Response to Reviewer #3

General comment

This study proposed a synoptic circulation-based approach to define the SCS monsoon onset date and found that the onset prediction using regime-based definition yields improvements compared to the conventional zonal wind criterion. The results are important for the seasonal prediction of monsoon onset and the paper is overall well-written. However, some analyses and conclusions need to be elucidated more clearly. Specific comments are listed below.

Response

We sincerely thank the reviewer for the careful reading of the manuscript and for the constructive comments. We appreciate the reviewer's positive assessment that the results are important for seasonal prediction of monsoon onset and that the paper is overall well written. The comments helped us clarify the physical and methodological distinction between the proposed regime-based definition and the conventional zonal-wind criterion, as well as the interpretation of the forecast-skill results. We note that several of the reviewer's concerns were also addressed through revisions made in response to Reviewers #1 and #2, including the addition of OLR and MTG diagnostics, cross-index validation, and representative case analyses. In response to the reviewer, we further clarified the W04 definition, the distinction between NL26 and a persistence-filtered U_{SCS} index, the domain choice, the EOF truncation procedure, the year-to-year differences between NL26 and W04, and the non-monotonic lead-time dependence of forecast skill.

Major comments

Comment 1: Comparisons of regime-based definition (NL26) and zonal wind criterion (W04)

(1) This paper shows that NL26 outperforms W04 in predicting monsoon onset, because W04 is sensitive to synoptic disturbances while NL26 requires persistence and capture the subseasonal variations. Is W04 defined by zonal wind on one day? If a persistence criterion applies to the zonal wind, can the predicting skills also obviously improve? If yes, then the simple definition based on zonal wind seems more easily applicable and what's the advantage of NL26?

(2) Lines 378-381: The composites based on zonal wind criterion are also supposed to demonstrate stable differences between pre-monsoon and monsoon periods. I think the transient wind reversal only occurs in some cases.

(3) Line 450: How do you deduce that the local zonal-wind threshold is sensitive to short-lived wind reversals and synoptic noise?

(4) Line 466: How do you deduce that the clustering-based definition effectively filters out unpredictable synoptic-scale fluctuations

Response

We thank the reviewer for this important set of comments.

(1) First, W04 is not defined by zonal wind on a single day in our analysis. Consistent with the standard application of the Wang et al. (2004) onset criterion, both W04 and NL26 are applied at the pentad scale using pentad-mean circulation fields. The W04 criterion is based on the area-averaged pentad-mean 850-hPa zonal wind over the SCS, U_{SCS}, whereas NL26 is based on transitions among synoptic circulation regimes derived from multiple pentad-mean low-level circulation fields. We agree that adding a persistence requirement to a zonal-wind index can reduce some false onsets and may improve skill in some cases. However, the key distinction is that NL26 does not simply impose persistence on a single variable. Instead, it identifies onset as a transition into large-scale circulation regimes characterized jointly by low-level winds and geopotential height structure, including the establishment of southwesterlies over the SCS and the retreat of the WNPSH. Thus, NL26 accounts for the spatial coherence and structural maturity of the monsoon circulation, not only the sign or magnitude of U_{SCS}.

(2) We agree that W04 generally captures the seasonal transition from pre-monsoon to monsoon conditions. Our intention was not to suggest that W04 is generally unstable or physically inconsistent. Indeed, NL26 and W04 are strongly correlated in both the dependent and independent periods, indicating that they capture the same dominant interannual variability in SCSSM onset timing. Rather, our point is that, in some individual years, threshold crossing in U_{SCS} can occur before or after the coherent large-scale circulation transition. We have revised the wording to make this interpretation more balanced.

(3) We revised the statement about short-lived wind reversals and synoptic noise to make it more directly supported by the analysis. The inference is based on the definition of W04, which relies on threshold crossing of area-averaged U_{SCS}, together with the representative case analyses shown in

Figs. S4 and S5. In particular, the 2006 case shows that W04 can identify onset during an early westerly event, while the broader SCS circulation remains transitional and lacks a mature monsoon structure. Previous work also suggested that the early onset signal in 2006 was influenced by Typhoon Chanchu (Mao and Wu, 2008). We therefore revised the text to state that W04 “can be sensitive in some years” to transient westerly events, rather than implying that this is always the case.

(4) We agree that the original wording about “filtering out unpredictable synoptic-scale fluctuations” was too strong. The revised NL26 definition does not explicitly decompose predictable and unpredictable synoptic-scale variability. Rather, it reduces sensitivity to isolated threshold-crossing events by requiring continuity of monsoon-regime occurrence and subsequent emergence of a mature monsoon regime. We have therefore revised the statement to avoid implying that the method formally filters all unpredictable synoptic-scale fluctuations. Instead, we now state that the regime-based definition reduces sensitivity to short-lived or spatially incomplete threshold-crossing events and better aligns onset timing with coherent large-scale circulation structures.

Changes in manuscript

Clarified in the Introduction that the circulation-based onset metrics used here are based on pentad-mean circulation fields.

Revised the final NL26 onset definition and clarified the continuity and maturity criteria.

Added representative case-based discussion of 2014 and 2006, illustrating years when U_{SCS} threshold crossing and coherent circulation-regime transition differ.

Added Supplementary Figs. S4 and S5 showing actual circulation evolution in representative discrepancy years.

Revised the statement on W04 sensitivity to short-lived wind reversals to clarify that this can occur in some years, rather than being a general property of W04.

Revised the interpretation of NL26 to avoid implying that the method formally filters all unpredictable synoptic-scale fluctuations.

Comment 2:

The author emphasized that this study aims to extend the lead time of monsoon onset prediction from three months to four or five months. I think the improvements of predicting skills under the same lead time should also be highlighted.

Response

We agree with the reviewer. In the revised manuscript, we emphasize not only the potential extension of useful lead time, but also the improvements under the same initialization month. In Sections 4.1 and 4.2, W04, NL26, and CIV skill are compared separately for each initialization month from December to April. This allows the added value of NL26 to be assessed under the same lead time as W04. The revised text highlights that NL26 generally improves deterministic, categorical, and probabilistic skill relative to W04 under comparable initialization months, particularly during the dependent period and for several independent-period metrics. This clarification better reflects the central result: the gain comes not only from longer-lead prediction, but also from improved skill at comparable lead times.

Changes in manuscript

Added clarification that W04 and NL26 are compared separately for each initialization month so that their skill can be evaluated under the same lead time.

Revised the deterministic-skill discussion to emphasize same-initialization comparisons between W04 and NL26.

Revised the categorical and probabilistic skill discussion to compare W04, NL26, and CIV for the same initialization months.

Comment 3: Methods

(1) Why is the studied domain chosen as 5°S–25°N and 95°E–135°E? Do the results sensitive to the spatial domain?

(2) Line 150: How to obtain d=144? Do you mean that the first 144 EOF modes are extracted, which totally explain 99% of the total variance? Please clarify it.

Response

We thank the reviewer for these helpful comments. The domain 5°S–25°N, 95°E–135°E was selected to include the main circulation systems associated with SCSSM onset, including the SCS, the Indochina Peninsula, the cross-equatorial flow near 105°E, the tropical eastern Indian Ocean–western Pacific pathway, and the WNPSH. This domain is broad enough to capture the large-scale transition from pre-monsoon easterlies to monsoon southwesterlies, while remaining focused on circulation features directly relevant to SCSSM onset. We have added this explanation to the

Methods section. We also acknowledge that SOM-based circulation regimes may depend to some extent on the chosen spatial domain. Therefore, we have added this point to the limitations paragraph and noted that sensitivity tests with alternative domains should be explored in future work.

Regarding d = 144, the reviewer's understanding is correct. The first 144 EOF modes were retained because their cumulative explained variance reaches 99% of the total variance. The associated principal components were then used as input to the SOM. We have revised the Methods section to state this explicitly.

Changes in manuscript

Added explanation of why the domain 5°S–25°N, 95°E–135°E was selected.

Clarified that the first d = 144 EOF modes were retained because their cumulative explained variance reaches 99% of the total variance.

Added domain sensitivity as a methodological limitation and suggested future sensitivity testing with alternative domains.

Comment 4: Figure 2

(1) Overlapping NL26 on Figure 2a rather than W04, so as to match with the transition of circulation regimes.

(2) In some years, NL26 and W04 are quite different. What happen in these years? The authors can specifically analyze the circulation evolution in these years to understand the differences. Albeit a specific day is classified to one cluster by the SOM or K-means methods, the actual circulation on the day might differ from the composite patterns. Case analyses might help better understand the remarkably different indices.

Response

We thank the reviewer for this useful suggestion. We revised Figure 2 so that panel (a) shows the onset dates identified by the synoptic clustering-based definition, which better matches the displayed transition of circulation regimes. Panel (b) then directly compares onset dates identified by NL26 and W04. This revised layout makes the relationship between the circulation-regime evolution and the NL26 onset definition clearer.

We also agree that case analyses are useful because the actual circulation on a given pentad can differ from the composite cluster pattern. To address this point, we added representative case analyses in the Supplementary Material. Figures S4 and S5 show the actual 850-hPa wind, U850, and Z850 evolution in two years when NL26 and W04 differ substantially. These examples illustrate that the differences arise when U_{SCS} threshold crossing and coherent large-scale monsoon reorganization occur at different times. In 2014, NL26 identifies onset earlier than W04 because a coherent monsoon-type circulation is already established. In 2006, W04 identifies onset earlier than NL26 because the U_{SCS} threshold is crossed during an early westerly event, while the broader SCS circulation remains transitional and lacks a mature monsoon structure.

Changes in manuscript

Revised Figure 2 caption and panel description.

Added representative discussion of 2014 and 2006 to explain years when NL26 and W04 differ substantially.

Added Supplementary Figs. S4 and S5 showing actual circulation evolution in representative discrepancy years.

Comment 5:

The correlation coefficients in Jan (Mar) is smaller than Dec (Feb). Why do the predicting skills fluctuate from December to April rather than stably increase as the lead time shortens?

Response

We thank the reviewer for this important point. We agree that seasonal forecast skill does not necessarily increase monotonically with shorter lead time. In the revised manuscript, we added a short explanation of the non-monotonic lead-time dependence. This behavior likely reflects the combined effects of limited sample size, initialization-dependent model errors, ensemble spread, and the evolving sources of predictability. SCSSM onset is influenced by both slowly varying boundary forcing and subseasonal circulation variability; therefore, shorter lead time does not always guarantee higher skill if the relevant circulation transition is controlled by processes that are not well initialized or represented in the model. We have revised the text to avoid implying a monotonic lead-time dependence.

Changes in manuscript

Added a paragraph explaining the non-monotonic lead-time dependence of forecast skill and why skill does not necessarily increase steadily from December to April.

Minor comments

Minor Comment 1

Line 26: “the South China Sea summer monsoon” should not be divided as “the South China Sea, summer monsoon”.

Response

We thank the reviewer for catching this formatting issue. We have corrected the phrase to “the South China Sea summer monsoon”.

Changes in manuscript

Corrected the phrase to “the South China Sea summer monsoon.”.

Minor Comment 2

Figure 1: The white color is not contained in the color bar. Can the subplots be resorted by pre-monsoon and monsoon regimes? This makes it more easily to remember the six patterns.

Response

We thank the reviewer for this helpful suggestion. We revised Figure 1 so that the color bar includes all colors used in the shading. We also reordered the panels to group the pre-monsoon and monsoon regimes more clearly: C2, C4, and C5 are now shown as pre-monsoon regimes, while C1, C3, and C6 are shown as monsoon regimes. This grouping makes the physical distinction between the two regime types easier to follow.

Changes in manuscript

Revised Figure 1 caption to reflect the reordered panels and the grouping of pre-monsoon and monsoon regimes.

Revised the text describing the pre-monsoon and monsoon regimes.

Minor Comment 3

Line 365: “northeasterly” change to “southeasterly”?

Response

We thank the reviewer for pointing this out. We re-examined the circulation pattern and revised the wording to “easterly or southeasterly,” which more accurately describes the low-level flow in the pre-monsoon regimes.

Changes in manuscript

Revised “easterly or northeasterly” to “easterly or southeasterly”.

Minor Comment 4

Line 565: “WL04” should be “W04”.

Response

We thank the reviewer for catching this typo. We have corrected “WL04” to “W04” throughout the manuscript.

Changes in manuscript

The typo “WL04” has been corrected to “W04” throughout the revised manuscript.

References

Chevuturi, A., Turner, A. G., Woolnough, S. J., Martin, G. M., and MacLachlan, C.: Indian summer monsoon onset forecast skill in the UK Met Office initialized coupled seasonal forecasting system (GloSea5-GC2), Clim Dyn, 52, 6599–6617, https://doi.org/10.1007/s00382-018-4536-1, 2019.

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Mao, J. and Wu, G.: Influences of Typhoon Chanchu on the 2006 South China Sea summer monsoon onset, Geophysical Research Letters, 35, 2008GL033810, https://doi.org/10.1029/2008GL033810, 2008.

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