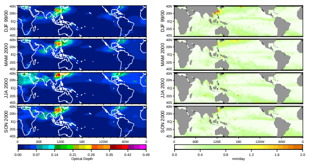
Preparatory Studies of Cloud/Aerosol/Precip Relationships during the AMF Deployment in Shouxian, China

Christian Kummerow, Wesley Berg, Steve Saleeby, Tristan L'Ecuyer and Scott Stevens, Colorado State University

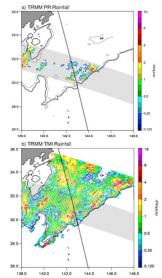
MOTIVATION



Seasonal mean sulfate aerosol optical depth (AOD) from SPRINTARS (left panel) and seasonal mean differences in rainfall estimates from TRMM PR and TMI (right panel).

Precipitation products from the Tropical Rainfall Measuring Mission (TRMM), CloudSat, and Aqua satellites has revealed new evidence for the suppression of precipitation in warm clouds in the aerosol-rich East China Sea (Berg et al., 2006). Seasonal mean rainfall differences between active (PR) and passive (TMI) sensors on board TRMM shown on the left indicate dramatic differences during Dec-Jan-Feb over the East China Sea. These differences indicate significant seasonal variability, however, the mean aerosol concentrations in this region are relatively consistent throughout the year, indicating the importance of the environmental conditions and large-scale forcing in producing these differences.

An example case from April 3, 2000 over the East China Sea, shown on the right, indicates the substantial differences in both the detection and intensity of rainfall estimates from PR and TMI. Berg et al. (2008) compared satellite observations from TRMM and CloudSat for this case, which indicated a broad region of light rain below the PR detection threshold. In anticipation of data from the AMF deployment in Shouxian, China, preparatory studies of aerosol indirect efffets on clouds and precipitation over China and adjacent ocean regions are presented here.



OBSERVATIONAL STUDIES

AMF deployment in Shouxian, China in 2008

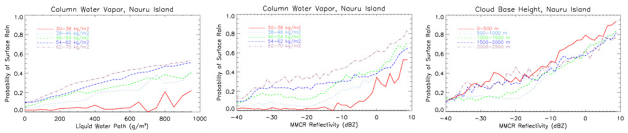
Our objective is to use data from the AMF deployment in Shouxian, China is to study precipitation onset at cloud base in distinct water vapor and aerosol environments. We are just starting our analysis of the data from that experiment as the data has only recently been released. In anticipation of the release of the data from the AMF, Observations from both Nauru Island and Niamey, Niger have been used to study relationships between clouds/aerosols and precipitation. Neither site is ideal for these studies.

Nauru Island, while ideal for oceanic studies, has very low and very uniform CCN concentrations. Observations are used to establish a baseline for the relationship between liquid water path, column water vapor (well correlated with low level humidity) and surface rainfall.

Niamey is ideally suited to study aerosol effects but lack of cloud radar observations make it difficult to separate water vapor effects from aerosol effects.

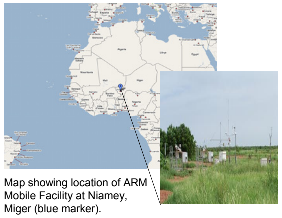
Results from ARM Site on Nauru Island

Satellite photo of Nauru island. The ARM facility is donoted by the blue marker on the northwest coastline of the island (Google Earth).

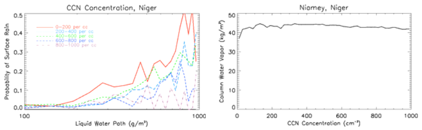


The relationship between cloud liquid water and precipitation at the surface depends strongly on the column water vapor. To assess the degree to which evaporation below cloud base is responsible for this behavior, the probability of surface rain is compared to reflectivities at cloud base. Similar slopes between the lines of different water vapor (except for 54-62 kg/m^2) indicates that evaporation below cloud base is not the main source of difference between environments. This is further borne out by the lack of sensitivity between cloud water and surface rainfall as the cloud base is allowed to vary. Instead, it appears as though clouds in a more humid environment are simply more likely to precipitate at lower liquid water contents. This will be verified using both in-situ and satellite sensors.

Results from AMF Deployment in Niamey, Niger



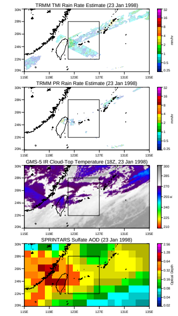
Map showing location of ARM Mobile Facility at Niamey, Miger (blue marker).

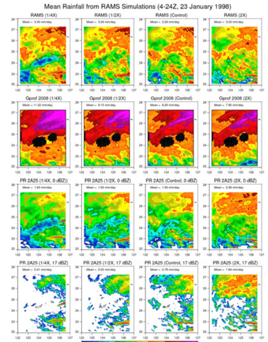


Niamey shows striking relation between cloud liquid water and surface precipitation in varying aerosol environments. Aerosol concentration were correlated with column water vapor to ensure that presumed aerosol effects were not correlated with water vapor. No relation is evident.

MODELING STUDIES

Satellite Observations and CRM Simulations over the East China Sea (January 23, 1998)



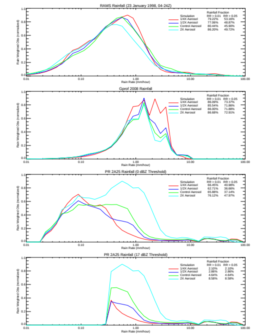


Cloud Resolving Model (RAMS)

TMI Retrieval (GPROF 2008)

PR Retrieval (0 dBZ Threshold)

PR Retrieval (17 dBZ Threshold)

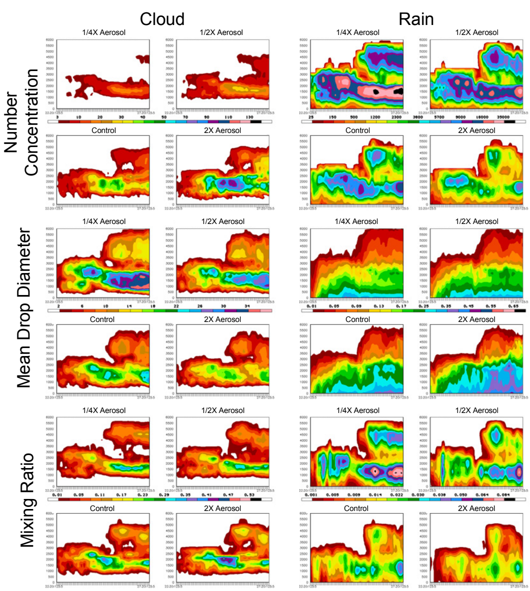


Differences between passive (TMI) and active (PR) rainfall estimates from TRMM over the East China Sea for 23 January 1998. TMI indicates a broad area of light to moderate precipitation with relatively warm cloud tops and signficant amounts of sulfate aerosols.

Surface rainfall from the RAMS CRM averaged over the period from 4Z to 24 Z are shown in the top row of the right-hand figure for four different simulations including 1/4X, 1/2/X, and 2X the "observed" aerosols (i.e. control run) from the SPRINTARS aerosol transport model. Increases in aerosol concentrations result in a small, but systematic decrease in the surface rain rate. Corresponding rain rate histograms from the CRM are shown in the top panel on the left-hand figure.

Results are also shown for the TMI and PR retrieval algorithms applied to synthetic observations from the CRM simulations. While the TMI retrieval indicates a small decrease in surface rain with increasing aerosol, the PR retrieval shows a large increase in the surface rain. Changing the detection threshold from 0 dBZ (typical rain/no rain cutoff) to 17 dBZ (PR sensitivity) greatly reduces the total rain indicating the presence of significant amounts of light rain below the PR detection threshold.

Cloud Microphysical Properties



Number Concentration: As the amount of aerosol increases there is a substantial increase in the number concentration of cloud drops, but a large decrease in the number concentration of rain drops.

Mean Drop Diameter: As the amount of aerosol increases the cloud droplets get significantly smaller, however, the mean diameter of the rain drops increase by around a factor of two over a significant portion of the domain.

Mixing Ratio: As the amount of aerosol increases there is only a slight increase in the cloud mixing ratio or total amount of cloud water, however, there is a significant decrease in the total amount of rain water. This result is consistent with the relatively small decrease in surface rainfall showed in the figure above.

Impact of Microphysics on TMI and PR Retrievals

The increase in drop diameter, and thus rain volume, associated with increasing aerosol concentrations is largely offset by the decrease in the rain drop number concentration. As shown above, this leads to a small decrease in the surface rainfall. Such large changes in the mean rain drop diameter, however, have dramatic effects on the PR retrieval. This is because the radar reflectivity increases with the sixth momemt of the raindrop size.distribution. As a result, maintaining the same rain volume by increasing the drop size and decreasing the rain drop number concentration will lead to a significant increase in the radar reflectivity for the same water content (i.e. rain mixing ratio). Because the PR retrieval assumes an apriori drop size distribution (DSD), it will overestimate the rain rate in this situation. For heavy rain rates the attenuation of the radar signal is used to adjust the apriori DSD, but for the light to moderate rain rates found in this case no such adjustment is possible.

Colorado State University