3.9 BOUNDARY-LAYER STRUCTURE IN THE SUMMERTIME HIGH ARCTIC DURING THE AOE2001

Michael Tjernström
Stockholm University, Stockholm, Sweden

1. INTRODUCTION

During the Arctic Ocean Experiment 2001 to the high Arctic (AOE2001[1]) on the icebreaker Oden, intensive measurements of the Arctic boundary layer was taken during a three-week ice-drift; 2-22 August 2001 when Oden was then moored to a 1.5-by-3 km large ice floe at ~ 89°N 0°E and drifted roughly southward with the ice.

On Oden, several remote-sensing instruments (wind profiler, cloud radar and scanning microwave radiometer) took continuous measurements of the PBL. On the ship was also a weather station and radio soundings were released six-hourly, using Vaisala, sonds with a GPS wind system. On the ice ~ 300 m, away from Oden, two sodar systems, a tethered sounding system, micro-barographs and an 18-m instrumented mast were deployed. On the mast, a five-level temperature and wind-speed profile was deployed, along with turbulence sensors (sonic anemometers and Krypton hygrometers) at two levels. There was also an ice temperature profile down to -1 meter and a full set of radiation instruments. Additionally, two NCAR PAM-stations were deployed on nearby ice floes, ~8 km away. A companion paper (4.9) contains an overview of the AOE2001 experiment.

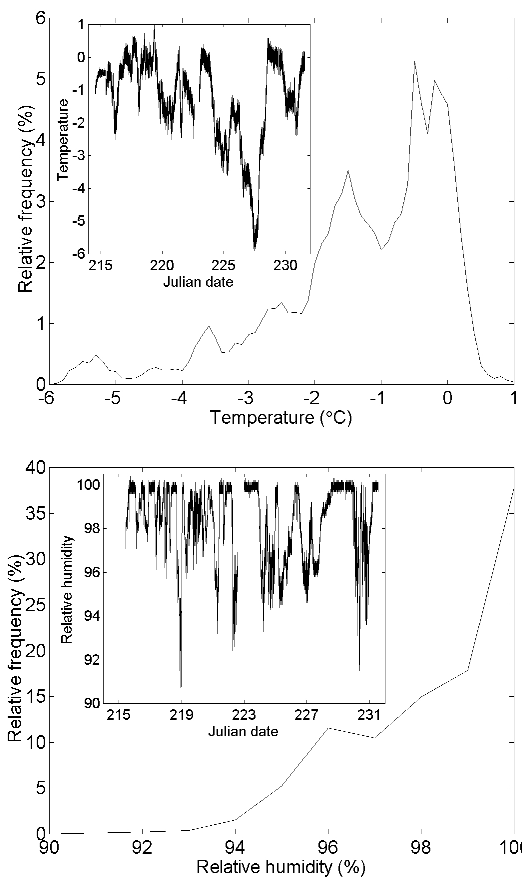

Figure 1. Frequency distributions of (top) near-surface temperature and (bottom) relative humidity during the ice drift. Time series are shown in the insert.

* ***Corresponding author address:*** **Michael Tjernström, Stockholm University, Department of Meteorology, SE-106 91 Stockholm, Sweden. Email:** michaelt@misu.su.se

[1] http://www.fysik.lu.se/eriksw/aoe2001/aoe2001.htm

2. CONDITIONS DURING THE ICE DRIFT

Low clouds and patchy fogs along with a relatively constant near-surface temperature and a very high relative humidity categorized near-surface conditions during the whole ice-drift. The temperature mostly fluctuated between the melting points of seawater (~ -1.5°C) and fresh water (0 °C) most of the time, with an exception around days 226 - 227 (Figure 1). The relative humidity remained very high all the time, hardly ever dropping below 94%. Consequently, low clouds prevailed (Figure 2). The by far most common lowest cloud base was ~100 m, while the cloud fraction was mostly >90%. At the same time, the visibility was surprisingly good, Figure 2. Clouds below 200 m and visibility > 20 km were thus quite common, in contrast to the mid-latitude PBL.

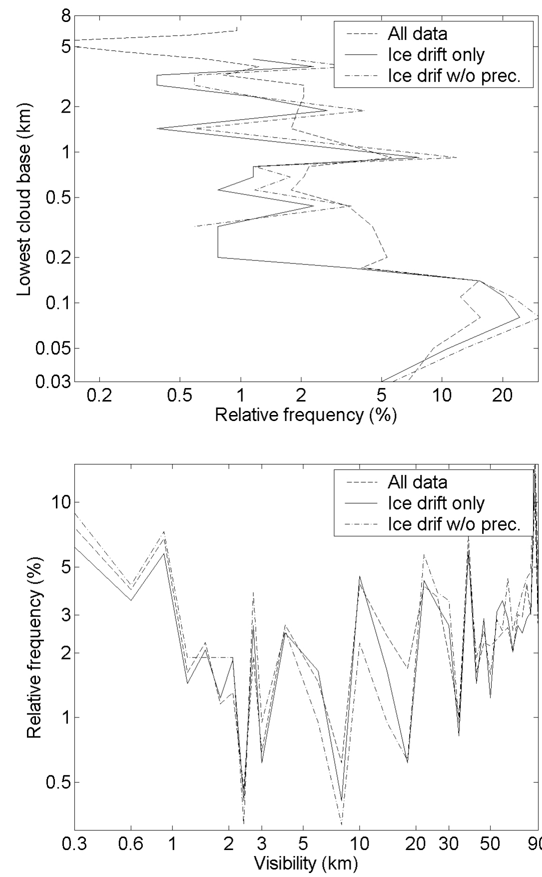

Figure 3. Frequency distributions of (top) the lowest cloud base and (bottom) visibility, from the instruments onboard Oden.

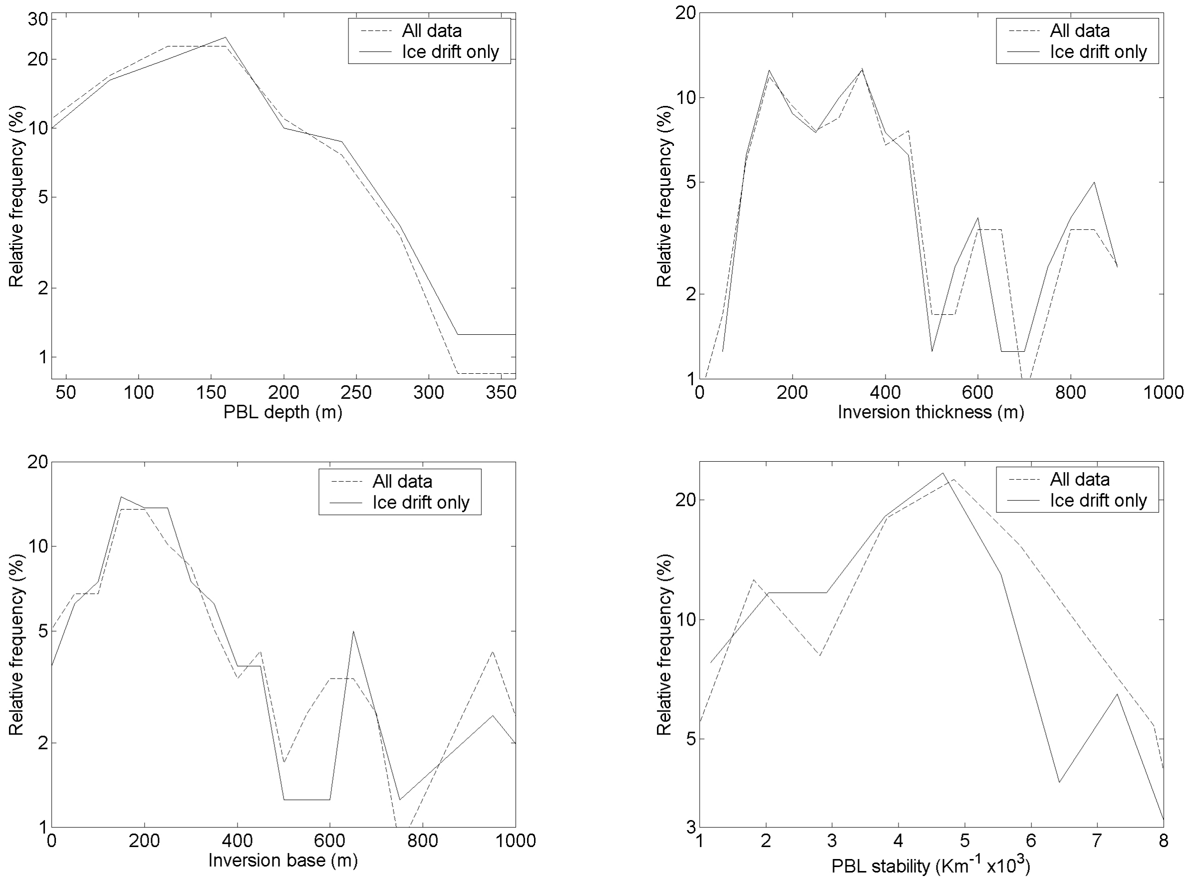

Figure 3. Statistics of some parameters characterizing the lower troposphere, showing (top left) PBL depth, (low left) the height to the inversion base, (top right) inversion thickness and (low right) the potential temperature gradient between the inversion base and the surface.

We believe this to be due to very low aerosol number concentrations. Reduced visibility was instead often related to precipitation, which came in all forms: warm rain, drizzle, frozen drizzle or snow. Winds were typically light to moderate; most common winds were ~ 4 ms^{-1}.

3. PBL STRUCTURE

The radio-sounding profiles were analyzed for statistics of some vertical structure parameters; the results are summarized in Figure 3 and 4. The PBL depth was analyzed from Richardson # profiles based on the soundings, while the remaining parameters were taken directly from the profiles. As can be seen in Figure 3, the PBL was typically quite shallow, usually around 150 m and seldom deeper than 300m. It was often capped by an inversion; the base of the inversion coincided with the top of the PBL most of the time. There were cases

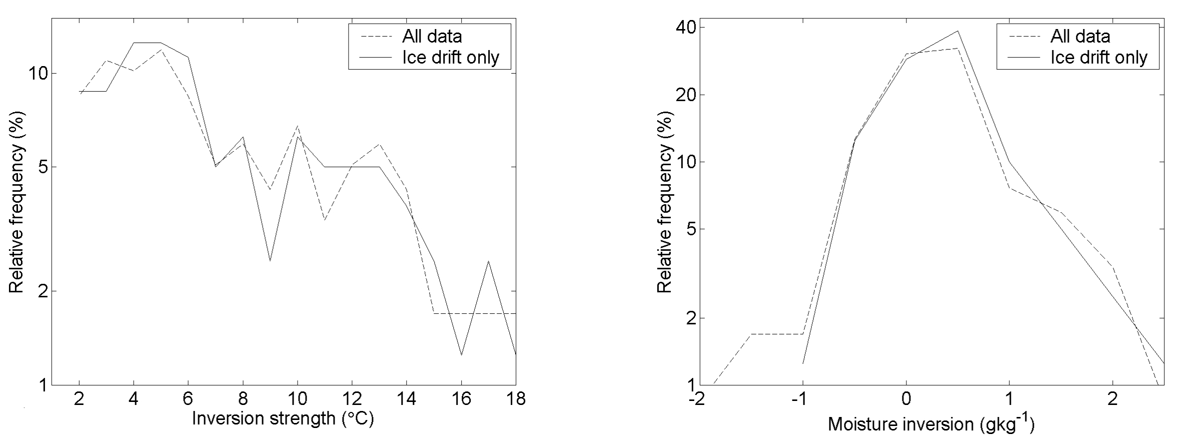

Figure 4. Same as Figure 3, but for the strength of the (left) inversion strength and (right) moisture inversion.

without an inversion directly capping the PBL. The inversion would then be found higher up. The depth of the inversions was typically 200 – 400 m.

The PBL remained well mixed. Only the day with the very lowest temperature (Figure 1) was stably stratified for a short while. The stability of the PBL was inferred from the soundings (Figure 3); the potential temperature typically increased by only 0.05 Km^{-1} between the surface and the inversion base. Given the most typical cloud base at ~ 100m, halfway through the PBL, this corresponds to a near-neutral PBL on average. Over the inversion the temperature most often increased by ~ 4-5 °C (Figure 4), but there were occasions with very strong inversions. During these periods the highest temperature was found around 1 km, often well above zero; the record high was ~ + 8 °C at 1 km on Julian day 222. Unlike in the mid-latitude PBL the specific humidity often increased over the inversion; this is only possible with a strong temperature inversion, as the saturation specific humidity in a function of temperature. In the mid-latitude PBL, very strong inversions capping the PBL are often associated with synoptic scale subsidence and thus with dry air out aloft. In the Arctic, we believe that the very strongest PBL-capping inversions are instead associated with advection of warm and moist air from beyond the ice edge. This is illustrated in time-height cross-sections of temperature, moisture and wind speed from radio soundings for the ice drift (Figure 5). Two main episodes can be seen; days 221-224 and days 228 – 229. Warm and moist air is advected from the open water in the Greenland Sea. The PBL adjusts to the local surface conditions and with sufficient mixing a shallow, cool and moist PBL form, isolated from air aloft by a sharp inversion; this air retains its properties from beyond the edge of the pack ice. The excess moisture lowest troposphere as the air is cooled from below falls out as drizzle.

The wind speed plot shows, as does the cloud-radar cross-section in the companion presentation (see paper 4.9), the most intense synoptic scale weather appearing during the first few days; a few weaker storms followed. During a shorter time, low-level (< 1.5 km) winds oscillates from 2 – 3 ms^{-1} to 7 – 8 ms^{-1}. Although the period of the oscillation does not agree with the inertial frequency, this is one of the very few cases with something similar to a low-level jet. Such low-level wind-speed maximums are often quoted to be frequent in the Arctic; that was not the case during summer 2001.

4. TURBULENCE

Figure 6 shows a composite of turbulence spectra from the entire ice drift. The solid line to the left is the power spectrum of scalar wind speed from a cup anemometer at the top of the 18-m mast. The three lines to the right are means of all 457 1-hour power spectra for longitudinal, crosswind and vertical wind speed components, respectively, from the upper sonic anemometer. The match in the overlap region is surprisingly good. The longitudinal spectrum does not roll off at low frequencies, while the transverse component has a significant spectral gap. There are minor relative peaks at the diurnal and inertial frequencies; the main peak corresponds to the average frequency of storms.

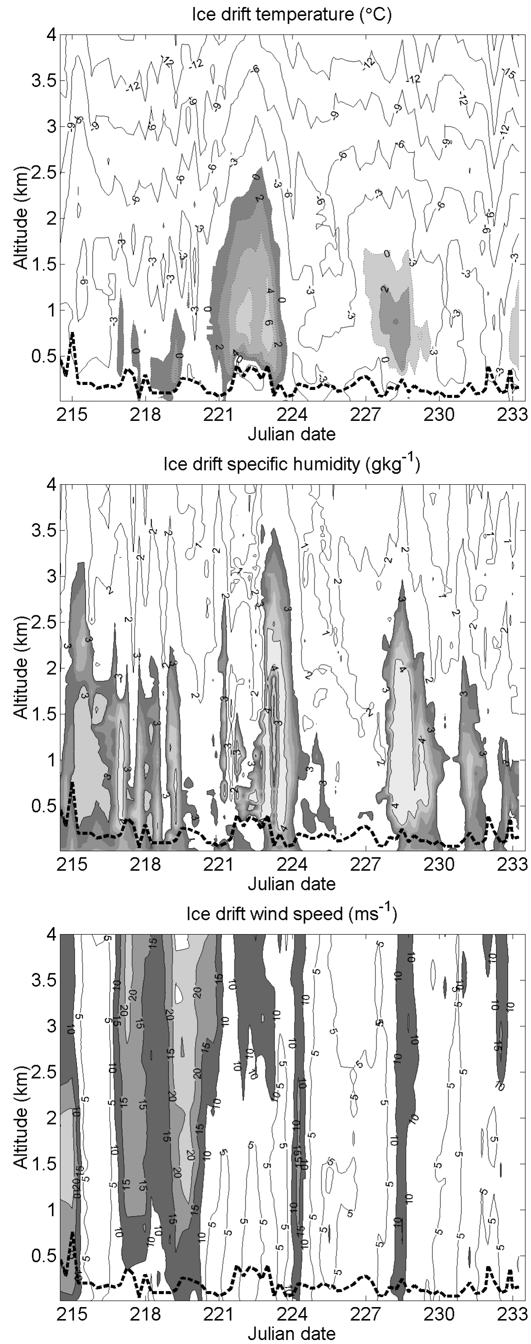

Figure 5. Time-height cross-sections from radio soundings for the ice drift, of (top) temperature, (mid) specific moisture and (bottom) wind speed. Temperatures above zero are shaded, as are moisture > 3 gkg^{-1} and wind speeds > 10 ms^{-1}. The thick dashed line indicates the PBL top.

Figure 7 shows examples from the conditions on two events, those with the very strongest inversions (Figure 5); note that these are plotted without any scaling. While the momentum flux appears quite normal during the first of these episodes, there is a very pronounced spectral gap in the crosswind component, with very high energy at the lower frequencies. In contrast, the power spectra

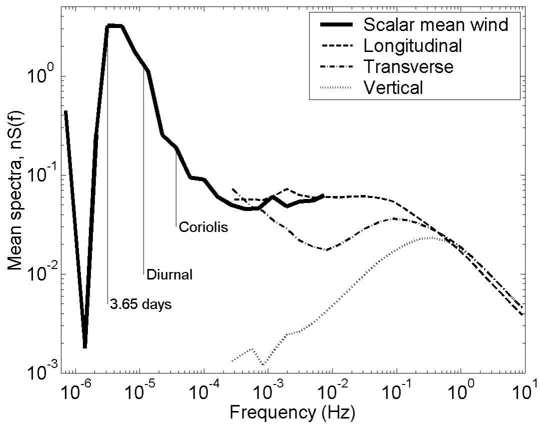

Figure 6. Power spectra of wind speed from a cup anemometer and a sonic anemometer near the mast top

for the second period rolls off sharply at low frequencies. On the other hand, the co-spectra show two strange features. The first, in the afternoon on the 15th, correspond to an overturning episode; the potential temperature gradient in the mast reverses during an hour-long period and a spike in turbulence appears; this coincide with the dissipation of a fog. The second strange period, with an upward momentum flux, occurs to during period when strong entrainment is evident in the scanning radiometer data, associated to a frontal passage.

4. SUMMARY

The main process forming the Arctic PBL appears to be local mixing combined with surface conditions set up by the ice during the melt season. Surface temperatures are seldom lower than the melting point of oceanic water and seldom higher than the fresh water melting point (melt ponds). The surface is also an efficient source of moisture. Together this results in a shallow and moist PBL dominated by low clouds and patchy fog. At the same time, rapid changes in local conditions are caused by both synoptic or mesoscale motions. Advection from beyond the ice edge seems to dominate the characterization of the air aloft. Periods with strong inversions with an increase in specific moisture occur with advection from oceans beyond the ice.

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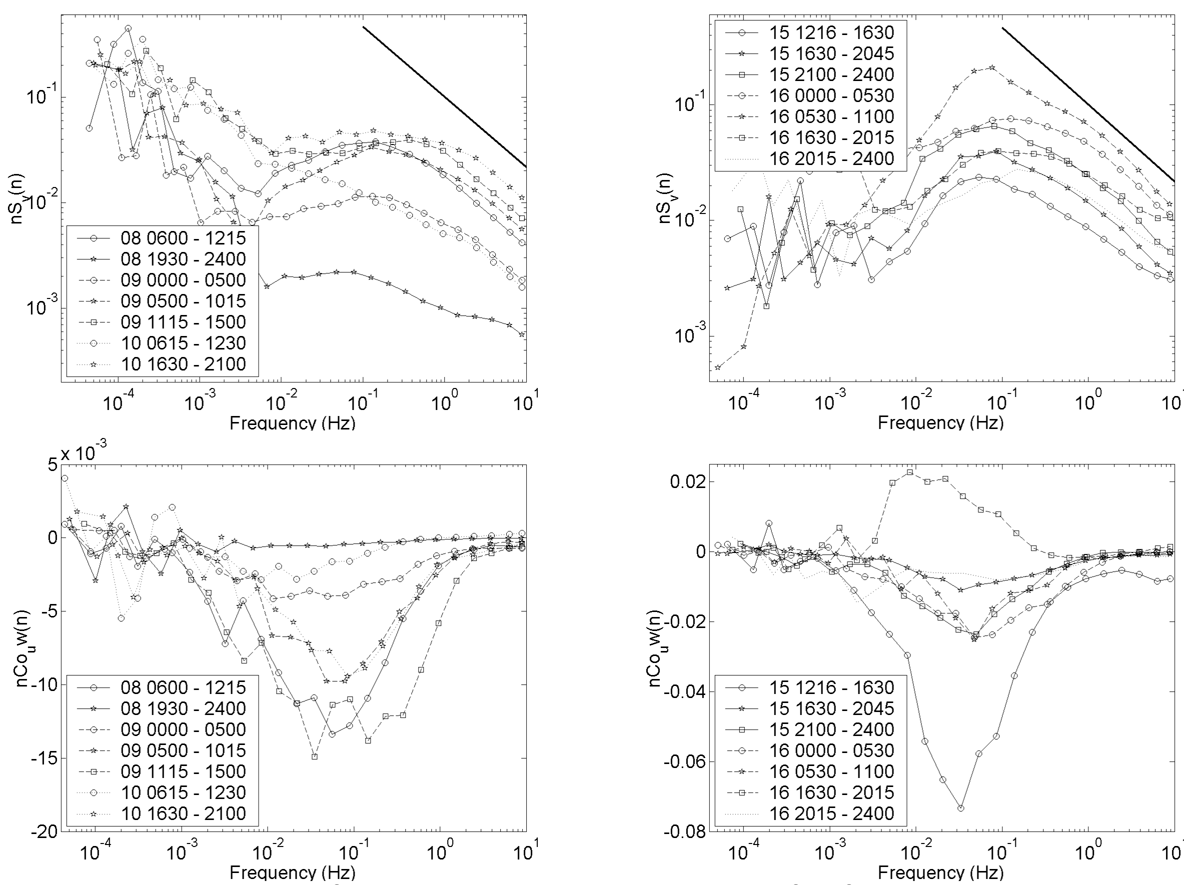

Figure 7. Power and co- spectra for two episodes with dramatic warming aloft: (left) 8 – 10 August (day 220 - 222) and (right) 15 – 16 August (day 227 – 228), showing (upper) the lateral component and (lower) the momentum flux.