Tethered balloon broadband radiation profiles during MOSAiC

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Summary: The Multidisciplinary drifting Observatory for the Study of the Arctic Climate (MOSAiC), held between 2019 and 2020, represented a major highlight for Arctic research. The Leipzig Institute for Meteorology (LIM) and the Institute for Tropospheric Research (TROPOS) contributed to MOSAiC in Summer 2020 by deploying the Balloon-bornE moduLar Utility for profilinG the lower Atmosphere (BELUGA). During four weeks of measurements, BELUGA provided a comprehensive data set characterizing the atmosphere thermodynamical conditions, turbulence, broadband radiation and aerosol particles. The major scientific goal of the LIM project is to measure profiles of broadband radiation to investigate the impact of clouds, temperature and humidity on heating rates profiles in the Arctic atmospheric boundary layer.

Zusammenfassung: Das Forschungsprojekt "Multidisciplinary drifting Observatory for the Study of the Arctic Climate" (MOSAiC), welches zwischen Herbst 2019 und Herbst 2020 stattfand, ist ein Meilenstein der internationalen Arktisforschung. Das Leipziger Institut für Meteorology (LIM) und das Insitut für Troposphärenforschung (TROPOS) nahmen im Sommer 2020 an der MOSAiC Expedition teil. Während einer Messzeit von vier Wochen, wurde das Fesselballonmessystem "Balloon-bornE moduLar Utility for profilinG the lower Atmosphere" (BELUGA) zu Erprobung der unteren Atmosphäre eingesetzt. Die Messungen lieferten einen umfangreichen Datensatz, welcher die Profile von thermodynamischen Parametern, Turbulenz, Breitbandstrahlung und Aerosol Partikel charakterisiert. Ein wichtiges Ziel der nun folgenden Auswertung der Messdaten ist die Analyse der Profile der Nettostrahlungsflüsse. Aus Änderungen des Nettostrahlungsfluss lassen sich Profile der atmosphärischen Heizraten ableiten. Insbesondere kann damit der Einfluss von Wolken auf die Thermodynamik in der arktischen atmosphärischen Grenzschicht untersucht werden.

1 Overview of the MOSAiC campaign

The ice camp based Multidisciplinary drifting Observatory for the Study of the Arctic Climate (MOSAiC, https://mosaic-expedition.org/) was one of the most extensive and relevant scientific expeditions of 2019-2020 (Brainard, 2019). The expedition is highlighted by its unique multidisciplinary approach, its internationality involving scientific institutes from 20 nations and its long duration (Fig. 1). The extraordinary logistical effort to conduct such a complex campaign was significantly increased, when in early 2020 the COVID-19 pandemic started. It represented a challenge to rearrange the exchange of the scientific crews and the schedule of MOSAiC. Despite this unfortunate

event, MOSAiC continued until its planned end in October 2020, providing a wealth of observations that will feed the whole Arctic academic community in the next decade.

In addition, the MOSAiC ice floe quickly crossed the central Arctic, ending up northwest of Svalbard as early as May 2020. As a result, the number of legs of MOSAiC was reduced from 6 to 5. The first two legs occurred in winter 2019 as planned. Leg 3 was extended until early June 2020. Leg 4 was delayed to June-August (from April-June) and leg 5 concluded the campaign. For the crew exchange between legs 3 and 4, the MOSAiC ice floe had to be abandoned for about four weeks. Only some instruments remained on the floe for continuous autonomous measurements. The camp was then re-established during the melting season in mid June 2020. As the ice floe reached the marginal sea ice zone and was close to break up, the camp was dismissed in late July 2020, after about 300 days of extensive survey. For the final leg of MOSAiC, in August-September 2020, a new location was used to re-establish the camp. An ice floe close to the North Pole was chosen to cover the central Arctic freezing season. A publication describing MOSAiC in detail is planned by Rex et al.

All LIM activities under the umbrella of $(AC)^3$ (ArctiC Amplification: Climate Relevant Atmospheric and SurfaCe Processes and Feedback Mechanisms) are described by Brückner et al. (2020). Tethered balloon observations originally were scheduled for the field during the original legs 4 and 5, and two airborne campaigns were planned for spring and autumn. Operations had to be adapted to the developing situation. The planned spring deployment of the tethered balloon was moved to summer (new leg 4), while its leg 5 activities had to be cancelled. Also the airborne spring campaign was cancelled. The second airborne campaign took place in autumn 2020. Unfortunately, at this time, RV Polarstern already left the original ice camp and moved further north, out of reach for the research aircrafts Polar 5 and 6.

2 BELUGA deployment

After 18 days of quarantine and 18 days of navigation between Bremerhaven and Svalbard, the combined balloon team from LIM and TROPOS boarded RV Polarstern on 5 June 2020. Having concluded the bunker operations in the harbour of Longyearbyen, RV Polarstern headed back to the original MOSAiC ice floe. During the transit, the balloon team worked together with the ATMOS team on the preparation of the laboratories and instruments for the upcoming work on the ice. Once the MOSAiC ice floe was reached, it was scouted for the onset of a new camp. Before tethered balloon operations could be started, instruments for the continuous measurement of atmosphere, ocean and ice were deployed in selected locations. The balloon team helped in building the shared infrastructure. Then the balloon site (Balloon town) was set up about 260 m from the starboard side of RV Polarstern. The balloon team also significantly contributed for the whole length of leg 4 to the 6-h radiosounding routine, as well as to polar bear guarding activities needed for safety on the ice.

Balloon town consisted of a tent to house the instruments, the 12-meter-long tethered balloon "BELUGA" (Balloon-bornE moduLar Utility for profilinG the lower Atmosphere, Egerer et al., 2019) and a winch with a deflection pulley used to operate it (Fig. 2). The 90 m^3 balloon was routinely inflated at RV Polarstern with the help of other scientists (Fig. 3). For safety reasons, the Helium was stored on the ship. The scientific

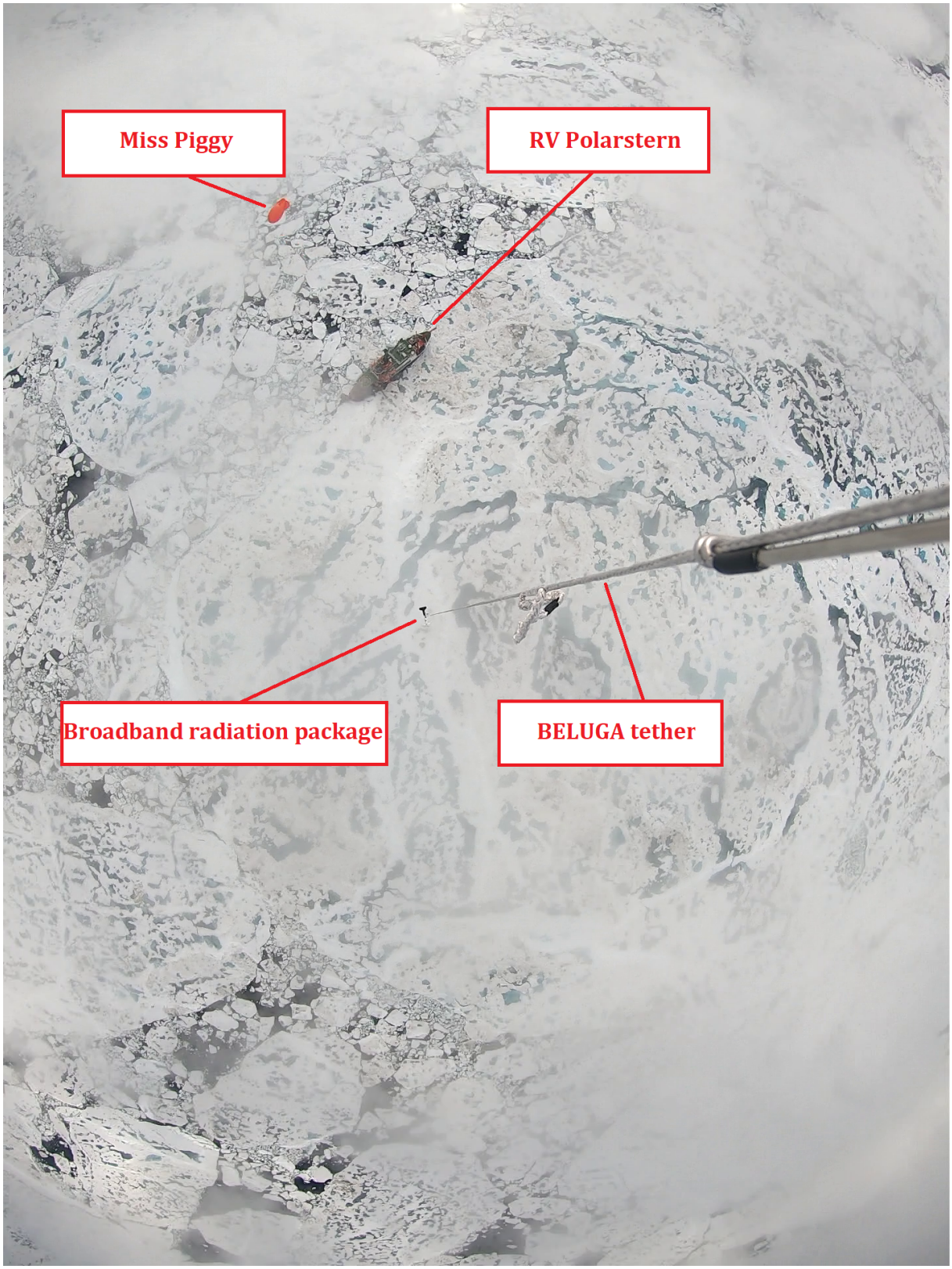

Figure 1: *Aerial view of MOSAiC. RV Polarstern, Miss Piggy balloon and the MOSAiC ice floe seen by a camera on BELUGA from about 600 m.*

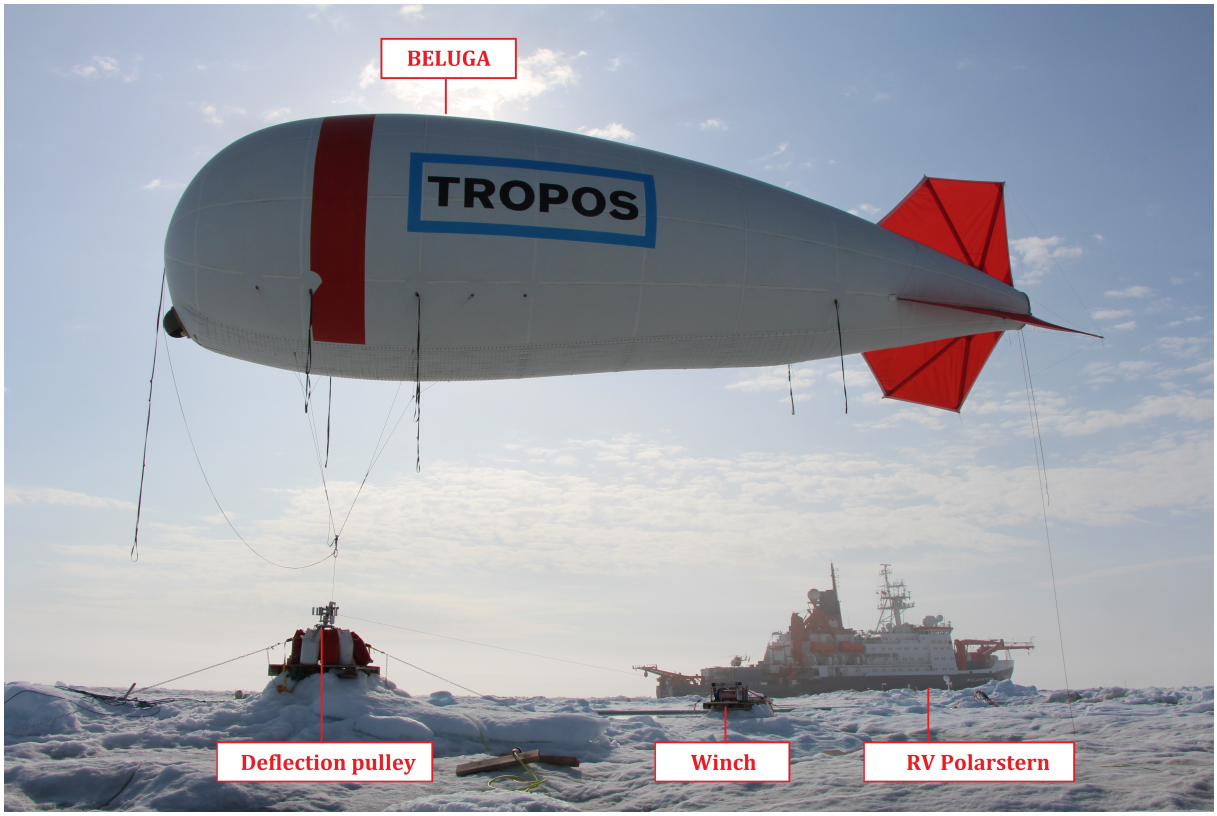

Figure 2: *BELUGA ground setup. The balloon is seen together with the winch and the deflection pulley for the tether. The tent for the storage of the instruments is not shown. In the background, RV Polarstern.*

observation schedule, conducted between 29 June and 29 July, aimed to profile the Arctic atmospheric boundary layer up to 1500 m using a set of probes mounted on the tether holding the balloon. The payload was modular, allowing to combine different instruments. These included a standard meteorology probe (StdMet), the broadband radiation package (BP) and the ultrasonic anemometer package (UP) described by Egerer et al. (2019), the newly developed Cubic Aerosol Measurement Platform (CAMP) for the study of aerosol, and the Video Ice Particle Sampler (VIPS) to characterize cloud particles. Profiles provide high resolution datasets due to the climbing speeds of about 0.5-1 ms^{-1}.

Due to strong winds and logistical constraints, including polar bears encounters (Wendisch et al., 2020), the operation of the balloon was intermittent during the first part of the campaign. Most of the profiles were obtained between 19-27 July. In total, 33 flights up to an average height of about 1000 m were obtained during the campaign. All instruments worked reliably for most of the time without large data gaps. Not all instrument payloads could be operated simultaneously due to the weight limitations of BELUGA. The daily combination of instrumentation was selected compromising between permanent routine measurements and specific measurements related to the given meteorological conditions. The operation time of VIPS, which purpose was to measure cloud ice particles, was significantly reduced due to the low amount of cloud ice observed in the summer season. BELUGA profiles represent different atmospheric scenarios, including cloudy and cloudless cases, as well as distributions of aerosol advected from various source regions.

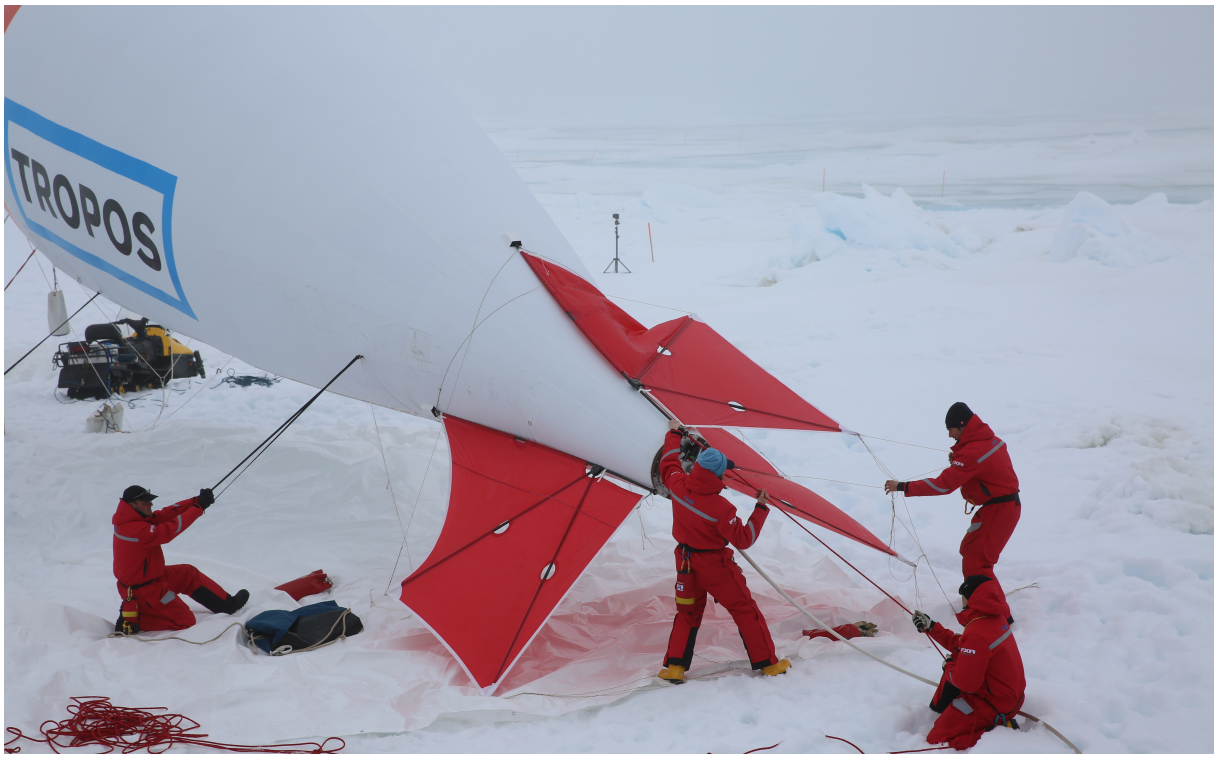

Figure 3: *The complexity of the preparation and maintenance of BELUGA required the help from several volunteers during the whole deployment period. During these operations, the balloon was secured with ropes to a snowmobile and controlled by the volunteers. Credits AWI/Grosfeld.*

3 Broadband radiation measurements

The measurement and analysis of broadband radiation profiles was the major scientific focus of LIM contributions to BELUGA. A total of 18 flights (36 profiles) were obtained using the broadband radiation package BP. Profiles always include data from StdMet and, depending on the scenario, are coupled with aerosol, turbulence or cloud microphysical properties. The observations include 4 cloudless and 14 cloudy cases, further divided into 6 cases of single-layer and 8 of multi-layer cloud cover. Every BP profile includes measurements of the four radiative flux densities (upward and downward terrestrial and solar irradiance). Based on these four components, profiles of net irradiances and the resulting radiative heating rates, as well as broadband albedo, were calculated. These profiles are being analysed at LIM to quantify the role of cloud top cooling and cloud base warming/cooling on the Arctic atmospheric boundary layer structure.

4 Summary & Outlook

MOSAiC provided one year of almost continuous observations of atmospheric, oceanic, sea ice, and biological processes in the central Arctic by a diversity of measurement methods. An overview of the atmospheric measurements will be provided by Shupe et al. (manuscript in preparation). Profiles of broadband radiation using the tethered balloon platform BELUGA were one part of the summer phase of MOSAiC. BELUGA

data obtained during the campaign, and its processing, are described in a publication planned by Pilz et al. Due to its peculiarity, the data management of BELUGA data during MOSAiC is planned to be described as a case study by Immerz et al. A scientific overview planned by Lonardi et al. provides an integrated analysis of general thermodynamical conditions, clouds, turbulence, broadband radiation and aerosol on three days with a similar cover of liquid water single layer clouds . Further studies are planned to explore the full depth of data observed during the four weeks of operation of BELUGA during MOSAiC. A detailed analysis will be conducted to quantify the sensitivity of broadband radiation and heating rates profiles to cloud microphysics and macrophysical conditions. However, the rather short time period of the BELUGA deployment during MOSAiC covers only a limited range of meteorological conditions. In particular typical Arctic mixed-phase clouds could not be observed during the summer. Therefore it is planned to extend the BELUGA observations by two campaigns in Ny-Ålesund, scheduled for autumn 2021 and spring 2022. The deployments will allow for the inclusion of mixed-phase clouds, typically present during those seasons as shown by Nomokonova et al. (2019).

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