Tethered balloon measurements during Arctic autumn conditions in the framework of HALO-(AC)^3

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Summary: The BalloonbornE moduLar Utility for profilinG the lower Atmosphere (BELUGA) was deployed in autumn 2021 in the Arctic at the AWIPEV research station in Ny-Ålesund (Svalbard). In-situ profiles of thermodynamic parameters, broadband radiation, turbulence, aerosol particle concentrations, and cloud microphysical structure, were performed. Additionally, samples of ice nucleating particles were collected. Thermal infrared radiation profiles are presented for different cloud conditions. The data provides the base for studying the vertical distribution of cloud radiative effects, and extends the common view of the bi-modal distribution of the Arctic surface energy budget.

Zusammenfassung: Das Fesselballonsystem BalloonbornE moduLar Utility for profilinG the lower Atmosphere (BELUGA) wurde im Herbst 2021 an der Forschungsstation Ny-Ålesund in der Arktis eingesetzt. Es wurden In-situ Profile von thermodynamischen Parametern, breitbandiger Strahlung, Turbulenz, Aerosolpartikelkonzentrationen und der mikrophysikalischer Wolkenstruktur erstellt. Zusätzlich wurden Proben von eiskeimbildenden Partikeln gesammelt. Strahlungsprofile wurden unter verschiedenen Wolkenbedeckungen gemessen und quantifizieren die vertikale Verteilung der Wolkenstrahlungseffekte. Die Profilmessungen erweitern damit die für bodennahe Messungen bekannte modale Verteilung des Energiehaushalts der Arktis.

1 Introduction

The tethered balloon system BELUGA (BalloonbornE moduLar Utility for profilinG the lower Atmosphere; Egerer et al., 2019) was deployed at the AWIPEV research station in Ny-Ålesund (Svalbard) for an extensive measurement period in autumn 2021 in cooperation with the Institute for Tropospheric Research (TROPOS) and the Alfred Wegener Institute (AWI). The deployment of BELUGA in Ny-Ålesund succeeds the operation of the balloon from the sea ice (Egerer et al., 2019; Lonardi et al., 2021) and extends the series of tethered-balloon operations in Ny-Ålesund (e.g., Ferrero et al., 2019, Pasquier et al., in review) and in Svalbard (e.g., Cappelletti et al., in review).

The site was chosen for the relative ease of access combined with a comprehensive setup providing time series of radiosoudings (e.g., Maturilli et al., 2013), cloudiness and cloud phase retrieved with ground-based remote sensing (e.g., Nomokonova et al., 2019), surface thermodynamics (e.g., Mazzola et al., 2016), radiation budget (e.g., Maturilli

Figure 1: *(a) The broadband radiation payload on BELUGA and (b) a profile measurement during the polar night.*

et al., 2015), and aerosol particle concentrations (e.g., Lupi et al., 2016). In particular, the daily radiosoundings yeld a valuable dataset for radiative transfer simulations and for the cross validation of some of the observed quantities. Furthermore, the area is subject to intense high-resolution Large-Eddy Simulations (LES) modelling activities by $(AC)^3$ (e.g., Kiszler et al., in review).

2 Overview

The balloon deployment lasted from 17 September to 15 November 2021 (Fig. 1). The BELUGA system followed to a large extent the setup and the techniques adopted during MOSAiC (Multidisciplinary drifting Observatory for the Study of Arctic Climate; Shupe et al., 2022) by Lonardi et al. (2021). Some changes had to be applied to operate in the specific conditions provided by Ny-Ålesund and to extend the research objectives.

A total of 48 flights was performed over 19 days, reaching typically up to 1000-1500 m above ground level (Fig. 2). Profiles were obtained in cloud free and cloudy conditions, with four profiles crossing the cloud layer (on 30 September and 8 November 2021). Snow covered the site from 13 October.

The significant flexibility gained by a potential 24/7 access to the measurement site proved to be important when facing harsh weather conditions that inhibited BELUGA operations during longer periods. The observations were also constrained by commercial

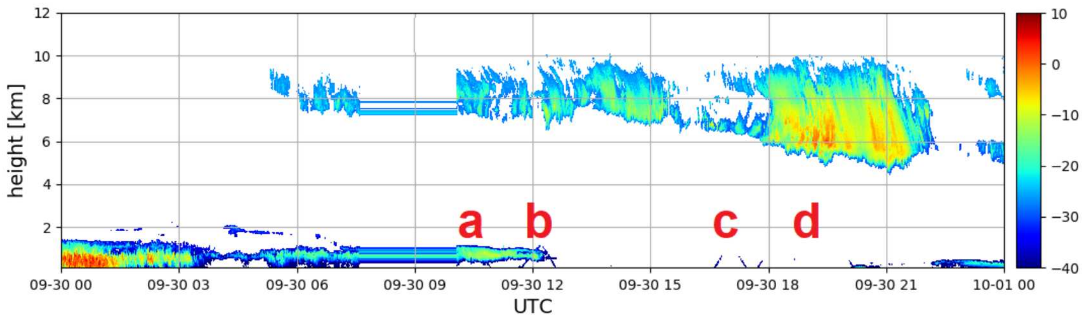

Figure 2: *Radar retrieval on 30 September 2021. BELUGA is partially detected while performing three profiles (a-c) and a two-hours stationary filter sampling (d).*

flights reaching Ny-Ålesund airport, which required the balloon to be at the ground (Fig. 3). BELUGA was also not operated during intermittently strong katabatic winds from the local glaciers. As a result, the balloon had to be stored overnight for safety reasons.

Additionally, the onset of the polar night, combined with cold temperatures (down to -20°C) and strong wind chill (down to -35°C) posed a serious challenge to the personnel in the field. Particular care had to be taken for the staff to be safe and relatively comfortable in such a hazardous environment, further facing the potential threat of polar bear encounters. Great effort was also successfully put in place to avoid to be hit by the ongoing COVID-19 pandemic, still relatively significant at the time.

The measured quantities were almost analogous to the setup presented by Lonardi et al. (accepted) for MOSAiC. An extended meteorological package (EP) served to monitor the basic thermodynamic parameters. A broadband radiation package (BP) measured up- and downwards terrestrial irradiances. An ultrasonic anemometer package (UP) measured 3D-winds to retrieve local energy dissipation rates. Unfortunately, the instrument was heavily damaged on 20 October 2021 and had to be substituted by an hot-wire anemometer package (HP) measuring 1D-wind. The Cubic Aerosol Measurement Platform (CAMP) was used to quantify the vertical distribution of aerosol particles in two different size ranges. The Video Ice Particle Sampler (VIPS) was operated, on a single flight, to characterize the phase of cloud particles. Two additional instruments complemented the setup with in-situ sampling at a fixed height. A cloud water sampler (CWS) was used, to collect water within the cloud. Unfortunately, the sampling efficiency turned out to be too low for in-cloud observations. The high-volume and light-weight balloon-borne filter sampler (HALFBAC) was used to collect ice nucleating particles (INP) for offline chemical analysis.

3 Radiation measurements

LIM in particular operated the broadband radiation measurements to study the vertical change of terrestrial and solar irradiances. Observations of solar irradiances were discontinued due to a low-to-none presence of the solar radiation during the polar night. A total of 39 radiation flights was obtained under various cloud conditions. Figure 4 shows an ensemble of the measured net terrestrial irradiance. Derived heating rates (not shown) from the three different types of scenario generally match with the case studies

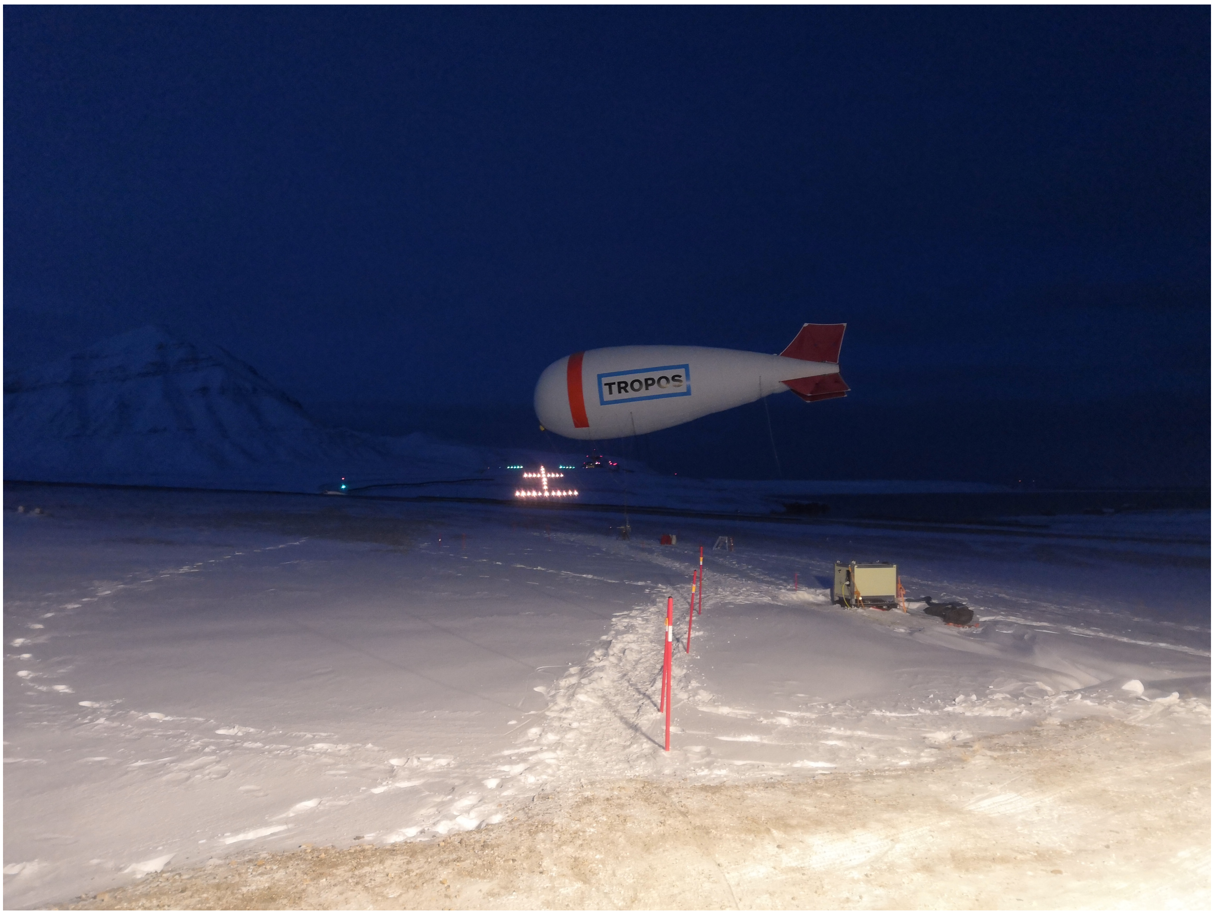

Figure 3: *View of BELUGA at the measurement site in November 2021. The lights in the background mark the runway of Ny-Ålesund airport. The mountain (left) and the open water (dark area on the right) showcase the typical geography of the area surrounding the research site.*

by Egerer et al. (2019).

In particular, 17 cases feature cloud free conditions (Fig. 4, green lines), while 18 cases represent an scenario with elevated clouds (Fig. 4, red lines), with clouds above the maximum height in reach of BELUGA. The cloud top was reached by BELUGA (Fig. 4, blue lines) only four times.

The opposing scenarios, with and without clouds, provide a base to study the vertical distribution of the cloud radiative effect (CRE). This extends the ground-based measurements of the radiation energy budget in Ny-Ålesund. In cloud free conditions, the net terrestrial irradiances are strongly negative and decrease with altitude. Furthermore, a large variability is observed among the single profiles as a result of the variations of temperature and humidity profiles due to seasonality and synoptic activity. In turn, under cloudy conditions there is no significant vertical variation in the total irradiance. As a result, the cloud radiative effect becomes stronger with altitude.

Profiles through clouds (Fig. 4, blue lines) were obtained 4 times during two distinct days (30 September and 8 November 2021). These complement the dataset by Lonardi et al. (2022) and allow for a similar analysis of single-layer clouds as presented by Lonardi et al. (accepted). Additionally, in at least one of these cases (30 September)

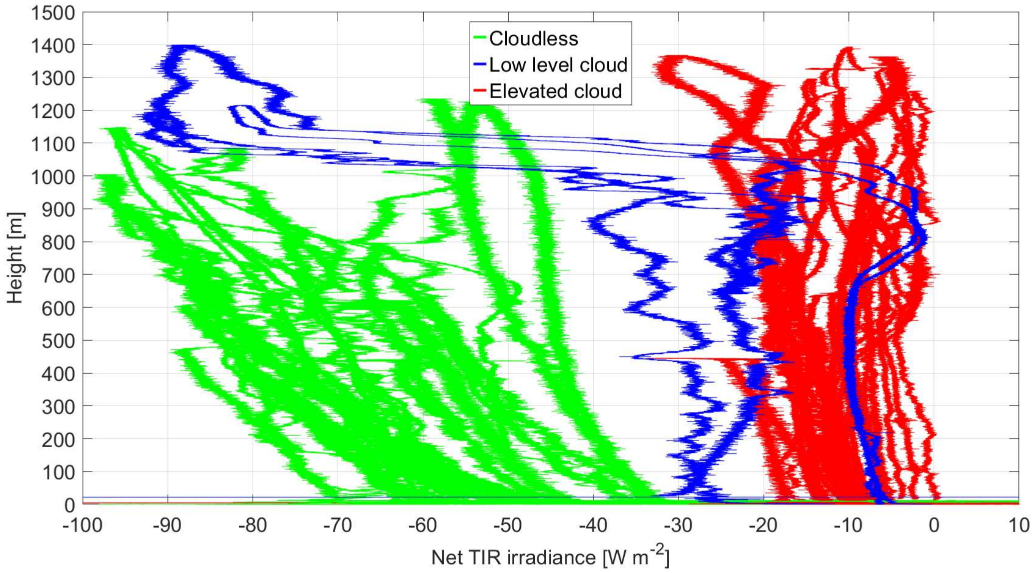

Figure 4: *Ensemble of profiles of net terrestrial irradiance. An immediate visual distinction can be made between the structure of the profiles obtained during cloud free (green), low level cloud (blue), and elevated cloud (red) conditions.*

there is a good agreement between balloon in-situ measurements, Cloudnet remote sensing retrievals, and simulations by the ICOsahedral Non-hydrostatic model (ICON). This case is currently being evaluated by a cross-cutting team within $(AC)^3$.

4 Summary and outlook

The operation of BELUGA in Ny-Ålesund during autumn 2021 provided a significant number of profiles combining thermodynamic properties, terrestrial radiation, turbulence, and aerosol particles, additionally complemented by stationary INP measurements.

Balloon-borne observations are complemented by the Ny-Ålesund time series of radiosoudings, cloudiness and cloud phase, surface thermodynamics, radiation budget, and aerosol particle concentrations.

By comparing opposing scenarios, with and without clouds, the measurements of terrestrial radiation can be used to study the vertical distribution of CRE.

A follow up tethered balloon campaign was conducted in spring 2022 and extended the autumn dataset with cold and dry spring conditions. This period was also partly covered by the airborne observations of the HALO-$(AC)^3$ campaign.

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References

Egerer, U., Gottschalk, M., Siebert, H., Ehrlich, A., and Wendisch, M.: The new BELUGA setup for collocated turbulence and radiation measurements using a tethered balloon: First applications in the cloudy Arctic boundary layer, Atmospheric Measurement Techniques, 12, doi:10.5194/amt-12-4019-2019, 2019.

Ferrero, L., Ritter, C., Cappelletti, D., et al.: Aerosol optical properties in the Arctic: The role of aerosol chemistry and dust composition in a closure experiment between Lidar and tethered balloon vertical profiles, Science of the Total Environment, 686, doi:10.1016/j.scitotenv.2019.05.399, 2019.

Lonardi, M., Ehrlich, A., and Wendisch: Tethered balloon broadband radiation profiles during MOSAiC, Wiss. Mitteil. Inst. f. Meteorolo. Univ. Leipzig, 59, 48–53, URL https://nbn-resolving.org/urn:nbn:de:bsz:15-qucosa2-780112, 2021.

Lonardi, M., Pilz, C., Siebert, H., Ehrlich, A., and Wendisch, M.: [dataset] Tethered balloon-borne measurements of terrestrial radiation during MOSAiC leg 4 in July 2020., doi:10.1594/PANGAEA.944200, URL https://doi.pangaea.de/10.1594/PANGAEA.944200, 2022.

Lupi, A., Busetto, M., Becagli, S., et al.: Multi-seasonal ultrafine aerosol particle number concentration measurements at the Gruvebadet observatory, Ny-Ålesund, Svalbard Islands, Rendiconti Lincei, 27, doi:10.1007/s12210-016-0532-8, 2016.

Maturilli, M., Herber, A., and König-Langlo, G.: Climatology and time series of surface meteorology in Ny-Ålesund, Svalbard, Earth System Science Data, 5, doi:10.5194/essd-5-155-2013, 2013.

Maturilli, M., Herber, A., and König-Langlo, G.: Surface radiation climatology for Ny-Ålesund, Svalbard (78.9° N), basic observations for trend detection, Theoretical and Applied Climatology, 120, doi:10.1007/s00704-014-1173-4, 2015.

Mazzola, M., Viola, A. P., Lanconelli, C., and Vitale, V.: Atmospheric observations at the Amundsen-Nobile Climate Change Tower in Ny-Ålesund, Svalbard, Rendiconti Lincei, 27, doi:10.1007/s12210-016-0540-8, 2016.

Nomokonova, T., Ebell, K., Löhnert, U., et al.: Statistics on clouds and their relation to thermodynamic conditions at Ny-Ålesund using ground-based sensor synergy, Atmospheric Chemistry and Physics, 19, doi:10.5194/acp-19-4105-2019, 2019.

Shupe, M. D., Rex, M., Blomquist, B., et al.: Overview of the MOSAiC expedition- Atmosphere, Elementa: Science of the Anthropocene, 10, doi:10.1525/elementa.2021.00060, 2022.