Authors' reply to Anonymous Referee #3

We are very grateful to the referee for his/her appreciation of the effort that went into the creation of our manuscript and we thank him/her for the detailed comments to our manuscript. We have done our best to answer all questions and incorporate the referee's suggestions. In our reply below, referee comments appear in *italics*, our reply in normal font, and changes to the manuscript in blue.

General Comments:
It is an overall well-written manuscript comprehensively addressing a truly important subject on freshwater fluxes over ocean and (the associated) water budget closure by using and intercomparing seven credible and lengthy globally-covered products of evaporation and/or precipitation (six generally satellite-based datasets, along with one reanalysis). This reviewer would like to acknowledge the authors for their willing to challenge themselves and tackle such a subject that would almost (if not absolutely) guarantee and require tremendous efforts and time, and persistent commitments, let alone equipping with solid expertise and knowledge, and great ideas and insights. However, a few relatively major concerns may need further elaboration or revisions. Several minor revisions are also suggested.
Finally, this reviewer considers that the authors deserve a solid credit, again for their tremendous efforts and crucial works. This reviewer will highly recommend this manuscript for publication by Hydrology and Earth System Sciences (HESS) (an Open Access Journal) should the following suggested revisions be properly conducted accordingly.
We are much obliged!

Major Comments/Suggestions/Revisions:
1) E-P uncertainty involving E uncertainty and P uncertainty:
The uncertainties of E-P of different sets of products involved and targeted in this study should mainly be depending on the respective uncertainties of the P and E products, e.g., for IFREMERG(E-P) = IFREMER(E) - GPCP(P), the uncertainty of IFREMER-G(E-P) should supposedly be an added sum of the uncertainty of IFREMER(E) and the uncertainty of GPCP(P). These respective E and P uncertainties, however, are not among the main focuses of this study (as the authors have indicated). It'd be very understanding and foreseeable that such (additional) tasks of investigating and analyzing (or may even need to newly generate or estimate) the respective P and E uncertainties would add up another level of difficulty and efforts, especially if/when researchers were not directly involved in those P and E productions, and the currently available related uncertainty info's have been quite limited (which have also been revealed in this manuscript). As for "We conclude that for a better understanding of the global water budget, the quality of E and P data sets themselves and their associated uncertainties need to be further investigated", this reviewer has fully agreed on this critical "conclusion" finding, which, honestly speaking, has also been "expected" during the midst of review. It might also be fair and reasonable to alternately say "for a better understanding of the global fresh water (E-P or P-E triggered by seeing the assumptions made in Eqs. 1-3)
The referee is correct in stating that the total E-P uncertainty is the sum of the uncertainty of both E and P components. Or, to be even more exact: the root of the squared sums. That is how we calculated total uncertainty ranges for HOAPS and OAFLUX-G (as described in Sect. 3). At the time of first submission, none of the other E (or LHF) satellite data sets contained uncertainty estimates. The recent publication of SEAFLUX version 3 allowed us to update our manuscript with much improved SEAFLUX E data. As these contain associated random uncertainty estimates, we updated Fig.2, where previously only HOAPS and OAFLUX-G were examined for significant differences with ERA5, with SEAFLUX-G data:

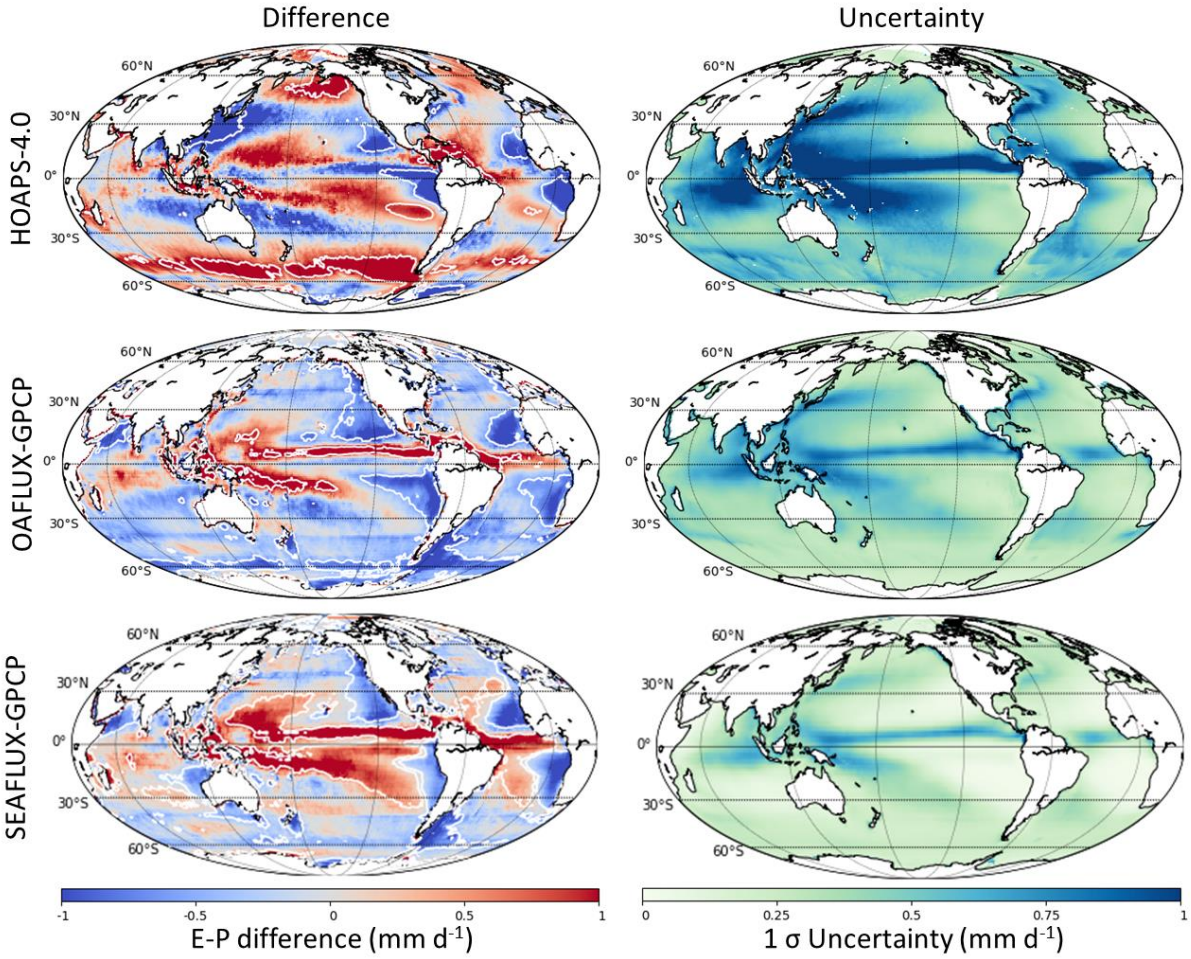

Figure 2. Left panels: Difference maps of HOAPS (upper), OAFlux-G (center), and SEAFLUX-G (lower) climatological mean E-P minus the corresponding collocated ERA5 climatology (1997-2013). Right panels: HOAPS (upper), OAFlux-G (center), and SEAFLUX-G (lower) climatological mean 1σ uncertainty. White lines in the left panels enclose regions where the difference with ERA5 E-P exceeds the 2σ uncertainty range.

Moreover, we changed the word "investigated" on line 23 to "improved", and the statement on line 568 was changed, following the suggestions of referees 2 and 3:

"In general, the quality of observations of the water cycle needs to improve before attempts at assessing effects of climate change from those data can be undertaken. The importance of accompanying high-quality uncertainty information cannot be overstated."

2) The assumptions of neglecting ∇Q or ΔW for global or regional scales have trigged this reviewer wondering about their potential impact on the E-P uncertainty. Here's the comment that the authors may feel free to respond or not (Optional).

In the case of omitting ∇Q or ΔW, it might cause two folds of potential impacts, hypothetically: 1) if neither ∇Q nor ΔW would carry uncertainties, then the currently estimated uncertainty of EP in this study could have been overestimated since part of the estimated uncertainty might have been implicitly contributed by the being-omitted "true" amounts of ∇Q or ΔW (even though being small, but had been neglected), 2) if either/both ∇Q or/and ΔW would carry uncertainties, then the currently estimated uncertainty of E-P in this study could have been underestimated, especially if/since the uncertainties of ∇Q or ΔW (if available and "certain") would be sufficiently large (greater than their true amounts) and add an additional net amount of uncertainty into E-P, otherwise. The E-P

uncertainty could have still been overestimated as in "1)" if the true amounts of ∇Q or ΔW are larger than their respective uncertainties.

To answer this interesting comment, we need to separate the treatment of ∇*Q* (corrected to ∇(*vq*) in in the revised manuscript) and ΔW. The global total of ∇(*vq*) is exactly 0, hence Eq.2 is exact on a global scale and not an approximation (please note that the non-zero global total ∇(*vq*) found in ERA5 was commented upon by Referee #2). This is not the case for ΔW, which we chose to ignore on regional scale for time periods larger than one month. Averaged over the globe, ΔW varies between -0.03 and 0.03 mm d^{-1} , balancing the global total E-P (Eq.2 and Fig.7 in the manuscript). Regionally, monthly ΔW are at least a factor of 10 smaller than E-P (or ∇(*vq*)), as shown exemplarily for December 2013 below.

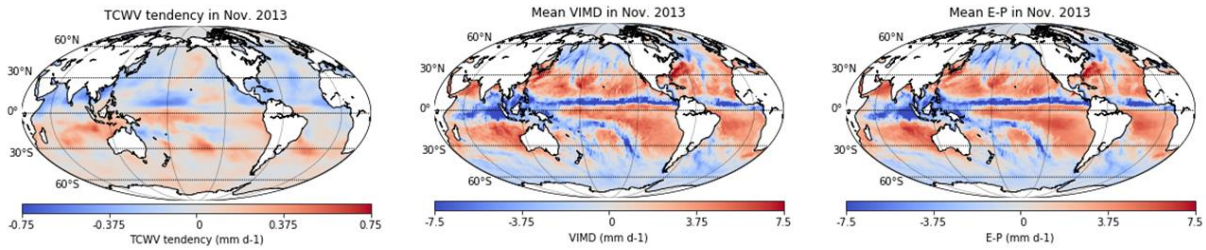

Figure A. Maps of TCWV tendency, VIMD, and E-P from ERA5 for November 2013. Note that the color scale is a factor of 10 smaller for TCWV tendency than for VIMD or E-P.

On a monthly and regional scale, ΔW and the associated uncertainty (which is small) can be safely ignored and ∇(*vq*) should be equal to E-P. This is very nearly exactly true for ERA5, as can be seen in the figure above, by the high correlations noted for ERA5 in Table 3 and in Fig. A2 in the manuscript. On lines 390—392, we note that: "It can, however, be argued that VIMD from reanalysis is a more reliable quantity than reanalysis E-P, since VIMD is calculated from the state variables wind and water vapor, whereas E and P are model-physics derived (e.g., Trenberth et al., 2011))." The uncertainty of VIMD is, therefore, smaller than that of E-P, but of its magnitude we can only say that the uncertainty range determined from the ensemble is, in all likelihood, a lower bound.
The correlation coefficients in Table 3 were calculated without taking into account uncertainties, and the uncertainty ranges for Table 4 were derived from the E, P, E-P and other data sets themselves.
Hence, we appreciate the thoughts of the referee on the neglect of terms (ΔW and ∇(*vq*)) as an additional source of uncertainty to budget calculations, but do not see at which point in the manuscript this may be relevant.

3) On line 272 (related to Fig. 1):
A seemingly correct but actually questionable (not quite proper) statement that needs a "major" attention and revision. "A and B shows that the E-P pattern is mainly determined by P, as there is less spatial variation in E."
It should be more accurate to state "A and B shows that the E-P pattern is mainly determined by P in the tropical and high-latitude regions, but determined by E in the subtropical regions." It's also the absolute magnitudes/intensities of E or P, not just only their spatial variation that would matter. Actually, if "warm" color (red) and "cold" color (blue) were applied for E (panels C and D) and P (panels E and F), respectively, such crucial features (reviewer's points) would have been better revealed. Perhaps, the authors may genuinely consider it.
The reviewer is right about the statement on line 272, and we corrected it as suggested. We also modified the color scale of the evaporation and precipitation plots in Fig. 1:

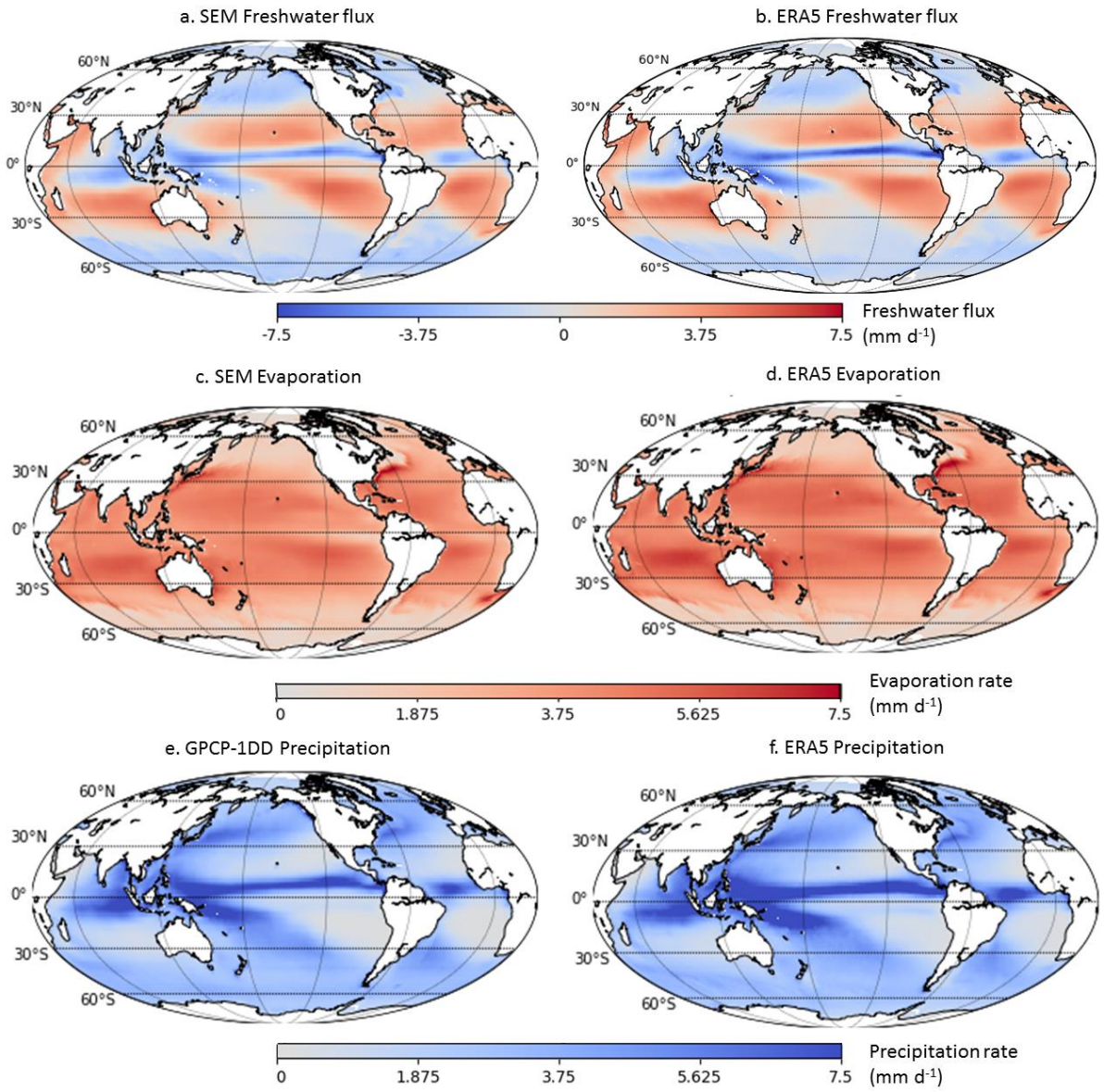

Figure 1. Satellite ensemble median (SEM) and ERA5 climatologies (1997-2013) of freshwater flux (a and b) and evaporation (c and d), and GPCP and ERA5 precipitation (panels e and f). ERA5 data coverage was reduced to match satellite data (see text for details).

4) The authors would sometimes describe, elaborate or discuss the features or findings shown via figures or panels, but without consistently and explicitly citing them along the presentation/writing.
The referee is right. We added references to the respective figure panels on lines 308, 325, and 337.

Minor Revisions:
1) On line 46:
Suggest change "are the most widely used data sets." -> "are among the most widely used data sets."
Done.

2) On lines 58-59:
Suggest change "With W the total column water vapor and ∇Q the moisture divergence, i.e., the amount of moisture removed by advection from the considered volume." -> "With W the total column water vapor and ∇Q the total moisture divergence or convergence, i.e., the amount of moisture associated with the moisture advection and the mass divergence or convergence scaled by water vapor from the considered volume."

The statement on lines 58-59 was not quite accurate. We replaced it with: "With W the total column water vapor and ∇(qv) the moisture flux divergence, i.e., the amount of moisture removed by dynamical transport from the considered volume."

3) On line 157:
Suggest change "Version 2 (GSSTF2.0, Shie et al. (2009))" -> "Version 2; 2c (GSSTF2.0, Chou et al. (2003); GSSTF2c, Shie et al. (2009))" and the following respective reference should thus be included: Chou, S.-H., E. Nelkin, J. Ardizzone, R. Atlas, and C.-L. Shie, 2003: Surface Turbulent Heat and Momentum Fluxes over Global Oceans Based on the Goddard Satellite Retrievals, Version 2 (GSSTF2), J. Climate, 16, 3256-3273. [10.1175/1520-0442(2003)016<3256:STHAMF>2.0.CO;2]
Done.

4) On line 206:
Suggest revise "see, e.g., Kidd and Huffman, 2011; Tapiador et al. , 2017)" -> "see, e.g., Kidd and Huffman, 2011; Tapiador et al., 2017)"
The spurious space is caused by the HESS LaTex template. Hopefully, the copy editor will remove it before publication.

5) On lines 207-208 :
Suggest revise "which makes us of its own P data)" -> "which makes use of its own P data)"
Done.

6) On line 210:
Suggest change "The Global Precipitation Climatology Project - 1 Degree Daily (GPCP-1DD; denoted GPCP hereafter)" -> "The Global Precipitation Climatology Project - 1 Degree Daily (denoted GPCP and GPCP-1DD, respectively, hereafter)"
In the presented study, only GPCP-1DD data are used for comparison and for calculation of E-P. In an attempt to make the manuscript, which contains many acronyms, more readable, we left out the versions of the algorithms in the main text (e.g., HOAPS-4.0 is referred to as "HOAPS"). For brevity and consistency, we prefer to denote GPCP-1DD as "GPCP" throughout the manuscript.

7) On line 235:
Suggest revise "consisting of 10 seperate model runs" -> "consisting of 10 separate model runs"
Following the advice of referees 1 and 3, the sentence was revised to: "consisting of 10 separate reanalysis runs".

8) On line 389:
Suggest revise "we are also examine the separate contributions" -> "we also examine the separate contributions"
Done.

9) On line 458:
Suggest revise "(Oki and Kanae , 2006 " -> "(Oki and Kanae, 2006;"
Please see our answer to comment 4.

10) On line 574:
Suggest revise "(e.g, Allen and Ingram , 2002; Held and Soden , 2006; Trenberth et al., 2007)." -> "(e.g., Allen and Ingram, 2002; Held and Soden, 2006; Trenberth et al., 2007)."
Again, please see our answer to comment 4.

11) In Fig. 3B:
There are four kinds of shading shown with three precipitation data sets. The extra "dummy" shading should be removed.

This is not dummy shading, but the overlap of two colors. This was apparently somewhat confusing and the addition of the SEAFLUX3 uncertainty range did not improve the readability of the plot, therefore, we changed Fig. 3 and its caption to:

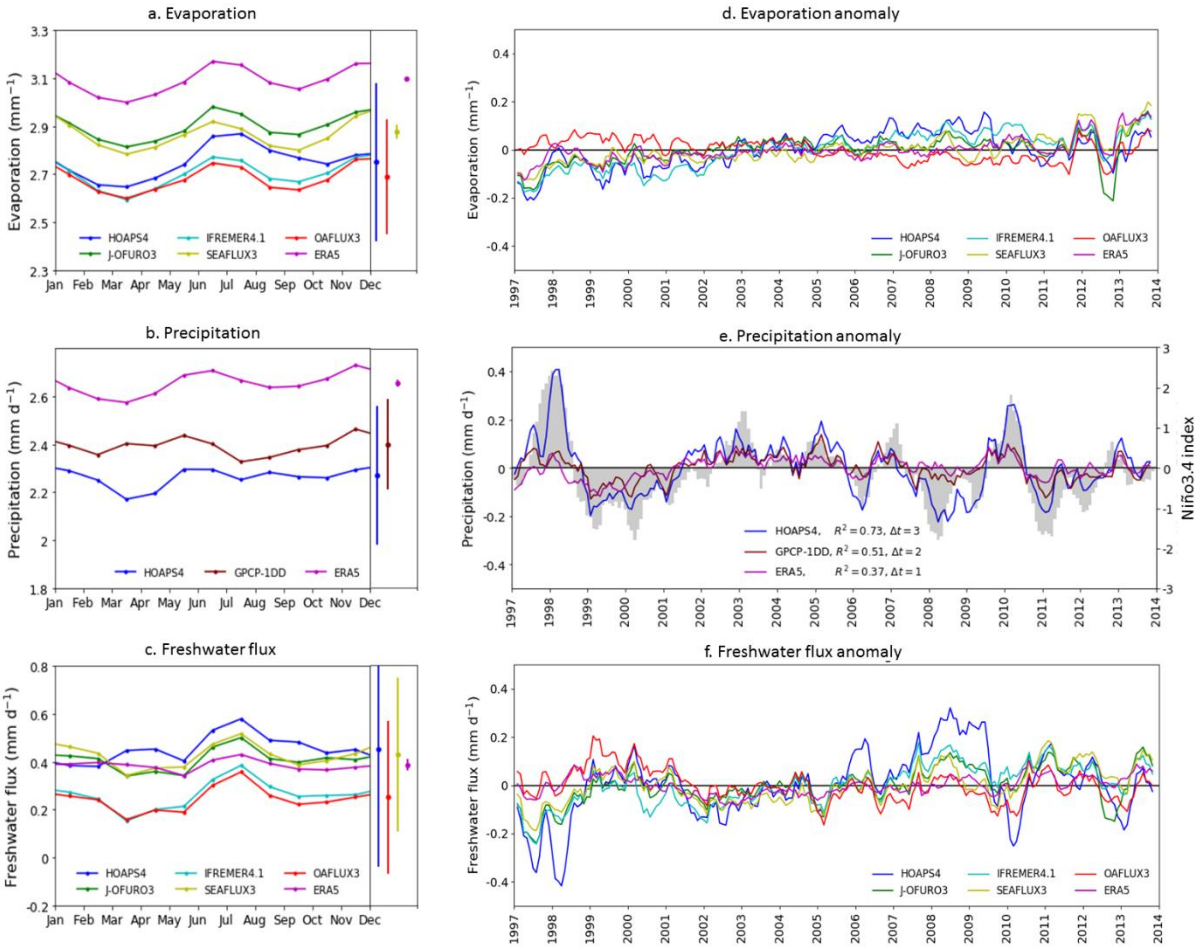

Figure 3. Climatological (1997--2013) seasonal cycle of global ocean mean evaporation rate (a), precipitation rate (b), and freshwater flux (c). HOAPS, ERA5, OAFlux, SEAFLUX, and GPCP mean values and associated 1σ uncertainty ranges are shown in the boxes to the right of the panels. Monthly mean anomaly (w.r.t. the climatological seasonal cycle depicted at left) over the global oceans (80°S--80°N) of evaporation rate (d), precipitation rate (e), and freshwater flux (f). The anomaly data are smoothed using a three-month running mean. Panel e additionally displays the Niño3.4 index shifted by +3 months (right y-axis). The legend additionally displays the correlation coefficient of the Niño3.4 index with P anomalies and the time lag of highest correlation (Δt in months). Ticks on the time axis mark January of the indicated year.

12) On line 573-574:
"its water-holding capacity increases at a rate consistent with the Clausius-Clapeyron relationship (e.g, Allen and Ingram , 2002; Held and Soden , 2006; Trenberth et al., 2007)"
Here's one paper (i.e., Shie et al., 2006) that also addressed a Clausius-Clapeyron scenario focusing on tropical oceans. It may be considered and included as one reference.
Shie, C.-L., W.-K. Tao, and J. Simpson, 2006: A note on the relationship between temperature and water vapor over tropical oceans, including sea surface temperature effects, Special Issue of Advances in Atmospheric Sciences, Vol. 3, No. 1, 141-148. doi: 10.1007/s00376-006-0014-5
Electronic copy may be accessible at
http://www.iapjournals.ac.cn/fileDQKXJZ/journal/article/dqkxjz/2006/1/PDF/231scl.pdf

Thank you for pointing us to this paper, we have included it into the manuscript!