

Interactive comment on “Investigation of negative cloud radiative forcing over the Indian subcontinent and adjacent oceans during the summer monsoon season” by B. V. Thampi and R. Roca

B. V. Thampi and R. Roca

bijoyvthampi@yahoo.com

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We thank the referee for the very constructive suggestions/comments. The specific replies to the comments are given below.

General Comments: The manuscript presents the satellite derived CRF observed over the Indian subcontinent and adjacent oceanic regions during the Asian monsoon season and discuss about various macro/micro physical and environmental variables that influence the observed negative NETCRF over this region. Sohn et al. (2006) discuss

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about the quantitative estimation of satellite-derived LWCRF due to the upper tropospheric water vapor change associated with cloud formation. In his paper, Sohn et al. (2006) promote an alternative computation of LWCRF to the traditional one and use a composite of clear-sky pixels away from the cloudy regions (TOA clear sky flux) in the estimation of LWCRF in order to avoid cloud contamination. While in the traditional LWCRF computation (used in the present study), TOA LW clear sky fluxes are based on sub sampling of the region of interest under clear sky conditions. There is no doubt that there are differences between these two methods of computing CRF and we can probably support the idea of Sohn et al. (2006) that their computations might be a closer estimate of the cloud radiative effect. Nevertheless here we have opted to use the traditional definition of the CRF mainly because it is readily available from satellite measurements. This is made possible by the usage of CERES EBAF TOA clear sky flux in the present study. Second, our paper relies on a confrontation between data and model simulations and our simulations have been performed with exactly the same definition as that used to derive CRF. Here a strong effort of consistency has been followed and yielded insights in to the processes at play. Now it would be interesting to explore how our mechanisms will be effective when a new or alternative definition of the CRF is used. We hope that present study and the discussions will indeed trigger such future works. In a nutshell, using a new definition of LWCRF will lower the negative NETCRF over the region provided all other things being equal. Will it still be possible to model it as we did? We hope so.

Reply to Comment 1: Figure 1 presented as a part of the review (Figure 6 in the manuscript) shows the variation of TOA LW flux (clear and total sky) with precipitable water vapor (PWV) for the Bay of Bengal region estimated using the RRTM. Since clear sky and total sky flux used in the LWCRF estimation belong to the same environment (same sampling area), the question of environmental difference in water vapor between clear sky and cloudy sky getting added to the CRF no longer exist. Hence we have used points C and B in the estimation of LWCRF instead of A and B. However, if the clear sky PWV values were lower (compared to total sky PWV) as indicated by the reviewer

(point A), it will definitely increase the LWCRF value and reduce the mismatch between SWCRF and LWCRF over the region. However, clear sky LW flux values estimated using the RRTM and from ISCCP compares well with that from CERES (table 5 in the manuscript). From the figure it can be seen that the rate of decrease in LW flux with increase in PWV (from 33 mm to 68 mm) is largest for clear sky LW flux (~ 45 W/m²) compared to total sky LW flux (~ 20 W/m²) over the Bay of Bengal region. This strong dependence of clear sky LW flux on water vapor compared to total sky LW flux is the reason for observed lower LWCRF over the Indian monsoon region. Reply to Comment 2: Using idealized radiative transfer computations, Roca et al (2004) confirmed the damping effect of the water vapor on LWCRF over the Bay of Bengal during month of July. From fig.6, it can be seen that water vapor damping of LWCRF is influenced by the relatively large scale damping of LW flux in clear sky conditions than all sky conditions for no environment difference assumed between clear sky and all sky. From Figure 7, it can be seen that there is a significant loading of water vapor in the atmosphere over the Indian region during the summer monsoon compared to winter months. Roca et al. (2004) states that this increase in water vapor over the Bay of Bengal region (during the monsoon season) decreases or negates the contribution of upper level clouds to the LWCRF while not at all influencing the SWCRF.

Reply to Comment 3: The assumption that there exist a large difference in water vapor between clear-sky and total-sky environment over western pacific does not hold since the satellite derived LWCRF uses the TOA flux (clear and total sky) estimated from the same sub-sampled area. Since there is not much difference in humidity between clear and total sky area over the western Pacific, the LWCRF is induced more or less between C and B (in figure 1 in the review). From Table 9 (and from table 10) in the manuscript, it can be seen that the clear and total sky LW flux (and cloudiness) over western Pacific is larger (smaller) than that observed over the Indian region. RRTM simulation of TOA flux and CRF (clear and total sky) using cloud vertical model over the western Pacific showed values comparable to that in Table 9. Also from Figure 9, it can be seen that the PWV content over the western Pacific is relatively lower than

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that observed over the negative NETCRF regions of the Bay of Bengal. This shows that the Bay of Bengal region is characterized by relatively large amount of clouds and atmospheric water vapor compared to the western Pacific region. Hence, it is the environment contrast (in cloudiness and atmospheric water content) between the Bay of Bengal and the western Pacific region is responsible for the observed NETCRF regimes.

Reply to Comment 4: The indirect effect of aerosols on monsoonal clouds is highly speculative at this stage and we do not think we should embark in such a discussion in the present paper. Also large aerosol loading is observed over the Indian region and near by oceanic region mainly during the winter and pre-monsoon season compared to monsoon region. During the summer monsoon season, aerosol loading observed in the Bay of Bengal region is usually associated with increase in sea salt production (their concentration being is largest in the lower troposphere). Over the Indian region, the NETCRF is mainly contributed by the middle and high-level clouds where aerosol concentration is relatively low compared lower atmosphere. Hence the influence of aerosol-cloud interaction may not have significant impact on the negative NETCRF. Also studies over the region (Kedia et al. 2010) showed that average shortwave aerosol radiative forcing over the Bay of Bengal is about ~ -12.0 W/m² at the top of the atmosphere (during the pre-monsoon season) when AOD values are higher. In the present study, we have only used the column aerosol optical depth and other optical properties to estimate the contribution of aerosols to the TOA flux and found that their contribution is relatively lower during the monsoon season.

Minor comments: The grammatical errors mentioned by the reviewer will be corrected in the revised manuscript. Also the discussion section in the manuscript will be modified incorporating the influence of environmental difference in water vapor between clear sky and cloudy sky affecting CRF estimation.

Interactive comment on Atmos. Chem. Phys. Discuss., 13, 28895, 2013.

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