LITE/NARCM Retrievals and Implications for Future Missions

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ABSTRACT

Data taken during the 1994 Lidar In-space Technology Experiment (LITE) has been used as a test data set for comparison with a Regional Climate Model which has been modified to include realistic aerosol predictions for sulphates and sea salt. The model, NARCM, underpredicts the light scattering seen by LITE over a large portion of the domain modeled. The reason for the underprediction has obvious causes due to omission of certain important aerosol types, such as organics, black carbon and soil dust. The model is being corrected to include these aerosol types. The results, however, near the source regions are promising enough to infer cases where on-line data assimilative models, coupled to the spaceborne lidar data, can aid interpolation and interpretation of aerosol behavior between successive orbits of a polar orbiting satellite, such as PICASSO-CENA.

1. Introduction

In 1998, an introduction to the intercomparison of the data from the Lidar In-Space Technology Experiment (LITE) and the Northern Aerosol Regional Climate Model (NARCM) was provided in the abstracts for the 19th International Laser Radar Conference (Hoff et al., 1998). In this paper, we synopsize the results of the intercomparison between spaceborne lidar aerosol retrievals from LITE and predictions from a sophisticated aerosol generation and transport model, and present the final results of the study (Vandermeer et al, 2000). The conclusions are important to future missions, such as PICASSO-CENA.

LITE was launched on the Space Shuttle Discovery on September 9, 1994 (McCormick, 1996). For ten days, LITE measured aerosol structures that had only been previously investigated in relatively localised missions. A significant number of measurements were made of stratospheric and tropospheric aerosols (Kent et al., 1996), from desert dust (Powell et al., 1996), biomass burning (Grant et al., 1996) and anthropogenic emissions (Strawbridge and Hoff, 1996; Hoff and Strawbridge, 1996) As a test data set to intercompare with global aerosol transport models, the LITE dataset is unique in that it provides global coverage of aerosol backscatter data which can be compared with a relatively short operational run of a regional climate model.

2. The Northern Aerosol Regional Climate Model (NARCM)

The Northern Aerosol Regional Climate Model (NARCM, Gong et al., 1997a,b) has been developed under the auspices of the Canadian Climate Research Network. NARCM evolved from the Canadian Regional Climate Model incorporating a size-segregated aerosol algorithm. As such, it uses the same physics as the Canadian General Circulation Model (GCM, McFarlane et al., 1992) and has been driven by the GCM fields. However, in this study NARCM is driven by real data from NMC objective analysis (i.e. in a forecast mode instead of a climate simulation mode).

In this application of NARCM (September 8 to 20, 1994), the model was run on the domain shown in Figure 1 (bold domain shows the region with anthopogenic sources). It was nudged at the boundaries using operational analyses from the U.S. NMC/NCEP. This mode of operation will not be the one used by NARCM for long-term climate studies, since normally a GCM generates its own dynamics over long time scales. NARCM predicts a wide range of physical and chemical parameters amongst which aerosol number distribution and speciated aerosol mass are obvious products. Northern hemispheric emissions of sulfur dioxide from GEIA 1985 base adjusted for changes to 1994 inventories were used to simulate the spatial distribution of sulfate and sea salt sources in eastern Northern

America.

The main purpose for NARCM is to include sulphate, black carbon, organics, soil, and sea salt aerosols in a hemispheric circulation model in a dynamic fashion. NARCM is unique that it handles the aerosols within 12-discrete particle size intervals.

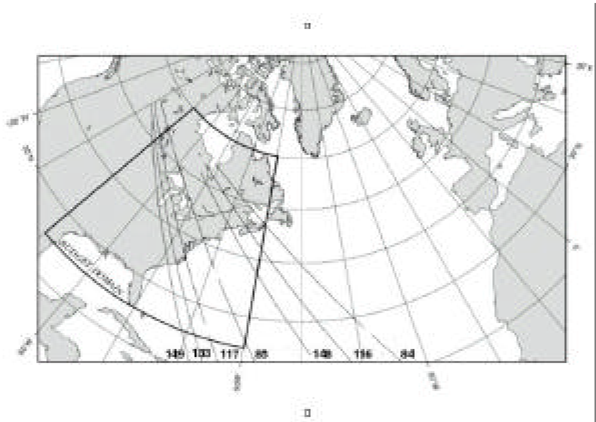

Figure 1: Orbits examined within the NARCM Domain (outer box) and the area with source inputs (budget domain).

Processes of coagulation, nucleation, and condensation are calculated in time steps of 20 minutes. The NARCM radiation code is being used by UQAM to derive optical depths, extinction and lidar backscatter within a domain which covers North America, the lower Arctic, North Africa and Europe during the LITE period (Figure 1). Model runs have been completed using simplified chemistry and aerosol production mechanisms and it is hoped that the LITE data set will allow assessment of both the accuracy of NARCM and to point out where aerosol species are seen by LITE but have been missed by the model.

3. LITE Data Used

Although the LITE instrument transmits at three wavelengths (355 nm, 532 nm and 1064 nm), only the 532 nm channel is used in this study. There is limited useful aerosol information in the 1064 nm signal because of the low signal-to-noise ratio (SNR) associated with this channel. The 355 nm signal experiences greater attenuation and backscattering at higher altitudes than the other wavelengths due to absorption by ozone and molecular backscattering. Of the two channels with good SNR in the LITE data, the 532 nm signal is most sensitive to aerosols in the troposphere. Level 1, altitude referenced profiles are interpolated using a geolocated altitude grid to produce 3000 element arrays ranging from –4.985km to 40km altitudes with a vertical resolution of 15m. Also included in the level 1 data are general parameters common to all three wavelengths such as the Greenwich Mean Time (GMT), meteorological data from the U.S. National Center for Environmental Prediction (NCEP), shuttle altitude and off-nadir angle, latitude, longitude, instrument status and operation mode. Wavelength specific parameters such as the laser energies in Joules, calibration constants, PMT gains and the attenuation imposed by electronics in the receiver assembly are also included. These parameters are necessary in order to calculate the aerosol backscattering coefficients from LITE level 1 data.

Not all species are currently implemented in NARCM. At this point, sulphate and sea salt have been simulated. The soil dust module is being added and comparison with LITE observations of Saharan dust are being examined (Guelle et al., 1997). The black carbon and organic components are not included in this run. Because of these factors, comparison of LITE signatures which are primarily sulphate and oceanic in origin appear to be the most fruitful.

4. Results

When comparing the LITE and NARCM images, differences in the magnitude of the aerosol backscattering coefficient were obtained in the PBL over the North American continent. In orbits 117, 133 and 149, (orbit 117 is given as an example in Figure 2) scattering due to aerosols was underestimated by the model below about 3 km altitude and north of about 40°N. This difference may be explained by either low production of sulfate from sulfur dioxide or the absence of organic aerosols in the model. Additional aerosol types, particularly organics, must be included in the model to produce more aerosol in the continental PBL.

Since the resolution of the model was lower than that of the measurements (100 km versus 1 km), it was not able to predict the fine aerosol features detected by the LITE instrument. To judge numerical correlation, the average LITE and NARCM aerosol backscattering coefficients were compared within each model grid box. Latitudes and longitudes of the LITE ground track were associated with a particular model grid box and the clear sky LITE profiles were averaged to produce an average profile for each box. The aerosol backscattering coefficients were then averaged vertically in three 2 km altitude intervals from 0 km to 6 km. Log-log plots of the average aerosol backscattering coefficients for NARCM versus LITE are shown in Figure 3 with the regression slope, correlation coefficients (R^2), and the number of points (N) indicated on each plot. In these plots, the average aerosol backscattering coefficients decreased with increasing altitude as a result of a decreasing concentration of aerosols. The plots for orbits 84, 85, 116 and 148 had slopes that were considered close to, but less than one, while orbits 117, 133 and 149 resulted in slopes which were significantly less than one. In several cases, it appears that the value of the slope does not match the figure. This was caused by that fact that this comparison is done using a log-log plot and because the larger values will weigh more heavily in the calculation of the slope. These results demonstrate that the model was consistently underpredicting the backscattering due to aerosols. This was likely due to the fact that at present, the model only incorporates a few different aerosol types. Also, it was seen in these figures that at higher altitudes the difference in the aerosol backscattering was greater.

It can also be said that the agreement is better at low altitude (0-2 km), near source (orbit 117 for example), and high backscatter ratio (>10^{-6} m^{-1} sr^{-1}). It is important not to attach too much significance to the log-log correlation plots since many of the low scattering cases can be orders of magnitude apart. The fact that NARCM produces the correct backscatter in these near surface, hazy cases shows some skill in predicting the aerosol loading. From a climate perspective, it is these cases which cause the greatest aerosol forcing.

4. Conclusions

The ability to use the LITE dataset for intercomparison with regional and global scale models was an extremely important result of the LITE experiment. It provided us with the ability to test the physics and chemistry in these large scale models and give us insight into the use of spaceborne lidar data for future missions.

It is apparent from these data that a high degree of confidence can be placed in estimates of backscatter derived from a regional scale model (<1500km) and less confidence can be placed on longer scale transport. This conclusion is important in designing data assimilation objectives for missions such as PICASSO-CENA. Important value added products can be derived from the use of numerical models constrained by observations from a polar orbiting satellite such as PICASSO-CENA. The ability to numerically move the aerosols from the orbit position of lidar overpasses to subsequent orbits (spaced approximately 1500 km away) should be a goal of assimilation for these new generation of sounders.

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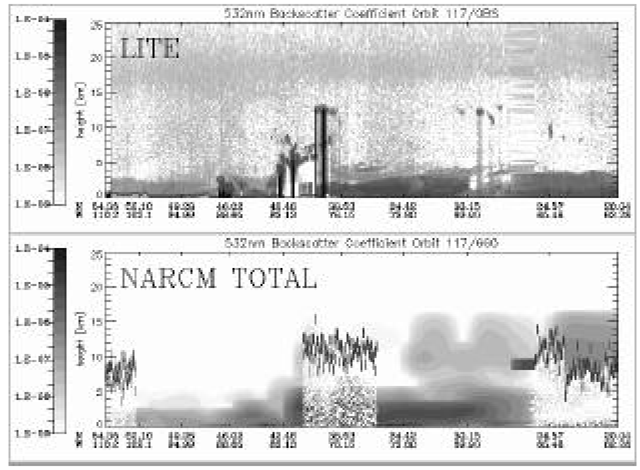

Figure 2: Orbit 117, Comparison of LITE backscatter retrieval (top) and NARCM model backscatter output(bottom). Cross-hatching indicates cloud systems.

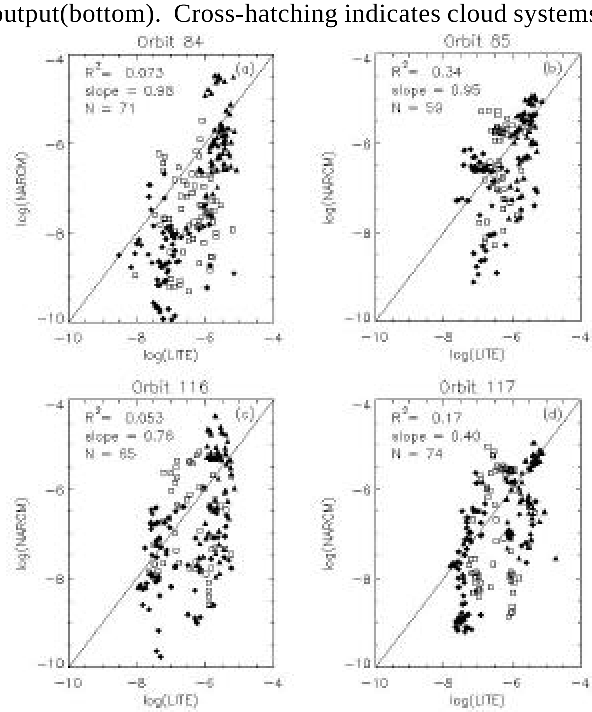

Figure 3: Correlation plots of LITE data vs. NARCM model backscatter at 3 levels in the atmosphere (from 0 km to 2 km, triangles; 2 km to 4 km, squares; and 4 km to 6 km diamonds).