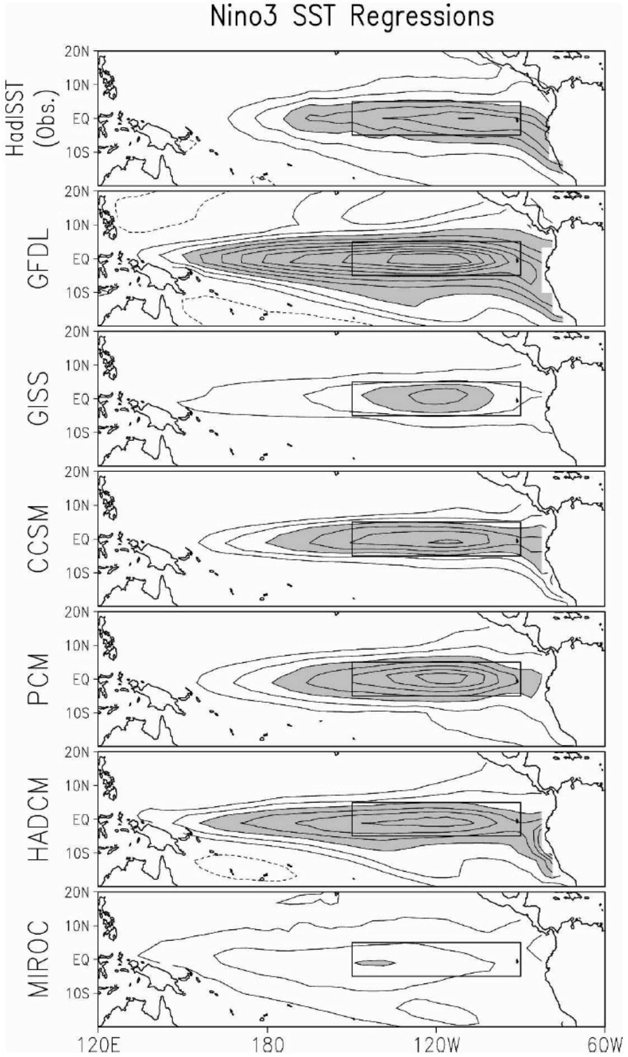
Rapid development of systematic ENSO-related seasonal forecast errors

Jonathan Beverley, Matthew Newman and Andrew Hoell

Systematic ENSO errors have persisted through multiple generations of climate models, from CMIP3…

- There are two prominent systematic model errors

- The first consists of a westward extension of ENSO SST anomalies

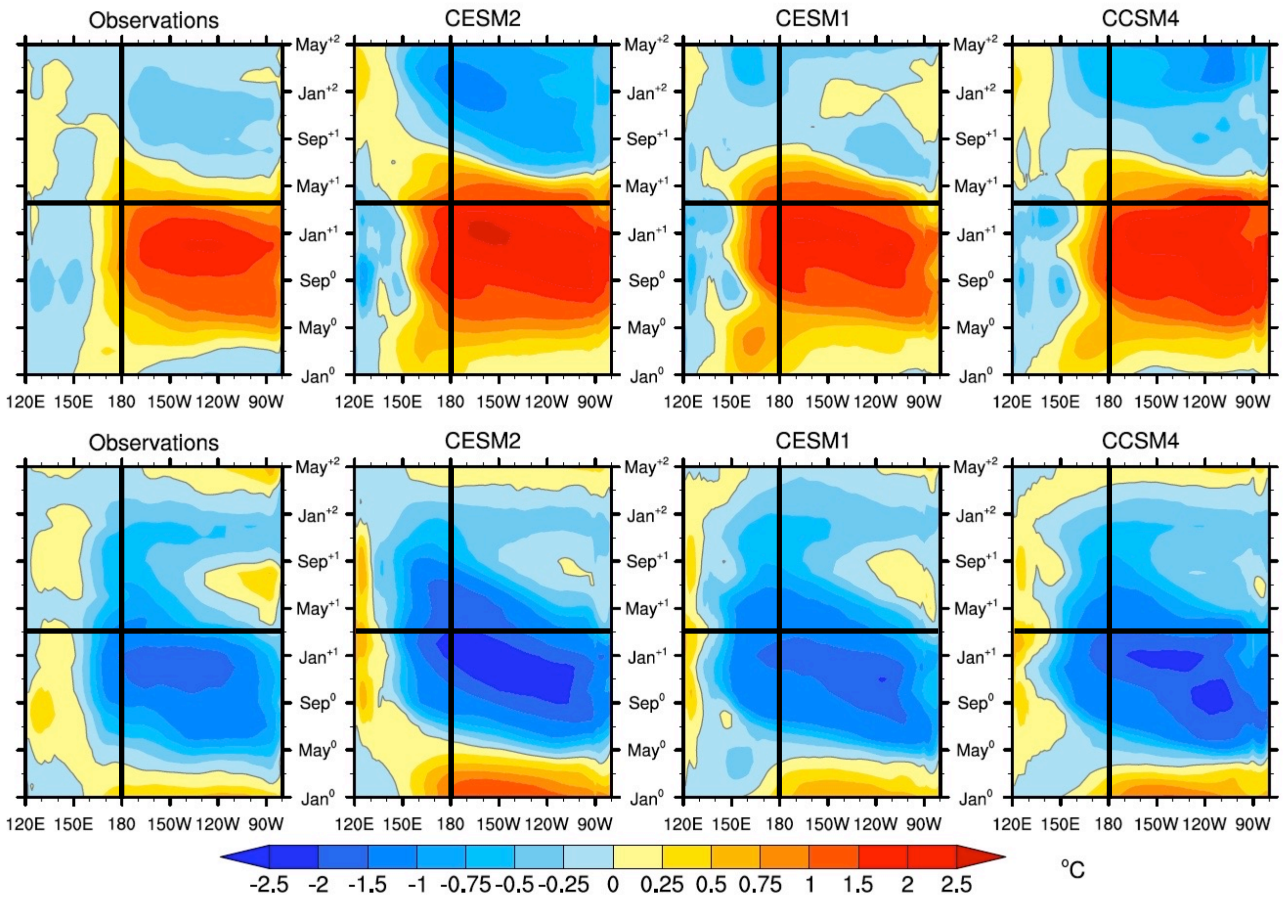


CMIP3 models,
from Joseph and Nigam 2006

…through to more recent model versions:

- This westward extension has therefore existed for many years

- The second prominent error involves overly persistent ENSO anomalies in the eastern equatorial Pacific in the spring after their peak

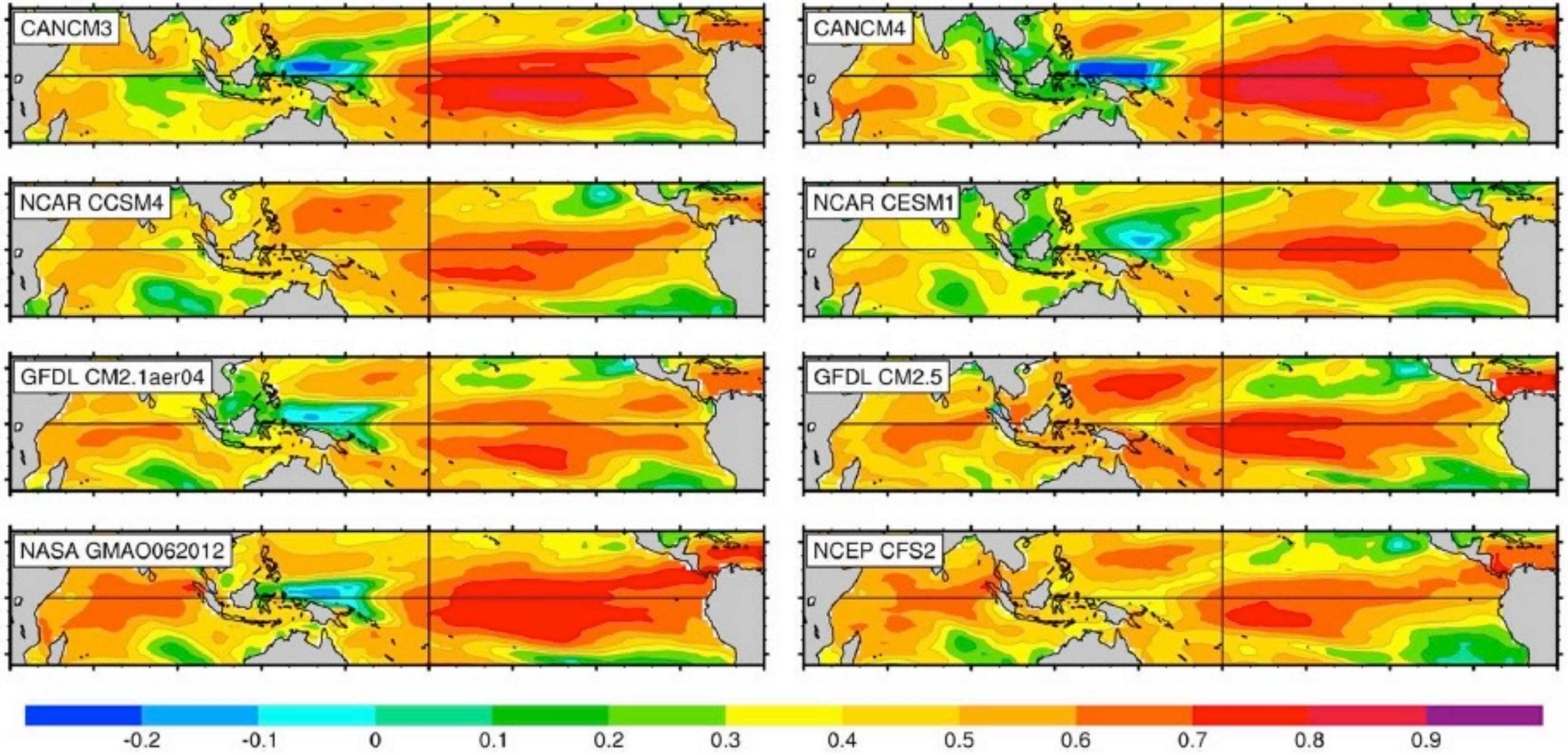


From Capotondi et al 2020

These errors exist in climate models, but what about seasonal forecasts?

- Seasonal forecast models have a skill “hole” in the west Pacific
- Note also that models which have higher central Pacific skill (i.e. have better ENSO phasing) tend to have lower skill in the west Pacific

Anomaly correlation skill of Month 6 SST anomaly hindcasts (NMME, 1982-2010)

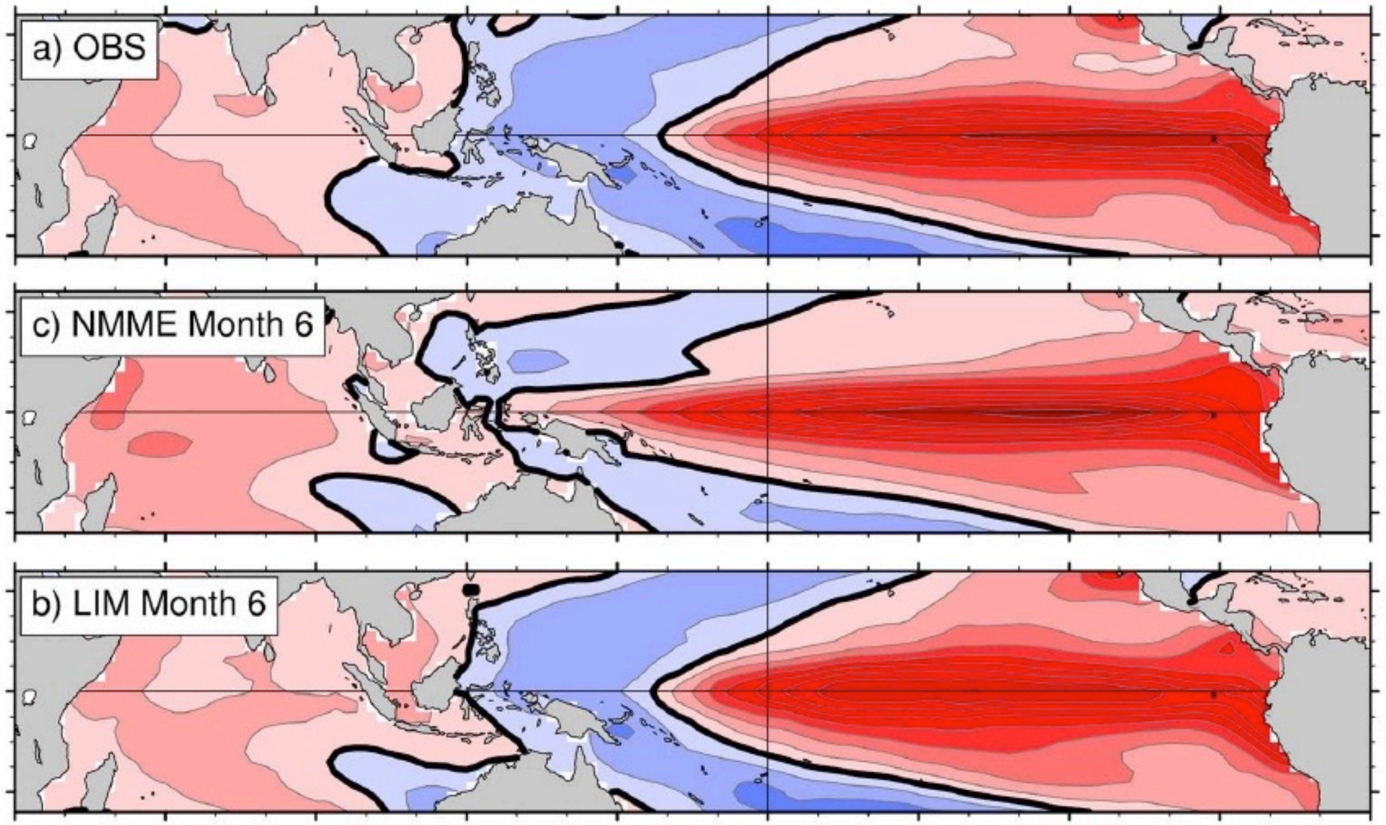


From Newman and Sardeshmukh (2017)

This skill hole is a result of the westward extension of SST anomalies

- Seasonal forecast models also suffer from the westward extension error, which causes the poor west Pacific skill
- The fact that a simple empirical model (the Linear Inverse Model, LIM) does not have this westward extension suggests that this is not simply a predictability issue, but that it is a model deficiency

Leading EOF of observations and month 6 forecasts (SST)



From Newman and Sardeshmukh (2017)

Aims

- We know these errors exist in seasonal forecast models and are having an impact on skill in the tropics
- Here, we perform a systematic evaluation to determine:
  - How much of these errors are related to ENSO
  - How rapidly the errors are developing
  - How the errors develop spatially
  - If there are any indications of where the errors are first developing (atmosphere vs ocean)

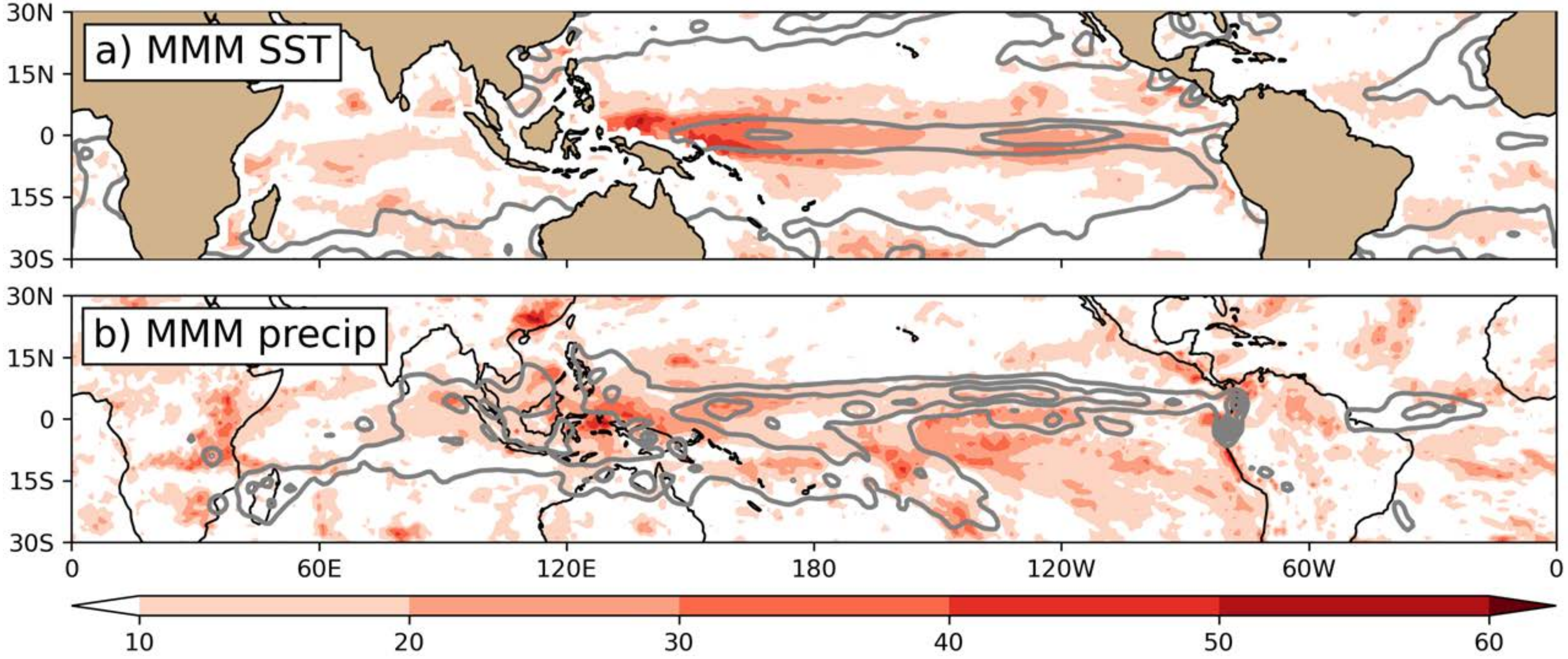
Models and data

- We analyse seasonal hindcasts from eleven models:
    - ECMWF SEAS5 (1981-2016)
    - DWD GCFS2.1 (1993-2019)
    - ECCC CanCM4i (1993-2019)
    - ECCC GEM5-NEMO
    - CMCC SPS3.5 (1993-2016)
    - GFDL-SPEAR (1991-2020)
    - NASA GEOS-S2S (1982-2016)
    - UKMO GloSea6-GC3.2 (1994-2016)
    - MeteoFrance System 8 (1993-2018)
    - NCEP CFSv2 (1993-2016)
    - JMA CPS3 (1993-2016)
- We look at eight different initialisations (Jul, Aug, Sep, Oct, Nov, Dec, Jan, Feb)
- Models are a mix of first-of-the-month initialisation and lagged ensemble, and are run for approx. 6 months
- All models have had their mean bias removed

ENSO explains a large percentage of SST and rainfall error variance:

- ENSO explains >20% of the error variance in much of the tropical Pacific, and up to 50% in the west Pacific (higher in individual models)
- Rainfall variance explained is slightly less, but still >40% in the west Pacific
- Therefore errors in SST and rainfall in the tropical Pacific are strongly linked to ENSO

October initialisation, DJF mean



Shading = Error variance explained by the observed Niño3.4 index
Grey contours = Variance of model error in each variable

Methods

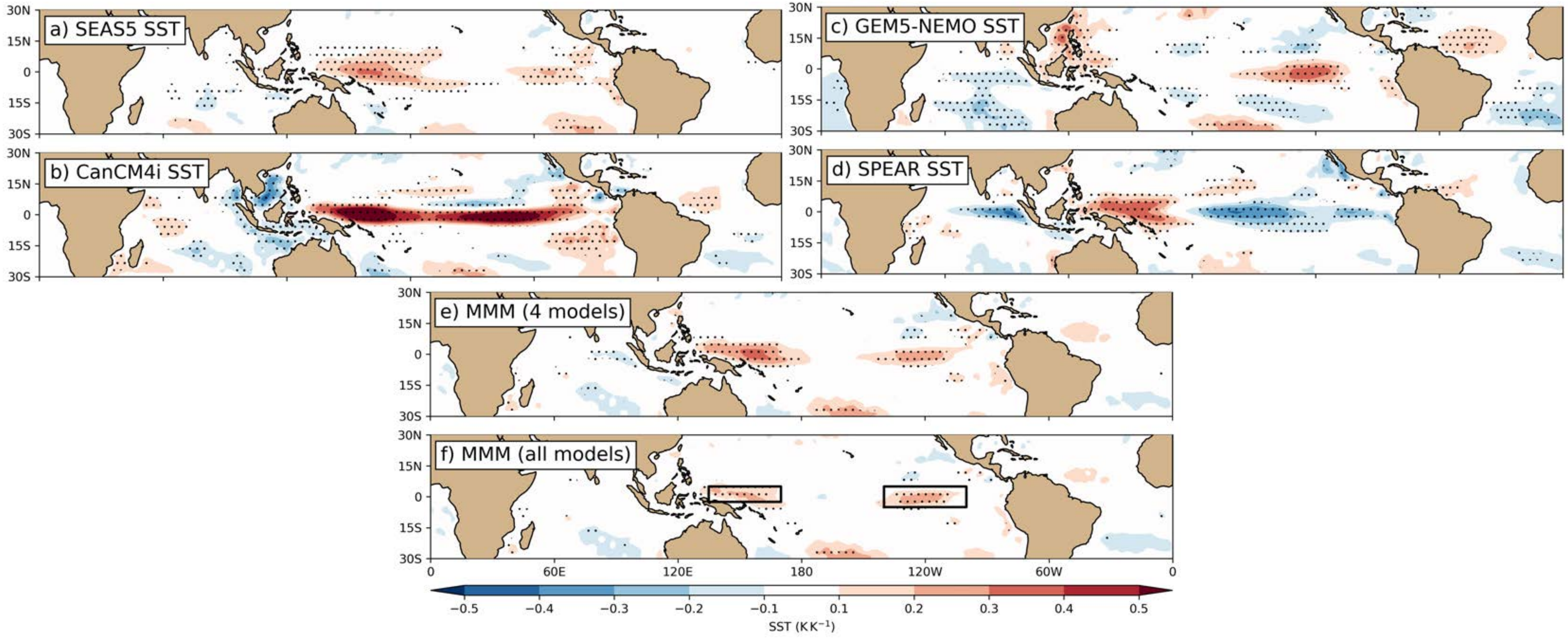
- We are interested in the part of the error that is related to ENSO, so we regress the error in a particular variable (model minus reanalysis) against the observed Niño3.4 Index (from ERA5) – we refer to this as the “ENSO-related error”
- Plots may be viewed as showing the El Niño error; for the La Niña error, flip the sign

There are systematic errors in SST related to ENSO:

- ENSO-related SST errors are apparent in all models in the tropical Pacific (representative examples shown below)
- In the west Pacific, these correspond to either a westward extension (e.g. SEAS5) or westward shift (e.g. SPEAR) of ENSO SST anomalies

Regression of **October initialisation** DJF SST error against the observed Niño3.4 index

Stippling indicates 95% significance

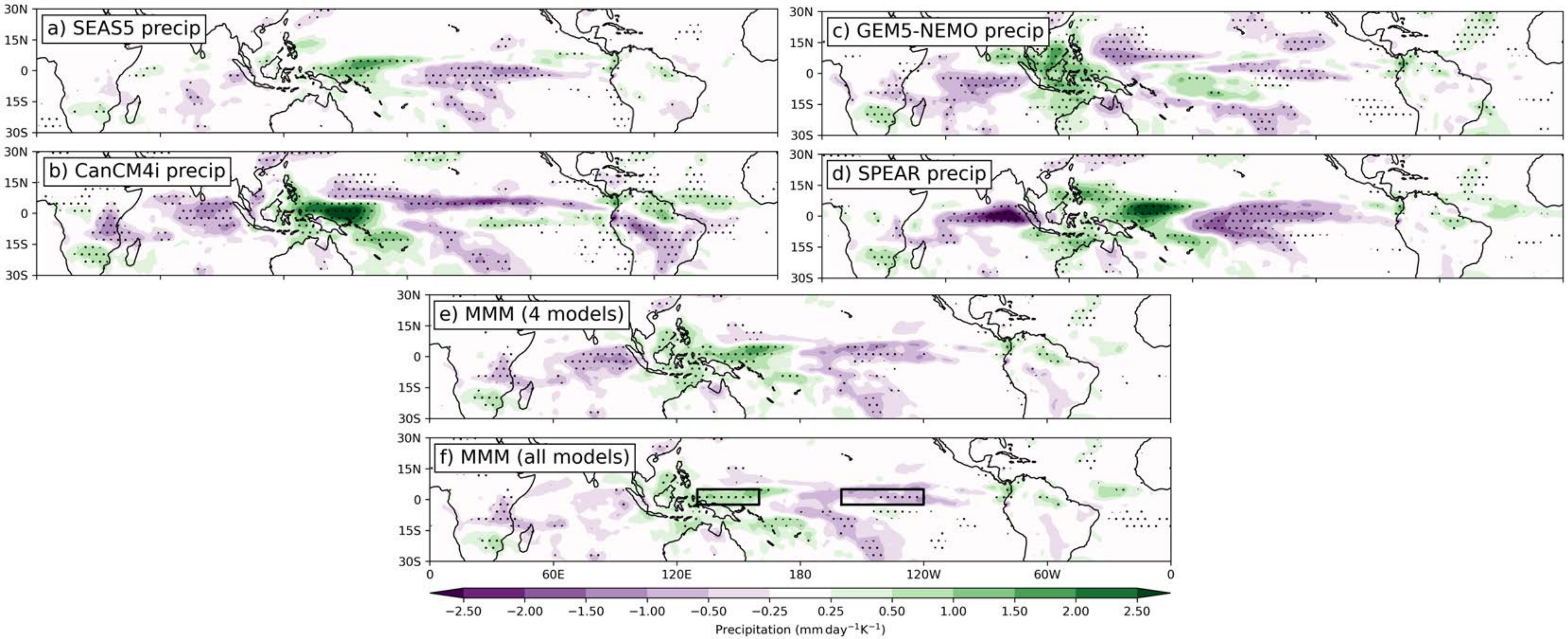


These SST errors have an impact on tropical rainfall errors:

Regression of **October initialisation** DJF precip error against the observed Niño3.4 index

Stippling indicates 95% significance

- These ENSO-related SST errors result in an overall westward shift of ENSO tropical rainfall anomalies
- This shift is largely consistent across the different models



How does the error pattern depend on forecast lead time?

ENSO-related
SST error

Lead time

+0 months | +1 month | +2 months | +3 months

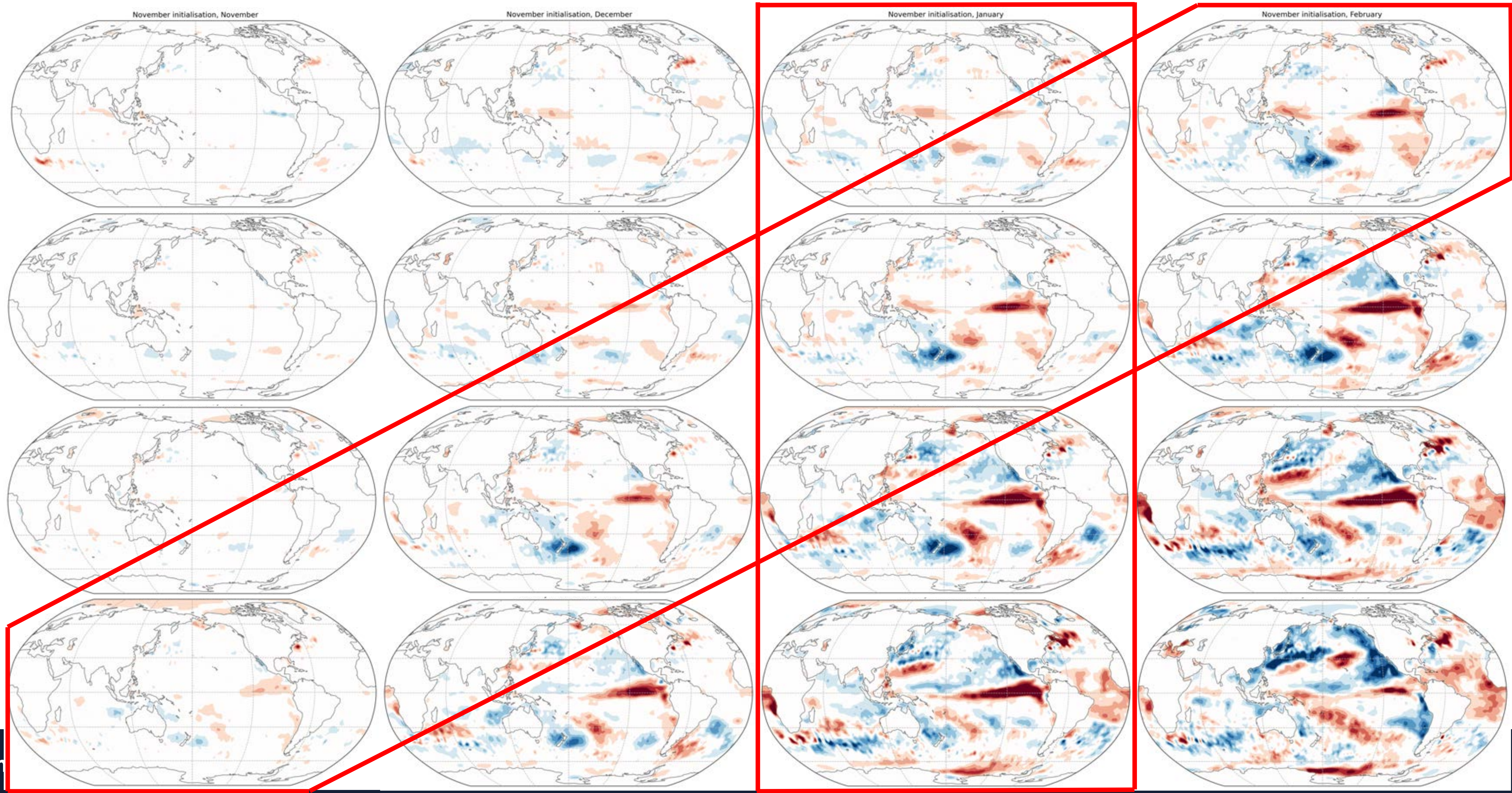
Initialisation

Nov init

Dec init

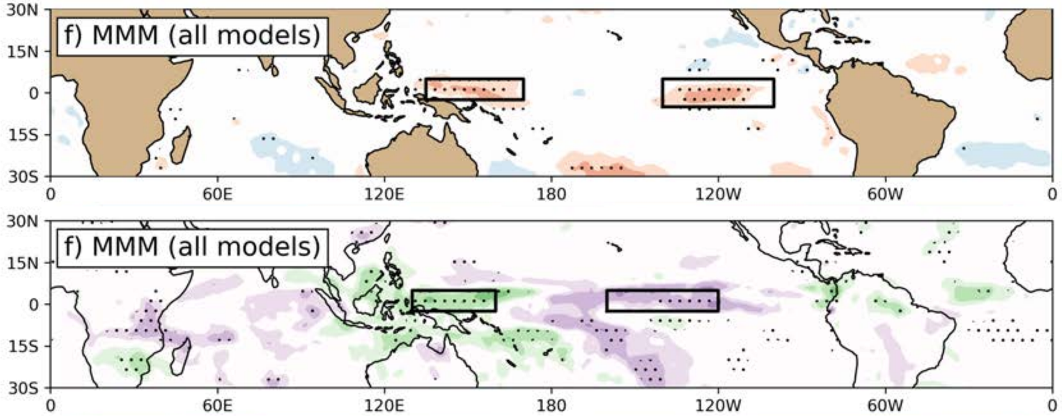
Jan init

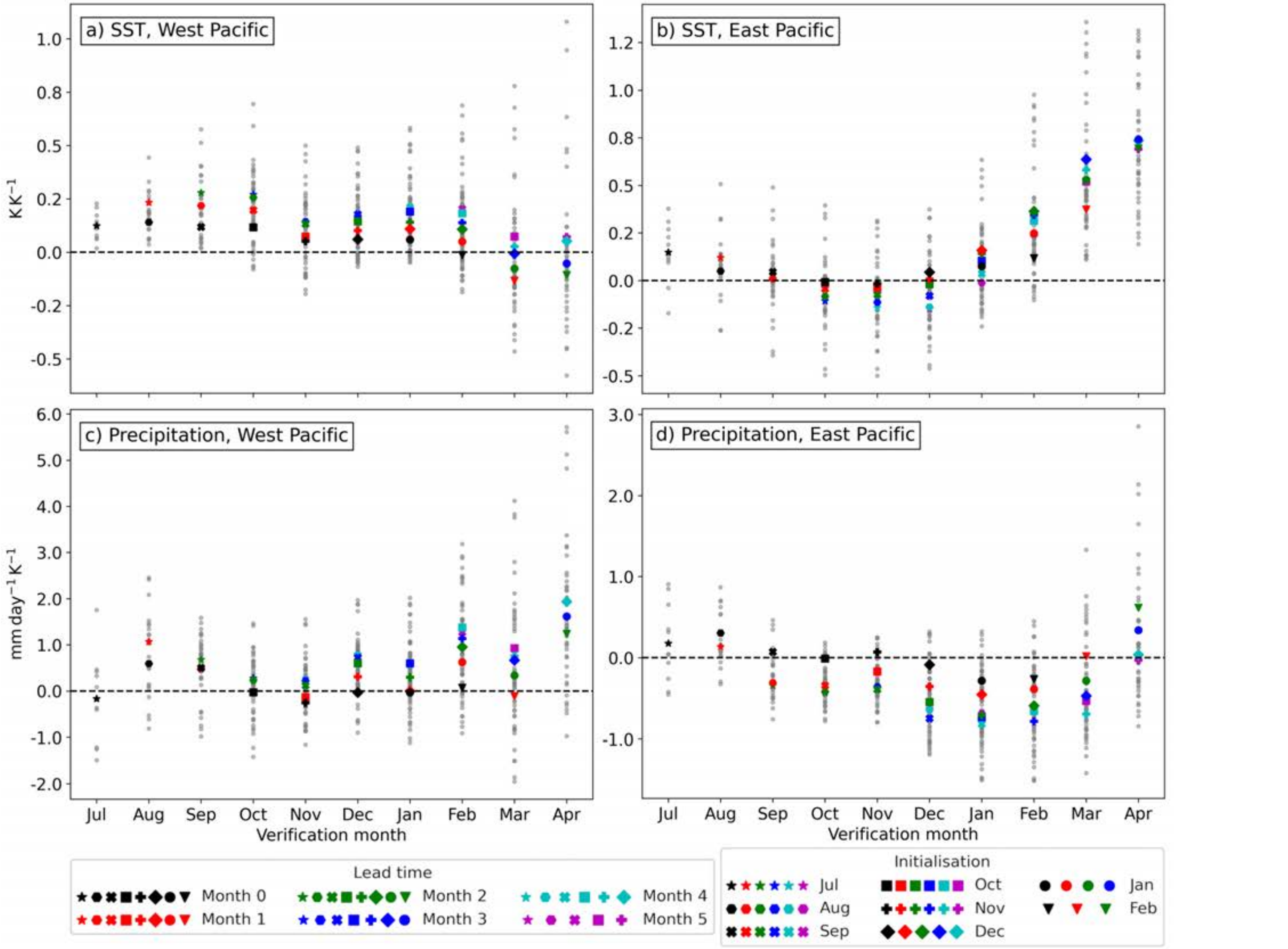
Feb init



The *magnitude* of ENSO-related error also depends mostly on verification month:

ENSO-related SST and rainfall error averaged over west and east Pacific regions



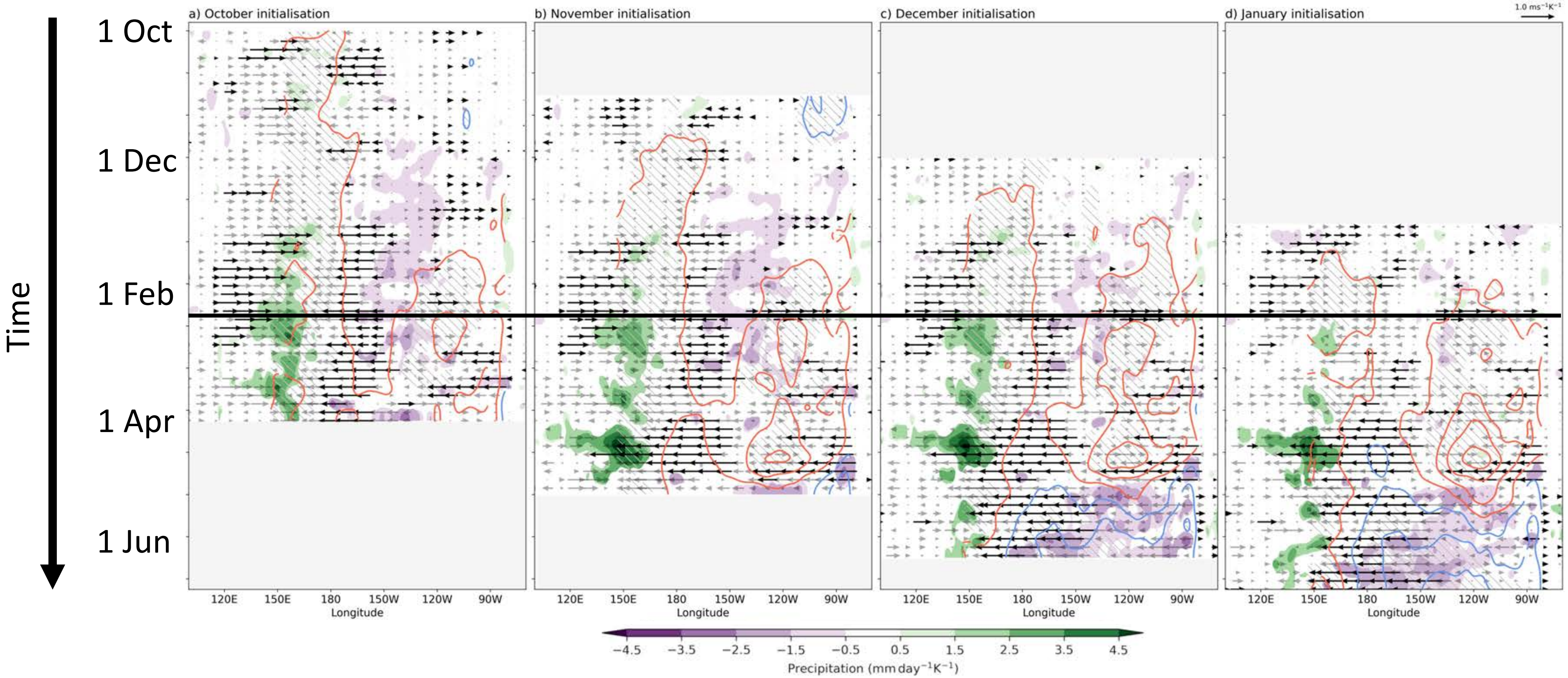


- To a certain extent, even the magnitude of ENSO-related error depends more on verification month than on lead time
- This is particularly noticeable for east Pacific SST and west Pacific rainfall

- Coloured dots: multi-model ensemble mean
- Grey dots: individual model simulations

These errors begin to develop very rapidly:

Pentad-averaged ENSO-related error for SEAS5 hindcasts



Hatching: Significant SST error

Only significant values for precip (shading) are shown. Significant 10m zonal wind vectors are black

- The ENSO-related errors in SST and near-surface zonal wind begin to develop soon after forecast initialisation (within 1—2 weeks)
- The seasonality of the error is also evident, particularly in the east Pacific

Trend errors also seem to develop rapidly:

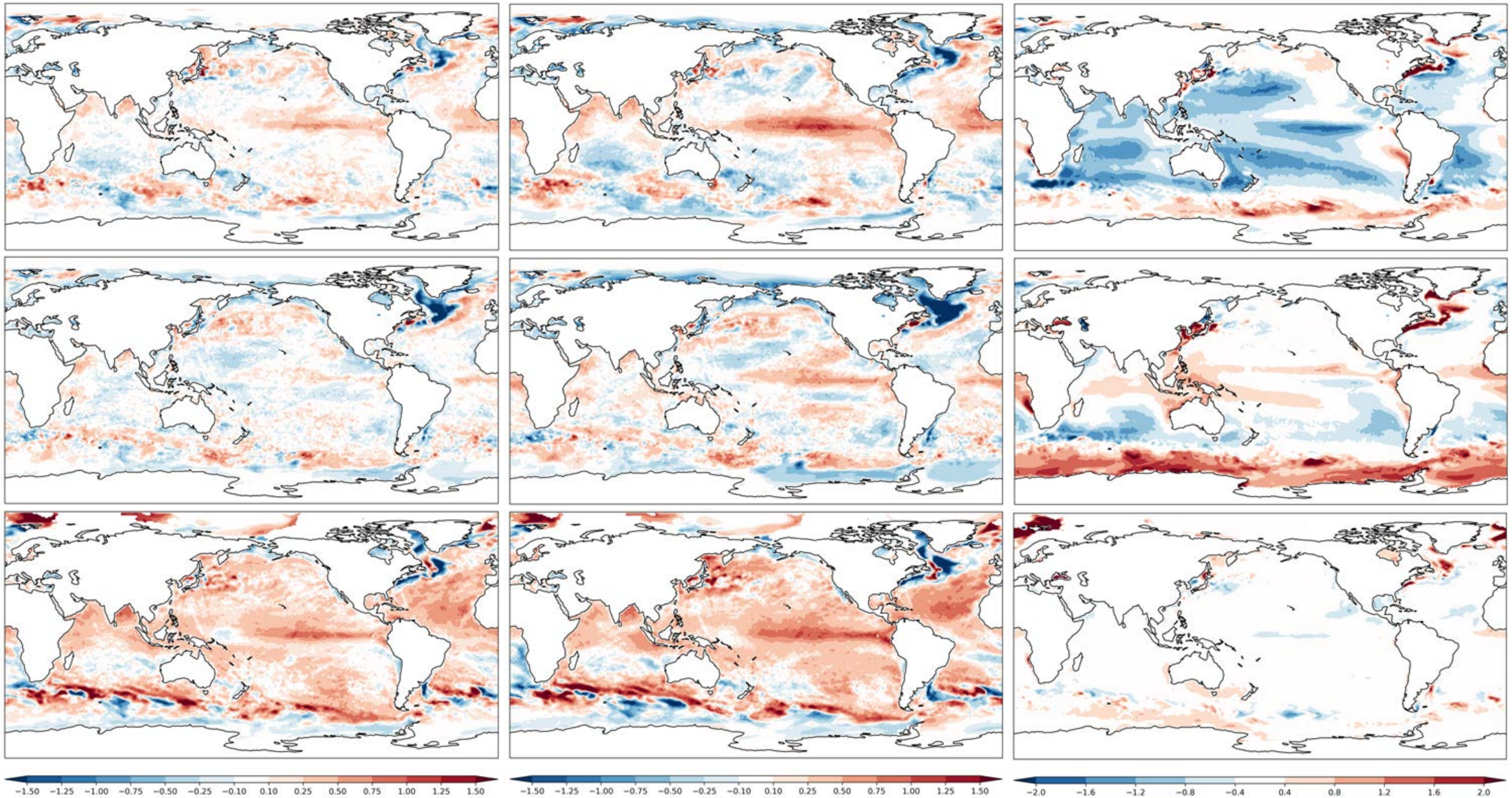
SST trend error

Month 1 | Month 5 | October initialisation DJF mean SST bias

GEM5-NEMO

SEAS5

SPEAR



- Following L'Heureux et al 2022, we've also begun looking at trend errors in these models globally
- The SST trend errors also look like the apparent historical climate model runs trend errors, and don't seem to be related to mean bias
- Trend errors may depend more on lead time, though

Summary

- Seasonal forecasts have errors related to ENSO:
    - ENSO SST anomalies are shifted or extended too far to the west
    - ENSO events persist for too long in the models
- The errors develop so rapidly (within the first fortnight following hindcast initialisation) that they become a function of the seasonal cycle, rather than lead time – they quickly transition from the initialised forecast space to the climate model space
- This suggests both that we might be able to understand forecast errors in terms of the climate model errors, and we might be able to diagnose the climate model errors by looking at the early development of the forecast error

Beverley J. D., M. Newman and A. Hoell, 2023: Rapid development of systematic ENSO-related seasonal forecast errors. *Geophysical Research Letters, 50, e2022GL102249*