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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Trajectory analysis on the origin of air mass and moisture associated with Atmospheric Rivers over the west coast of the United States" *by* J.-M. Ryoo et al.

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We thank the Referee for taking the time to read and comments on our paper. We appreciate the fact that this work is interesting and important topic. We agree that this work will be improved for publication by rephrasing sentences, reducing the repetitive text and improving figures. However, we do not agree that this paper is of a low technical quality. As noted this paper uses a trajectory model to understand the origin and pathways of air masses and moisture associated with Atmospheric Rivers (ARs). Satellite observation shows that most moisture resulting in heavy precipitation associated with ARs comes from the tropics along the Low Level Jet near the sur-

face. However many studies also show that ARs often occur along frontal zones, in particular, the warm part of extratropical cyclones. In addition, although satellite measurements (Neiman et al., 2008) confirm that precipitation events associated with ARs in North America are closely related to the enhanced atmospheric moisture transport, they do not represent the sources or transport of water vapor because the observed water vapor bands are just snapshots. Therefore, to find the transport pathway and the origin of air masses and moisture associated with atmospheric rivers it is necessary to use a Lagrangian trajectory model. That was the goal of this work. Although ARs contribute as much as 20-50 Therefore, we feel strongly that these novel results and methods make this paper worthy of publication and it is certainly appropriate for ACP, which has published many transport studies in the past. Differences in parcel pathways and in moisture transport from varying processes suggest possible mechanisms need to be taken into account in future AR studies. This is further justification for publication. Detailed responses to major comments are as follow, with double quotation marks paraphrasing the Referee's concerns.

1) Technical aspects: i) "The language is in parts substandard and some passages are unnecessarily complicated and redundant." We will correct and remove the repetitive citations in the result section. The text can be shortened as well. Complications in the figures may come from the overplots of many different dataset (we deal with high time resolution trajectory data using three different reanalysis data: NCEP, MERRA, ECMWF-interim). Supplementary figures and detailed explanations of the method were intended to highlight the merit of the method used in this study. We will replace this part with simplified figures and explanations in a revised version.

2) Method: i) "Concern that our statement regarding no parameterization of the model is incorrect, because all wind field and diabatic heating rates from the reanalysis data are determined by model physics and parametrization schemes." That is certainly valid, and we will be more careful in pointing this out in the text. But, our original intention was not to hide the impact of parameterizations on reanalysis data, but to emphasize

the simplicity of our trajectory model. We have fully compared the trajectory result using different reanalysis data, which are based on different model physics, but there is no large sensitivity in trajectory pattern no matter what reanalysis data is used. This strongly supports the general conclusions reached by our methodology. ii) “The reconstruction of trajectory simulated water vapor shown in figure 4 doesn’t agree with reanalysis water vapor.” However, the point of this figure is that moisture transport by the large-scale circulation is the primary factor explaining the moisture transport associate with AR events. Although there is some mismatch between trajectory simulated and reanalysis water vapor, trajectory simulations recreate the shape of the moisture field in both reanalysis data sets, to first order. Trajectory simulated water vapor shows excellent agreement in the upper level water vapor measured by AIRS satellite, because the advection by the mean flow is the dominant process in the moisture transport at upper levels (250 hPa) (not shown, Dessler and Minchwaner, 2007). In this paper we tested the extent to which advection of moisture by large-scale flow can explain moisture transport associated with extreme precipitation events near the surface (3km above the surface, 300K isentropic surface). This shows that the advection of moisture by the large-scale mean flow is still the primary factor in determining the moisture associated with extreme precipitation event affecting the west coast of the U.S. From figure 4 we are able to obtain important information indicating other important factors controlling water vapor transport, such as condensation, mixing etc. Of course this can be expected, but no study has been performed to show trajectory models at this level. Therefore, this could be seen as imprecise figure, but actually the right figure that we wanted to present. The vertical structure of reconstruction of water vapor shown in Figure 5 is not very good, but this may come from the coarse resolution of vertical interpolation. Approaching the tropics, trajectory accuracies become poorer, making the mismatch between trajectory water vapor and reanalysis water vapor large. But there is still general agreement over the 30-50N region where we focused, especially when using ECMWF-interim.

3) Trajectory length: i) “The trajectory length we use in this paper cannot be appro-

priate.” We think this seems to be a result of some misunderstanding. The choice of trajectory length has been discussed in several studies (e. g., Bao et al., 2006, Waugh, 2005). The lead author of this study has reviewed several papers, and trajectory length that authors used were always of concern to readers as well. But there were always reasons for choosing the specific length. Of course we could shorten the length of trajectory, but we chose to simulate trajectory for two weeks after performing many sensitivity tests. As seen in Fig 2a, the correlation between trajectories from three different dataset are very high (> 0.9) within 7days, and it decreases with time, as we expected. However, the correlation was still high (up to 0.7 or so) even from 7 to 14 days. Trajectory length is important for determining not only the origin of moisture, but also transport pathways. As mentioned in the paper, the reason for choosing two weeks as the trajectory simulation periods is that we are interested in the synoptic scale motions (larger than 1000 km, time scale is about 1week) as well as the planetary scale wave motions (10000 km, time scale is about 1 month), so these phenomena are expected to occur during those time periods. Furthermore, we utilize only 7 day trajectories when we performed pdf analysis to find locations of last saturation, considering that moisture property may be conserved in a short period of time in the mid to lower atmosphere (please see p22236, line 9-13). More importantly, the trajectory length (such as 7, 10, 14 days shown in Figure 2a) do not change the main conclusion, and rather enables us to have a broad view looking at the processes controlling extreme precipitation events. The short trajectory length may help the reconstruction of water vapor to be more reasonable (in the sense moisture can be conserved within short time periods), but this also varies among cases. In general, for most cases, and for the cases shown in this study, there is little sensitivity whether using 14 days or less than 7days. Thus, we consider two weeks to be an appropriate period for this study.

4) Conclusions: i) “We draw general conclusions from only a handful of case studies.” We select several important cases, and perform the analysis based on a new clustering method. The AR events are random, so it could not be adequate to composite the cases without thorough understanding. Composites could mix the characteristics of

individual cases, so we rather focused on the several individual cases. ii) “This study did not provide enough information to contrast to other studies, which used much more extensive statistics to get robust results.” We chose to examine individual cases to establish the validity of clustering method and concept of last saturation. In addition, the variability of different cases does not change the main point we try to address in this paper: the source and origin of moisture and air mass is not limited to the tropics, but also includes the extratropics. Also, the moisture transport is both by direct transport of moisture from the tropics, but also by interactions between tropics and extratropics (due to advection of moisture by the mid-latitude storm track). Furthermore, we performed the composite analysis for the pdf of last saturation location in order to obtain general conclusions regarding the location of last saturation of parcel based on several AR cases. This explains that the location of the moisture source is not only the lower level tropics, but also upper level extratropics, which are consistent with the result obtained from the case study discussed in the earlier part of the study. Because this paper presents several case studies, the results are not to be interpreted as representative of transport for all extreme precipitation associated with AR events on the west coast of U.S., but rather as illustrative of well documented cases and examples of different moisture transport processes (Ralph et al., 2010). We believe documenting the prominent case can help better explain such a complicated phenomenon. While a composite study of many such events would be ideal, case studies should receive more attention, since substantial understanding and documenting of individual storms must first be completed. Therefore, a composite study is beyond the scope of this case study. This will be the focus of future work.

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