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Interactive comment on "Understanding the development of systematic errors in the Asian Summer Monsoon" *by* Gill M. Martin et al.

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Author response to comments by Anonymous Referee 1.

Overall comments

Using the MetUM unified modelling framework to decompose systematic modelling errors for the Asian Summer Monsoon is a wonderful example of the great utility of applying one framework to a science problem, in this case, quantifying systematic modelling errors in a monsoon system. The paper contains an enormous amount of information that will be useful to modellers to improve skill for prediction (and projections) for the EASM. Although I appreciate the challenge of presenting this work in a concise and digestible way, I feel some improvements can be made, primarily to figure organization and better descriptions in the manuscript. To help guide the reader and improve the readability, I suggest the following: 1. To help guide the reader on experimental design, I recommend use of flowcharts for modelling tools and experiment description. 2. To help summarize the regional climate modelling results in Section 3.2, consider summary table (see specific comments). 3. To help digest and follow discussion on the initialized hindcasts in Section 3.3., consider reorganizing your figure suite such that specific locations (or errors foci in the text) are highlighted (see specific comments). If this is not possible, perhaps sub-heading per error topic, and better labelling on the figures will help.

We thank the reviewer for these helpful suggestions. We have added a Table of configurations to clarify each and how they related to one another, and a summary Table for the RCM results. We have divided the EASM and Indian Ocean analysis in section 3.3 under separate sub-headings and reordered the Figures accordingly. We have also separated the seasonal NWP hindcast analysis into separate sub-section 3.4. More details in answer to the specific comments below.

Specific Comments

Line 95: An explanation of N is needed for this grid system beyond what you have here. This will also help define the reader interpret “768” from N768 on Line 129, and N96 on Line 134.

In order to avoid confusion with our terminology, we have removed reference to N216 etc (except where used in a naming convention) and simply refer to the actual longitude x latitude grid resolution.

Figure 1: What is the reference vector?

A reference vector has been added.

Line 115: This isn't clear to me: Did you originally run RCM with GA6.0 physics? Or is your statement on a better Indian subcontinent simulation based on the GA6 vs GA7 comparison? I am not suggesting re-running anything, just a clarification on the justification for using GA7.0 configuration rather than that what was used for the global simulations. Also, to be clear, you used GA7.0 to force RCM (and not simply using the same model configuration)?

We apologise for the confusion caused by poor wording of this paragraph, which has been rewritten. The RCM was only configured with GA7.0, which differs from GA6.0 as mentioned here, but in which the overall pattern of ASM errors is very similar. The RCM is forced at the boundaries by 6-hourly ERA interim re-analysis. An additional corresponding 20-year atmosphere-only GCM simulation was run for comparison with this RCM configuration.

In response to a comment made by the other reviewer, we have added a Table showing the different model configurations used in this study.

Line 169 and Figure 2: The mean JJA cold bias of GloSea5 for parts of the Indian Ocean, around Malaysia, and perhaps Western Pacific look larger than the individual months?

This is because the JJA seasonal mean is from hindcasts initialised in April, so the lead time is longer for this plot. This has been clarified in the text.

Figure 3: The caption should note where domains overlap and also describe what N1 represents.

NI (no India) was not used in these experiments so this domain has been removed from Fig 3.

We have added information on the different domains, and how they overlap, to the caption. In addition, we have included the coordinates of the domains in the form $(x_0, y_0)(N_x, N_y)$ where (x_0, y_0) is the position of the lower left hand corner of the region (in rotated pole coordinates) and (N_x, N_y) is the number of grid points in the x and y direction.

Line 222 and Figure 4: It is hard to compare the GA7 GCM with Figure 1 top left with different color contours, scales, and vector arrows. It might be helpful to add a panel in this figure to truly compare the two. Also, it might be a good opportunity to discuss the improvements moving from GA6 to GA7 which would be interesting to readers of GMD.

We are reluctant to add yet another panel to this Figure; in addition, the GA7 GCM is atmosphere-only while Figure 1 top left is a coupled simulation. However, we have now reconciled the colour scales between Figures 4 and 5 and Figure 1, making the comparison easier. We have also calculated the pattern correlation between the rainfall errors in AGCM-N216 and those in GC2.0 for JJA (over the region shown in Fig 1 top left), which is 0.70. The changes between GA6 and GA7 are detailed in Walters et al. (2019, their section 4.2) so we do not go into detail here, but we have added an additional reference to this paper, and to an equivalent paper by Williams et al. (2017) for GC3 vs GC2, at the end of this paragraph.

Line 239: The westward extension in ChinaW seems to have a rather large impact over the Indian subcontinent. Explanation?

Extending the domain in China1W to include the Arabian Sea and part of the western equatorial Indian Ocean allows the dry bias over India and anti-cyclonic circulation bias to develop as it does in the GCM, while the circulation over the Indian subcontinent is very much constrained by reanalysis in China1. We have commented on this in the revised text.

Section 3.2: To elucidate the local/remote implications of each domain, one suggestion would be to make a summary table, i.e. something like, one row per domain; one column for remote influence notations; one column for local influence notations.

We have included such a summary table as Table 2. In addition, we have re-drawn Figures 4 and 5 in such a way as to highlight the influence of the different domain extensions on the errors developing within the core China1 domain, by including differences from observations in the peripheral regions of the extended domains around the central domain (in which differences are shown against China1).

Figure 6: What is the reference vector?

A reference vector has now been added to the Figure.

Paragraph 259 and Figure 6: Comments on the dry biases in the Bay of Bengal?

See reply to next point.

Figure 7: What are your thoughts on what is going on in the Bay of Bengal. This cannot be explained by SSTs.

Thank you for noting that we should comment on this. It is related to the anticyclonic error over India which develops rapidly after initialisation and is associated with a weakening of the monsoon trough, combined with excessive rainfall over the steep orography of the eastern Himalaya that promotes convergence from the south and drying over the head of the Bay. Levine and Martin (2018) showed that the MetUM typically underestimates the number, and rainfall contribution from, monsoon lows and depressions, which also are unable to progress across northern India. In the absence of these features, rainfall over the Bay of Bengal is reduced and that over the Myanmar orography is increased, with an associated acceleration of the westerly flow across the Bay of Bengal and SE Asia into the South China Sea. This converges with the southerly anomalies from the Maritime Continent region, promoting further rainfall and creating a positive feedback that develops a westerly wind error (extension of the westerly jet) across the SCS and the Philippines into the western Pacific.

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Discussion paper

In the head of the Bay, we think the SSTs in the coupled model warm in response to the reduced rainfall and cloud and to convergence of warm low-level winds from northern India, while further south, as we show subsequently, the SSTs respond to these changes by (ultimately) cooling. Both are likely to be exacerbated by an ocean mixed layer that is too shallow. It appears to be mostly the atmosphere that is driving the ocean here, with limited compensating feedback, although further sensitivity tests will be needed to confirm this, and these will be the subject of future work.

We have added comments on these features to the text in section 3.3 and in the Summary.

Line 280: The N/S dipole seems weak.

We have noted this in the text.

Section 3.3: It is hard to follow specific locations for much of the discussion. I recommend picking a few key areas and designing your figures (6-9) around specific locations/error sources (i.e. one location/error per figure but include the information contained across 6 – 9 but also 10-13) This might help to clearly show the progressions and biases. For example, the South China sea area, or the Bay of Bengal, or EEIO. Full plots as shown here can be supplemental for readers interested in something the authors do not highlight, but for the discussion explicitly called out in the text, there needs to be better organization of figures.

We appreciate the point made by the reviewer here, but we feel it is important to show how the regional-scale errors fit into the wider pattern, and we are also keen to avoid increasing the number of figures too much. For the Indian Ocean region, however, we agree that zooming in would be helpful. We have therefore kept the full plots as they were for Figures 6, 7 and 10 (and actually extended the panels in Fig.s 6 and 10 (now Fig. 9) westwards to match the region shown in Fig. 7 as requested by the other reviewer, but reduced the region plotted for Fig.s 8 and 9 (now Fig.s 10 and 11). We have also reorganised section 3.3 under different sub-headings in order to focus the reader on each particular region, and separated out the analysis using the NWP hindcasts (which largely focusses on the EEIO as an example) into an additional sub-section 3.4.

Figures 7 and 9: Please define all components of the figures in the captions or note them in the text. I don't see an explanation of the red dashed box?

This has been corrected.

Line 306: Define SCSSM.

South China Sea Summer Monsoon – this has been expanded in the text.

Figure 11d: I feel like there is much to unpack from this panel beyond the few paragraphs in the text. I see that the dashed/dashed-dotted lines are defined in the caption, but some attention to these should be paid in the text with further explanation as to interpretation.

There was already some discussion on this in lines 312-315 of the original manuscript, but we agree that more detail is warranted. Additional discussion of the EASMI panel has been added in the new subsection 3.3.2.

Figure 12: Shading = color contours? What is the reference vector?

Yes shading refers to the colour scale. This, and a reference vector, have been added.

Lines 351,357,370 and Figure 13: CPLDNW, UNCPLD, and FOAM, although we can guess, should be explicitly defined.

This has been done, both in the text and through the addition of Table 1 which details the configurations used.

Figure 14: Labelling and boxes should be cleaned up and consistent.

We have removed Figure 14 as the boxes are shown on the subsequent Figure (formerly Fig. 15, now Fig. 14).

Figure 16: What is the reference vector?

Reference vector has been added.