Abstract

In this thesis, we have presented a systematic analysis of the change of cloud properties due to variation in aerosol concentration over Indian region using satellite observations, and Weather Research and Forecasting Model coupled with Chemistry (WRF-Chem) simulations. The Tropical Rainfall Measurement Mission (TRMM) based Microwave Imager (TMI) estimates (2A12) have been used to compare and contrast the characteristics of cloud liquid water and ice over the Indian land region and the surrounding oceans, during the premonsoon (May) and monsoon (June–September) seasons. Based on the spatial homogeneity of rainfall, we have selected five regions for our study (three over ocean, two over land). In general, we find that the mean cloud liquid water and cloud ice content of land and oceanic regions are different, with the ocean regions showing higher amount of CLW. A comparison across the ocean regions suggests that the cloud liquid water over the orographically influenced Arabian Sea (close to the Indian west coast) behaves differently from the cloud liquid water over a trapped ocean (Bay of Bengal) or an open ocean (Equatorial Indian Ocean). Specifically, the Arabian Sea region shows higher liquid water for a lower range of rainfall, whereas the Bay of Bengal and the Equatorial Indian Ocean show higher liquid water for a higher range of rainfall. Apart from geographic differences, we also documented seasonal differences by comparing cloud liquid water profiles between monsoon and premonsoon periods, as well as between early and peak phases of the monsoon. We find that the cloud liquid water during the lean periods of rainfall (May or June) is higher than during the peak and late monsoon season (July-September) for raining clouds over central India. However, this is not true over the ocean. As active and break phases are important signatures of the monsoon progression, we also analyzed the differences in cloud liquid water during various phases of the monsoon, namely, active, break, active-to-break (a2b) and break-to-active (b2a) transition phases. We find that the cloud liquid water content during the b2a transition phase is significantly higher than that during the a2b transition phase over central India. We speculate that this could be attributed to higher amount of aerosol loading over this region during the break phase. We lend credence to this aerosol-liquid water/rain association by comparing the central Indian cloud liquid water with southeast Asia (where the aerosol loading is significantly smaller) and find that in the latter region, there are no significant differences in cloud liquid water during the different phases of their monsoon.

The second part of our study involves evaluating the ability of the Weather Research and Forecasting Model coupled with Chemistry (WRF-Chem) to simulate the observed variation of cloud liquid water and rain efficiency. We have used no chemistry option, and the model was run with constant aerosol concentration. The model simulations (at 4.5 km resolution) are done for the month of June–July 2004 since this period was particularly favorable for the study of an active–break cycle of the monsoon. We first evaluate the sensitivity of the model to different parametrizations (microphysical, boundary layer, land surface) on the simulation of rain over central India and Bay of Bengal. This is done to identify an "optimal" combination of parametrizations which reproduces the best correlation with observed rain over these regions. In this default configuration (*control* run), where the aerosol concentration is kept constant throughout the simulation period, the model is not able to reproduce the observed variations of cloud liquid water during the different phases of an active-break cycle. To this end, we proceeded to modify the model by developing an aerosol-rain relation, using Aerosol Robotic Network (AERONET) and TRMM 3B42 data, that realistically captures the variation of aerosol with rain. It is worth highlighting here that our goal was to primarily isolate the indirect effect of aerosols in determining the observed changes in cloud liquid water (CLW) during the active-break phases of the Indian monsoon, without getting into the complexity of a full chemistry model such as that incorporated in WRF-Chem. Moreover, the proposed modification (*modified* run) is necessitated by the lack of realistic emission estimates over the Indian region as well as the presence of inherent biases in monsoon simulation in WRF.

The main differences we find between the *modified* and *control* simulations is in the mean as well as spatial variability of CLW. We find that the proposed modification (i.e., rate of change of aerosol concentration as a function of rain rate) leads to a realistic variation in the CLW during the active-break cycle of Indian monsoon. Specifically, the peak value of CLW in the b2a (a2b) phase is larger (smaller) in the *modified* as compared to the *control* run. These results indicate a stronger change in CLW amount in the upper levels between the two transition phases in the *modified* scheme as compared to the *control* simulation. More significantly, we also observe a change in sign at the lower levels of the atmosphere, i.e., from a strong positive difference in the *control* run to a negative difference in the *modified* simulation, similar to that observed. Additionally, we investigated the impact of the proposed modification, via CLW changes, on cloud coverage, size of clouds and their spatial variability. We find that the transformation of optically thin clouds to thick clouds during the break phase was associated with larger cloud size in *modified* compared to the *control* simulation. Moreover, the higher rate of decay of the spatial variability of CLW with grid resolution, using the *modified* scheme, suggests that clusters of larger clouds are more in the *modified* compared to *control* simulation. Taken together, the interactive aerosol loading proposed in this thesis yields model simulations that better mimic the observed CLW variability between the transition phases.