P3.4 MODELING WET DEPOSITION OF PARTICULATES USING OBSERVED WEATHER DATA, SATELLITE DATA, AND RAMS MODEL OUTPUT

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1. INTRODUCTION

Modeling movements of particulates in the atmosphere involves its own set of complexities as compared to modeling gaseous materials. Whether inert or biota, particulate deposition can be a minor or overwhelming loss mechanism. Dry deposition has been analyzed fairly extensively in the literature (Seinfeld and Pandis 1998, Slinn 1983a) with a resistance scheme used in many transport-dispersion models (MODELS-3 1999). Wet deposition on the other hand, has not been as widely studied and is less accurately modeled. The physical interaction of particles and raindrops producing interception and impaction scavenging can be estimated if the raindrop and particle size distributions are known. The largest uncertainty in wet deposition, however, is determining the temporal and spatial distribution of precipitation. The most common source of rainfall data comes from standard surface weather observations. These data are sparse in both space and time. Prognostic models such as RAMS or MM5 can be used to predict non-convective and convective rainfall. The ability to accurately predict when and where precipitation will occur, even in a diagnostic sense, is difficult for prognostic models. Recently, new data sets are available that could significantly improve wet deposition estimates. Composite rainfall data derived from NEXRAD data in the United States are now available within a few hours after real time. However, outside the continental United States, these data are not available. Within the last year, satellite derived rainfall estimates over much of the globe are available within a few days of real time. This paper will compare estimates of wet deposition within the Short Range Layered Atmospheric Model (SLAM) from surface data, NEXRAD derived precipitation data, and satellite derived rainfall estimates.

2. DESCRIPTION OF MODEL AND DATA

2.1. Wet Deposition

Wet deposition is defined as the process by which material is scavenged from the air by hydrometeors. A complete discussion of wet deposition, originally by Slinn(1983b), is given in Seinfeld and Pandis (1998). Scavenging can occur from raindrops, cloud droplets or fog, or by snow. The portion of wet deposition discussed in this paper is the removal of material by raindrops. The scavenging coefficient is defined by:

$$\Lambda = \int_0^\infty \frac{p}{4} D_r V_r N_r E \, dD_r \qquad (1)$$

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where D_r is the raindrop diameter, V_r is the raindrop fall velocity, N_r is the raindrop size distribution, and E is the collision efficiency. If we assume a narrow bandwidth for D_r, and assume an average raindrop diameter D_r, the scavenging coefficient can be defined by:

$$\Lambda = \frac{3Ep_o}{2\,\overline{D}_r} \qquad (2)$$

where p_o is the rainfall rate (mm hr^{-1}). Assuming the Marshall Palmer (1948) raindrop distribution, $N(D) = N_0 \, e^{-lD}$, where $l = 4.1(p_0)^{-0.21}$ mm^{-1}, and N_0 =8000 m^{-3} mm^{-1}, the average raindrop diameter becomes $\overline{D}_r = 3/l$. Using experimental data, Slinn estimated that the collection efficiency E could be decomposed by $E = E_1 + E_2 + E_2$ where:

$$E_1 = \frac{4}{\mathrm{Re}\,Sc}[1 + 0.4\,\mathrm{Re}^{1/2}\,Sc^{1/3} + 0.16\,\mathrm{Re}^{1/2}\,Sc^{1/2}] \qquad (3)$$

(contribution due to Brownian diffusion),

$$E_2 = 4f[w^{-1} + (1 + 2\sqrt{\mathrm{Re}})\,f] \qquad (4)$$

(contribution due to interception), and

$$E_3 = [\frac{St - S^*}{St - S^* + 2/3}]^{3/2} \qquad (5)$$

(contribution due to impaction), where

$$S^* = \frac{1.2 + (1/12)\ln(1+\mathrm{Re})}{1 + \ln(1+\mathrm{Re})}, \qquad (6)$$

$\mathrm{Re} = D_p U_t r_a / 2m_a$ the Reynolds number of raindrop based on its radius, $Sc = m_a / r_a D$, the Schmidt number of the collected particle, $St = 2t(U_t - u_t)/D_p$ the Stokes number of the collected particle, $f = D_p / D_r$, and $w = m_w / m_a$ (the ratio of absolute viscosities of water and air), and r_a is the air density. τ is the characteristic relaxation time, U_t is the velocity of the raindrop, and u_t is the velocity of the particle. The collection efficiency terms and the sum of the three terms are shown as a function of particle diameter in Figure 1.

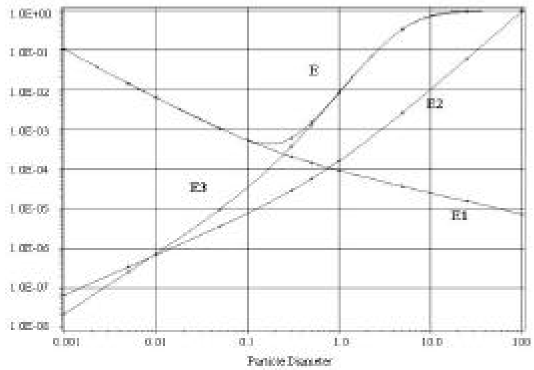

Figure 1. Wet deposition collection efficiency terms E1 (Brownian diffusion), E2 (interception), E3 (impaction), and E (E1+E2+E3) as a function of particle diameter (µm).

The wet deposition calculation is being performed within the Short-Range Layered Atmospheric Model (Atchison and Kienzle 2002). SLAM models gaseous and particulate materials and calculates dry deposition, wet deposition, and decay for different types of particulates. The particle size is defined as a size bin or a group of size bins with a given particle density. SLAM is a multi-layer trajectory puff model using Gaussian dispersion around each puff. Advection times vary between one minute and one hour. Its range of application is from a few kilometers to several days of transport. The model ingests standard WMO surface and upper-air observations, 1° and 2.5° global gridded datasets, as well as RAMS (Regional Atmospheric Modeling System) and COAMPS prognostic model data.

In an effort to isolate the effects of wet deposition for this study, identical trajectories with uniform wind speed and direction were enforced regardless of the source of the wind data. A sample trajectory is shown in Figure 2. In addition, dry deposition calculation was also turned off. The only difference between the SLAM configuration for the different model executions was the source of the precipitation data.

Figure 2. Uniform wind SLAM trajectory.

2.2. Data Sources

The precipitation data for this study came from several different sources. A forty-eight hour period during July 9-10 2002 in Florida was chosen for this study. This period had precipitation associated with a low-pressure area in the region interacting with a sea breeze producing thunderstorms during the afternoon and evening. Observational data were derived from the raw METAR data in the southeastern United States to obtain an hourly precipitation rate with each available observation. Observations with no precipitation field were assumed to have a rain rate of zero. A map with typical observations is shown in Figure 3. The METAR data distribution within Florida is a problem because most of the data are situated along the coastline and there is sparse data inland. Missing data in the hourly observations were handled using persistence from the next available observation with up to a three-hour and ten-minute delay. In many parts of the world, however, large temporal data gaps are common and can increase the uncertainty in wet deposition estimates. Another problem with data from many underdeveloped countries is there is no way to tell the difference between an observation that failed to report precipitation even though it occurred and an observation that did not report precipitation because there was none.

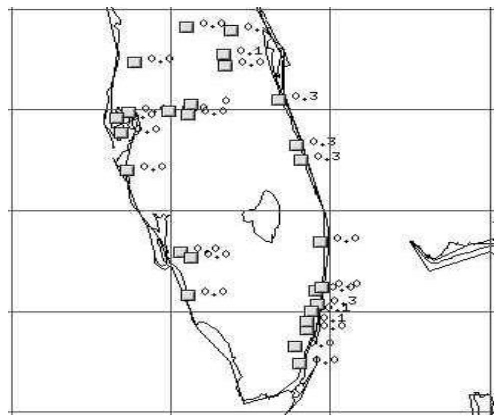

Figure 3. Sample observed hourly precipitation (mm) data.

With the increased availability of NEXRAD data from the National Centers for Environmental Prediction (NCEP), the potential for improved precipitation estimates has increased greatly. The National Precipitation Analysis (NPA) produced by NCEP (Baldwin 2002) is a prototype system to produce hourly rainfall estimates from several different data sources. Hourly digital precipitation analysis (DPA) estimates are produced by the WSR-88D Radar Product Generator on a 131x131 4km grid over each radar site in the contiguous United States (Fulton et al. 1998) These data are augmented and bias adjusted by a network of approximately 3000 automated rain gauges. Then satellite data are used to augment the radar data in regions of radar mountain shadows and in gauge-sparse regions (Fulton et al. 2002). New procedures are being developed to merge satellite precipitation estimates with the radar-gauge estimates.

While the NPA data may be quite useful within the contiguous United States, these types of data are not available elsewhere. In many underdeveloped nations, local weather observations are either of poor quality or non-existent. Even in countries where surface observations are good, the spatial resolution is quite poor. This leaves satellite derived precipitation estimates the only additional rainfall estimates beyond local weather observations. Several datasets are available in a near real-time basis on the Internet. These data are from Tropical Rainfall Measuring Mission (TRMM) instruments and are designed to produce precipitation estimates over tropical and sub-tropical regions of the Earth. The TRMM 3B data are available via anonymous ftp at three-hour intervals on a 0.25° latitude/longitude grid in the band 50° N-S within about six hours of observation time. These data are supplied by Huffman et al (2002) at NASA GSFC. Three data products are available: SSM/I and TMI merged high quality (HQ) estimates, geostationary infrared estimates, and a combination of the first two datasets where the IR data are used to fill in missing HQ data. A sample data plot from August 1, 2002 is shown in Figure 4.

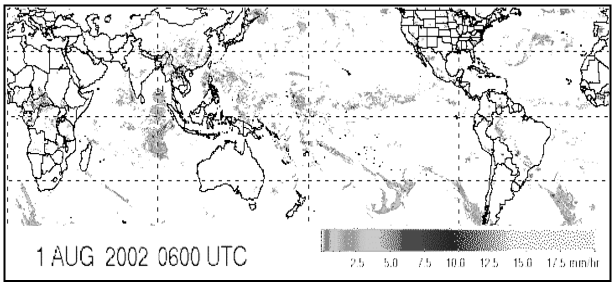

Figure 4. Sample SSM/I-TMI derived precipitation data.

The TRMM 3G data are also available through the Internet (Stocker 2002). Historical data are available from December 1997 - present. These data are available hourly on a 0.5° latitude/longitude grid. These data are from approximately 38°S to 38°N and are usually available within several days after real time. As part of the 3G products, however, data with a 0.1° grid resolution are available for South America and Africa. Software to decode these data are available on the web.

The fourth data type evaluated in this study was precipitation data from the RAMS model version 4.3 (Walko and Tremback 2001). Three nested grids were used at 64, 16, and 4 km resolution. Cumulus parameterization was used with the bulk microphysics parameterization activated. The *resolved plus convective surface precipitation* variable was used to retrieve the precipitation from the model.

3. ANALYSIS

3.1. Precipitation Comparison

Rainfall during the two-day study period varied substantially both spatially and temporally. Much of the rainfall was synoptically driven though the sea breeze enhanced rainfall over the Florida peninsula. At 1800 UTC 10 July, hourly rainfall observations are shown in Figure 5. Radar derived rainfall is shown in Figure 6a, the TRMM 3G rainfall estimate is shown in Figure 6b, and the TRMM 3B rainfall estimate is shown in Figure 6c. For this time period the TRMM 3B rainfall matched the radar derived data fairly well. The TRMM 3G data had higher rainfall over the northeastern Gulf of Mexico as compared to the other datasets. The RAMS precipitation field (Figure 6d) tended to be dominated by sea breeze convection over the Florida peninsula with additional areas of rain mainly away from the peninsula. RAMS predicted a diurnal sea breeze convection pattern over the two-day period.

When evaluating the different rainfall datasets, it is important to examine the existence of biases in the data. For this study, the average precipitation for a 6°x5° latitude-longitude area including the Florida peninsula is shown in Figure 7. If we treat the radar data as the closest to ground truth, the 3B data tracks closest to the radar data with the 3G and RAMS data significantly below the other two datasets. The 3B dataset also tracks the trend over the two-day period closer to the radar data than either RAMS or the 3G data. To fully evaluate the existence of biases, a larger data set in both space and time than that used in this study is needed.

3.2. Wet Deposition

The choice of the precipitation data source has a significant impact on the wet deposition calculation. For the SLAM model calculation with wet deposition, a common source near Homestead, Florida was chosen. This site was picked so that trajectories would track up the Florida peninsula, moving in to and out of areas of precipitation. Trajectory duration was twenty-four hours, with a trajectory step size of fifteen minutes. Plots only show data every thirty minutes for clarity. The particle size distribution was fixed at 10 µm with a particle density of 1.0 g cm^{-3}. The mass associated with each puff is tracked as a percent of the original mass. Percent mass profiles using each of the different rainfall datasets varied considerably. Figure 8 shows a sample plot with trajectories starting at 1800 UTC, 9 July. If the percent mass remaining is averaged over trajectories starting during the period 1200 UTC to 2300 UTC, average percent mass profiles can be examined. Figure 9a shows average percent mass over the first twelve hours of transport for the five different data sources for 09 July. Figure 9b shows similar data for 10 July. The TRMM 3B data agreed with the radar data along the trajectories quite well for 09 July trajectories. The TRMM 3G data showed little wet deposition after more than two hours away from the source. The observed surface data derived wet deposition is somewhat different over time from the radar data but on the average was fairly similar. For 10 July, the TRMM 3B still matched the pattern fairly well with the other datasets performing not as well. The drop in percent mass associated with the radar data after six hours indicates that there was precipitation within the radar data north of six hours transport (east of Fort Myers) that was not resolved by the other data types.

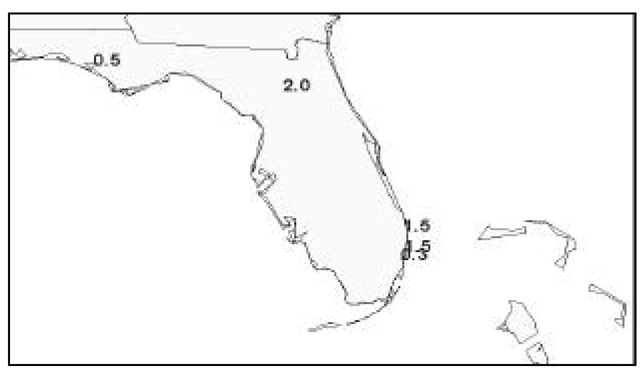

Figure 5. Observed precipitation (mm) at 1800 UTC, 10 July 2002

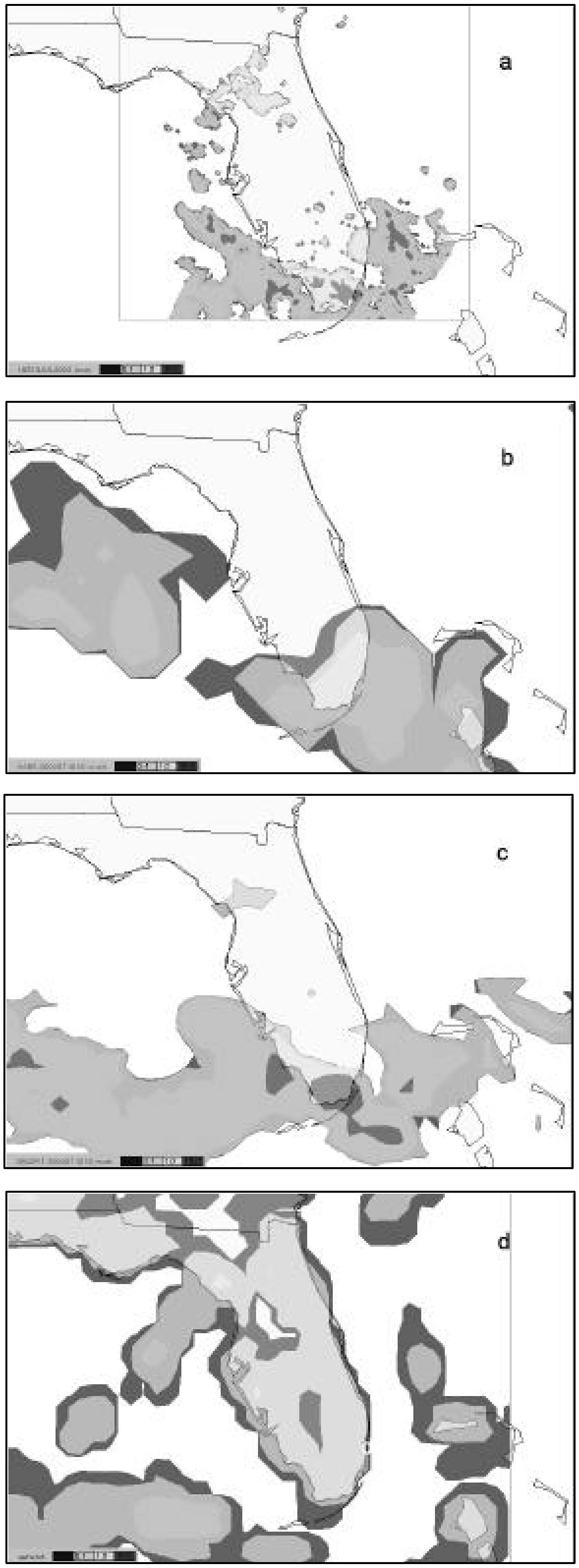

Figure 6. Precipitation data derived from a) radar data, b) TRMM 3G data, c) TRMM 3B data, and d) RAMS data.

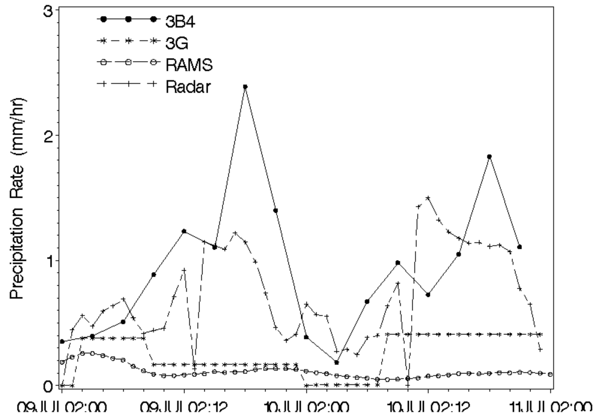

Figure 7. Average precipitation rates for a latitude longitude box around the Floida peninsula.

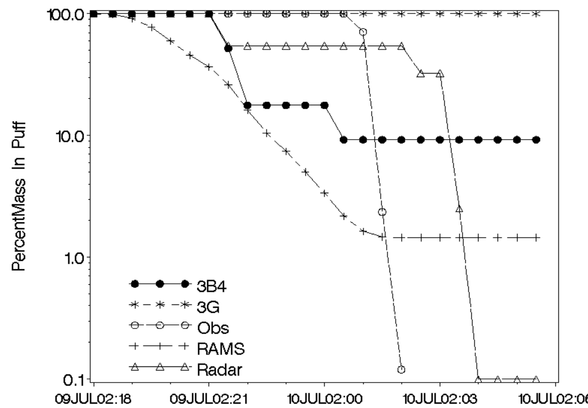

Figure 8. Percent mass in SLAM puff with wet deposition mass loss for trajectories starting at1800 UTC 09 July 2002.

All analysis to this point has been for 10µm particles. Figure 10 shows percent mass loss for particles 0.01 µm, 0.1 µm, 1 µm, 3 µm, 5 µm, and 10 µm using radar derived precipitation. This figure shows the particle size dependency of collection efficiency described in Figure 1. The lowest mass los is associated with the 0.1 µm particle. The mass loss increases dramatically with increasing particle size above 1µm.

4. SUMMARY

Accurate modeling of wet deposition is extremely important when trying to model the transport of particulates through a precipitating atmosphere. This is particularly true when dealing with larger particles. Traditional use of hourly observations may not be sufficient for defining precipitation patterns. Radar derived and to a lesser extent, satellitederived precipitation estimates can provide improved wet deposition modeling, particularly in data sparse regions. These newly available precipitation datasets should be exploited to improve particulate modeling. In the United States, the 4km precipitation dataset should be used. In other parts of the world, the dataset chosen is somewhat dependent on the region of interest since higher resolution datasets are available for South America and Africa. For this case study, the TRMM

3B data appears to be the best choice. The correct definition of particle size ranges is also important when modeling wet depositions. Models need to be able to handle a wide range of particle diameter sizes.

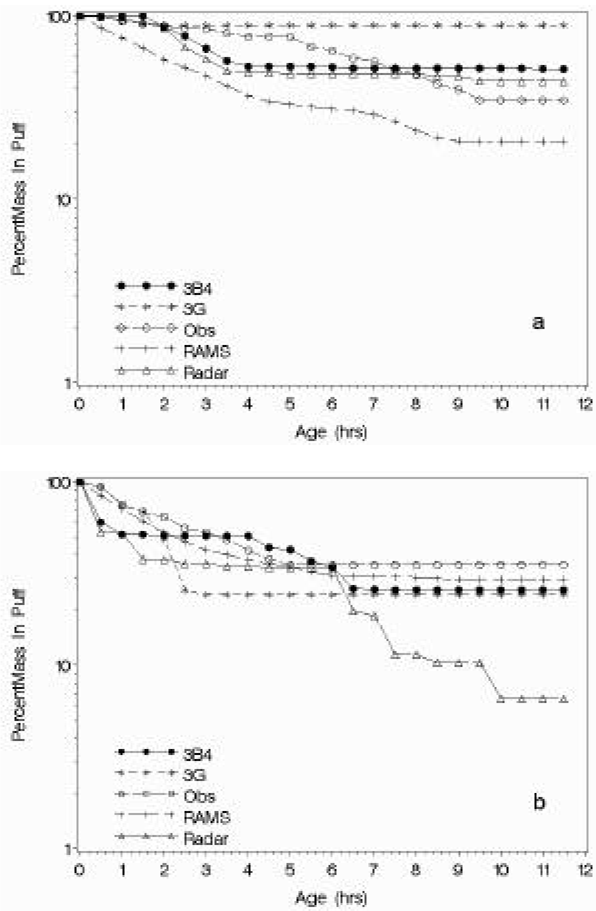

Figure 9. Average percent mass in SLAM puffs with wet deposition mass loss for a) 09 July and b) 10 July 2002.

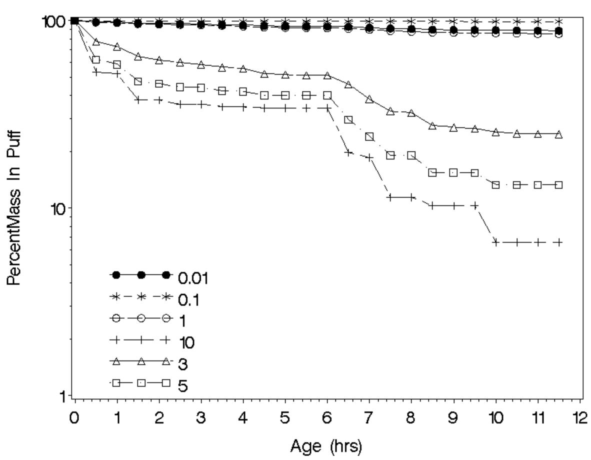

Figure 10. Average percent mass with wet deposition losses in SLAM puffs with varying particle diameters for 10 July 2002

5. REFERENCES

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