Understanding the development of systematic errors in the Asian summer monsoon

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A – Overview

We highlight a number of different techniques that can be employed to investigate the sources of model error.

We demonstrate how this methodology can be used to identify the regions and model components responsible for the development of long-standing errors in the Asian summer monsoon.

Once these are known, further work can be done to explore the local processes contributing to this behaviour and their sensitivity to changes in physical parameterisations and/or model resolution.

B - Introduction

Error patterns in circulation and rainfall over the Asian summer monsoon (ASM) region in Met Office models are similar between multidecadal climate simulations and seasonal hindcasts initialized in spring.

This allows us to use range of configurations within the seamless modelling system to shed light on various aspects and drivers of these errors.

Characteristics of the error pattern include:

- deficient rainfall over Indian peninsula and Maritime Continent, excess over Eq. Indian Ocean and W Pacific;
- anticyclonic anomaly over India, cyclonic anomaly over W Pacific;
- dipole SST error resembling positive Indian Ocean Dipole (IOD) phase;
- cold SST errors around Maritime Continent and W Pacific.

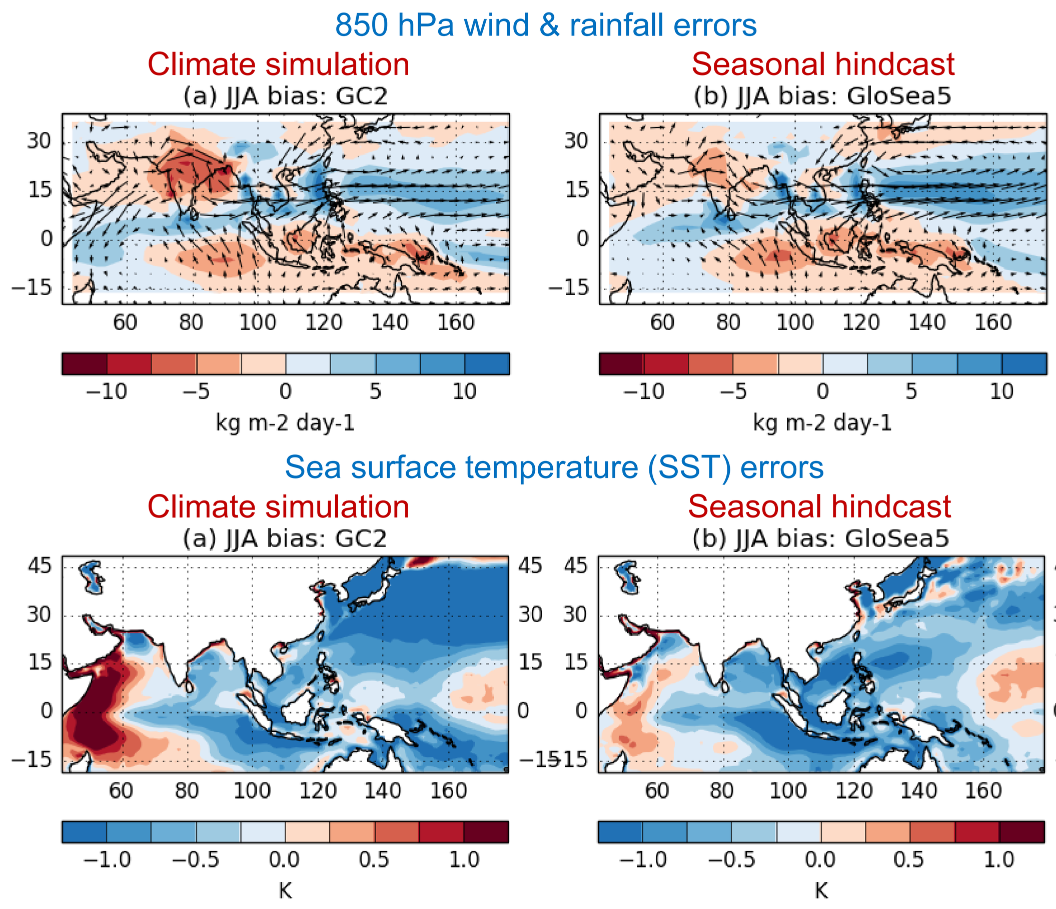


Figure B1: June to August (JJA) climatological errors in precipitation (against GPCP observations), 850 hPa winds (against ERA-Interim reanalyses) and SST (against OISSTv2) in (left) Global Coupled model version 2 (GC2) multi-decadal climate simulation and (right) 23-year GloSea5GC2 seasonal hindcasts initialised in April (28 members each year, 1993-2015).

C – Regional Climate Modelling

We use Regional Climate Model (RCM) simulations to investigate the local and remote sources of the East Asian Summer Monson (EASM) errors.

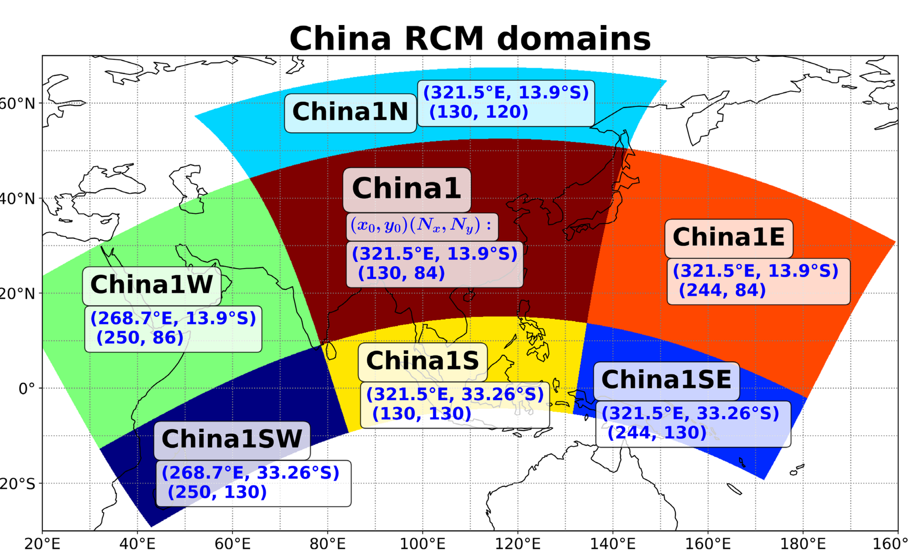


Figure C1: Domains used in RCM experiments.

- Central domain over China: "China1"
- Forced at the lateral boundaries with ERA-I 6-hourly reanalyses and using time-varying observed SSTs.
- Compare RCM simulations at 0.44° × 0.44° resolution with atmosphere-only global (AGCM) simulations at 0.833° × 0.556°.
- Such experiments isolate the effects of any remote errors in the AGCM that are located outside the RCM domain from those developing within the domain.
- Adjusting the lateral boundary locations will include/exclude the effect of different remote regions.

- Comparing AGCM errors with those from China1 suggests that errors over China are not locally-driven.
- Extending the domain to the south and east (China1SE) recovers much, though not all, of the AGCM error pattern.
- Neither the eastward extension (China1E) nor the southward extension (China1S) alone reproduces the main aspects of the AGCM error pattern.
- Extending the domain to the north, south and west has only a limited effect on the errors over China (not shown).

This analysis suggests that errors arising in the AGCM over the Maritime Continent and W Pacific are important contributors to the EASM errors over China.

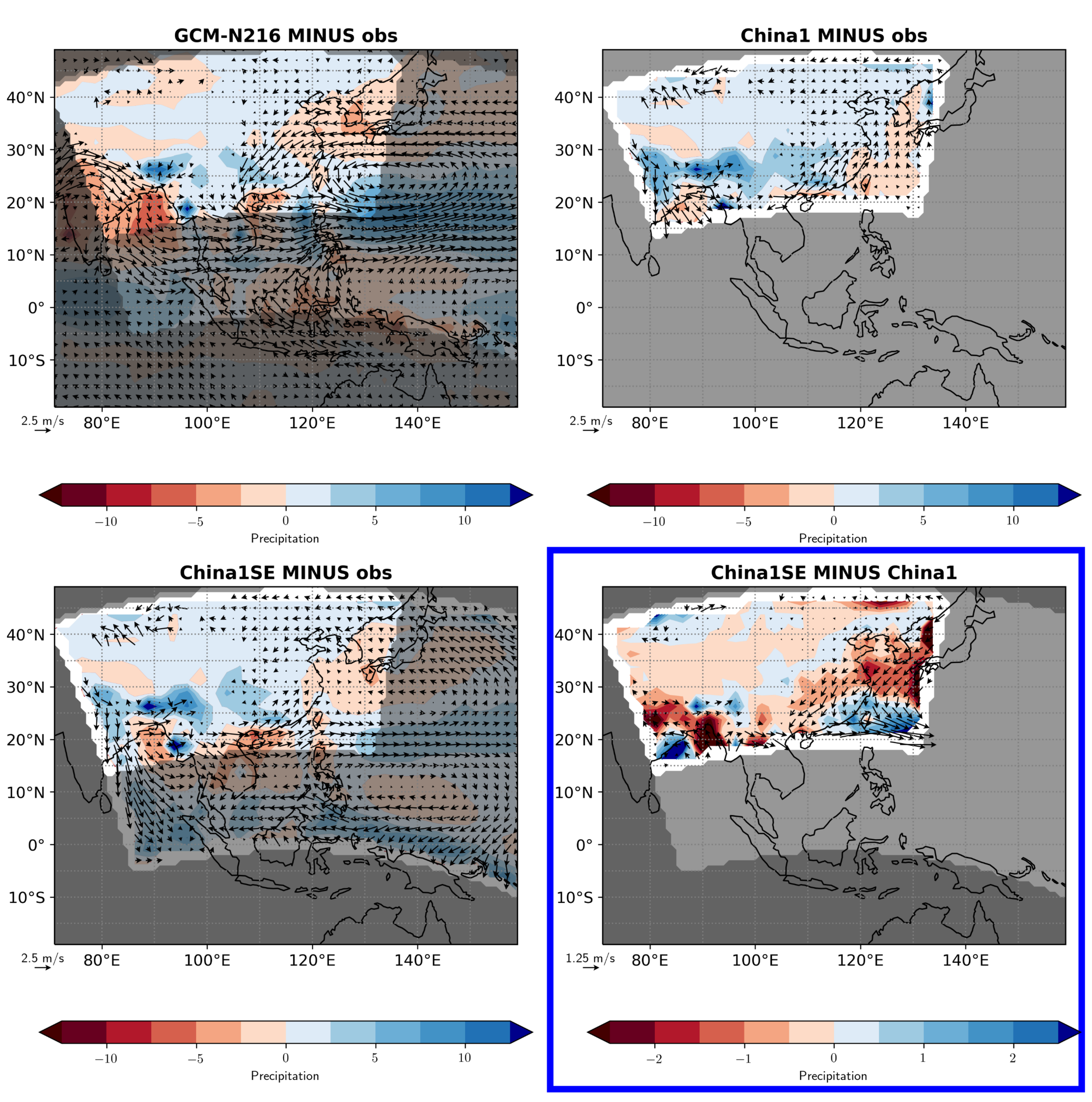


Figure C2: JJA climatological (1989–2008) precipitation and 850 hPa wind errors in the AGCM simulation and the China1 RCM simulation vs. TRMM and ERA-Interim (obs), and the effects of extending the domain towards the south and east (China1SE).

D – Development of errors in seasonal hindcasts

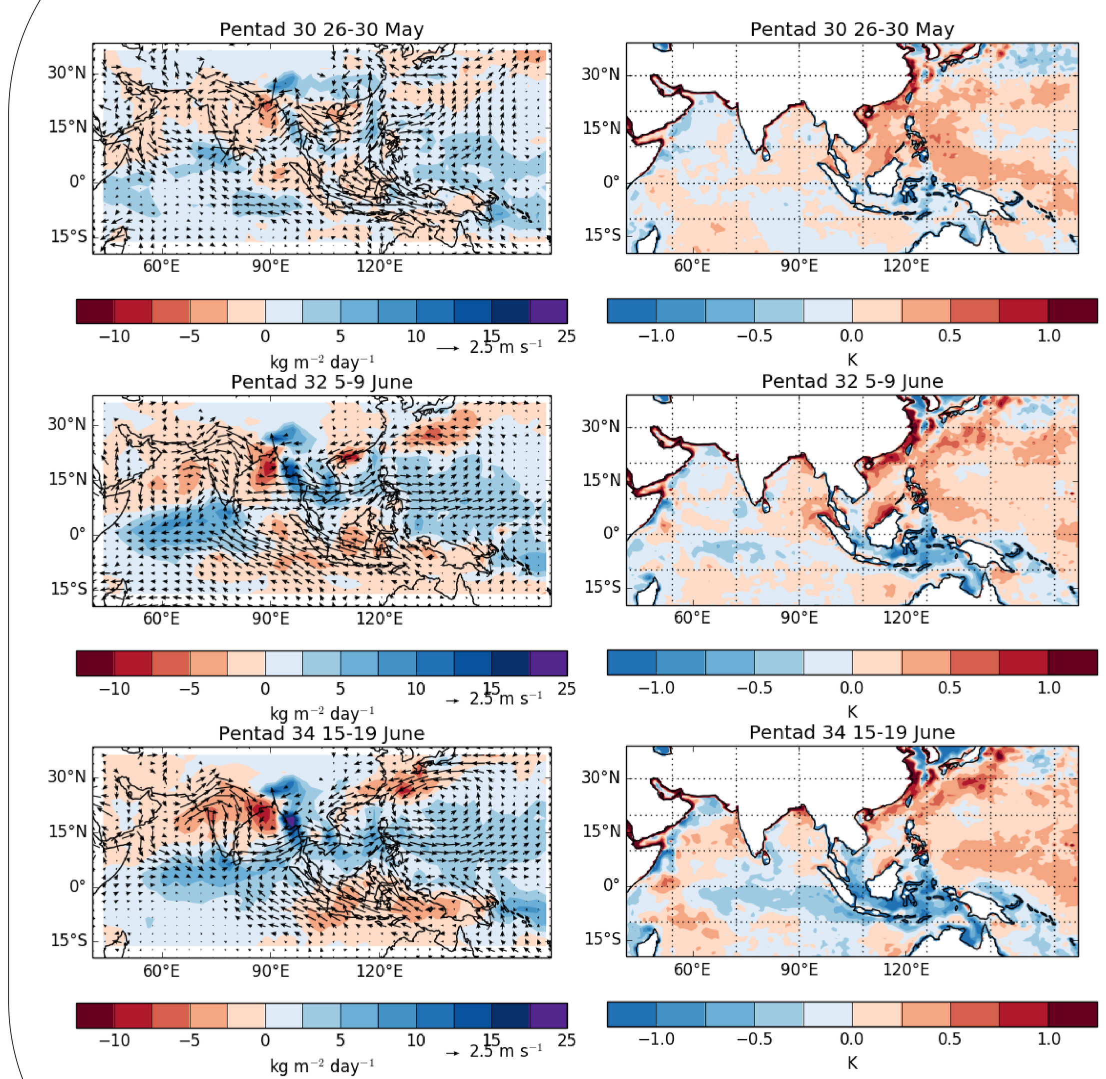


Figure D1: Development of climatological errors in GloSea5GC2 seasonal hindcasts (1993-2015) in (left) 850 hPa winds and precipitation and (right) SST, pentad by pentad after initialisation on 25 May.

- Anomalous divergence over the Maritime Continent with deficient precipitation and cooling SSTs.
- 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 which represents the weakening and displacement of the Western North Pacific Subtropical High.
- The westerly anomalies intensify after the South Asian Summer Monsoon (SASM) onset at the start of June, related to anticyclonic anomalies that develop over India rapidly after initialisation and are associated with weakening of the SASM trough.
- Monsoon lows and depressions are underestimated and unable to progress across northern India, contributing to dry bias there.

E – Using regional relaxation experiments to identify sources of error in the ASM

We use regional relaxation ("nudging") experiments in climate simulations, GloSea5 seasonal hindcasts and coupled NWP experiments to show that the Maritime Continent (MC) region plays a large role in the EASM errors.

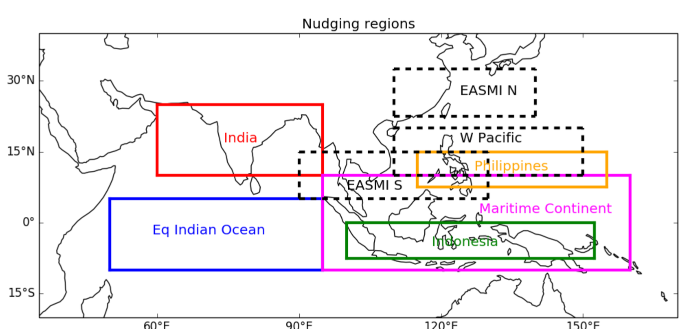


Figure E1: Regions where regional relaxation has been applied in various experiments. Temperatures and winds are "nudged" back to reanalyses with a 6-hourly relaxation time scale at all model levels. Assuming a linear response, the difference between the Control and the "Nudged" simulations then gives an indication of the role played by the nudged region in the errors that occur in the Control in other locations.

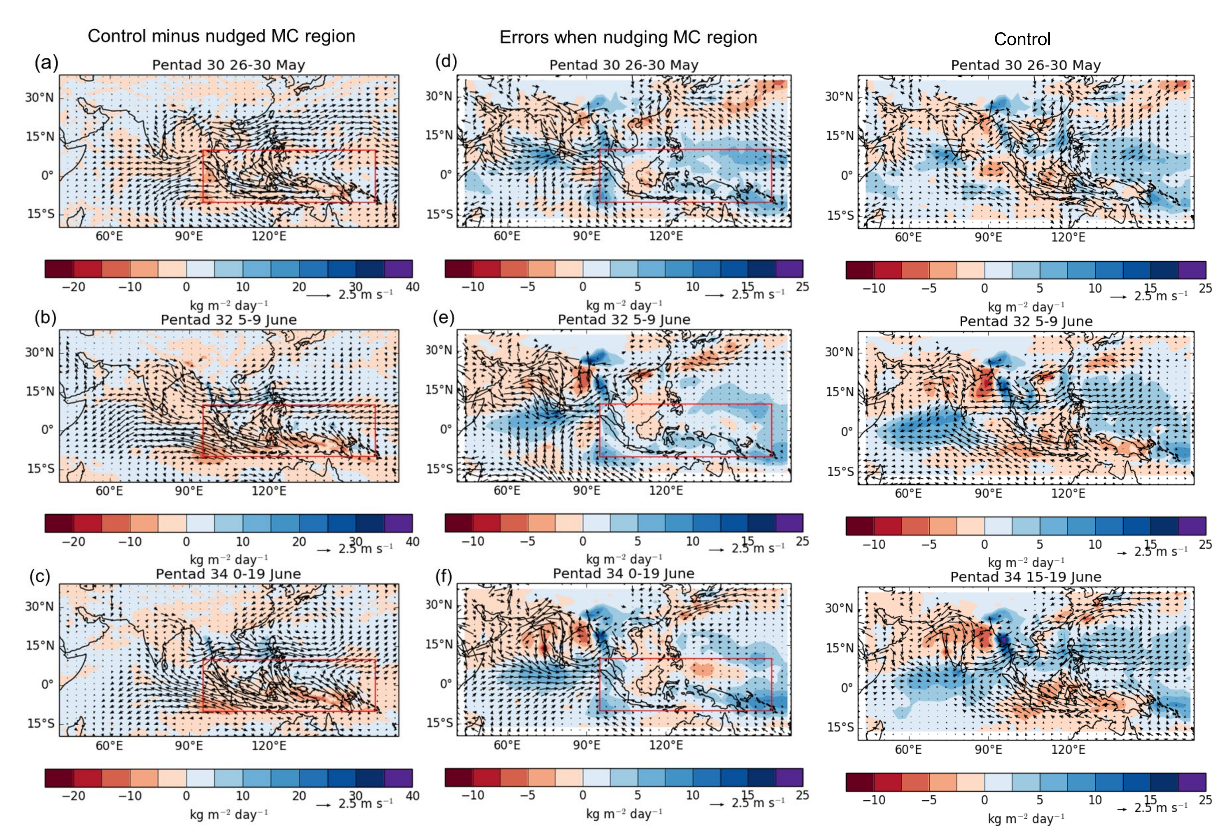


Figure E2: Effects of relaxing air temperatures and winds in the Maritime Continent (MC) region, indicated by the red box, back to ERA-interim reanalyses. Left: Control minus nudged MC, indicating contribution to errors from the MC region; Middle: errors arising while MC region is nudged; Right: errors in Control. All hindcasts initialised 25 May.

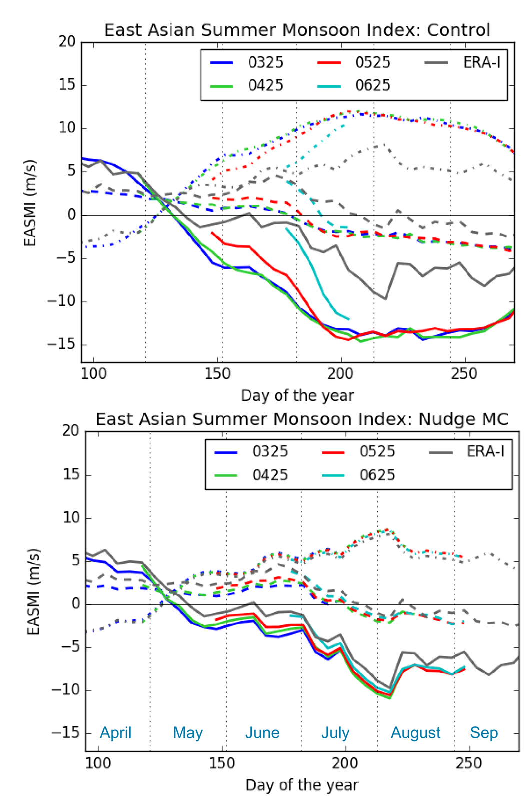


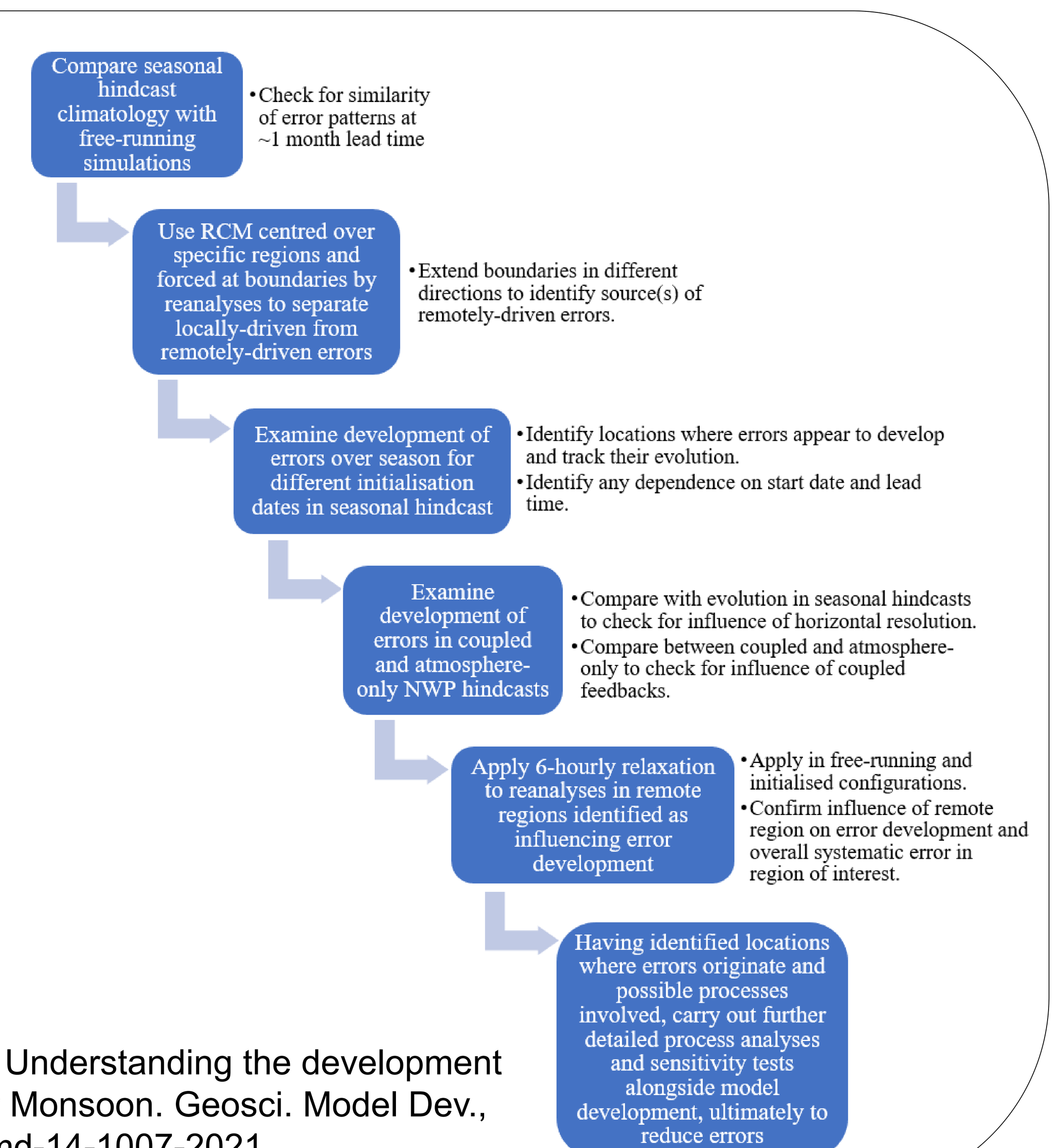
Figure E3: EASMI index: 850 hPa U wind difference [22.5–32.5°N, 110–140°E] minus [5–15°N, 90–130°E]. Solid: index; dashed: northern box, dot–dash: southern box. Colours = hindcast start dates

F – Conclusions

Application of a hierarchical approach can aid investigation into the sources of systematic errors in the Asian summer monsoon.

Using a seamless modelling system we can study the evolution of errors, separate their local and remote contributions, analyse the role of model resolution and atmosphere–ocean coupling and start to identify processes requiring attention.

While further analysis is needed to investigate the processes involved and how they are misrepresented in the models, this approach paves the way for further targeted analysis and sensitivity tests as part of future model development.



For more details see 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

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