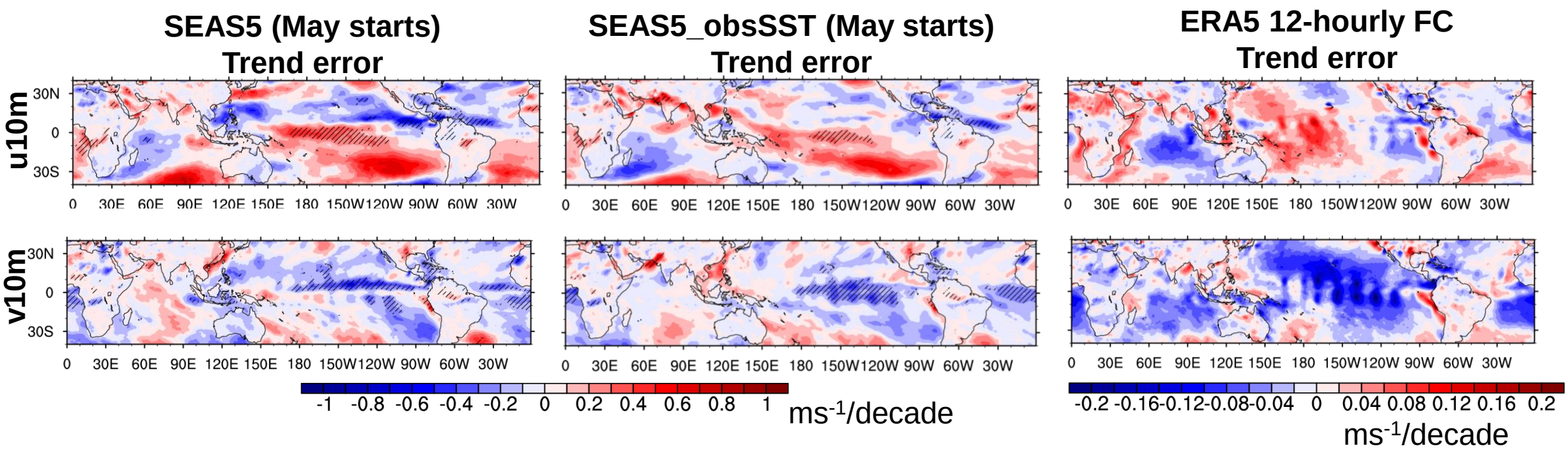


# Hindcast trends in JJA 1993-2019: role of atmosphere model

- Wind trend errors of uncoupled forecasts with observed SSTs similar to those of SEAS5

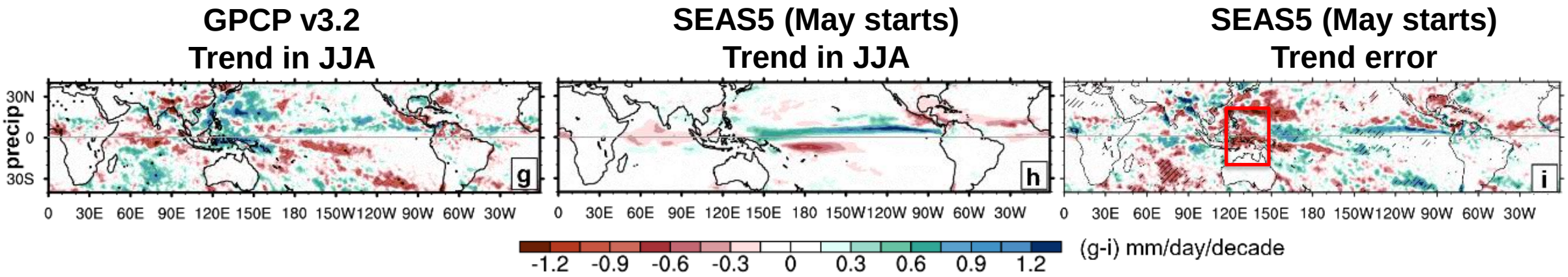
- **Note:** Already 12-hourly forecast errors of ERA5 winds show key features of seasonal forecast trend errors



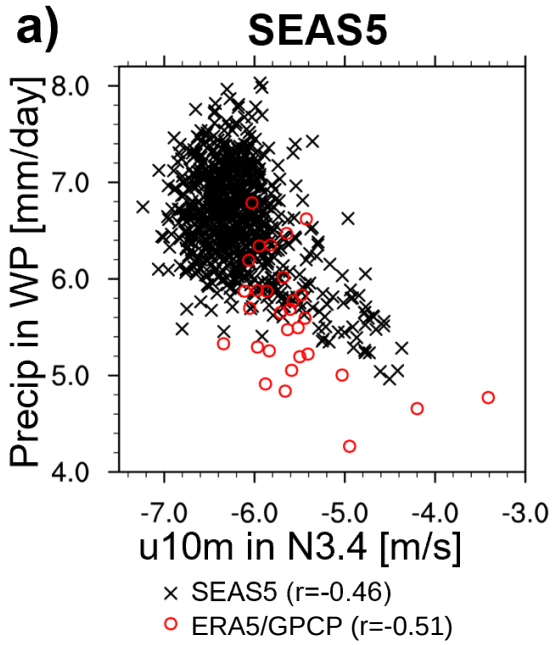
# Relationship of biases and trend errors

# Winds and precipitation

- Observed precip in Western Pacfic increases, consistent with strengthening easterlies
- Coupled (and uncoupled) hindcasts underestimate Western Pacific trends

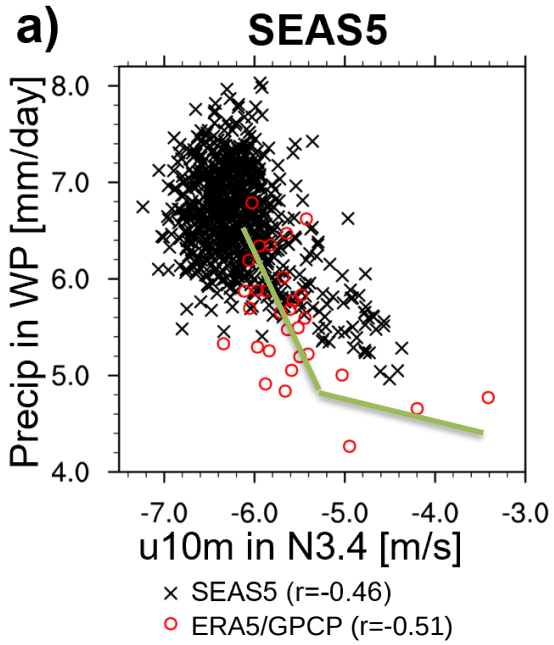


# Winds and precipitation




- Observed u10m/precip relationship shows two regimes:
  - high precip/strong easterlies + low wind sensitivity regime
  - Low precip/weak easterlies + strong wind sensitivity regime
- SEAS5 is predominantly in high precip regime
- Positive precip bias may hamper sensitivity to observed strengthening SST gradients and u10m strength (energetic constraints)

# Winds and precipitation

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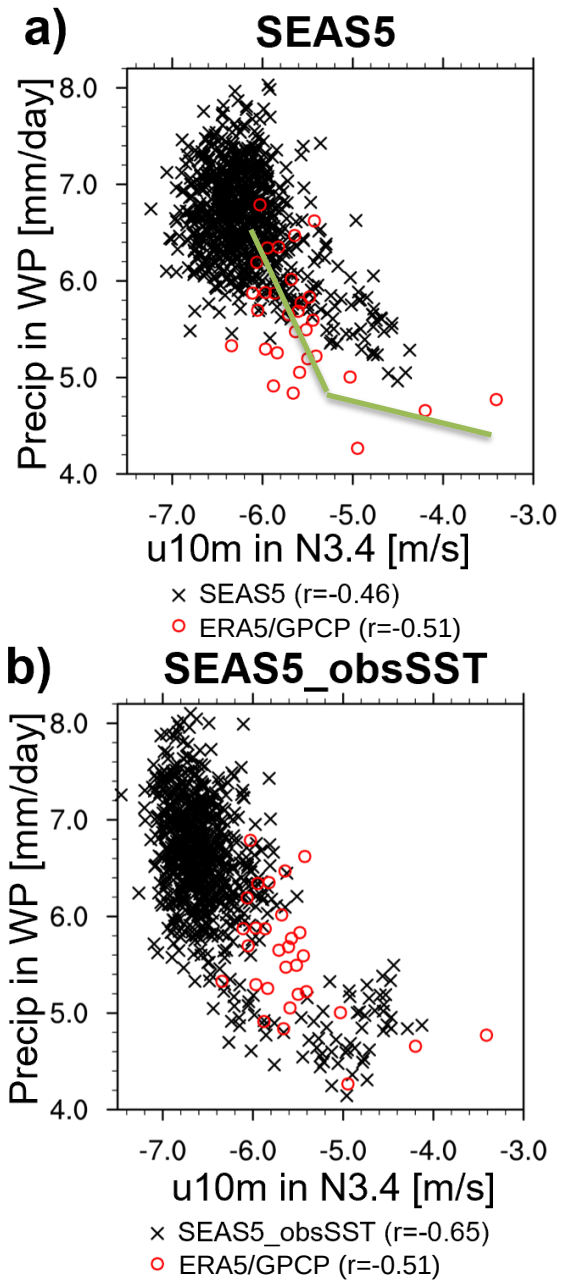


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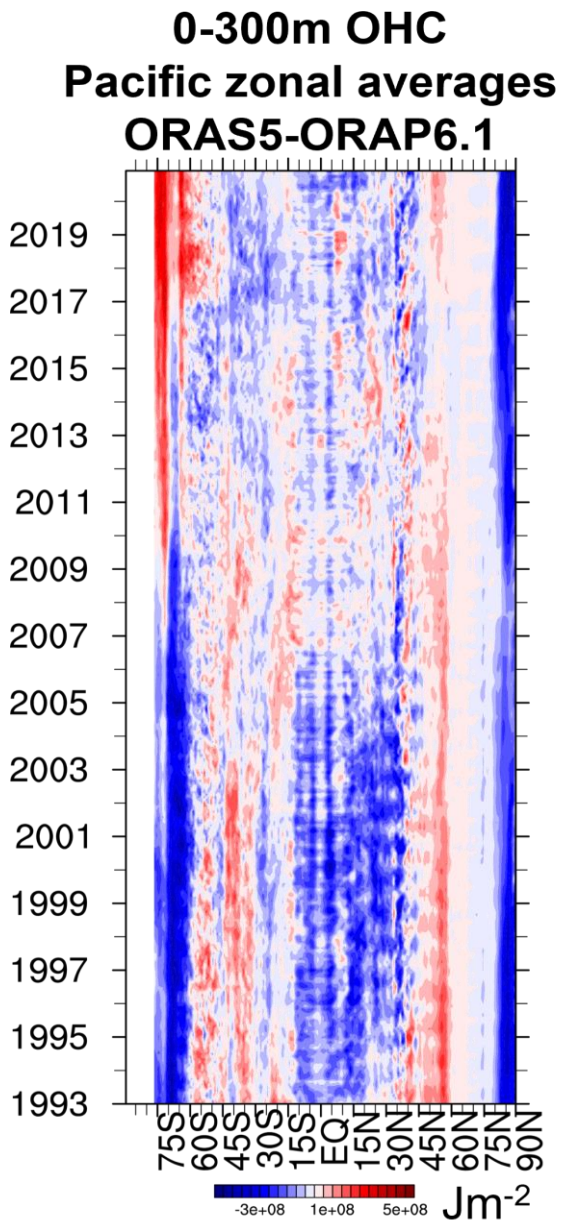
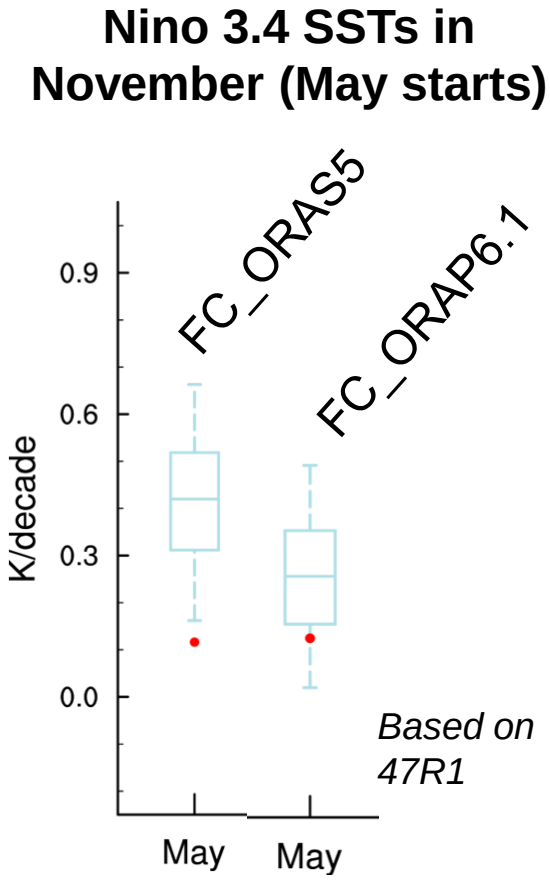
- SEAS5 is predominantly in high precip regime
- Positive precip bias may hamper sensitivity to observed strengthening SST gradients and u10m strength (energetic constraints)
- SEAS5_obsSST with similar predominance of high precip regime

# Role of ocean initial conditions

# Impact of ocean initial conditions on trends



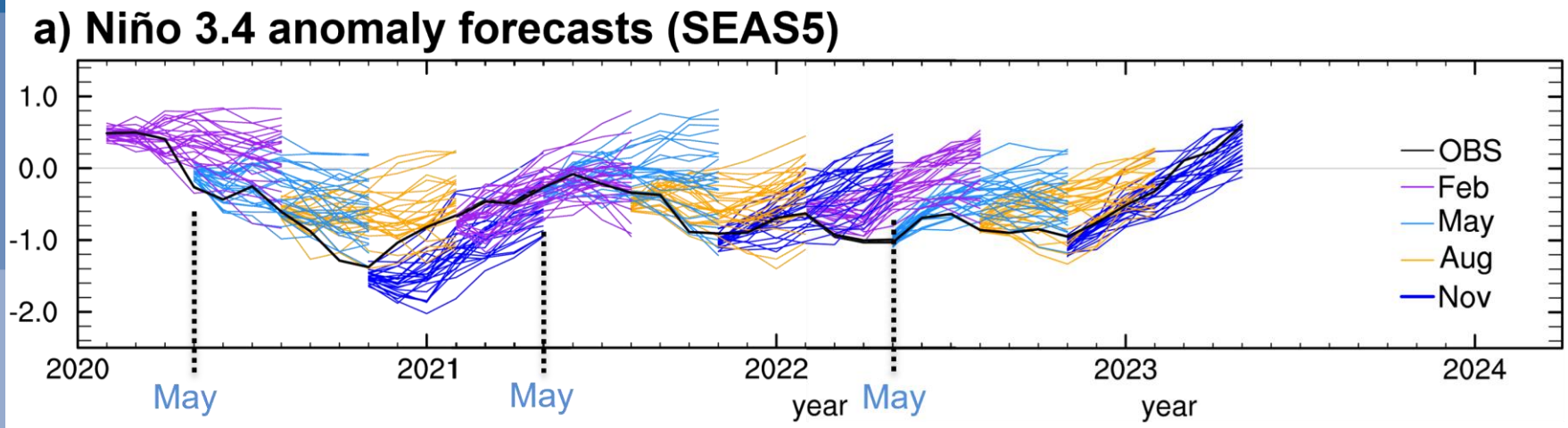

- In ORAS5, tropical Pacific is relatively cool pre-Argo → likely enhances trends of hindcasts
- Using ORAP6 ICs reduces trend error



# Implications for recent ENSO forecasts

# Triple La Niña 2020-2023

- SEAS5‘s 2020 – 2022 predictions continue the tendency towards too warm ENSO state




**Nino 3.4 in Nov 2020-22**

Obs: -1.1 K

May start ens mean: -0.1 K

May start ens mean error: **+ 1.0 K**

# Triple La Niña 2020-2023

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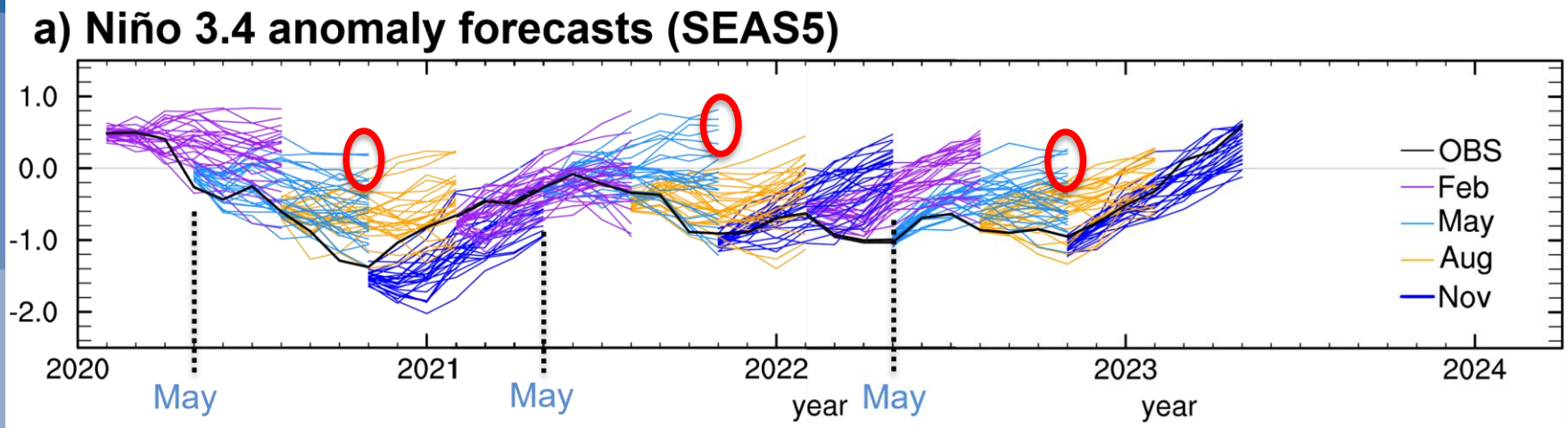


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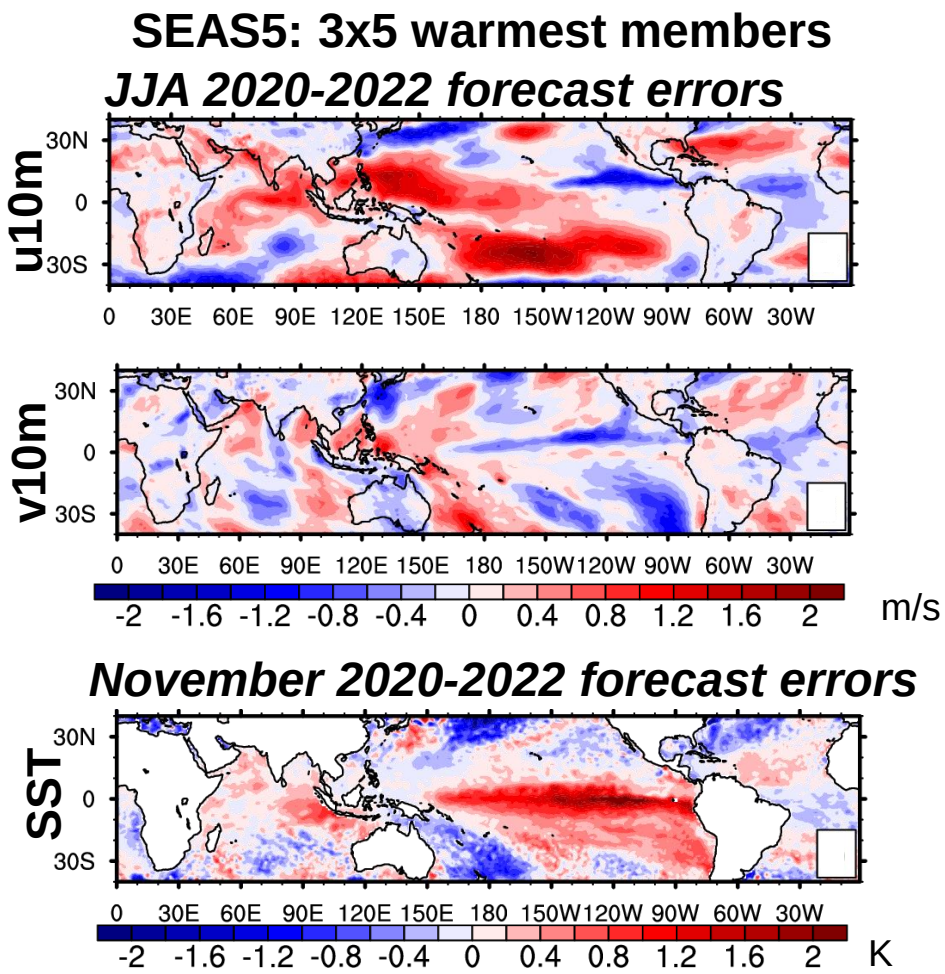
- Look at warmest members of forecasts initialized in May 2020-2022

# Triple La Niña 2020-2023: forecast errors

- Composite of five warmest (=worst) forecast members started in May 2020-2022 (totalling 15 members) exhibit similar circulation and SST errors as 1993-2019 trend errors



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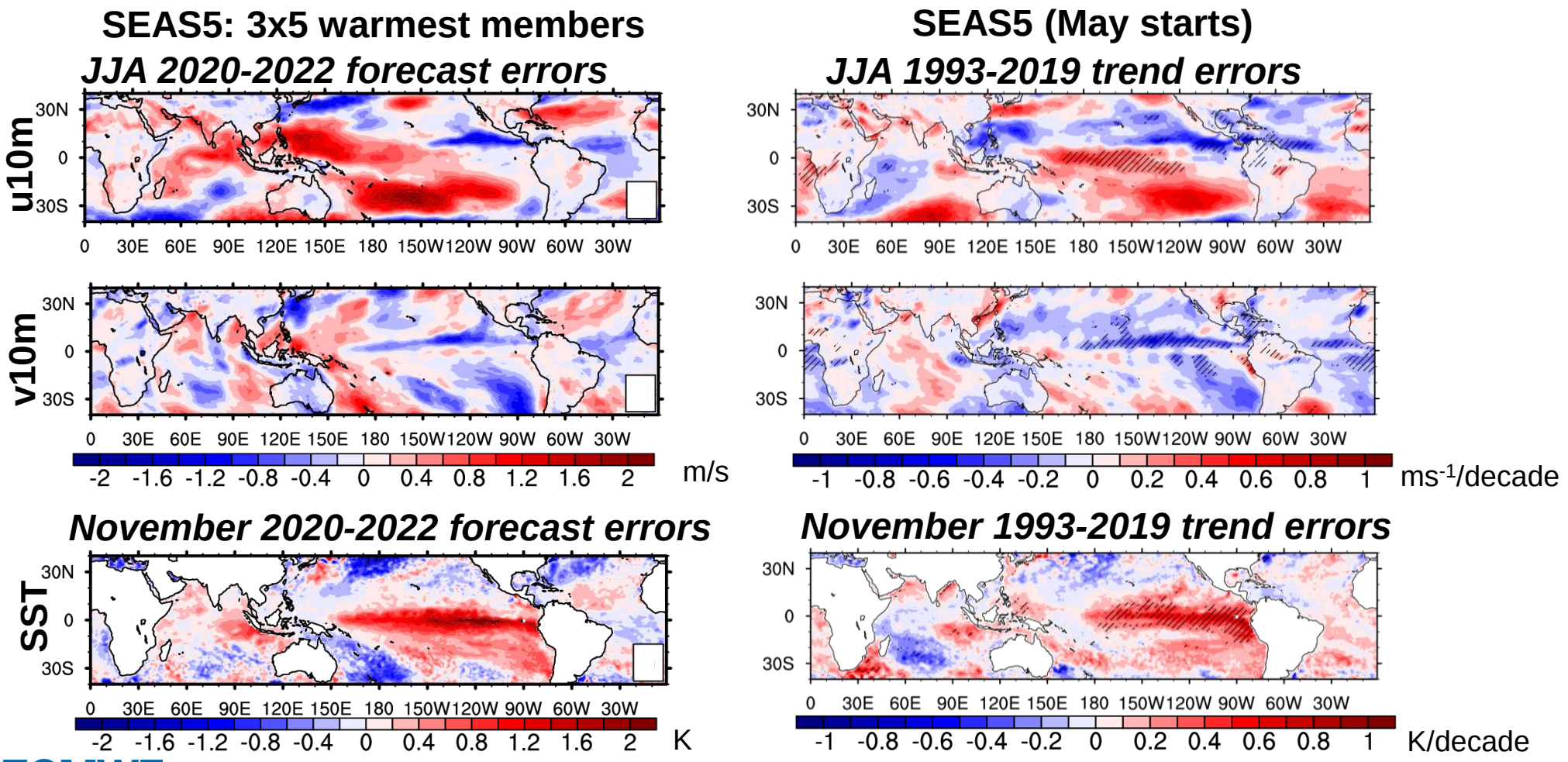
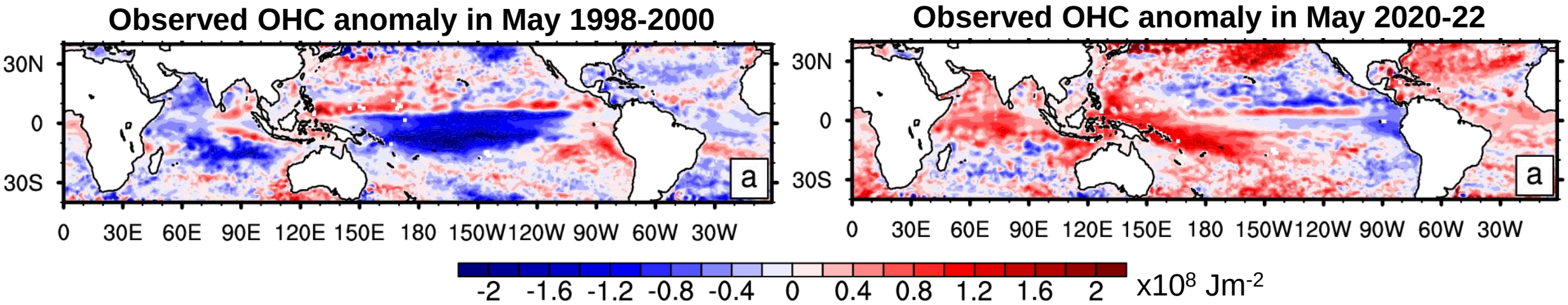
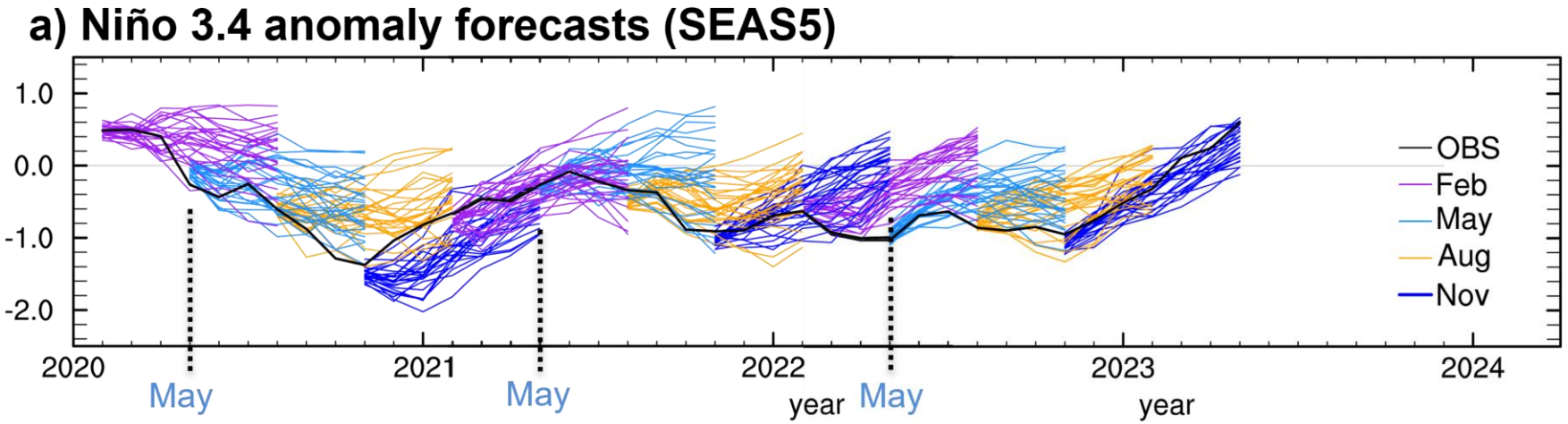


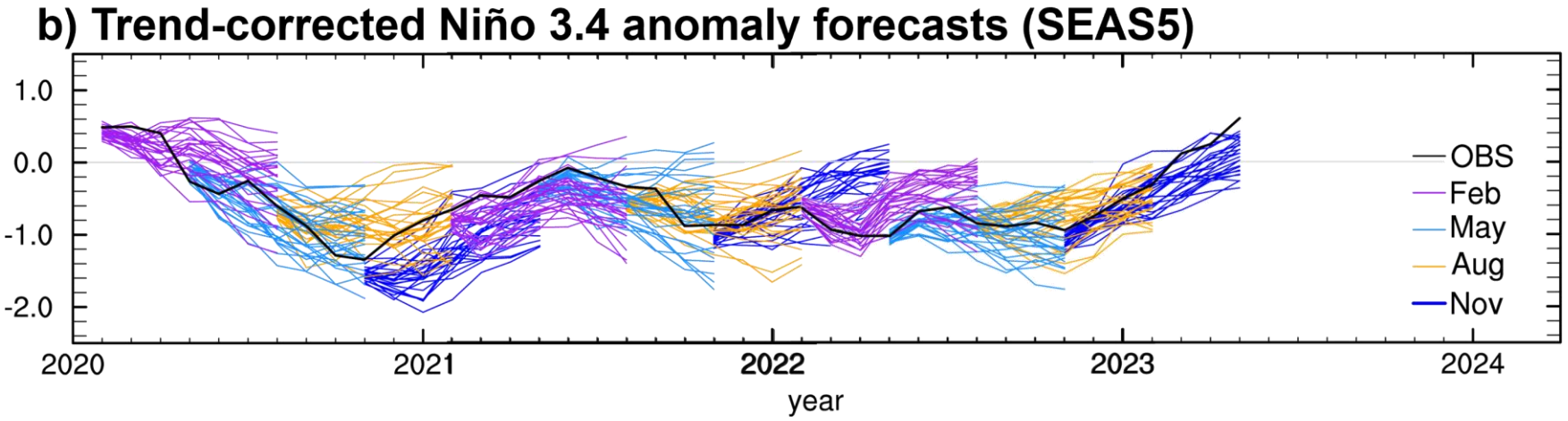
# Weak subsurface precursors during triple-dip La Niña 2020-2023

- Pacific was much cooler after 1997/98 El Niño, providing a strong source of predictability for subsequent years
- Pacific was in a neutral state in recent years, being susceptible to small perturbations (and small errors).



# Trend-aware calibration




**Nino 3.4 in Nov 2020-22**

Obs: -1.1 K

May start ens mean: -0.4 K

May start ens mean error: **+ 0.7 K**

**With trend correction**

May start ens mean error: **+ 0.1 K**

RMS error 1993-2022: **-15%**

# Summary

- SEAS5 does not reproduce observed atmospheric circulation and SST trends over the tropical Pacific 1993-2019
- Circulation trend errors are present also in SEAS5_obsSST and even ERA5 short-term forecasts, with a possible link between precipitation bias and the response to changing SST gradient and winds
- Additional role for possible non-stationary subsurface biases in ORAS5 which seem improved since ORAP6
- Underestimation of circulation trends (too weak easterlies, lack of southerlies at equator) in the forecasts persisted during 2020-2022 and contributed to too warm forecasts during triple La Niña period
- Lack of strong ocean subsurface signal in ocean initial conditions posed additional challenge on forecasts during 2020-2022
- A simple linear trend correction during calibration reduces RMSE of SEAS5 Nino 3.4 SST forecasts in November by ~15% (May starts 1993-2022)

***Further reading:*** Mayer, M., Balmaseda, M.A., Vitart, F., Tietsche, S., 2025: Tropical Pacific trends in the ECMWF seasonal system and implications for predictions of the 2020-2022 triple-dip La Niña, *J. Climate,* doi: 10.1175/JCLI-D-24-0467.1