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Atmospheric Measurements Using the LAMP Lidar during the LADIMAS Campaign

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SUMMARY

The results of the LAtitudinal DIstribution of Middle Atmosphere Structure (LADIMAS) experiment have provided a unique data set to improve our understanding of the middle atmosphere. The project included ship-board and rocket range coordinated measurements between 70N to 65S to study the structure, dynamics and chemistry of the atmosphere. Results on important dynamical processes, such as gravity waves, tidal components, as well as the formation of the layers of meteoric ion and neutral species, have been obtained with lidar, digisonde, microwave radiometer, and spectrometers. The cooperative study of the atmosphere was undertaken by researchers from several laboratories, including Penn State University, University Bonn, University Wuppertal, Lowell University, and others. Several of the parameters studied have never been measured before over such a wide range of latitudes. Instruments were assembled aboard the German research vessel RV POLARSTERN while this vessel was sailing from the Arctic to the Antarctic seas between October 8, 1991 and January 2, 1992. This paper presents an introduction to the data gathered by the PSU investigation with the LAMP lidar.

MEASUREMENTS

The LAMP (Lidar Atmospheric Measurements Program) instrument is an advanced laser remote measurement sensor which has been built-up during 1990-1991. The design follows the progressive development of our two previous lidar designs [1,2]. This instrument extends the measurement range to cover the troposphere as well as the stratosphere and mesosphere, using the molecular and Raman scatter signals at several wavelengths to determine the profile distributions of density, temperature, extinction, particle back-scatter, and water vapor concentration. The instrument uses a high power Nd:YAG laser with an output of 1.5 J/pulse at 20 Hz. The fundamental wavelength is doubled to obtain 600 mJ pulses at 532 nm and mixed to obtain 250 mJ pulses at 355 nm. The transmitter, receiver, detector, and data system combination have been integrated into a standard shipping container, which serves as a field laboratory. The primary receiver is a 41 cm diameter Cassegrain telescope. The measurements of the back-scatter radiation are made at the fundamental wavelengths of 532 and 355 nm with several different detectors in order to cover the dynamic range. Figure 1 shows an example of the raw lidar signal, corrected for R^2 dependance, which is typical of the signals measured on several of the data channels. The low altitude channels for 532 and 355 nm receive about 5% of the collected intensity and the measurement is made in analog mode with an A/D converter at 10 MHz (15 meter altitude steps) with 12 bit resolution. The high altitude channels are mechanically shuttered below 15 km to prevent the PMT's from being saturated. The high altitude channels and the Raman channels for N_2, at 607 nm, and for H_2O, at 660 nm, use photon counting detectors, with range bins of 500 nanoseconds (75 meter altitude steps). A smaller telescope, 20 cm diameter, was used for independent measurements, most frequently at the 532 nm wavelength. In Figure 2, the profiles of the low and high altitude channels have been overlapped to provide continuous profiles from 200 meters to 80 km. The back-scatter and extinction associated with the stratospheric aerosols, clouds and the boundary layer can be readily observed in the profiles of these two wavelengths. Notice that the scattering ratio of the 532 nm compared to the 355 nm changes significantly with the changing size of the particle scatterers. When the stratospheric aerosol scattering intensities are compared to those for the tropospheric clouds, the change in extinction and back-scatter cross-section with particle size is obvious.

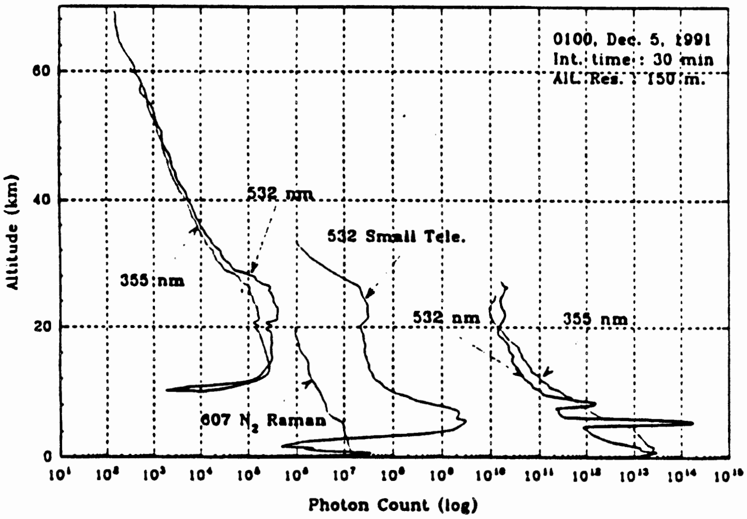

Figure 1. The raw signals, corrected for R^2, for the low and high altitude channels, small telescope, and N_2 Raman are shown.

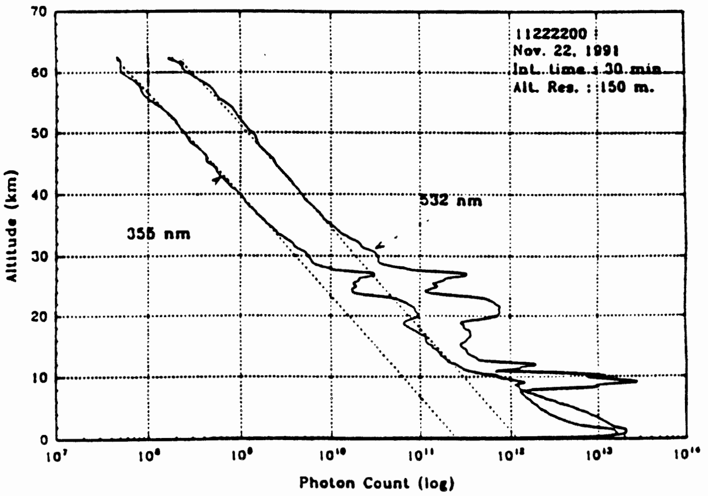

Figure 2. Low and high altitude channels are joined to form continuous profiles.

The initial data of LADIMAS, for the LAMP instrument, were gathered at Andoya Rocket Range, Norway. On the leg between Tromso, Norway, and Bremerhaven, Germany, the operational testing of the instrument on the ship was completed. Measurements were made on each clear night, and on some occasions, the measurements were made below and into the clouds. The measurements included high and low altitude channels for the 532 and 355 nm wavelengths, Raman shifted N_2 at 607 nm, Raman shifted H_2O at 660 nm, and 532 nm measurements from a second telescope simultaneously recorded. The variation in the profile, see Figures 1 and 2, near 25 km is due to particle scattering. One of the more striking features observed by the LADIMAS instruments is the lower stratospheric aerosol and particle layer. The high altitude signal, above about 30 km, can be easily analyzed to provide density and temperature profiles [3]. The two-color approach [1, 2] allows the detection of the molecular and particle components. Note that the particle scattering relative intensity is much stronger for the 532 than for the 355 signals. The cross-section for the molecular scatterers is much larger at 355 nm, while the particle cross-section may not differ significantly between the two wavelengths [for example, see 4]. Figure 3 shows the measured signals of the 355 and 532 nm channels, together with the profiles of the aerosol scattering ratio to the molecular scattering, in this case, unity has been subtracted. Figure 4 shows the latitudinal plot of the scattering ratio for the 355 and 532 nm wavelengths. The strong variation in the scattering ratio as a function of latitude may be a result of the recent Pinatubo volcano eruption which transported dust to stratospheric heights [see 5]. The two color lidar shows a strong difference in relative back-scatter intensity from the stratospheric aerosols. The extinction due to the layers is obvious in the profiles.

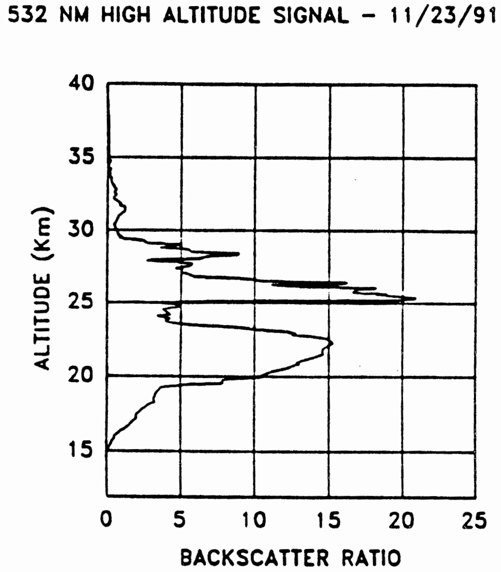

Figure 3. The high altitude channel of the 532 nm signal shows the stratospheric layers enhanced by the Pinatubo volcano.

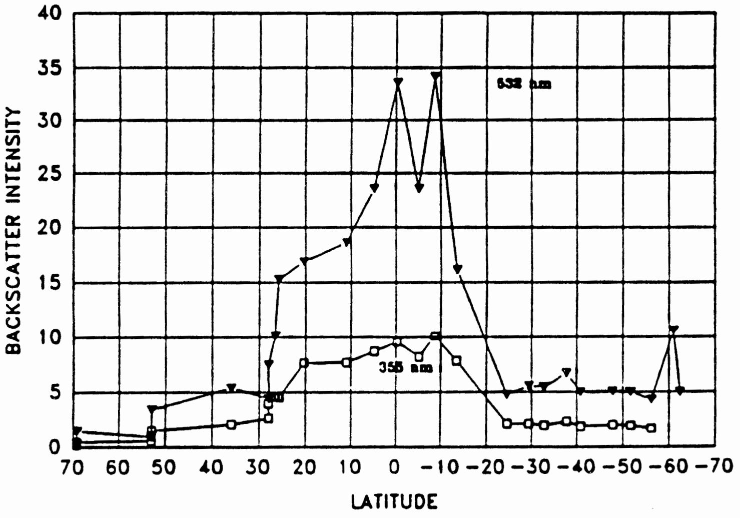

Figure 4. The latitudinal profile of the peak back-scatter intensity at the 532 and 355 nm wavelengths.

At tropospheric altitudes, the Raman N_2 profile together with the two-color back-scatter should allow the separation of the extinction, back-scatter due to particles and the molecular back-scatter signals. The advantage in using the Raman signals in the lower atmosphere is clear from the profiles shown above. Figure 5 shows a representation of the spectral signatures which would be expected from the back-scatter due to the 532 nm laser radiation in an atmospheric volume (after Inaba and Kobayasi [6]). The laser is injection seeded to give a line-width of about 80 MHz and thus the particle back-scatter is of that spectral width, while the molecular peaks are broadened by the thermal Doppler spreading. The vibrational Raman scattering peaks are shown for O_2, N_2 and H_2O. Each of the peaks is also broadened at their base due to the rotational splitting of each vibrational state. Only the first Stokes vibrational states are indicated. The figure indicates the large cross-section difference in the processes involved. The Raman H_2O signal ratio to the Raman N_2 signal provides a good measure of the water vapor concentration. Figure 6 shows the profiles of the water vapor concentration at two of the times when rawinsonde balloon data were available for comparison. The previous work of Melfi [7] has shown the power of the Raman technique for obtaining water vapor measurements. The results gathered here have provided a data base to study the marine boundary layer.

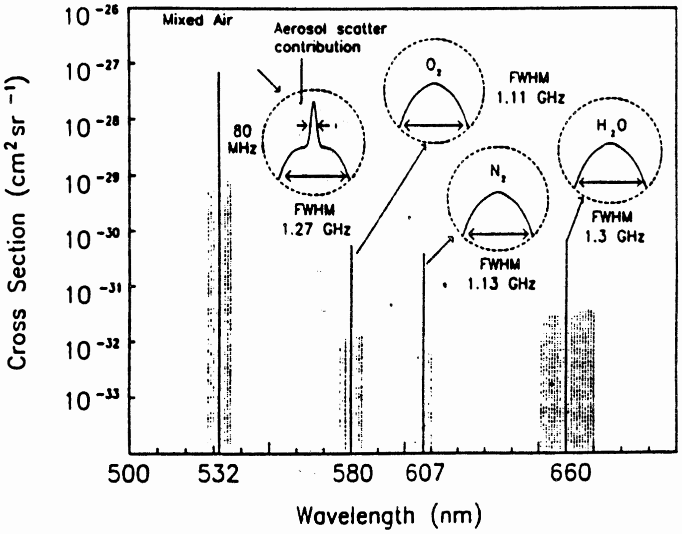

Figure 5. Descriptive representation of the vibrational and rotational Raman signals expected for radiation of an atmospheric volume with 532 nm laser.

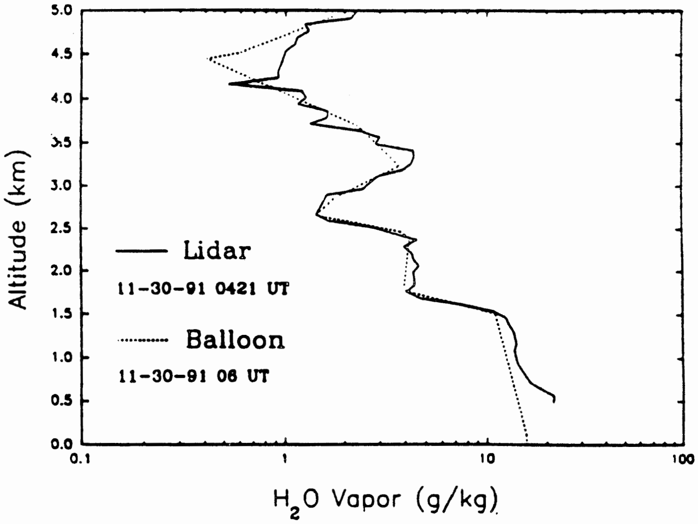

Figure 6. Examples of the water vapor concentration obtained from the Raman signals.

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