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COASTAL AEROSOL PHASE FUNCTION MEASUREMENTS WITH A  
CUSTOM POLAR NEPHELOMETER

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INTRODUCTION

The aerosol phase function describes the angular distribution of light scattered from aerosol particles. This aerosol phase function, along with the aerosol scattering and absorbing coefficients are typically the main unknown parameters needed to model atmospheric radiances in radiation models. The molecular optical properties are fairly well known. In carrying out radiance calculations, the aerosol phase function is typically obtained from MIE calculations based on aerosol models. These describe the aerosol size distribution (concentration as a function of diameter) and the aerosol composition which affects the aerosol index of refraction. In doing these calculations the modeler must attempt to choose the correct aerosol model for the situation being studied. This is often difficult as aerosol types can vary dramatically, relatively few aerosol models exist, and the quality of the existing models is questionable. Due to these limitations, direct measurement of the atmospheric phase function (a combination of aerosol and molecular phase functions) is valuable and allows for test of the aerosol models being used as well as for the development of phase function libraries which can be used in radiative transfer models. Indeed a suite of aerosol phase functions under different aerosol types would prove valuable for radiation modeling efforts. Here we report our first direct measurement of the aerosol phase function using a polar nephelometer.

INSTRUMENT DESIGN

Our design follows the system described by Winchester Jr. (1983, Optical Engineering, pg. 40) and is shown in Figure 1. Two large area silicon detectors are used. One detector scans from ~2 degrees to 165 degrees on a moving arm which is moved by a stepper motor under computer control with a position encoder. Average measurements are made at each one degree interval taking approximately 14 min to complete the range of scattering angles. The second detector is mounted at a fixed angle (~10 degrees) and makes coincident measurements which are used to normalize out variations in aerosol concentrations and laser fluctuations during the time the first detector scans the range of angles. As the moving detector moves to forward scattering angles, a neutral density filter comes into place allowing the same moving detector to measure the total laser power. This measurement, along with the fixed angle detector and the complete phase function measurement can be combined to obtain the total aerosol scattering coefficient.

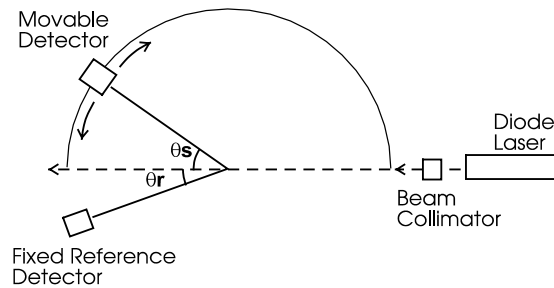


Figure 1. Design of a polar nephelometer to measure the aerosol phase function. The fixed detector is used monitor variations in laser power and aerosol concentrations while the scanning detector moves to different scattering angles. It can also be used to monitor the aerosol scattering coefficient once the phase function and total laser power measurements have been made.

## MEASUREMENTS

Our first measurements were made at Bellows beach directly downwind of small breaking waves ( Figure 2). The left panel shows dark measurements made by blocking the laser beam to asses the signal to noise. The right panel shows all the measurements together. It can be seen that the phase function had a strong forward scatter component and an oscillation near 155 degrees which is consistent with large salt aerosol.

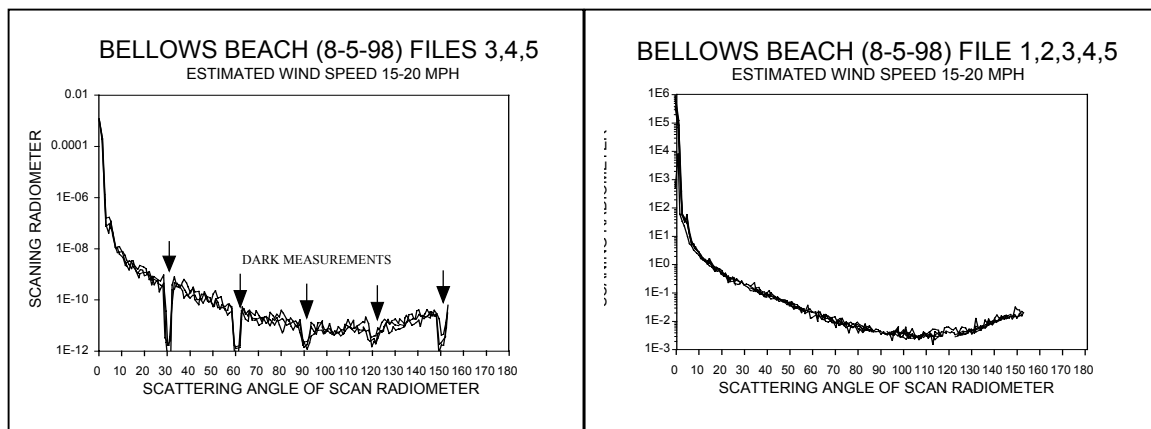


Figure 2. Phase function measurement made at approximately 1 degree intervals and four second averaging was done at each angle. The values were obtained by dividing the scanning radiometer measurement by the fixed angle measurement in order to remove fluctuations in aerosol scatter and laser intensity. The measurements are made at a wavelength of 808 nm.

The system was also built so that when the scanning detector moves to the forward scattering angle (less than 1 degree) a neutral density filter comes into place and the laser power can be measured with the scanning angle detector. This total power measurement can be combined with the phase function measurement, and the fixed angle detector to derive the aerosol scattering coefficient. Although we have not yet carried out these calculations, Figure 3 shows a time series of measurements made by the fixed angle detector. These measurements would then be converted into scattering coefficients using a phase function value and the total laser power.

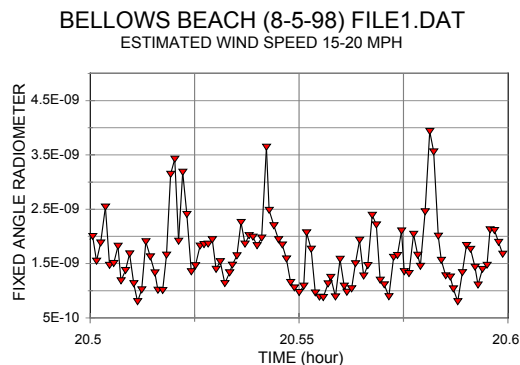


Figure 3. Time series of light scattering measurements from the fixed angle detector. Combining these measurements with the laser power and phase function value (both approximately constant for a certain aerosol type) it is possible to derive the aerosol scattering coefficient.

While these initial measurements are certainly encouraging, it can be seen that the signal to noise near the bottom of the phase function is not too large (Fig. 2). This means we will have problems when aerosol scattering coefficients are smaller than those we found in the coastal region. Therefore we have ordered new optical components which will provide a stronger laser, a chopper system and measurements extending to greater than 175 degrees backscattering angles.

#### AEROSOL PHASE FUNCTIONS FROM AEROSOL MODELS

Using the aerosol models described in Porter and Clarke (1997, JGR Atmospheres, pg 6035) we have modeled the aerosol phase function for several common types of aerosol with very different optical properties. The aerosol cases are shown in Figure 4 and include three accumulation mode types and one coarse mode. The smallest accumulation mode is typical background free troposphere aerosol (15% relative humidity) with low concentration and low relative humidity (curve 1 in Fig. 4). The next largest accumulation mode corresponds to typical background sulfate concentrations (75% relative humidity) and is labeled as curve 3 in Figure 4. The largest accumulation mode corresponds to a polluted air mass (75% relative humidity) and is labeled curve 5 in Figure 4. The coarse mode sea salt in Figure 4 corresponds to wind speeds of 7 m/s at a relative humidity of 75%.

The aerosol phase functions for combinations of these cases has been calculated from MIE code (550 nm) and are shown in Figure 5. It can be seen that the free troposphere aerosol has the smallest forward scatter and behaves similar to molecular scatter with forward and backward scatter having similar values. The VOG case (aerosol type 3) has more forward scatter and less side and back scatter. The addition of a coarse mode only affects the forward scattering angles increasing the values from 0-10 degrees. The coarse mode alone and the coarse mode with a background amount of sulfate accumulation mode aerosol (aerosol type 2) are identical and have a very strong forward scattering peak and a rainbow effect near 150 degrees. It is interesting to note that as the aerosol changes from smaller effective diameters to larger diameters the forward scatter phase function changes from smaller to larger values and the side scatter regions do the opposite. The back scatter regions (~145-180) are different in that as the aerosol effective diameter increases, the phase function goes from large to smaller and back to larger values. This effect creates problems in both Lidar and satellite efforts.

Comparing the phase function we measured (Figure 2) with the modeled ones (Figure 5) we can see the sea salt model fits our measurements best. Both have a strong forward scattering

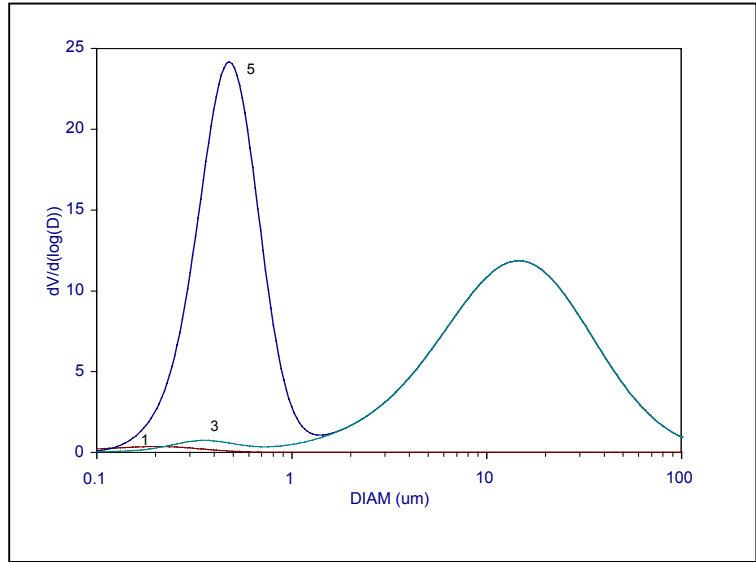


Figure 4. Aerosol size distributions which include three accumulation modes and one coarse mode. These distributions have been shifted to larger sizes depending on ambient relative humidities. The smallest accumulation mode is representative of free troposphere at 15% relative humidity (curve 1) and it has been multiplied by 10 to show up on this graph. The accumulation mode labeled 3 corresponds to a clean marine troposphere accumulation mode at 75% relative humidity. The largest accumulation mode (curve 5) corresponds to a polluted case at 75% relative humidity. The coarse mode represents sea salt at 75% relative humidity for a wind speed of  $\sim 7$  m/s.

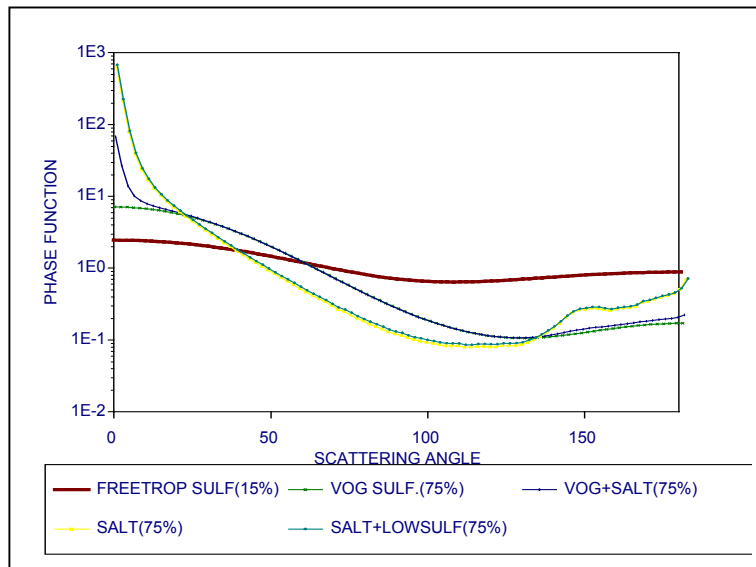


Figure 5. Aerosol phase functions calculated from combinations of the aerosol distributions shown in Figure 4.

peak and a rainbow type oscillation near 150-160 degrees. It can also be seen that the forward scatter peak is larger in our measurements even though the measurements were made at 808 nm and the MIE calculations were at 550 nm. This suggests larger aerosol were present in the coastal measurements which is consistent since the aerosol model is for the marine free troposphere and not a breaking wave region. Future studies will be done to see if larger aerosol models agree with the aerosol phase function measurements.

## CONCLUSION

We have described measurements made with a new polar nephelometer. Measurements were made at coastal site ~40 feet from breaking waves. A normalization approach was used to remove fluctuations during the time the instrument scanned from ~2-165 degrees. The system can also be used to measure the scattering coefficient as a function of time by combining the various measurements. Comparisons were made with MIE calculations from a published aerosol model and qualitative agreement was found with a sea salt model. Further comparison efforts will be carried out. The dark count measurements shown in Figure 2 show that our signal to noise is not optimal even though differences between each scan were small. We are currently upgraded several components out our system with a chopper, stronger laser and better optics to improve on the signal to noise. We are also making plans to water proof the system for in water measurements of the particulate phase function.