Meteorological observations from ship cruises during summer to the central Arctic: A comparison with reanalysis data

C. Lüpkes,[1] T. Vihma,[2] E. Jakobson,[3] G. König-Langlo,[1] and A. Tetzlaff[1]

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[1] Near-surface meteorological observations and rawinsonde soundings from Arctic cruises with the German icebreaker RV Polarstern during August 1996, 2001, and 2007 are compared with each other and with ERA-Interim reanalyses. Although the observations are usually applied in the reanalysis, they differ considerably from ERA data. ERA overestimates the relative humidity and temperature in the atmospheric boundary layer and the base height of the capping inversion. Warm biases of ERA near-surface temperatures amount up to 2 K. The melting point of snow is the most frequent near-surface temperature in ERA, while the observed value is the sea water freezing temperature. Both observations and ERA show that above 400 m, in the North Atlantic sector 0–90 E, the warmest August occurred in 2001, and August 2007 had the highest humidity. In the Eastern Siberian and Beaufort Sea region ERA temperatures along 80 and 85 N were highest in 2007. **Citation:** Lüpkes, C., T. Vihma, E. Jakobson, G. König-Langlo, and A. Tetzlaff (2010), Meteorological observations from ship cruises during summer to the central Arctic: A comparison with reanalysis data, *Geophys. Res. Lett.*, *37*, LXXXXX, doi:10.1029/2010GL042724.

1. Introduction

[2] Projections of climate models for the 21st century show an especially pronounced warming in high latitudes usually called the arctic amplification [e.g., *Serreze et al.*, 2009], and the presently available data already indicate a strong warming of the Arctic in the last decade. Arctic in-situ data are, however, rare, since longer time series of observations result from a few coastal stations only, and in the inner Arctic mainly from buoys and rarely from drifting stations or from ship cruises. Especially, time series from Central Arctic in-situ observations above the surface layer are rare. They are available only from rawinsonde and tethersonde soundings performed at drifting stations [e.g., *Serreze et al.*, 1992; *Vihma et al.*, 2008] and during ship cruises. The analysis of climate trends on the basis of these data is a challenging task, because drifting stations and ship trajectories of different years are often separated from each other by hundreds of kilometers.

[3] In this work we will investigate routine meteorological observations and soundings from the German icebreaker RV Polarstern from three different years and consider as the first goal the differences between these years and to what extent such data can contribute to the analysis of climate change, while paying attention to the spatial representativeness of the observations. We concentrate on the summer expeditions 1996, 2001, and 2007 to the Central Arctic (Figure 1). The focus on these years is especially interesting, since the sea ice conditions differed strongly from each other and the identification of differences in the meteorological conditions might help to better understand the reasons for the recent sea ice retreat. According to NSIDC (http://nsidc.org/) a large mean August sea ice extent was observed in 2001 (7.5 mill. km^2) and 1996 (8.2 mill. km^2), but, as well known, in 2007 it was extremely low (5.4 mill. km^2) resulting finally in the historical September minimum. Also the sea ice surface characteristics differed considerably in these years with only very few or, north of 84°N, even no melt ponds along the cruise track in 1996 [*Augstein et al.*, 1997; *Haas and Eicken*, 2001] and a large melt pond coverage in 2001 [*Thiede*, 2002] and 2007 [*Schauer*, 2008].

[4] The spatial representativeness of the ship data will be investigated with the help of reanalysis data. However, since the accuracy of reanalysis in the Central Arctic regions is not well known, we concentrate also on the performance of the reanalysis by comparing it with the measurements along the ship tracks. For this task, ERA-Interim data are used representing the newest set of reanalysis data from the European Centre for Medium-Range Weather Forecasts (ECMWF). Although the routine meteorological Polarstern observations are always transmitted to the Global Telecommunication System (GTS) of the WMO and thus contribute to ERA, it cannot be expected that observations are perfectly reproduced by the reanalysis, and our study will help to identify the shortcomings of ERA-Interim over sea ice covered regions.

2. Data Used

[5] As in-situ data we use the routinely observed near-surface temperature from Polarstern and data from rawinsondes launched from the ship during the summer cruises ARK-XII (1996), ARK-XVII/2 (2001), and ARK-XXII/2 (2007), whose meteorological data are compiled by *König-Langlo* [2005, 2008]. We concentrate on the August data and in case of soundings on data north of 80°N, since there the ship tracks (Figure 1) were always north of the ice edge and the overlapping times of the cruises were largest. The routine temperature measurements from Polarstern considered here in a 10-minute resolution were carried out at 30 m height.

[6] The Polarstern temperature sensors (PT-100) are well protected against radiation and mounted at a well ventilated position at 30 m height [*König-Langlo et al.*, 2006]. They are calibrated during each cruise using an aspiration

[1]Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany.
[2]Finnish Meteorological Institute, Helsinki, Finland.
[3]Tartu Observatory, Toravere, Estonia.

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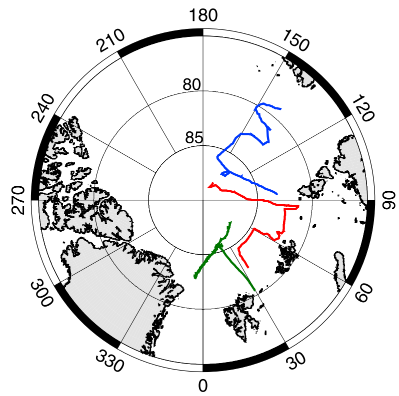

Figure 1. Cruise tracks of RV Polarstern during August 1996 (blue), 2001 (green) and 2007 (red).

psychrometer (Assmann) as reference. Rawinsondes (Vaisala) were usually launched twice a day, in 1996 at 02.30 and 10.30 UTC, in 2001 at 05.00 and 10.00 UTC, and in 2007 at 06.00 and 11.00 UTC. According to the above position criteria we consider the soundings between 7 and 31 August of 2007 (44 soundings), between 4 and 31 August (55 soundings) of 2001 and between 1 and 29 August of 1996 (58 soundings). All data are publicly available via http://www.pangaea.de/.

[7] We compare the Polarstern near-surface data with ERA-Interim data from the second-lowest model level (about 38 m height) at the ship positions in 6-hour resolution. All reanalysis data represent means over 0.72 × 0.72° in longitude and latitude. Furthermore, vertical profiles of meteorological variables at the sounding locations are used, interpolated to the above-mentioned ship times. This interpolation caused only slight changes in the monthly averages considered in section 3.3. Sounding data are not distributed regularly in height. Hence, before averaging, the data were interpolated to a regular grid with 40 m vertical resolution.

3. Results

3.1. August Conditions Along 80 and 85°N

[8] A hint on the spatial representativeness of temperature and humidity measured in the considered years at an arbitrary position in the Arctic can be obtained from Figure 2 showing ERA-Interim results along 80° and 85°N.

[9] According to these results 2007 had the warmest and most humid August along 85°N. Differences to other years were especially large east of 150°E, outside of the sector studied by the ship. In 1996 and 2001 temperatures and specific humidities decreased slightly towards the east, which was in contrast to 2007 with an almost constant near-surface temperature and humidity along 85°N.

[10] A large difference exists between the sector 0–90°E (North Atlantic sector, NA) and the remaining part. In the first one, 2001 was by far the warmest year at 80°N, especially at the height of the 850 hPa pressure level, where along 80°N the NA sector was in August 2001 up to 3.5 K warmer than in both other years. Everywhere else August 2007 had the highest 850 hPa temperatures with nearly 6 K difference to 1996 and 2001 at 80°N and 180°E. This was similar for 85°N, except that 2001 was not that much warmer in the NA sector and the warm 2007 anomaly was most pronounced at 210–240°E.

[11] At 80°N the near-surface temperature and humidity strongly decrease in all years towards east in the region at about 270°E. This is due to the influence of the Greenland ice sheet region, which we do not consider in the present analysis.

[12] The above findings show that a comparison of data obtained from the three cruises should be considered with caution, since possible differences between ship observations from different years can result from different ship locations. On the other hand, it is important to note that all ship tracks were in the sector 0–150°E and more close to the 85°N latitude, where the near-surface horizontal gradients along the latitude were found to be relatively small.

3.2. Near-Surface Data Along Ship Tracks

[13] Figure 3 shows the observed probability distributions of the 30 m real air temperature as well as the distributions obtained from ERA at the second-lowest model level (≈38 m height) along the ship tracks. Based on these distributions the following two conclusions are possible.

[14] The first refers to an intercomparison of the data from the different years. Obviously, the 1996 temperature distribution has a larger width and shows lower temperatures than in both other years. This holds for both observations and ERA-Interim giving confidence to the ERA-based result that 1996 was colder almost everywhere in the circumpolar Arctic at 80 and 85°N (Figure 2). It may partly explain, why the amount of observed open melt ponds was so small in 1996 compared with the other years.

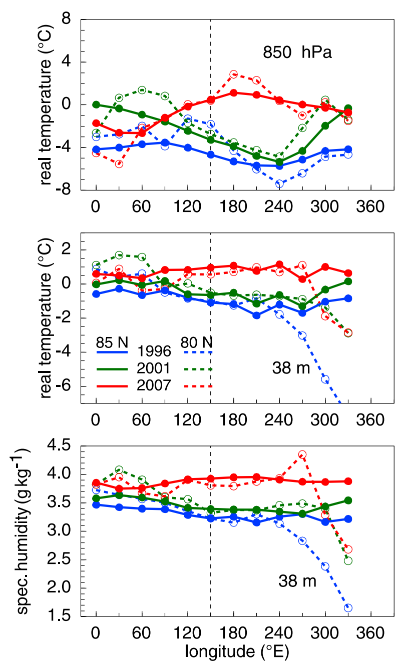

Figure 2. August averages, as calculated from ERA Interim results, for the real air temperature and specific humidity in steps of 30 degrees longitude along 80°N and 85°N for 850 hPa and 38 m height. Polarstern operated mainly in the region left of the vertical dashed line. Values of 38 m at 270–330°E and 80°N are low, since locations are over mountains.

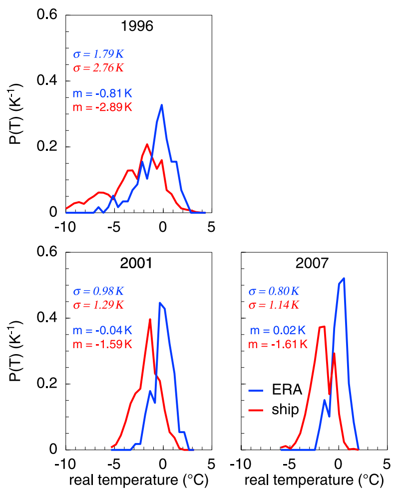

Figure 3. Probability density functions, mean values *m* and standard deviation σ of the 30 m real air temperature observed by Polarstern (red) and calculated from ERA-Interim along the ship tracks at ≈38 m height. The values are calculated for 0.5 K bins.

[15] The second conclusion is related to the large qualitative and quantitative differences between the distributions based on ship and ERA data. The most frequently observed temperature is in all years the freezing point of sea water (≈−1.8°C), whereas in the reanalysis the peak occurs approximately at the melting point of snow (0°C). The latter temperature appears in 1996 and 2007 also in the observed distributions as a secondary peak. A related difference between observation and ERA concerns the warm bias of ERA in all the three August distributions, most pronounced in 2007.

3.3. Soundings

[16] Profiles of temperature and humidity in Figure 4 are approximately August averages (as explained in Section 2) along the cruise tracks. Four results can be derived:

[17] 1. In heights above 400 m both the 2001 observations and ERA data show clearly the highest temperatures (Figure 4, top). Differences at 1200 m amount to roughly 3.5 K, while near the surface only small differences can be found between 2001 and 2007, and slightly larger differences between 2007 and 1996.

[18] 2. August 2007 differs from the other years mainly by its large humidity values, especially when compared with 2001.

[19] 3. Obviously, there is a large bias of the ERA results in the height range below 800 m. This concerns both temperature and specific humidity. The bias in the latter data is especially pronounced in 2001 and 1996, where ERA humidity is close to saturation in heights below 400 m, but observed values are much lower.

[20] 4. ERA considerably overestimates the base height of the boundary layer capping inversion, which can be seen in the monthly averages, but it is especially obvious comparing individual profiles at selected times (not shown). Differences were most pronounced in cases with observed surface based inversions, while the ERA-Interim showed mostly elevated inversions.

[21] We also found that ERA wind and observed wind agreed well with almost identical mean values near the surface and increasing differences in higher levels, which were, however, smaller than 1 ms^{-1} and not significant on the 95% confidence level.

4. Summary and Conclusions

[22] Both ERA Interim results and Polarstern observations reveal large and consistent differences in the mean August temperatures and humidities of 1996, 2001, and 2007. Along 80 and 85°N and east of 90°E the highest August temperatures occurred in 2007. However, in the North Atlantic sector (0–90°E), where a large part of the Polarstern cruises in 2007 and 2001 was carried out, the 2007 August near-surface temperature close to 80°N was similar as in 2001. But further north 2001 was by far the warmest year and the upper-level temperatures were up to 3.5 K higher than in other years. In August 2007 the near-surface temperature along 80 and 85°N peaked in the East Siberian Arctic. *Serreze et al.* [2009] and *Overland and Wang* [2010] suggest that the recent temperature increase in autumn is a combined effect of sea ice loss and atmospheric circulation. The latter is probably the main reason for the high upper-level temperatures in the North Atlantic sector, since there the 2001 sea ice cover was similar as in 1996 [see also *Graversen et al.*, 2008]. In 2007, however, also the excessive sea ice loss may have affected air temperatures already in August. The ship data show that in the second half of

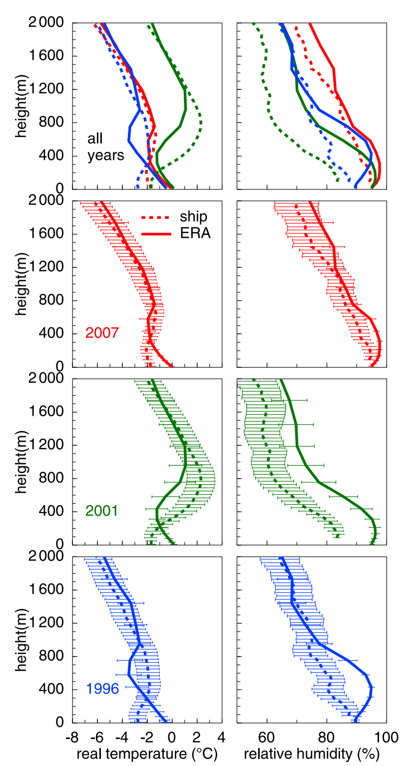

Figure 4. Mean August profiles (dashed, rawinsondes; solid, ERA-Interim at the sounding positions; horizontal bars are the 95% confidence intervals). Figure 4 (top) shows the same profiles as below to allow a comparison between years.

August the air temperature often dropped well below −1.8°C, i.e. an upward heat flux could develop over open leads preventing the atmosphere from a stronger cooling. ERA Interim near-surface data show a warm bias of 1.5–2 K, although the Polarstern data were assimilated into the reanalysis. This confirms similar findings of *Liu et al.* [2005] on the basis of SHEBA data and demonstrates a strong need to improve methods of near-surface data assimilation for ERA. The differences in the most frequent values of surface temperatures (−1.8°C measured and 0°C in ERA) might hint at a non-adequate treatment of thermodynamic effects of open leads, whose surface temperature is usually at the freezing point of sea water. In ERA the sea ice concentration north of 84°N is always 100%, which is unrealistic, particularly for 2007. The comparison of the whole time series (not shown here) of ERA and ship data revealed that a similar warm bias of ERA occurred also between −2 and −10°C air temperature so that also an overestimation by ERA of warm air advection, cloud cover or turbulent mixing could explain the differences. A possible measurement error can be excluded due to the often calibrated sensors. Solar radiation and heating by the ship could only contribute to a warm bias of the observations.

[23] Large differences between ERA and observations occur also in the boundary layer. ERA overestimates the base height of the capping inversion sometimes by more than a factor of two and the stratification is biased towards neutral values. These biases may be attributed to too excessive turbulent mixing. Relative humidity is overestimated by ERA in the boundary layer especially in 2001 by about 15% in the August mean value. This finding earns much attention, since clouds play a critical role for variations in the Arctic sea ice cover [*Francis and Hunter*, 2006]. Note that errors in the cloud cover would cause a long chain of other drawbacks in the modeling of meteorological parameters.

[24] Finally, we stress the need for a regular validation of reanalysis data against independent observations, since our present knowledge of arctic climate change strongly relies on high quality reanalyses. So the present comparison should also be carried out for other reanalyses than for ERA. Vice versa, we have shown that to some extent, data from ship cruises in different years can be used to identify differences in the climatic conditions. However, to account for spatial variations, this should always be done in combination with reanalysis data keeping in mind, however, their uncertainties.

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E. Jakobson, Tartu Observatory, 61602 Toravere, Tartumaa, Estonia.

G. König-Langlo, C. Lüpkes, and A. Tetzlaff, Alfred Wegener Institute for Polar and Marine Research, Postfach 120161, D-27515 Bremerhaven, Germany. (christof.luepkes@awi.de)

T. Vihma, Finnish Meteorological Institute, PO Box 506, FIN-00101 Helsinki, Finland.