The Radiative Impact of a Correction for a Sonde Humidity Bias Over the Tropical Western Pacific

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Introduction

The impact of water vapor on the radiative flow of energy through the atmosphere and across the earth's surface is a major concern for achieving the goals of the Atmospheric Radiation Measurement (ARM) Program. Any inaccuracy in the moisture distribution can lead to substantial discrepancies between the actual and calculated radiative fluxes (e.g., Gutzler 1993). A dry bias was recently identified in radiosonde measurements of humidity (Zipser and Johnson 1998). A correction procedure has been proposed based on extensive laboratory and atmospheric data (Cole and Miller 1999). This correction (Miller et al. 1999) leads, on average, to moister profiles over the whole column as illustrated in Figure 1. The present study analyzes how this correction impacts radiative fluxes.

Data

The sonde data used hereafter were acquired during the Coupled Ocean Atmosphere Response Experiment (COARE) for three different cruises of the Moana Wave, which covered a total period of 64 days: November 11 to December 5, 1992; December 16 to January 11, 1993; and January 28 to February 13, 1993. During these cruises, four soundings were launched every day, except for a few missing dates. The correction of relative humidity (RH) (Figure 1a) is relatively uniform over the whole troposphere up to 300 mb, about 4% in terms of RH units, except at the lowest level, where it is slightly larger. Above 300 mb, the amplitude of the correction increase significantly, reaching a maximum of more than 15% around 100 mb. The corresponding modification of water vapor mixing ratio (Figure 1b) is maximum in the lower troposphere, reaching more than 1g kg^{-1} below 950 mb. The vertical structure of this correction is similar among the soundings. However, its magnitude widely fluctuates, as shown on the time series of precipitable water modification (Figure 2).

Method

Radiative calculations are performed with a Column Radiation Model corresponding to a stand-alone version of the radiation model implemented in the National Center for Atmospheric Research (NCAR) Community Climate Model, version 3 (Kiehl et al. 1998). In order to account for the presence of clouds, cloud fraction and cloud liquid water path vertical profiles are diagnosed with a simple method. For each column's level, the cloud cover takes the value 0 or 1 according to a relative humidity threshold—modified with respect to ice above 273 K, and the cloud liquid water path is parameterized as a function of height, following Kiehl et al. (1994). Comparing surface and top of the atmosphere (TOA) radiative

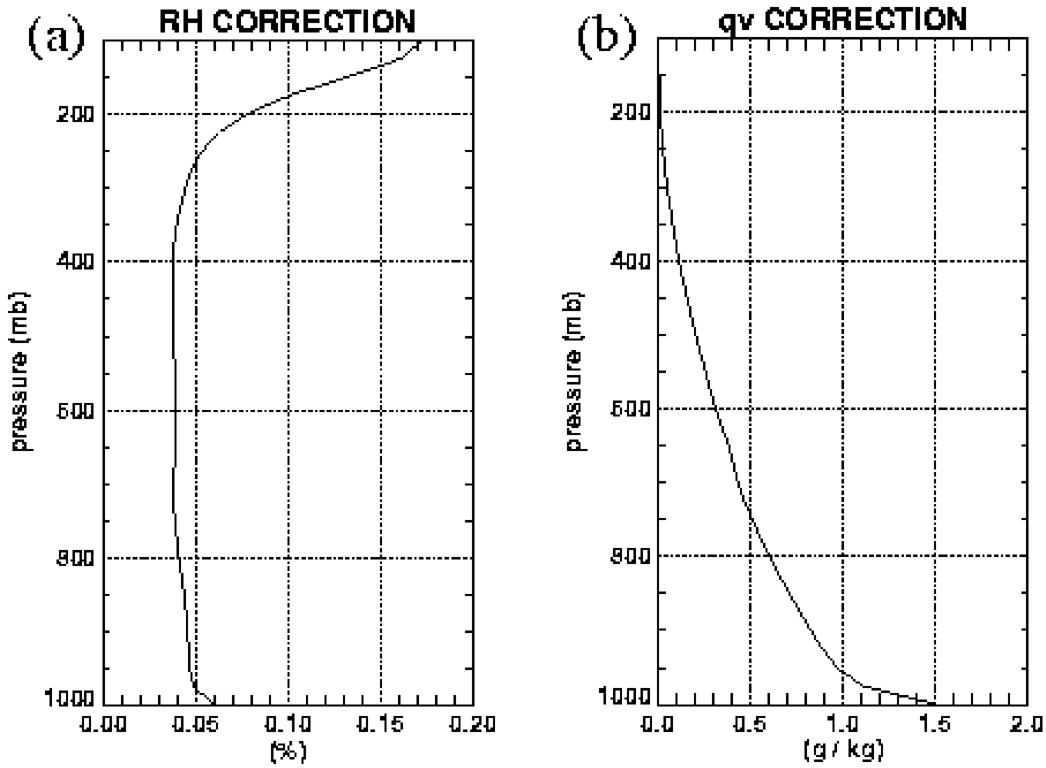

Figure 1. Correction of (a) relative humidity and (b) water vapor mixing ratio, averaged over 219 soundings.

fluxes (calculated with the corrected data) to Intense Flux Array (IFA) mean values observed during an intensive operational period (IOP) shows a reasonable agreement, when the diagnosed clouds are taken into account. Thus, this method provides the first order estimate of the cloud field needed for the present study (see Guichard et al. 1999 for further details).

Radiative Impact

Modification of the Fluxes at the Surface and TOA

Figure 3a shows the average modification of radiative fluxes that occurs when correcting the moisture profiles—without changing the cloud field. The moister atmosphere absorbs more incoming radiation, resulting in a decrease of the downward shortwave (SW) flux at the surface of -0.8 Wm^{-2}. Because the ocean has a low albedo, the impact on the SW flux at the TOA is weak. At the same time, the atmospheric greenhouse effect is increased, with an enhancement of the longwave (LW) downward flux at the surface of 2.9 Wm^{-2}, whereas the radiation lost to space decreases by 1.2 Wm^{-2}.

At the surface, the decrease of the SW downward flux only partly balances the increase of the LW radiative flux, resulting in a net input of energy for the ocean. The same computation assuming clear sky columns (Figure 3b) leads to the same qualitative effect of the moisture correction (except for the upward SW flux at the TOA), but with a magnitude twice larger than for cloudy conditions.

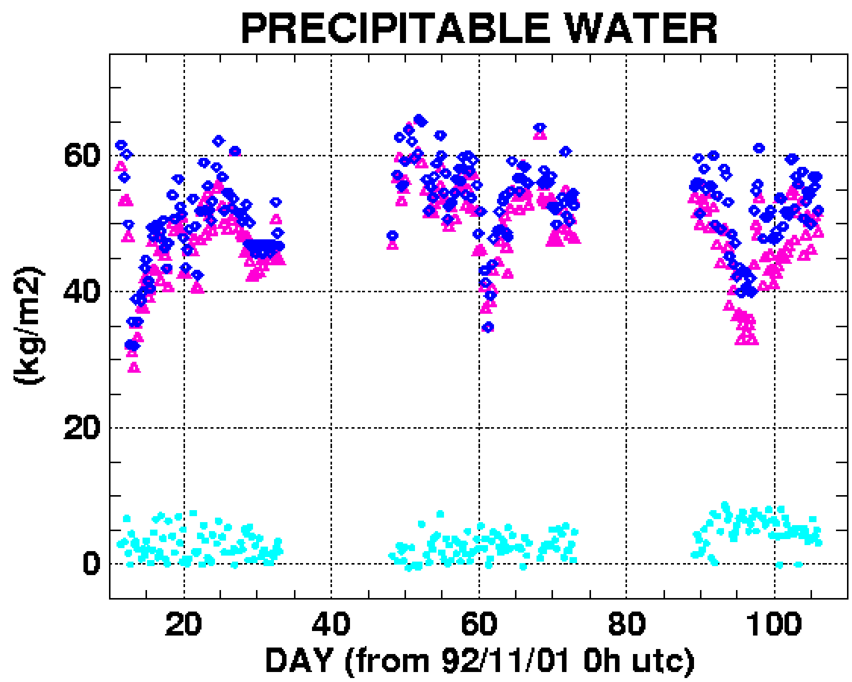

Figure 2. Time series of precipitable water: uncorrected (pink triangles), corrected (blue diamonds), and the difference corrected minus uncorrected (green circles).

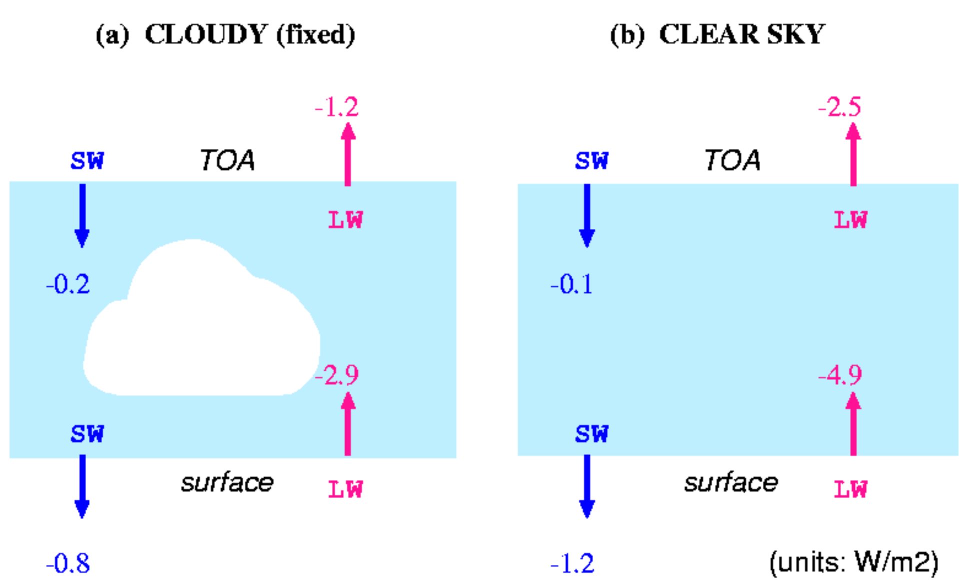

Figure 3. Modification of radiative fluxes induced by the moisture correction (a) with the same cloud field for the two computations, (b) assuming clear-sky conditions—averaged over 219 soundings.

Compared to estimates of the radiative forcing of greenhouse gas, or aerosols (Schimel 1995), the radiative impact of this moisture correction is of the same order of magnitude. This indicates that this correction is climatologically significant.

Interpretation in Terms of Precipitable Water Correction

The modifications of radiative fluxes are very strongly correlated to the correction of precipitable water, as shown in Figure 4. This correlation shows that the most important parameter controlling the modification of radiative fluxes is the "homogeneous shift" of relative humidity over the whole tropospheric height, not the large increase of relative humidity in the upper levels.

Except for the upward SW flux at the TOA, clouds tend to partly shadow the impact of the moisture correction. The scatter, for a given value of precipitable water (PW) is related to the structure of the cloud cover. For example, shallow optically thick clouds significantly reduce the radiative impact of the correction on the downward LW flux at the surface (Figure 5). These results stress the importance of introducing clouds. Without them, the impact of the correction is greatly overestimated.

Indirect Radiative Effects Through the Cloud Cover Increase

When taken into account in a numerical model, this correction also should have a strong radiative impact through the modification of the simulated cloud cover—existing parameterizations always relate, in one way or another, the cloud fraction to the relative humidity. This impact is illustrated in Figure 6, showing the modification of radiative fluxes induced by the moisture correction, when the cloud field is also changed according to the corrections of relative humidity. This impact is very large: about 50 Wm^{-2} additional solar radiation is reflected to space, a net increase of the atmospheric radiative heating occurs, and the radiative flux available for the ocean decrease by 40 Wm^{-2}. This change is due in particular to the large increase of the high cloud cover. In fact, relative humidities simulated by large-scale models sometimes depart from the observations by far more than the few percent corresponding to the present correction. So, any improvement of the simulated moisture field should lead to very important and various changes in these models so as to maintain a reasonable radiative budget.

Summary

The radiative impact of correcting a sonde humidity bias has been presented, analyzed and discussed. The whole series of sonde data acquired during the COARE experiment by the Moana Wave is used. For this tropical dataset, the purely radiative impact of the moisture correction is of the same order as the CO^2 radiative forcing. It leads to a net increase of the radiative flux for the ocean of 2 Wm^{-2}. The mean bias and the sonde-to-sonde variations equal or exceed the accuracy required to answer many questions related to the radiative budget, questions that must be addressed in order to understand and predict climate change. This result is mostly explained by the increase of the total column precipitable water, not by the large increase of relative humidity in the upper troposphere.

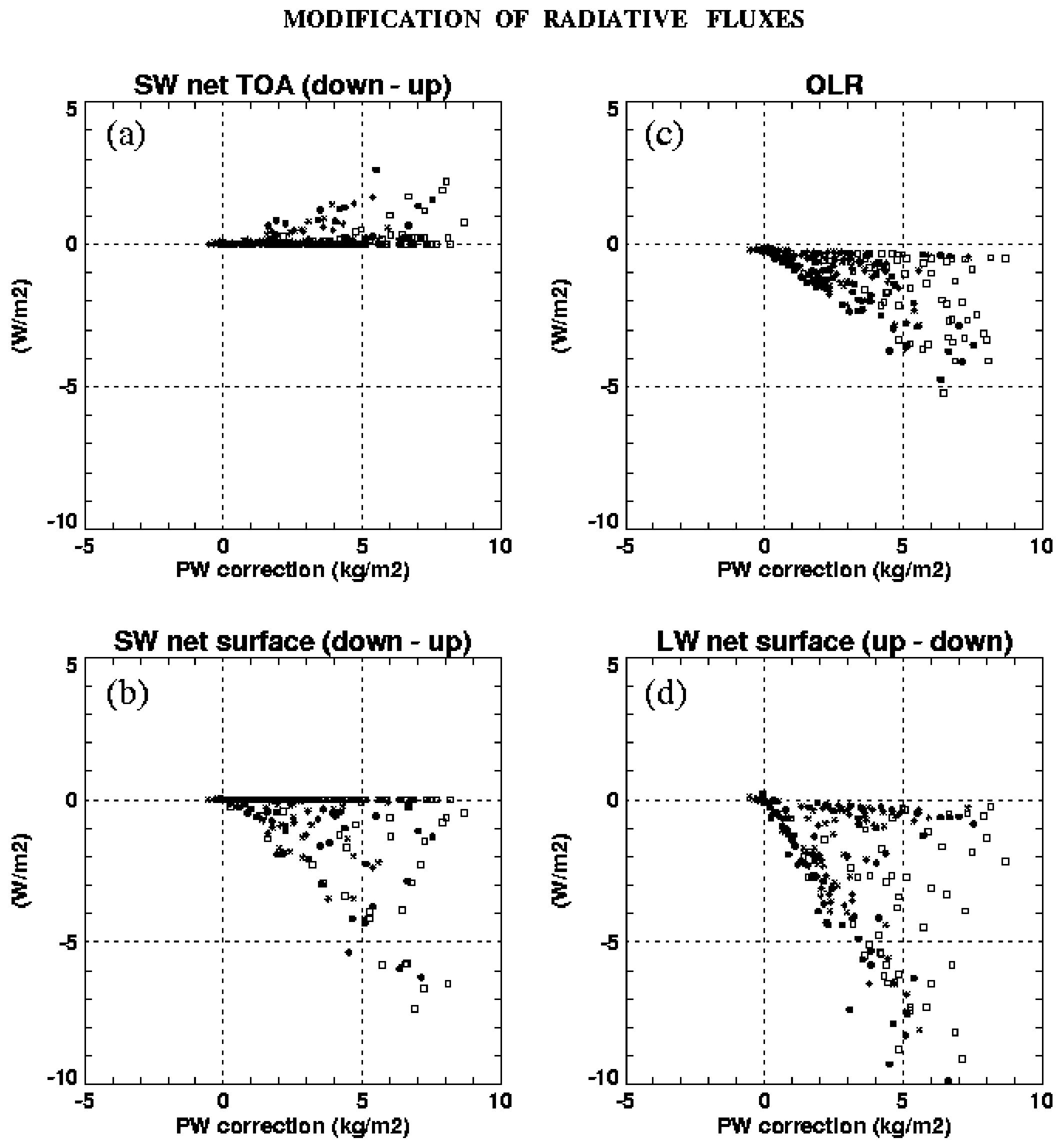

Figure 4. Scatter plots of the modification of radiative fluxes as a function of the precipitable water correction at the TOA and the surface in the SW (a) and (b) and the LW (c) and (d); each symbol corresponds to a sounding.

The indirect radiative effect of this moisture correction that would occur in a numerical model through a modification of the cloud cover is also investigated. The impact is very large for the atmosphere as a whole and the surface. It is explained in particular by a large increase of the cloud fraction in the upper troposphere.

Finally, these calculations have been performed for a moist oceanic tropical area, where the correction of sonde humidity is expected to be the largest. It would be interesting to further extend this analysis to a mid-latitude case.

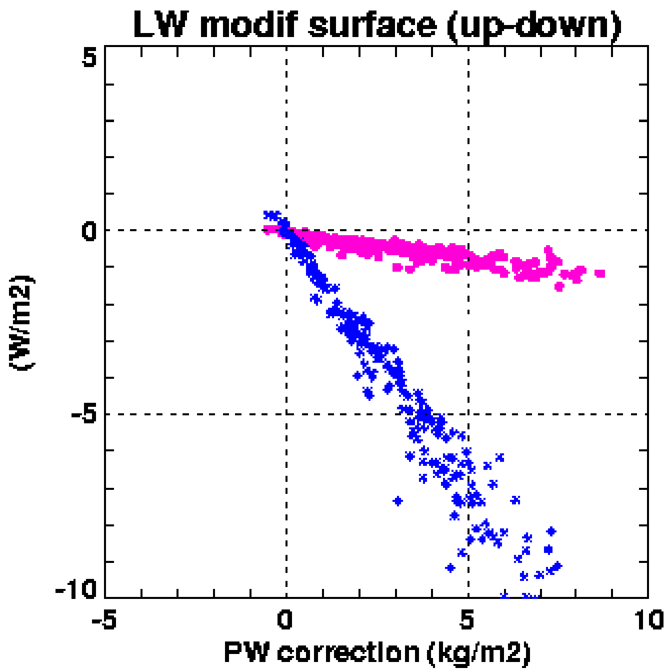

Figure 5. Same as Figure 4d except assuming either an optically thick shallow cloud layer (pink circles) or a totally clear column (blue stars) for each of the 219 radiative computations.

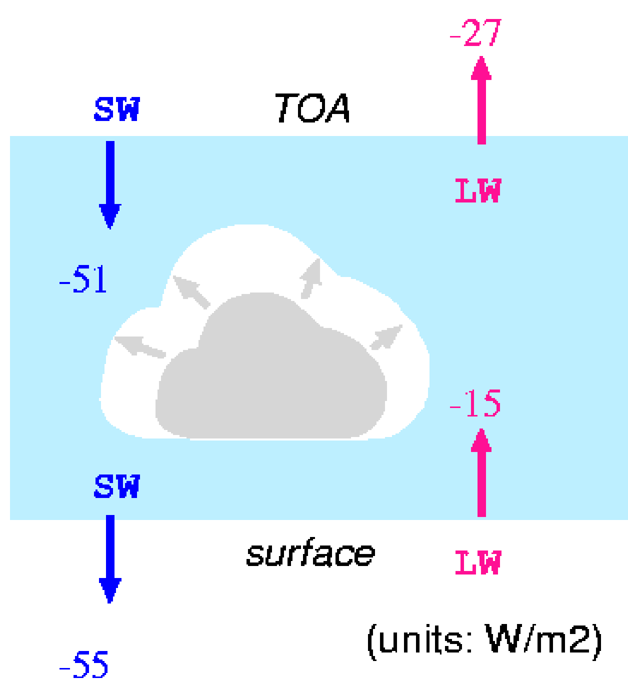

Figure 6. Modification of radiative fluxes induced by the moisture correction when the cloud field is changed according to relative humidity correction—averaged over 219 soundings.

Acknowledgments

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