Meteorological Profiling of the Arctic Boundary Layer

Marion Maturilli[1], Klaus Dethloff[1], Jürgen Graeser[1], Annette Rinke[1], Moritz Mielke[1]

[1]Alfred Wegener Institute for Polar and Marine Research,Telegrafenberg A43, D-14473 Potsdam, Germany, marion.maturilli@awi.de
klaus.dethloff@awi.de, juergen.graeser@awi.de, annette.rinke@awi.de, moritz.mielke@awi.de

ABSTRACT

The PBL is the lowest part of the atmosphere, where exchange processes of momentum and heat occur between the Earth's surface and the atmosphere. In the Arctic, the boundary layer is characterized by a frequent occurrence of temperature inversions, thus being a stable layer that effectively suppresses the vertical motion of air. To characterize the state and variability of the Arctic boundary layer, we apply aerological soundings at the AWIPEV research base in Ny-Ålesund, Spitsbergen, and on the North Pole drifting ice station NP-35. Focus is set on the meteorological profiling with a tethered balloon system. The experimental set-up includes up to 6 tethersondes mounted along the tether, measuring a meteorological profile over several hours and thus allowing the detection of the strengthening and degeneration of ground based and elevated inversions. The results are used e.g. to validate the boundary layer representation in the regional climate model HIRHAM under different atmospheric stability conditions.

1. INTRODUCTION

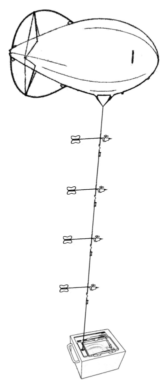
The Arctic has been characterized in recent decades by complex interrelated, pan-arctic changes occurring across oceanic, atmospheric, terrestrial and human systems. The complex of interconnected changes is driven by global change but also influenced by regional Arctic feedbacks. As one of these Arctic key processes that are highly relevant but poorly understood, the atmospheric planetary boundary layer processes have been identified, including the exchange of momentum, heat and moisture between the surface and the lower atmosphere.

Generally, the Arctic boundary layer (ABL) is characterized by the frequent occurrence of surface inversions and low-level atmospheric jets [1,2]. During winter, the snow-covered sea ice insulates the atmosphere from the relatively warm ocean. Combined with the absence of solar warming (polar night), the strong longwave surface cooling facilitates the formation of long-lasting surface inversions with strongly stable conditions. Thus, the Arctic boundary layer is stably stratified about 75% of the time [3]. Yet the long periods of stable conditions in winter are interspersed with periods of near neutral conditions, forced by longwave radiation [3] directly related to boundary layer clouds - a known problem for climate models.

Here, we present the characterization of the spatio-temporal ABL structure over land and over sea ice by utilizing a tethered balloon system.

2. INSTRUMENTS AND MEASUREMENT SET-UP

Continuous profiling of the meteorological parameters pressure, temperature, humidity, and wind over the time period of several hours is realized by a stable tethered balloon system. Our measurements are based on the commercial tethered balloon equipment from Vaisala, with a 7 m^3 balloon and 6 tethersondes of type TTS111. Temperature is measured by a F-Thermocap capacitive wire in the range of -50°C to +60°C, with a resolution of 0.1°C and an uncertainty of 0.5°C (all values given by Vaisala). For measurements under daytime conditions, a potential heating effect of the temperature sensor caused by the solar radiation has to be considered due to the lack of ventilation. The same holds for the humidity sensor (H-Humicap with 0.1% resolution and 5% uncertainty in sounding). While wind speed is measured with an anemometer (resolution 0.1 m/s), the wind direction is obtained by a digital compass. The compass encounters severe problems in very high latitudes (>80°N), so during the NP-35 expedition close to the North Pole, wind direction measurements have been discarded. The wind direction measurement also fails during ascent and descent of the tethered balloon due to the mounting of the sonde in the twisted tether that slightly rotates during upward and downward movement.



As our analyses focus on the spatial and temporal characterization of the Arctic boundary layer, the experimental set-up includes up to 6 tethersondes mounted along the tether while the balloon is in a stable position during the whole measurement period. Commonly, the balloon is positioned in about 800 to 1200 m altitude, with the sondes distributed in constant interspace. Time series of all parameters are retrieved in about 10-sec time resolution from each sonde.

Figure 1. *Schematic of the tethered balloon system set-up.*

3. OBSERVATIONS: NY-ÅLESUND, SVALBARD

The Ny-Ålesund environment on Svalbard (78.9°N, 11.9°E), with its semi-permanent snow cover in the vicinity of glaciers and mountainous orography, sets up special atmospheric boundary layer conditions. At the AWIPEV research base in Ny-Ålesund, a broad

© Proceedings of the 8th International Symposium on Tropospheric Profiling, ISBN 978-90-6960-233-2
Delft, The Netherlands, October 2009. Editors, A. Apituley, H.W.J. Russchenberg, W.A.A. Monna

atmospheric profiling program is operated. Apart from specific measurements of e.g. aerosols by lidar, vertical profiles of meteorological parameters like temperature, humidity and wind are monitored by radiosondes on a daily basis. These regular observations are complemented by campaign-based measurements as e.g. the meteorological profiling of the planetary boundary layer (PBL) with a tethered balloon system. So far, operation of the tethered balloon system took place in spring 2005, autumn 2005, spring 2006, spring 2007, spring 2008, and spring 2009.

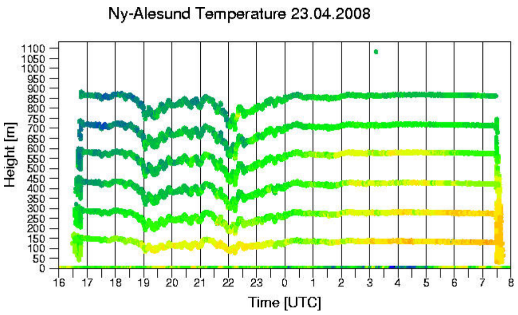


Figure 2. *Temperature (color-coded) as observed by tethersondes and 10m-mast in Ny-Ålesund on 23 and 24 April 2008.*

Generally, the Ny-Ålesund observations show the dynamic formation and degeneration of ground based inversions. An example of a typical measurement is given in Fig.2, showing the inversion layer and the temporal evolution of temperature in the lower 900 m.

Clearly, the operation of the tethered balloon is limited by the meteorological conditions (e.g. too much wind or danger of icing). In any case, the tethered balloon measurements provide PBL data in a much better temporal resolution than the regular radiosondes. Due to the surrounding orography, effects of e.g. catabatic winds from the mountains or humidity advection from the fjord are found in the measurements.

4. OBSERVATIONS: THE NORTH POLE DRIFTING ICE STATION NP-35

The Arctic environment with its semi-permanent sea ice sets up unique atmospheric boundary layer conditions. The sea ice covered Central Arctic is an ideal laboratory for investigations of the stable stratified boundary layer, surface based inversions and low-level jets and its interaction with the underlying surface. During the International Polar Year (IPY) 2007/2008, we had the possibility to participate in the 35th Russian North Pole Drifting Ice Station Expedition, and to perform tethered balloon measurements on the Arctic sea ice.

The station NP-35 was constructed on an ice floe north of Servnaya Zemlya on 21 September 2007, and drifted with the Arctic Ocean currents north-westward (see Figure 3). On 10 April 2008, our colleague Juergen Graeser was picked up by AWI aircraft Polar-5 at 84.1°N, 39.9°E. During the 7 months on the sea ice, he performed multi-hour tethered balloon measurements on 55 days. As expected, in most cases a surface based inversion of several degrees was observed, intermitted only by few events of neutral stratification.

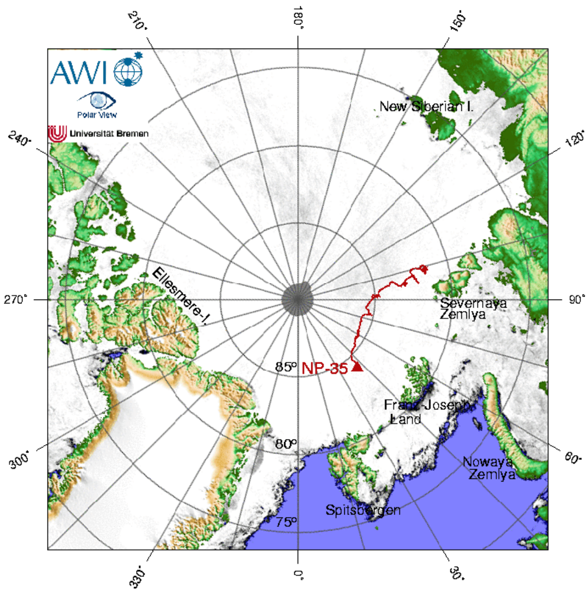


Figure 3. *Track of the drifting ice station NP-35 from 21 September 2007 to 10 April 2008.*

An example for the pronounced strength of the inversion is presented in Figure 4: in 200 m altitude, the temperature is about 14 K higher than at the surface (10 m). Also, small temperature fluctuations occur in at least one of the observations levels (around 75 m).

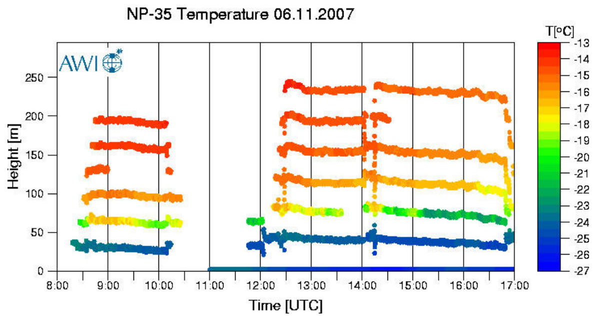


Figure 4. *Temperature (color-coded) as observed by tethersondes on the drifting ice station NP-35 on 6 November 2007.*

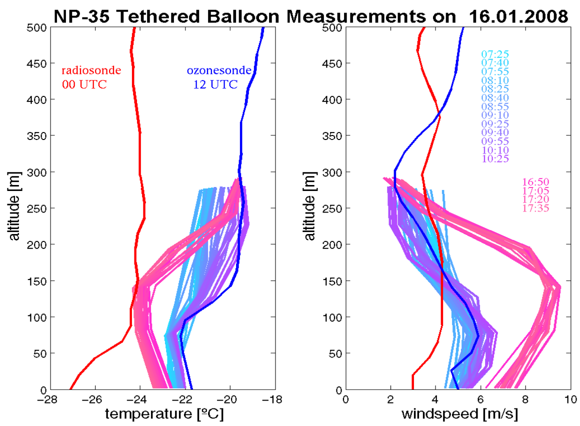


Figure 5. *Temperature (left) and wind speed (right) profiles from radio- and ozonesonde at 00 UTC (red) and 12 UTC (blue) on 16 January 2008, respectively. 5-minute-mean profiles up to about 300 m from tethersondes during morning hours (blueish-purple) and afternoon (pink colors) of the same day.*

In some cases, also the occurrence of low-level jets has been observed. An impressive example is shown in Figure 5, presenting the temperature and wind speed measurements on 16 January 2008. Here, the temporally high resolved data of the tethersondes have been averaged in intervals of 5 minutes to produce vertical profiles. Although their spatial resolution is much coarser than the radiosonde data, they provide a good insight to the temporal changes of the temperature and wind speed profile.

The extensive tethered balloon measurements during the NP-35 expedition are used to characterize the PBL over the ice-covered Arctic, with special emphasis on the dynamics of surface-based inversions. The measurements are combined with profile data from the radiosondes that have been launched twice daily by the Russian colleagues. Investigations are targeted to the analysis of inversion strength, height, and occurrence frequency.

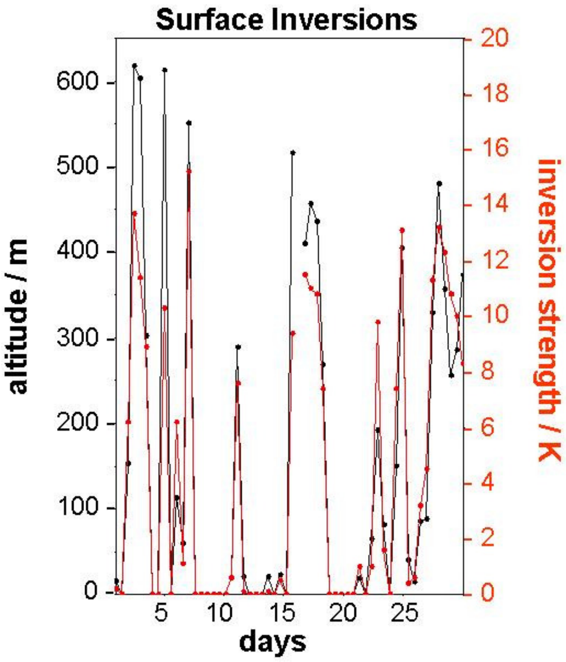


Figure 6: *Height (black line) and strength (red line) of all surface based inversions observed on NP-35 in February 2008.*

The statistical analysis of the NP-35 radiosonde and tethered balloon data for autumn 2007 to spring 2008 revealed the frequent, strong (up to 15K) surface and multiple elevated temperature inversions (up to 20) as shown for February 2008 in Figures 6 and 7, respectively. The data have been used to evaluate numerical model outputs, e.g. the Arctic regional climate model HIRHAM.

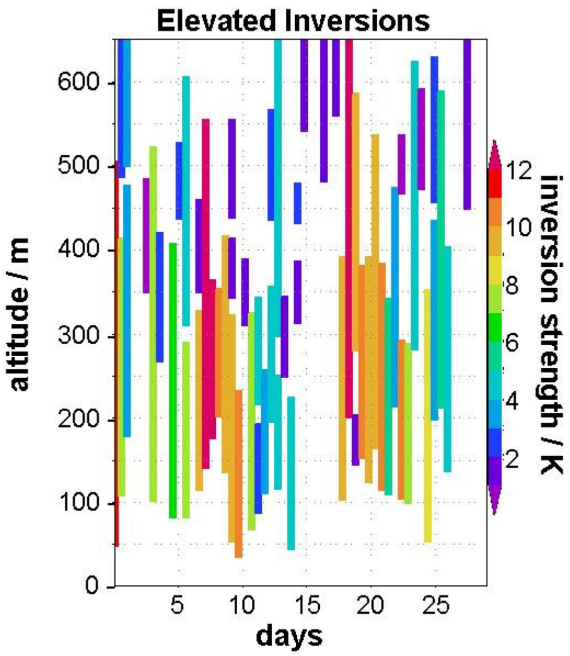


Figure 7: *Vertical extent and strength (color coded) of all elevated inversions observed on NP-35 in February 2008.*

5. ARCTIC REGIONAL MODEL HIRHAM

The HIRHAM domain consists of 100 x 110 grid points, with a horizontal resolution of 0.5° (50 km). In the vertical, 10 of the 25 levels are distributed in the lowest 800 m of the atmosphere. As the use of different PBL parameterizations for climate model integrations leads to different energy fluxes from the surface into the atmosphere, there is the necessity of improvements in the atmospheric PBL parameterization for a better description of the stable vertical stratification and atmosphere–surface energy exchange [4]. Our observation data are used to validate the HIRHAM PBL parameterization scheme. The model can be operated in different modes. While in the forecast mode, initialization occurs every 12 hours, the ensemble climate mode (for 1 month) applies a mean of different start times (-12 hr, -6hr, 0hr, +6hr, +12hr).

The simulated temperature-, wind-, and humidity profiles from HIRHAM have been compared with the NP-35 data. HIRHAM running in the climate mode shows larger biases compared to forecast from the German Weather Service and has difficulties to represent the observed complex temperature profile, while HIRHAM simulations in the forecast mode show better agreement. In any case, simulating the vertical temperature distribution observed by radio- and tethersondes HIRHAM has a larger bias under very stable atmospheric conditions and inversions compared to less stable conditions. Sensitivity experiments concerning the atmospheric initial state, sea ice thickness and planetary boundary layer parameterization demonstrate further improvements in the simulations.

6. SUMMARY

The Arctic is a region of particular vulnerability to global climate change. Uncertainties in current modelling of Arctic climate can be reduced by improving important process descriptions and current parameterizations by a close coordination between model simulations and measurements. With focus on boundary layer processes in the Arctic, we obtained temperature, humidity, and wind data from tethered balloon measurements in Ny-Alesund, Svalbard, and on the North Pole drifting station NP-35. The dynamical strengthening and degeneration of ground-based and elevated inversions has been observed and is subject to further analysis. Especially the observations above sea ice revealed the occurrence of frequent, strong (up to 15K) surface and multiple elevated temperature inversions. Simulations with the regional climate model HIRHAM are carried out to support the data interpretation and to validate the model.

REFERENCES

[1] Makshtas, A. P., V. F. Timachev, E. L. Andreas, 1998: Structure of the lower atmospheric layer over ice cover of the Weddell Sea, *Russian Meteorology and Hydrology*, **10**, pp. 68-75.

[2] Andreas E. L., K. J. Claffey, A. P. Makshtas, 2000: Low-level atmospheric jets and inversions over the Western Weddell sea, *Boundary Layer Meteorology*, **97**, pp. 459-486.

[3] Persson P. O. G., C. W. Fairall, E. L. Andreas, P. S. Guest, D. K. Perovich, 2002: Measurements near the Atmospheric Surface Flux Group tower at SHEBA: Near surface conditions and surface energy budget, *J. Geophys. Res.*, **107**, 8045pp.

[4] Dethloff, K., C. Abegg, A. Rinke, I. Hebestadt, V. F. Romanov, 2001: Sensitivity of Arctic climate simulations to different boundary-layerparameterizations in a regional climate model, *Tellus*, 53A, pp. 1-26.

ACKNOWLEDGEMENTS

We would like to thank Nikita Zinovyev, Vasiliy Kustov, Alexander Makshtas, and Vladimir Sokolo from AARI St. Petersburg for fruitful cooperation on NP-35.