Using seasonal forecasts as a tool to diagnose coupled model ENSO errors

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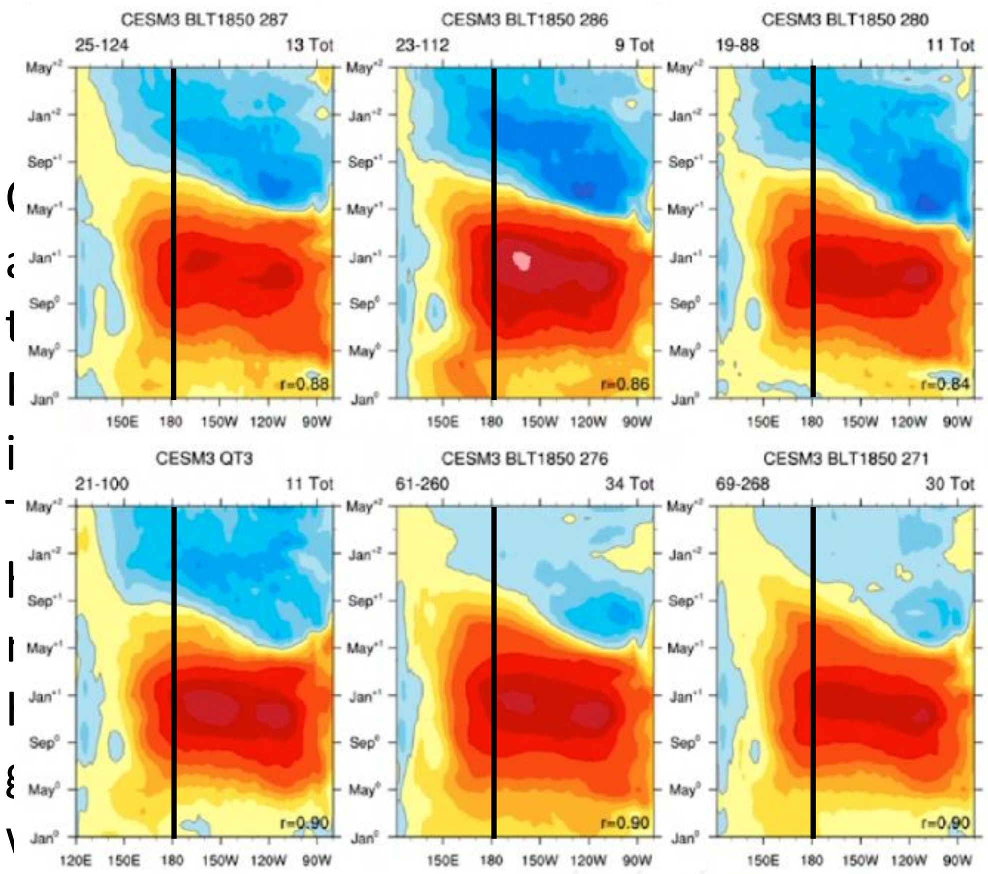
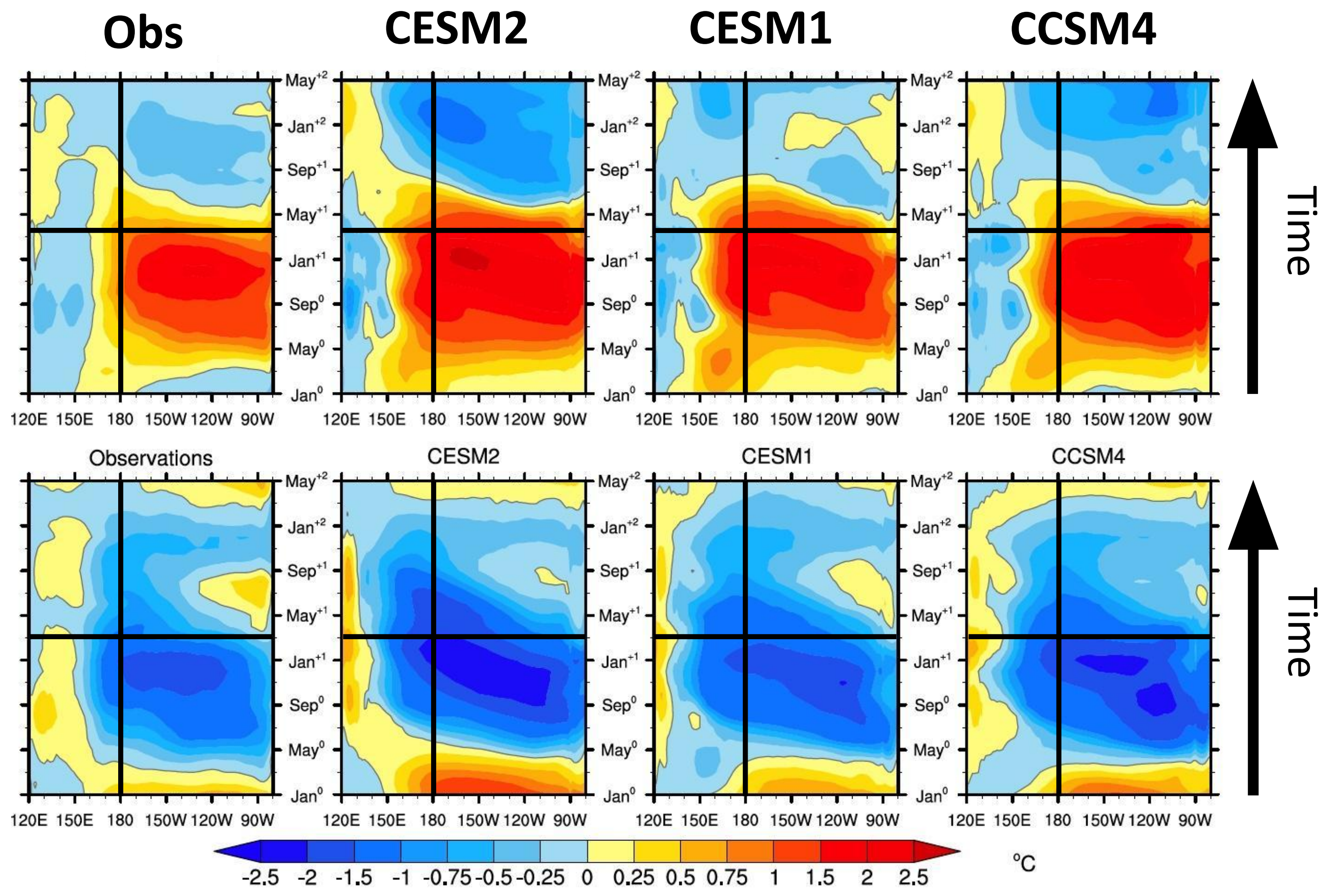
Systematic ENSO errors have persisted through multiple generations of climate models, from CMIP3 through to more recent model versions:

From Isla's talk yesterday:



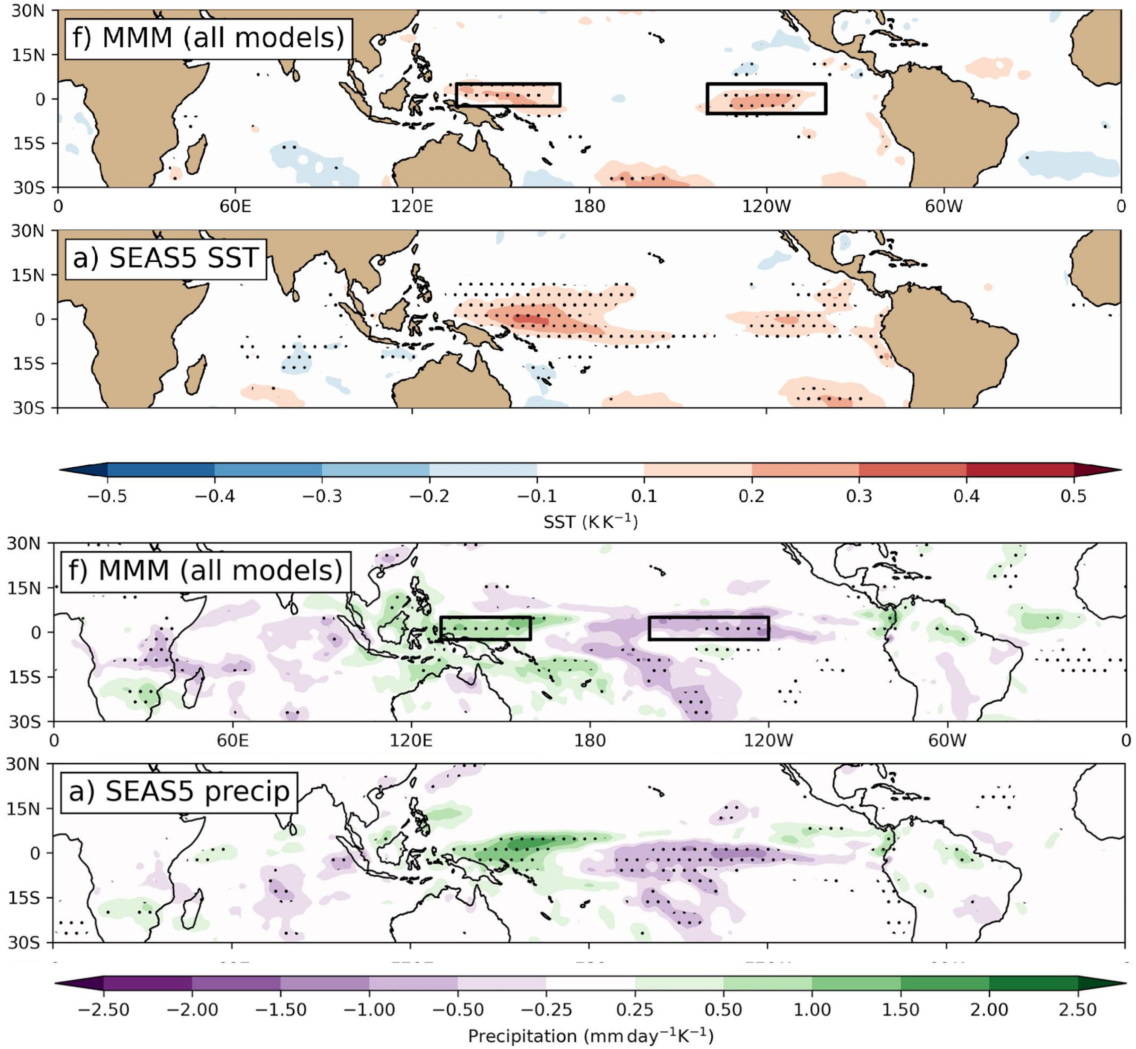


other?

From Capotondi et al 2020

These same ENSO errors are also present in seasonal forecasts:

- Models systematically extend or shift ENSO anomalies to the west
- Errors in the east Pacific are related to ENSO phasing
- The errors develop rapidly, within two weeks of forecast initialisation, and quickly lock to the seasonal cycle
- ECMWF SEAS5, which we focus on here, is very representative of models as a whole



Regression of error against observed Nino3.4 Index

From Beverley et al 2023

Key points

Today, I will show that:

- Seasonal forecast model errors in the surface wind field **develop almost immediately in response to the initial (observed) SST field**

- In the coupled system, these **erroneous winds drive westward extension of ENSO SSTs** through surface latent heat flux and wind stress errors

- This **coupled error develops within one month**, as the model gradually adjusts to its ENSO phase space, after which the initial flux errors diminish

Models and data

- We analyse seasonal hindcast data from the ECMWF SEAS5 model:
  - One fully coupled hindcast experiment
  - One uncoupled hindcast experiment, which uses prescribed (observed) SSTs, in which the atmosphere is free to evolve
  - Both have 25 members, we show on the ensemble mean
- We focus on an initialisation from the growth, mature and decay phases of ENSO events (August, November and February initialisations)
- Hindcast years are 1993-2016
- Reference datasets are ERA5 for SST and atmospheric variables, and ORAS5 for sea surface height (SSH)

Methods

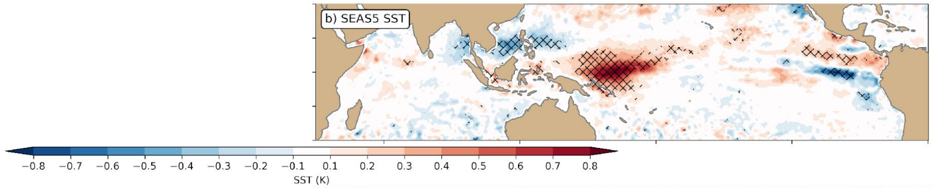
- We are interested in the "ENSO-related" systematic error
- We compute the error in a given variable (model minus reanalysis) and calculate a **warm minus cold** ENSO composite of these errors
- We focus on errors in the first two months after hindcast initialisation

The initial westward shift error appears to be atmospherically driven:

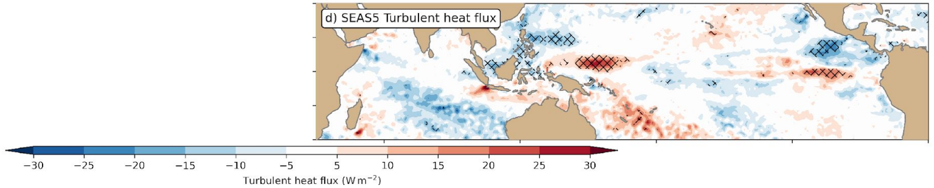
Observed SST hindcasts | Fully coupled hindcasts

August initialisation, August-September verification: warm minus cold errors

SST



Turbulent heat flux



SSH

Surface wind stress

Precip

Shortwave radiation

Shortwave and precip errors are largely reduced in the west Pacific in the uncoupled, suggesting that these are **more directly driven by SST here**

The initial westward shift error appears to be atmospherically driven:

November initialisation,
November-December verification:
warm minus cold errors

Observed SST hindcasts | Fully coupled hindcasts

SST

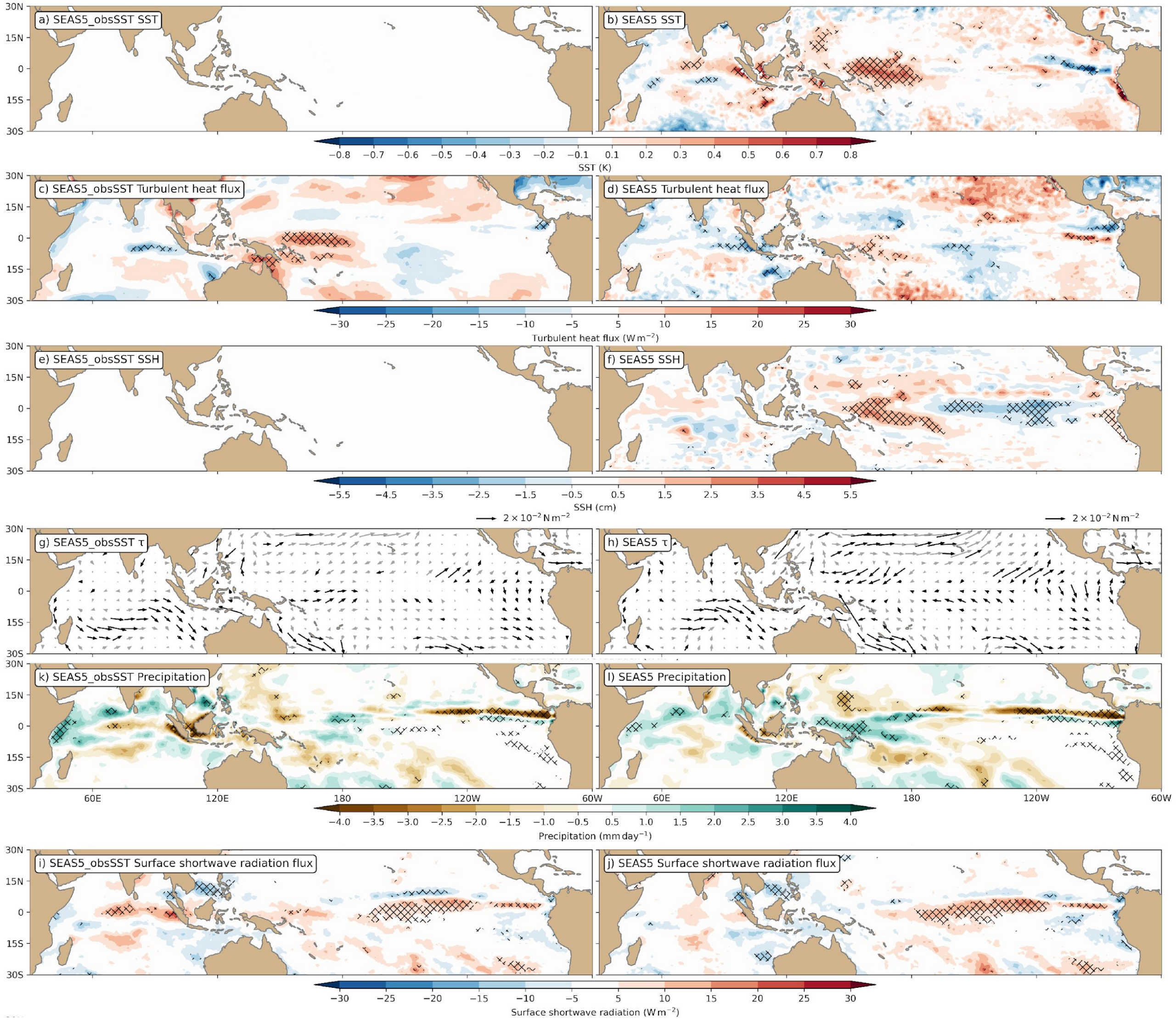
Turbulent heat flux

SSH

Surface wind stress

Precip

Shortwave radiation



The initial westward shift error appears to be atmospherically driven:

February initialisation, February-March verification: warm minus cold errors

Observed SST hindcasts | Fully coupled hindcasts

SST

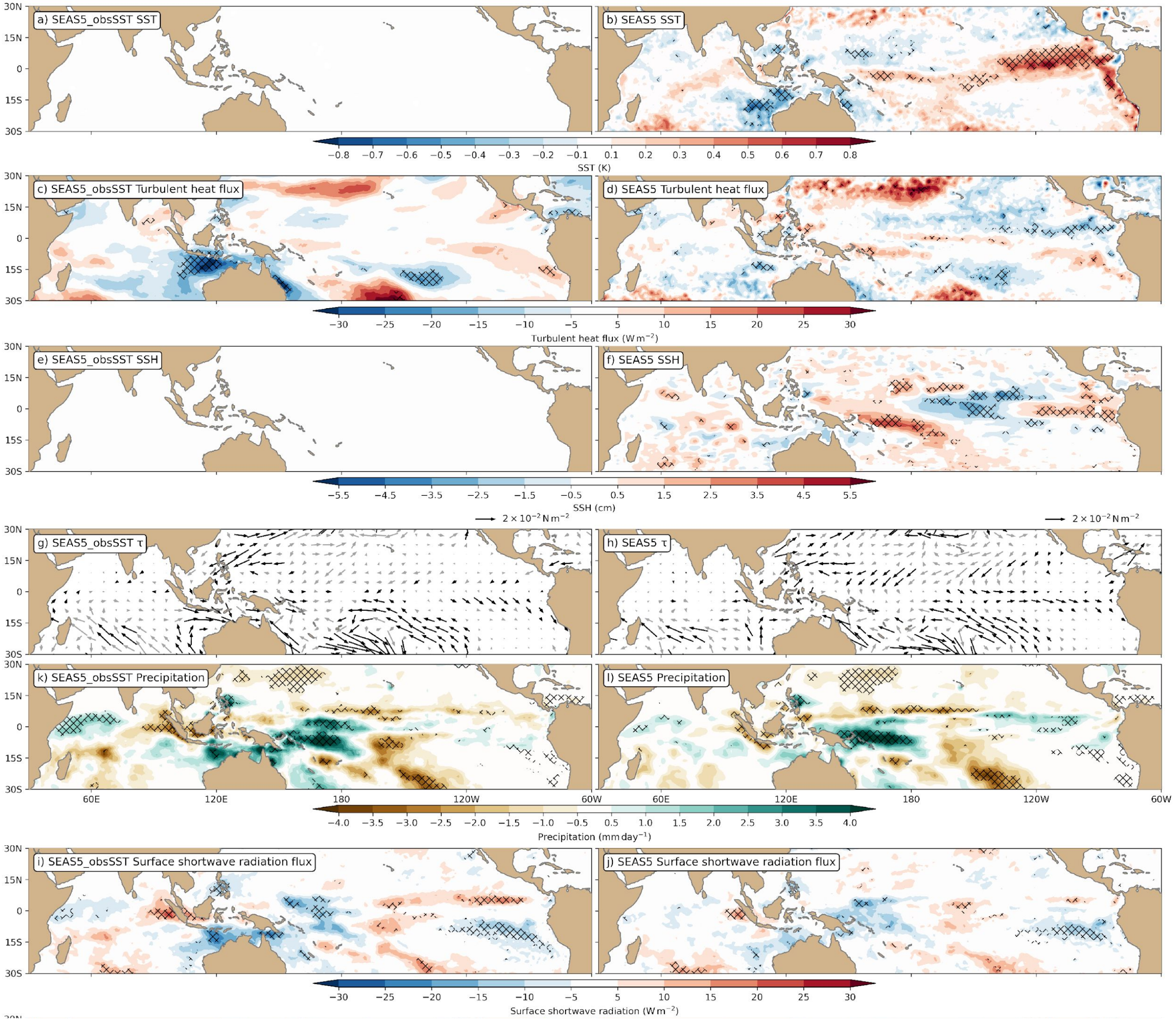
Turbulent heat flux

SSH

Surface wind stress

Precip

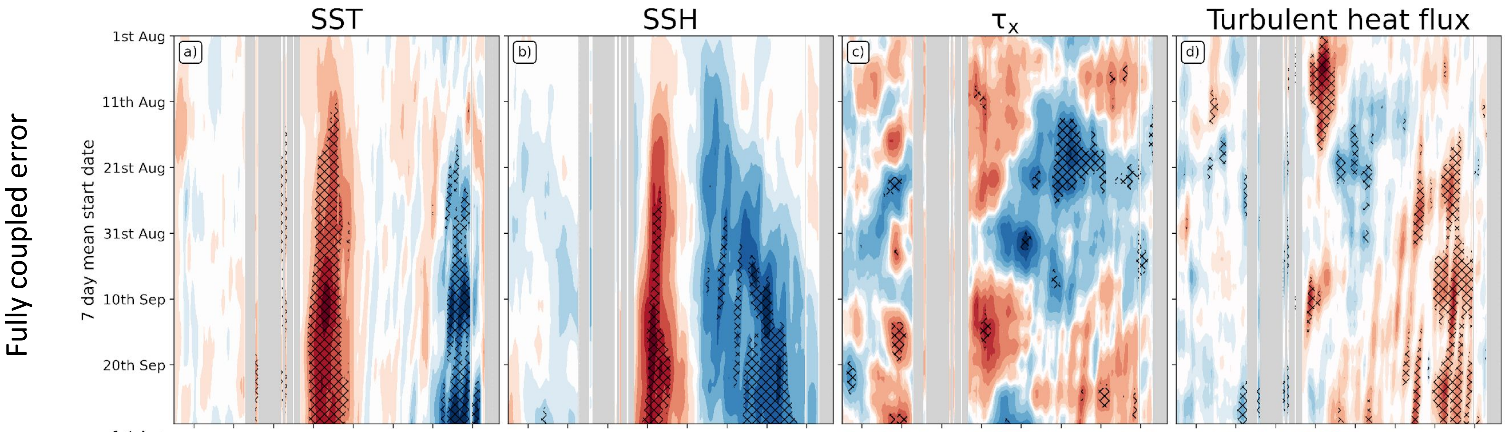
Shortwave radiation



Errors develop almost immediately; coupled error takes ~2-3 weeks:

- **Errors in all variables develop rapidly** in both coupled and uncoupled hindcasts
- Initial **surface wind errors drive heat flux errors which warm the ocean** in the coupled hindcasts, but then subsequently reduce as the model adjusts
- Initial imbalance between atmosphere and ocean also seems to excite an eastward-propagating Kelvin wave
- Errors in coupled and uncoupled hindcasts are similar for the first 2-3 weeks, but then diverge as the uncoupled model ocean is unable to adjust

7 day running means, August initialisations



Latent heat flux errors are almost entirely driven by ENSO-related wind errors:

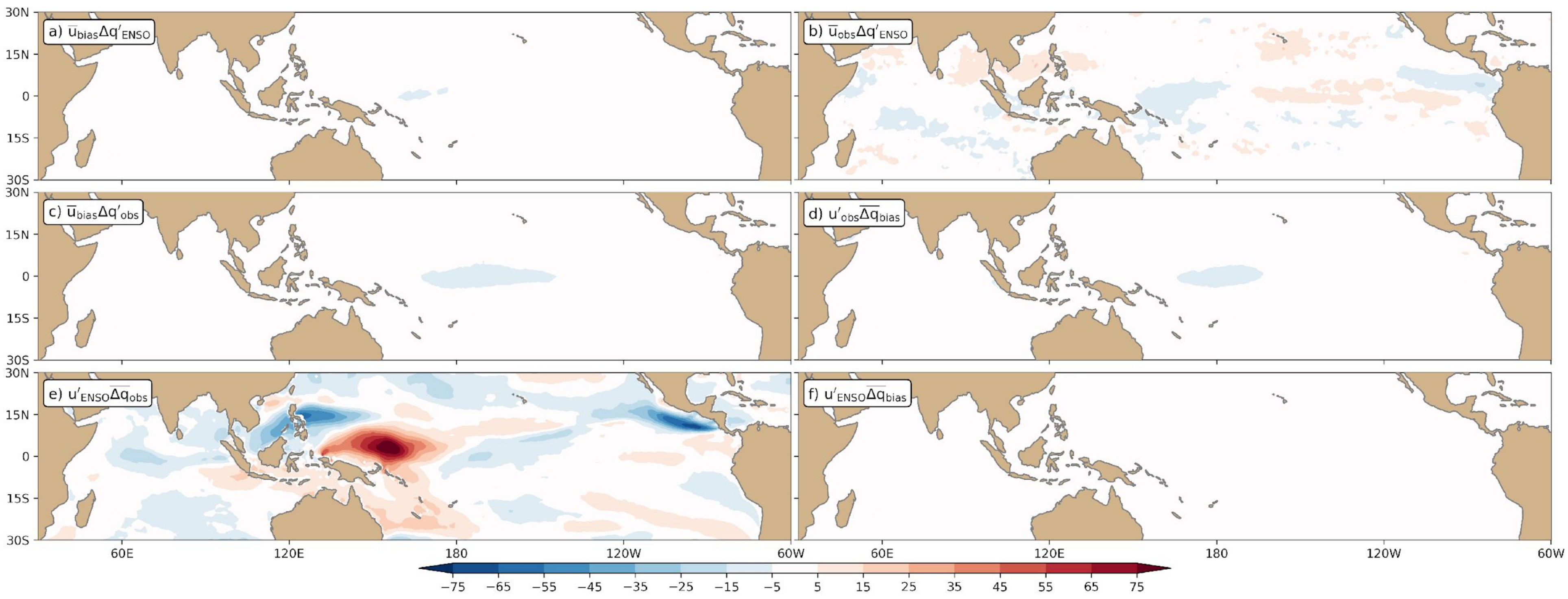
$\bar{u}_{bias}, \overline{\Delta q}_{bias}$ = Mean biases

$u'_{ENSO}, \Delta q'_{ENSO}$ = ENSO-related errors

$u'_{obs}, \Delta q'_{obs}$ = Observed ENSO anomalies

$\bar{u}_{obs}, \overline{\Delta q}_{obs}$ = Observed means

- **We break the latent heat flux down into mean bias, ENSO-related error, observed ENSO anomaly and observed mean terms**
- **Almost all of the latent heat flux error is due to the ENSO-related wind error, rather than mean biases**



Summary

- The **initial westward shift of ENSO SST anomalies seems to be driven by the atmosphere**, which immediately responds incorrectly to the initial observed ocean
  - Surface wind errors drive turbulent heat flux errors, which lead to an erroneous westward extension of ENSO anomalies
  - Wind errors also drive wind stress errors, which appear to excite an erroneous eastward-propagating Kelvin wave, resulting in a delayed impact on SSTs in the far eastern tropical Pacific
- In the coupled hindcasts, **the model gradually adjusts due to a coupled response between atmosphere and ocean**, as the model moves towards its ENSO phase space
  - The uncoupled model is kept out of balance, resulting in larger wind and turbulent heat flux errors, as the atmosphere tries to warm the ocean
- We suggest that **climate models should also be run as forecast models**, and include **parallel coupled/uncoupled hindcasts** to aid error attribution and model development
  - Determining the cause of an error is more difficult in a coupled system in which errors feed back on each other, thus changing the model climate and the nature of the errors
- Why do the surface winds respond incorrectly to the observed ENSO SST anomaly?