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Data Set Description:

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Instrument: Lidar
Site(s): Thule, Greenland
Measurement Quantities: Aerosol profiles

Doi: not assigned

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<u>Instrument Description:</u>
The lidar in Thule was installed within a collaborative effort between the University of Rome, the Danish Meteorological Institute DMI, and ENEA in November 1990. The lidar was primarily dedicated to the measurement of upper tropospheric and stratospheric aerosols. In the following years, since 1993, the capability to measure the temperature vertical profile in the stratosphere and mesosphere was added. During the winter campaign 2008-09 the lidar system was improved by the addition of two channels for the tropospheric aerosols. in October 2010 the lidar has been moved from main base to South Mountain in Building #1971, together with others NDACC instruments. The lidar has been operational during many of the last twenty years, particularly during the winter season.

The system presently includes a linearly polarized Nd:YAG laser (1064nm and 532 nm, 20 Hz pulse repetition rate, 300 mJ energy pulse), a 800mm diameter Cassegrain telescope, with two receiving channels at crossed polarizations; two 50 mm diameter refractive telescopes for the measurements of backscattered signals from the lower troposphere in two polarizations. The 800mm telescope is equipped with a rotating chopper to prevent saturation of the detectors from the low-altitude signals, for the detection of the signal from the upper troposphere, stratosphere and mesosphere.

At present, the Lidar system measures vertical profiles of:

-temperature in the stratosphere and mesosphere, during night-time (from the Rayleigh signal). The data are archived in the NDACC network.

-backscattering coefficient at 2 polarisations of aerosol and clouds (with particular attention to the polar stratospheric clouds PSC), from the surface to the stratosphere. The data between 1991-1996 are archived in the NDACC network.

-aerosol colour ratio (from signals at 1064 and 532 nm) in the troposphere

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.

<u>Algorithm Description:</u>

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.
November 2008:	two channels for the tropospheric aerosols backscattering and depolarization
October 2010:	moving to South Mountain building #1971 Thule High Arctic Atmospheric Observatory (THAAO)
February 2014:	1064nm receiving channel for the tropospheric aerosols

The Thule High Arctic Atmospheric Observatory (THAAO) at Thule Air Base (76.5°N, 68.8°W) is located on South Mountain, at a 20-minute drive from main base, and is superintended by the National Science Foundation (NSF) of United States. Various ground-based instruments installed in the observatory are part of the international Network for Detection of Atmospheric Composition Change (NDACC), run by the NCAR (National Center for Atmospheric Research, USA), the Danish Meteorological Institute (DMI, Denmark), the Stony Brook University (SUNY New York,USA) and Istituto Nazionale di Geofisica e Vulcanologia (IGNV, Italy).

The Italian effort at Thule started in 1990 and is based on a collaboration between personnel of Univ. of Rome “La Sapienza”, ENEA and INGV, which together installed, maintained and operate a number of ground-based instruments devoted to the observation of the Arctic environment.
Other atmospheric measurements made at this site:

- water vapor column and vertical profiles from VESPA22 (INGV)
- surface downwelling and upwelling shortwave and longwave irradiance (ENEA)
- aerosol optical depth (AERONET, NCAR)
- temperature/humidity profiles, liquid water path, column water vapor by Microwave Radiometer (ENEA)
- all-sky images (ENEA)
- cloud base brightness temperature by IR pyrometer (ENEA)
- surface temperature/humidity (INGV)
- PM10 concentration and chemical composition (ENEA/Univ. of Florence, Italy)
- Aerosol and clouds profiles by Ceilometer Nimbus CHM 15k (ENEA)

CAMPAIGNS

Measurement campaigns have been carried out since 1990; during several winters the lidar was operated jointly with DMI instruments (ozone sondes, backscatter sondes, etc.) and the SUNY mm-wave spectrometer for the study of the stratospheric structure and chemical composition.

Based on the lidar measurements, studies have been carried out on the properties and the evolution of stratospheric aerosols, their interactions with stratospheric ozone, in particular after the 1991 eruption of volcano Pinatubo; on polar stratospheric clouds; on the polar vortex structure and evolution; on the thermal structure of the vortex; and on the occurrence of cirrus clouds at the tropopause.

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