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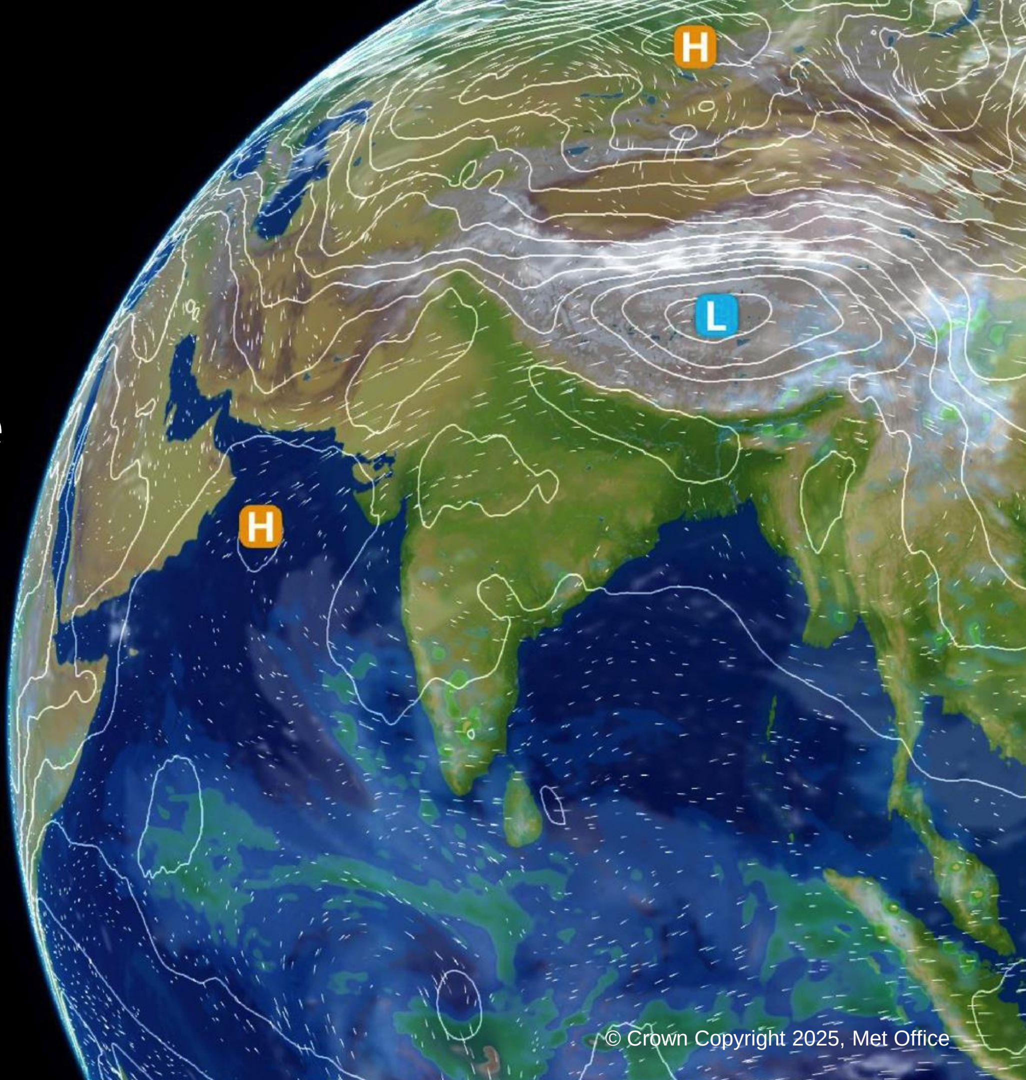
Using regional relaxation experiments to understand the development of errors in the Asian Summer Monsoon

Gill Martin & José M. Rodríguez

Eighth International Workshop on Monsoons
Pune, India, March 2025

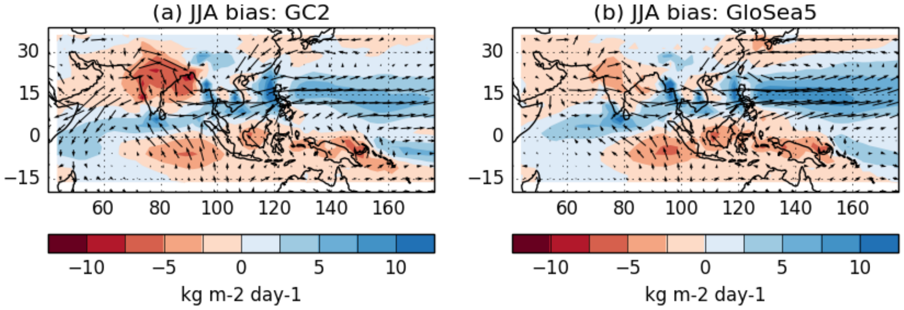


Background

ASM biases develop rapidly after initialisation to resemble, or even exceed, long-term systematic errors within a few days

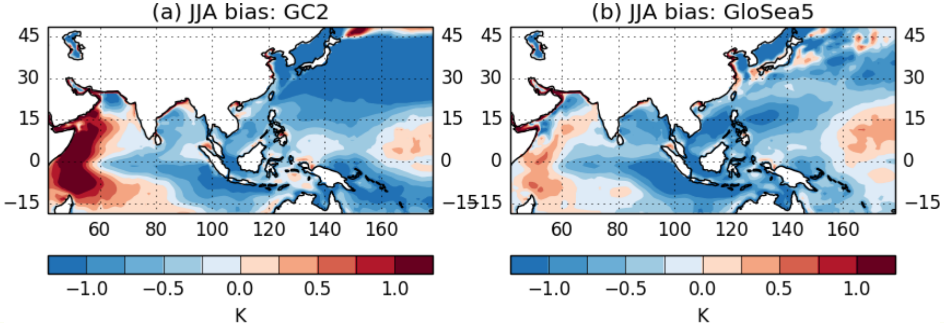
850 hPa wind & rainfall errors

Climate simulation — Seasonal hindcast



Sea surface temperature errors

Climate simulation — Seasonal hindcast



Martin et al. (2021) showed:

- anomalous divergence over the Maritime Continent, with deficient precipitation and cooling SSTs, develops soon after initialisation;
- southerly anomalies into the South China Sea develop into westerly anomalies that form the southern flank of an anomalous cyclonic pattern over the W Pacific;
- anticyclonic anomalies develop over India rapidly after initialisation;
- a SST & rainfall dipole anomaly pattern (resembling a positive IOD) develops over the Eq. Indian Ocean, associated with anomalous southeasterlies along Sumatran coast.

Martin et al (2021), Understanding the development of systematic errors in the Asian Summer Monsoon.Geosci. Model Dev., 14, 1007-1035, https://doi.org/10.5194/gmd-14-1007-2021

GloSea5 hindcast Start dates 25th June 1993-2015

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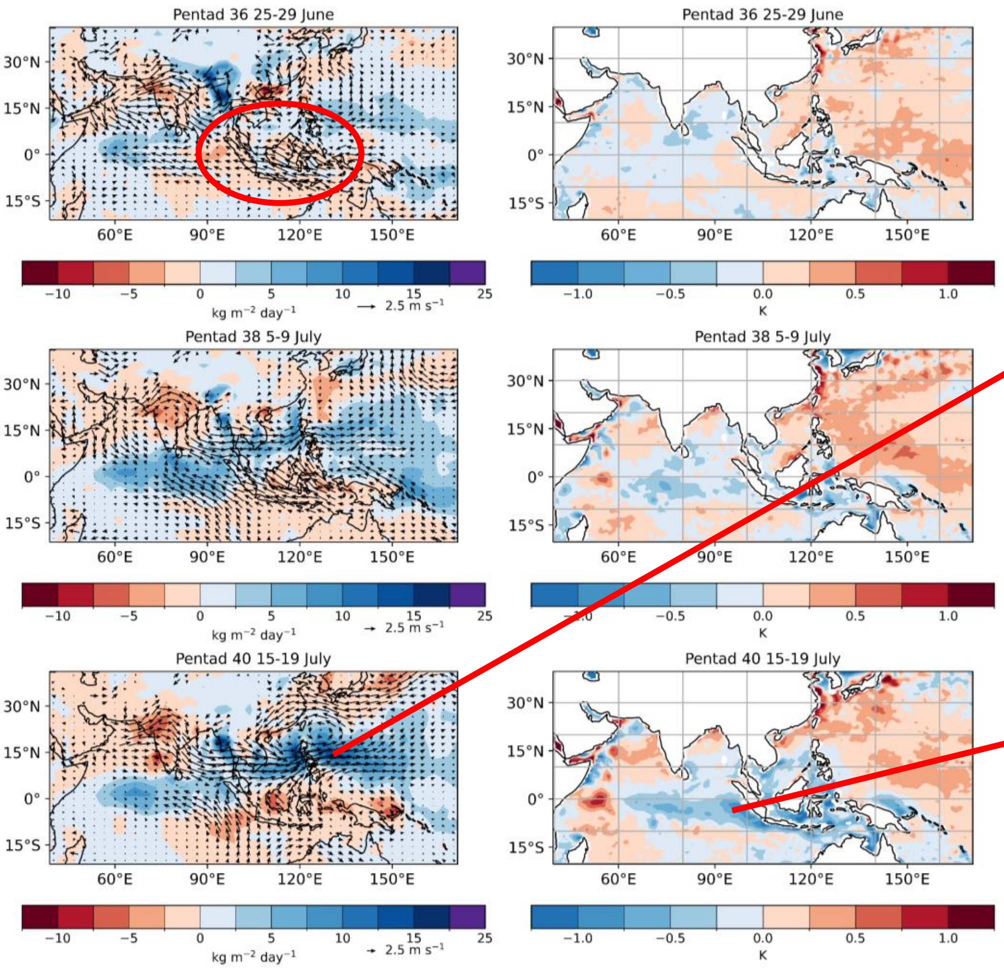
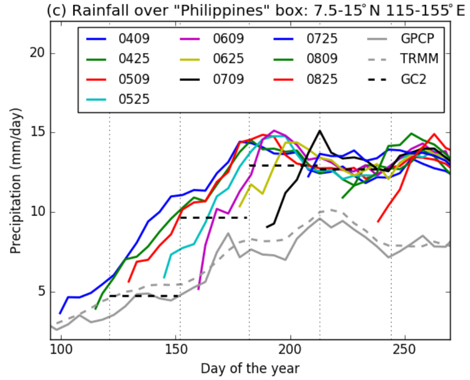
25-29 Jun

5-9 Jul

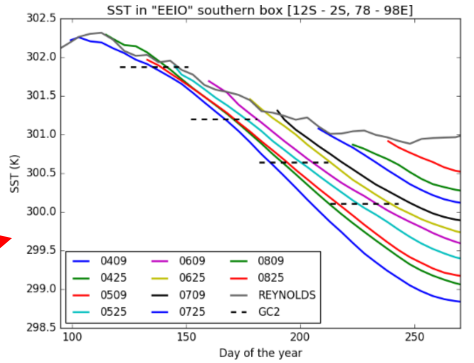
15-19 Jul



Rainfall over 'Philippines'



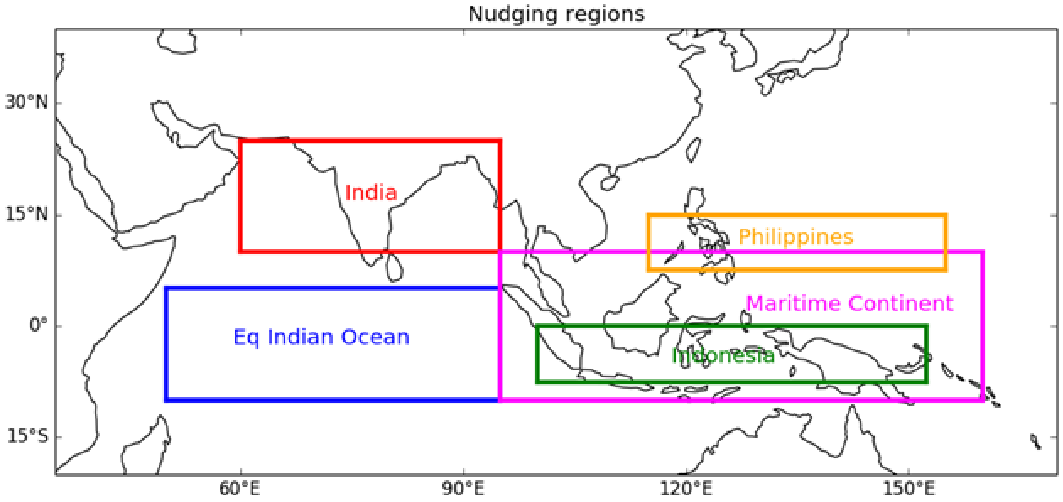
SST in EEIO



Martin et al. (2021),
https://doi.org/10.5194/gmd-14-1007-2021

Regional relaxation ("nudging") experiments

- Temperatures and winds "nudged" back to reanalyses with a 6-hourly relaxation time scale at all model levels.
- Assuming a linear response, the difference between the Control and the "Nudged" simulations then gives an indication of the role played by the nudged region in the biases that occur in the Control in other locations.
- Parallel experiments in GloSea5 hindcast ensemble and coupled NWP (José Rodriguez).



Martin and Rodriguez (2024): Weath. Clim. Dyn., 5, 711–731, https://doi.org/10.5194/wcd-5-711-2024

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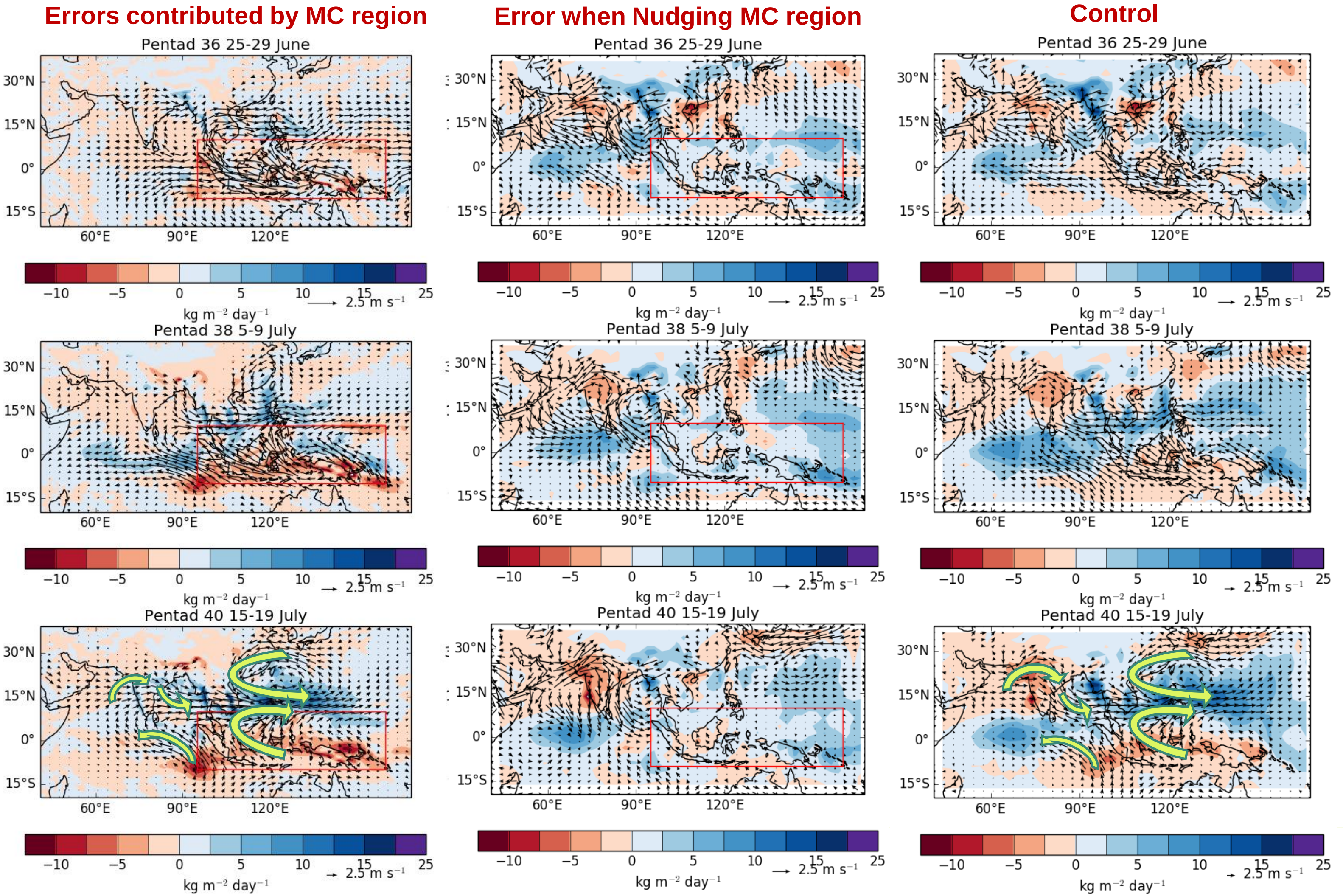
850 hPa winds and rainfall

Start dates 25th June

Nudging Maritime Continent (MC)



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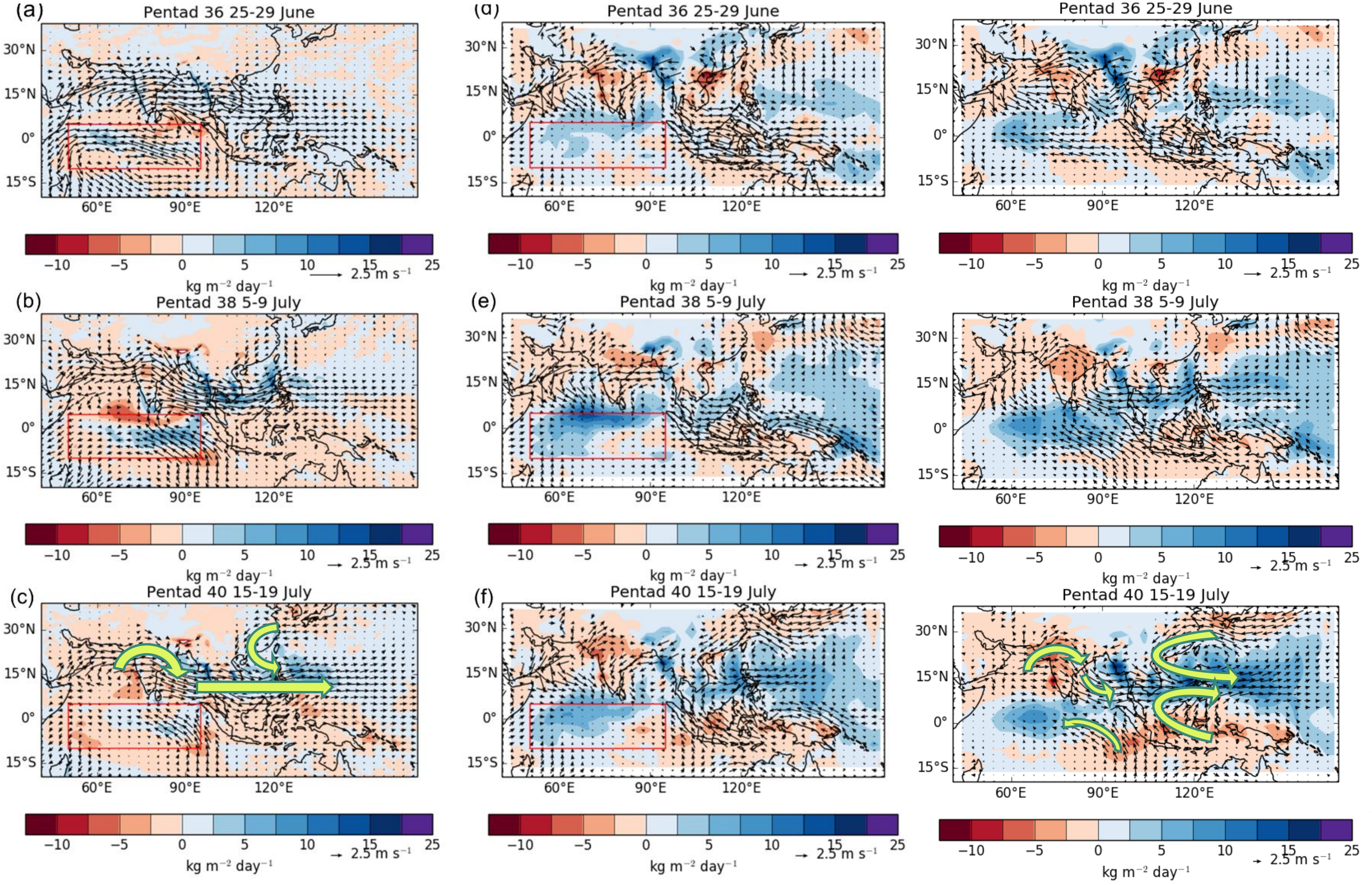
850 hPa winds and rainfall

Start dates 25th June

Nudging Eq Indian Ocean (EIO)

Errors contributed by EIO region | **Error when Nudging EIO region** | **Control**



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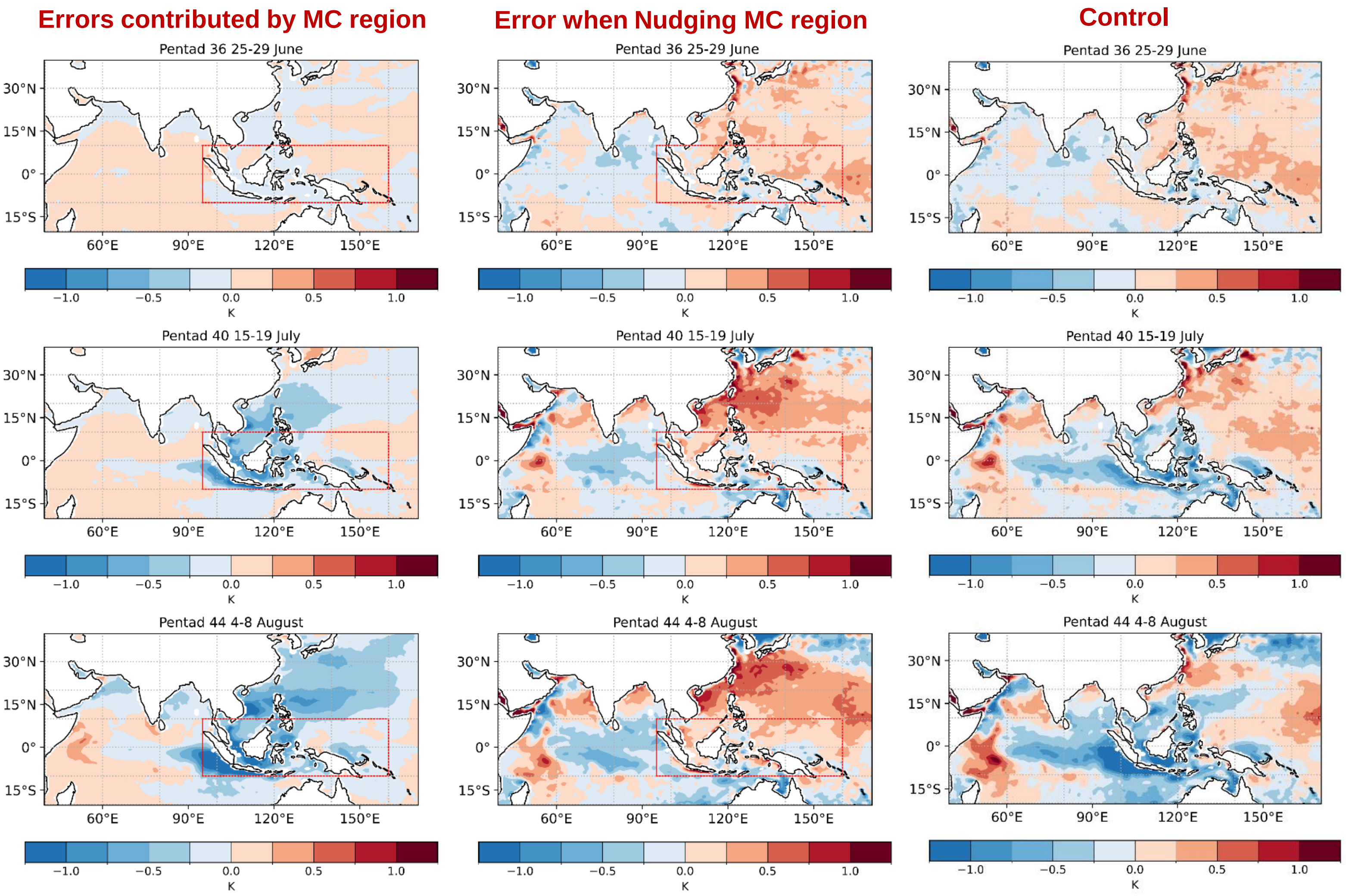
SST

Start dates
25th June

Nudging
Maritime
Continent
(MC)



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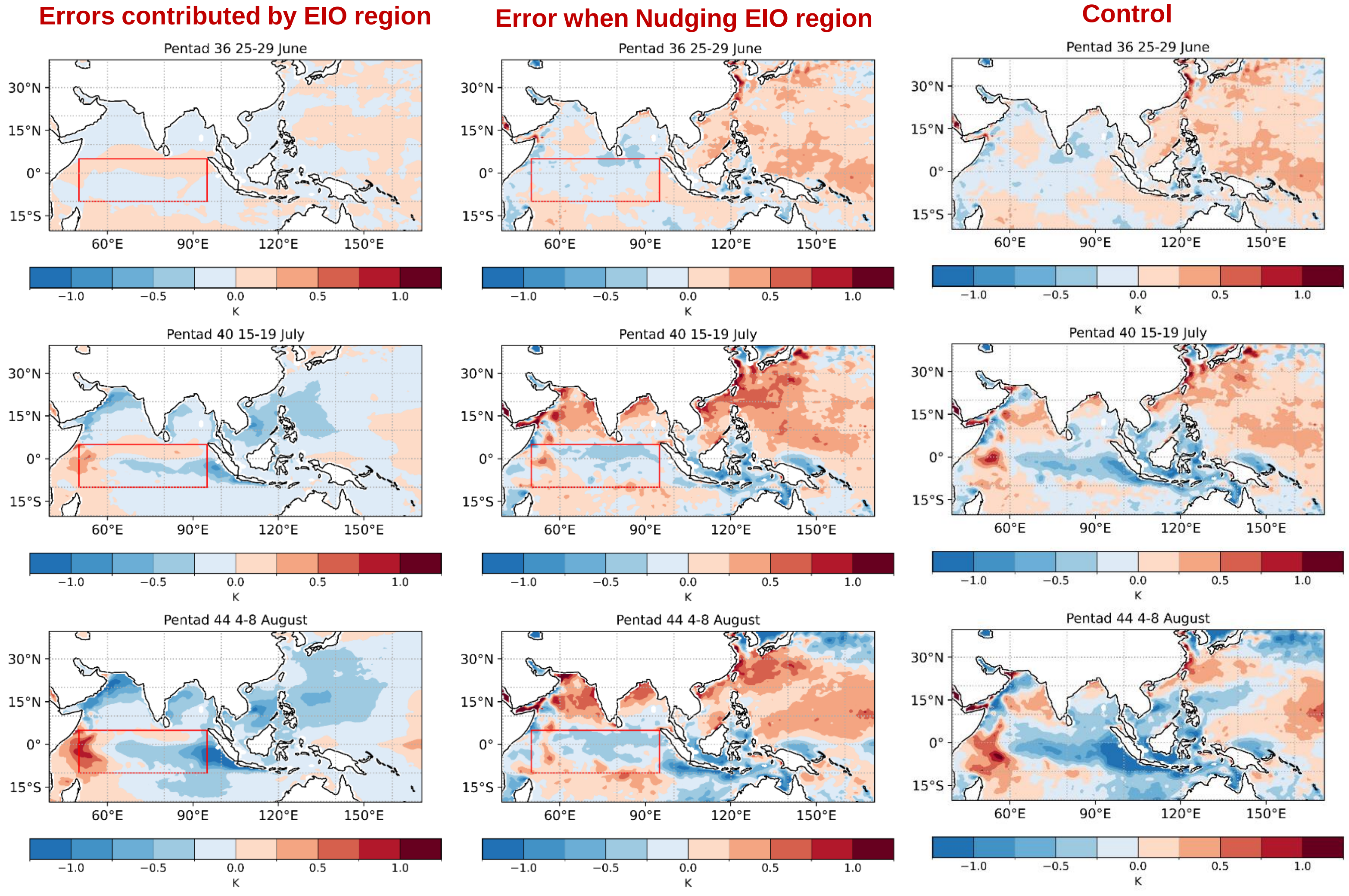
SST

Start dates 25th June

Nudging Eq Indian Ocean (EIO)



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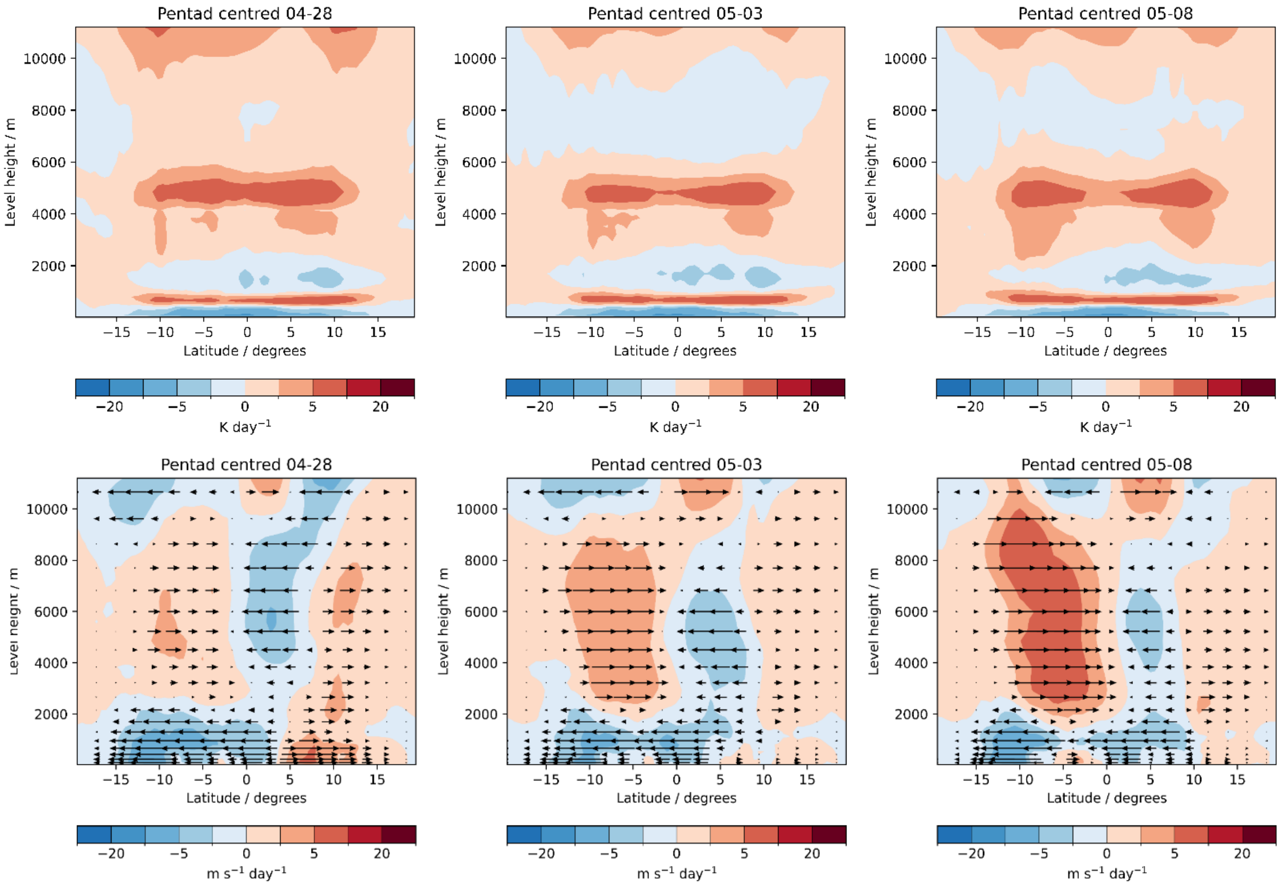
Temperature (K day^{-1})

Nudging increments for the first 3 pentads after initialisation on 25 April, averaged over 10-member ensembles and from 1993-2015.

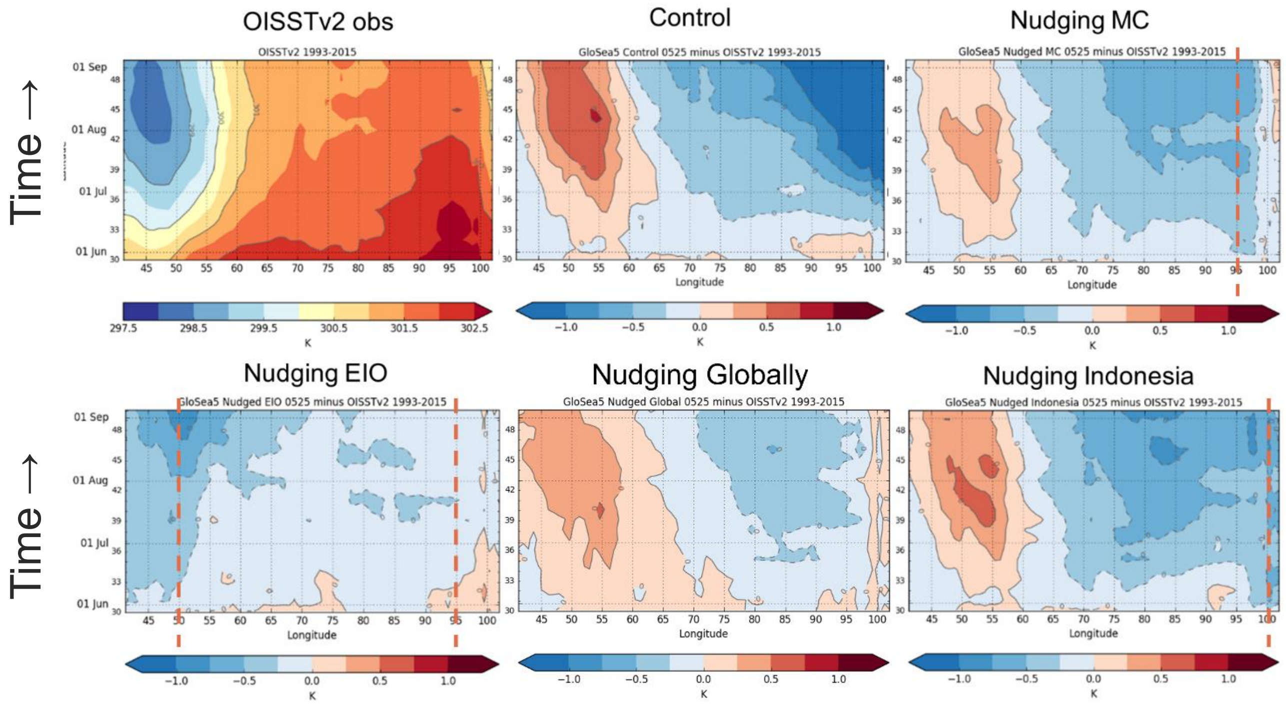
Meridional wind (m s^{-1} day^{-1})



Latitude-height cross sections across MC nudging region (95°-160°E, 10°S-10°N, with 10° damping zone on all sides).

Equatorial Indian Ocean SST errors

Correcting the circulation errors over the MC region reduces the SST dipole errors in the EIO, but there are remaining SST errors even when the global atmospheric fields are nudged back to reanalyses.



Longitude/time Hovmöller plots of SST in the EIO averaged between 10°S – 5°N in observations, Control and various Nudging runs initialised on 25 May 1993-2015.

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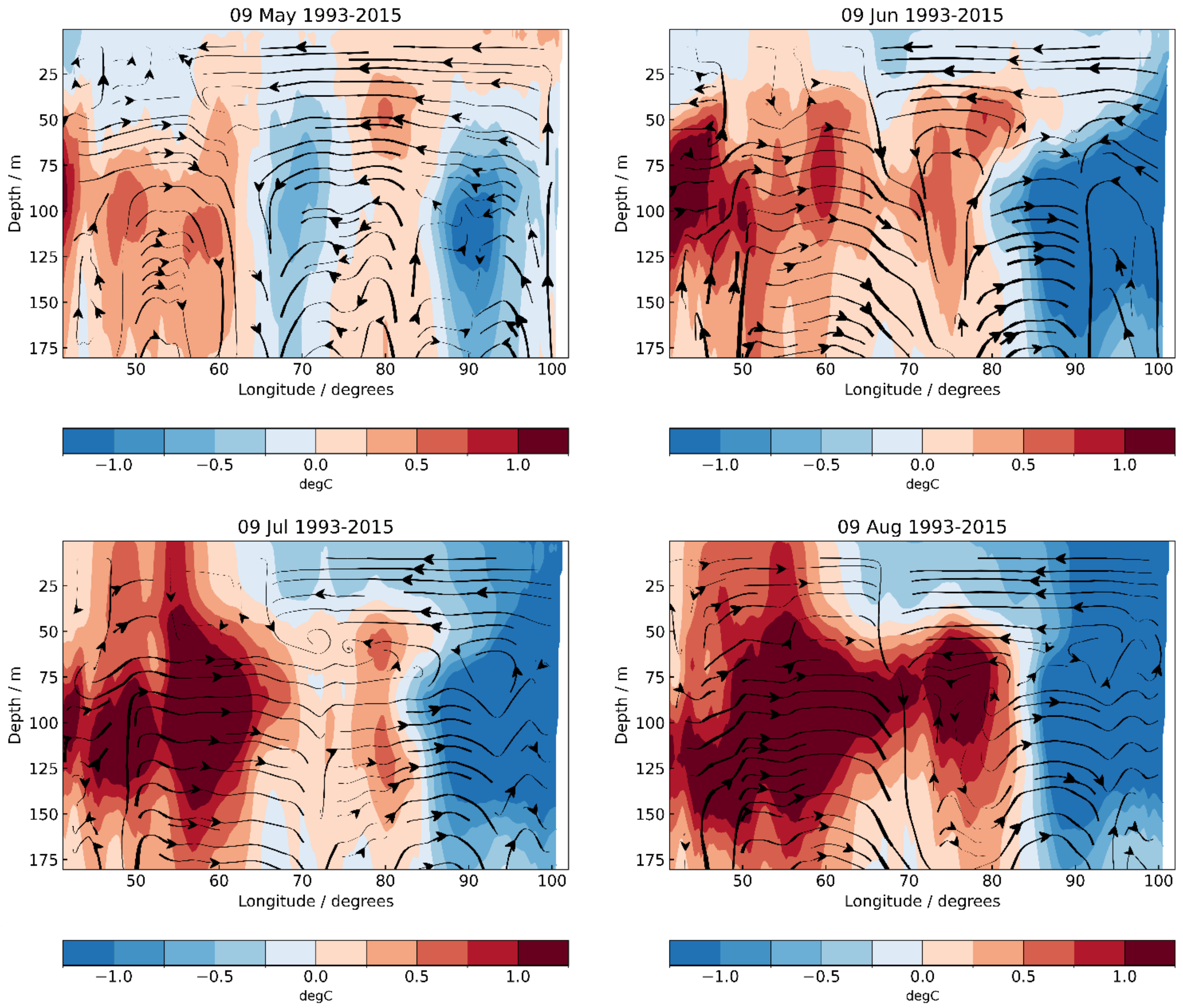
Ocean cross sections

Differences in sea water potential temperature (shaded), and upward sea water velocity and zonal current (streamlines), between GloSea5 hindcasts and ocean reanalyses at various intervals after initialisation.

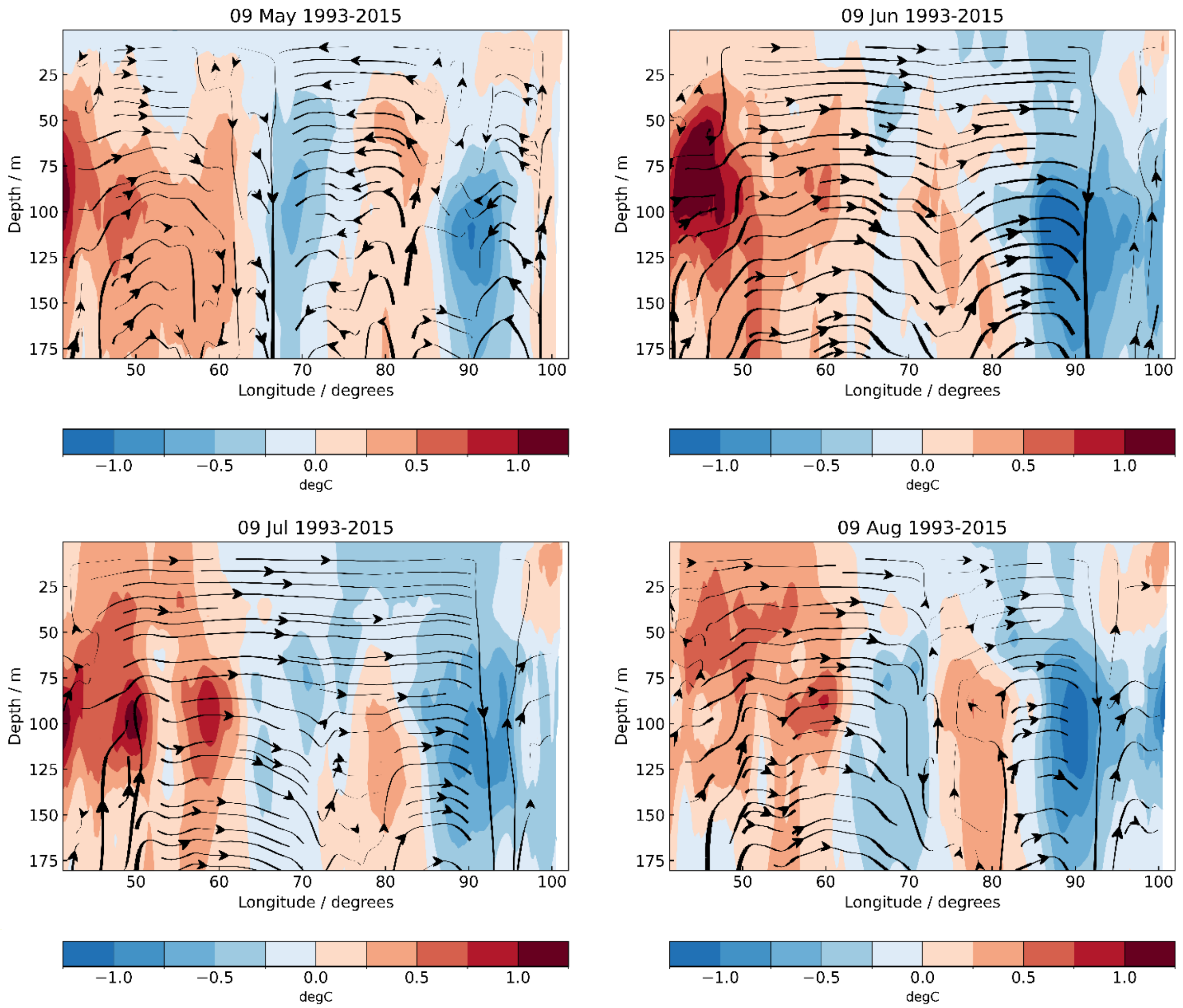
Control hindcasts initialised on 25 April 1993-2015.



Ocean cross sections

Differences in sea water potential temperature (shaded), and upward sea water velocity and zonal current (streamlines), between GloSea5 hindcasts and ocean reanalyses at various intervals after initialisation.

Globally-nudged hindcasts initialised on 25 April 1993-2015.

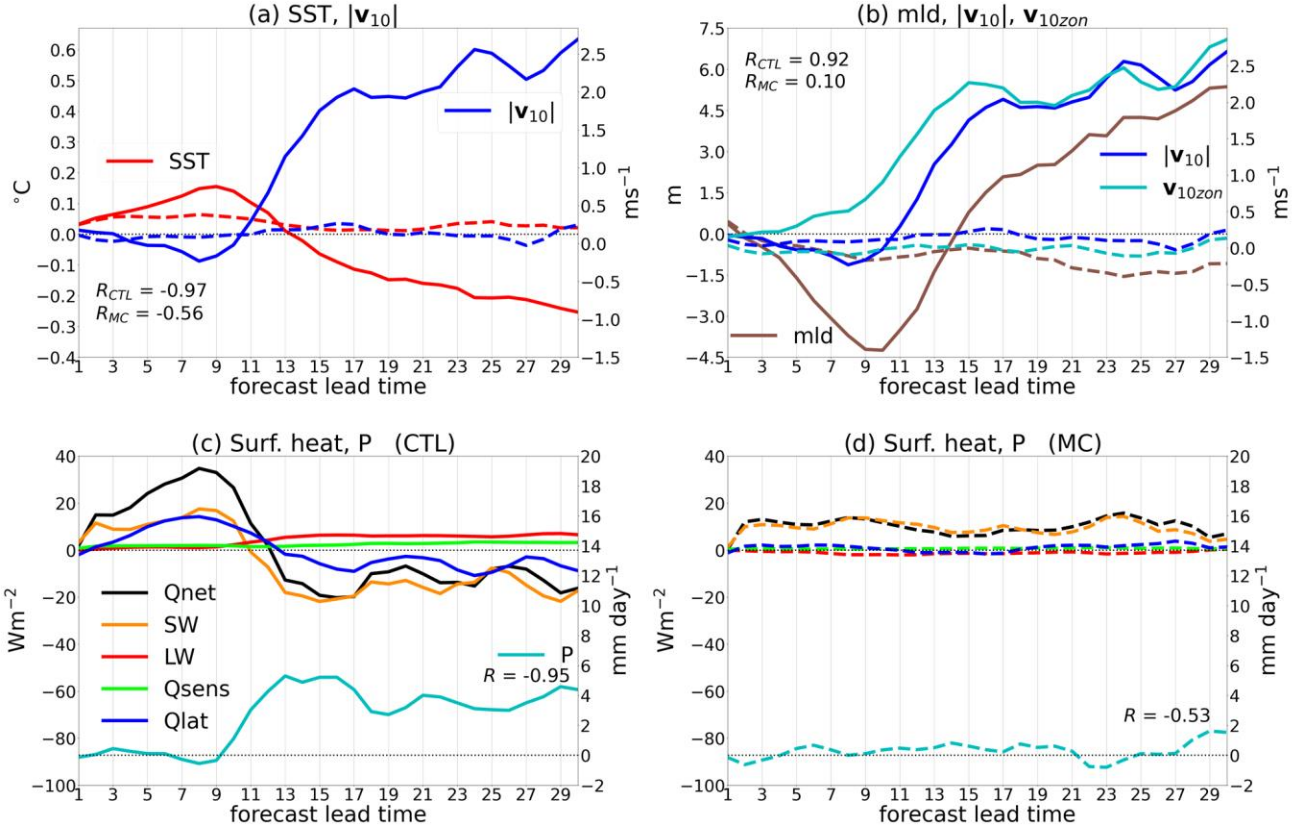


Spinup in Coupled NWP

Eastern EIO (N of Eq)

Mean biases over the eastern tropical Indian Ocean region (90 - 97.5E, 7.5 - 15N) in CNWP-N320 hindcasts (CTL, solid lines) and with nudging applied to the Maritime Continent region (dashed lines), plotted against forecast lead time (days).

- Initial warming via positive net downward heat flux
- Subsequent increased surface (zonal) wind error, deepening ocean mixed later, bringing colder water to surface.
- Errors much reduced with MC nudging.



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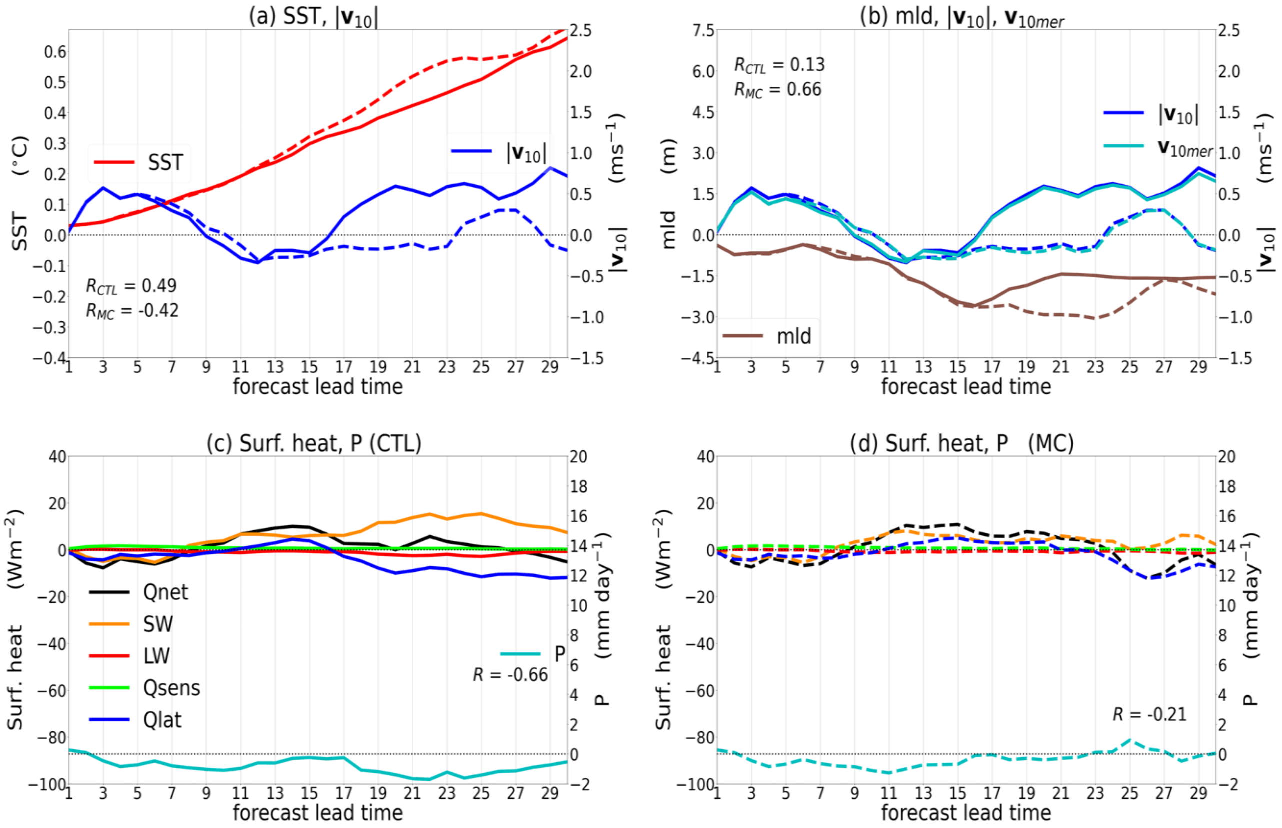
Spinup in Coupled NWP

Western EIO

Mean biases in SST (red) and 10-m windspeed ($|v_{10}|$, blue) over the western tropical Indian Ocean region (50 - 60E, 7.5S – 2.5N) in CNWP-N320 hindcasts (CTL, solid lines) and with nudging applied to the Maritime Continent region (dashed lines), plotted against forecast lead time (days).

- Warm bias grows monotonically with lead time, with or without MC nudging.
- Wind error is meridional (southerly) and not related to SST error.
- Surface flux errors make little contribution to SST error.
- Suggests contribution from ocean transport errors.



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Summary

- Nudging experiments confirm that errors in the Maritime Continent region contribute substantially to the Asian summer monsoon (ASM) circulation errors through their effects on the western North Pacific subtropical high.
- Locally forced errors over the Indian region also contribute to the ASM errors.
- Errors arising over the Maritime Continent region also affect the circulation and sea surface temperatures in the equatorial Indian Ocean region, contributing to a persistent error pattern resembling a positive Indian Ocean dipole phase.
- This is associated with circulation errors over India and the strengthening and extension of the westerly jet across southeast Asia and the South China Sea into the western Pacific, thereby affecting the Asian summer monsoon circulation and rainfall patterns as a whole.
- However, errors developing rapidly in the deeper equatorial Indian Ocean, apparently independently of the local atmosphere errors, are also contributing to this bias pattern.
- Analysis of atmospheric nudging increments to temperature and winds over the Maritime Continent suggests that the errors in this region may at least partly be related to deficiencies in the convection and boundary layer parameterisations.

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Thoughts and questions

- Circulation, rainfall and SST errors in the Asian monsoon region have persisted through several generations of global models.
- Examining how such systematic errors develop after initialisation in hindcast ensembles allows possible contributing regions to be identified before feedbacks occur.
- Constraining the development of errors (e.g. by nudging variables to reanalyses) in such regions can help to confirm their role in the wider monsoon systematic errors.
- Nudging increments can shed light on where in the model such errors originate (e.g. convection, boundary layer schemes), thereby allowing targeted model development.
- This technique is being used to further understand SST errors in the equatorial Indian Ocean *(see poster Th-3.39 by Hannah Ellis on Wednesday).*
- However, untangling and solving such robust systematic errors is a lengthy and complex process. Can machine learning help with this in future??

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Thank you!