Anonymous Referee #2

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The paper deals with the sensitivity of climate models to grid resolution and atmosphere/ocean coupling in simulating moisture transported from ocean/land moisture sources ending up as precipitation over East Asia. The study is innovative and the subject itself is of great interest, especially for the climate modelling community. The manuscript is well introduced, well organised and well written. Their analysis of biases is well founded, and findings are robust. However, I have some concerns about the discussion section and the use of reanalysis and observational data which need to be addressed prior to publication (see major comments below).

We thank the reviewer for the evaluation and comments. We have replied following each specific comment.

Major points

- It is not clear what is the exact period used to calculate the climatological annual mean precipitation for MetUM simulations, ERA-interim and Aphrodite datasets. Is this the common matching period 1982-2007 (if MetUM AN & CN512 is included the common period would be limited to 1992-2007), or different periods i.e. 1979-2007 for Aphrodite, 1982-2012 for MetUM AN/CN 96/216, etc. If significant trends are present in these timeseries (which is the case over several regions of East Asia in the Aphrodite timeseries) the choice of period may have significant impacts on the calculated climatological annual mean patterns. Ideally a common matching period for all datasets should be used, or, at least the associated inconsistencies when comparing annual mean precipitation patterns of products of different periods should be discussed in the text (i.e. in addition to inconsistencies related to AN/CN 512 shorter period simulations already discussed in the text).

As suggested by the reviewer, a common period of 1982-2012 is now used to calculate the precipitation climatologies for ERA-Interim, APHRODITE and MetUM simulations at N96 and N216 resolutions.

To accomplish this, the APHRODITE dataset has been extended from 2007 to 2012 using its product V1101EX-R1 obtained from the second phase of the APHRODITE project. According to its guidance (https://climatedataguide.ucar.edu/climate-data/aphrodite-asian-precipitation-highly-resolved-observational-data-integration-towards), this extension uses an algorithm consistent with that of the original dataset, but with added data and improved quality control.

We leave the precipitation climatology for the MetUM at N512 resolution for the period 1992-2012, as this is the period for which we have data and can track moisture for precipitation using WAM. Restricting all datasets to this period would greatly reduce the sample size for analysis in the other datasets (from 30 years to 20 years). Figure 2 in the revision has now been updated along with its caption. The climatological annual mean precipitation pattern in APHRODITE has not dramatically changed, as the pattern correlation coefficient between the old (1982-2007) and updated (1982-2012) periods is 0.99. In addition to Figure 2, data information in Section 2 is also updated accordingly.

Page 3 Lines 30-31 of the revised paper will read: "*To match with MetUM simulations, the period between 1982-2012 is used for both ERA-Interim and APHRODITE.*"

Page 4 Lines 18-20: "*Periods of simulation are listed in Table 1. Most simulations match the period of ERA-Interim (1982-2012) except N512 simulations which have a shorter simulation period (1992-2012).*"

- Along with Aphrodite, I could use an additional observationally-based dataset for land EA precipitation such as the CPC Unified Gauge-Based Analysis of Global Daily Precipitation (at 0.5 deg. resolution, available from 1979-present) which, in contrast with Aphrodite, is fully matching ERA-I and MetUM simulation periods, to estimate precipitation biases w.r.t. ERA-I and MetUM. Although these datasets are based more or less on the same gauge data stations, different interpolation methods to fill the gaps and different periods can have significant impacts on calculating the climatological mean pattern of precipitation.

Although we have matched the data availability of APHRODITE with ERA-Interim and the MetUM (see response to comment above), we have also followed the reviewer's suggestion to compare these products with an additional dataset. We chose another gauge-based gridded precipitation product, from the Global Precipitation Climatology Center (GPCC), which covers the same period and has a similar resolution to the CPC dataset. In terms of annual mean precipitation climatology, GPCC and APHRODITE are similar, with a pattern correlation coefficient of 0.89. With this information in mind, we continue to use APHRODITE in the rest of our manuscript.

The following modification will be added in the revisited manuscript on Page 3, Lines 31-33: "*Other precipitation observations from the Global Precipitation Climatology Center (GPCC; Schneider et al., 2014) are also used in comparison. Because of the similarity between the two datasets, only results from the APHRODITE are showed in the following text.*"

- Discussion section 5.1 is too short. Although the paper is focusing on the impact of model grid resolution and air-sea coupling on biases in moisture transport from ocean/land moisture sources ending up as precipitation over East Asia, more text could be included in the discussion section about representation of physical processes involved in moisture transport in East Asia in the reanalysis and MetUM simulations. You could briefly compare your findings with previous moisture source/transport diagnostic studies in East/Southeast Asia using Langragian models and reanalysis data (e.g. Sun and Wang, 2015; Baker et al. 2015; Chu et al. 2017).

The focus of this study is the comparison between reanalysis and simulations, as well as the sensitivity of simulated moisture sources to horizontal resolution and atmosphere-ocean coupling. We agree with the reviewer that understanding the physical processes that connect the moisture sources with the precipitation in target regions is equally important. In fact, we have prioritised the connection with the physical processes by publishing results on this topic prior to evaluating simulations. Details can be found in Guo et al. (2018, 2019).

We will add a comparison with the previous studies to the Discussion on Page 10-11 from Lines 25 onward: "*Moisture sources tracked using the WAM-2layers and the physical processes that link the source regions with the precipitation over EA have been discussed in detail in Guo et al. (2019). Compared with studies employing other moisture methods, the results are consistent (Sun and Wang, 2015; Baker et al., 2015; Chu et al., 2017). As also shown herein, the Indian Ocean provides the largest portion of moisture during boreal summer for precipitation over southeast EA. This contribution to precipitation decreases with the latitude of precipitation. Meanwhile, the moisture contribution from land sources increases with latitude. Local evaporation makes a larger contribution over the Tibetan Plateau compared to other EA subregions. During the boreal winter, due to the prevailing westerly and the frozen soil over the Eurasian continent, the Mediterranean Sea and other adjacent waterbodies become the major moisture contributor for precipitation over the mid-latitude EA subregions. MetUM simulations can generally capture most of these contributions, albeit with notable biases that vary with resolution and coupling. Similar biases have also been reported in Peatman and Klingman (2018), Stephan et al. (2017a, b).*"

- Although ERA-Interim shows indeed a good skill in simulating mean and inter-annual variations in land precipitation over East Asia this is not always the case for water cycling over the ocean. For example, P-E interannual variability in the tropical Indian Ocean is not well represented in ERA-Interim as compared to observationally-based products (see Skliris et al. 2014). This may affect the simulation of moisture transport from Indian Ocean moisture sources for SE Asia precipitation in ERA-Interim. In general, there are large discrepancies between the different reanalyses in representing E & P variations over the ocean (see Schanze et al. 2010). A more critical discussion is needed in the text concerning the use of a single reanalysis product as a benchmark to compare moisture sources traced from climate model simulations.

We thank the reviewer for this suggestion. We will add a discussion on Page 11 between Lines 3-10: "*ERA-Interim is employed here for evaluating the simulations. It is chosen for its small residual in the global hydrological budget, its accurate representation of the mean and interannual variability of EA monsoon precipitation and its resemblance to the observation of evaporation over China (Trenberth et al., 2011; Lin et al., 2014; Sun and Wang, 2015). However, the ERA-Interim has noticeable biases in the representation of the water cycle over the ocean, i.e., the P-E interannual variability in the tropical Indian Ocean is not well represented compared to observations (Skliris et al., 2014; Schanze et al., 2010). This bias could potentially affect the moisture contribution from the Indian Ocean estimated with ERA-Interim. To deliver more accurate information on the performance of MetUM in terms of tracking moisture sources, multiple reanalysis datasets should be included, so that biases from any single reanalysis dataset can be identified and considered.*".

- I would suggest to additionally use the ERA5 dataset (which replaced ERA-Interim a year ago) in your analysis which has much higher horizontal resolution (_30km) and with considerable improvements w.r.t. ERA-interim including better global balance of precipitation and evaporation and better precipitation over land, especially in the tropical regions. In addition, this way you may also investigate the impact of higher model resolution on the reanalysis biases and compare changes due to increasing resolution in products with similar resolution in ECMWF and MetUM products (i.e. ERA-Interim/AN216 vs. ERA5/AN512). Although I recognise that this requires a considerable extra effort and while the paper is publishable in its current form, I think it could strengthen your analysis and further improve the robustness of your findings.

We will include the ERA5 in a future multi-reanalysis comparison of moisture sources, which has been suggested by the reviewer in a previous comment. However, at this stage of the work, it is too much effort to recompute the moisture sources and model biases against ERA5, rather than the ERA-Interim. Although ERA5 is an improvement on ERA-Interim, there are few studies published so far to suggest a better representation of the circulation in ERA5 for East Asia and the surrounding regions. The purpose of the manuscript is to show the large-scale biases in moisture sources in MetUM, which we think are adequately depicted when MetUM is compared against ERA-Interim, which was the state-of-the-art reanalysis when we performed the analysis and the WAM-2layers simulations.

Minor points

- You should provide the ERA-Interim space grid resolution in section 2.1

ERA-Interim space grid resolution has been specified in Section 2.1.

- I would suggest to use MetUM AN216 (rather than AN96) to compare with ERA-Interim in figures 2 & 4 as these two datasets have similar horizontal grid resolution.

As answered in previous comment, we downloaded ERA-Interim on a 1.5°×1.5° grid from its data portal. Therefore, keeping the comparisons with AN96 in Figures 2 and 4 seems reasonable. As mentioned in our manuscript, the sensitivity of simulated moisture sources to horizontal resolution (i.e., the difference between AN96 and AN216) is small compared to the model bias of either simulation against ERA-Interim. Figures 2 and 4 look quantitatively similar when replacing AN96 with AN216:

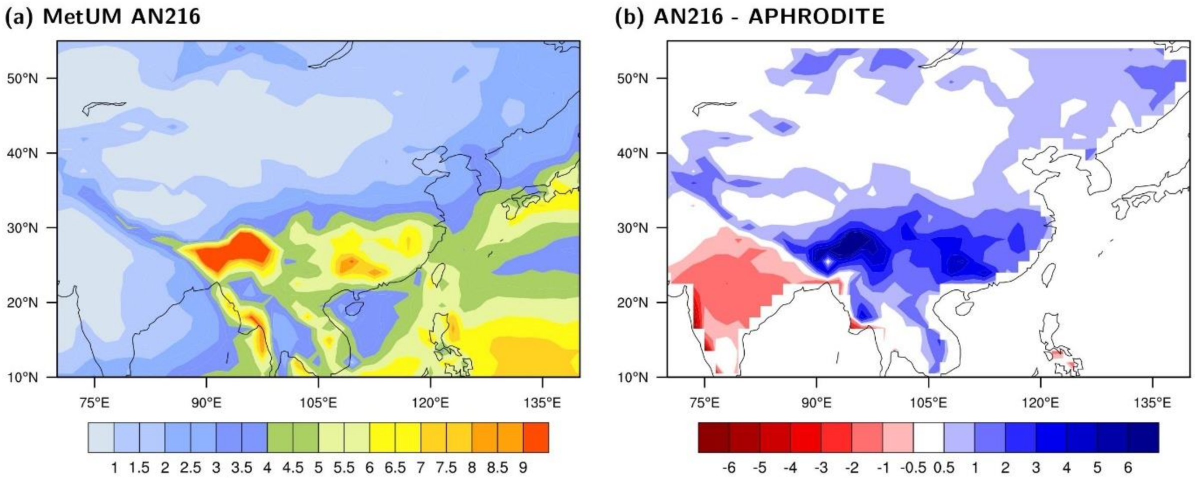

Figure R1. Annual mean precipitation of (a) MetUM AN216 and its difference with APHRODITE. Units: mm/day. The annual precipitation are averaged over 1982-2012.

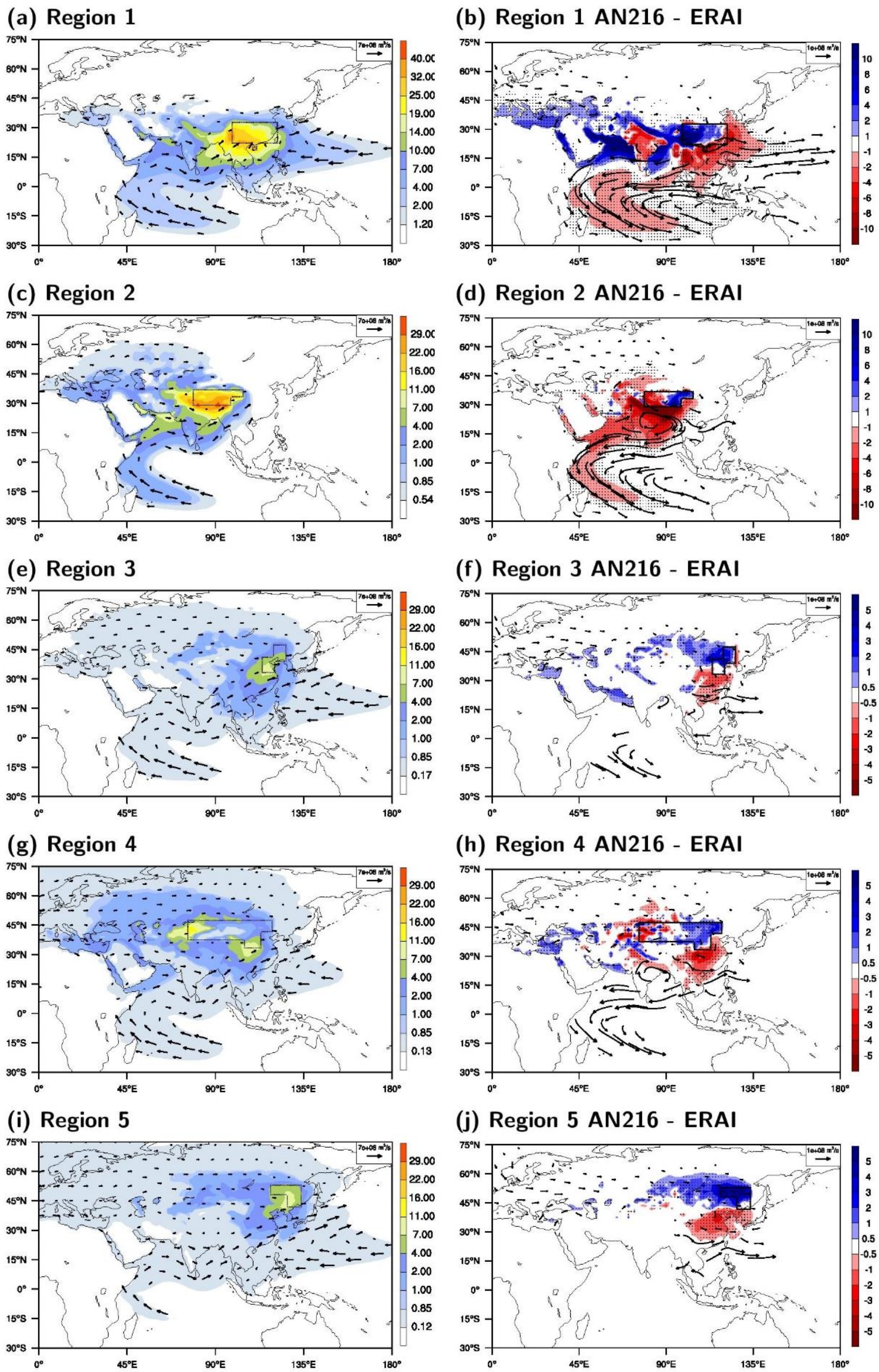

Figure R2. Annual mean moisture source for EA subregions (a, c, e, g and i, units: mm/month) and vertically integrated moisture flux (vector, units: m^3/s) calculated from ERA-Interim. Moisture source accounts for 80% of precipitation is shown. Difference in annual mean moisture sources between AN216 and ERA-Interim (b, d, f, h and j). Units: mm/month (Skliris et al. 2014). Black box in each panel indicates the target region.

- Table 1: Please indicate units for horizontal grid resolution (degrees) and vertical resolution (levels)

Units have been added to the Table 1. Text in both the Table 1 caption and Section 2.2 have been modified.

- Typing errors Line 274: " . . . the eastern Tibetan Plateau, where the sruface is wetter. . ." Change into "surface

Correction has been made.

References

Baker, Alexander J., Harald Sodemann, James U. L. Baldini, Sebastian F. M. Breitenbach, Kathleen R. Johnson, Jeroen Van Hunen, and Pingzhong Zhang. 2015. 'Seasonality of westerly moisture transport in the East Asian summer monsoon and its implications for interpreting precipitation δ18O', *Journal of Geophysical Research: Atmospheres*, 120: 5850-62.

Chu, Qu-Cheng, Qi-Guang Wang, and Guo-Lin Feng. 2017. 'Determination of the major moisture sources of cumulative effect of torrential rain events during the preflood season over South China using a Lagrangian particle model', *Journal of Geophysical Research: Atmospheres*, 122: 8369-82.

Guo, Liang, Nicholas P. Klingaman, Marie-Estelle Demory, Pier Luigi Vidale, Andrew G. Turner, and Claudia C. Stephan. 2018. 'The contributions of local and remote atmospheric moisture fluxes to East Asian precipitation and its variability', *Climate Dynamics*.

Guo, Liang, Ruud J. Van Der Ent, Nicholas P. Klingaman, Marie-Estelle Demory, Pier Luigi Vidale, Andrew G. Turner, Claudia C. Stephan, and Amulya Chevuturi. 2019. 'Moisture Sources for East Asian Precipitation: Mean Seasonal Cycle and Interannual Variability', *Journal of Hydrometeorology*, 20: 657-72.

Skliris, Nikolaos, Robert Marsh, Simon A. Josey, Simon A. Good, Chunlei Liu, and Richard P. Allan. 2014. 'Salinity changes in the World Ocean since 1950 in relation to changing surface freshwater fluxes', *Climate Dynamics*, 43: 709-36.

Sun, Bo, and Huijun Wang. 2015. 'Analysis of the major atmospheric moisture sources affecting three sub-regions of East China', *International Journal of Climatology*, 35: 2243-57.