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Data Set Description:

PI: Giorgio Fiocco
Dipartimento di Fisica, Universita' "La Sapienza"
Roma, Italy
Instrument: Lidar
Site(s): Thule, Greenland
Measurement Quantities: Aerosol profiles

Contact Information:
Name: Daniele Fua
Address: Dipartimento di Fisica, G24
Universita' "La Sapienza"
P.le Aldo Moro, 2
00185 Roma Italy
Phone: (396)4991-3523
FAX: (396)4991-3522
Email: fua@g24ux.sci.uniroma1.it

Reference Articles:
di Sarra, A., M. Cacciani, P. Di Girolamo, G. Fiocco, D. Fua`, B. Knudsen, N. Larsen, and T.S. Joergensen: 1992; Observations of correlated behavior of stratospheric ozone and aerosol at Thule during winter 1991-1992. Geoph. Res. Lett., 19, 1823-26.

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Larsen, N., B. Knudsen, T.S. Joergensen, A. di Sarra, D. Fua`, P. Di Girolamo, G. Fiocco, M. Cacciani, J.M. Rosen, and N.T. Kjome: 1994; Backscatter measurements of stratospheric aerosols at Thule during January-February 1992. Geoph. Res. Lett., 21, 1303-1306.

Di Girolamo, P., M. Cacciani, A. di Sarra, G. Fiocco, and D. Fua`: 1994; Lidar observations of the Pinatubo aerosol layer at Thule, Greenland. Geoph. Res. Lett., 21, 1295-1298.

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Fiocco, G., M. Cacciani, A. di Sarra, D. Fua`, P. Colagrande, G. De Benedetti, and R. Viola: 1996; The evolution of the Pinatubo stratospheric aerosol layer observed by lidar at South Pole, Rome, Thule: a summary of results. The Mt. Pinatubo Eruption. Effects on the Atmosphere and Climate, NATO/ASI Series, eds. G. Fiocco, D. Fua`, and G. Visconti, Springer-Verlag, Berlin, pp 17-32.

Marenco, F., A. di Sarra, M. Cacciani, G. Fiocco, and D. Fua`: 1996; Thermal structure of the winter middle atmosphere observed by lidar at Thule, Greenland, during 1993-94. J. Atmos. Terr. Phys., (in press).

Instrument Description:

The lidar installed in Thule (76.5N, 68.8W) is based on a Nd:YAG laser, with a second harmonic generator, capable of emitting short pulses at 532 nm. The pulse energy is generally kept around 100 mJ for aerosol and 300 mJ for temperature with a pulse repetition frequency of 4 Hz. The beam is sent through a beam expander, with an outgoing divergence of 0.15 mrad. The receiving telescope is a 0.8 diameter, vertically pointing Cassegrain. Parallel and cross polarized signals are detected by two photomultipliers and acquired both in A/D and photon counting modes. A rotating shutter inserted in the optical path of the receiver prevents saturation from short range echoes. The data acquisition and storage are controlled by a personal computer. The aerosol analysis is generally based on one hour integrated profiles with a vertical resolution of 75 m. For temperature measurements, the signal is recorded at a height resolution of 150 m with 30 minute integration period; subsequently the 30 minute profiles are added together, thus obtaining an integration time equal to the full duration of the measurement. The observations are carried out during nighttime (arctic winter) and occasionally in daylight (arctic summer) on a schedule depending on weather conditions.

Algorithm Description:

1) Aerosol

The inversion algorithm for aerosol needs molecular density profiles routinely obtained with radiosondes launched by the Thule Weather Station, and, in addition, by ozonesondes launched by the Danish Meteorological Institute. The sondes typically reach 25-30 km. When high altitude data are not available, the AASE 1989, 75N, stratospheric model (Chan et al., 1990, Geophys. Res. Lett. 17, 341) is used. The data analysis proceeds by successive approximations. A molecular echo intensity profile is calculated on the basis of the molecular density, taking into account molecular extinction and range attenuation. The lidar signal is fitted to the molecular profile in the aerosol-free regions expected to exist below and above the stratospheric aerosol layer; normalization factors for the two regions, respectively m0 and m1, are then obtained and used to calculate the one-way aerosol optical depth tau=1/2 log(m0/m1). The backscatter ratio R=(Sa+Sm)/Sm, where Sa and Sm are portions of the signal due to the aerosol and the molecules respectively, the backscattering coefficient, beta, and the extinction-to-backscatter ratio, c, are determined by an iterative method, in which c is assumed to be constant. The error on R (one standard deviation) involved in this analysis is estimated to be, for clear sky conditions, below 5% up to 15 km, and below 8% up to 25 km. The one standard deviation error estimate on tau is around 15%, and is around 7% on c. Larger errors are involved in the presence of tropospheric clouds. It has been assumed that in the so-called aerosol-free regions Sa is zero: this is a potential source of error which is difficult to quantify, and is disregarded in the analysis. The error introduced assuming a constant extinction-to-backscatter ratio has been discussed by Thomas et al.(1987, Ann. Geophys., 5A(1), 47-56).

2) Temperature
The number of photoelectrons counted in each height interval, Deltaz, is corrected for the discriminator deadtime, and the background is subtracted. The relative density of the layer at height zi, drel, is then calculated:

drel(zi) = N(zi)*zi^2*exp{2 tau(zi,z1)}   (1)

where N is the number of counts, z1 is the lowest level at which we calculate the temperature, and tau(zi,z1) is the optical depth of the layer in the height range (z1,zi). The optical depth (< 0.0025 between 35 and 75 km) is calculated by taking into account the Rayleigh scattering from the molecular atmosphere and the ozone absorption, using suitable atmospheric models. In the absence of aerosols, the relative density is directly proportional to the molecular air density:

rho(zi) = K*drel(zi)   (2)

where K, denoted as the lidar constant, accounts for pulse energy fluctuations, receiver efficiency, and extinction in the height range (0,z1).

Normalization of the data at 36 km with the CIRA 1986 model (Barnett and Corney, 1985, Handbook for MAP. 16, 47-137) yields the value of the lidar constant. A running average on the relative density profile is carried out in order to smooth the final temperature curve, degrading the vertical resolution to 4.5 km. The temperature is computed assuming that the atmosphere obeys the perfect gas law and is in hydrostatic equilibrium, with the method described by Hauchecorne and Chanin (1980, Geophys. Res. Lett., 7, 565-568) and Jenkins et al. (1987, J. Atmos. Terr. Phys., 49, 287-298):

T(zi) = M*g(zi)*Deltaz / {R*ln(1+x)}   (3)

where R and M are the perfect gas constant and the mean molecular weight, g(zi) is the acceleration due to gravity at zi,

x = {drel(zi)*g(zi)*Deltaz} /
    {p2/K + Deltaz*SUM[for j=i+1,i2][drel(zj)*g(zj)]} (4)

p2 is the pressure at height z2 = zi2 obtained from the CIRA model, and z2 is the altitude of the highest level at which we calculate the temperature. We have conservatively chosen z1 = 32 km, being the aerosol confined to the underlying layers; z2 is taken at the level where the signal-to-noise ratio reduces to 2.5. The use of a model only affects the result through the ratio p2/K in equation (4). This influence decreases with decreasing height, as the sum in the denominator increases, and the retrieved temperature becomes almost independent from the model about 10 km below z2. A reasonable doubt exists about the reliability of the measurements in the upper parts of the profiles, since the signal-to-noise ratio decreases and the p2/K value affects considerably the result. Sensitivity tests indicate that even for a 5% variation of p2, the T curve remains within the measurement error.

<u>Expected Precision/Accuracy of Instrument:</u>

An error estimate (one sigma) is listed in the files.

<u>Instrument History:</u>

November 1990:	The lidar is installed in a building of Thule Air Force Base. Analog acquisition mode only.
September 1991:	Photon counting mode is introduced.
July 1993:	Daylight aerosol measurement operation is introduced.
November 1993:	Temperature measurement operation is introduced.