Comparison of atmospheric aerosol backscattering and air mass back trajectories

J. M. Vaughan¹, R. H. Maryon², and N. J. Geddes³

With 6 Figures

Received July 14, 2000
Revised May 14, 2001

Summary

Atmospheric backscattering from aerosol particulates has been measured over the Atlantic at 10.6 μm wavelength with an airborne, coherent heterodyne, lidar, and corresponding air mass back trajectories have been calculated. These back trajectories (usually extended up to 10 days prior to the backscatter measurement) have shown very diverse origins for the air parcels at different altitudes. In many cases it has been possible to attribute the observed levels of scattering to these origins over oceanic, arctic, continental, industrial etc. regions. This is illustrated by 6 flight records: out of Ascension Island in the South Atlantic; over the Azores in the mid North Atlantic; over the UK and the North Sea; and in the Arctic along 71° North. In each of these regions the profiles of backscatter versus altitude show highly variable features; remarkably different origins for air masses at different altitudes are evident from the corresponding back trajectory analyses. It is thus possible for the first time to present probable explanations for the different levels of scattering observed at different altitudes.

1. Introduction

During the period 1988–90 extensive measurements of atmospheric backscattering were made over the North and South Atlantic with an airborne, coherent heterodyne, lidar operating at 10.6 μm (Alejandro et al., 1990, 1995). The results have been presented in a lengthy compendium (Vaughan et al., 1995) providing an Atlantic climatology of atmospheric aerosol backscatter at altitudes of up to 16 km. For several of these flight records the back trajectories of the air masses traversed by the lidar have now been analyzed with the NAME (Nuclear Accident Model) programme of the Meteorological Office; six records of this kind are presented and discussed in this paper. The investigation of the nature, sources, transports and chemistry of atmospheric aerosol is assuming steadily greater importance in atmospheric science. Transport and dispersion models are an important component of the numerical modelling machinery applied to investigation in these areas; they form the necessary linkage with source emissions and inventories, and are used to simulate the concentration and dilution (typically due to turbulence) of airborne material of all kinds.

These activities include the modelling of air pollution and quality, involving, for example, sulphur, nitrogen and photochemistry – a huge topic, for which a major recent text is Seinfeld and Pandis (1998) and a typical example of recent work Malcolm et al. (2000). Increasingly sophisticated and accurate transport modelling is being widely used in studies of the source strength and background concentrations of radiatively active trace gases (Derwent et al., 1998; Ryall et al., 1998). Operationally, the modelling
of aerosol transports features in the simulation of the spread of volcanic ash, of critical importance to aviation (Heffter and Stunder, 1993), and of course pollution resulting from nuclear or major chemical accidents and conflagrations. International protocols are in place for the management of such emergencies, and extensive collaborative work has been carried out on the testing and intercomparison of transport and dispersion models (for example, Mosca et al., 1998). Transports of airborne pathogens, and biota in general, also require suitable transport and dispersion models which, in brief, have been applied to pollution problems and the physics of atmospheric dispersion on all motion scales from street canyons to global diffusion (Maryon and Buckland, 1995). A second area of aerosol and gaseous transport studies of pressing importance is concerned with the evolution of climate forcing and change, in which sulphate aerosol and volcanic effluent are just two of a range of airborne substances subject to intensive investigation, typically involving general circulation models.

2. Backscatter measurements

The backscatter measurement programme was conducted in 6 principal regions and seasons. The data has recently provided the basis for a global evaluation of aerosol backscatter (Vaughan et al., 1998) and has also been used by the European Space Agency for modelling the performance of space-borne Doppler wind lidars for the Atmospheric Dynamics Mission (ESA Report, 1999). The backscatter measurements were made with the LATAS (Laser True Airspeed System) coherent lidar (Woodfield and Vaughan, 1983; Vaughan et al., 1988) developed at DERA Malvern, which is used a continuous wave 3 to 4 Watt CO₂-laser. In the coherent lidar technique backscattering from aerosol particles is collected at the telescope receiver and mixed with an optical local oscillator beam at the surface of a detector. Processing of the resultant heterodyne signal provides an optical spectrum of the sum of backscattering from the particles within the effective probe volume of the lidar. Coherent heterodyne techniques are best known for providing wind and airspeed from measurement of the resultant Doppler shift frequency. However, with a well calibrated system such as LATAS, the strength of the Doppler spectrum additionally provides a good measure of the absolute value of back scattering from atmospheric aerosols at the laser wavelength (10.6 μm). In generally clear air in the mid levels (~2 to 8 km) such scattering is mostly due to aerosol particles in the approximate size range ~0.1 to ~5 μm; larger particles tend to settle out while smaller ones scatter weakly at the comparatively long wavelength of 10.6 μm. In incipient and well developed cirrus cloud (at typically 10–15 km) the scattering is often very strong from somewhat larger particles. This is also true at low levels within the planetary boundary layer, below ~2 km, where dust and sea spray may be uplifted from the earth and sea surface. In addition back scattering from aerosols tends to increase at high relative humidity by typically factors of 2–3 at

![Fig. 1a. Altitude record of backscatter for the southerly part of Flight 17 out of Ascension Island (in the region of 16°S, 20°W) recorded from 06.10 to 07.10 Universal Time Clock (UTC) (November 9, 1988). Note the increased scattering above 9 km altitude which was not present closer to Ascension Island (at 8°S 14.4°W), also the horizontal bars at the right-hand side showing the heights at which the back trajectories were calculated for Fig 1b](image-url)