Development and Deployment of a Powered Tethered Balloon System at the SHEBA Ice Station for Measurements of Cloud Micro-Physical and Radiative Properties

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Introduction

A tethered balloon system that can operate under arctic conditions was developed for deployment at the SHEBA (Surface HEat Budget of the Arctic Ocean) Ice Station. This system consists of a winch with a tether line that can transmit data from, and control commands to, the balloon profiler as well as provide power to continuously operate the instrument package and de-ice the tether line.

The balloon profiler consists of a cloud droplet and ice particle videometer, an aerosol counter, a radiometer, a camera, and a datalogger. The profiler has been developed especially for deployment from standard commercially available tethered balloons.

Tethered Balloon Sonde Power and Communication System

A novel tethersonde system that provides continuous power and communications for a balloon-borne microphysical instrumentation package operating in Arctic clouds has been developed by SPEC, Inc. for the SHEBA project. A diagram of the system is shown in Figure 1. Features of the system include the following:

- hot tether stays deiced while in clouds
- 15 kW continuous power is available for deicing the tether and long duration operation of the balloon instrumentation
- data and power multiplexed onto a single pair of wires
- high-strength Culver core tether (>600 lbs.)
- no battery required in instrumentation payload
- cooled winch allows soundings with hot tether

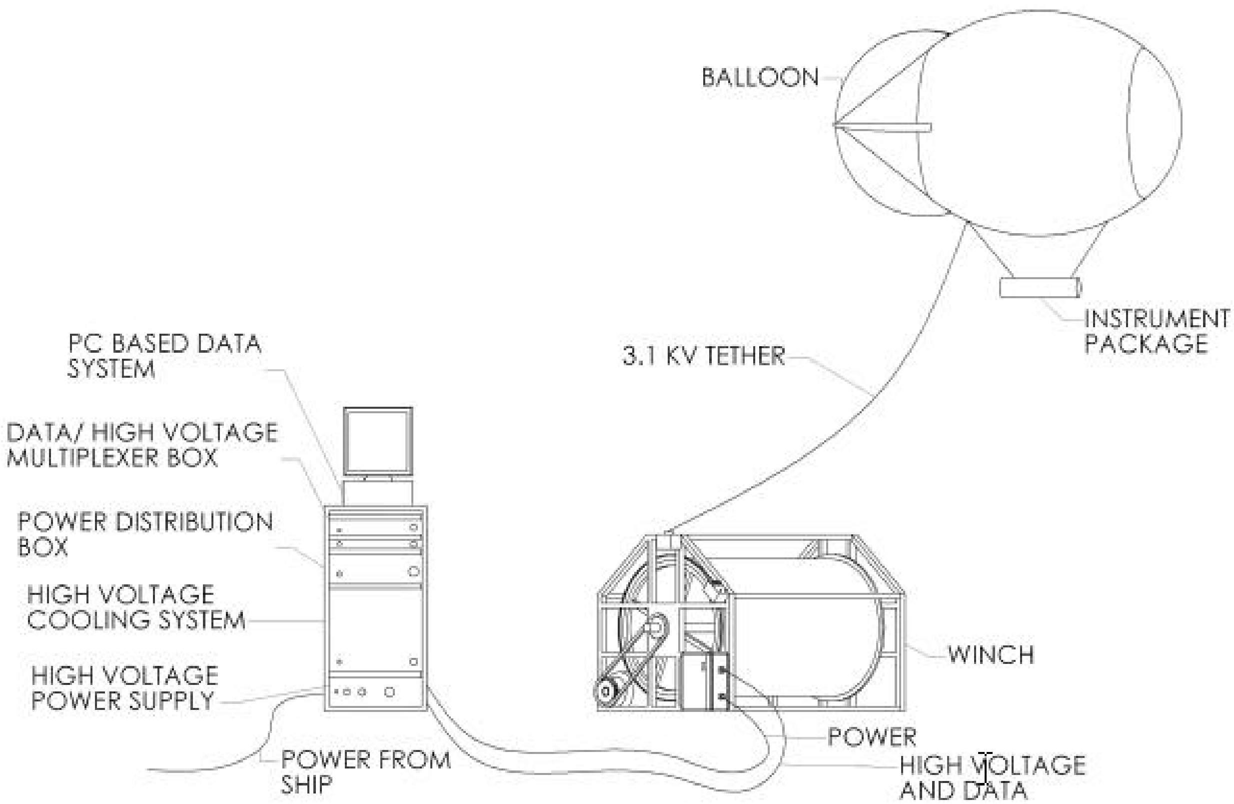

Figure 1. Diagram of hot tether balloon system.

- winch has adequate power to operate large or tandem balloons

- serial data interface to instruments:
  - full duplex 1200 bits/second
  - data integrity ensured with high-noise immunity Loanwords protocol
  - data carried at 125 kHz to eliminate radio frequency interference.

4π Radiometer

A 4π Radiometer was developed especially for the SHEBA project by the Norwegian Institute of Air Research (NILU). The development of this instrument was motivated by the desire to quantify the radiation field in spite of the lack of a leveled platform to measure irradiant incident on a horizontal surface. To capture the basic information on the directional dependence of the radiation field, we decided to mount irradiant sensors on each side of a cube. By subtracting irradiants from opposite sides, we obtain a direct measure of the flux divergence. Similarly, the sum of the irradiants is proportional to the mean intensity.

4π Radiometer Characteristics

Following are a list of the characteristics of the 4π Radiometer:

- It measures irradiant simultaneously in six directions on each face of a cube.
- Each irradiant sensor has two photodiode detectors situated behind a diffuser and a filter.
- The filter response curves have approximate bandwidths of 10 nm (Figure 2).

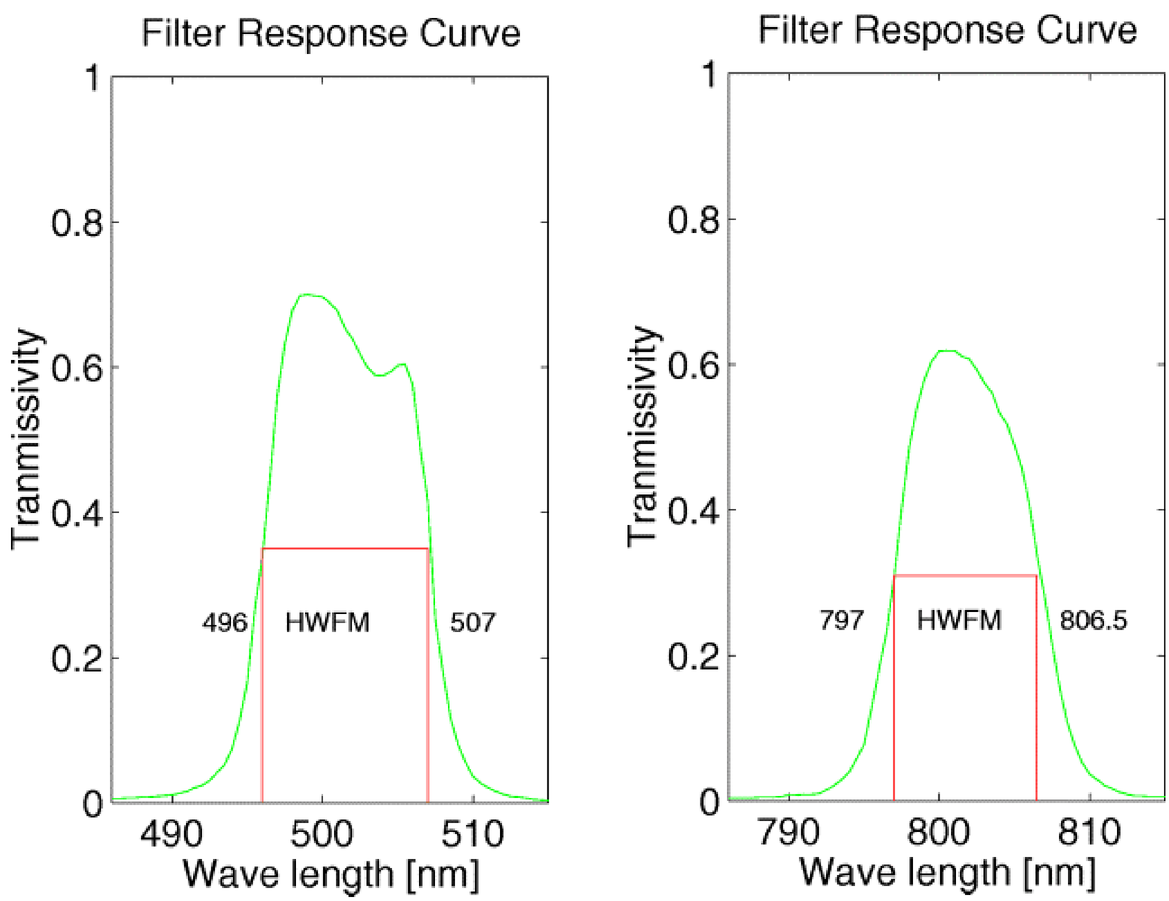

Figure 2. Detector filter response curve for 500-nm channel (left panel) and 800-nm channel (right panel).

Irradiant on the Surface of the Cube

In Figure 3, we have plotted the sum of the irradiants on opposite sides of the cube. The left column is based on irradiant profiles taken during the ascent. Note the effect of a thin cloud layer between 100 meters and 150 meters. This particular cloud was advocated away from the scene before the profiles were taken in the right panel, which were obtained during the balloon decent. Both profiles were taken as the sun was setting. Planned future work includes comparing the irradiants with radiative transfer model results.

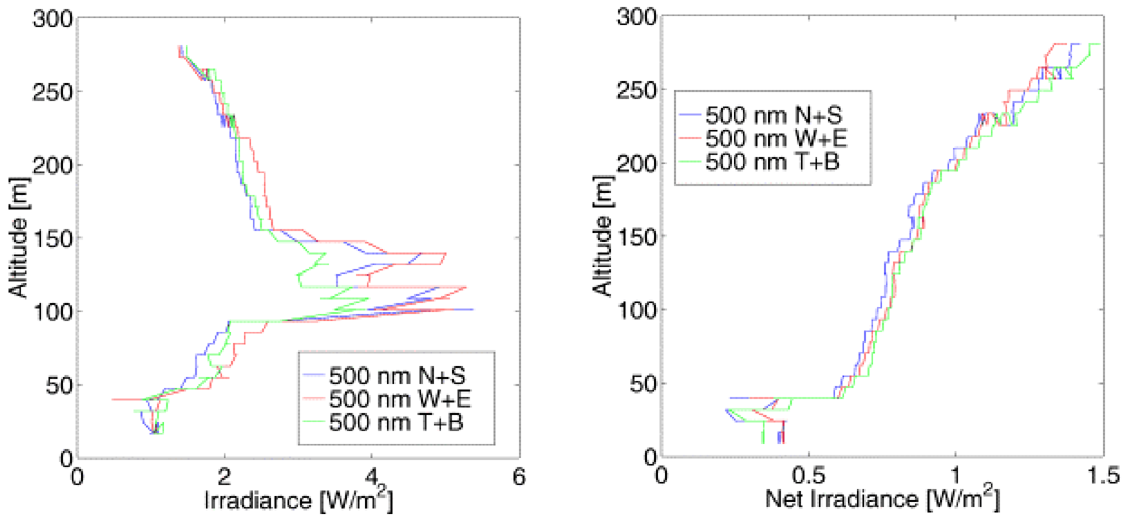

Figure 3. This figure shows the sum of the measured irradiance from opposite sides of the cube for the 500-nm channel. The left panel shows the profile taken during the ascent and the right panel shows the profile obtained during the decent about 30 minutes later.

Imhomogenity of the Radiation Field

Figure 4 shows the percentage difference between the irradiances measured on opposite surfaces of the radiometer cube. We observe a decrease in the homogeneity of the irradiance inside the cloud. When

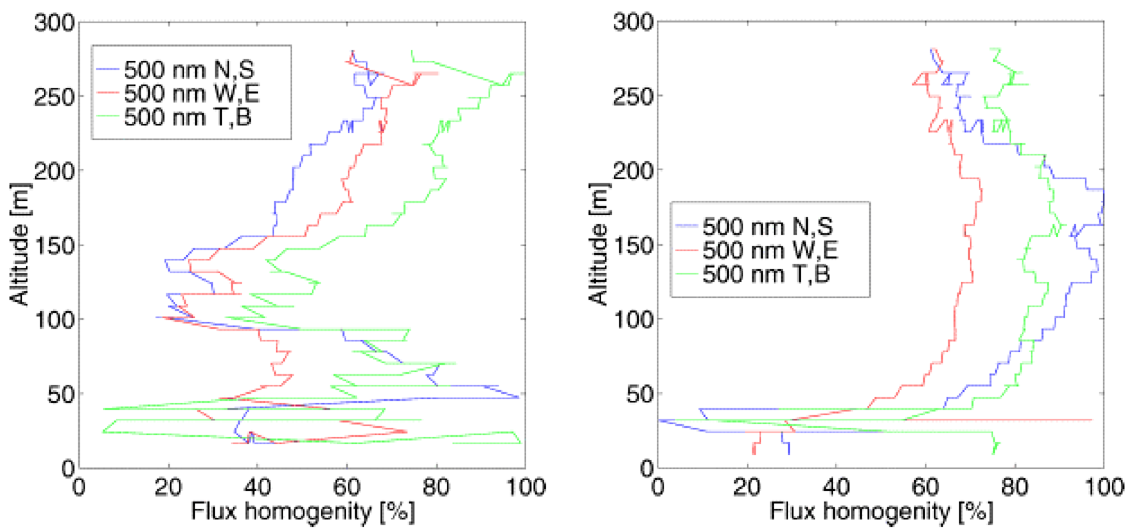

Figure 4. This figure shows the percent difference between the irradiance measured on opposing sides of the cube for the 500-nm channel. The left panel shows the profile taken during the ascent and the right panel shows the profile obtained during the decent about 30 minutes later.

the cloud is optically thin, scattering by cloud particles increases the radiance parallel to the cloud plane, since the scattering optical depth in the cloud plane is greater than in any other direction.

Desert Research Institute (DRI) Cloud Droplet and Ice Particle Videometer Specifications

A description of the DRI cloud droplet and ice particle videometer system and data analysis are outlined below.

System Description

The system includes:

- inertial impaction of cloud particles with microvideography and PC-based image analysis
- 12 VDC power requirement from Li-ion batteries (1.25 hr endurance) or powered tether
- weight: 3.5 kg; condensation nuclei (CN) module: 1.5 kg
- 13-cm diameter x 130-cm long
- data rate: 10 s for droplet spectra (100 cm^{-3}), 1 hr for ice spectra (l^{-1})
- remote control of film speed, focus, pump, illumination, heated inlet, and heat pads
- frequencies: video transmitter – 1687.0 MHz, radio frequency (RF) modem – spread spectrum
- ancillary data: atmospheric pressure and temperature, flow rates, film speed, condensation nuclei concentration (r > 0.02 micrometer)
- max altitude: 2500 m with battery pack, 1 km on powered tether
- measured and derived cloud parameters – droplet size and concentration, ice particle size and concentration, liquid water content (LWC), ice water content (IWC), interstitial aerosol concentration, cloud condensation nuclei (CCN) (by difference), ice particle habit, cloud drop effective radius.

Data Analysis

The video captured by the cloud videometer is analyzed using PC-based image analysis software at DRI. Figure 5 shows derived droplet size spectra from data collected on May 3, 1998. The left panel shows the droplet-size spectrum at the base of a 300-meter-thick stratus cloud while the right panel shows the droplet-size spectrum in mid-cloud. Figure 6 shows an example of a video frame captured while the videometer was situated in mid-cloud.

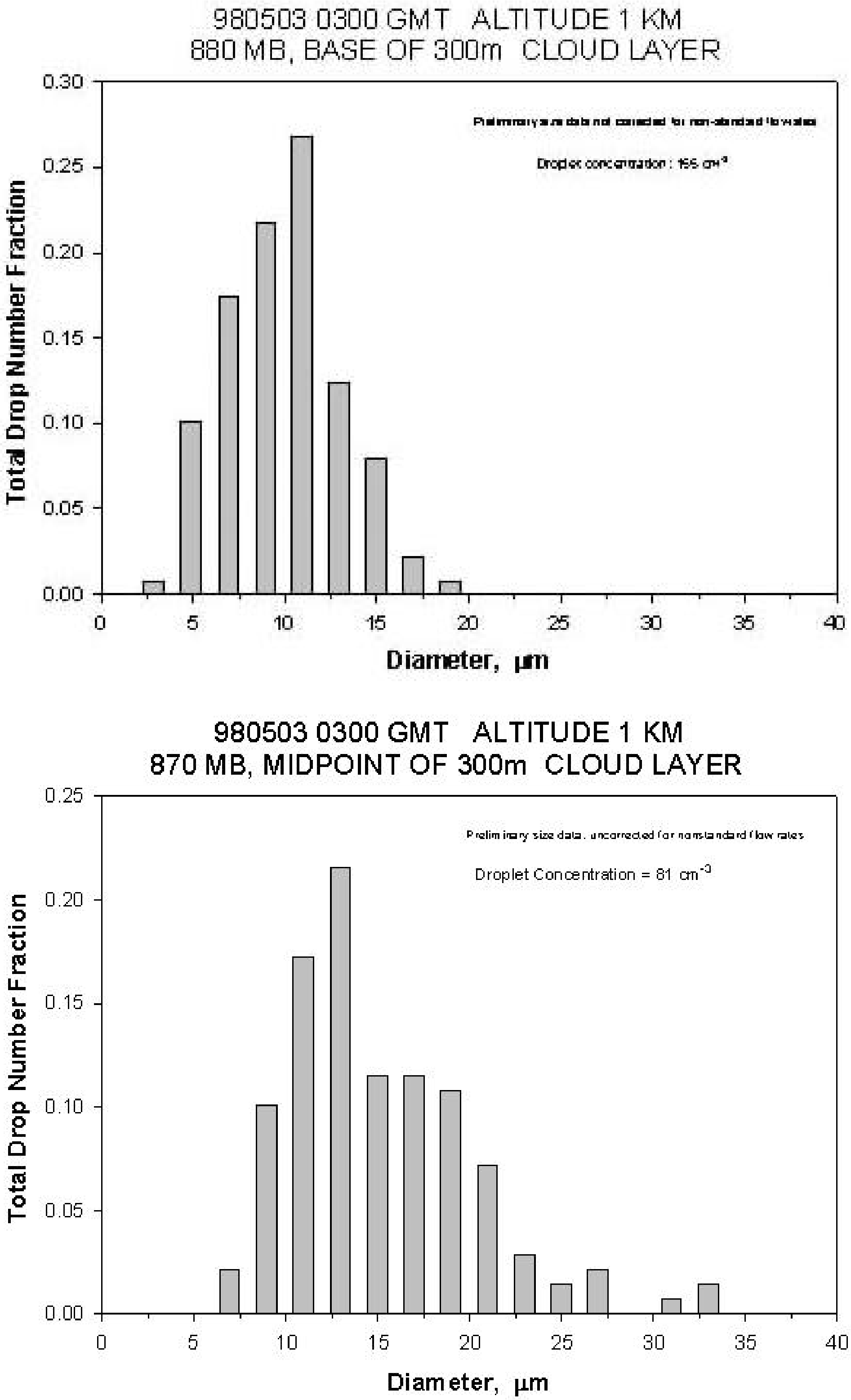

Figure 5. Cloud droplet-size distribution derived from measurements by the DRI cloud videometer on May 3, 1998.

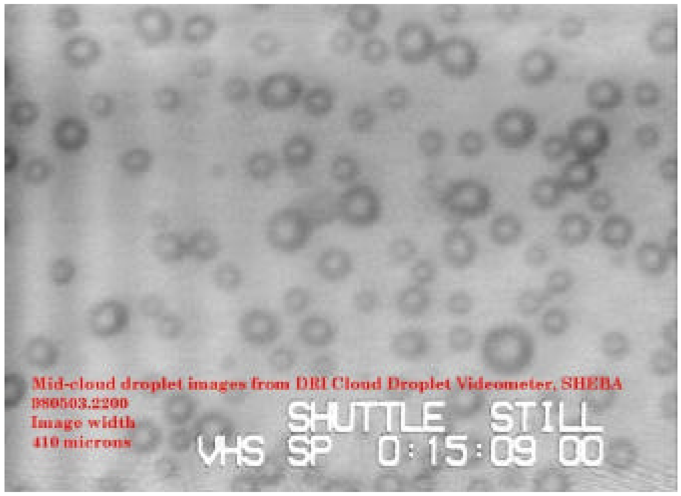

Figure 6. Captured video frame from cloud videometer during mid-cloud measurements on May 3, 1998.

Summary

A novel system has been developed for in-situ measurements of cloud microphysical and radiative properties. This system is capable of measuring true vertical profiles and time series of microphysical properties. Such in situ measurements are not feasible using aircraft or ground-based remote sensing instruments only. The powered tether approach allows for long time series and uninterrupted operation. This feature is especially valuable in cold climates where battery lifetime is limited.