The airborne Polar Nephelometer probe

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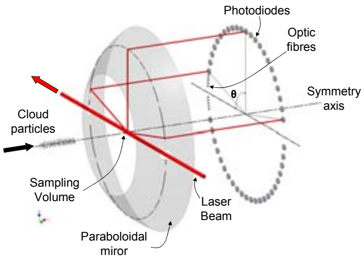
OBJECTIVES

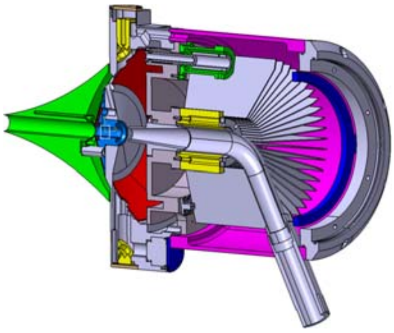
Accurate determination of the optical cloud properties related to particles having complex shape (ice crystals) is crucial for better description of the cloud-radiative interactions. Detailed observations of cloud microphysical and optical characteristics are also required for the validation of retrieved cloud parameters obtained from remote sensing devices. The airborne Polar Nephelometer is the first attempt to measure the scattering phase function of an ensemble of cloud particles (either water droplets or ice crystals or a mixture of these particles) over a size range from a few micrometers to about 1 mm (Gayet et al., Ann. Geophys.,1997). The sensitivity of the instrument allows to detect ice crystals as small as a few microns in diameter and with a detection threshold close to one particle per litre. Direct measurement of the scattering phase function allows particle types (water droplets or ice crystals) to be distinguished and calculation of the optical parameters to be performed, i.e. scattering coefficient and asymmetry parameter. Non-absorbing ice particles randomly oriented in the sampling section are assumed in deriving bulk quantities. Cloud microphysical properties (particle size distribution, liquid water and ice contents, particle concentration,…) can be derived from the inversion technique by Jourdan et al. (JGR, 2003). Since 1996, the Polar Nephelometer has been extensively used on several research aircraft and during ground experiments within numerous research projects with results published to date in about 40 peer review papers.

PRINCIPLE OF MEASUREMENTS



The cloud particles are streamed in a sampling tube equipped with a boundary layer trap. The particles (water droplets or ice crystals or a mixture of these particles) intersect a collimated high-energy laser beam (1 W, λ = 800 nm) at the focal point of a paraboloidal reflector (see figure above). The scattered light is reflected onto a circular array of 54 detectors located in front of the miror. Each detector senses signal corresponding to a range of scattering angles. Ten detectors (located in the forward direction : 3.49° to 10.6° ; resolution : 0.79°) consist of optical fibres (1.5 mm diameter) which drive the light energy onto photodiodes. The other 44 detectors are equipped with lenses which focus the light energy onto the active part of the photodiodes. The corresponding scattering angles are ranged from 15.0° to 169.0° (resolution : 7°). The measurements are independent of the airspeed in the sampling section. The data acquisition system is designed to provide a continuous sampling volume by integrating the measured signals of each of the detectors over a selected period. The sampling volume (v) is determined by the sampling surface (10 mm long and 5 mm diameter beam) multiplied by the Falcon cruise speed of approximately 200 ms^{-1}, i.e., 1 L for an acquisition frequency of 10 Hz.

DESIGN



The Polar Nephelometer is designed to fit with a standard PMS canister and can be used on jet aircraft with airspeed of 200 $m.s^{-1}$.
The shape of the inlet has been designed from aerodynamical modeling in order to optimize the sampling efficiency.
The data acquisition system allows to record the data with a frequency up to 1 kHz or a space resolution of 20 cm at 200 $m.s^{-1}$.

A new version of the Polar Nephelometer is currently made and include improvements :

- to reduce the diffraction effects due to the laser divergence with a new optical system
- to dump the illuminated beam by using a proper light trap
- to modify the design of the detector housing (anti-reflective coated lenses)
- to use Programmable Integrated Circuits for each detector
- to monitor the de-icing cycle of the heating elements

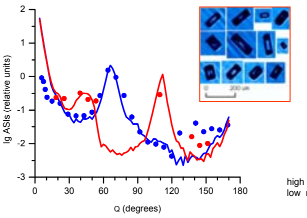
EXAMPLE OF AIRCRAFT INSTALLATION

The Polar Nephelometer on the ATR-42 (Météo-France) during the POLARCAT experiment (Kiruna, 2008) with the Cloud Particle Imager (CPI) and the PMS 2D-P.

Experiments which involved the Polar Nephelometer :

- AEROCONTRAIL (Falcon 20 DLR, 1996)
- ARAT97 (ARAT Fokker 27, 1997)
- CIRRUS98 (TBM700, 1998)
- JACCS (Beech 200, 1999)
- INCA (Falcon 20 DLR, 2000)
- FRENCH (TBM700, 2001)
- SPICE (South Pole, 2002)
- ASTAR (Do 228 AWI, 2004)
- PAZI 2 - LAUNCH (Falcon 20 DLR, 2005)
- ASTAR (Do 228 AWI, 2007)
- CIRCLE 2 (Falcon 20 DLR, 2007)
- IN11 (AIDA chamber, 2007)
- CONCERT (Falcon 20 DLR, 2008)
- POLARCAT (ATR 42 SAFIRE, 2008)
- SPICE (South Pole, 2009)
- SoRPiC (BT 67 AWI, 2010) …

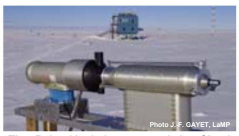
DIAMOND DUST STUDY (SOUTH POLE, 2002)



Parameter	CASE (1)
α °	268 ± 2
β °	34 ±2
γ °	34 ±2
Aspect ratio	5 ±1
η	0.75 ±0.02
σ	0.1 ±0.02
MFPL ratio	10 ±1
D (µm)	70

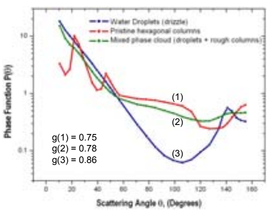
MFPL ratio = MFPL / D
high ratio => small density of inclusions
low ratio => high density of inclusions

Example of measurements of optical properties for single ice particles performed at the South Pole Station. The figure displays angular scattering intensities (ASI) measured by the Polar Nephelometer (full circles blue and red coloured according to the upward and downward values respectively). ASIs modeled by the ray tracing technique (upward and downward components are represented with red and blue curves, respectively). The table summarizes the retrieved parameters values, namely : the three Euler angles (α, β, γ) defining the orientation of the ice particle in the sampling volume, the particle aspect ratio, two surface roughness parameters (η, σ), the inclusion density (MFPL ratio) and the particle diameter (D).
The ice particles columnar shaped simultaneously measured by the Cloud Particle Imager (CPI) (see examples) nicely confirm the results of the retrieving technique (from Shcherbakov et al., JAS, 2006).

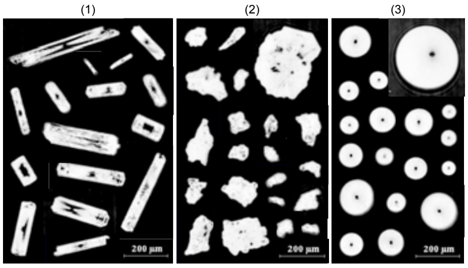


The Polar Nephelometer and the Cloud Particle Imager (CPI) mounted in tandem at the South Pole Station.

PARTICLES SHAPE EFFECTS ON SCATTERING PHASE FUNCTION (ASTAR 2004)

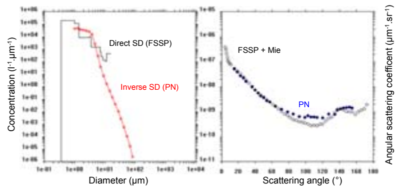


Examples of scattering phase function measurements for different shape of particles simultaneously sampled with the Cloud Particle Imager (CPI). The results highlight that the scattering behavior is strongly dependent on the particle shape (ref. Jourdan et al., JGR, 2010). The corresponding asymmetry factors are indicated on the figure.



Pristine particles · Mixed phase cloud particles · Drizzle particles

CONTRAIL STUDY (CONCERT 2008)



Altitude : 10670 m
Temperature : -56.2 °C
Particule Concentration : 68 cm^{-3}
Effective Diameter : 8.1 µm
Ice Water Content : 3.1 $mg.m^{-3}$
Extinction Coefficient : 1.14 km^{-1}
Asymmetry Factor : 0.828

Example of unique measurements in contrail 150 sec. aged emitted by a large body A380 aircraft during the DLR CONCERT experiment. The right figure represents the measured scattering phase function (full blue circles) and the theoretical scattering phase function calculated from the direct FSSP-300 measurements (see left figure) with Mie theory assuming spherical ice spheres (open circles). The left figure represents the direct FSSP-300 size distributions and the inverse size spectra (red curve) retrieved from the Polar Nephelometer data. The mean microphysical and optical properties of the contrail are reported. The results show a very good consistency between the two independent measurements (PN and FSSP) and confirm that ice particles are quasi-spherical (see also Febvre et al., JGR, 2009).

Picture of contrails taken from the DLR Falcon aircraft with the boom.

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