Response to Reviewer #1:

Thank you for your professional review and instructive comments. We have revised the paper carefully based on your comments. These are described as follows (*italic text in blue color is from your review*).

This manuscript evaluates how ERA5, JRA-55, and MERRA-2 represent the summertime diurnal cycle of precipitation (DCP) over China, using IMERG and CMORPH as observational references. The authors diagnose regional differences in precipitation phase and amplitude and relate them to diabatic heating (Q1/Q2), subgrid-scale transport proxies, cloud vertical structure, vertical velocity, and CAPE versus dCAPE over three representative regions (TP, SECN, SCB). The process-oriented framing is a strength and could be useful for understanding reanalysis behavior and guiding model development. However, key methodological details are missing for time handling, event selection, and the derivation of several diagnostics. Because several conclusions hinge on phase offsets of only a few hours, these gaps limit reproducibility and weaken the robustness of the physical interpretation.

Major comments:

1. Several highlighted phase differences are only a few hours, comparable to the sampling intervals of some products (for example, JRA-55 3-hourly precipitation and 6-hourly pressure-level fields). The manuscript provides temporal resolution information and a generic Fourier description, but it does not document the actual implementation used to produce the diagnostics. Please explicitly document:

- *Whether precipitation time series are analyzed at native temporal sampling or interpolated to a common time grid prior to Fourier analysis?*
- *For composite diurnal variation figures, how the diurnal cycle is constructed in time (native timestamps versus interpolation for display)?*
- *For JRA-55 pressure-level fields (6-hourly), how diurnal variations of pressure-level diagnostics (Q1/Q2, vertical velocity, CAPE/dCAPE) are obtained from this sampling? If interpolation is used, specify method.*

Thanks for your instructive comments. In the original manuscript, all analyses were conducted using the data at their native temporal resolutions. No interpolation to a common temporal resolution was performed, as our study does not involve direct intercomparison between datasets that would require synchronized time steps. Below are detailed responses to each of your points and some of them have been incorporated to the revised manuscript:

1) The precipitation data were analyzed at their native temporal resolutions. As described in Appendix A, we first calculated the summertime (JJA) mean diurnal cycle of precipitation for each dataset, yielding a diurnal time series with a sample size of $N=24/\Delta t$, where Δt is the native temporal resolution (i.e., hourly for ERA5 and MERRA-2, 3-hourly for JRA-55). This results in 24 time steps for ERA5 and MERRA-2, and 8 time steps for JRA-55. Fourier analysis was then applied to these mean diurnal series, and the diurnal phase and amplitude were extracted from the first harmonic component.
2) All composite diurnal variations for both surface and pressure-level variables are constructed using their native time resolutions, by averaging each timestep over all selected days. No interpolation was used in statistical analysis or diagnostics. It is the plotting procedure that uses linear interpolation to visualize the diurnal evolution more smoothly between timesteps.
3) For JRA-55, variables such as Q_1/Q_2, vertical velocity, and the diagnosed CAPE/dCAPE were analyzed at their native 6-hourly resolution. Linear interpolation was only invoked by the plotting procedure for graphical display.

Required robustness check:

- *Add a sampling sensitivity test by down-sampling ERA5 (and MERRA-2 where applicable) to JRA-55 sampling (3-hourly for precipitation, 6-hourly for pressure-level diagnostics) and show whether the inferred phase relationships and key conclusions (for example, ERA5 phase lead magnitude, CAPE versus dCAPE alignment) remain.*

According to your suggestion, we down-sampled ERA5 and MERRA-2 to match the 3-hourly (surface) and 6-hourly (pressure-level) sampling of JRA55 (Figure R1–R3).

The diurnal phase after down-sampling remains virtually unchanged (Figs. R1). For composite precipitation, the peak timing shifts by ±1 hour due to the coarser temporal sampling, but the characteristic premature onset and termination of ERA5 convection over TP and SECN persist (Fig. R2). The CAPE/dCAPE relationship also remains robust: over TP, dCAPE continues to lag CAPE as observed at native resolutions (Fig. R3). Over SECN, CAPE and dCAPE tend align closely, consistent with the behavior seen in native resolutions. We thus confirm that, while coarser temporal sampling can introduce minor quantization effects, the key findings concerning phase-lead relationships are not affected. These results have been included as supplementary material with brief discussion in the revised manuscript. See Line 175.

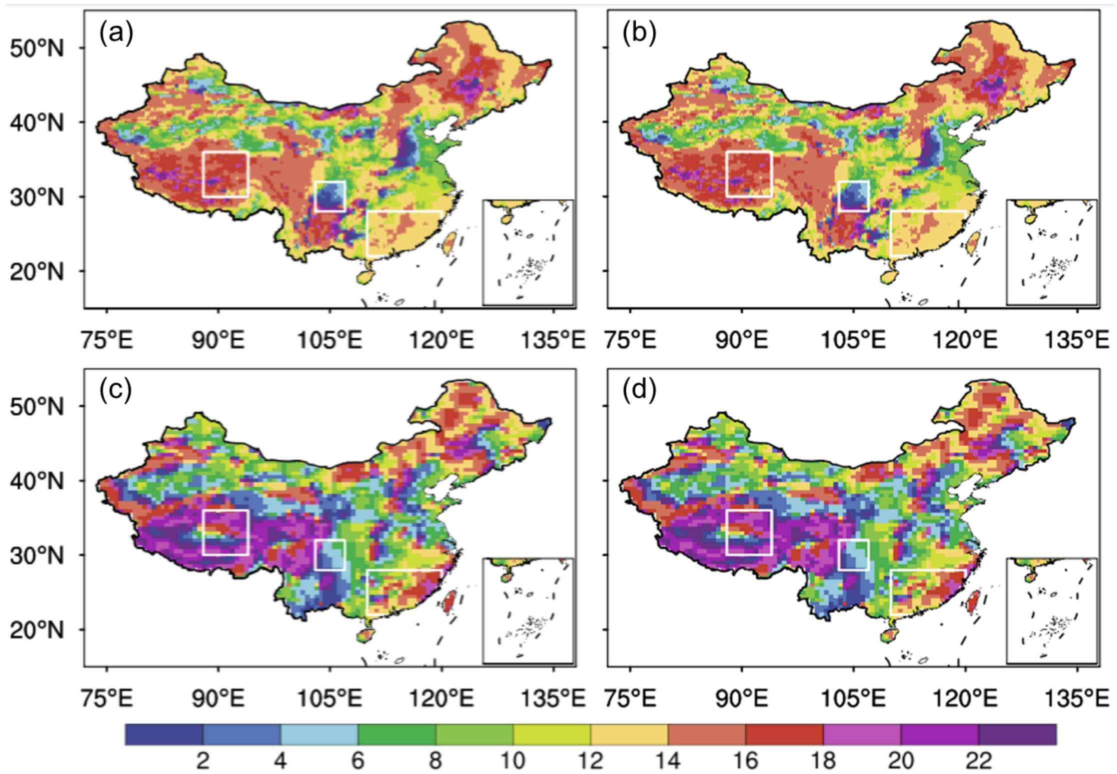

Figure R 1 Diurnal phase (local solar time, LST; the same hereafter) of total precipitation averaged over June–July–August (JJA) 2019–2023 for China from (a, b) ERA5 and (c, d) MERRA-2. **Left and right columns denote 3-hourly and 1-hourly (original) sampling, respectively.** White boxes mark the three representative regions: the Tibetan Plateau (TP, 30°–36°N, 88°–94°E), southeastern China (SECN, 22°–28°N, 110°–120°E), and the Sichuan Basin (SCB, 28°–32°N, 103°–107°E).

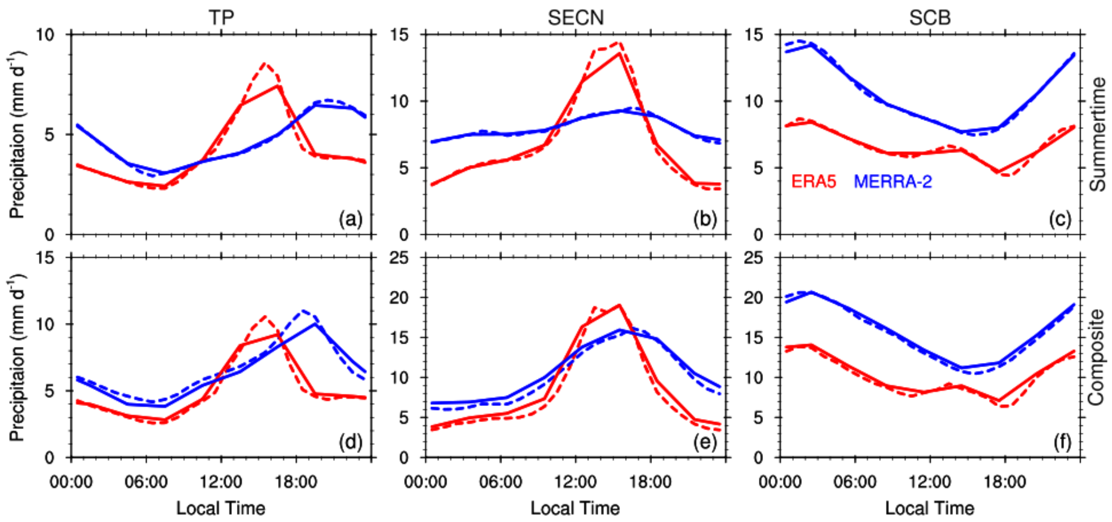

Figure R 2 Five-year JJA-averaged (top row) and case-composite (bottom row) diurnal variations of precipitation over TP (left), SECN (middle) and SCB (right). Solid and dashed lines denote down-sampled (3-hourly) and original (1-hourly) results, respectively.

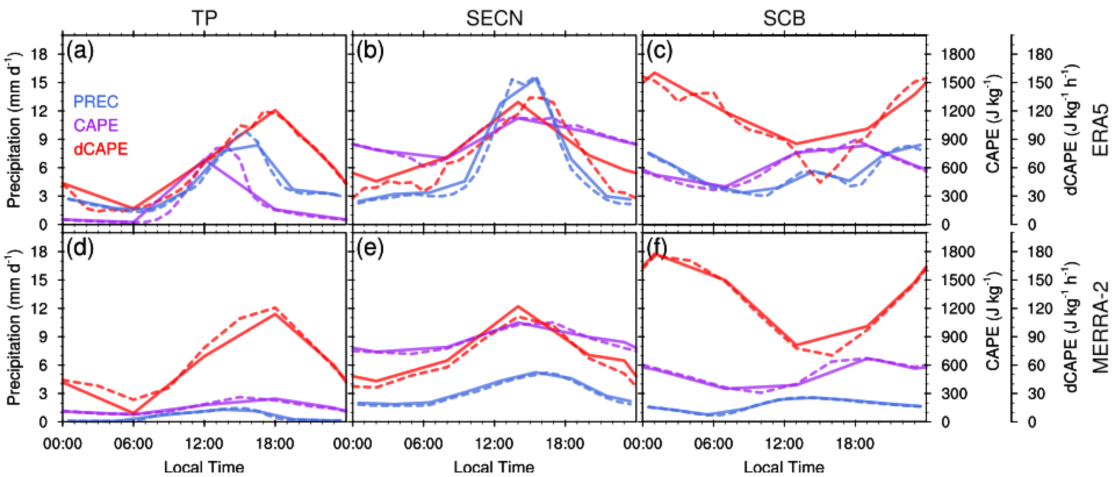

Figure R 3 Diurnal variations of convective precipitation, CAPE and dCAPE over TP (left), SECN (middle) and SCB (right) from ERA5 (top) and MERRA-2 (bottom). Solid and dashed lines denote down-sampled and original results, respectively.

2. Table 1 reports substantially different numbers of selected events across datasets, implying that event days are selected independently for each dataset. If so, composites of heating/cloud/omega may reflect different synoptic populations rather than purely differences in modeled physics.

Please clarify whether the same dates are used across datasets. To strengthen attribution, add a sensitivity composite where event days are defined using IMERG (and/or CMORPH) and then applied to all reanalyses on the same dates.

We appreciate the reviewer for bringing up this important point. In the original analysis, event days were selected independently for each dataset based on the same precipitation threshold and peak-time criteria, which ensures that each composite reflects the dataset's "typical" diurnal events. We acknowledge that this may introduce sampling differences and varying synoptic backgrounds. We did not opt to use the same fixed event dates, given that the synoptic environments in the reanalyses inherently diverge across datasets, as reflected by their differing precipitation fields (Fig. R4). To address your concern, we performed a sensitivity analysis using event dates defined by observed precipitation and applied these fixed dates to all reanalyses. Figure R5 shows the composite diurnal cycles for the selected events from the observations. The overall phase characteristics remain consistent with those reported in the original manuscript, although the magnitude for MERRA-2 and JRA-55 are underestimated over SECN. This underestimation is accompanied by noticeably weaker vertical velocities (Fig. R6), again indicating differences in the synoptic background among the reanalyses. We have included a description of this sensitivity analysis in the revised manuscript and add the supporting figures to the Supplemental Material. See Line 161.

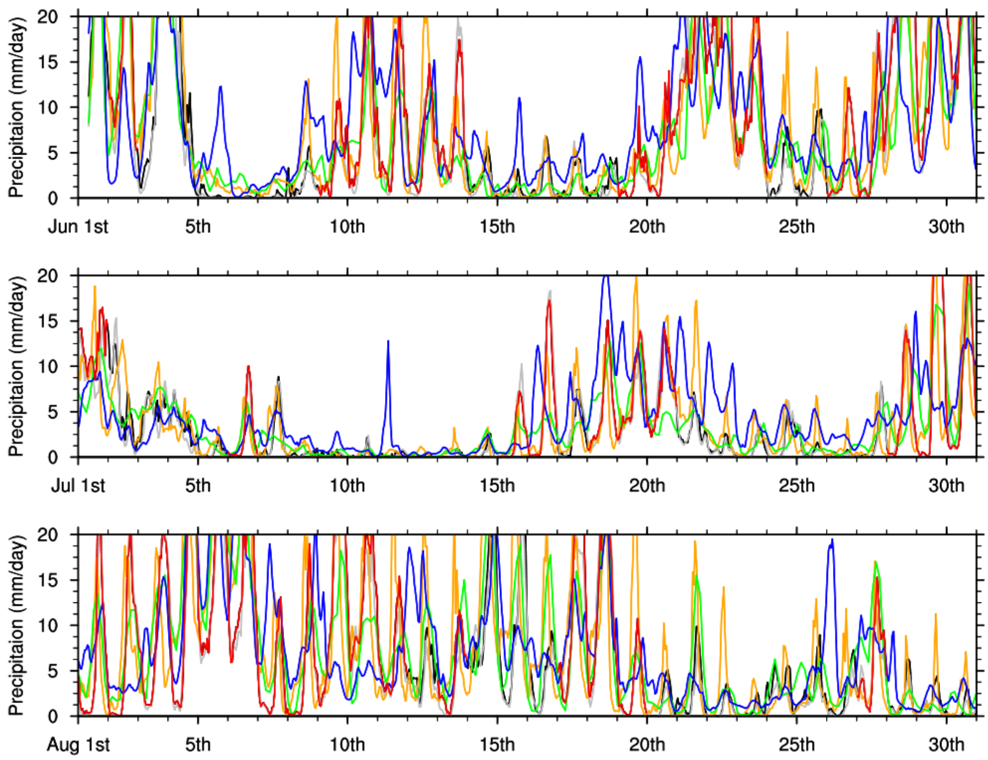

Figure R 4 Precipitation evolution of IMERG (black), CMORPH (gray), ERA5 (orange), JRA-55 (green) and MERRA-2 (blue) over SECN. Red lines denote the IMERG observation events.

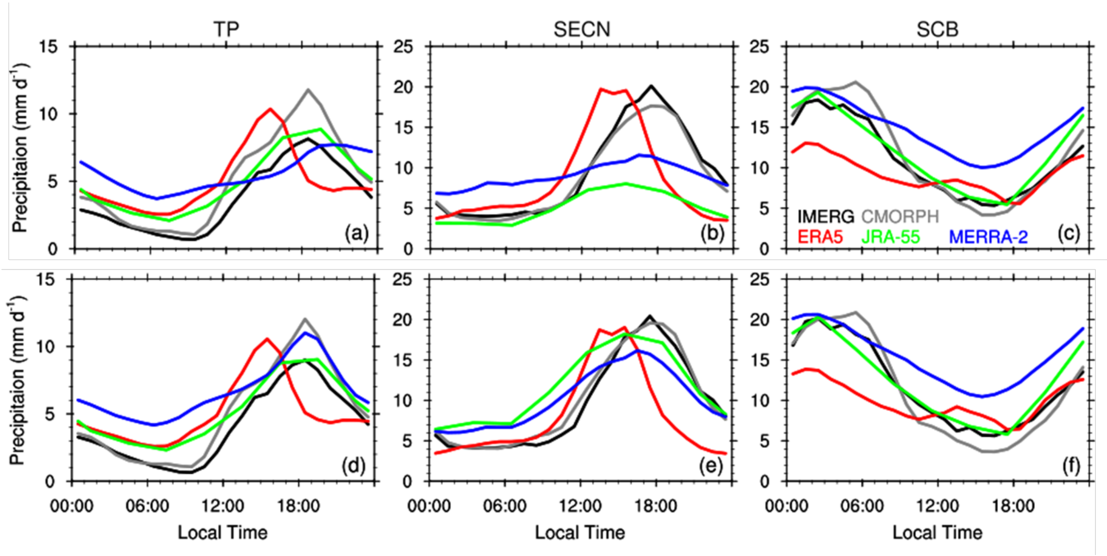

Figure R 5 Case-composite diurnal variations of precipitation over (a, d) TP, (b, e) SECN and (c, f) SCB. Top and bottom rows are derived from observation events and the original case, respectively.

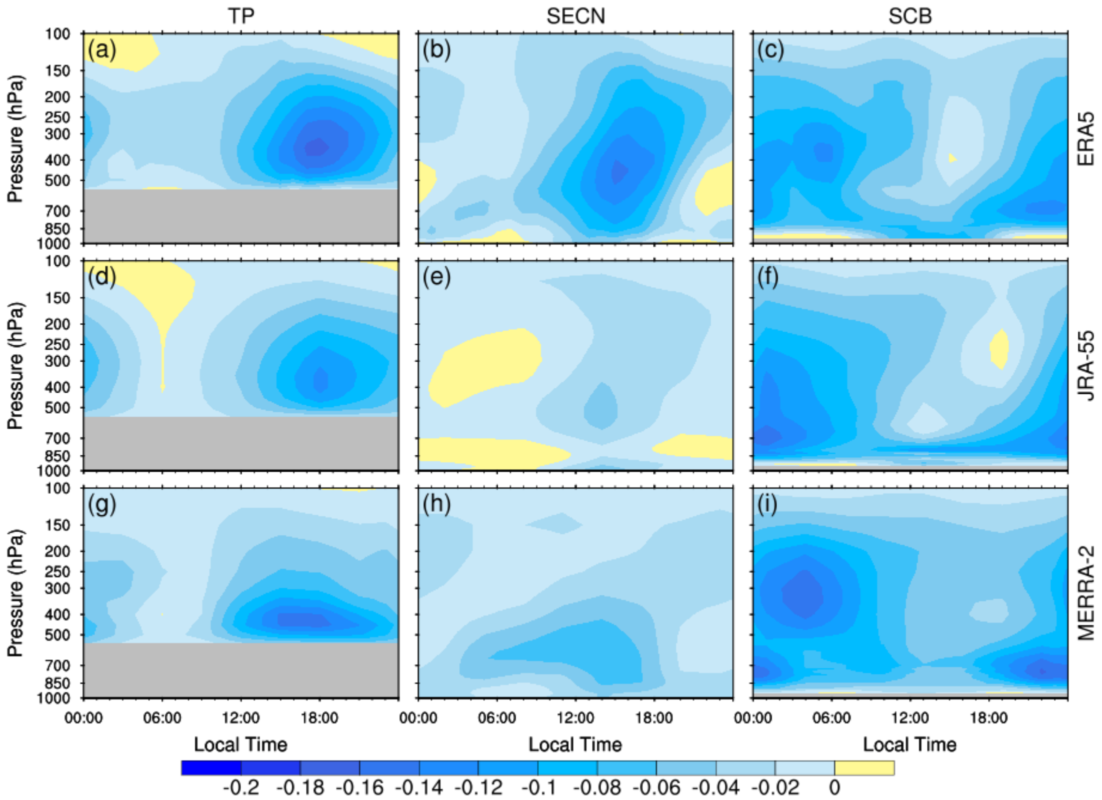

Figure R 6 Diurnal variation of vertical velocity over TP (left), SECN (middle) and SCB (right) from ERA5 (top), JRA-55 (middle) and MERRA-2 (bottom) averaged over observation events. Units: Pa s^{-1}.

3.The claim that convective precipitation in ERA5 and MERRA-2 follows CAPE more closely while JRA-55 aligns better with dCAPE is plausible but currently qualitative. Please add quantitative metrics (for each region and dataset), such as:

- *phase offsets between precipitation and CAPE/dCAPE,*
- *lead-lag correlations, or*
- *a simple regression-based phase estimate for each series with uncertainty.*

Also, briefly document (with citations) the relevant convective trigger/closure characteristics in the forecast models underlying each reanalysis, to support the triggering interpretation.

Thanks for your constructive suggestion. Following your recommendation, we quantified the phase offset of CAPE and dCAPE relative to convective and observed precipitation, as summarized in Fig. R7. Over TP, dCAPE lags CAPE by 3 hours in ERA5, 6 hours in JRA-55, and 3 hours in MERRA-2. Convection precipitation is nearly concurrent with CAPE in MERRA-2 (offset = 0.5 hour), whereas in JRA-55 it aligns more closely with dCAPE (offset =1.5 hours) than with CAPE (offset = −4.5 hours). In ERA5, convective precipitation falls between the two metrics, lagging CAPE by 1.5 hours and leading dCAPE by 1.5 hours. Over SECN, the phase differences between CAPE and dCAPE are relatively small (0.5–3 hour). The peak time of convective rainfall in MERRA-2 still aligns more closely with CAPE (offset = 0.5 hour) than with dCAPE (offset = −2.5 hour), while in ERA5 it falls between the two. Over SCB, ERA5 and MERRA-2 generate daytime convective rainfall peaks that coincide with the increase in CAPE, whereas JRA-55 exhibits nearly synchronized rainfall with dCAPE, with a peak offset of approximately 1.5 hours. We also compared the phase offsets between CAPE/dCAPE and observed precipitation. The results show that, with the exception of MERRA-2 over SECN, dCAPE exhibits a stronger alignment with observed precipitation than CAPE in all other cases. These are updated in the revision, see Line 326.

According to your suggestion, we also documented the relevant convective parameterization schemes for each forecast models (See Line 335).

"ERA5 employs a Tiedtke mass-flux scheme with a buoyancy-based (CAPE-like) trigger and a closure that scales the cloud-base mass flux to CAPE (ECMWF, 2016). Although the revised closure introduced by Bechtold et al. (2014) removes boundary-layer generated CAPE and thereby delays the convective response relative to

CAPE, rainfall in ERA5 still peaks ahead of dCAPE. This indicates that the modification remains insufficient to correct the premature development of convection, particularly over TP. The convective scheme in MERRA-2 is a modified Arakawa-Schubert formulation (Molod et al., 2015). It constrains convective intensity via relaxation of the cloud work function—an instability-based analogue of CAPE—so that rainfall peaks are tightly linked to CAPE evolution. JRA-55 employs a similar prognostic Arakawa-Schubert scheme, but incorporates a dCAPE-based trigger mechanism proposed by Xie and Zhang (2000) rather than relying solely on the absolute value of CAPE (JMA, 2013; Kobayashi et al., 2015). This explains why convective precipitation in JRA-55 is better synchronized with dCAPE."

Reference:

Bechtold, P., Semane, N., Lopez, P., Chaboureau, J.-P., Beljaars, A., and Bormann, N.: Representing Equilibrium and Nonequilibrium Convection in Large-Scale Models, J. Atmospheric Sci., 71, 734–753, https://doi.org/10.1175/JAS-D-13-0163.1, 2014.

European Centre for Medium-Range Weather Forecasts (ECMWF): IFS Documentation CY41R2, Part IV: Physical Processes, ECMWF, Reading, UK, available at: https://www.ecmwf.int/en/elibrary/79697-ifs-documentation-cy41r2-part-iv-physical-processes (last access: 15 March 2026), 2016.

JMA: Outline of the operational numerical weather prediction at the Japan Meteorological Agency, Tech. rep., Japan Meteorological Agency, Tokyo, available at: http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/outline2013-nwp/index.htm (last access: 15 March 2026), 2013.

Kobayashi, S., Ota, Y., Harada, Y., Ebita, A., Moriya, M., Onoda, H., Onogi, K., Kamahori, H., Kobayashi, C., Endo, H., Miyaoka, K., and Takahashi, K.: The JRA-55 reanalysis: General specifications and basic characteristics, J. Meteorol. Soc. Jpn., 93, 5–48, https://doi.org/10.2151/jmsj.2015-001, 2015.

Molod, A., Takacs, L., Suarez, M., and Bacmeister, J.: Development of the GEOS-5 atmospheric general circulation model: Evolution from MERRA to MERRA2, Geosci. Model Dev., 8, 1339–1356, https://doi.org/10.5194/gmd-8-1339-2015, 2015.

Xie, S. and Zhang, M.: Impact of the convection triggering function on single-column model simulations, J. Geophys. Res. Atmospheres, 105, 14983–14996, https://doi.org/10.1029/2000JD900170, 2000.

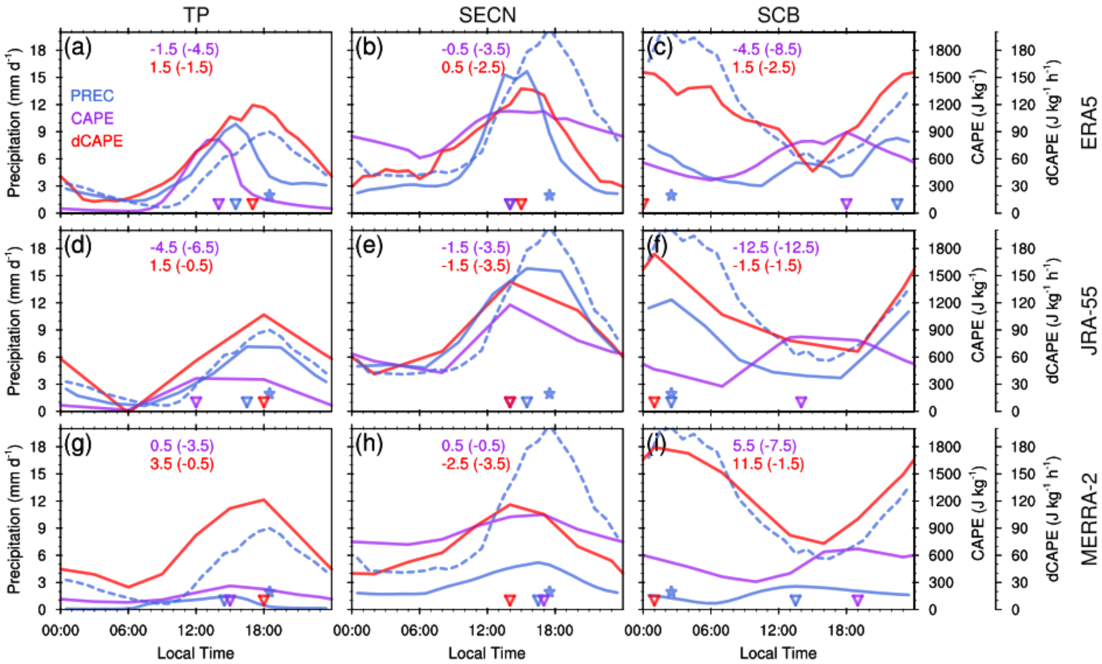

Figure R 7 Diurnal variations of simulated convective precipitation, CAPE and dCAPE over TP (left), SECN (middle) and SCB (right) from ERA5 (top), JRA-55 (middle) and MERRA-2 (bottom), with triangles marking the peak time. Dashed blue lines and stars represent the observed IMERG precipitation and its corresponding peak time, respectively. The numbers at the top of each panel indicate the peak time lead (-) or lag (+) in hours relative to the convective precipitation peak (values in brackets denote offsets relative to IMERG peak).

Minor comments:

Line 40-45: revise "continue still show" to "continue to show" or "still show".

Line 115-120: Change "Specially," to "Specifically,".

Line 115-120: Change "such the Sichuan Basin" to "such as the Sichuan Basin".

Data availability: "IMERGE" should be "IMERG".

All typos and gramma mistakes are corrected. Thank you.

Response to Reviewer #2:

Thank you for your professional review and instructive comments on our manuscript. We have revised the paper carefully based on your comments. These are described as follows (*italic text in blue color is from your review*).

The JJA diurnal precipitation cycle in China for reanalysis products – ERA5, JRA-55, MERRA-5 are evaluated using CMORPH and IMERG as observational baselines. With a process-oriented approach across three representative regions—Tibetan Plateau, southeast China, and Sichuan Basin—differences in the diurnal cycles are diagnosed using variables relevant to convection. It is shown that some reanalysis products are able to reproduce the correct diurnal cycle for the wrong reasons—MERRA-2 and ERA5 do so by suppressing convective precipitation. Findings are thoroughly discussed and biases in reanalyses are explained clearly. The study provides valuable information towards the limitations of these reanalysis products for model diagnostics and development. The only outstanding issue I find in its current form is how the comparisons between the products are handled—tests for robustness including more quantitative lead-lag correlations would greatly strengthen the results.

Major comments:

3.2 Composite Analysis

- *Do you change the precipitation threshold for the larger domain data? It seems you might be missing some days of precipitation if this is not taken into account. Or could you provide some plot that shows this isn't the case?*
- *It also seems MERRA-2 has a low sampling bias for its selected days. I'd recommend some type of test for robustness—perhaps using the pdfs of precipitation/ probability of precipitation?*
- *Again, with the convective mass flux, is this domain size dependent?*
- *How are the differences in the time resolution dealt with?*
- *You can average/resample the data according to your lowest resolution and repeat the results, or show how averaging impacts your plots.*

1) We applied the same precipitation threshold to each reanalysis. To assess the sensitivity of our results to this threshold, we conducted an extreme-case test in which the threshold was set to zero—selecting days based solely on the time criterion. As shown in Figure R8, the threshold primarily affects rainfall magnitude, while the key features relevant to our conclusions (e.g., phase and peak timing) remain unchanged. This demonstrates that the precipitation threshold does not introduce bias into phase-lead relationships.

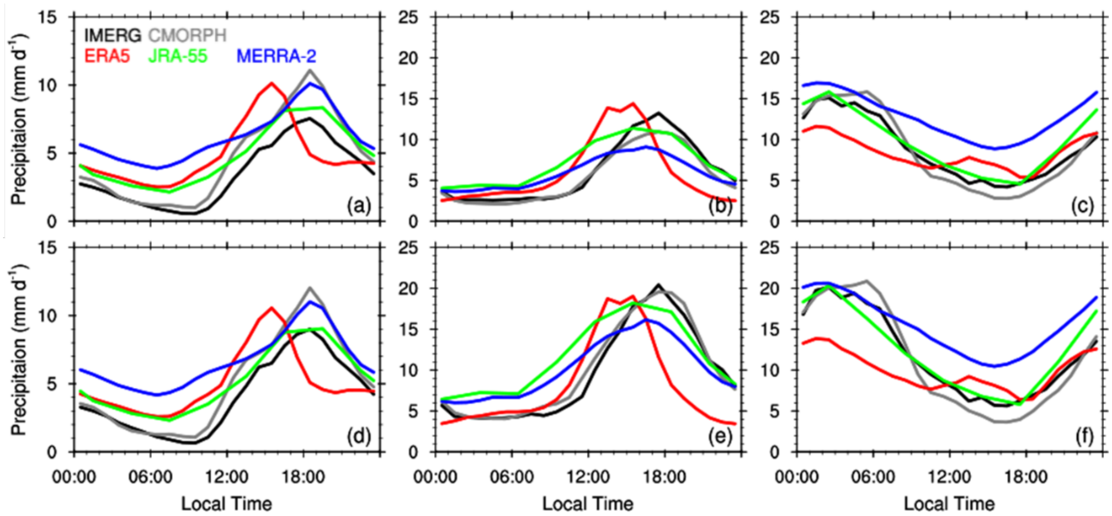

Figure R 8 Case-composite diurnal variations of precipitation over (a, d) TP, (b, e) SECN and (c, f) SCB. Top and bottom rows denote composite results with zero precipitation threshold and the original case composite, respectively.

2) The smaller number of selected events in MERRA-2 indeed reflects its intrinsic behavior in simulating afternoon rainfall phase and intensity. As shown in Fig. R9, over TP and SECN, MERRA-2 produces fewer afternoon peaks compared to the other datasets, resulting in fewer qualifying events after selection. Importantly, the phase characteristics remain robust regardless of the precipitation threshold applied, as demonstrated in Fig. R8. Therefore, we maintain that the features captured in the MERRA-2 composites are attributable to the model's inherent physical representation of afternoon rainfall.

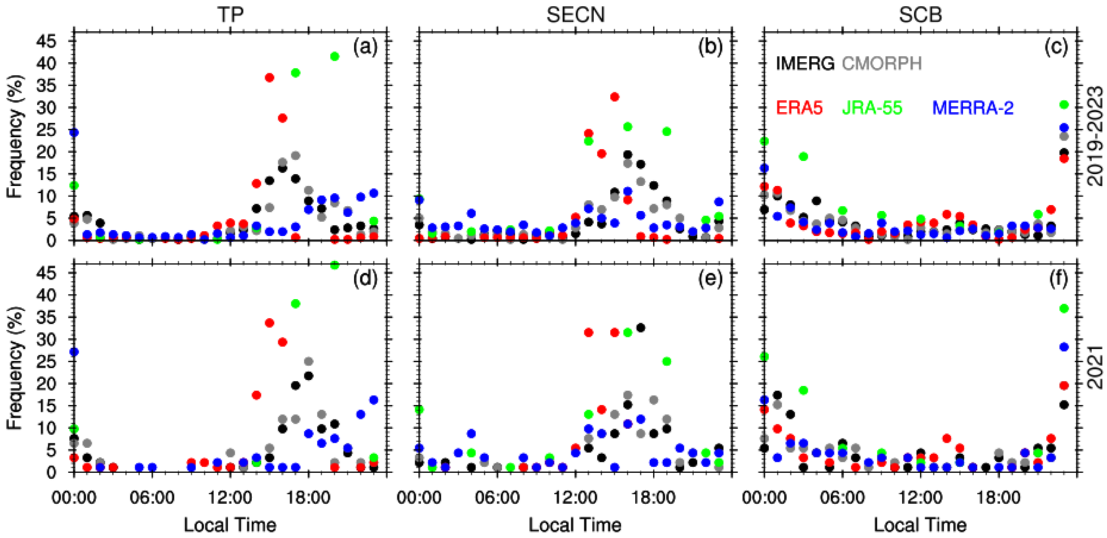

Figure R 9 Frequency of peak time for JJA of (a) 2019-2023 (top row) and 2021 (bottom row) over TP (left), SECN (middle) and SCB (right)

3) The convective mass flux was composited solely based on the precipitation event days identified in Table 1, with no additional thresholds or selection criteria applied. To assess the robustness of the results, we conducted an extreme-case test corresponding to the sensitivity analysis described in point 1 (i.e., setting the precipitation threshold to zero). As shown in Fig. R10, the overall patterns remain consistent with those in the original manuscript, despite a weaker mass flux over SECN and SCB—which corresponds to the reduced precipitation in Figs. R8b and R8c.

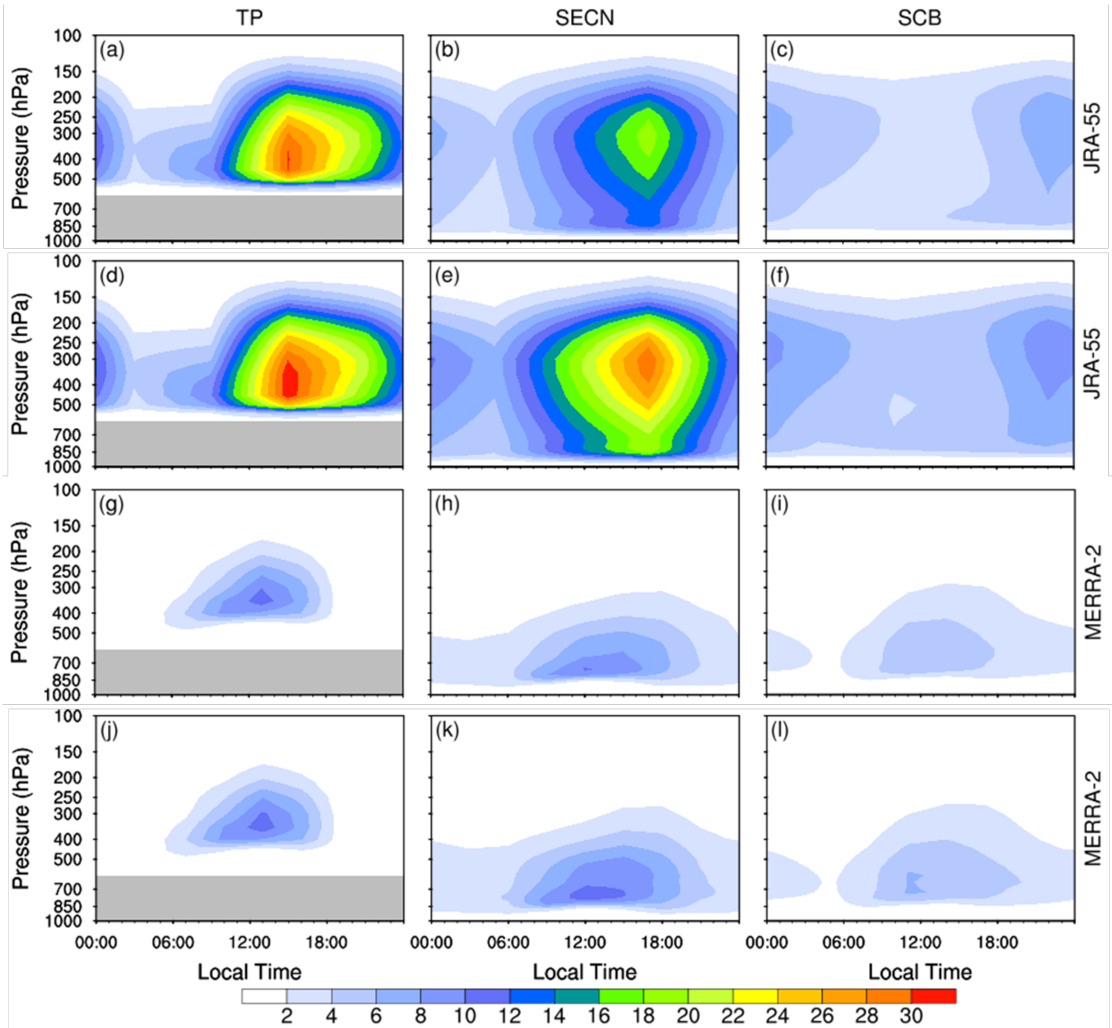

Figure R 10 Diurnal variation of cumulative mass flux (kg m^{-2} s^{-1}) for selected cases from (a–f) JRA-55 and (g–l) MERRA-2 over TP (left), SECN (middle) and SCB (right). (a–c, g–i) are case-composite results with thresholds of 0, (d–f, j–l) display the original one.

4) All variables were analyzed at their native temporal resolutions, with no interpolation applied during the analysis.

5) Following your suggestion, we resampled ERA5 and MERRA-2 to match the 3-hourly (surface) and 6-hourly (pressure-level) sampling of JRA55 (Figs. R11–R13). Results show that the diurnal phase distribution remains virtually unchanged (Fig. R11), and the characteristic biases in ERA5—such as premature onset and termination of convection over TP and SECN—remain evident despite the minor peak timing shifts (± 1 hour) due to the coarser temporal sampling (Fig. R12). The CAPE/dCAPE phase relationship also remains consistent with our native-resolution

analysis across all regions (Fig. R13). Therefore, while coarser sampling can introduce minor quantization effects, we confirm that the fundamental lead-lag relationships and physical inferences are not affected. These results have been included as supplementary material with brief discussion in the revised version. See Line 175.

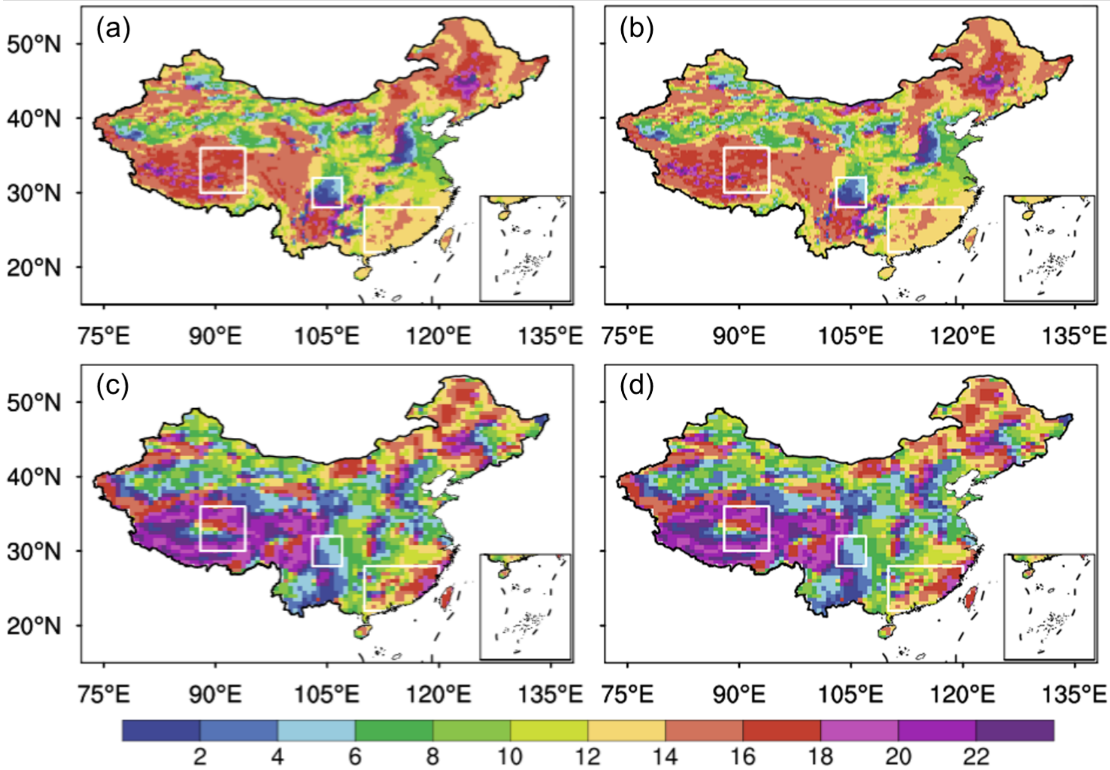

Figure R 11 Diurnal phase (local solar time, LST; the same hereafter) of total precipitation averaged over June–July–August (JJA) 2019–2023 for China from (a, b) ERA5 and (c, d) MERRA-2. **Left and right columns denote 3-hourly and 1-hourly (original) sampling, respectively.** White boxes mark the three representative regions: the Tibetan Plateau (TP, 30°–36°N, 88°–94°E), southeastern China (SECN, 22°–28°N, 110°–120°E), and the Sichuan Basin (SCB, 28°–32°N, 103°–107°E).

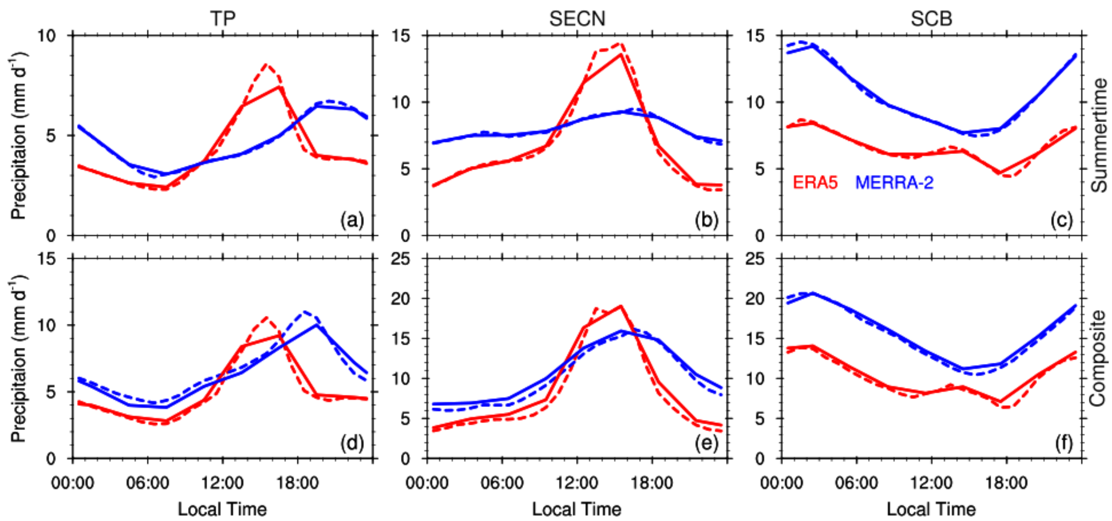

Figure R 12 Five-year JJA-averaged (top row) and case-composite (bottom row) diurnal variations of precipitation over TP (left), SECN (middle) and SCB (right). Solid and dashed lines denote down-sampled (3-hourly) and original (1-hourly) results, respectively.

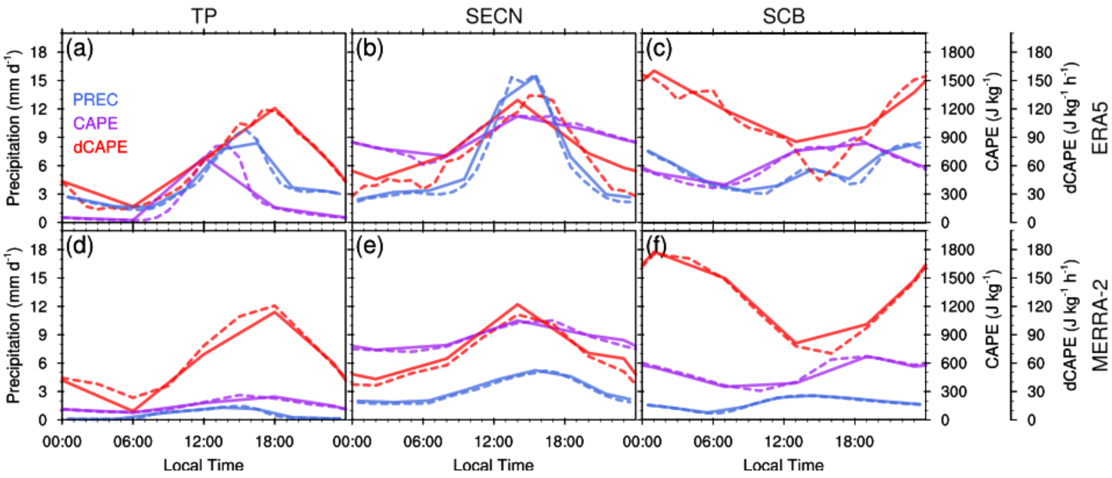

Figure R 13 Diurnal variations of convective precipitation, CAPE and dCAPE over TP (left), SECN (middle) and SCB (right) from ERA5 (top) and MERRA-2 (bottom). Solid and dashed lines denote down-sampled and original results, respectively.

5.1 Vertical Velocity

- *Figure 12 is very nice. I would like to see something more quantitative with it—lead-lag correlations with precip and dcape and cape? Alternatively, an intercomparison between models by scattering dcape vs precip should show the precipitation pickup and helps you compare region to region and model to model. See Ahmed et al. 2018 or Emmenegger et al. 2024.*

Thanks for your constructive comments. Given the limited sample size (4 time steps for JRA-55 and 8 for MERRA-2 in the composite diurnal series), which precludes robust lead-lag correlation analysis, and because scatter plots mainly reflect qualitative relationships rather than the timing alignment that is our focus here, we instead quantified the phase offset of CAPE and dCAPE relative to both convective and observed precipitation, as summarized in Fig. R14. Over TP, Observed precipitation aligns more closely with dCAPE and lags behind CAPE—by 4.5 hours in ERA5, 6.5 hours in JRA-55, and 3.5 hours in MERRA-2. Convection precipitation is nearly concurrent with CAPE in MERRA-2 (offset = 0.5 hour), whereas in JRA-55 it aligns more closely with dCAPE (offset = 1.5 hours) than with CAPE (offset = −4.5 hours). ERA5 shows an intermediate behavior, lagging CAPE by 1.5 h and leading dCAPE by

1.5 h. Over SECN, the lag of dCAPE behind CAPE is less pronounced (0.5–3 hour) than over TP, but convective rainfall peak in MERRA-2 still aligns more closely with CAPE (offset = 0.5 hour) than with dCAPE (offset = −2.5 hour), while in ERA5 it falls between the two. Over SCB, ERA5 and MERRA-2 generate daytime convective rainfall peaks that coincide with the increase in CAPE, whereas JRA-55 exhibits nearly synchronized rainfall with dCAPE, with a peak offset of approximately 1.5 hours. We have modified this figure and description in the revised manuscript, See Line 326.

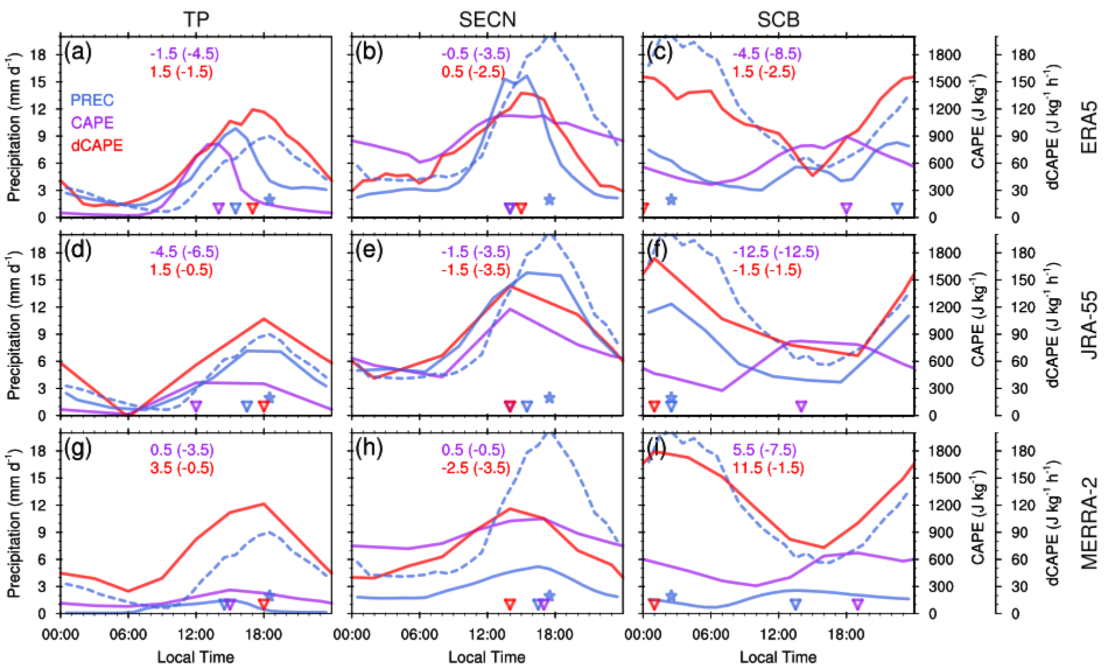

Figure R 14 Diurnal variations of convective precipitation, CAPE and dCAPE over TP (left), SECN (middle) and SCB (right) from ERA5 (top), JRA-55 (middle) and MERRA-2 (bottom), with triangles marking the peak time. Dashed blue lines and stars represent the observed IMERG precipitation and its corresponding peak time, respectively. The numbers at the top of each panel indicate the peak time lead (-) or lag (+) in hours relative to the convective precipitation peak (values in brackets denote offsets relative to IMERG peak).

Reference:

Ahmed, F. and Neelin, J. D.: Reverse engineering the tropical precipitation–buoyancy relationship, Journal of the Atmospheric Sciences, 75, 1587–1608, https://doi.org/10.1175/JAS-D-17-0333.1, 2018.

Emmenegger, T., Ahmed, F., Kuo, Y.-H., Xie, S., Zhang, C., Tao, C., and Neelin, J. D.: The physics behind precipitation onset bias in CMIP6 models: The pseudo-entrainment diagnostic and trade-offs between lapse rate and humidity, Journal of Climate, 37, 2013–2033, https://doi.org/10.1175/JCLI-D-23-0227.1, 2024.

Minor comments:

L81: Repeated citation

L117: I would change 'Specially' to 'Specifically'

L118: 'Such the' to 'Such as the'

All typos and gramma mistakes are corrected. Thank you.