UNIVERSITY of BAYREUTH
Department of Micrometeorology

The Arctic Turbulence Experiment 2009

Long-term measurements of near-surface turbulent fluxes in the Arctic environment - additional laser Scintillometer measurement campaign 2009 at the Bayelva catchment on Svalbard (ARCTEX-2009)

Technical documentation and visualization of the near surface measurements during the

ARCTEX 2009 campaign

August, 10th to August, 20th 2009

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Contents

1 Introduction

Accurate quantification of turbulent fluxes between the surface and the atmospheric boundary layer in polar environments, characterized by frequent change of weather and exchange conditions (stable to very stable or intermittent; rapid, short term neutral to unstable stratified conditions) is a fundamental problem in soil-snow-ice-vegetation-atmosphere interaction processes. The observed rapid climate warming in the Arctic requires improvements in the permafrost and carbon cycle monitoring. To address these problems, it is essential to improve the databases with high-quality in-situ measurements of turbulent fluxes above tundra landscape surfaces applying the Eddy-Covariance method and the laser scintillometry.

Results from the Arctic Turbulence Experiment 2006 on Svalbard helped to better understand physical exchange processes of energy and matter transport and to improve instrumentation standards as well as quality assessment techniques (Lüers and Bareiss 2010, 2011; http://www.arctex.uni-bayreuth.de).

Therefore, the primary goal of this additional laser scintillometer measurement campaign is to estimate the flux contributions covering typical tundra surfaces across the Bayelva catchment during a summer season south-west of the Ny-Ålesund village, Kongsfjord, Svalbard.

This effort makes it possible to define the spatial context of the fluxes, and to include land use features of the surrounding terrain in the quality assessment of all observations in the Bayelva catchment over the last 10 years performed by the Alfred Wegener Institute for Polar and Marine Research (AWI).

The primary goals of this ARCTEX-campaign were:

1. continuous measurements of high-resolution (20 Hz) turbulent heat fluxes near the tundra surface using an ultra sonic anemometer (eddy-covariance method) and an open path CO2/H2O infrared gas analyzer,
2. continuous measurements of the turbulent sensible heat flux near the tundra surface using the laser scintillometry,
3. measurements of standard meteorological data sampled at 1 minute intervals using the AWI meteorological tower (2 m and 10 m) and 30 minute intervals using the Bayelva Permafrost Station from the AWI,
4. pre- and post- processing of high-quality data sets of turbulent fluxes using state of the art flux data quality assessment techniques,
5. understanding of exchange processes and their parameterization for neutral and stable conditions.

Lüers, J; Bareiss, J: Direct near-surface measurements of sensible heat fluxes in the arctic tundra applying eddy-covariance and laser scintillometry - The Arctic Turbulence Experiment 2006 on Svalbard (ARCTEX-2006), Theoretical and Applied Climatology, 105, 387-402 (2011)

Lüers, J; Bareiss, J: The effect of misleading surface temperature estimations on the sensible heat fluxes at a high Arctic site – the Arctic turbulence experiment 2006 on Svalbard (ARCTEX-2006), Atmospheric Chemistry and Physics , 10(1), 157-168 (2010)

2 General Information

2.1 Location

The Bayelva climate and soil monitoring site is located in the Kongsfjord region at the west coast of the Svalbard Island. The observation site is part of the Brøgger peninsula, and located in the Bayelva River catchment, about 3 km from the village of Ny-Ålesund (78°55'N, 11°50'E).

The terrain of the Bayelva catchment is bordered eastward by hilly tundra and in the southeast by the Zeppelin Mountain (554 m). From south to southwest the 655 m high Brøgger Mountain and the two flanks of the Brøggerbreen glacier ending into moraine rubble and the Bayelva riverbed. The Bayelva River is even located in the west of the measurement place with its bed mainly consisting of sand and gravel. The southwest border is the 695 m high Schetelig Mountain. To the north of the measurement place the terrain is flattening and at about 1 km distance the Bayelva River reaches the shore line of the Kongsfjord (Arctic Ocean).

In the catchment area sparse vegetation alternates with exposed soil and sand and rubble fields. Typical permafrost features, such as mud boils and non-sorted circles, are found in many parts of the study area. The Bayelva permafrost site itself is located at 25 m above mean sea level, on top of the small Leirhaugen hill and the eddy-flux complex is positioned southward half way down the slightly inclining (< 5°) slope (Westermann et al., 2009).

The dominant ground pattern at the study site consists of non-sorted soil circles which were formed after the last glacial period. The bare soil circle centers are about 1 m in diameter and are surrounded by a vegetated rim consisting of a mixture of low vascular plants of different species of grass (*Carex* spec., *Deschampsia* spec., *Eriophorum* spec., *Festuca* spec., *Luzula* spec.), catchfly, saxifrage, willow and some other local common species (*Dryas octopetala*, *Oxyria digyna*, *Polegonum viviparum*) and unclassified species of mosses and lichens (Ohtsuka et al., 2006). The vegetation cover at the measurement site was estimated to be approximately 60%, the remainder being bare soil with a small proportion of stones (Lloyd et al., 2001). The silty clay soil has a high mineral content, while the organic content is low, with volumetric organic fractions below 10% (Boike et al., 2008).

The fetch area close to the eddy-flux complex is characterized by dry tundra. The covering of the soil with mud boils increases and the structure of the vegetation is changing slightly to a shorter growth height with a maximum of 5 cm to 10 cm.

The Bayelva station has provided a long-term record of climatological parameters and permafrost temperatures since 1998 and eddy-flux data from 2008. At present, the permafrost at Leirhaugen hill is relatively warm, with a mean annual temperature around −2 °C at 1.5 m depth. The maximum active layer depth in summer 2008 was on the order of 1.5 m.

Westermann S., J. Lüers, M. Langer, K. Piel, and J. Boike (2009), The annual surface energy budget of a high-arctic permafrost site on Svalbard, Norway, The Cryosphere, 3, 245-263.

Ohtsuka, T., M. Adachi, M. Uchida, and T. Nakatsubo (2006), Relationships between vegetation types and soil properties along a topographical gradient on the northern coast of the Brøgger Peninsula, Svalbard, Polar Bioscience, 19, 63-72.

Lloyd, C.R., R. J. Harding, T. Friborg, and R. Aurela (2001), Surface fluxes of heat and water vapour from sites in the European Arctic, Theor. Appl. Climatol., 70, 19-33.

Boike, J., O. Ippisch, P. Overduin, B. Hagedorn, and K. Roth (2008), Water, heat and solute dynamics of a mud boil, Spitsbergen, Geomorphology, 95, 61-73.

Detailed geographic locations of the “Arctic Turbulence Experiment 2009” (ARCTEX-2009) at the Bayelva catchment 3 km west of Ny-Ålesund (Svalbard, Kongsfjorden); August 2009, University of Bayreuth, Germany.

General location	Svalbard, Kongsfjorden, Ny-Ålesund, Position (Center of settlement): 078° 55’ 24’’ N, 011° 55’ 15’’ E	
Scintillometer UBT01 dry Tundra (SLSdry), Bayelva:	Coordinates:	078° 55’ 24’’ N, 011° 49’ 55’’ E (Transmitter) 078° 55’ 22’’ N, 011° 49’ 42’’ E (Receiver)
	Altitude:	16 m a. s. l.
	Land use:	dry Tundra
Scintillometer UBT02 wet Tundra (SLSwet) , Bayelva:	Coordinates:	078° 55’ 27’’ N, 011° 49’ 53’’ E (Transmitter) 078° 55’ 25’’ N, 011° 50’ 07’’ E (Receiver)
	Altitude:	14 m a. s. l.
	Land use:	wet Tundra
Bayelva Eddy-Flux complex AWI (EF):	Coordinates:	078° 55’ 17’’ N, 011° 49’ 51’’ E
	Altitude:	18 m a. s. l.
	Land use:	dry Tundra
Bayelva Permafrost Station AWI, (BPS)	Coordinates:	078° 55’ 15’’ N, 011° 49’ 59’’ E
	Altitude:	25 m a. s. l.
	Land use:	Tundra
Bayelva Meteorological tower AWI (BMT):	Coordinates:	078° 55’ 18’’ N, 011° 50’ 12’’ E
	Altitude:	16 m a. s. l.
	Land use:	Tundra
Meteorological tower AWI Ny-Ålesund (MT):	Coordinates:	078° 55’ 04’’ N, 011° 55’ 26’’ E
	Altitude:	14 m a. s. l.
	Land use:	Tundra
BSRN AWI Ny-Ålesund (BSRN):	Coordinates:	078° 56’ 05’’ N, 011° 56’ E
	Altitude:	11 m a. s. l.
	Land use:	Tundra
Time zone		Central European Time: CET = GMT + 1 h (winter) CEST = GMT + 2 h (summer). Given times and filenames reflect starting time of intervals

UBT = University of Bayreuth; AWI = Alfred Wegener Institute for Polar- and Marine Research; BSRN = Baseline Surface Radiation Network

2.2 Surface and weather conditions

Table 2.1 lists the weather conditions during the ARCTEX-2009 campaign. There was midnight sun during the whole campaign. The surface conditions were constant (except the short precipitation events listed below).

Table 2.1: Weather conditions during the ARCTEX-2009 campaign, time is CEST.

August 12	overcast, predominantly light air, partly light breeze, temperature range: +4.2 °C to +6.8 °C
August 13	predominantly overcast, partly light breeze during the day, drizzle at 9 p.m., temperature range: +3.7 °C to +7.2 °C
August 14	predominantly overcast in the morning, later partly cloudy (midday till afternoon), windy from 9 a.m. to 10 p.m. (5 to 6 m s^{-1}), temperature range: +3.1 °C to +6.2 °C
August 15	overcast, partly windy up to gentle breezes, temperature range: +1.7 °C to +3.5 °C
August 16	fog in the morning hours and overcast until midday, later predominantly sunshine and partly cloudy (high clouds), predominantly calm, partly light breezes, temperature range: –0.7 °C to +5.0 °C
August 17	sunshine until afternoon, later few high clouds and increasing wind, from 5 p.m. strong wind (7 to 8 m s^{-1}), temperature range: +0.9 °C to +7.5 °C
August 18	strong Foehn wind (8 to 10 m s^{-1}) until afternoon, drizzle at 4 p.m. (app. 15min), light rain at 5:15 p.m. and 6:30 p.m. (app. 15min), later predominantly overcast, temperature range: +2.6 °C to +8.5 °C
August 19	predominantly cloudy until midday, later overcast, windy until 13 a.m., later light breeze, temperature range: +3.9 °C to +7.1 °C

3 Overview of measurement sites

The satellite image below (Figure 3.1) gives an overview of the Bayelva catchment including the installed instrument sites. It is located about 3 km west of the village of Ny-Ålesund.

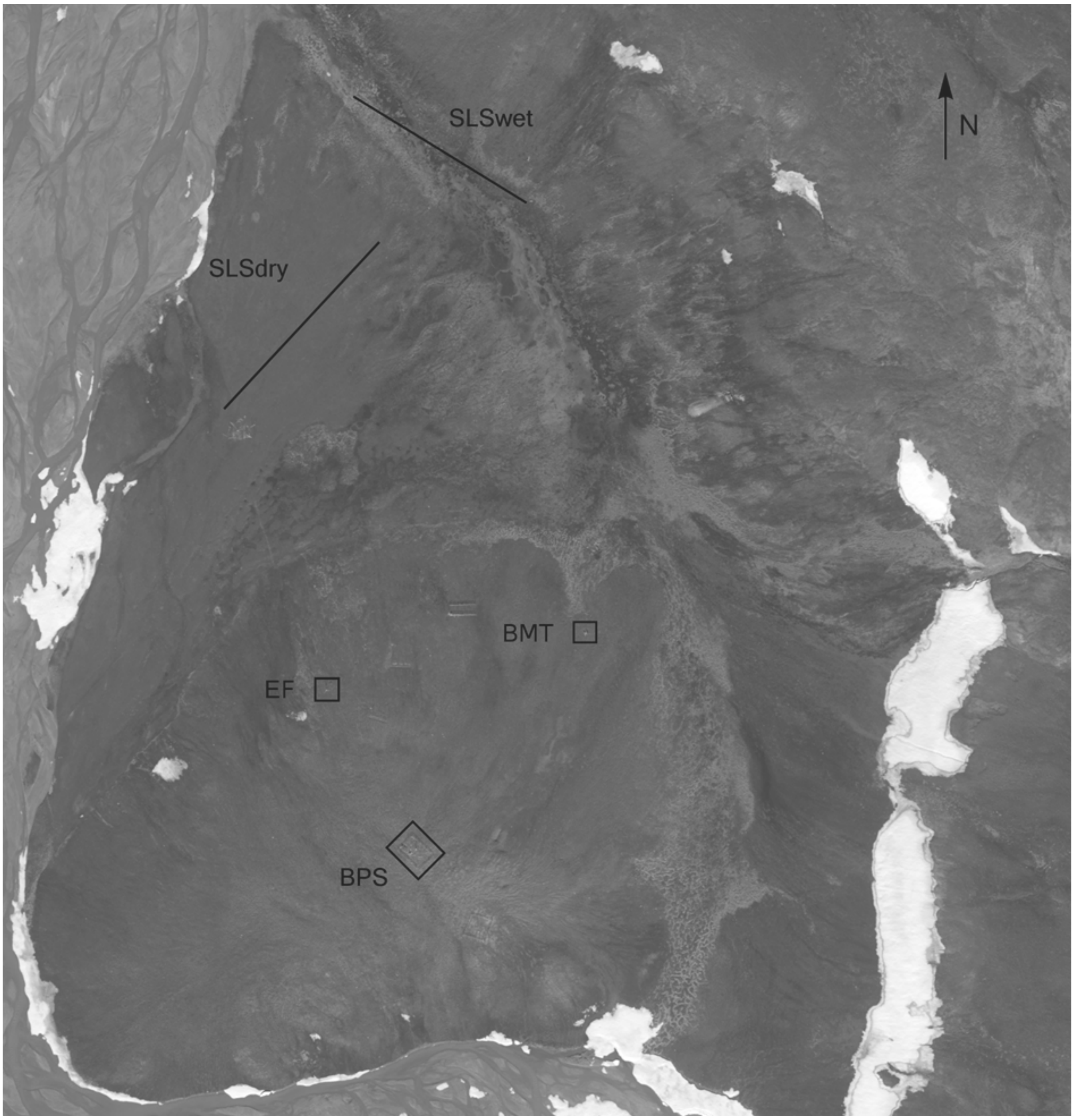


Figure 3.1: Crop of a high resolution satellite image of the Bayelva catchment with the installed measurement sites (EF = Bayelva Eddy-flux complex, BMT = Bayelva Meteorological tower, BPS = Bayelva Permafrost Station, SLSdry = Scintillometer UBT01 dry Tundra, SLSwet = Scintillometer UBT02 wet Tundra). The original image was processed by Ernst Hauber from the DLR (High Resolution Stereo Camera *HRSC-AX*; Resolution: 20 cm/pixel; Projection: UTM (WGS44); central meridian: 15 degree), ARCTEX-2009 campaign.

3.1.1 Meteorological tower AWI Ny-Ålesund (MT)

The permanent, 10 m tall meteorological tower (MT) of the AWI (Figure 3.2) is located about 100 m south-east of the Building of the atmospheric observatory (AWI-OBS) and south of the village of Ny-Ålesund in the protected monitoring instrument area (about 5 m next to the driveway towards the Corbel-Station). The measurements of this station are part of the routine meteorological observation program (surface radiation and mast measurements) operating since 1994 and headed by the AWI.

(http://www.awi-potsdam.de/MET/NyAlesund/wettertab.html).

Figure 3.2: Ten meter tall meteorological tower (MT) of the Alfred Wegener Institute south of the AWI Scientific Observatory. Routine meteorological measurements AWI/IPEV station Ny-Ålesund (Svalbard), ARCTEX-2009 campaign.

3.1.2 Bayelva Eddy-Flux measurement complex AWI (EF)

The Eddy-Covariance Flux measurement complex (EF), set up in March 2007 at the Bayelva catchment 3 km west of Ny-Ålesund, consists of a CSAT3 ultra sonic anemometer (Campbell Scientific) to measure the turbulent variation of all three wind vectors as well as the sonic temperature (sensible heat flux) and a LI7500 open-path gas-analyzer (LI-COR Biosciences) to measure CO_2 and H_2O surface fluxes Figure 3.3. To measure the snow height around the Station a SR50 sonic ranging sensor (Campbell Scientific) is used.

This station is operated by the Permafrost group of the AWI, headed by Dr. Julia Boike, Potsdam.

Figure 3.3: Eddy-Flux measurement complex (EF), monitoring area Bayelva 3 km west of Ny-Ålesund (Svalbard) in the Bayelva catchment, ARCTEX-2009 campaign.

3.1.3 University of Bayreuth Laser Scintillometer (SLS)

In addition to the Eddy-Flux measurement complex located in the Bayelva catchment, two displaced laser beam Scintillometer (SLS20, Scintec A.G.) should be installed for this experiment on August 12, 2009 (Figure 3.4) by the ARCTEX-2009 Team, headed by the University of Bayreuth. One device was planned to measure above a dry-tundra area and the second one above a wet tundra place.

But for unknown reason (maybe a damage during transportation) and despite several tests without success, the receiver unit of the 2nd Scintillometer was damaged beyond repair. The only way to proceed with the experiment, was to replace the one working Scintillometer every two days from the dry tundra area to the wet area and back.

The path length across the dry and wet tundra monitoring area was each time 100 m and the height of the laser beam above the ground each time 1.2 m. The surface condition at both sites did not change during the observation period (except the short precipitation events, see Table 2.1).

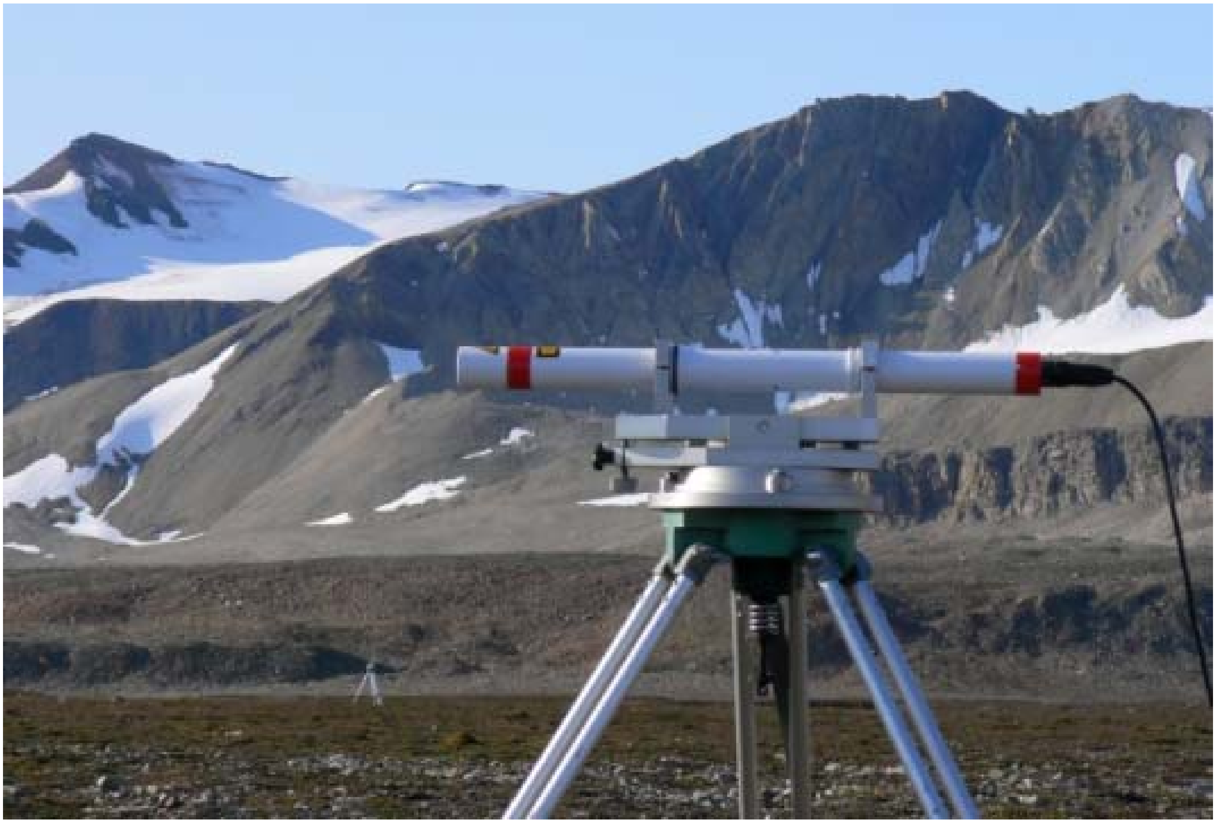


Figure 3.4: Laser Scintillometer, Scintec SLS20 (SLS) of the University of Bayreuth, monitoring area west of Ny-Ålesund (Svalbard) in the Bayelva catchment, ARCTEX-2009 campaign.

3.1.4 Bayelva Permafrost Station AWI (BPS)

The Bayelva Permafrost Station of the AWI exists since 1998. It is located on a small hill 25 m above sea level and approximately 3 km apart from the village of Ny-Ålesund. On August 13, 2009, the new NR01 4-component radiation instrument was installed and the recording of the Bayelva Permafrost Station was interrupted for a few hours. This station is operated by the Permafrost group of the AWI, headed by Dr. Julia Boike, Potsdam.

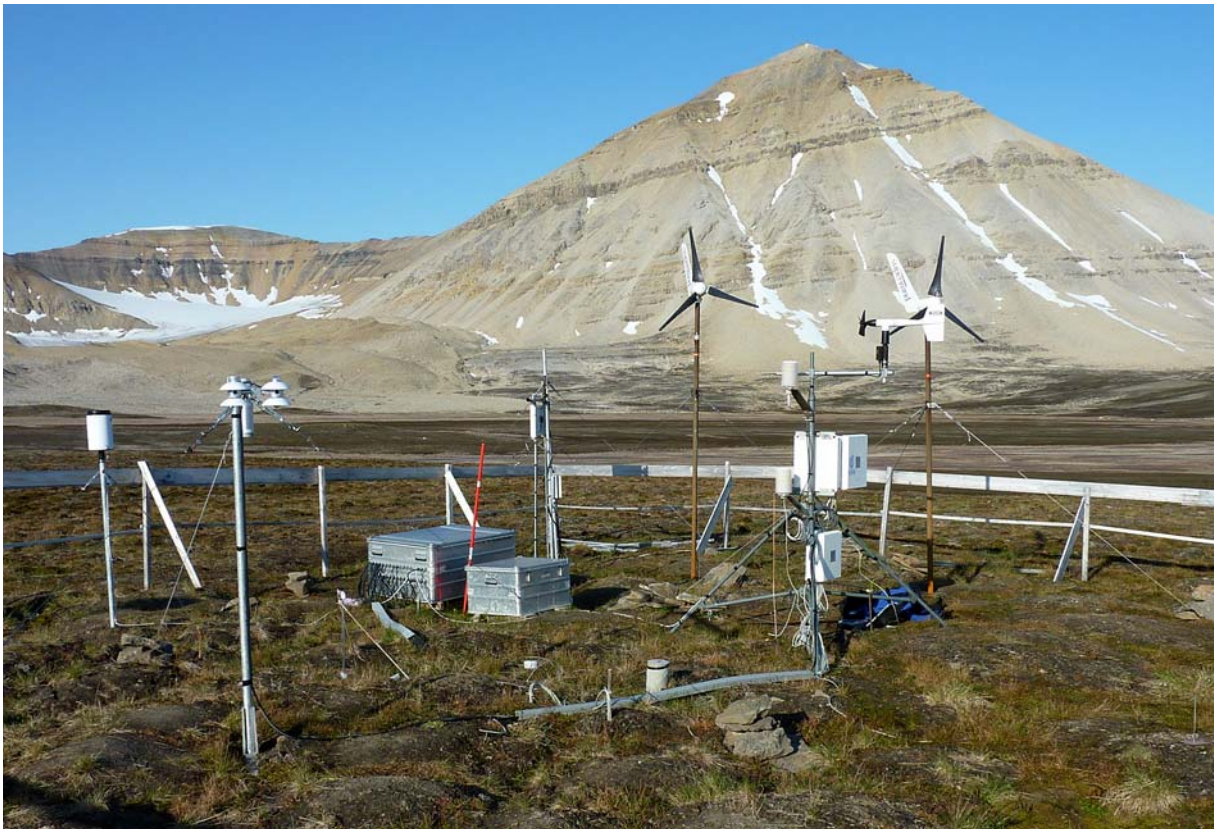


Figure 3.5: Bayelva Permafrost Station AWI (BPS), monitoring area west of Ny-Ålesund (Svalbard) in the Bayelva catchment, ARCTEX-2009 campaign (Photo by Konstanze Piel).

4 Detailed description of instrumentation

4.1 Meteorological tower AWI (MT)

No.	Meteorological element	Position	Sensor type	Period
1	air temperature 2 m and 10 m (°C)	MT	ventilated thermometer	permanent
2	relative humidity at 2 m (%)	MT	capacitive humidity sensor	permanent
3	wind speed 2 m and 10 m (m s^{-1})	MT	cup anemometer	permanent
4	wind direction 2 m and 10 m (°)	MT	wind vane	permanent
5	surface pressure 11 m a.s.l. (hPa)	MT	piezoelectric pressure sensor	permanent

4.2 Eddy-flux measurements (EF)

No.	Name	Position	Instrument	Period
1	3D ultra sonic anemometer	EF	Campbell Scientific (U.S.A.) CSAT3	measuring since March 2007
2	open path CO_2/H_2O infrared gas analyzer	EF	LI-COR Biosciences (U.S.A.), LI-7500	measuring since March 2007
3	sonic ranging sensor (snow height)	EF	Campbell Scientific (U.S.A.), SR50	measuring since March 2007
4	Logger Unit	EF	Campbell Scientific (U.S.A.) CR3000 Logger, OS 10	New OS since August 12, 2009

4.3 Laser Scintillometer (SLS)

No.	Name	Position	Instrument	Period
1	Displaced Beam Scintillometer	UBT SLS	1st pair: Scintec A.G. (GER) SLS20, S/N: 010-A-00009 Sensor separation (path length) both dry and wet tundra:100 m, measurement height 1.21 m a. g. l (height of laser beam) 2nd pair: Scintec A.G. (GER) SLS20, S/N: 010-A-00010	August 12, 2009, 16:46 CET – August 19, 2009, 13:44 CET. Alternated between: dry (12.08. 16:50 to 15.08. 11:25), wet (15.08. 11:50 to 18.08. 08:50), and dry (18.08. 09:20 to 19.08. 13:45) tundra 2nd pair of SLS20 was damaged beyond repair, no data
2	PC control systems	UBT SLS	Desktop-PCs with Scintec standard software	
3	Data cables	UBT SLS	200 m RS-485 serial connection	

4.4 Bayelva Permafrost Station AWI (BPS)

No.	Meteorological element	Position	Sensor type	Period
1	air temperature 2 m (°C)	BPS	MP100 (Rotronic)	since 1998
2	relative humidity 2 m (%)	BPS	MP100 (Rotronic)	since 1998
3	wind speed and direction 2.2 m ($m\ s^{-1}$) and (°)	BPS	Anemometer 05103 (RM Young)	since 1998
4	radiation components ($W\ m^{-2}$)	BPS	NR01 (Hukseflux)	since August 13, 2009
5	snow height 1.45 m a.s.l	BPS	SR50 (Campbell)	since 1998
6	precipitation 1.68 m a.s.l. (mm)	BPS	Tipping bucket rain gauge 52203 (RM Young)	since 1998

5 Data acquisition and recording

5.1 Laser Scintillometer (SLS)

The SLS20 Scintillometer was operated using the Scintec DOS-based software SLSRUN.exe version 2.10 (Figure 5.1). Path length and height were set as described before; average air temperature and pressure were adjusted for every measurement period (usually one day). Before any measurement period an automatic Background Alignment test was executed to eliminate signal noise and to handle the channel crosstalk. To recalculate the turbulent fluxes the required representative temperature values and the representative air pressure values were taken from the AWI meteorological tower (MT).
All recorded raw and post-processed data is available in the Archive of the Dept. of Micrometeorology, Univ. of Bayreuth, see Chapter 8 “Archived Data”.

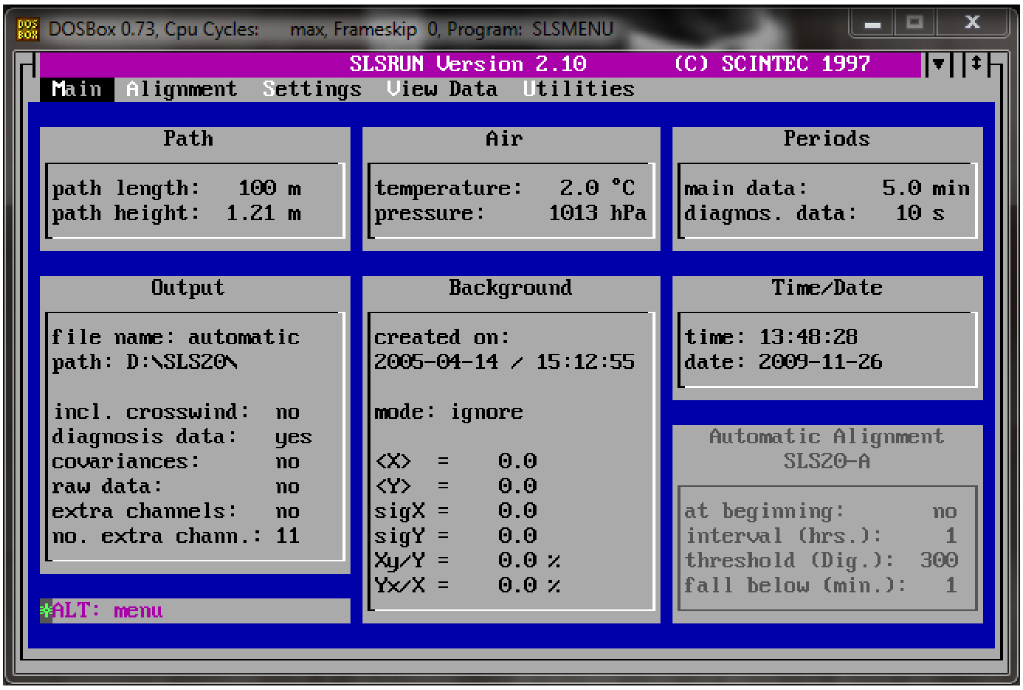


Figure 5.1: Example of the Scintec DOS-based SLSRUN software to receive the scintillometer raw data, ARCTEX-2009 campaign.

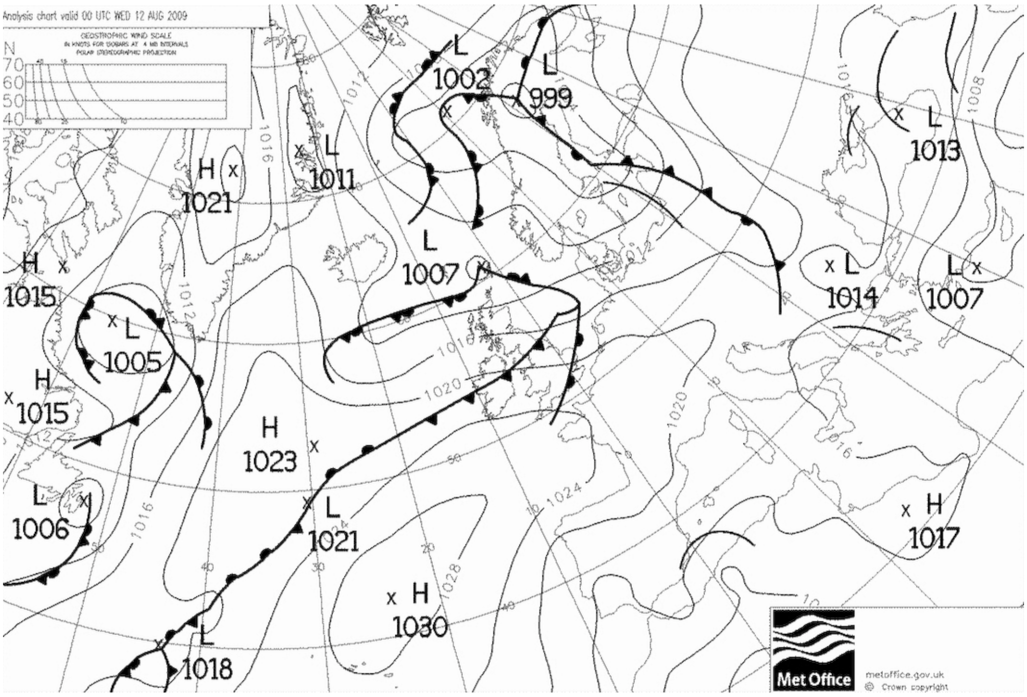
5.2 Eddy-flux data (EF), Bayelva Permafrost Station AWI data (BPS) and Meteorological tower AWI data (MT)

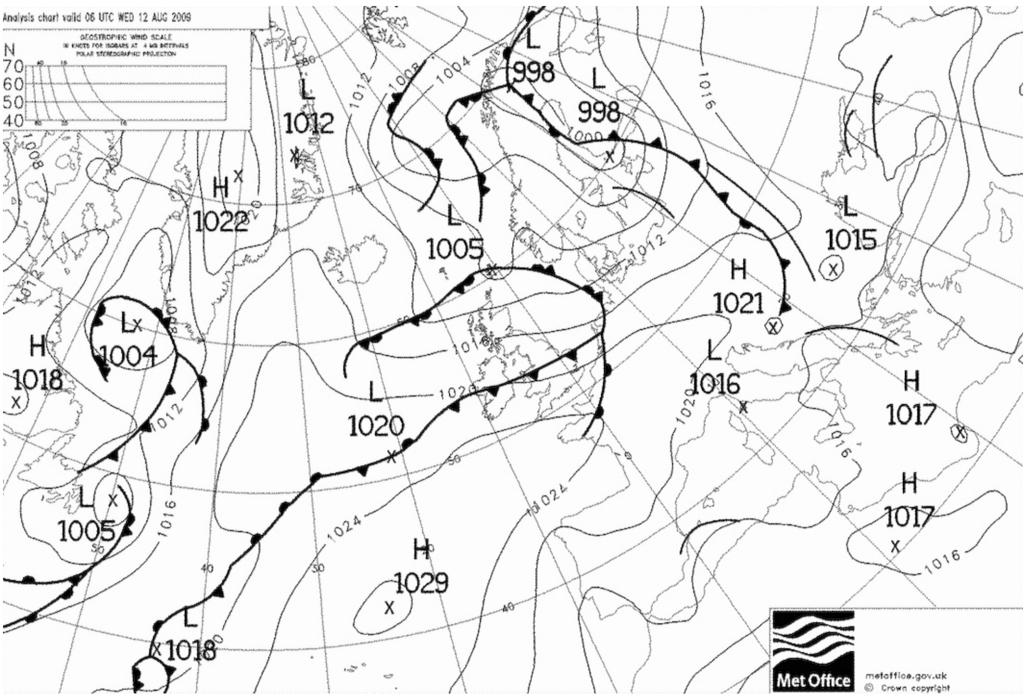
The necessary Eddy-flux and Bayelva Permafrost Station data were provided by Konstanze Piel (AWI-Potsdam). The Meteorological tower AWIPEV data were provided by Marcus Schumacher, station leader 2009 of the AWIPEV Arctic Research base. All recorded raw and post-processed data is available in the Archive of the Dept. of Micrometeorology, Univ. of Bayreuth, see Chapter 8 “Archived Data”.

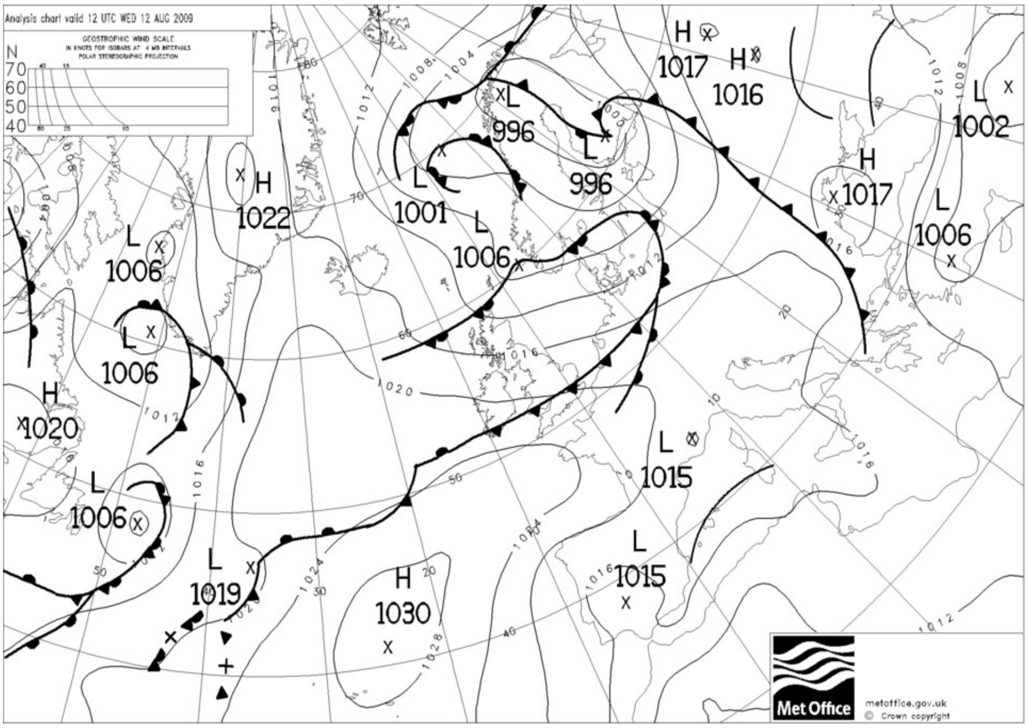
6 Visualization of standard meteorological measurements

6.1 Synoptic situation

Synoptic weather charts (mean sea level pressure analysis = MSLP) were provided by the UK Meteorological Office (UKMO), showing the isobars including fronts and troughs. The following charts outline the synoptic situation between August 12 and August 19, 2009, at 00 UTC, 06UTC, 12 UTC and 18 UTC. The chart of August 17, 2009, 12 UTC is missing.



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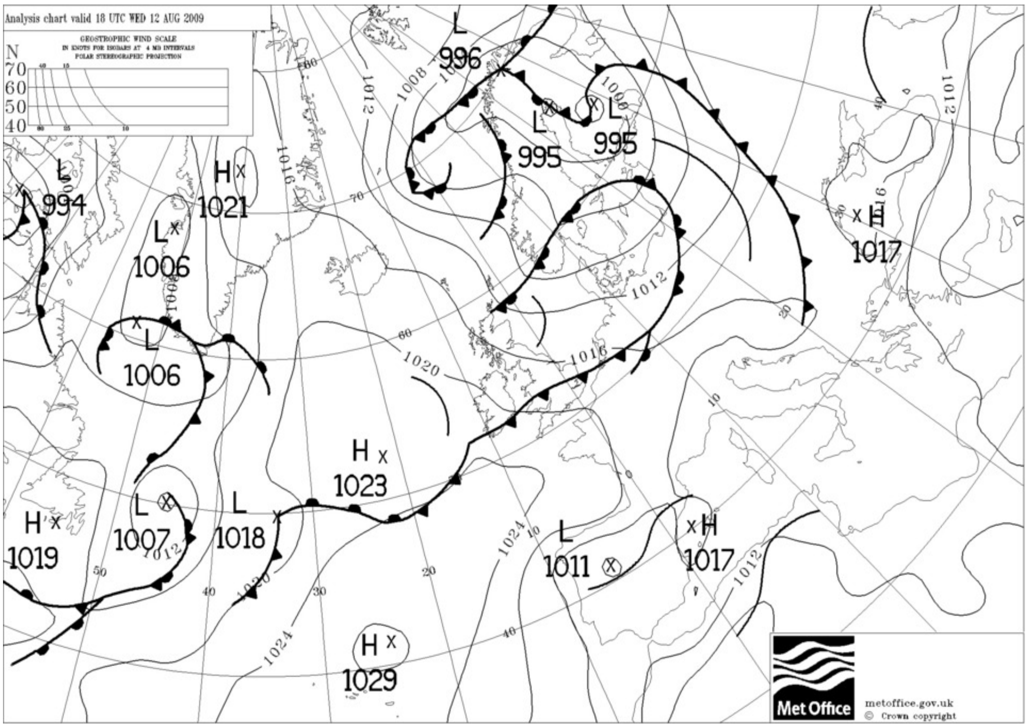
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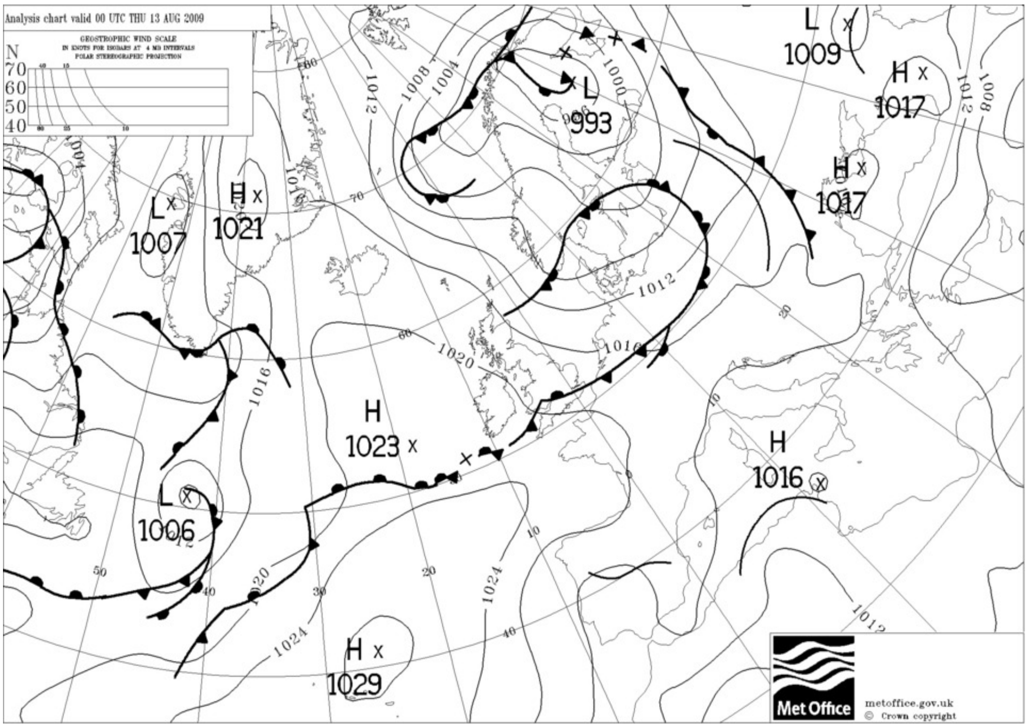
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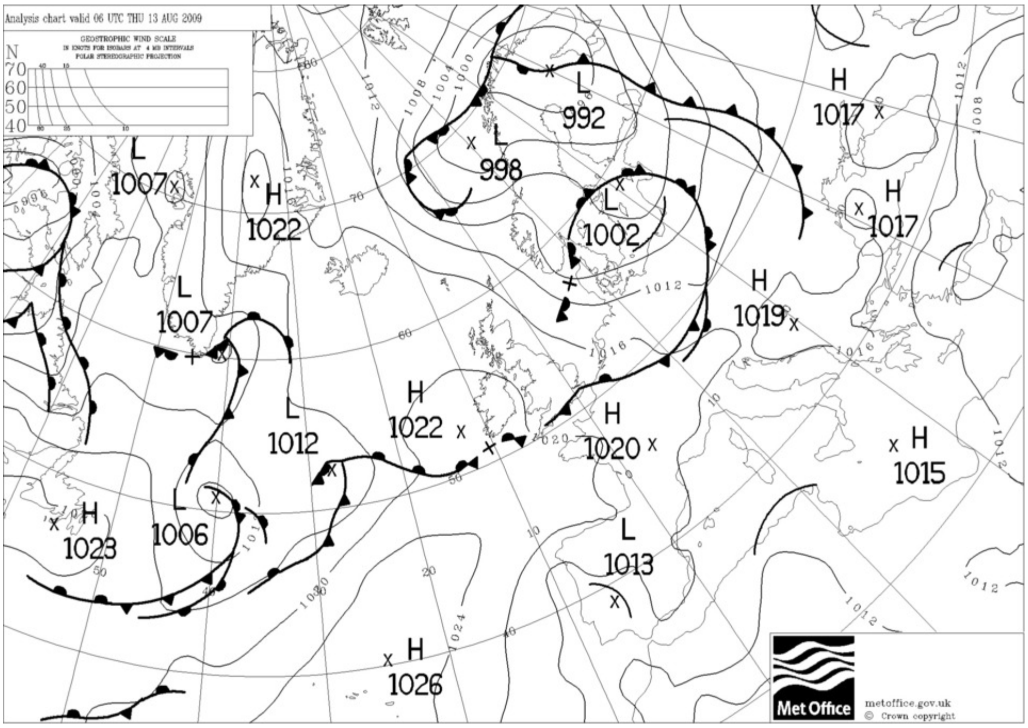
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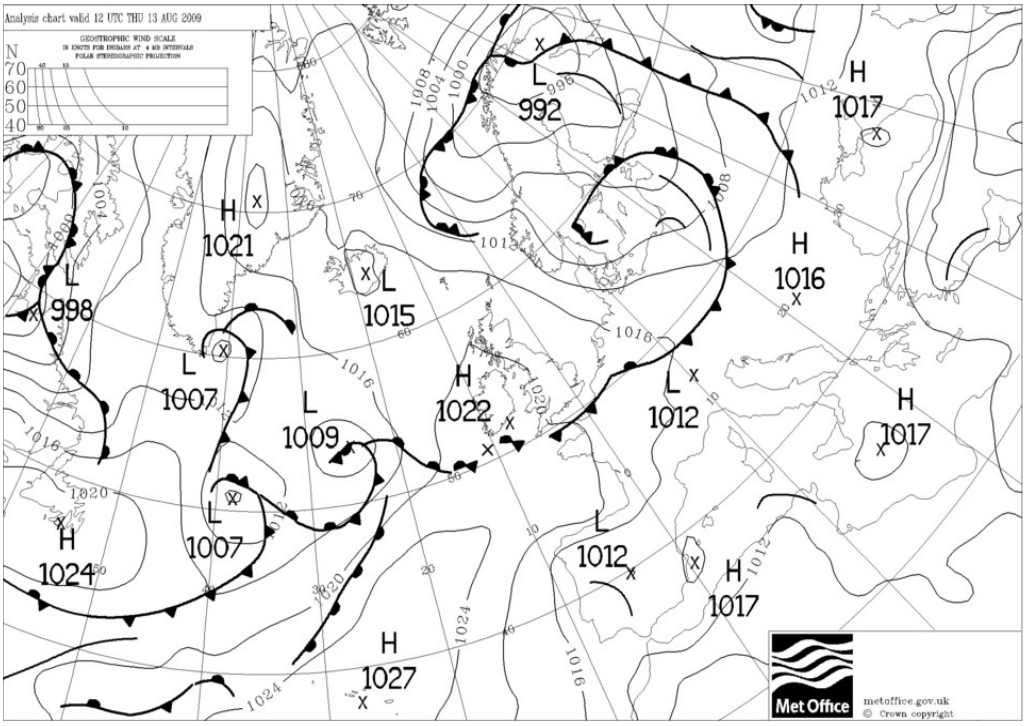
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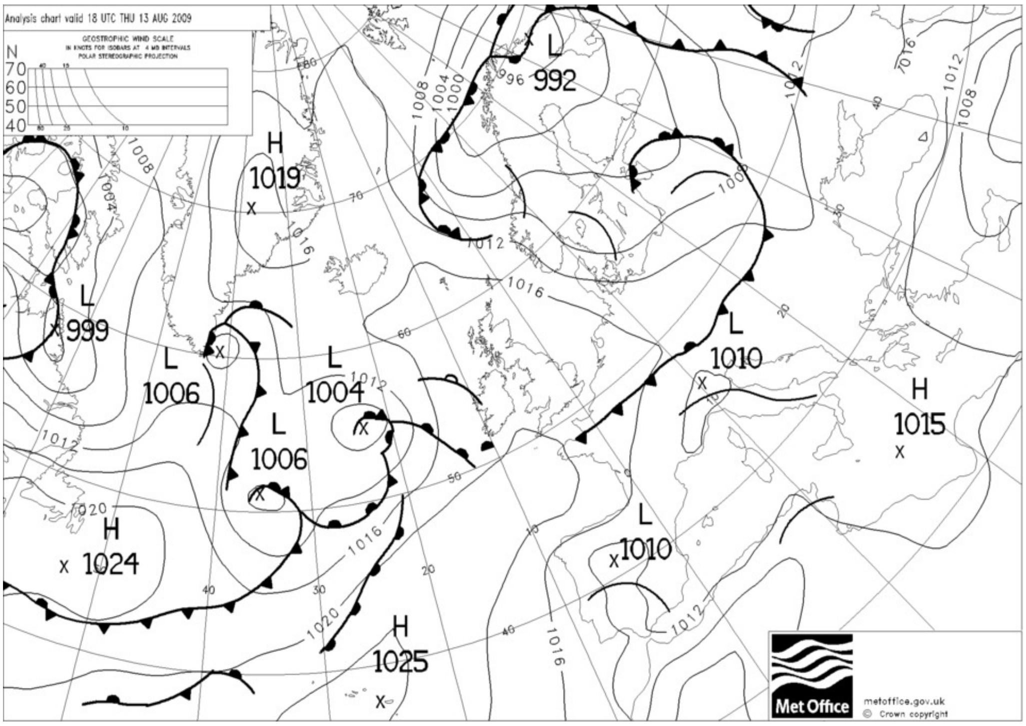
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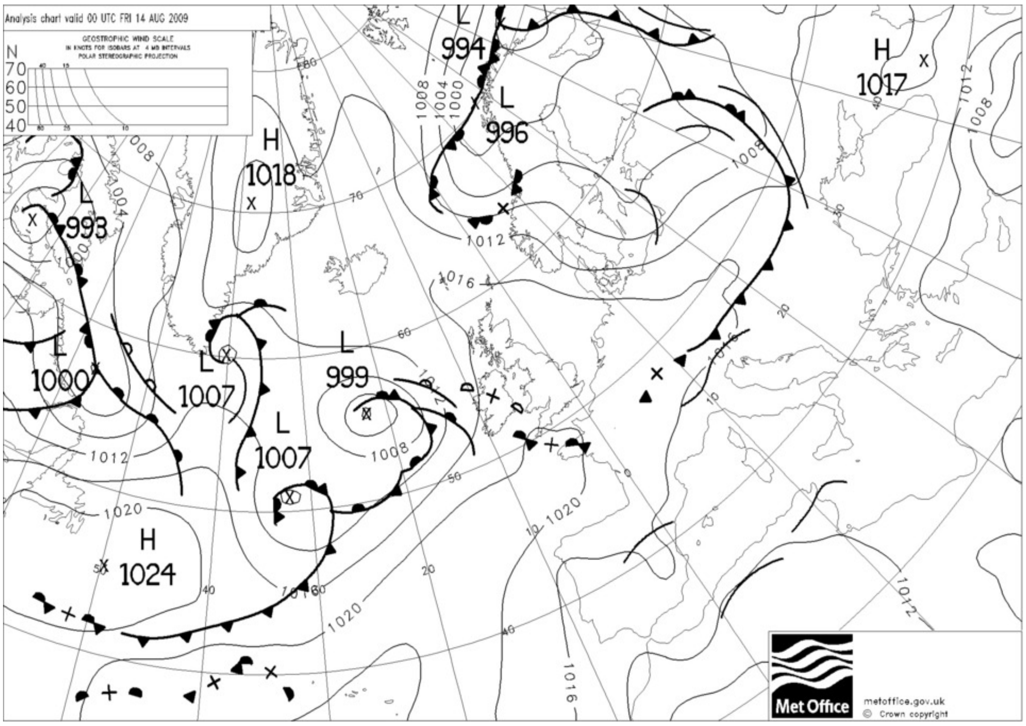
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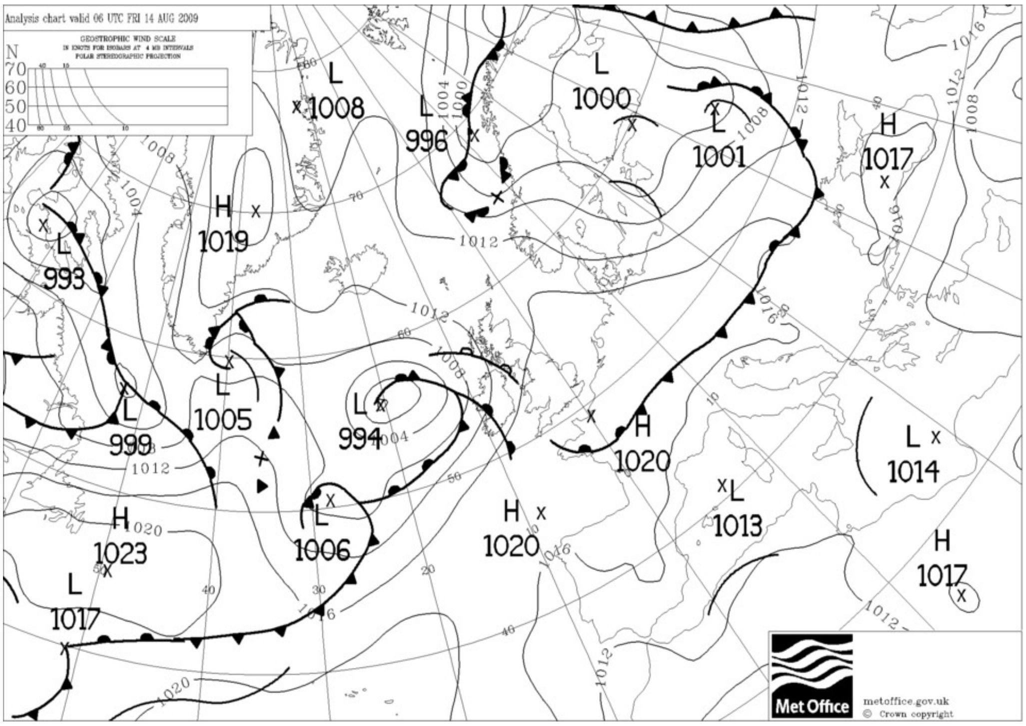
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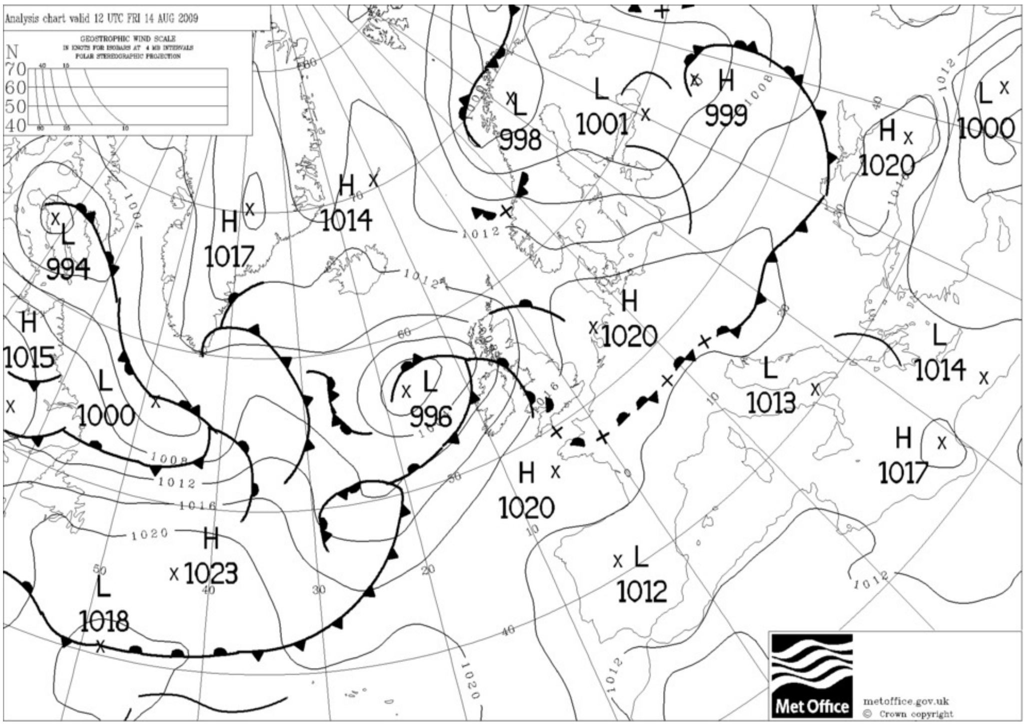
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H 1015
L 1000
H 1017
H 1014
L 998
L 1001
H 999
H 1020
L 1000
L 996
H 1020
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L 1018
L 1012
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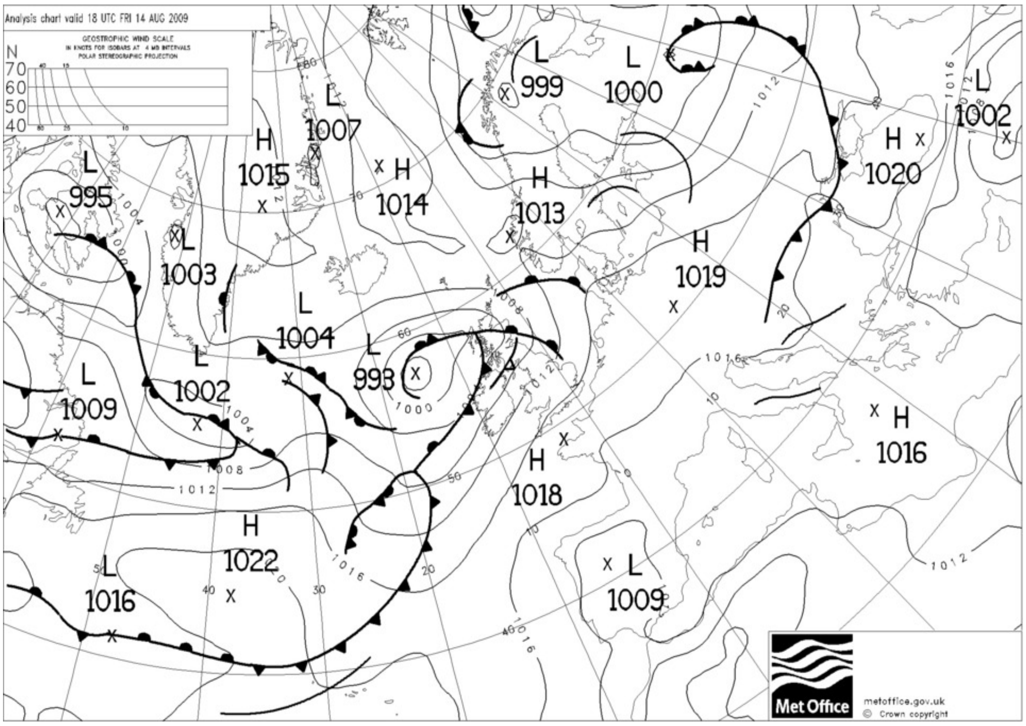
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H 1020
L 1007
H 1015
H 1014
H 1013
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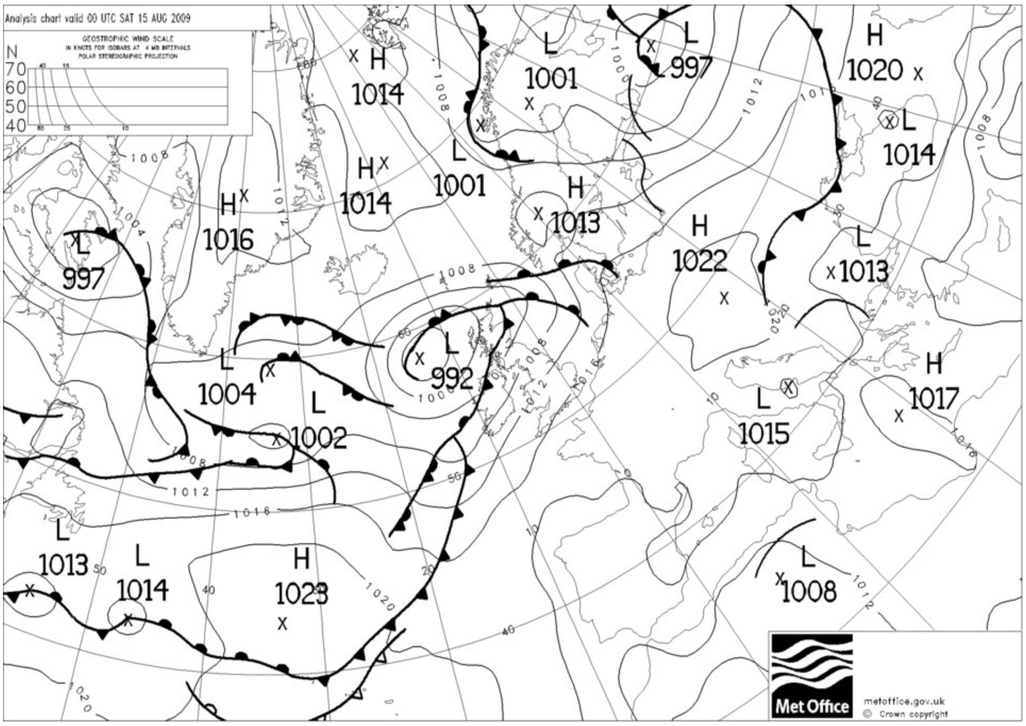
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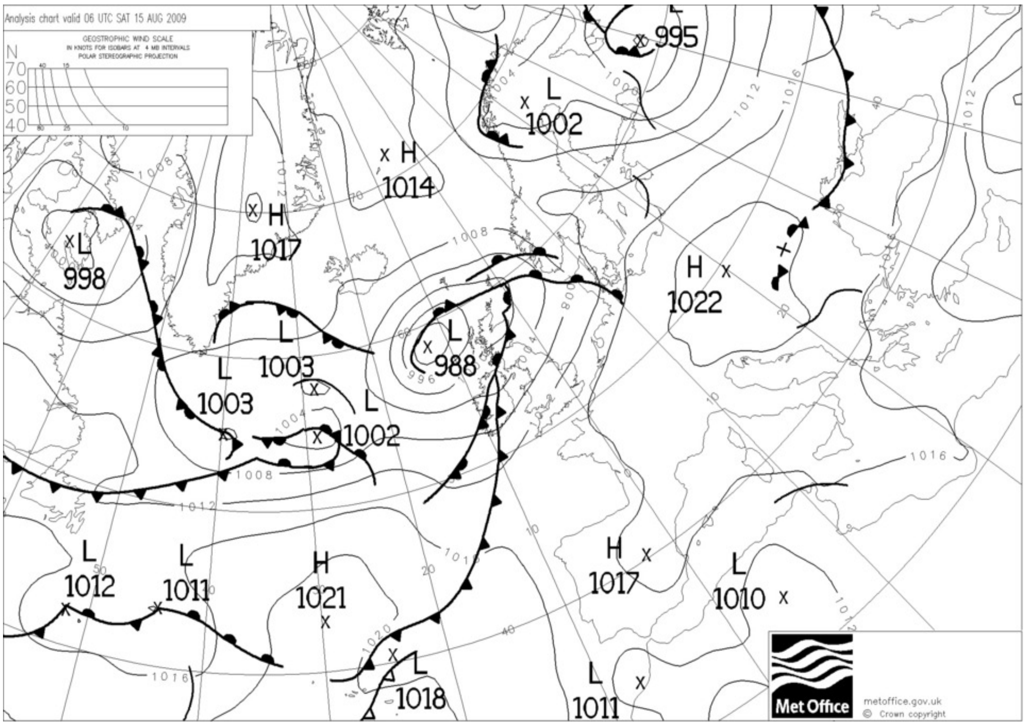
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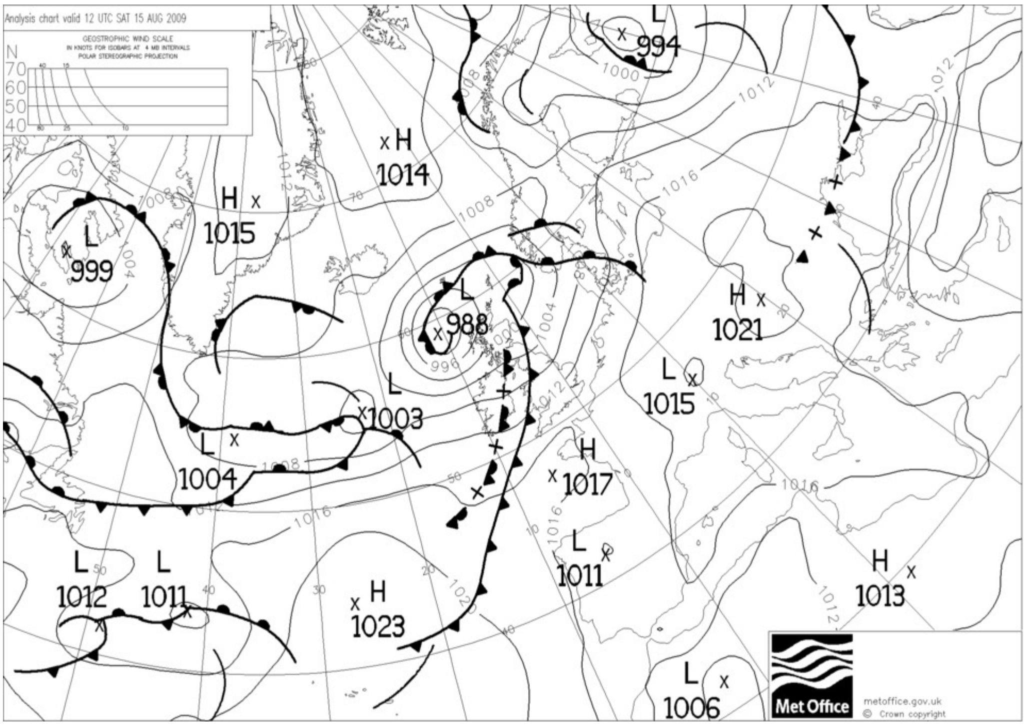
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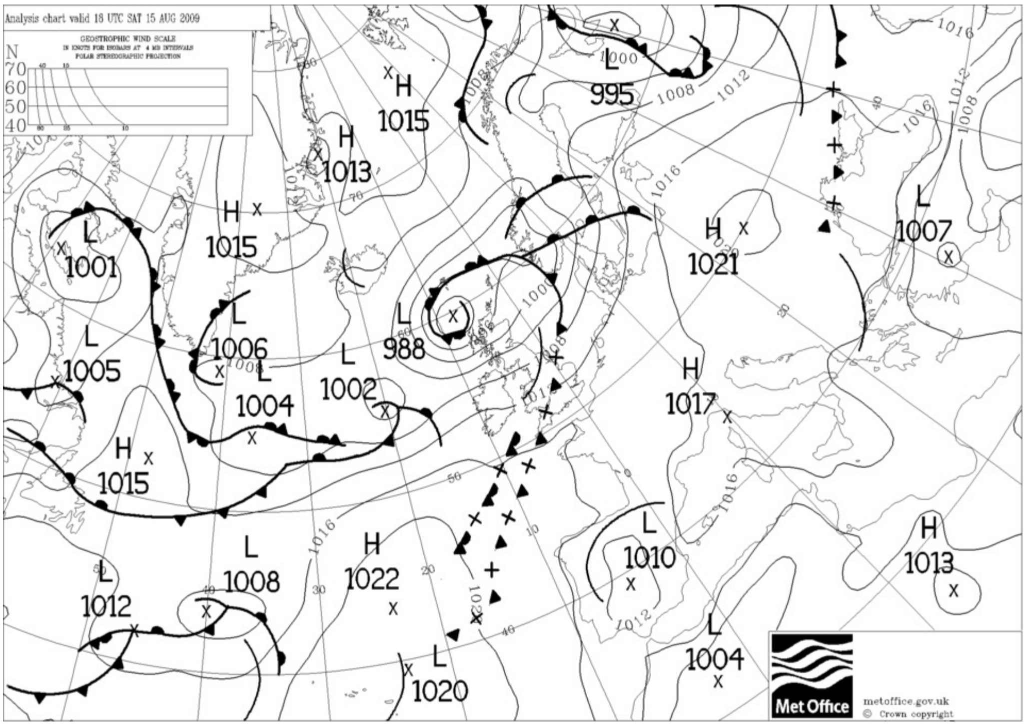
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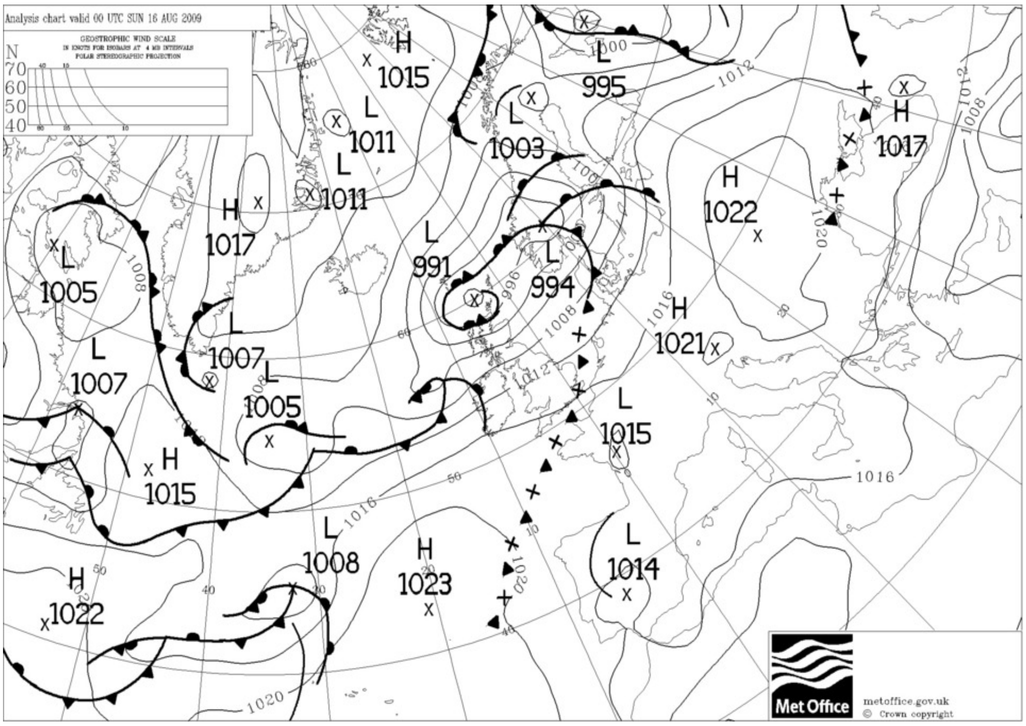
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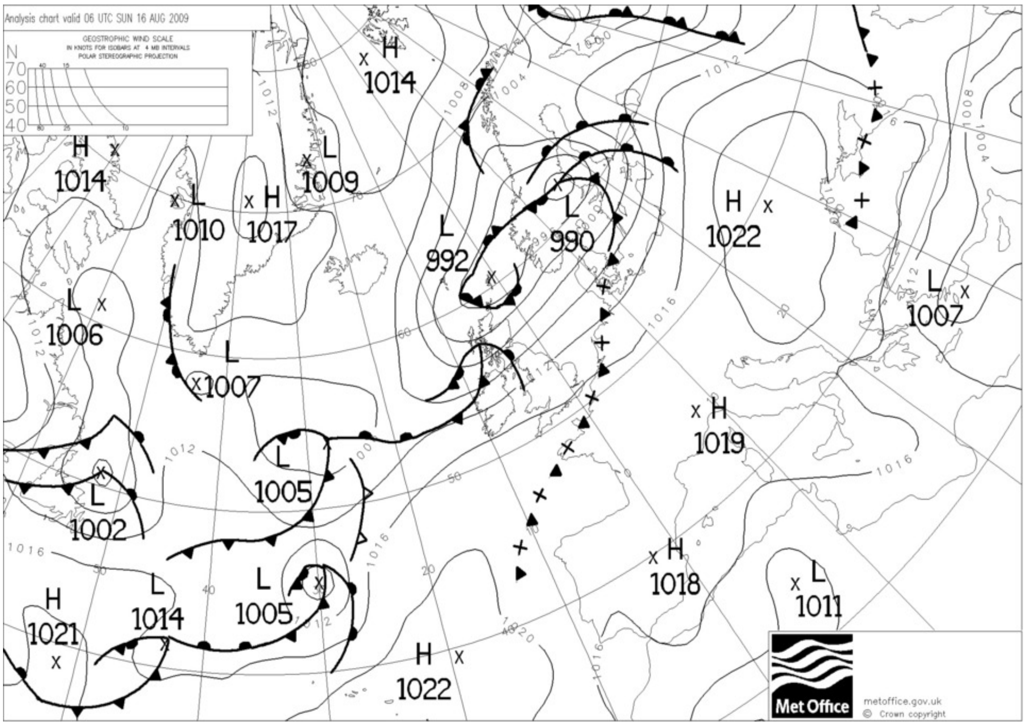
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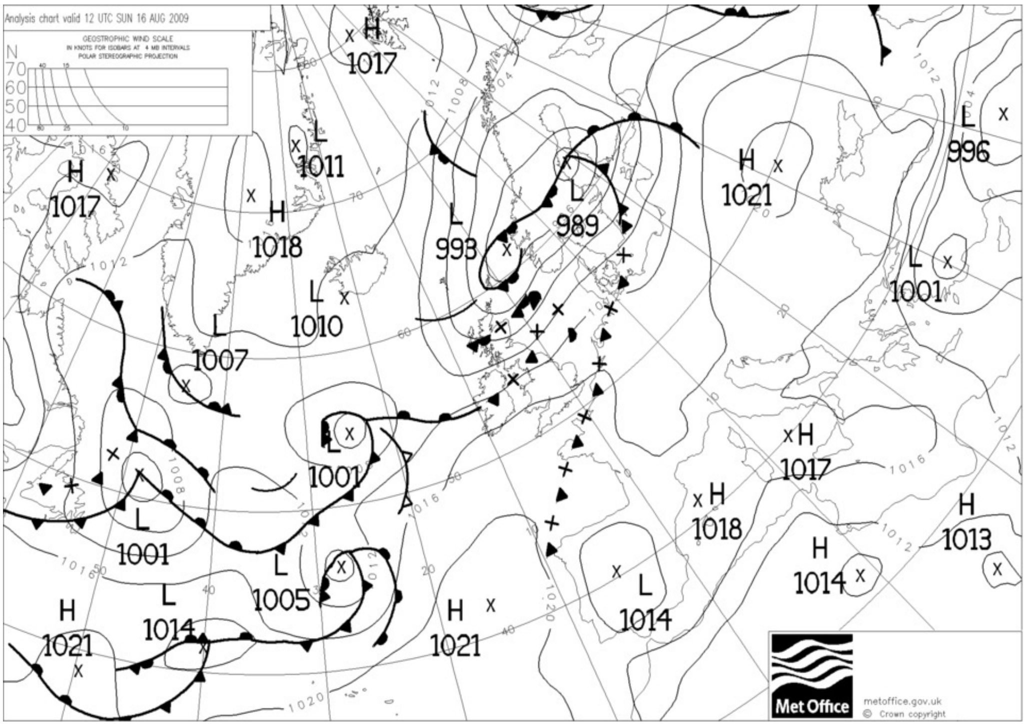
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H 1017
H 1018
L 993
L 989
H 1021
L 996
L 1010
L 1007
L 1001
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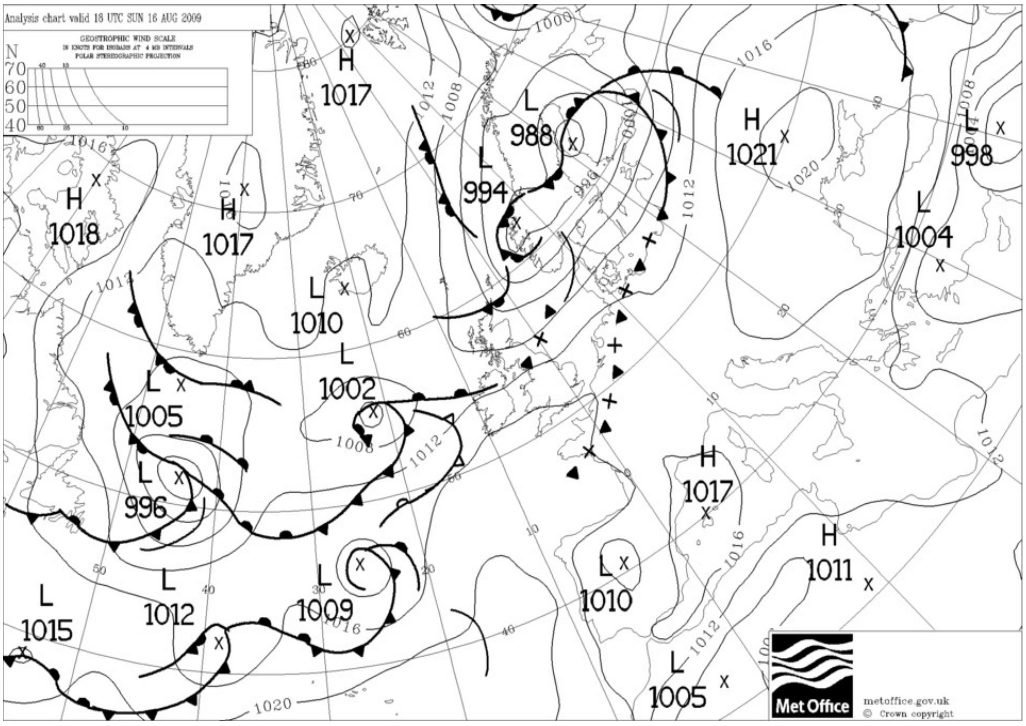
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L 994
H 1021
L 998
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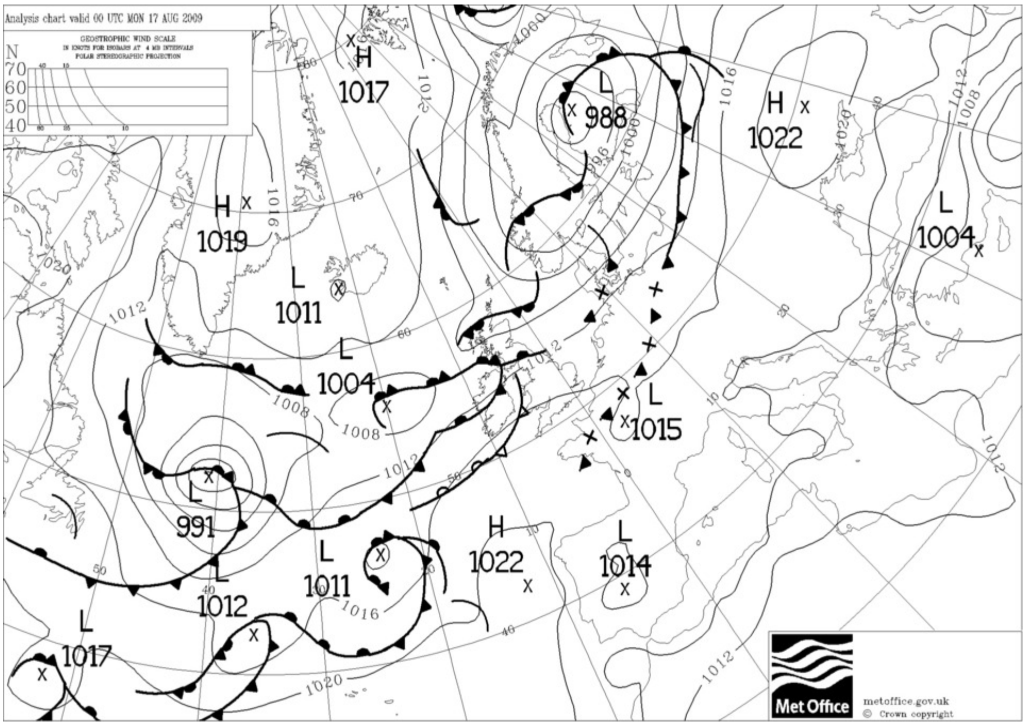
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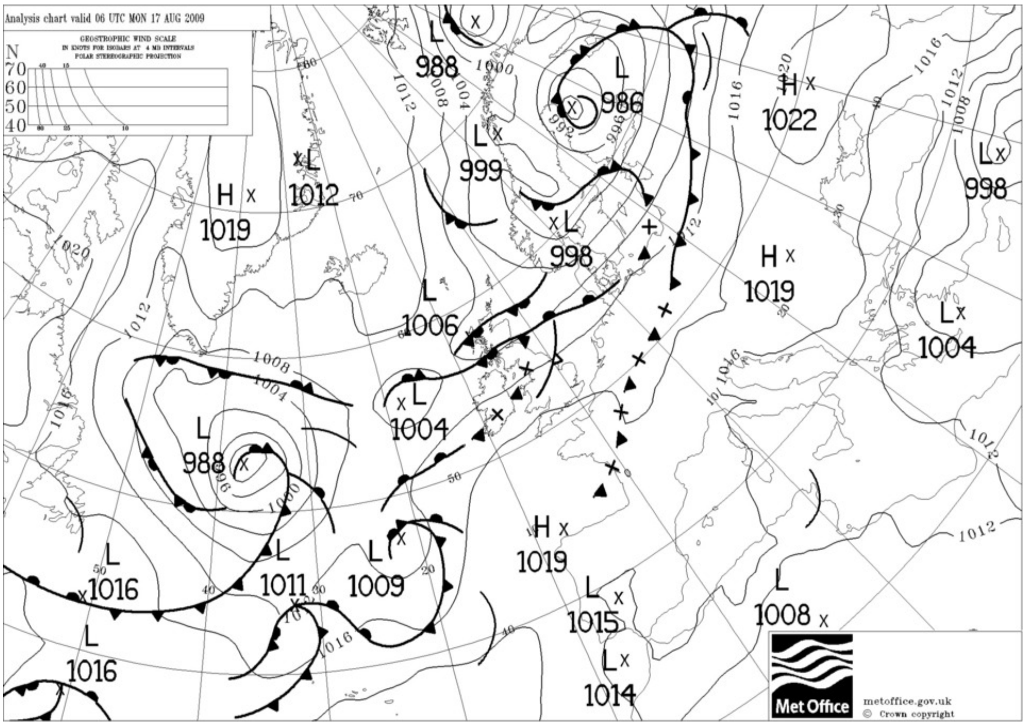
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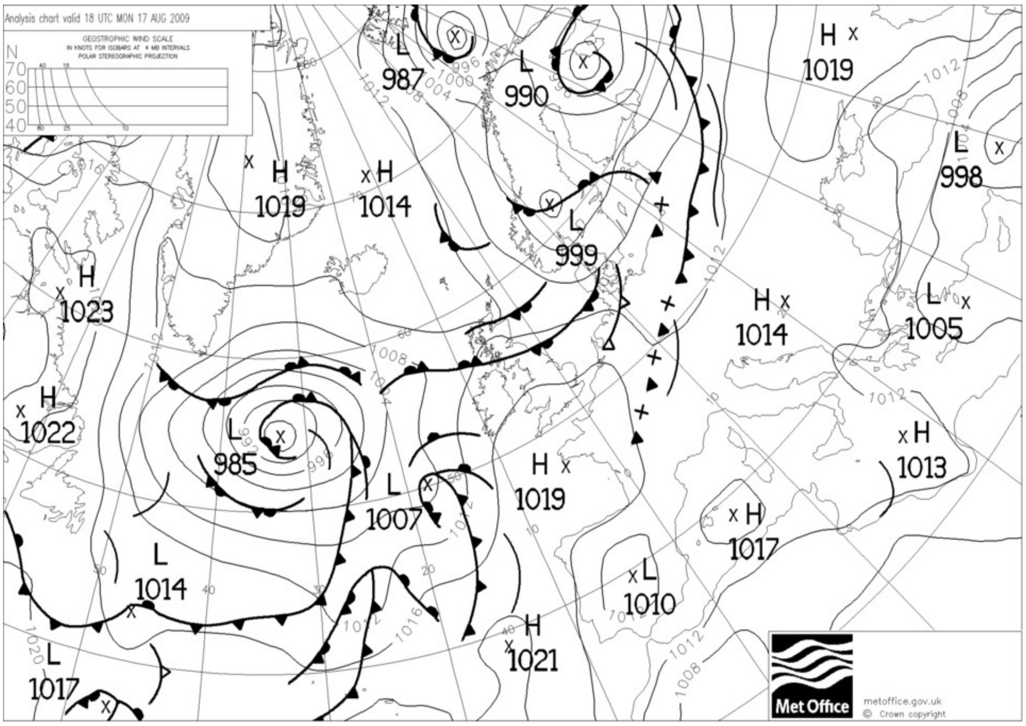

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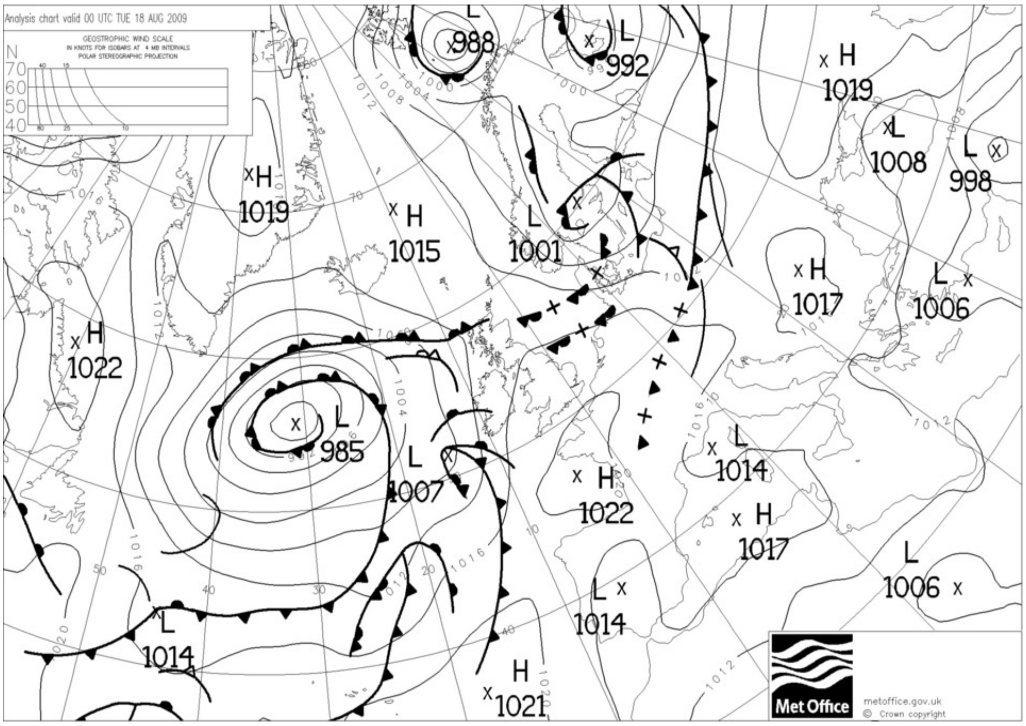

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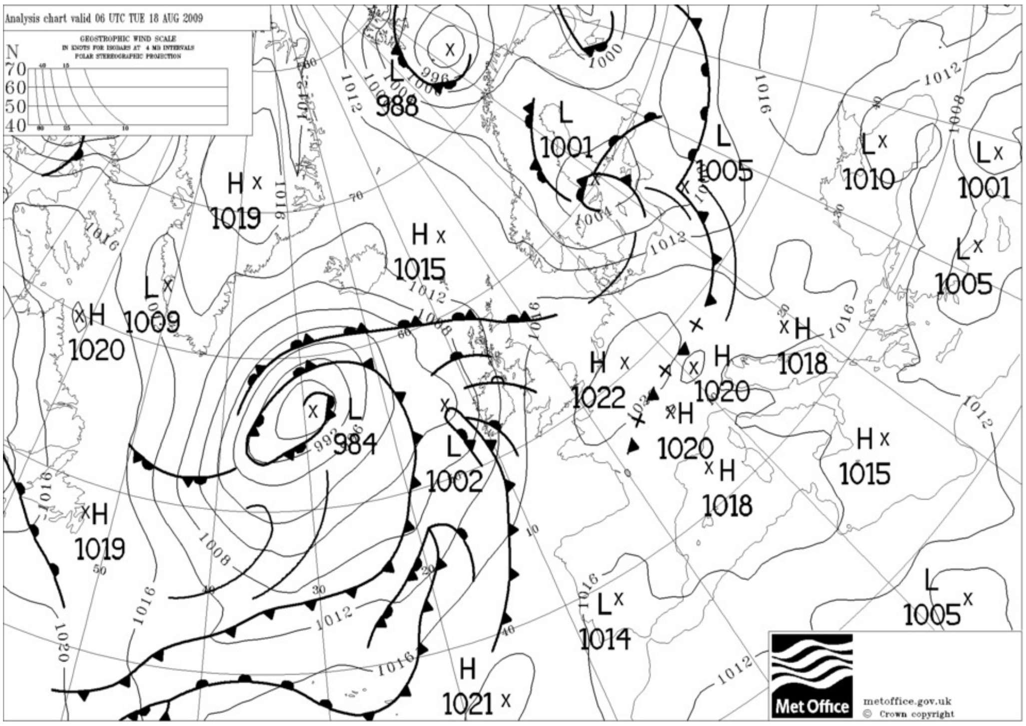
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GEOSTROPHIC WIND SCALE
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L 1005
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L 1001
H 1019
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L 1005
H 1020
L 1009
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H 1020
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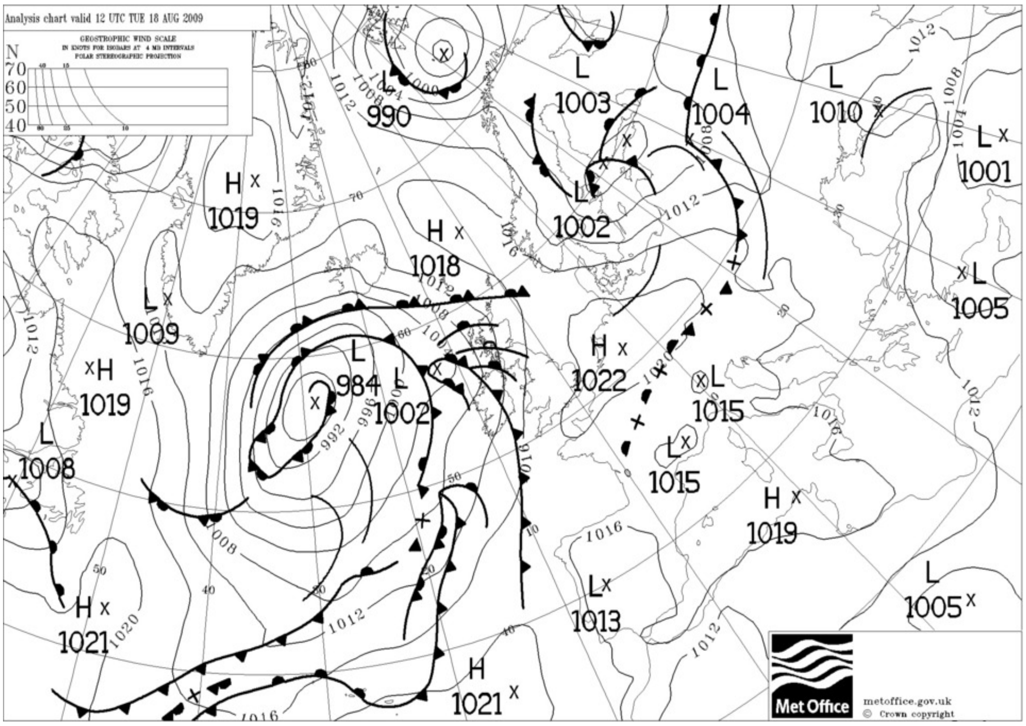
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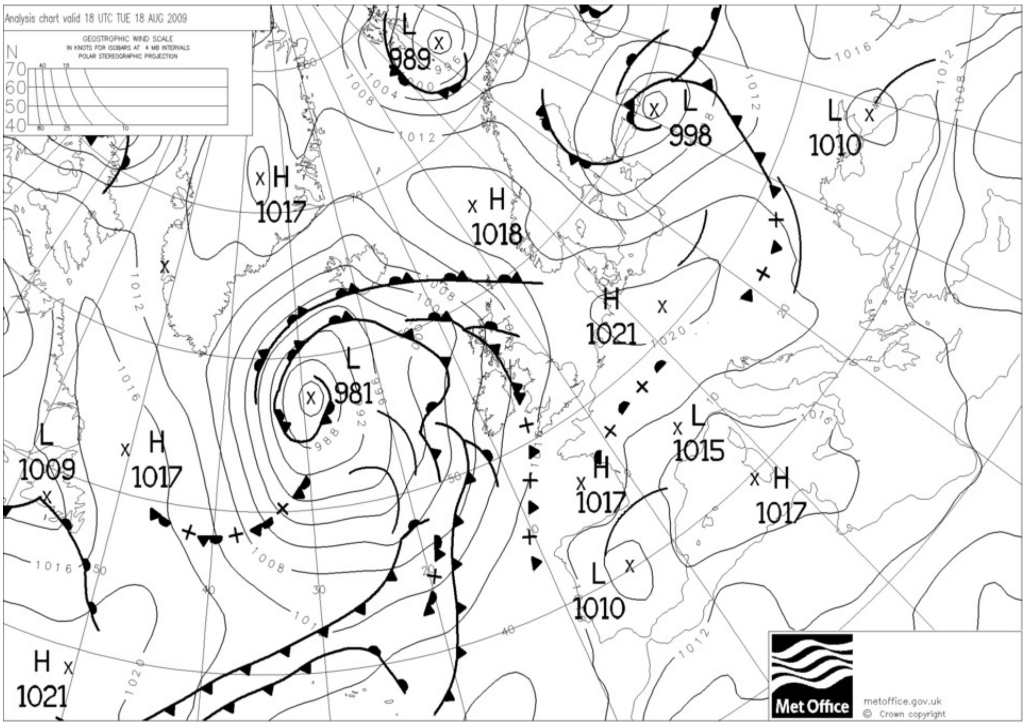
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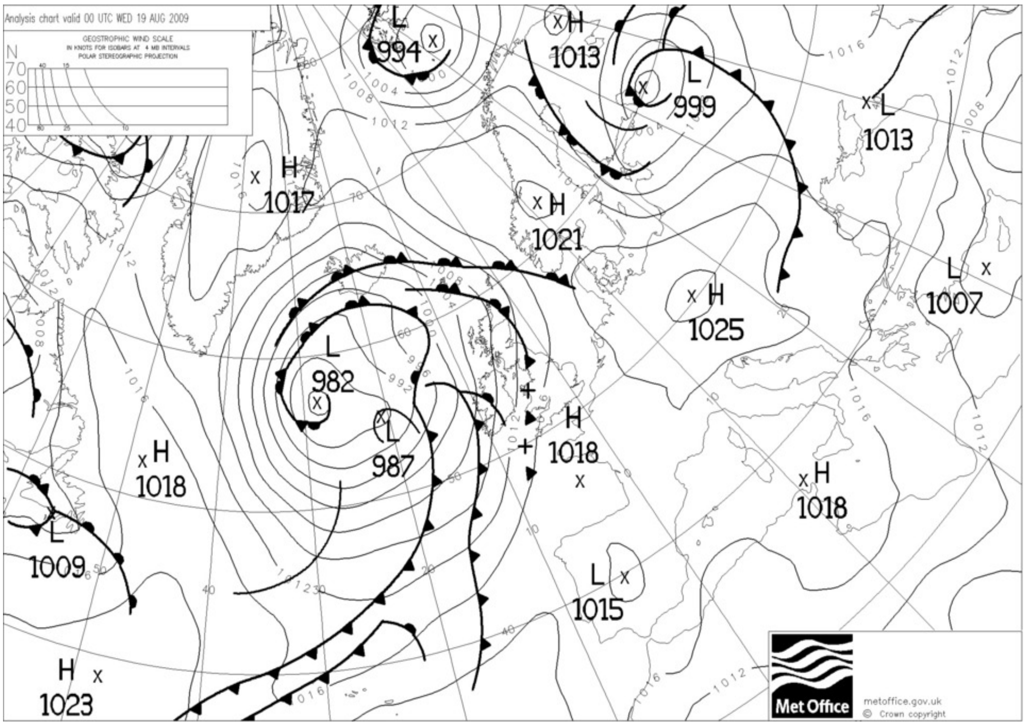
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GEOSTROPHIC WIND SCALE
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L 999
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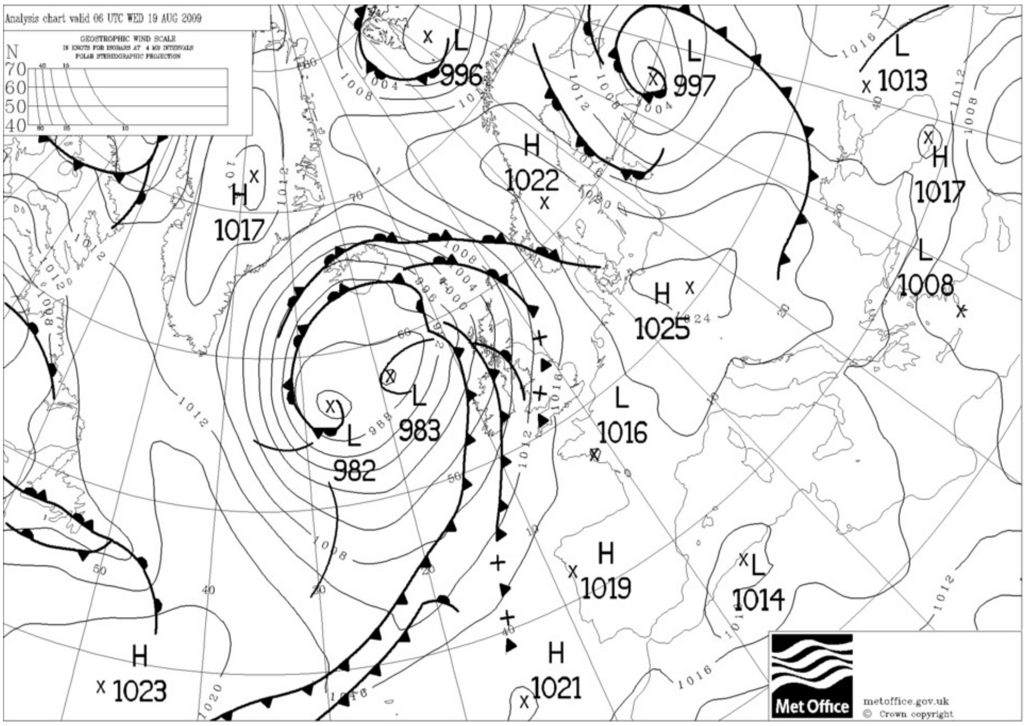
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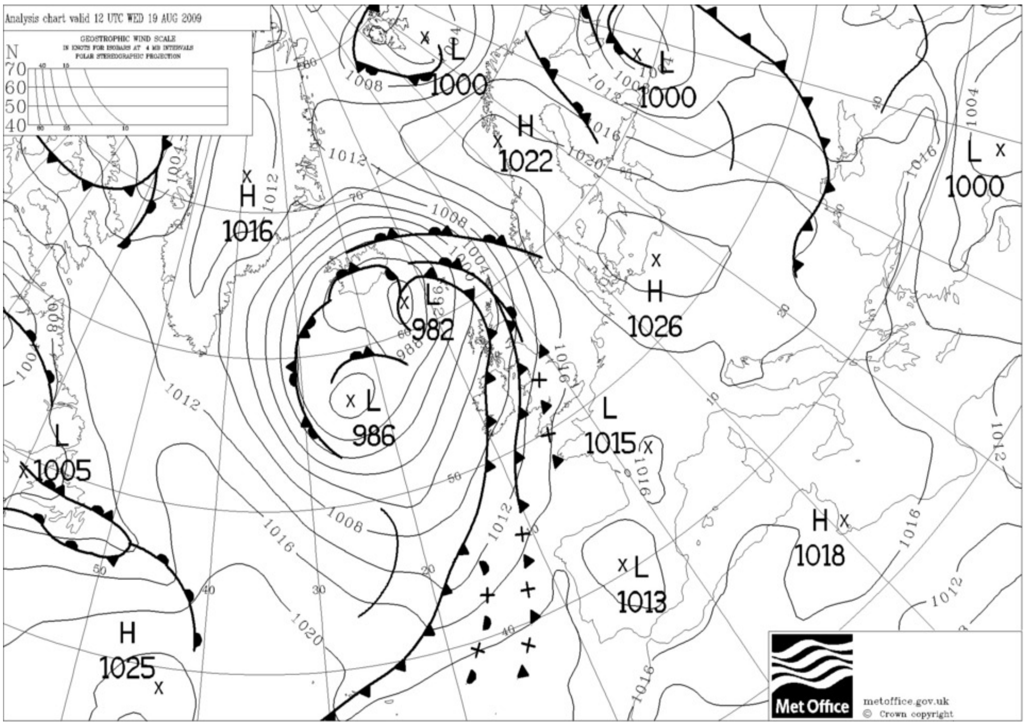
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H 1026
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L 1015
L 1005
H 1018
L 1013
H 1025
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6.2 Entire observation period

The experiment period starts on August 12 and ends on August 20, 2009. During that time the data recording of the Bayelva permafrost station BPS was interrupted for maintenance on August 13 (11:30 to 19:30 CET) to replace the radiation sensors (new installation of a NR01 (Hukseflux) 4-component radiation instrument). Additionally, the logger software was changed to increase the sampling interval form 60 minute averaged values to 30 minute averaged values.

Air Temperature

During the ARCTEX-2009 campaign the air temperature measured in 2 m above ground level at the Bayelva permafrost station BPS ranged from +7.7 °C (Aug. 14) to –0.2 °C (Aug. 16), as shown in Figure 6.1. After the interruption on August 13 the sampling interval changed from hourly to half hour values.

The half hourly averaged temperature obtained from the nearby Bayelva meteorological tower BMT shows a comparable variation but clearly influenced by a radiation effect (both sensors in 2 m and 10 m were not ventilated and without radiation protection. A failure of the 10 m sensor from the BMT on August 16 at 1:30 AM (CET) resulted in data loss for the rest of the measurement campaign. For both reasons (radiation error and data loss) the total temperature measurement of the Bayelva meteorological tower BMT were not used for any analysis.

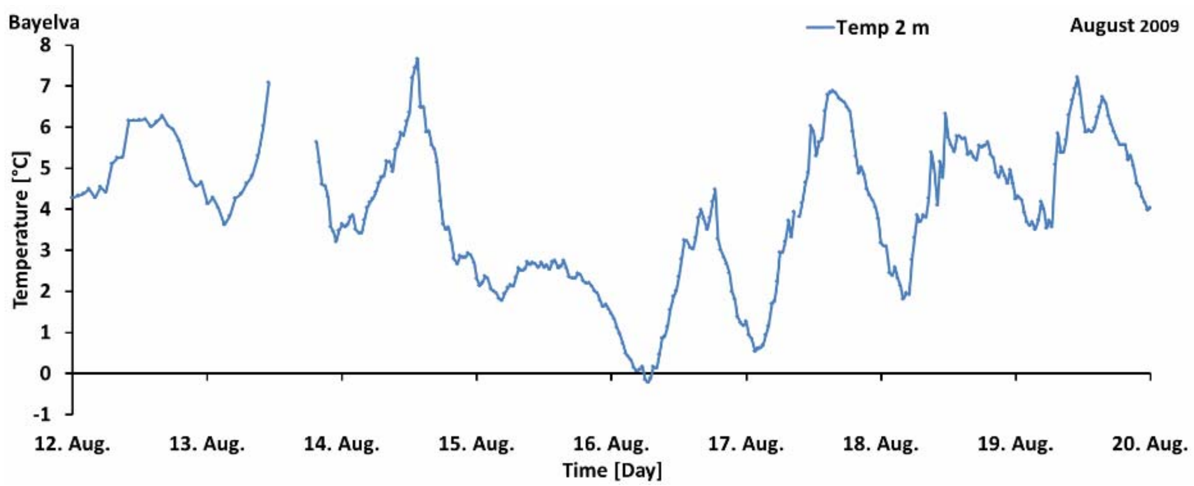


Figure 6.1: Air temperature between August 12 and August 20, 2009. Blue line: air temperature in °C at 2 m a. g. l. (Bayelva permafrost station BPS, Alfred Wegener Institute for Polar and Marine Research). Bayelva (Svalbard), ARCTEX-2009 campaign.

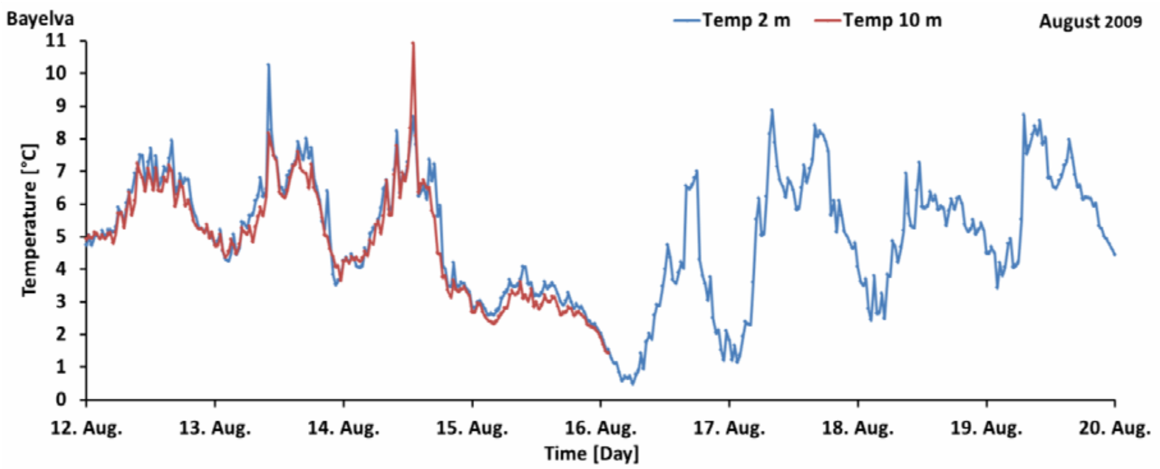


Figure 6.2 Air temperature between August 12 and August 20, 2009. Blue line: air temperature in °C at 2 m a. g. l., red line: air temperature in °C at 10 m a. g. l. (both Bayelva meteorological tower BMT, Alfred Wegener Institute for Polar and Marine Research). Bayelva (Svalbard), ARCTEX-2009 campaign.

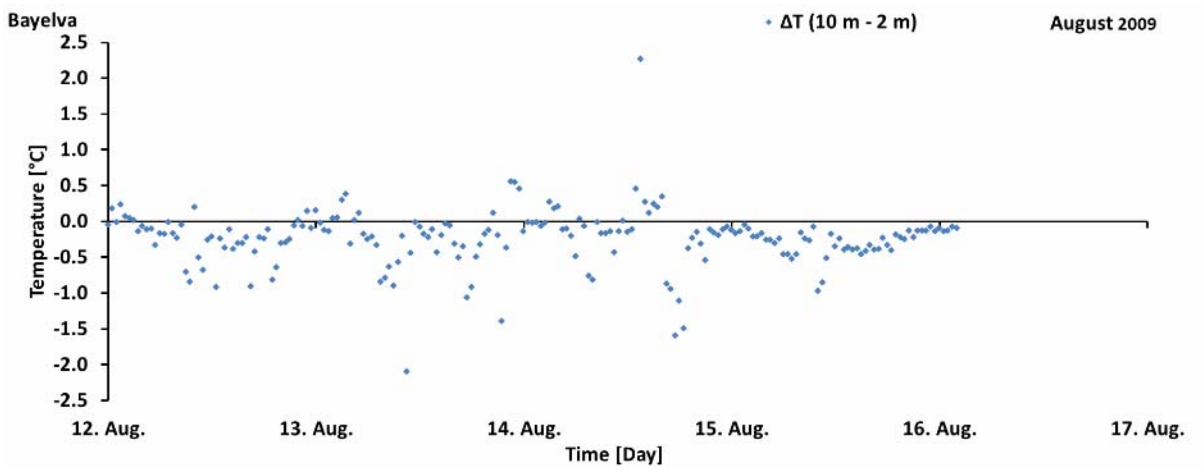


Figure 6.3: Vertical difference of air temperature between August 12 and August 20, 2009. Blue dots: ΔT difference of air temperature in K between 10 m and 2 m a. g. l (Bayelva meteorological tower BMT, Alfred Wegener Institute for Polar and Marine Research). Bayelva (Svalbard), ARCTEX-2009 campaign.

Humidity

The observed relative air humidity (Figure 6.4) did not show much variation between August 12 and August 20. During Aug. 17 the level drops slightly from 90 to 80% to 70 to 60% caused by offshore advection of dry air mass from the east (inland).

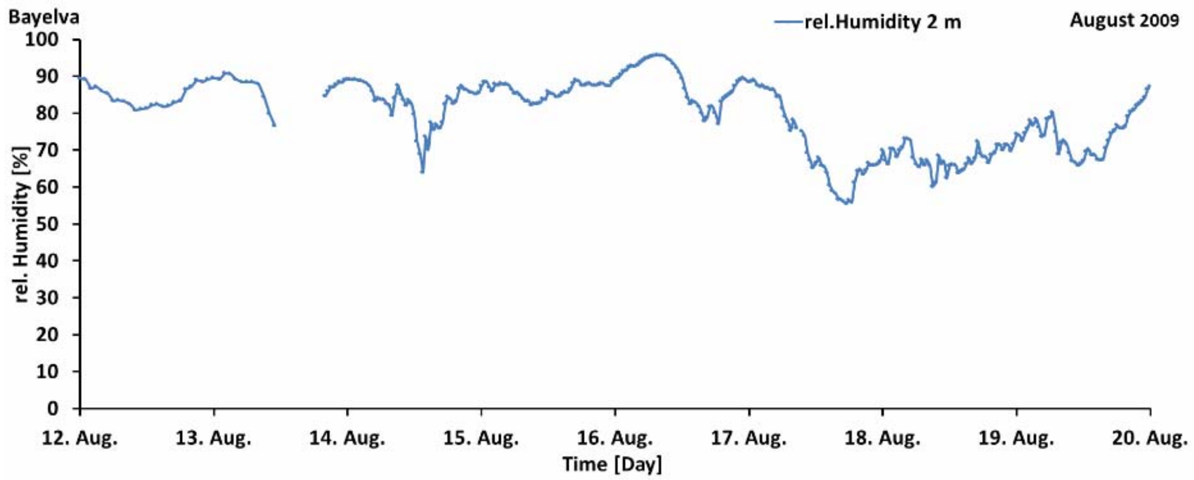


Figure 6.4: Humidity between August 12 and August 20, 2009. Blue line: relative humidity in % at 2 m a. g. l. (Bayelva permafrost station BPS, Alfred Wegener Institute for Polar and Marine Research). Bayelva (Svalbard), ARCTEX-2009 campaign.

Wind speed and wind direction

The horizontal wind speed at different heights above ground level (2 m and 10 m) was obtained by the routine observation of the meteorological tower (MT) at Ny-Ålesund of the Alfred Wegener Institute for Polar and Marine Research (Figure 6.5). A second wind speed and wind direction measurement at 2 m a. g. l. was retrieved from the Bayelva permafrost station of the AWI (BPS) in the Bayelva catchment itself (Fig. 6.6).

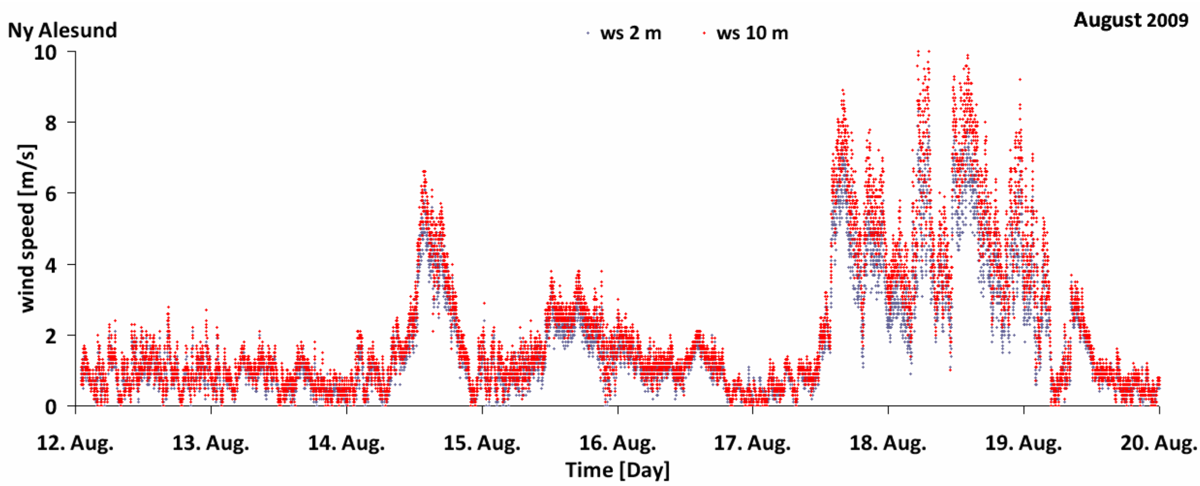


Figure 6.5: Wind speed between August 12 and August 20, 2009. Blue dots: wind speed in m s^{-1} at 2 m a. g. l., red dots: wind speed in m s^{-1} at 10 m a. g. l. (both meteorological tower MT, Alfred Wegener Institute for Polar and Marine Research). Ny-Ålesund (Svalbard), ARCTEX-2009 campaign.

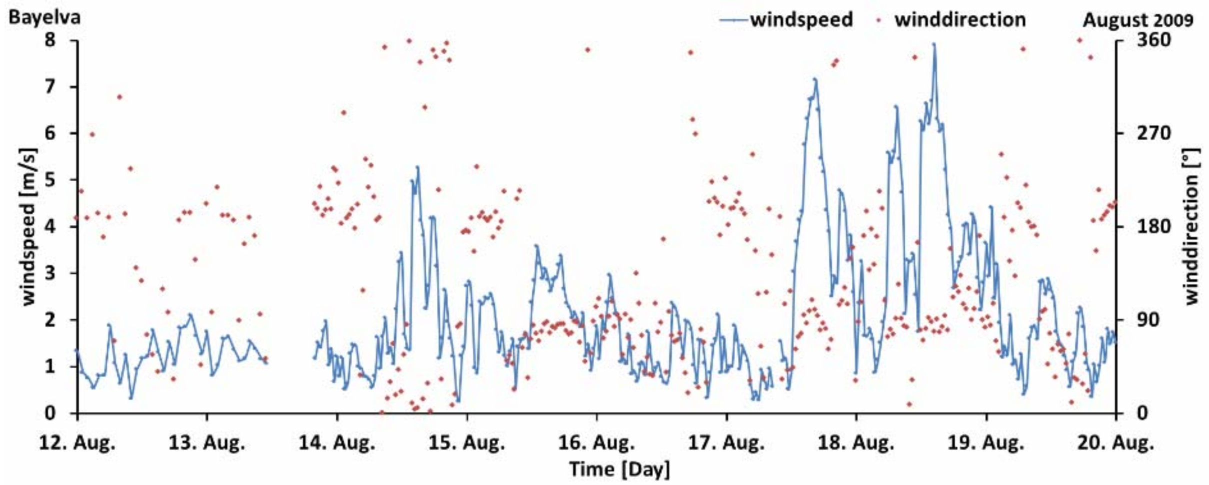
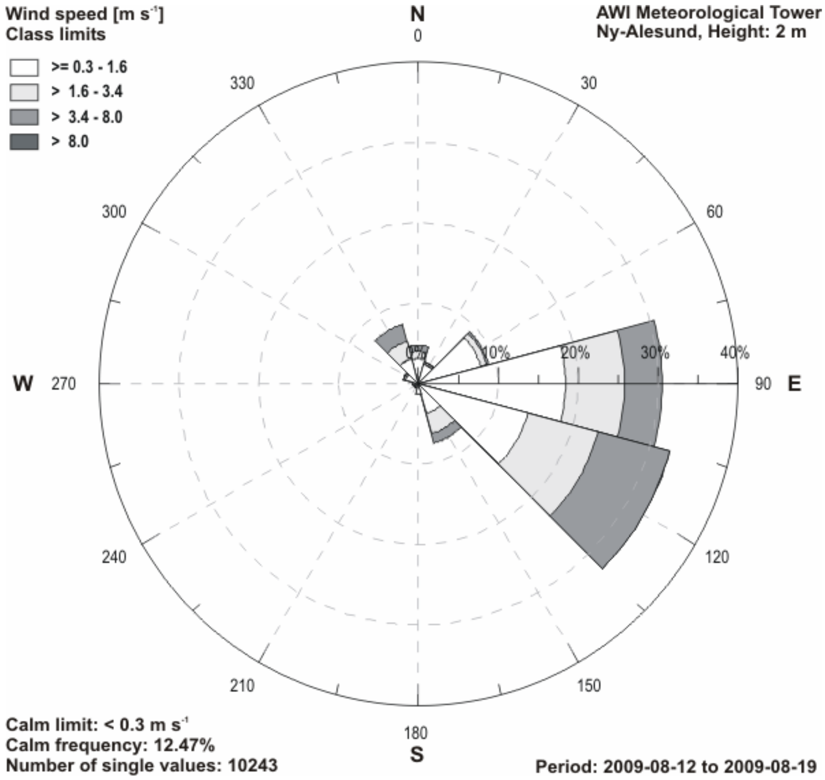


Figure 6.6: Wind speed and wind direction between August 12 and August 20, 2009. Blue line: wind speed in m s^{-1} at 2 m a. g. l., red dots: wind direction in degree at 2 m a. g. l. (both Bayelva permafrost station BPS, Alfred Wegener Institute for Polar and Marine Research). Bayelva (Svalbard), ARCTEX-2009 campaign.

The wind direction (at 2 m and 10 m a. g. l.) was obtained by the meteorological routine observation of the 10 m tall meteorological tower (MT) at Ny-Ålesund and directly at Bayelva by the eddy-flux complex EF (at 2.90 m a. g. l.) of the Alfred Wegener Institute for Polar and Marine Research. The used wind sensor from the MT is a combined cup-anemometer and wind vane (Thies Clima, Germany), the EF-Station used the Ultrasonic CSAT3 anemometer. The Figure 6.7 shows the main wind direction sectors at Ny-Ålesund and at the Bayelva catchment during the ARCTEX-2009 campaign.

This pattern of either south-easterly or easterly directions (more or less canalized air flow up and down the Kongsfjord and the glaciers) is typical most of the time during the year. The eddy-flux complex in the Bayelva catchment measured a southern to south-eastern component which could be an air flow from the glacier located in the south of the measurement site.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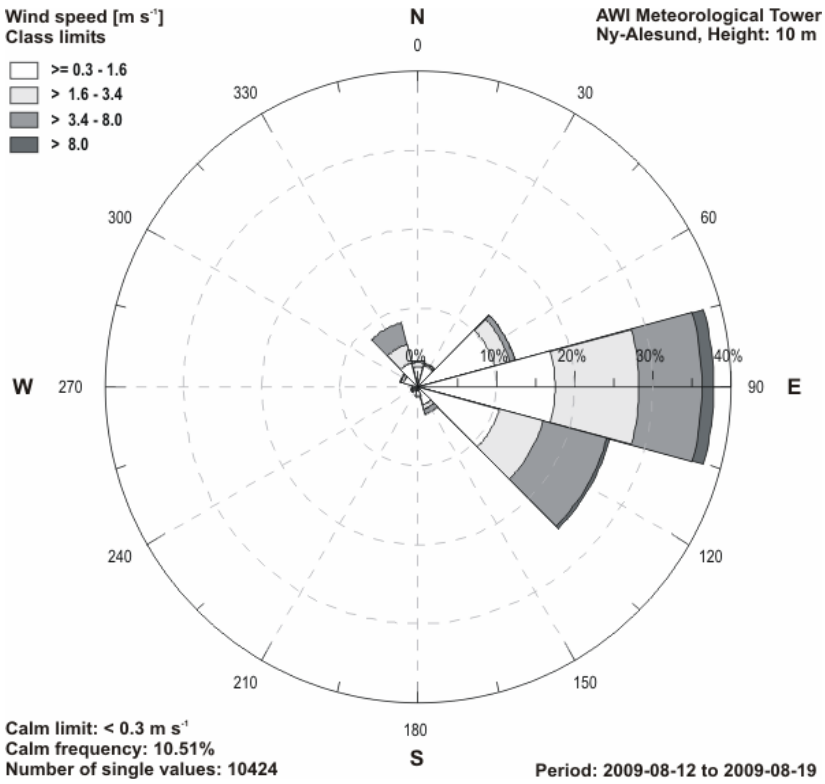
Class limits
>= 0.3 - 1.6
> 1.6 - 3.4
> 3.4 - 8.0
> 8.0
N
0
AWI Meteorological Tower
Ny-Alesund, Height: 2 m
330
30
300
60
W 270
90 E
0%
10%
20%
30%
40%
240
120
210
150
180
S
Calm limit: < 0.3 m s⁻¹
Calm frequency: 12.47%
Number of single values: 10243
Period: 2009-08-12 to 2009-08-19


Wind speed [m s⁻¹]
Class limits
>= 0.3 - 1.6
> 1.6 - 3.4
> 3.4 - 8.0
> 8.0
N
0
AWI Meteorological Tower
Ny-Alesund, Height: 10 m
330
30
300
60
W 270
90 E
0%
10%
20%
30%
40%
240
120
210
150
180
S
Calm limit: < 0.3 m s⁻¹
Calm frequency: 10.51%
Number of single values: 10424
Period: 2009-08-12 to 2009-08-19

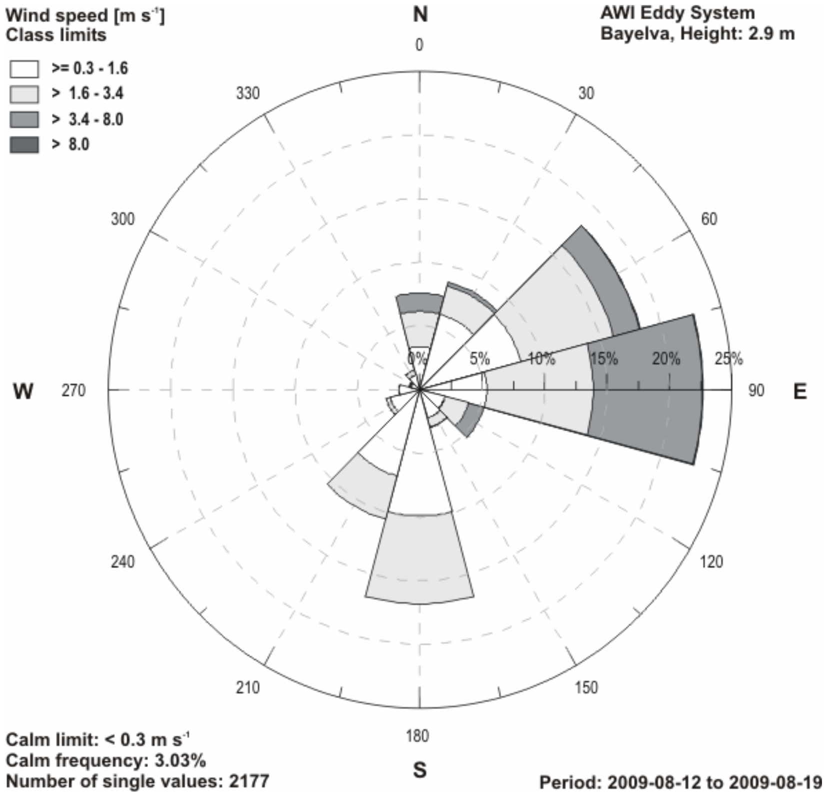


Figure 6.7: Frequency distribution of wind direction separated in 12 wind sectors and classified in 4 wind speed classes, August 12 to August 19, 2009. Top: distribution of the wind directions in degree measured at 2 m height a. g. l. Middle: distribution of the wind direction in degree measured at 10 m a. g. l. (both AWI meteorological tower (MT)). Bottom: distribution of the wind directions in degree measured at 2.90 m height a. g. l. (Bayelva eddy-flux complex AWI (EF)). Ny-Ålesund and Bayelva (Svalbard), ARCTEX-2009 campaign.

Radiation

The main radiation measurements (1 min sampling) took place at the routine BSRN station of the AWI in Ny-Ålesund (Figure 6.8). An additional measurement (30 min sampling) took place at the Bayelva permafrost station BPS of the AWI (Figures 6.9 to 6.12), 3 km west of Ny-Ålesund, close to the Eddy-flux complex EF and the both University of Bayreuth Scintillometer pathways.

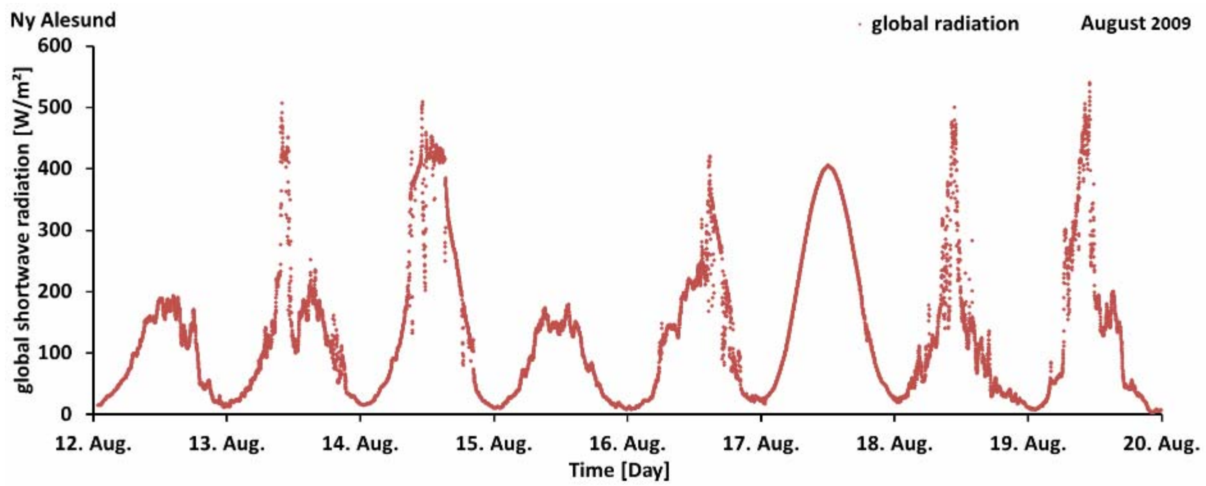


Figure 6.8: Shortwave radiation between August 12 and August 20, 2009. Red dots: global radiation in W m^{-2} measured with a CM11 (Kipp & Zonen) pyranometer (BSRN station, Alfred Wegener Institute for Polar and Marine Research). Ny-Ålesund (Svalbard), ARCTEX-2009 campaign.

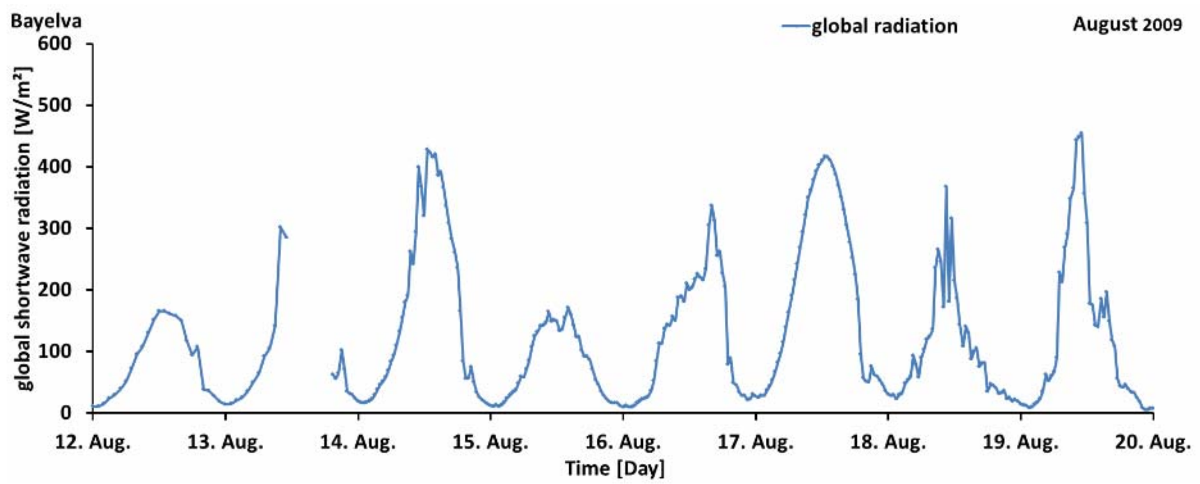


Figure 6.9: Shortwave radiation between August 12 and August 20, 2009. Blue line: global radiation in W m^{-2} measured with a NR01 (Hukseflux) (Bayelva permafrost station BPS, Alfred Wegener Institute for Polar and Marine Research). Bayelva (Svalbard), ARCTEX-2009 campaign.

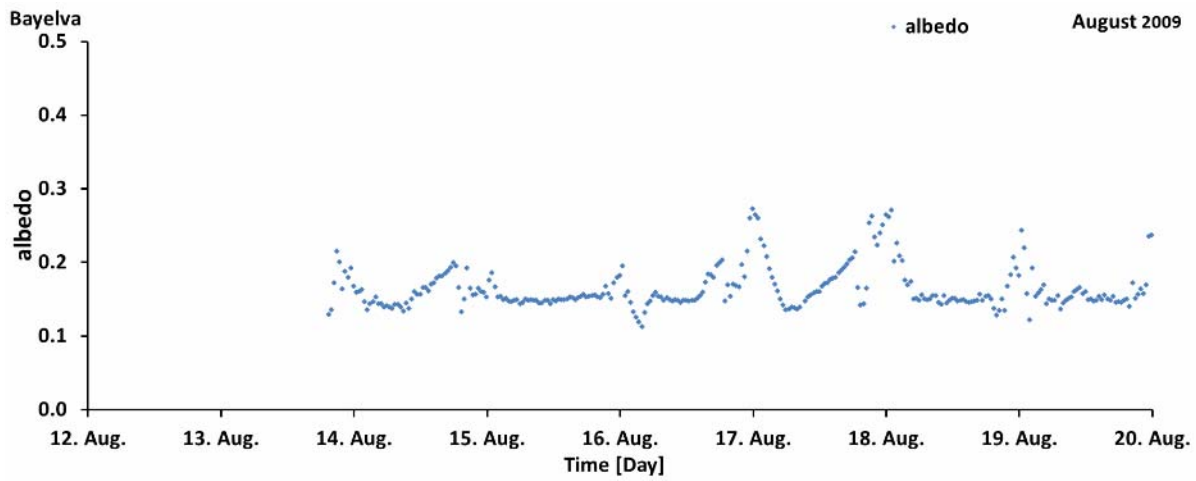


Figure 6.10: Ratio of reflected to global shortwave radiation (albedo) measured with a NR01 (Hukseflux) (Bayelva permafrost station BPS, Alfred Wegener Institute for Polar and Marine Research), August 12 to August 20, 2009. The Blue dots are showing the variance of the Albedo due to different elevation angles of the sun and due to different fraction of the half space from witch diffuse sky radiation or the - from the surface - reflected radiation can reach the sensors. Bayelva (Svalbard), ARCTEX-2009 campaign.

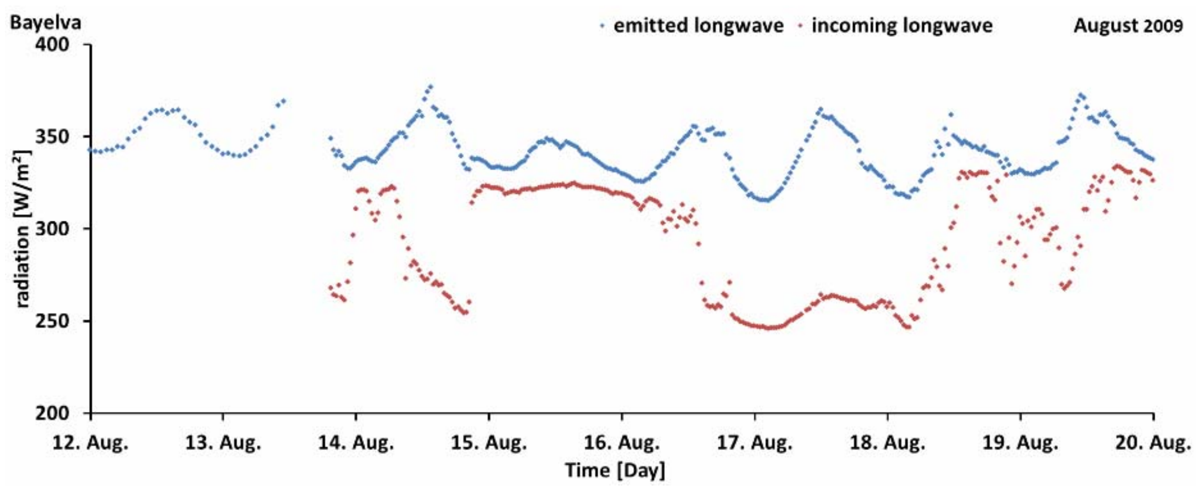


Figure 6.11: Longwave radiation measured with a NR01 (Hukseflux) (Bayelva permafrost station BPS, Alfred Wegener Institute for Polar and Marine Research), August 12 to August 20, 2009. Red dots: incoming longwave radiation in W m^{-2}. Blue dots: emitted longwave radiation in W m^{-2}. Bayelva (Svalbard), ARCTEX-2009 campaign.

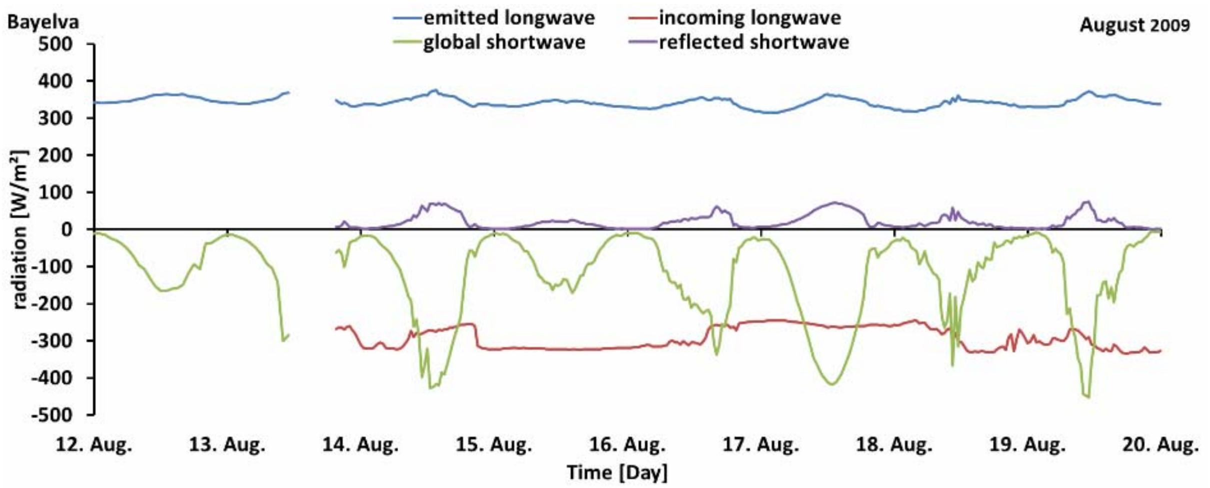


Figure 6.12: Surface radiation balance: radiation was measured with a NR01 (Hukseflux) (Bayelva permafrost station BPS, Alfred Wegener Institute for Polar and Marine Research), August 12 to August 20, 2009. Constituted by the micrometeorological convention, downward directed fluxes (global shortwave and incoming longwave radiation) are negative and upward directed fluxes (reflected shortwave and emitted longwave radiation) are positive. Bayelva (Svalbard), ARCTEX-2009 campaign.

Cloud Base height in meter

For cloud base height measurements a laser (LIDAR) based ceilograph LD-40 is used since 1998 with a ceiling range between 23 m and 12 650 m height and with a measuring deviation of ±23 m (at solid objects). The ceilometer is part of the BSRN measuring field at Ny-Ålesund operated by the Alfred Wegener Institute.

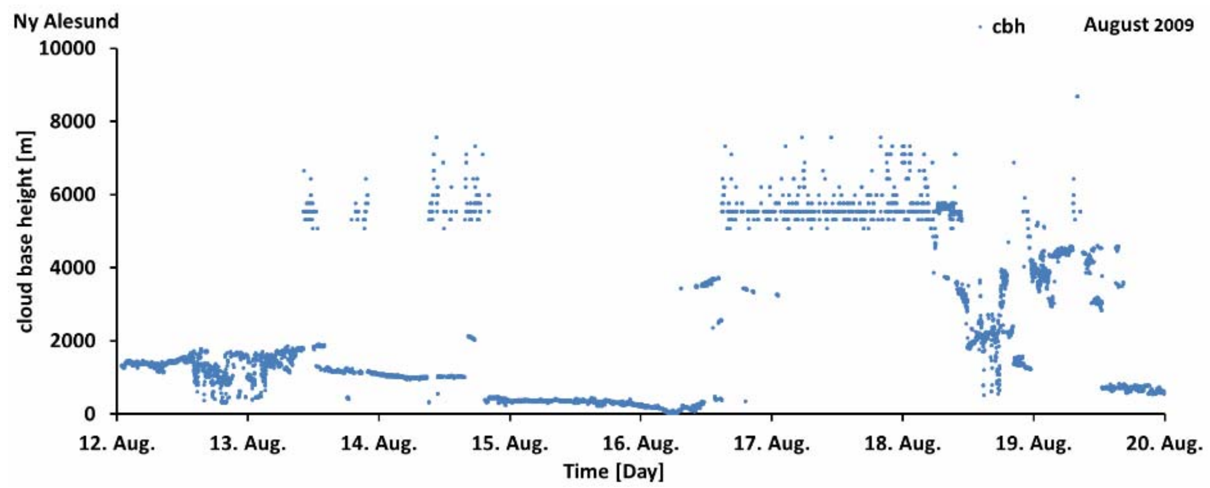


Figure 6.13: Cloud base height (cbh) in meter above ground between August 12 and August 20, 2009. Laser (LIDAR) based ceilograph measurements of the BSRN (Baseline Surface Radiation Network) station Ny-Ålesund operated by the Alfred Wegener Institute. Ny-Ålesund (Svalbard), ARCTEX-2009 campaign.

Accumulated precipitation in mm

For precipitation measurements a tipping bucket rain gauge 52203 (RM Young) is used and is installed in the Bayelva catchment since 1998. Figure 6.14 shows no measurable precipitation in the time from August 12 to August 20 when the ACRTEX-2009 campaign took place. Nevertheless we noticed some drizzle on August 13 and August 18.

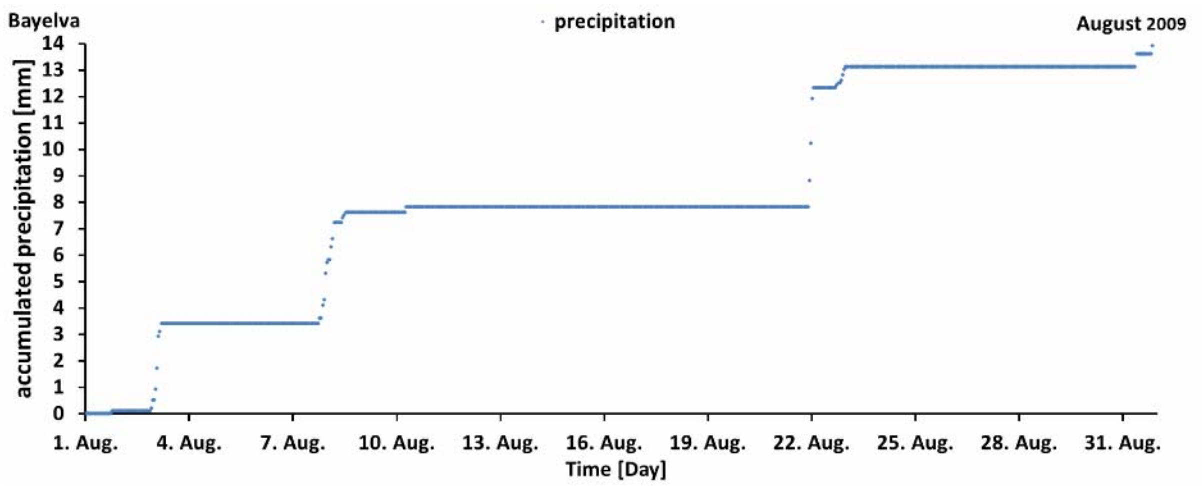
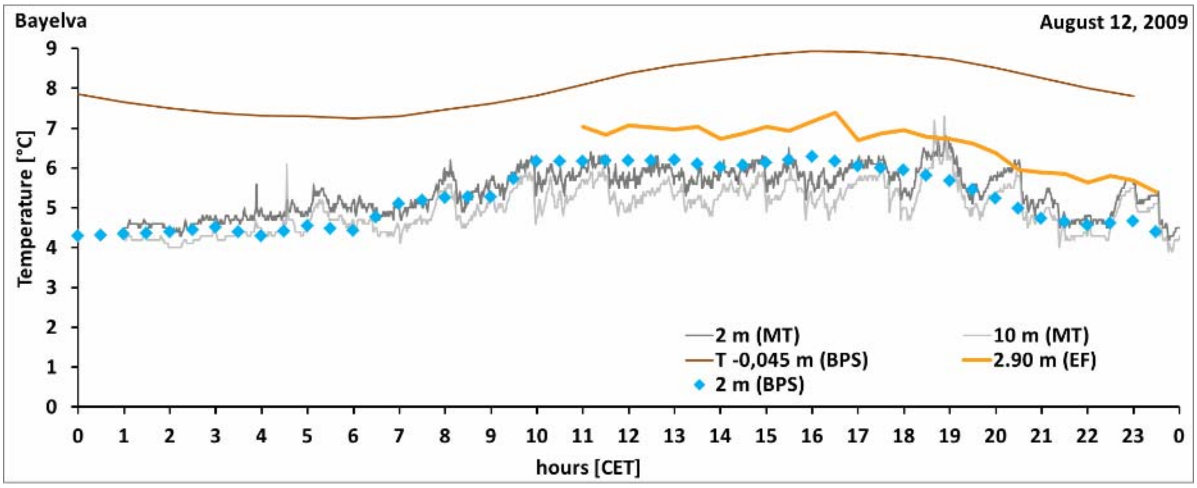


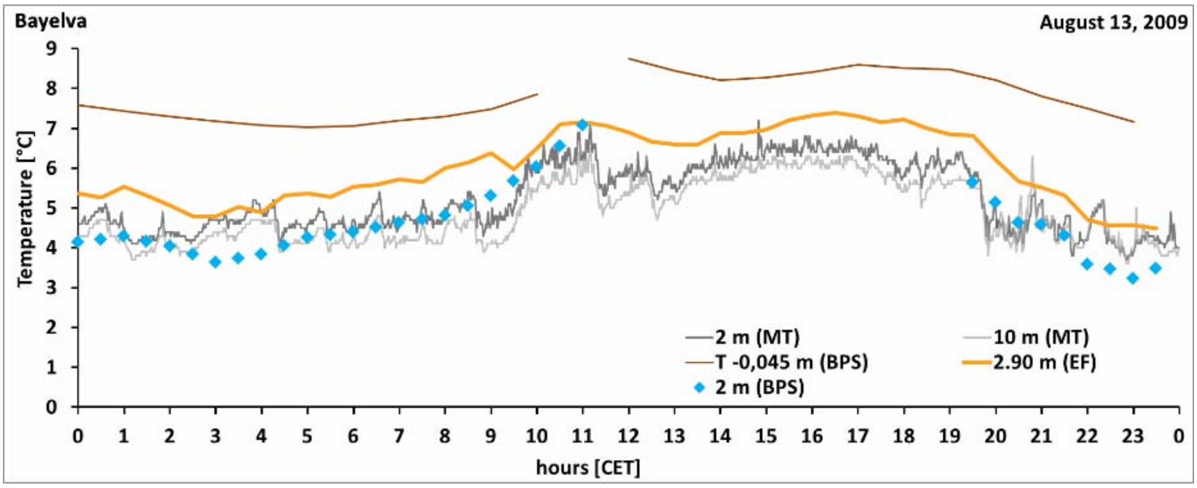
Figure 6.14: Accumulated precipitation from August 1 to August 31, 2009. The measurement based on 60 minute summed up measurements of the BPS (Bayelva permafrost station BPS, Alfred Wegener Institute for Polar and Marine Research). Bayelva (Svalbard), ARCTEX-2009 campaign.

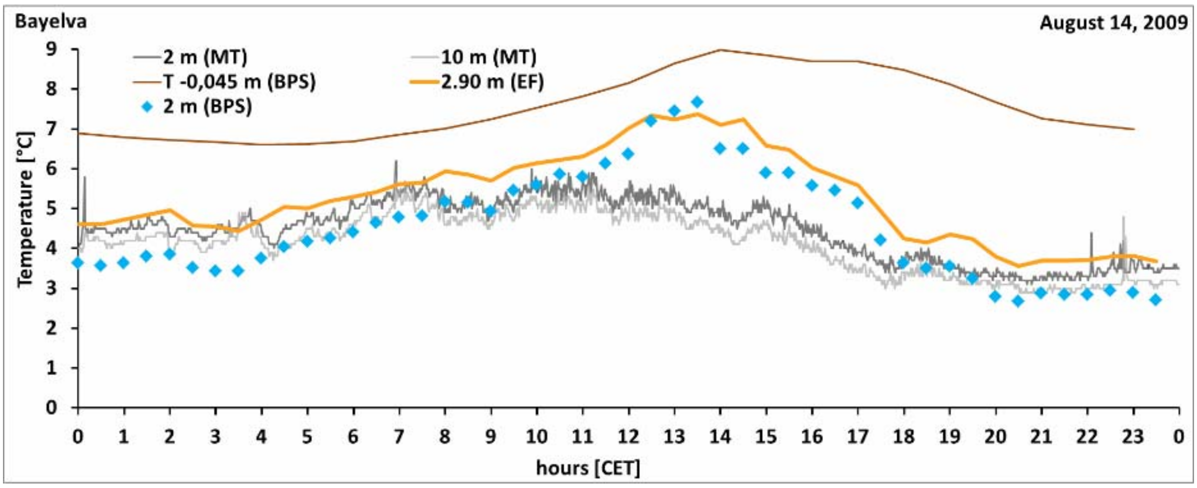
6.3 Daily charts

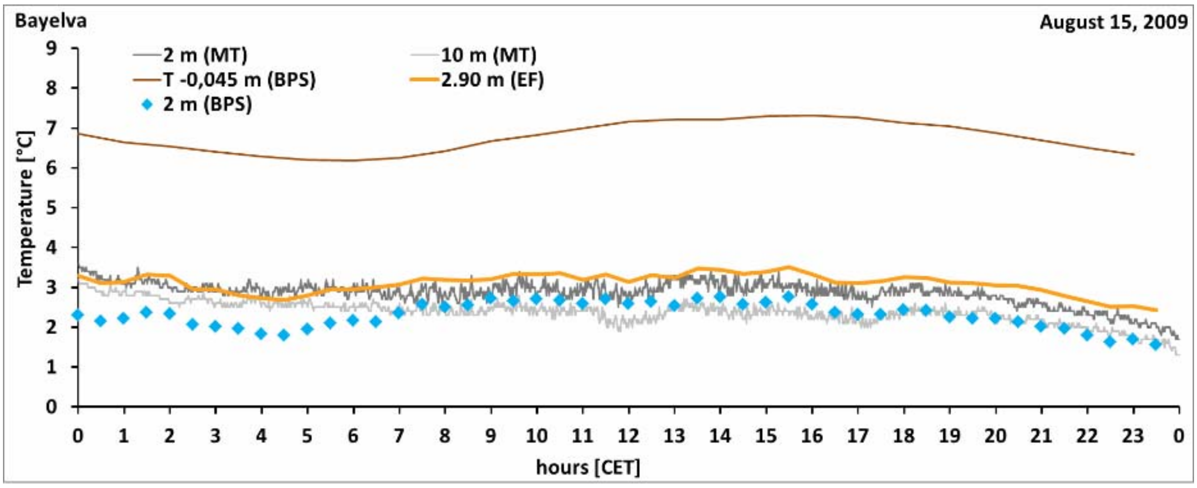
Air temperature

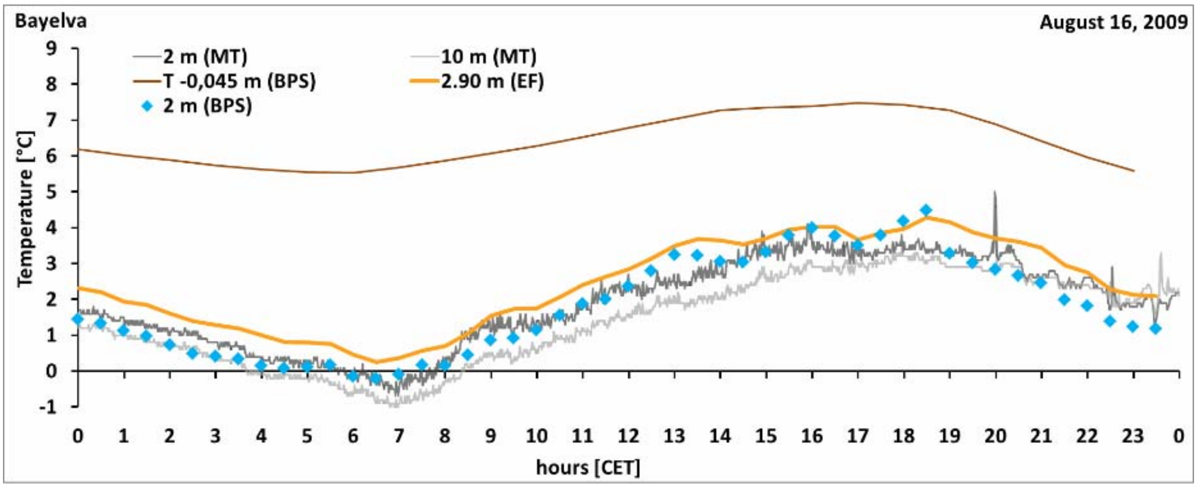
During the ARCTEX-2009 campaign air temperature was recorded by different instruments in the Bayelva catchment and different heights above ground using ventilated and radiation-shielded thermometers (BPS and MT), a CSAT3 from the eddy-flux complex (EF) to obtain the sonic temperature, as well as a soil temperature probe (4.5 cm depth) at the Bayelva Permafrost station (BPS). The heights are given in each figure. A sampling integral of 30 minutes was used at the Bayelva stations (BPS, EF) and of 1 minute at the Ny-Ålesund site (MT).

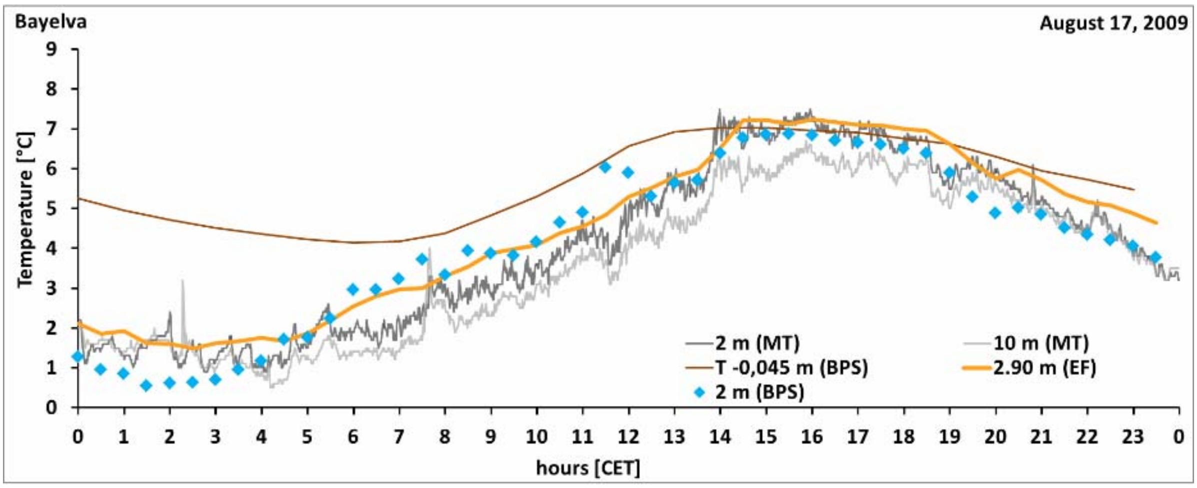


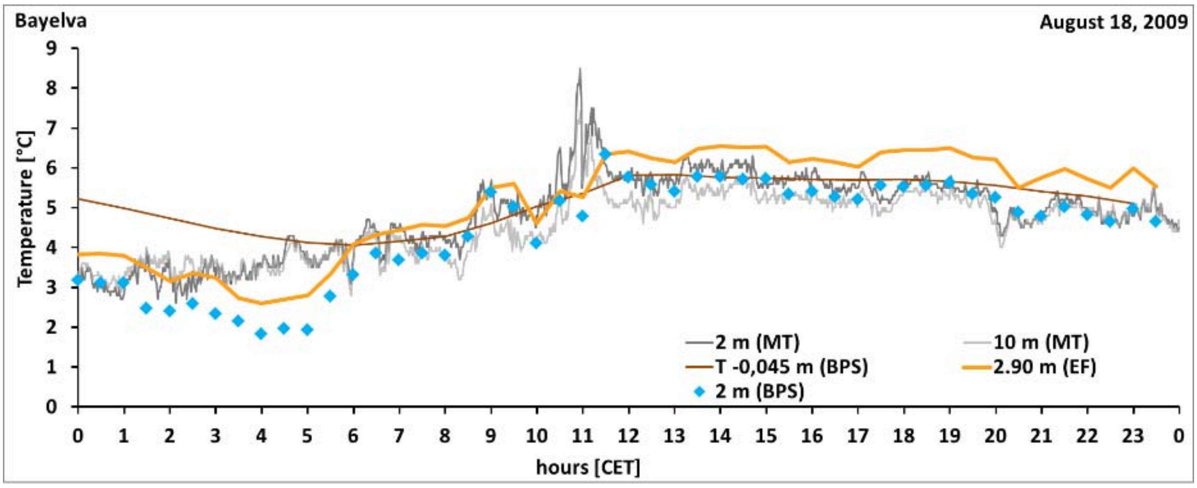


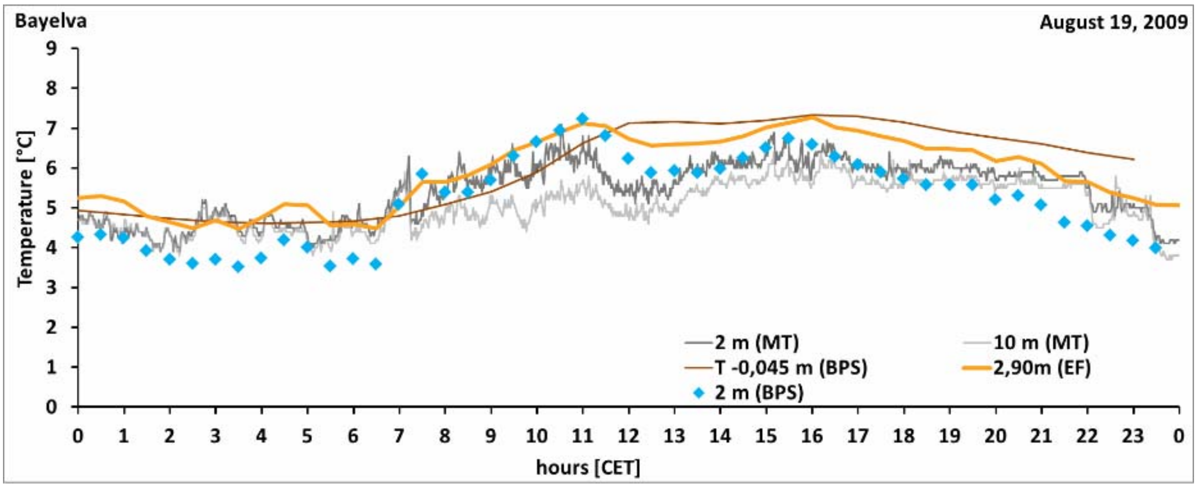

Bayelva
August 14, 2009
2 m (MT)
10 m (MT)
T -0,045 m (BPS)
2.90 m (EF)
2 m (BPS)
Temperature [°C]
hours [CET]


Bayelva
August 15, 2009
2 m (MT)
10 m (MT)
T -0,045 m (BPS)
2.90 m (EF)
2 m (BPS)
Temperature [°C]
hours [CET]


Bayelva
August 16, 2009
2 m (MT)
10 m (MT)
T -0,045 m (BPS)
2.90 m (EF)
2 m (BPS)
Temperature [°C]
hours [CET]

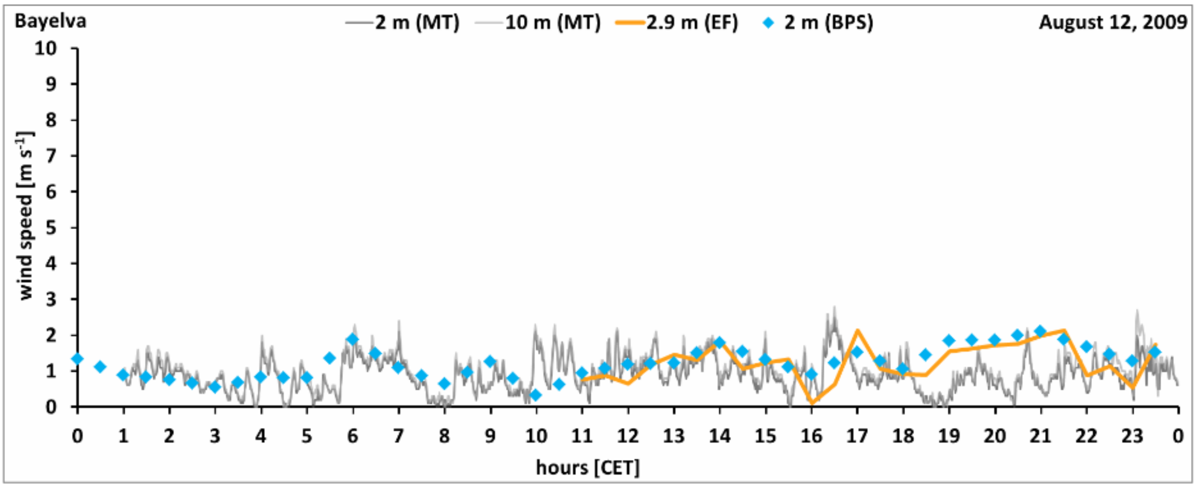

Bayelva
August 17, 2009
Temperature [°C]
hours [CET]
2 m (MT)
10 m (MT)
T -0,045 m (BPS)
2.90 m (EF)
2 m (BPS)

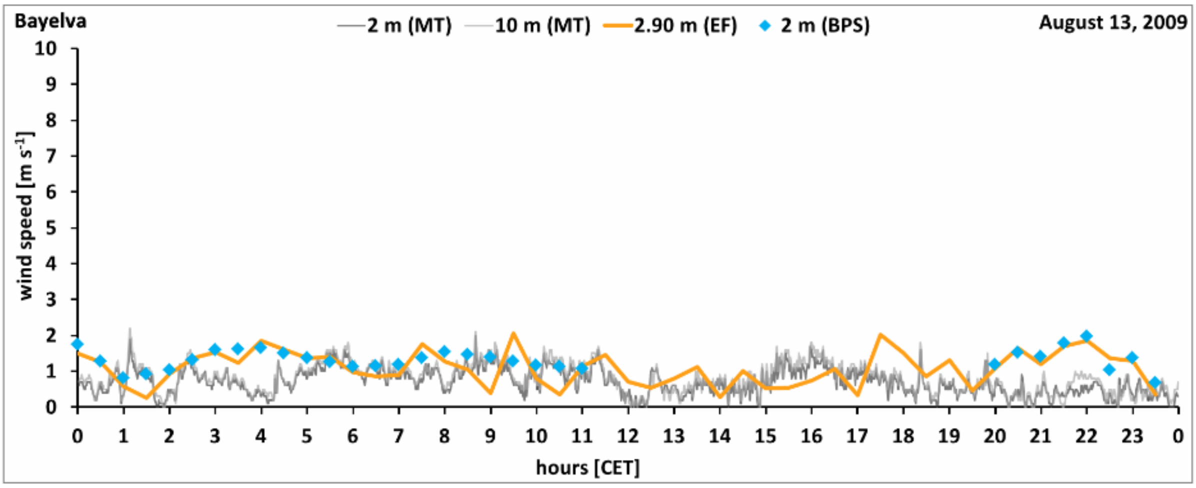

Bayelva
August 18, 2009
Temperature [°C]
hours [CET]
2 m (MT)
10 m (MT)
T -0,045 m (BPS)
2.90 m (EF)
2 m (BPS)

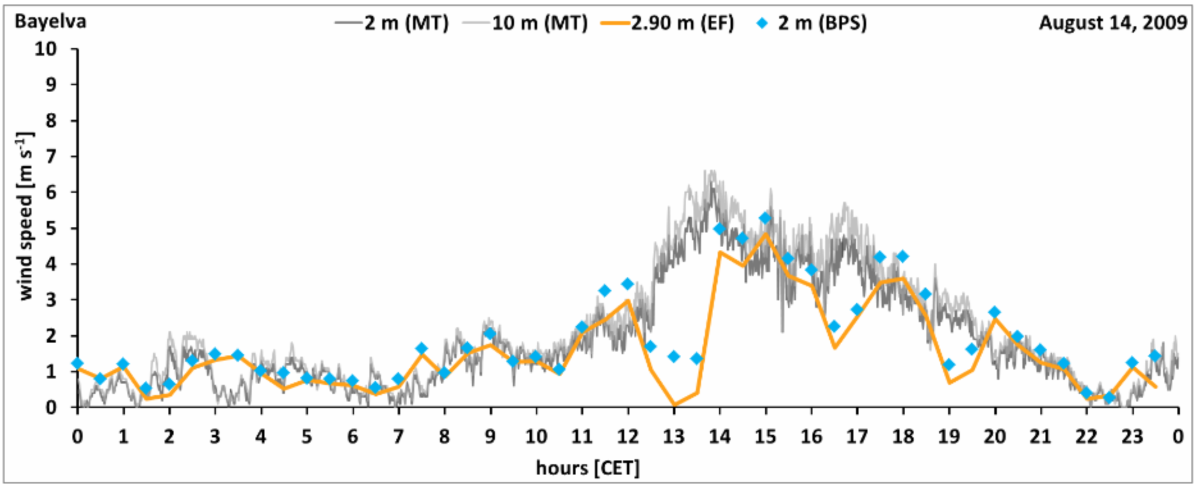

Bayelva
August 19, 2009
Temperature [°C]
hours [CET]
2 m (MT)
10 m (MT)
T -0,045 m (BPS)
2,90m (EF)
2 m (BPS)

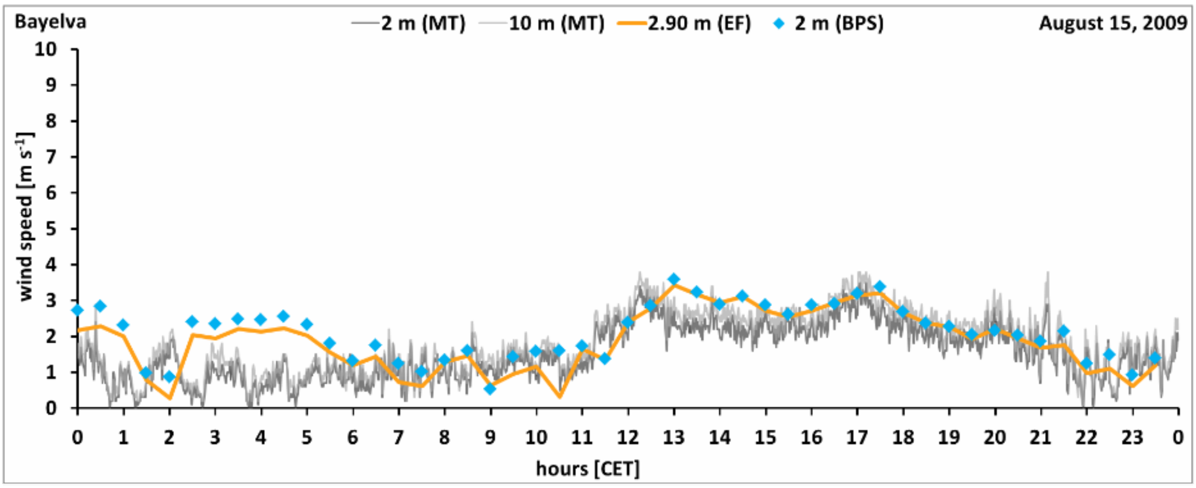
Wind speed

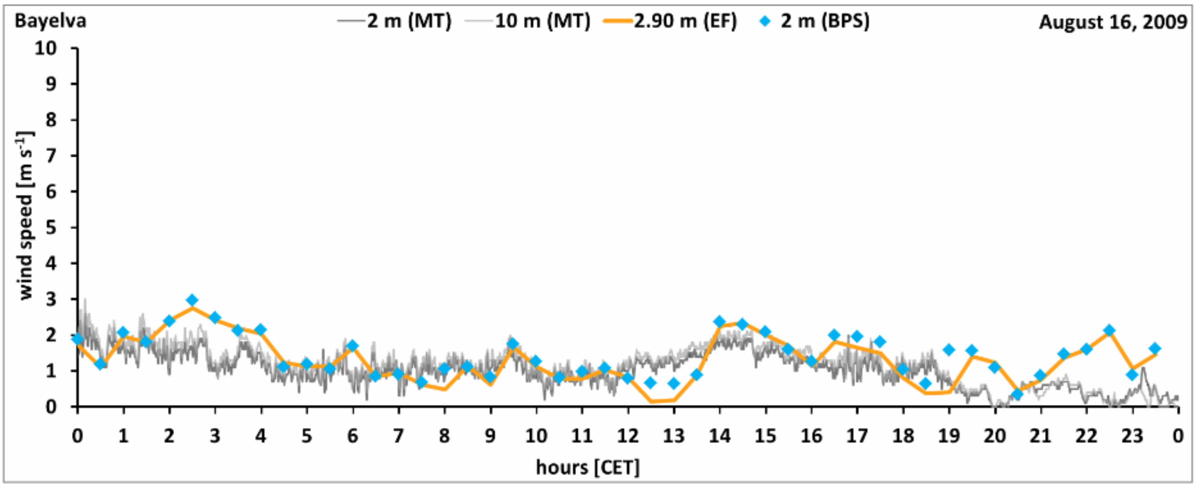
Wind speed was recorded in different heights above ground (given in each chart) using cup anemometers (MT), a CSAT3 (EF) and a vane (Flügelrad) Anemometer RM05103 (BPS). A sampling integral of 30 minutes was used at the Bayelva stations (BPS, EF) and of 1 minute at the Ny-Ålesund site (MT).

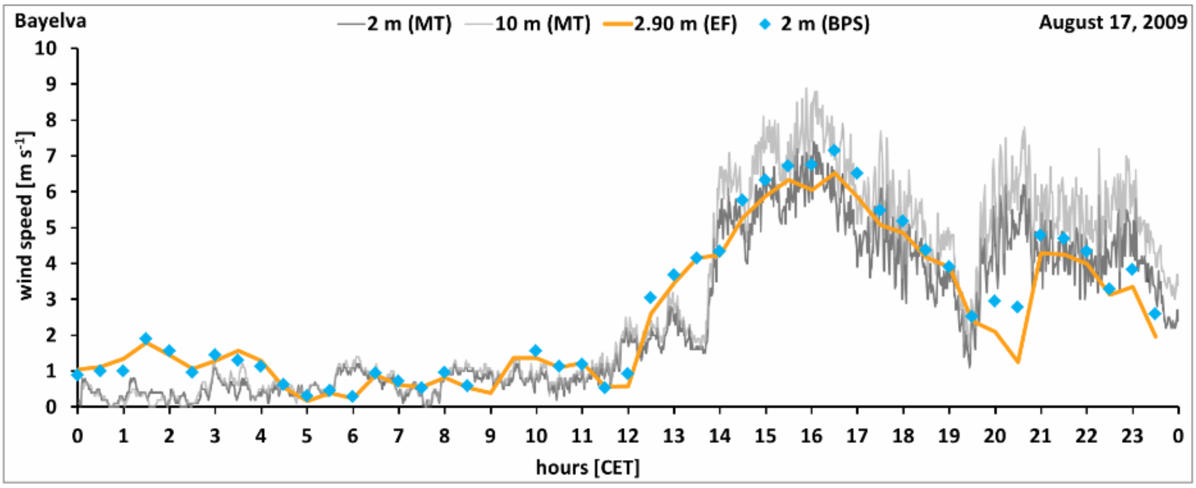


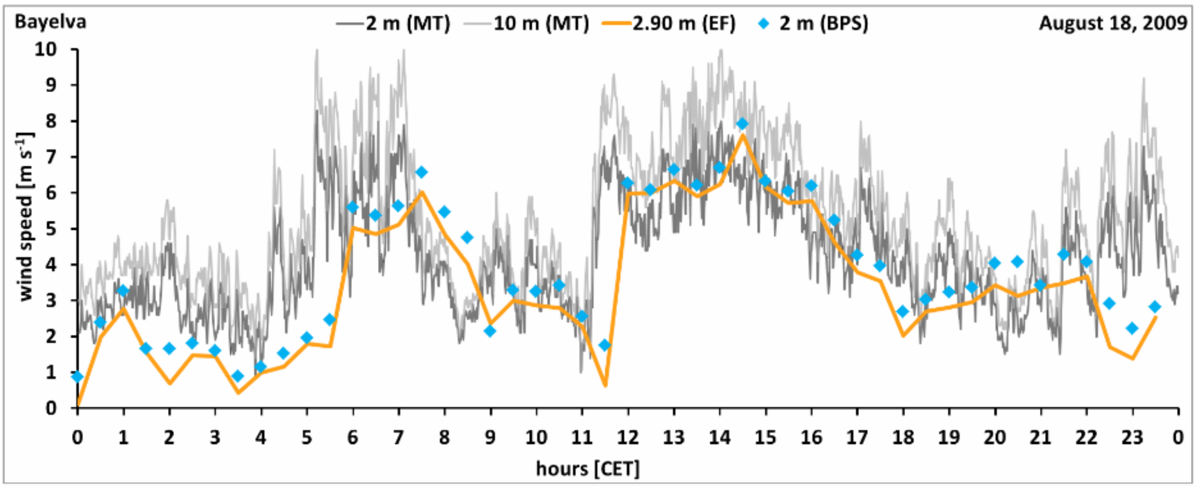


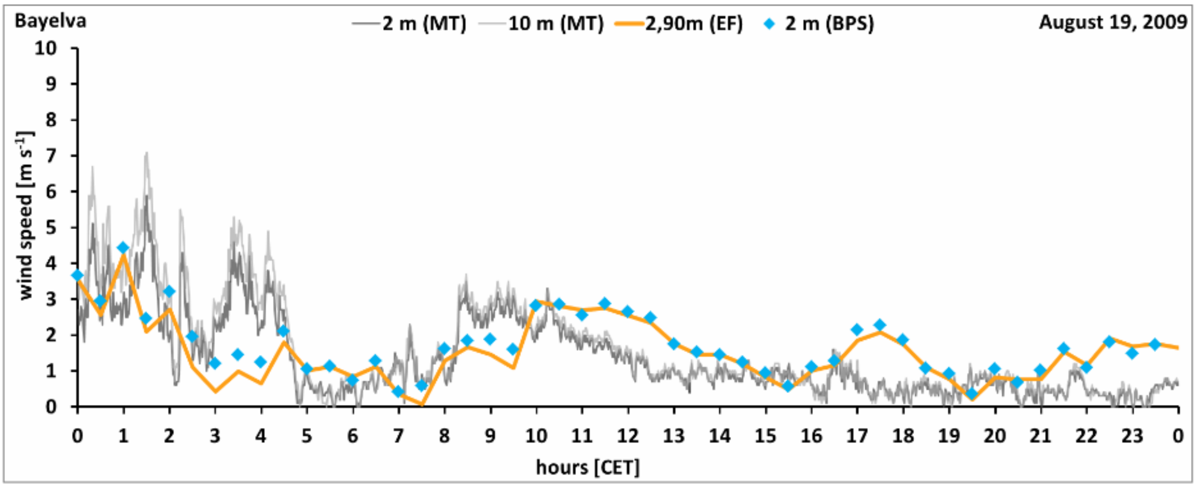



Bayelva
2 m (MT)
10 m (MT)
2.90 m (EF)
2 m (BPS)
August 15, 2009
wind speed [m s-1]
hours [CET]


Bayelva
2 m (MT)
10 m (MT)
2.90 m (EF)
2 m (BPS)
August 16, 2009
wind speed [m s-1]
hours [CET]


Bayelva
2 m (MT)
10 m (MT)
2.90 m (EF)
2 m (BPS)
August 17, 2009
wind speed [m s-1]
hours [CET]


Bayelva
2 m (MT)
10 m (MT)
2.90 m (EF)
2 m (BPS)
August 18, 2009
wind speed [m s-1]
hours [CET]

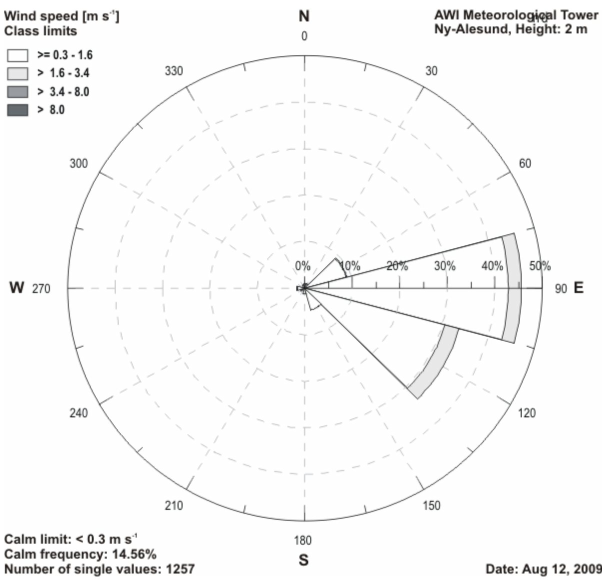

Bayelva
2 m (MT)
10 m (MT)
2,90m (EF)
2 m (BPS)
August 19, 2009
wind speed [m s-1]
hours [CET]

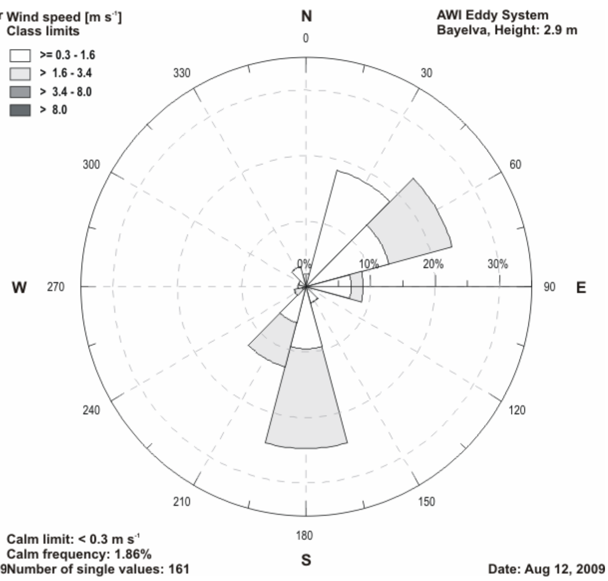
Wind direction

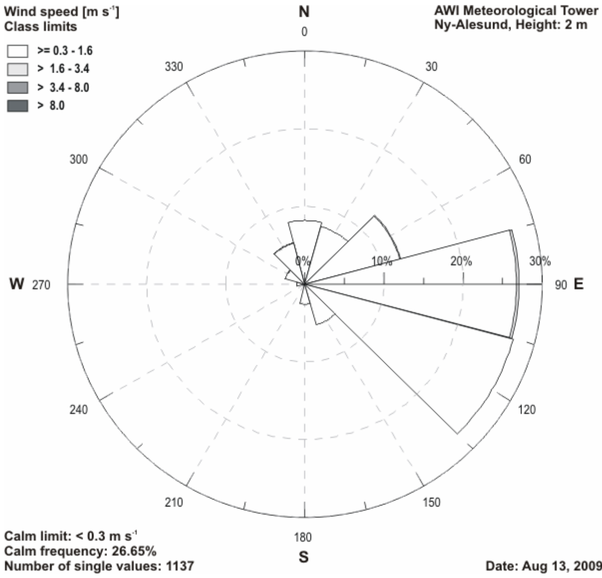
The wind direction was recorded with a wind vane at the meteorological tower of the Alfred Wegener Institute for Polar and Marine Research in Ny-Ålesund (MT) in 2 m above the ground and with a CSAT3 sonic anemometer of the eddy-flux complex of the Alfred Wegener Institute for Polar and Marine Research in the Bayelva catchment (EF) in 2.90 m above the ground. Calms have been defined as < 0.3 m s^{-1}. Between August 12 and August 19 the percentage of calms varies between 0 % and 26.6 % of all measurements per day (related to the 1 minute averaged values of the MT in Ny-Ålesund).

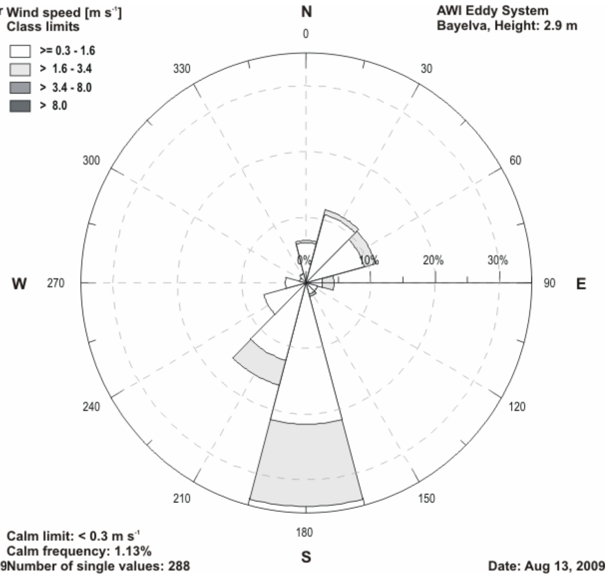
The wind rose plots are a combination of wind speed and related direction to succinctly show the daily distribution or frequency of particular directions separated in 12 sectors. The chosen wind speed class limits are >= 0.3 to 1.6, > 1.6 to 3.4, > 3.4 to 8.0 and > 8.0 m s^{-1}.

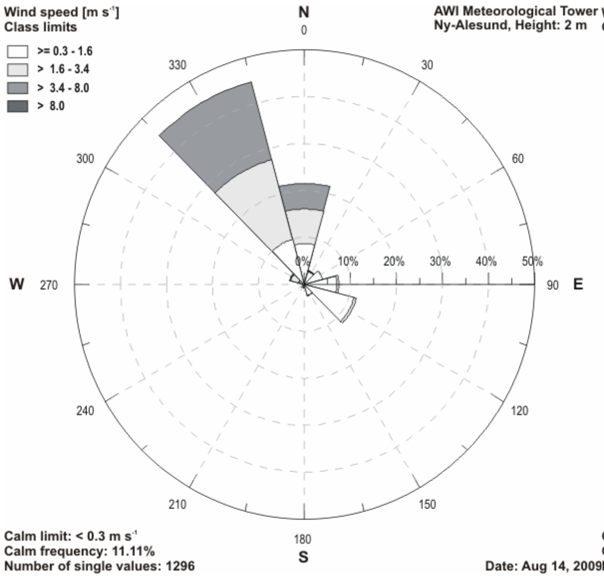
The left wind rose plots are from the AWI Meteorological tower from 2 m a. g. l. and the right plots are from the eddy-flux complex of the AWI from 2.90 m a. g. l. The direct distance between both sites MT and EF is around 3 km.

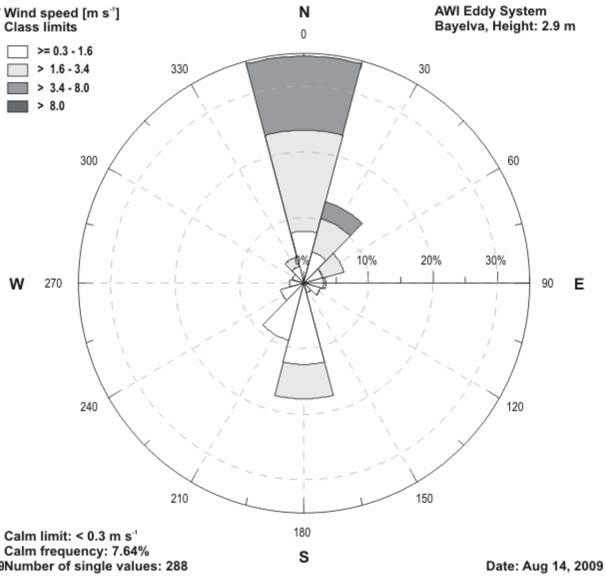


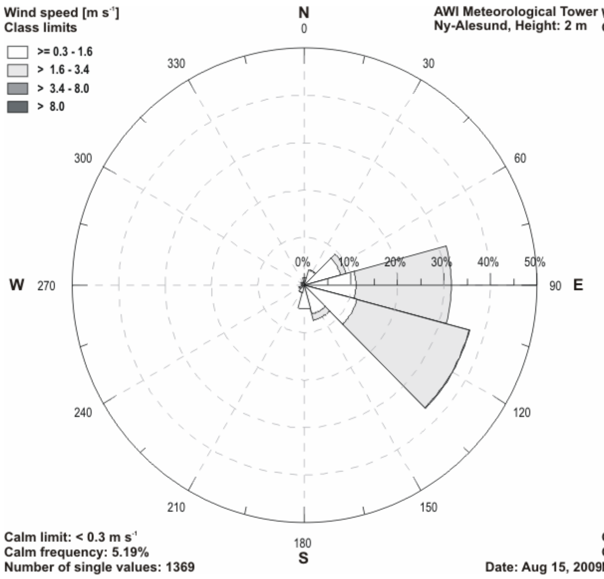


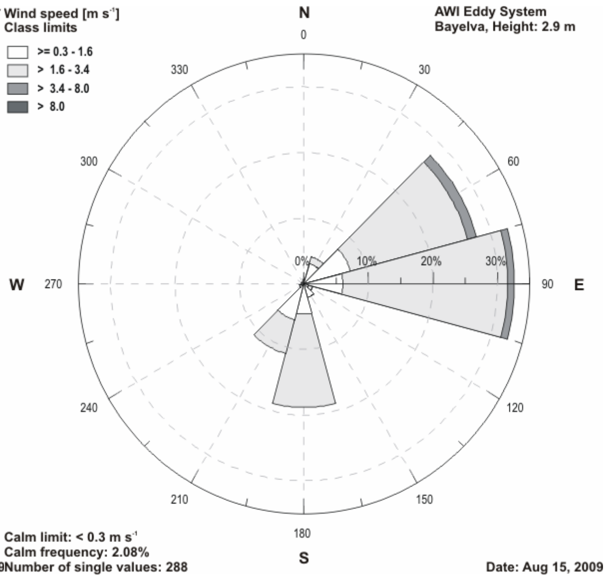

Wind speed [m s⁻¹]
Class limits
>= 0.3 - 1.6
> 1.6 - 3.4
> 3.4 - 8.0
> 8.0
AWI Meteorological Tower
Ny-Alesund, Height: 2 m
N
S
W
E
0%
10%
20%
30%
Calm limit: < 0.3 m s⁻¹
Calm frequency: 26.65%
Number of single values: 1137
Date: Aug 13, 2009

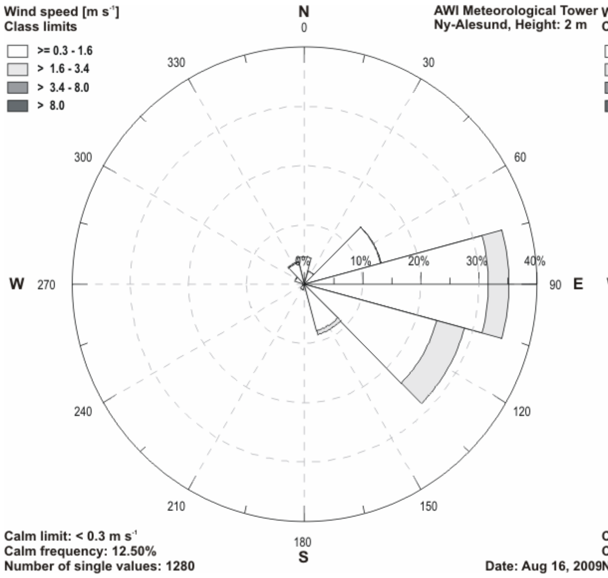
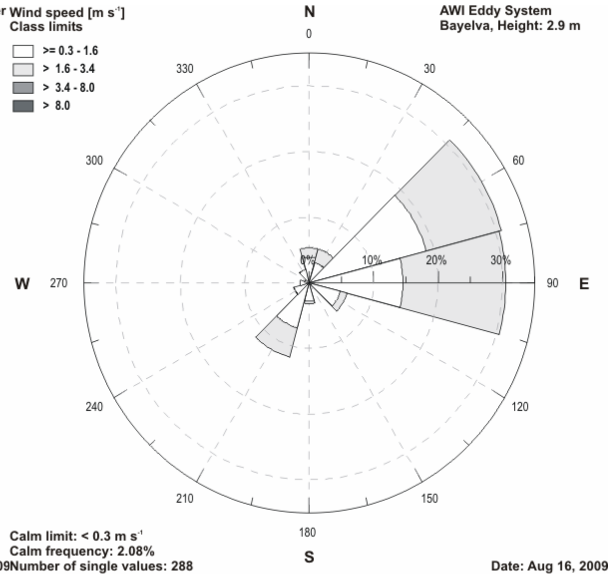
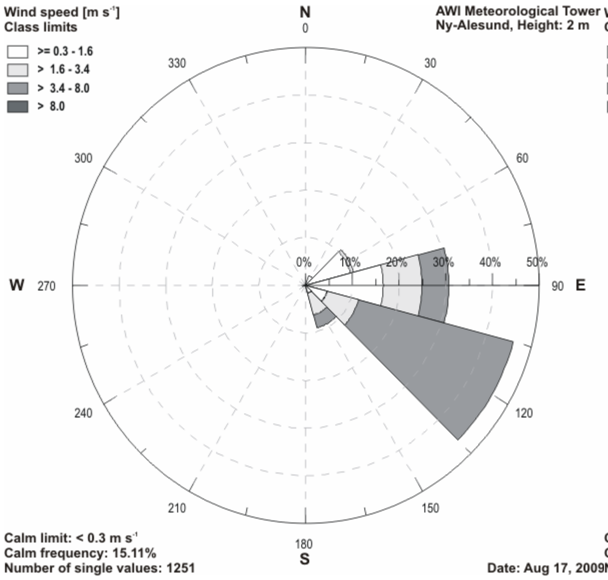
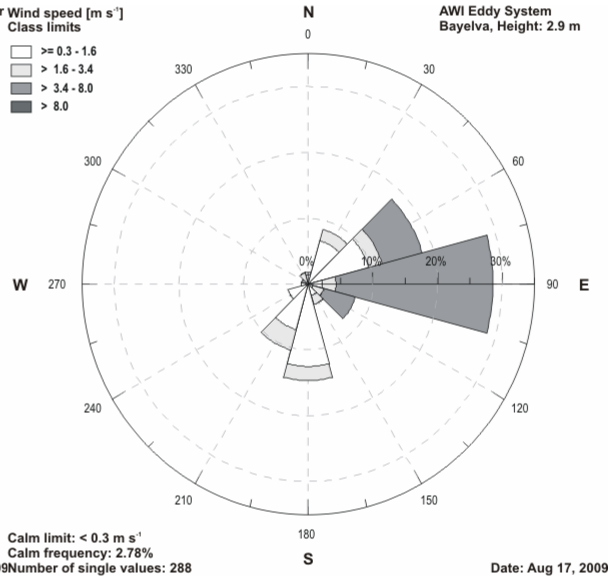
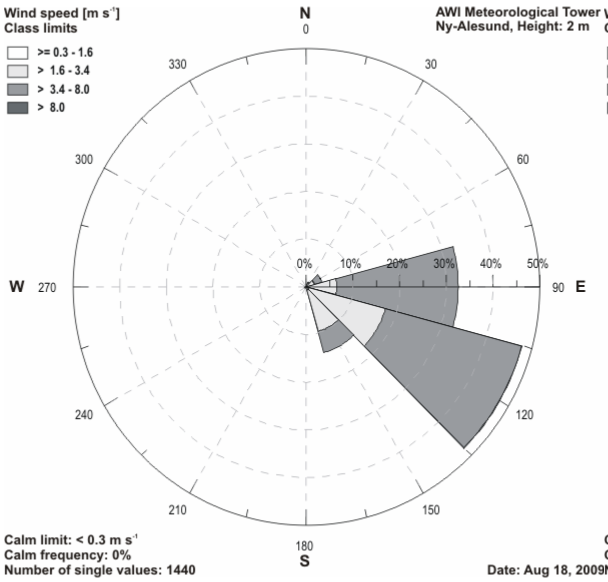
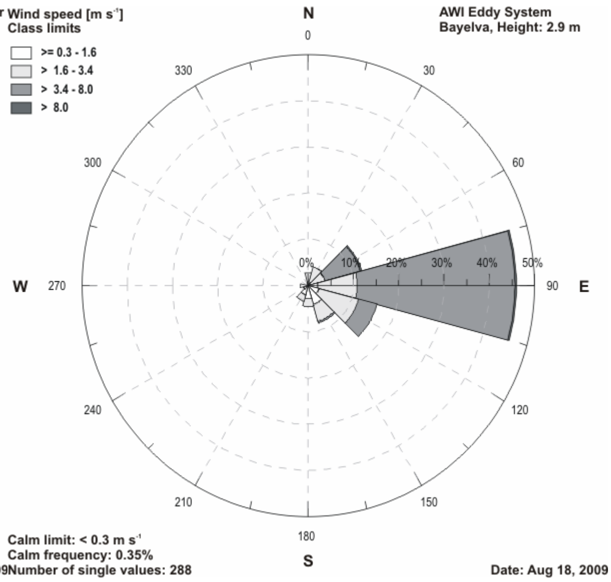

Wind speed [m s⁻¹]
Class limits
>= 0.3 - 1.6
> 1.6 - 3.4
> 3.4 - 8.0
> 8.0
AWI Eddy System
Bayelva, Height: 2.9 m
N
S
W
E
0%
10%
20%
30%
Calm limit: < 0.3 m s⁻¹
Calm frequency: 1.13%
Number of single values: 288
Date: Aug 13, 2009

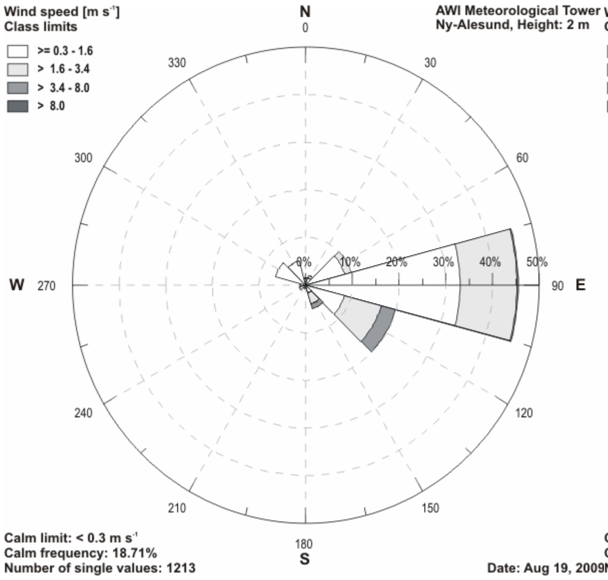

Wind speed [m s⁻¹]
Class limits
>= 0.3 - 1.6
> 1.6 - 3.4
> 3.4 - 8.0
> 8.0
AWI Meteorological Tower
Ny-Alesund, Height: 2 m
N
S
W
E
0%
10%
20%
30%
40%
50%
Calm limit: < 0.3 m s⁻¹
Calm frequency: 11.11%
Number of single values: 1296
Date: Aug 14, 2009

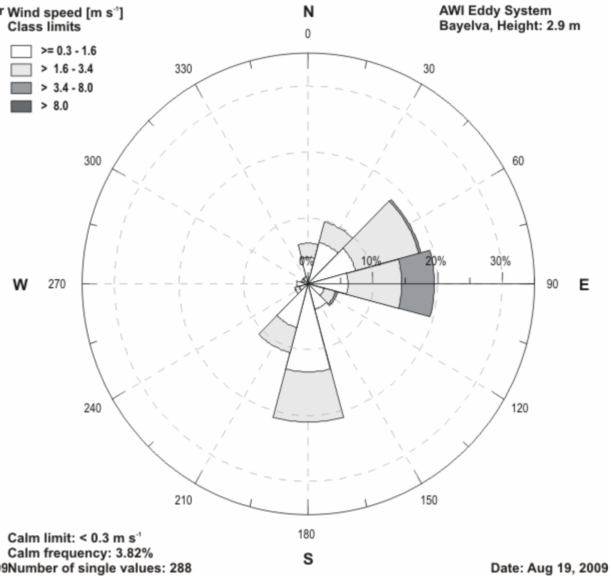

Wind speed [m s⁻¹]
Class limits
>= 0.3 - 1.6
> 1.6 - 3.4
> 3.4 - 8.0
> 8.0
AWI Eddy System
Bayelva, Height: 2.9 m
N
S
W
E
0%
10%
20%
30%
Calm limit: < 0.3 m s⁻¹
Calm frequency: 7.64%
Number of single values: 288
Date: Aug 14, 2009


Wind speed [m s⁻¹]
Class limits
>= 0.3 - 1.6
> 1.6 - 3.4
> 3.4 - 8.0
> 8.0
AWI Meteorological Tower
Ny-Alesund, Height: 2 m
N
S
W
E
0%
10%
20%
30%
40%
50%
Calm limit: < 0.3 m s⁻¹
Calm frequency: 5.19%
Number of single values: 1369
Date: Aug 15, 2009


Wind speed [m s⁻¹]
Class limits
>= 0.3 - 1.6
> 1.6 - 3.4
> 3.4 - 8.0
> 8.0
AWI Eddy System
Bayelva, Height: 2.9 m
N
S
W
E
0%
10%
20%
30%
Calm limit: < 0.3 m s⁻¹
Calm frequency: 2.08%
Number of single values: 288
Date: Aug 15, 2009

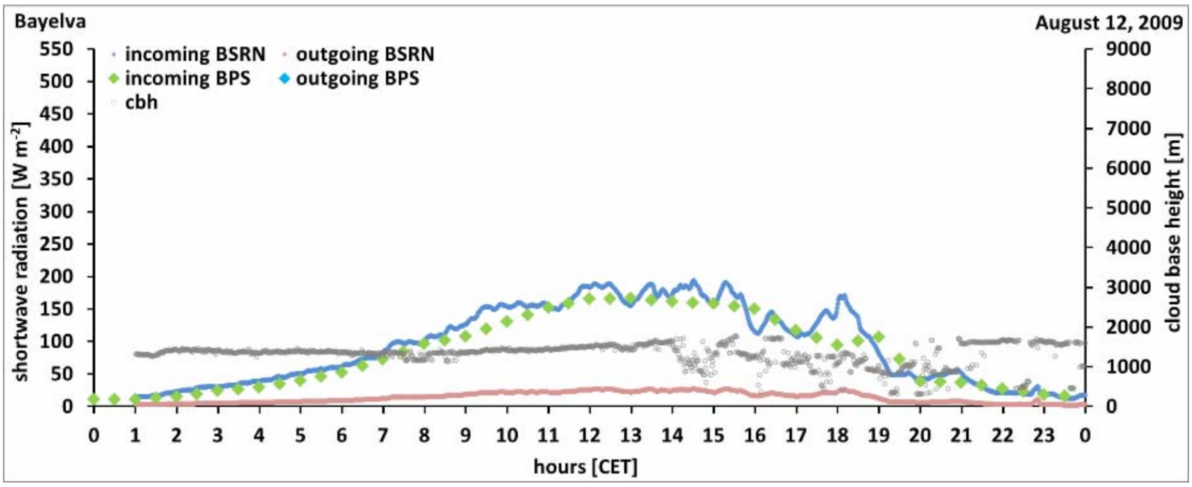

Wind speed [m s-1]
Class limits
>= 0.3 - 1.6
> 1.6 - 3.4
> 3.4 - 8.0
> 8.0
N
E
S
W
AWI Meteorological Tower
Ny-Alesund, Height: 2 m
Calm limit: < 0.3 m s-1
Calm frequency: 12.50%
Number of single values: 1280
Date: Aug 16, 2009

Wind speed [m s-1]
Class limits
>= 0.3 - 1.6
> 1.6 - 3.4
> 3.4 - 8.0
> 8.0
N
E
S
W
AWI Eddy System
Bayelva, Height: 2.9 m
Calm limit: < 0.3 m s-1
Calm frequency: 2.08%
Number of single values: 288
Date: Aug 16, 2009

Wind speed [m s-1]
Class limits
>= 0.3 - 1.6
> 1.6 - 3.4
> 3.4 - 8.0
> 8.0
N
E
S
W
AWI Meteorological Tower
Ny-Alesund, Height: 2 m
Calm limit: < 0.3 m s-1
Calm frequency: 15.11%
Number of single values: 1251
Date: Aug 17, 2009

Wind speed [m s-1]
Class limits
>= 0.3 - 1.6
> 1.6 - 3.4
> 3.4 - 8.0
> 8.0
N
E
S
W
AWI Eddy System
Bayelva, Height: 2.9 m
Calm limit: < 0.3 m s-1
Calm frequency: 2.78%
Number of single values: 288
Date: Aug 17, 2009

Wind speed [m s-1]
Class limits
>= 0.3 - 1.6
> 1.6 - 3.4
> 3.4 - 8.0
> 8.0
N
E
S
W
AWI Meteorological Tower
Ny-Alesund, Height: 2 m
Calm limit: < 0.3 m s-1
Calm frequency: 0%
Number of single values: 1440
Date: Aug 18, 2009

Wind speed [m s-1]
Class limits
>= 0.3 - 1.6
> 1.6 - 3.4
> 3.4 - 8.0
> 8.0
N
E
S
W
AWI Eddy System
Bayelva, Height: 2.9 m
Calm limit: < 0.3 m s-1
Calm frequency: 0.35%
Number of single values: 288
Date: Aug 18, 2009

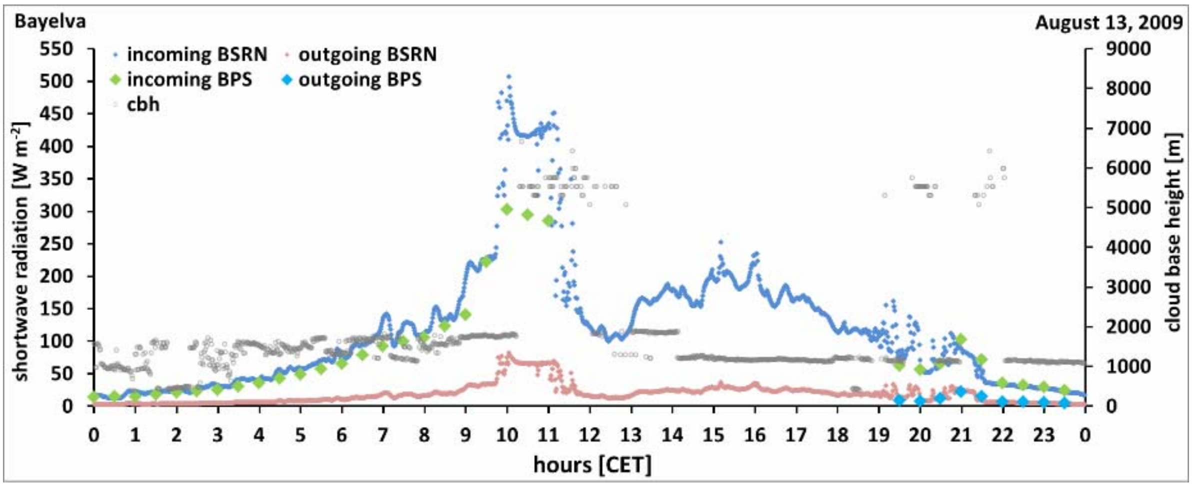

Wind speed [m s⁻¹]
Class limits
>= 0.3 - 1.6
> 1.6 - 3.4
> 3.4 - 8.0
> 8.0
AWI Meteorological Tower
Ny-Alesund, Height: 2 m
N
S
E
W
0
30
60
90
120
150
180
210
240
270
300
330
0%
10%
20%
30%
40%
50%
Calm limit: < 0.3 m s⁻¹
Calm frequency: 18.71%
Number of single values: 1213
Date: Aug 19, 2009

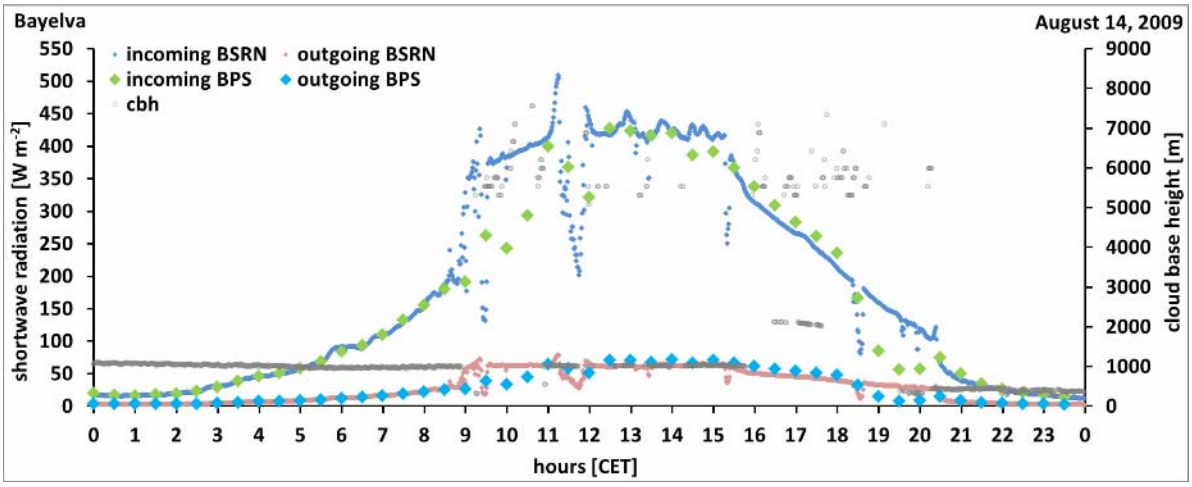

Wind speed [m s⁻¹]
Class limits
>= 0.3 - 1.6
> 1.6 - 3.4
> 3.4 - 8.0
> 8.0
AWI Eddy System
Bayelva, Height: 2.9 m
N
S
E
W
0
30
60
90
120
150
180
210
240
270
300
330
0%
10%
20%
30%
Calm limit: < 0.3 m s⁻¹
Calm frequency: 3.82%
Number of single values: 288
Date: Aug 19, 2009

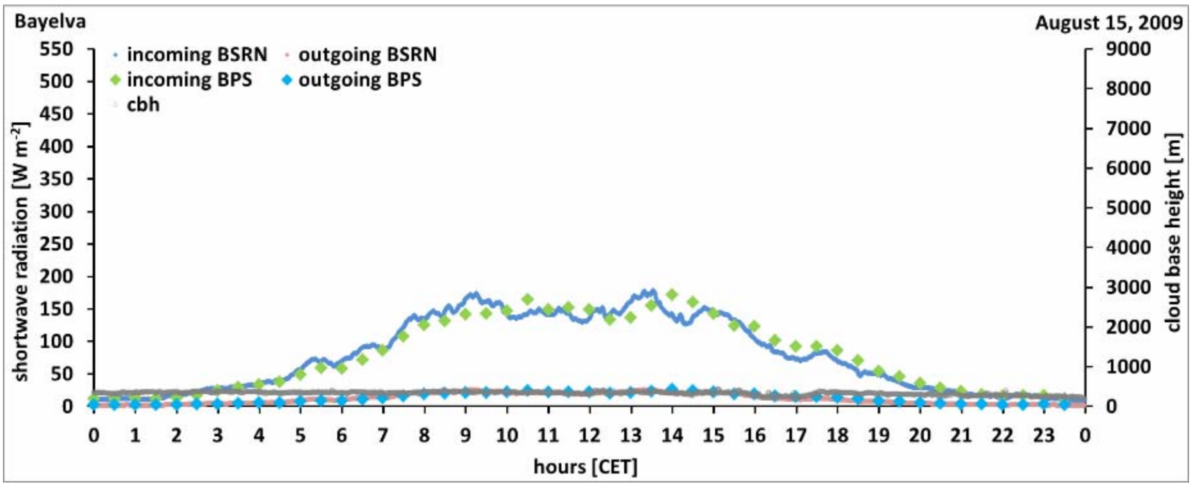
__Shortwave radiation and cloud base height__

The recordings of solar radiation and cloud base height were obtained from the international standardized radiation measurements of the Baseline Surface Radiation Network (BSRN), the laser ceilometer (cloud base height) and the Bayelva Permafrost station (BPS), all maintained by the Alfred Wegener Institute for Polar and Marine Research. The figures show the global (incoming) and reflected (outgoing) parts of the shortwave spectral range and the according cloud height.

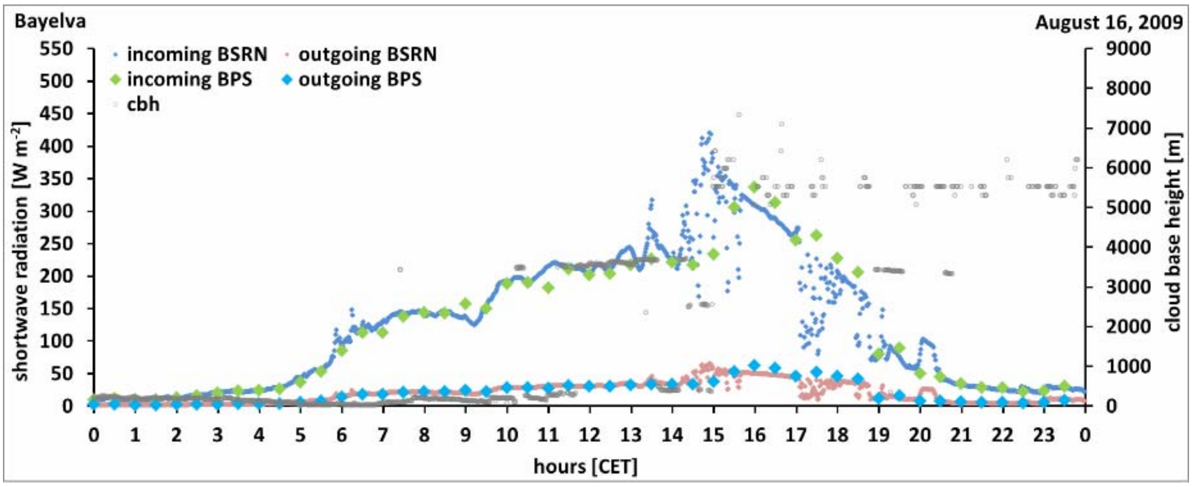




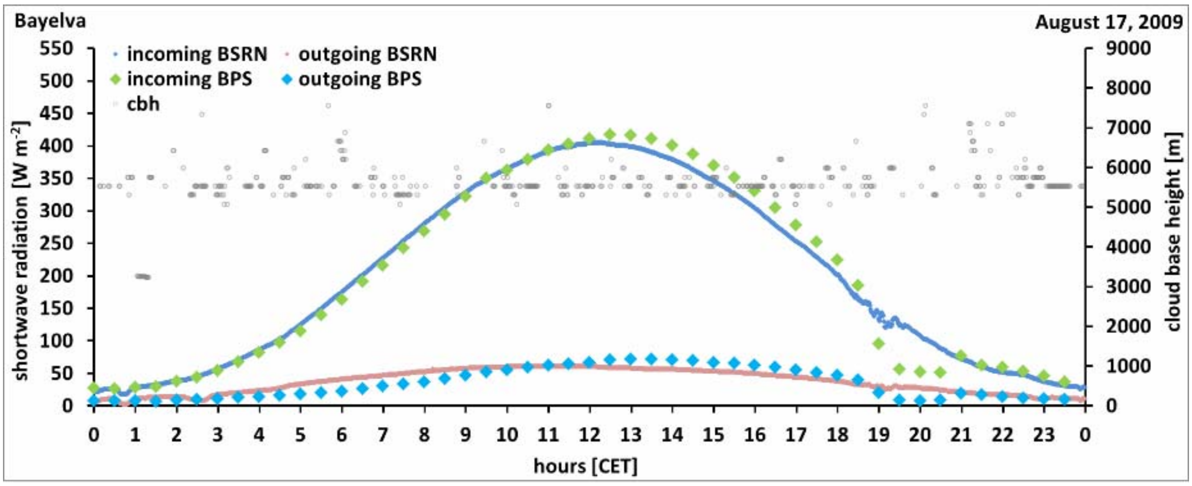




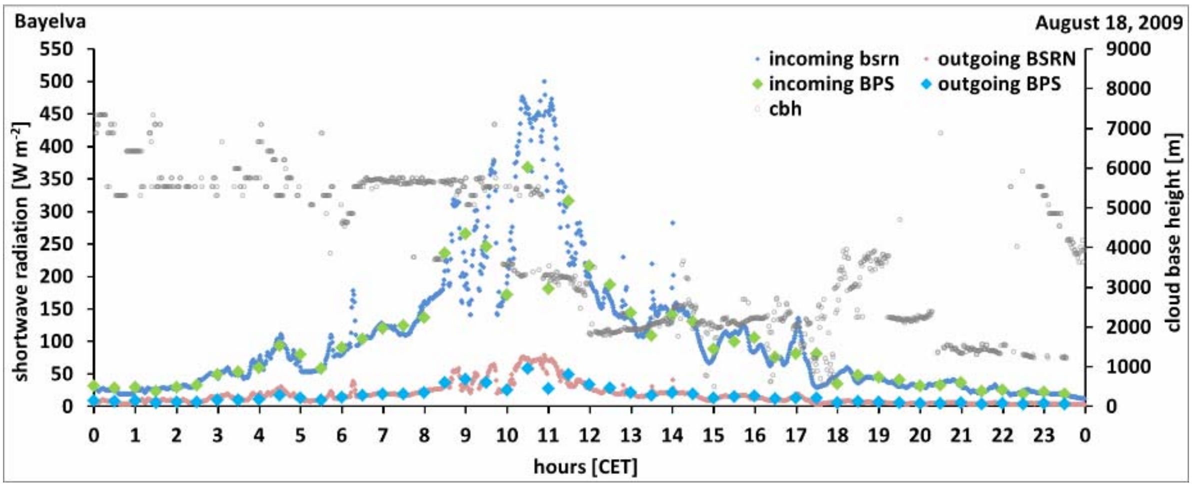
Bayelva
August 15, 2009
incoming BSRN
outgoing BSRN
incoming BPS
outgoing BPS
cbh
shortwave radiation [W m-2]
cloud base height [m]
hours [CET]

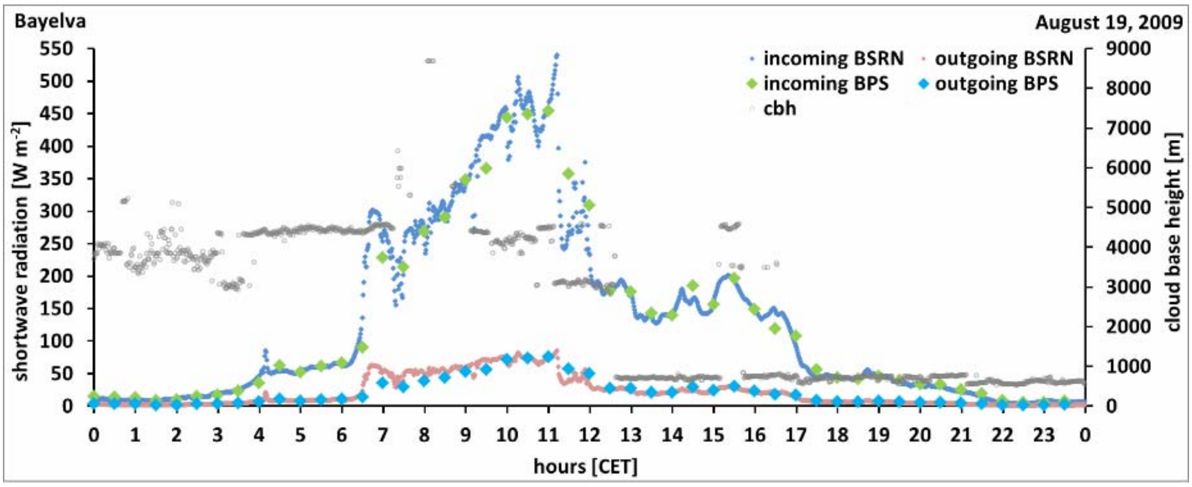


Bayelva
August 16, 2009
incoming BSRN
outgoing BSRN
incoming BPS
outgoing BPS
cbh
shortwave radiation [W m-2]
cloud base height [m]
hours [CET]



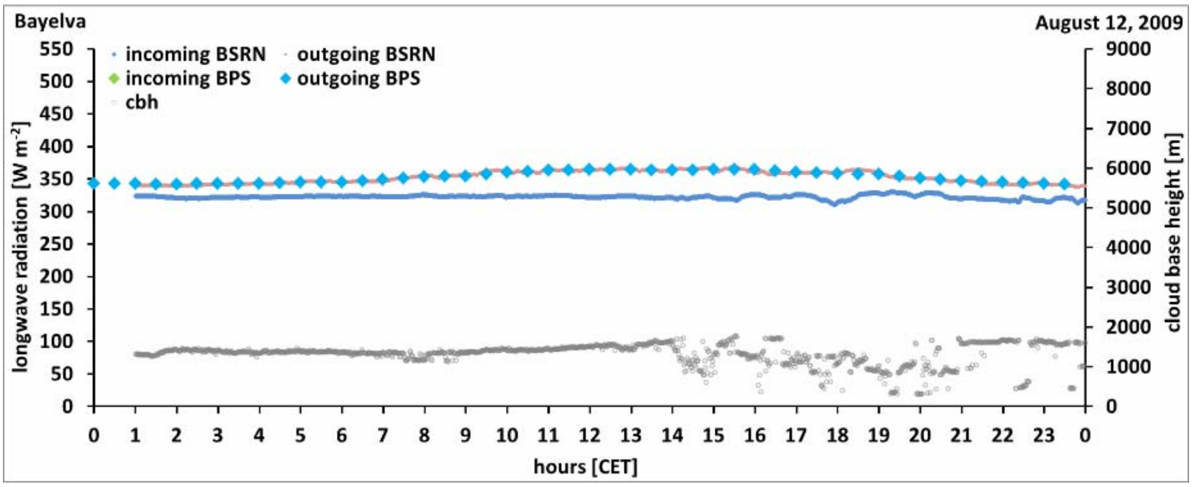
Bayelva
August 17, 2009
incoming BSRN
outgoing BSRN
incoming BPS
outgoing BPS
cbh
shortwave radiation [W m-2]
cloud base height [m]
hours [CET]

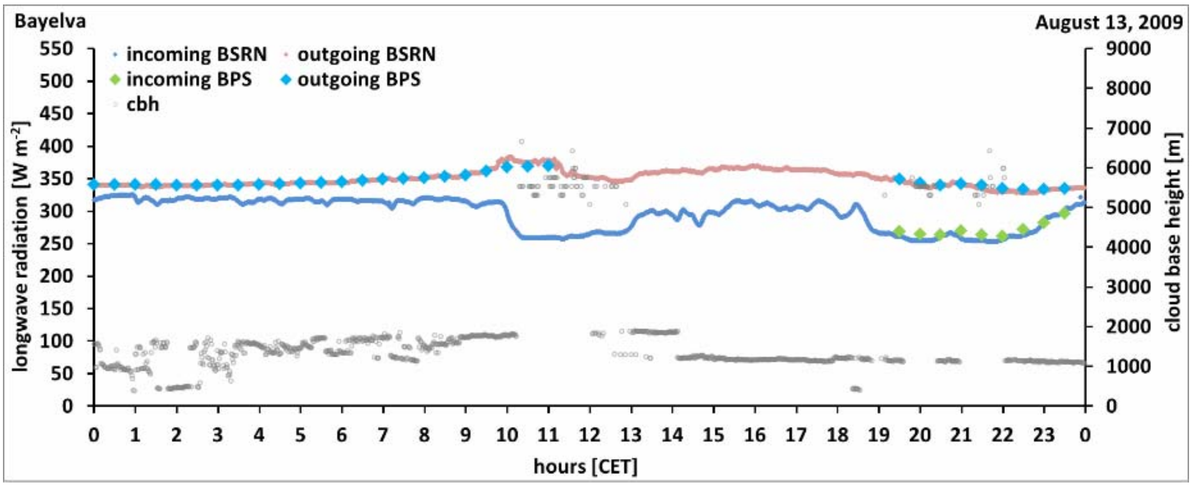

Bayelva
August 18, 2009
incoming bsrn
outgoing BSRN
incoming BPS
outgoing BPS
cbh
shortwave radiation [W m-2]
cloud base height [m]
hours [CET]

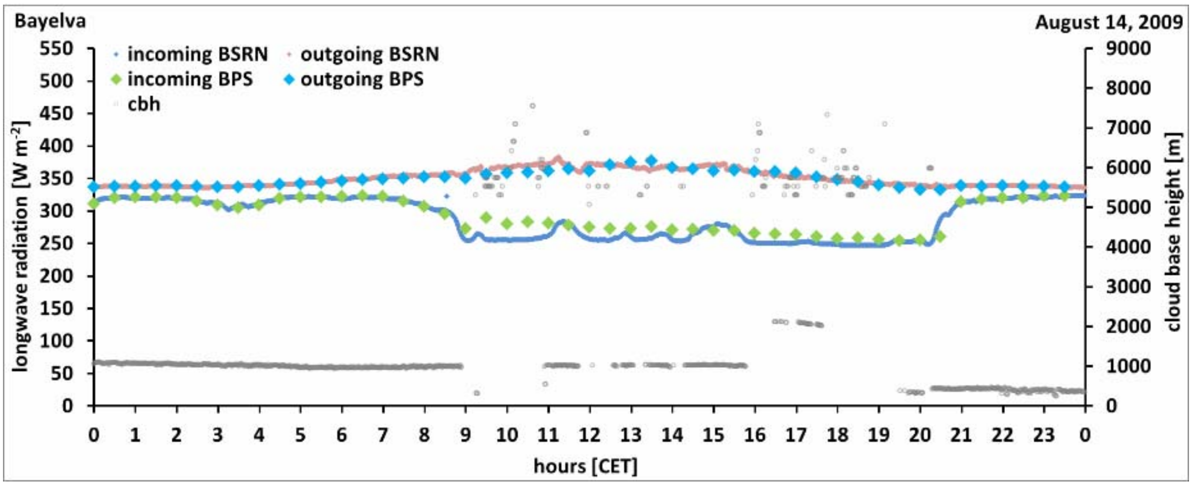

Bayelva
August 19, 2009
incoming BSRN
outgoing BSRN
incoming BPS
outgoing BPS
cbh
shortwave radiation [W m-2]
cloud base height [m]
hours [CET]

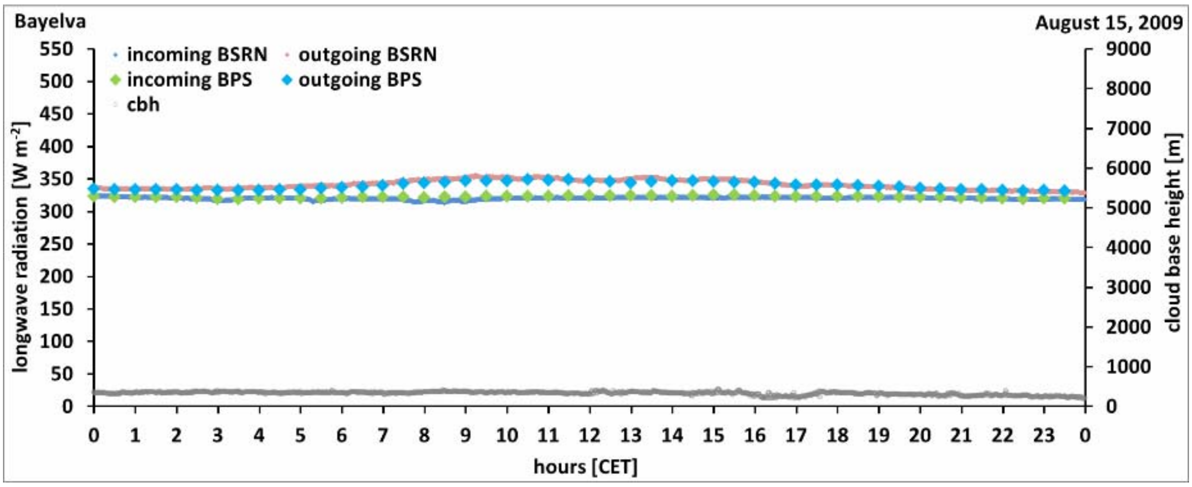
Longwave radiation and cloud base height

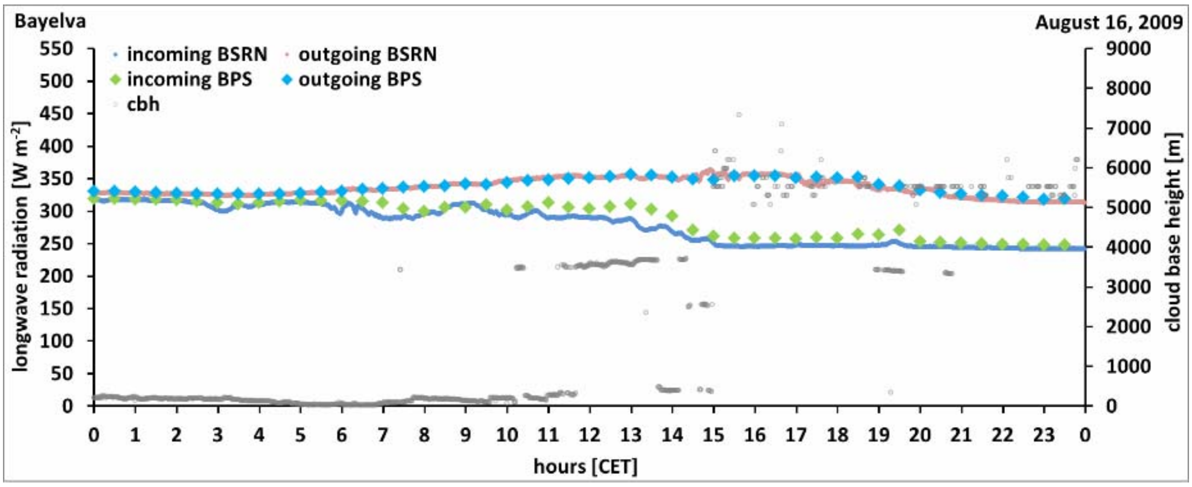
The recordings of the terrestrial radiation and the cloud base height were obtained from the international standardized radiation measurements of the Baseline Surface Radiation Network (BSRN), the laser ceilometer (cloud base height) and the Bayelva Permafrost station (BPS), all maintained by the Alfred Wegener Institute for Polar and Marine Research. The figures show the incoming and outgoing fluxes in the longwave spectral range and the corresponding cloud height.

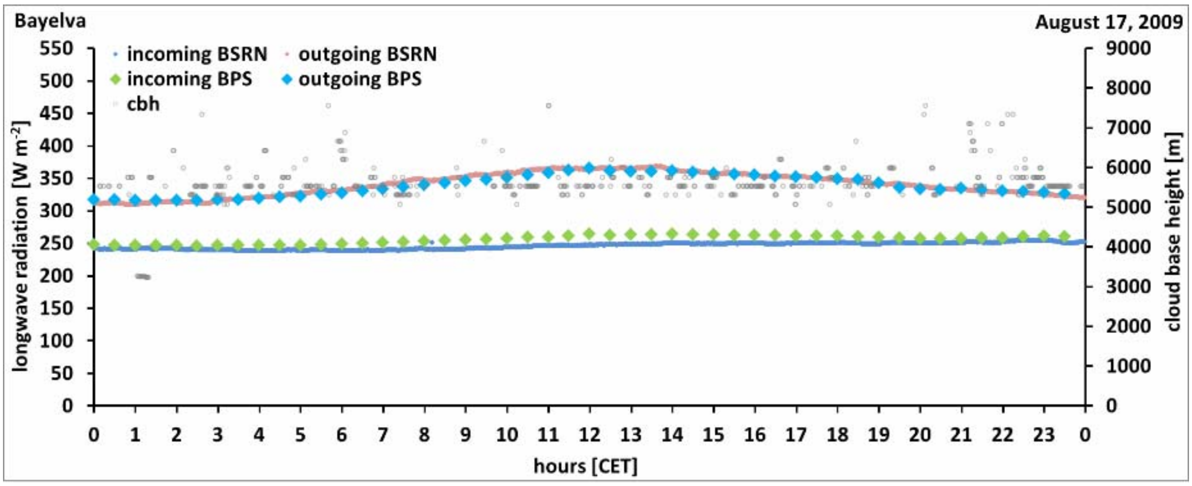


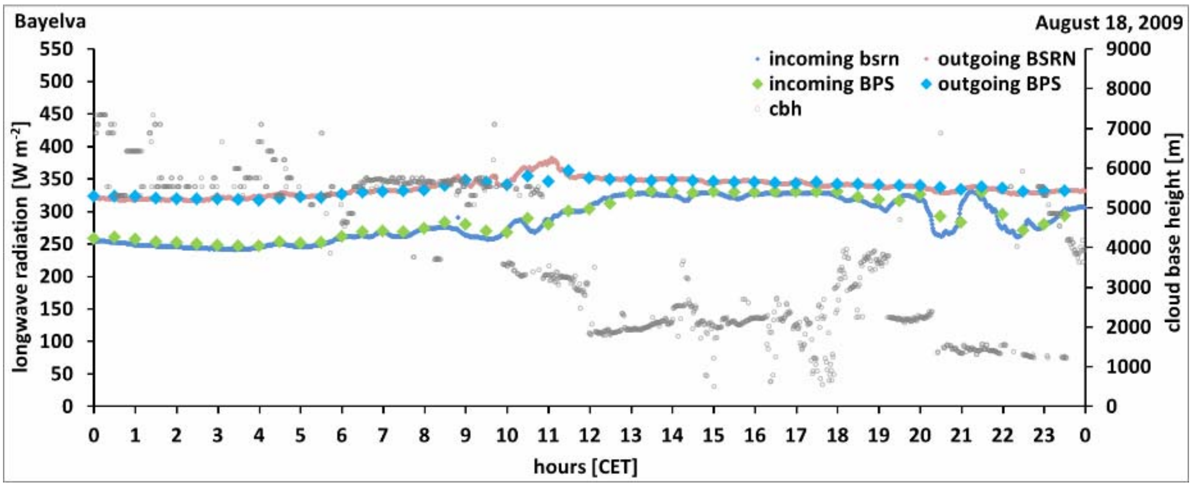




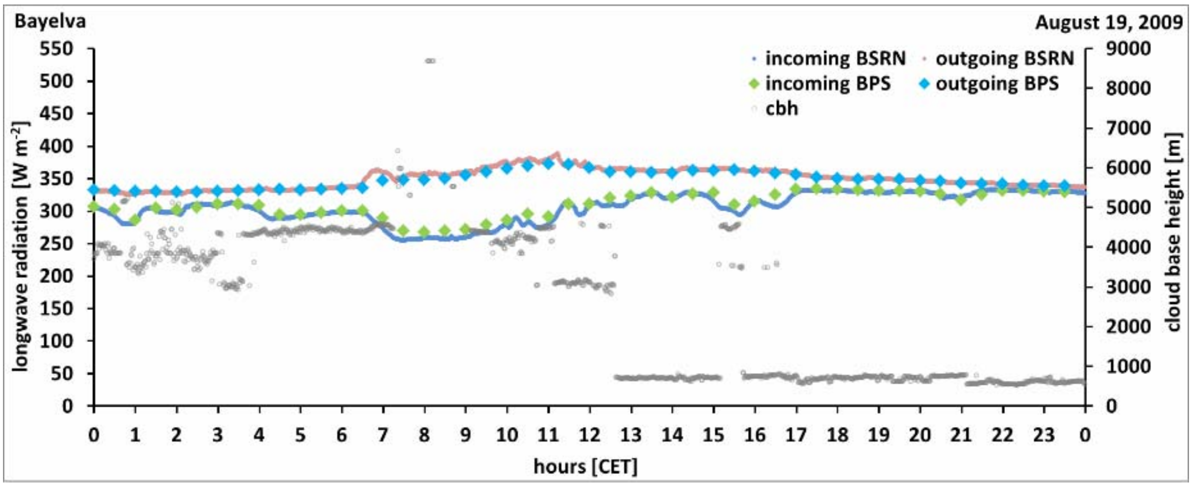

Bayelva
August 15, 2009
incoming BSRN
outgoing BSRN
incoming BPS
outgoing BPS
cbh
longwave radiation [W m-2]
cloud base height [m]
hours [CET]


Bayelva
August 16, 2009
incoming BSRN
outgoing BSRN
incoming BPS
outgoing BPS
cbh
longwave radiation [W m-2]
cloud base height [m]
hours [CET]


Bayelva
August 17, 2009
incoming BSRN
outgoing BSRN
incoming BPS
outgoing BPS
cbh
longwave radiation [W m-2]
cloud base height [m]
hours [CET]



Bayelva
August 18, 2009
incoming bsrn
outgoing BSRN
incoming BPS
outgoing BPS
cbh
longwave radiation [W m-2]
cloud base height [m]
hours [CET]



Bayelva
August 19, 2009
incoming BSRN
outgoing BSRN
incoming BPS
outgoing BPS
cbh
longwave radiation [W m-2]
cloud base height [m]
hours [CET]

7 Visualization of directly measured turbulence fluxes

7.1 Calculation of turbulent fluxes with the software package TK21

The turbulent fluxes were pre- and post-processed with the internationally standardized QA/QC software package TK21, developed by the Department of Micrometeorology, University of Bayreuth (Mauder and Foken, 2004; Mauder et al., 2008). The software package TK21 is based on 15 years of experiences. It was developed to calculate turbulent fluxes automatically for several international micrometeorological experiments since 1989. TK21 is capable of performing all of the post processing of turbulence measurements producing quality assured turbulent fluxes for a station automatically in one single run. It includes all corrections and tests, which are state of science (i.e. detection of spikes, application of Planar Fit method for coordinate transformation, determination of the time delay between sensors) and a quality assessment. The latter following a procedure proposed by Foken and Wichura (1996) and further developed by Foken et al. (2004).

Two quality tests were applied to the flux data. The Steady State test is designed to detect non steady state conditions, which are an assumption of the eddy covariance method. This test compares a 30-minute covariance with the arithmetic mean of the six 5-minute co-variances in this 30-minute interval. The agreement between both values is a measure of steady state conditions. The second test is based on the flux-variance similarity, which means that the ratio of the standard deviation of a turbulent parameter and its turbulent flux is nearly constant or a function, e.g. of the stability. These normalized standard deviations are called Integral Turbulence Characteristics (ITC). This test compares measured integral turbulence characteristics with modeled ones. The agreement between both values is a measure of well-developed turbulence.

Foken, T; Göckede, M; Mauder, M; Mahrt, L; Amiro, BD; Munger, JW (2004): Post-field data quality control. *in* Lee X., Massman W, Law B : Handbook of Micrometeorology: A Guide for Surface Flux Measurement and Analysis, Kluwer, Dordrecht, 181-208.

Foken, T; Wichura, B (1996): Tools for quality assessment of surface-based flux measurements. Agric Forest Meteorology, 78, 83-105.

Mauder, M; Foken, T (2004): Documentation and Instruction Manual of the Eddy Covariance Software Package TK2. Work report University of Bayreuth, Dept of Micrometeorology, 26, ISSN 1614-8916.

Mauder, M; Foken, T; Clement, R; Elbers, JA; Eugster, W; Grünwald, T; Heusinkveld, B; Kolle, O (2008): Quality control of CarboEurope flux data – Part 2: Inter-comparison of eddy-covariance software, Biogeosciences, 5, 451-462.

7.2 Entire observation period

The comparison (Figure 7.1) of the two independent wind measurements a) from the vane anemometer at the Bayelva Permafrost station (BPS) and b) derived from the turbulent wind fluctuation measured by the ultrasonic anemometer at the eddy-flux complex (EF) shows a good agreement between both sites in the Bayelva catchment (distance of both sites ca 100 m) and consequently a good data quality.

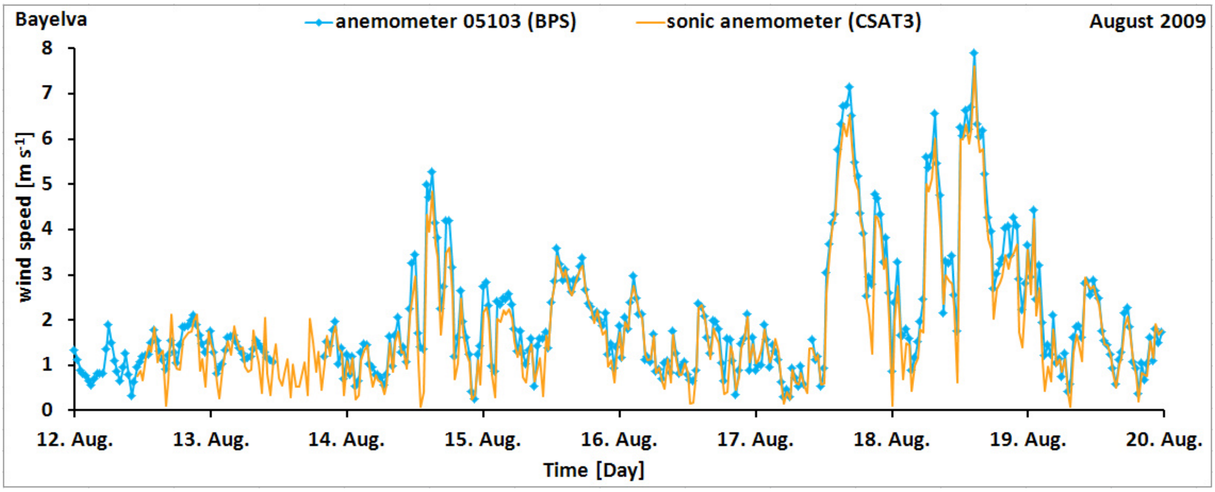


Figure 7.1: Comparison of wind speed measured with a vane (Flügelrad) anemometer 05103 at 2 m height above ground mounted in the BPS (blue line) and the CSAT3 sonic anemometer at 2.90 m a. g. of the eddy-flux complex EF (orange line), August 12 to August 20, 2009. Bayelva (Svalbard), ARCTEX-2009 campaign.

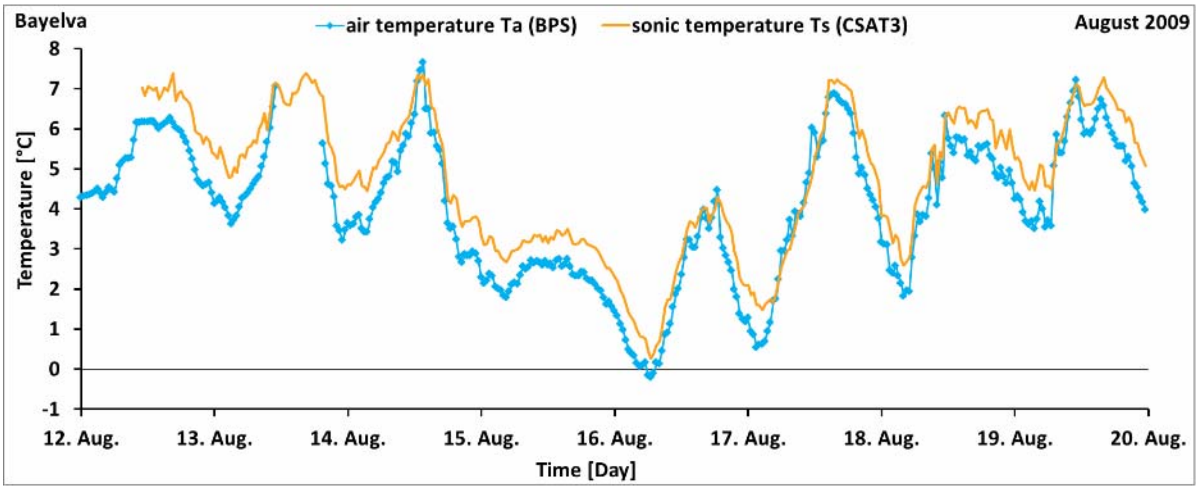


Figure 7.2: Comparison of temperature measured with a ventilated thermometer RP100 at 2 m height above ground mounted in the BPS (air temperature Ta, blue line) and the CSAT3 sonic anemometer at 2.90 m a. g. of the eddy-flux complex EF (sonic temperature Ts, orange line), August 12 to August 20, 2009. Bayelva (Svalbard), ARCTEX-2009 campaign.

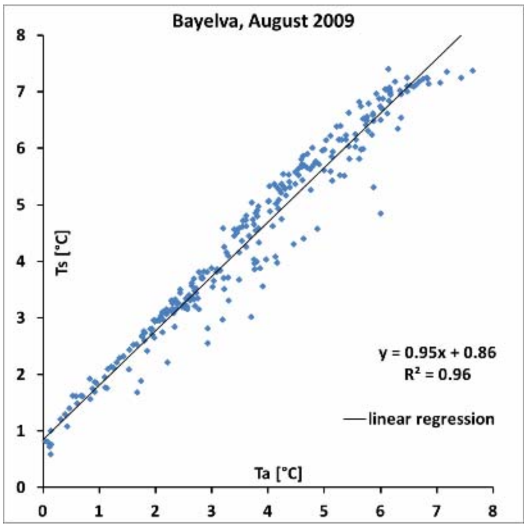


Figure 7.3: Correlation between temperature measured with a ventilated thermometer RP100 at 2 m height above ground mounted in the BPS (air temperature Ta) and measured with the CSAT3 sonic anemometer at 2.90 m a. g. of the eddy-flux complex EF (sonic temperature Ts), based on data from August 12 to August 20, 2009. Bayelva (Svalbard), ARCTEX-2009 campaign.

The comparison between air temperature and sonic temperature (Figure 7.2) and (Figure 7.3) shows that the relation between air temperature (ventilated thermometer) and the temperature derived from the sonic speed (CSAT3 anemometer) is close to 1:1 with a small, more or less constant offset of about 0.5 K. This is in total agreement with results found by Mauder et al. (2007).

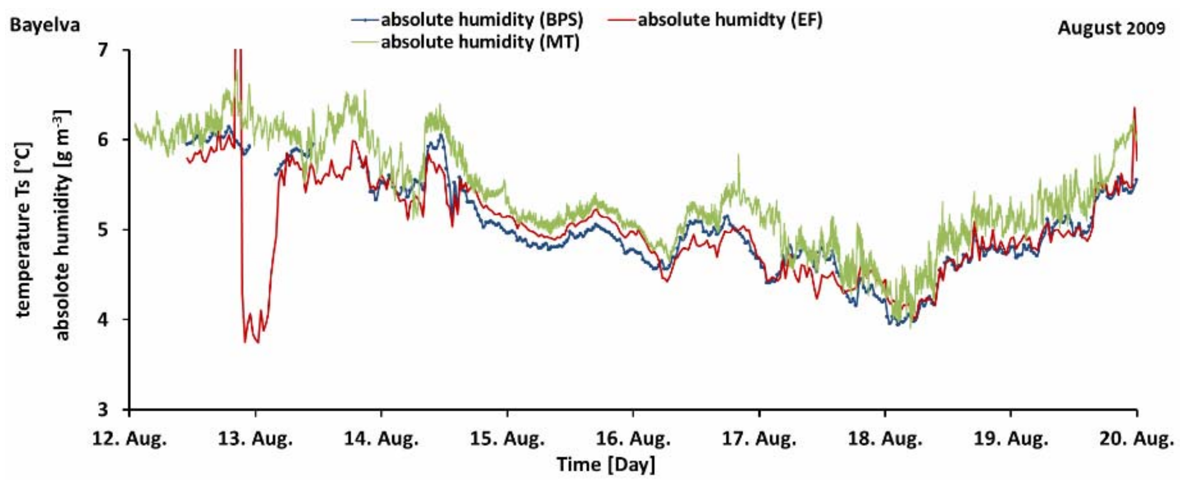


Figure 7.4: Absolute air humidity a (blue line) derived from measurements of relative humidity (in the BPS) at 2 m aboveground, absolute air humidity a (red line) derived from the LI-COR-7500 at 2.90 m a. g. of the eddy-flux measurement complex (EF) and absolute air humidity a (green line) measured at the meteorological tower of the AWI (MT). Bayelva (Svalbard), ARCTEX-2009 campaign.

The influence of the dependency of the sonic speed regarding air density or amount of water vapor respectively, is relatively small due to the observed low values of the absolute humidity between 4 g m^{-3} and 7 g m^{-3} (Figure 7.4) during the ARCTEX-2009 campaign.

Accordingly, the effect of the correction of the covariance of the vertical wind component and the sonic temperature to obtain the proper sensible heat flux (Q_H) as recommended by Schotanus et al. (1983) and Liu et al. (2001) is very limited. The unrealistic drop of absolute humidity measured by the LI-7500 open-path gas analyzer (EF) during the night Aug. 12 to Aug. 13 is a measurement error.

Liu, H; Peters, G; Foken, T (2001): New equations for sonic temperature variance and buoyancy heat flux with an omnidirectional sonic anemometer. Boundary-Layer Meteorology, 100: 459-468.

Mauder, M; Oncley, SP; Vogt, R; Weidinger, T; Riberio, L; Bernhofer, C; Foken, T; Kohsiek, W; DeBruin, H; Liu, H (2007): The Energy Balance Exprriment EBEX-2000. Part II: Intercomparison of eddy covariance sensors and post-field data processing methods; Boundary-Layer Meteorology, 123, 29-54.

Schotanus, P; Nieuwstadt, F.T.M; De Bruin, H.A.R (1983): Temperature Measurement with a Sonic Anemometer and its Application to Heat and Moisture Fluctuations; Boundary-Layer Meteorology, 26, 81-93.

The Figure 7.5 compares independently measured wind directions and Figures 7.6 independently derived atmospheric stratification indices or stability parameter z/L (Ultrasonic) and Bulk Richardson number (meteorological values).

The Figures 7.7 and 7.8 show the relation between the friction velocity u* and a) the atmospheric stability parameter z/L and b) the quality classification determined after Foken and Wichura (1996) respectively.

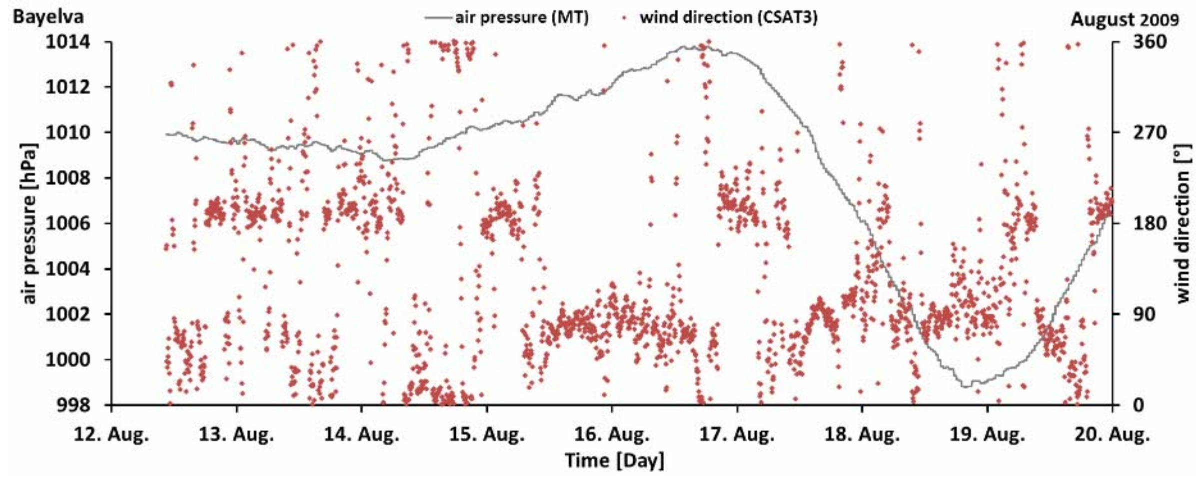
The Figures 7.9 and 7.10 show the relation between the sensible heat flux Q_H and the quality classification determined after Foken and Wichura (1996) respectively.

Figure 7.11 presents an overview of the frequency of the different quality classes determined after Foken and Wichura (1996).

Figure 7.12 shows the result of the Planar-Fit coordinate rotation.

Figure 7.13 shows the relation between the sensible heat flux Q_H and the atmospheric stability parameter z/L.

Figure 7.14 shows the comparison of the sensible heat flux obtained by the two independent measurement systems a) CSAT3 ultrasonic anemometer and b) the SLS20 laser Scintillometer.



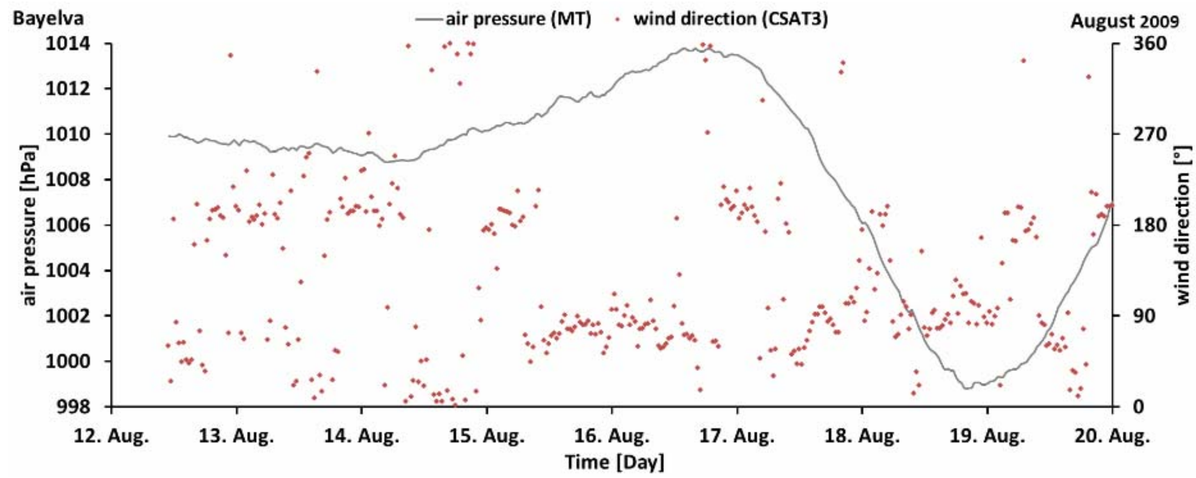


Figure 7.5: Top: 5 minute averaged values. Bottom: 30 min averaged values. Surface air pressure p (grey line) measured at the meteorological tower and the wind direction in degree (red dots) derived from the CSAT3 sonic anemometer at 2.90 m a. g. of the eddy-flux complex EF. Bayelva (Svalbard), ARCTEX-2009 campaign.

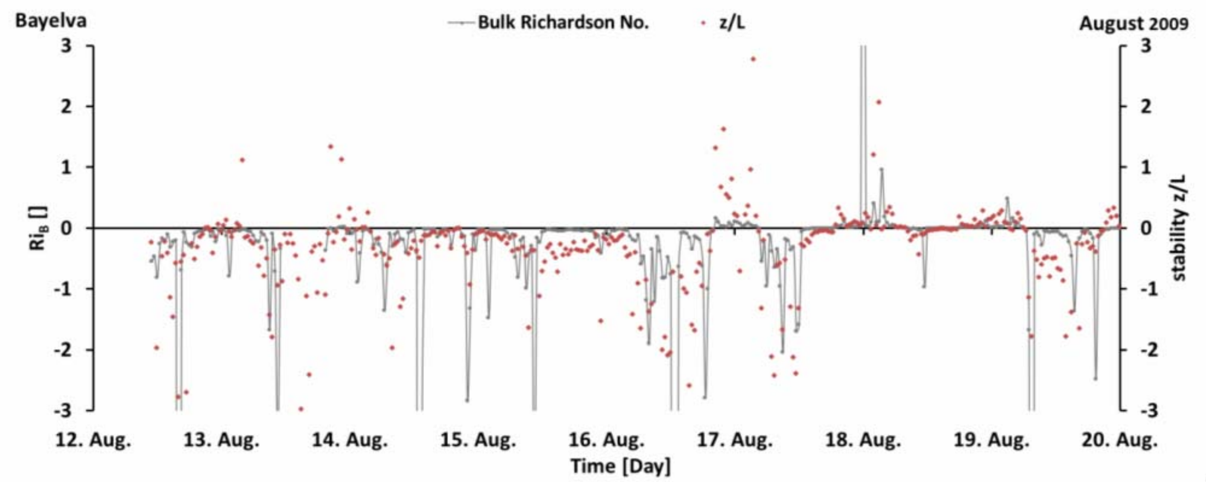
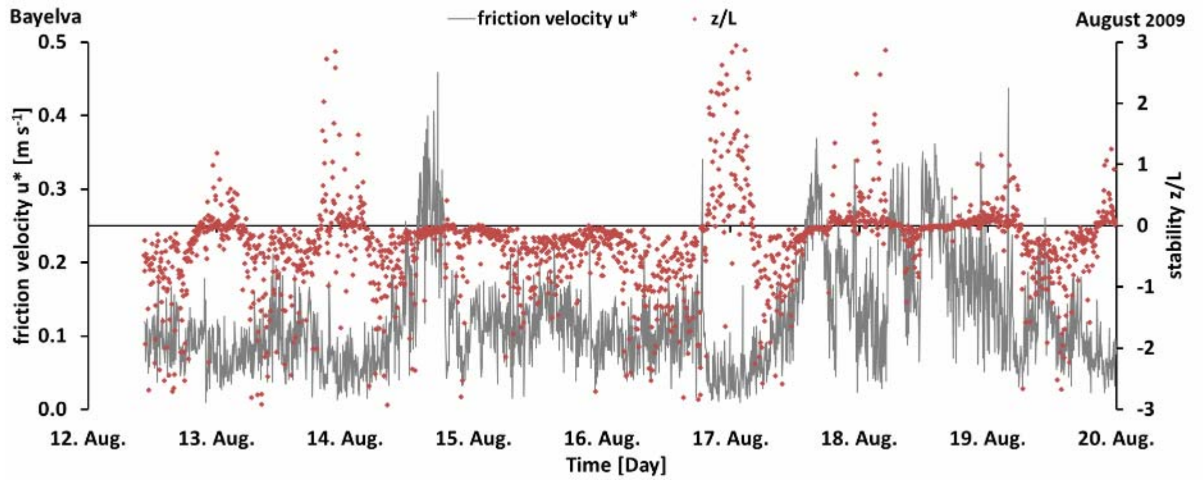


Figure 7.6: Comparison of the atmospheric stability parameter ζ (z/L) whereas L is the Obukhov-length and z is the measurement height (2.90 m), obtained by the eddy-flux complex EF and the independently determined Bulk Richardson number Ri_B. For calculation of Ri_B the from the outgoing longwave radiation measurement (BPS) deduced ground surface temperature and the wind velocity at 2.90 m height (eddy-flux complex EF) were used. Bayelva (Svalbard), ARCTEX-2009 campaign.



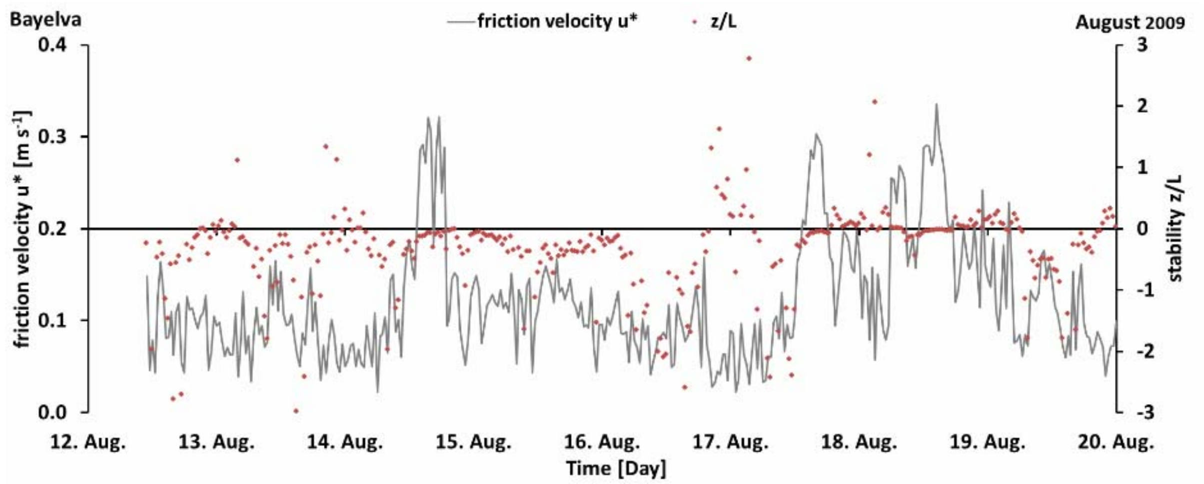
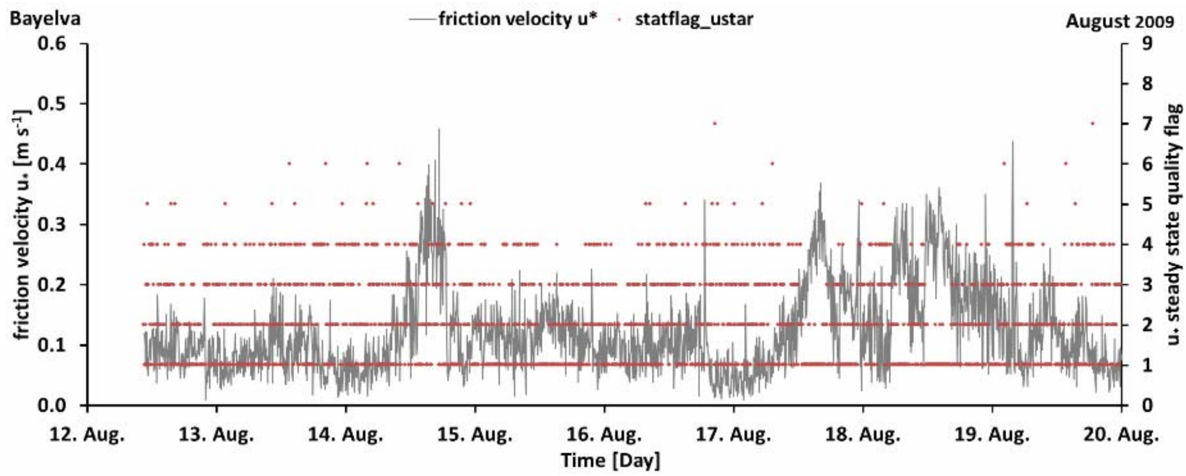


Figure 7.7: Top: 5 min averaged values. Bottom: 30 min averaged values. Comparison of the atmospheric stability parameter ζ (z/L), whereas L is the Obukhov-length and z is the measurement height (2.90 m), the friction velocity u_*, both obtained by the eddy-flux complex EF. Bayelva (Svalbard), ARCTEX-2009 campaign.



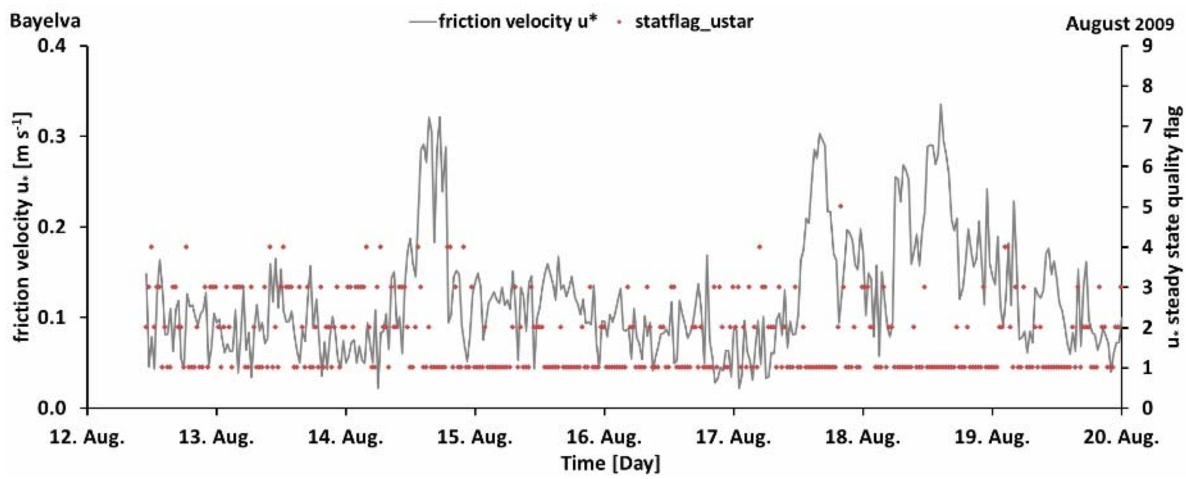
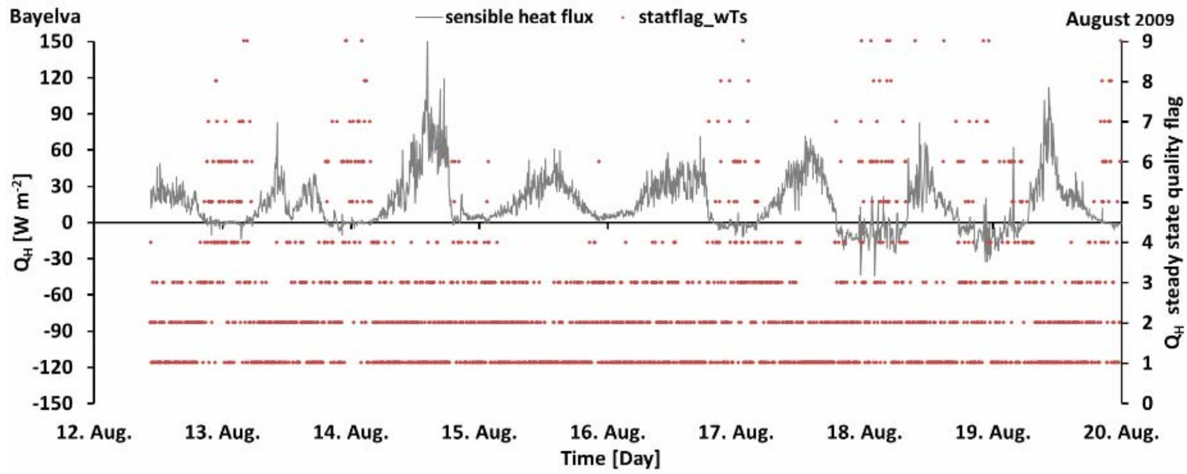


Figure 7.8: Top: 5 min averaged values. Bottom: 30 min averaged values. Friction velocity u_* (2.90 m a. g.) obtained by the eddy-flux complex EF and the related quality flags of the Steady State test (Foken & Wichura, 1996; TK21-software) of the covariance of the fluctuations of the horizontal (u', v') and vertical (w') wind components (statflag_ustar). The classes 1 to 3 are good quality, the classes 4 to 6 are usable quality, class 7 and 8 are only for orientation, 9 has to be neglected, August 12 to August 20, 2009. Bayelva (Svalbard), ARCTEX-2009 campaign.



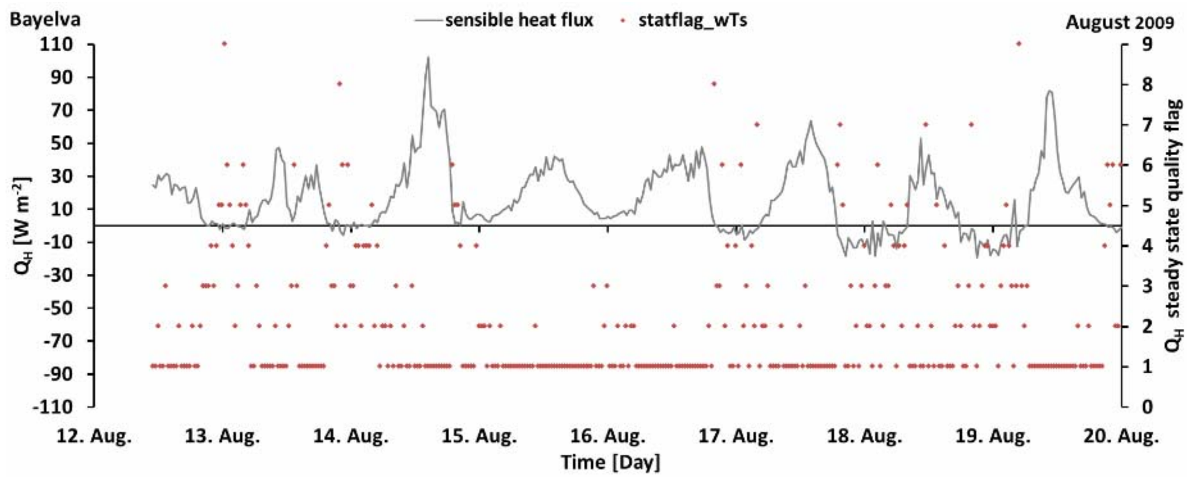
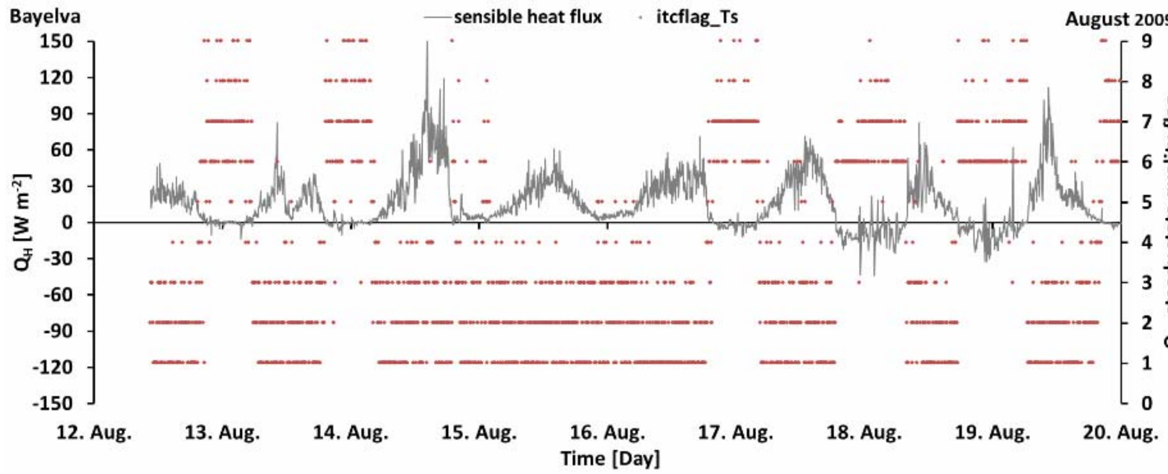


Figure 7.9: Top: 5 min averaged values. Bottom: 30 min averaged values. Sensible heat flux Q_H at 2.9 m a. g. (grey line) obtained by the eddy-flux complex EF and the related quality flags of the Steady State test (Foken & Wichura, 1996; TK21-software) of the covariance of the fluctuations of the sonic temperature (Ts′) and vertical (w′) wind component (statflag_wTs). The classes 1 to 3 are good quality, the classes 4 to 6 are usable quality, class 7 and 8 are only for orientation, 9 has to be neglected, August 12 to August 20, 2009. Bayelva (Svalbard), ARCTEX-2009 campaign.



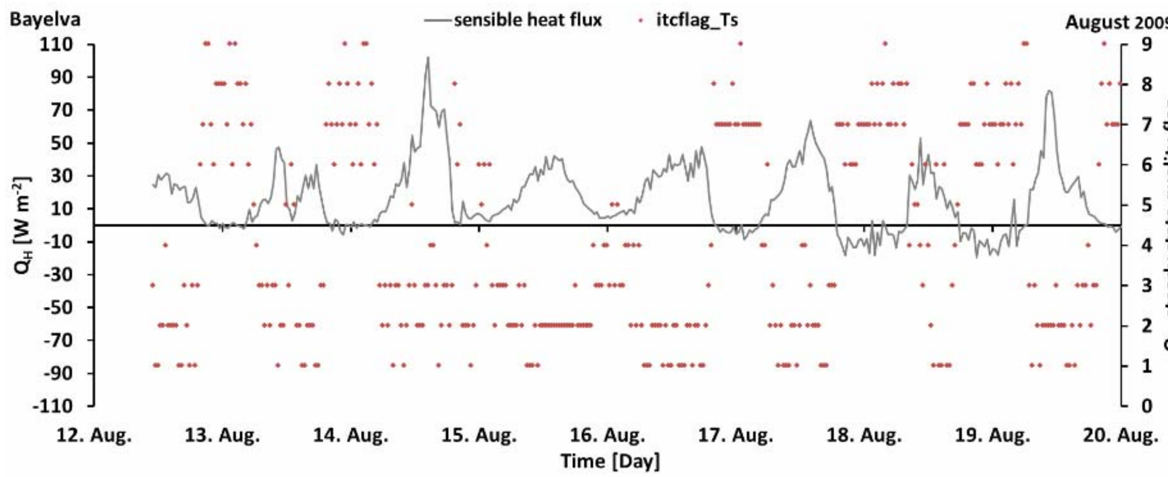


Figure 7.10: Top: 5 min averaged values. Bottom: 30 min averaged values. Sensible heat flux Q_H at 2.90 m a. g. (grey line) obtained by the eddy-flux complex EF and the related quality flags of the Integral Turbulence Characteristic test (ITC-test, Foken & Wichura, 1996; TK21-software) of the standard deviation (σ_{Ts}) normalized by its dynamical parameter T_* (itcflag_Ts). The classes 1 to 3 are good quality, the classes 4 to 6 are usable quality, class 7 and 8 are only for orientation, 9 has to be neglected, August 12 to August 20, 2009. Bayelva (Svalbard), ARCTEX-2009 campaign.

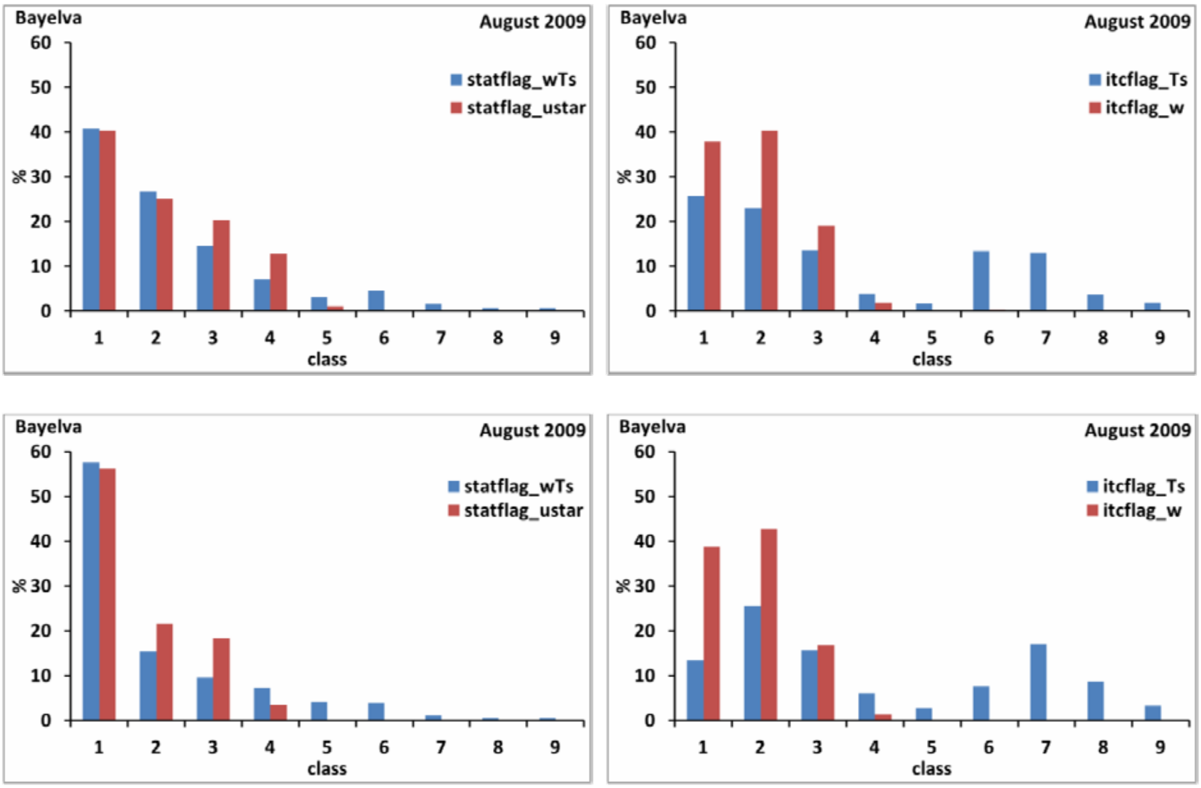


Figure 7.11: Quality control using the quality flag system after Foken & Wichura (1996) by applying the TK21-software. Top: 5 min averaged values. Bottom: 30 min averaged values. Left: Steady State test of the covariance of the fluctuations of a) the horizontal wind components (u′, v′) and b) the sonic temperature (Ts′) and the vertical (w′) wind component (statflag_ustar and statflag_wTs). Right: Integral Turbulence Characteristic test (ITC-test) of the standard deviations (σ_w and σ_{Ts}) normalized by their dynamical parameters u_* and T_* (itcflag_w and itcflag_Ts). The classes 1 to 3 are good quality, the classes 4 to 6 are usable quality, class 7 and 8 are only for orientation, 9 has to be neglected, August 12 to August 20, 2009. Bayelva (Svalbard), ARCTEX-2009 campaign.

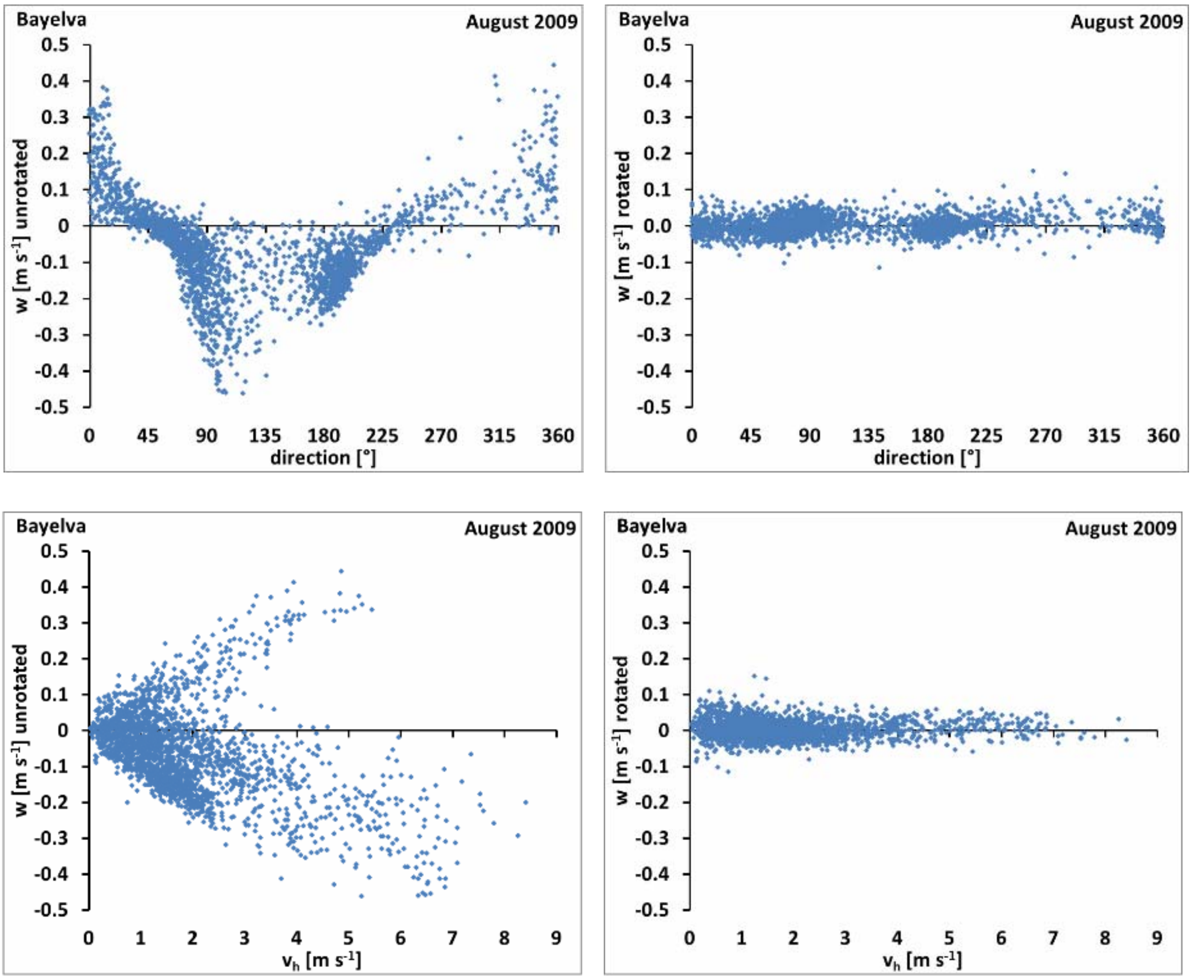


Figure 7.12: Quality control of the turbulent fluxes obtained by the eddy-flux complex EF applying the Planar Fit coordinate rotation method after Wilczak et al. (2001) ideally resulting in a w-value of zero averaged across the full data set August 12 to August 20, 2009. The plots show the correction effect (left with unrotated, right with rotated coordinate matrix) regarding the vertical wind component w in relation to the according wind direction (top) and regarding the vertical wind component w in relation to the according horizontal wind speed v_h (bottom). Bayelva (Svalbard), ARCTEX-2009 campaign.

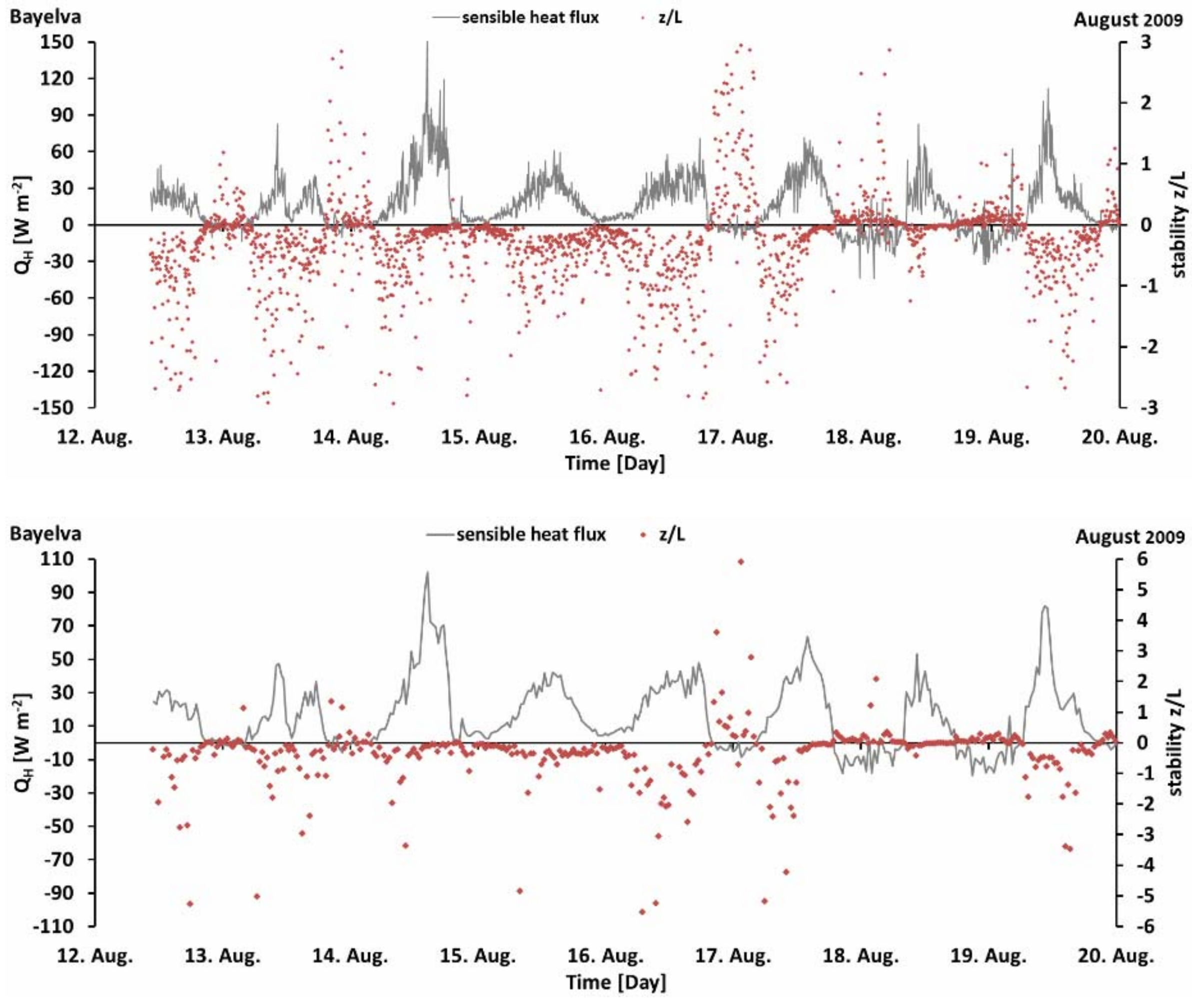


Figure 7.13: Top: 5 min averaged values. Bottom: 30 min averaged values. Sensible heat flux Q_H at 2.90 m a. g. (grey line) and the related atmospheric stability parameter ζ (z/L), whereas L is the Obukhov-length and z is the measurement height (2.90 m), both obtained by the eddy-flux complex EF. Bayelva (Svalbard), ARCTEX-2009 campaign.

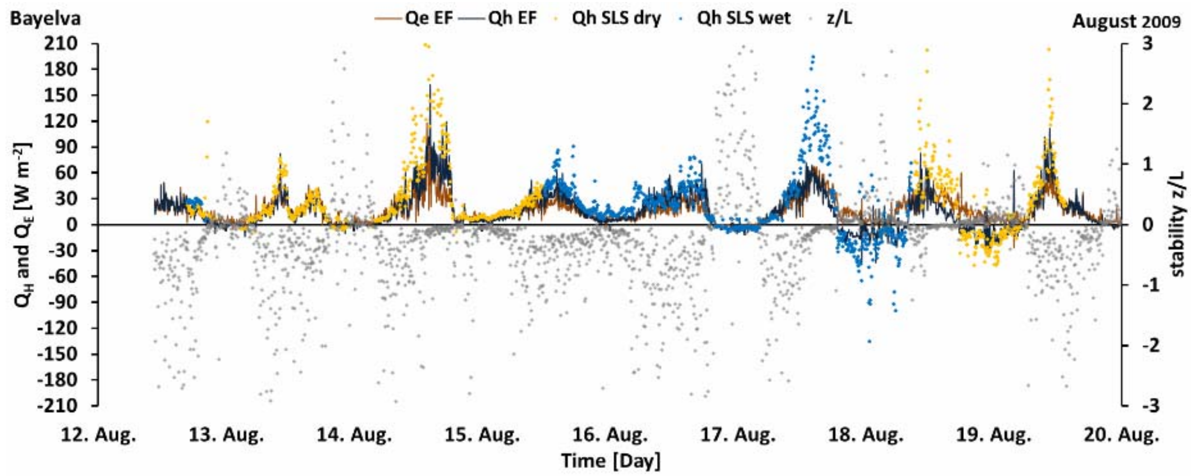


Figure 7.14: Comparison of the sensible heat flux obtained by two independent measurement systems during August 12 to August 20, 2009, in the Bayelva catchment near Ny-Ålesund (Svalbard). The dark blue line (Qh EF) indicates the sensible heat flux Q_H and the brown line (Qe EF) indicates the latent heat flux Q_E at 2.90 m a. g. obtained by the eddy-flux complex EF using a Campbell CSAT3. The orange dots (Qh SLS dry) are indicating the sensible heat flux along a 100 m long laser scintillometer pathway (Scintec SLS 20) 1.21 m above dry ground near the fetch of the eddy-flux complex EF. The blue dots (Qh SLS wet) are indicating the sensible heat flux along a 100 m long laser scintillometer pathway (Scintec SLS 20) 1.22 m above wet ground near the fetch of the eddy-flux complex EF. For Q_H of the scintillometers the stability z/L was used to decide the appropriate flux directions. Bayelva (Svalbard), ARCTEX-2009 campaign.

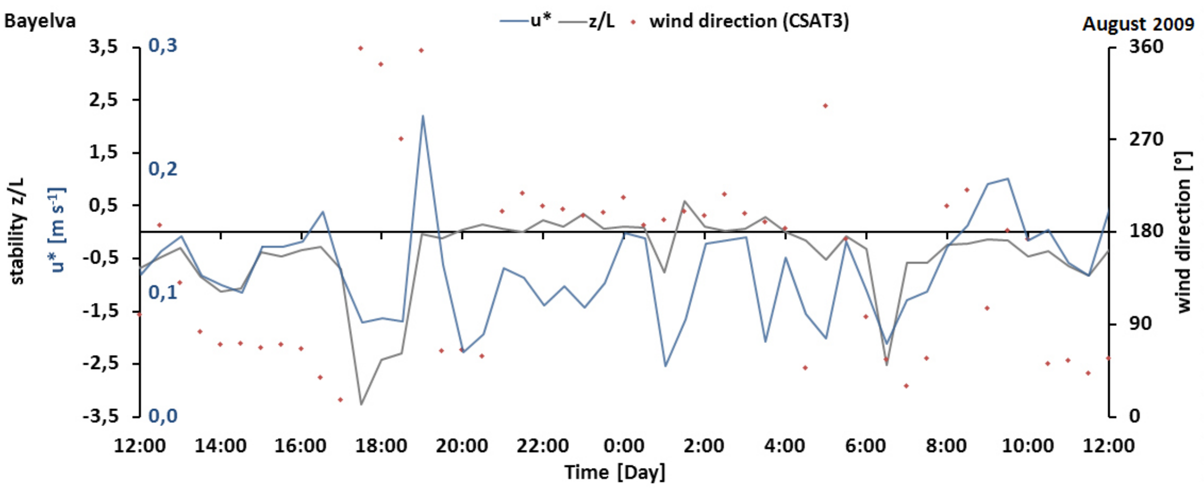


Figure 7.15: Recorded wind direction (red dots) and friction velocity u_* (blue line), and the related atmospheric stability parameter ζ (z/L, dark grey line, pos. values = stable, neg. values = unstable), whereas L is the Obukhov-length and z is the measurement height (2.90 m), all obtained by the eddy covariance complex EF, August 16 and August 17, 2009. Bayelva (Svalbard), ARCTEX-2009 campaign.

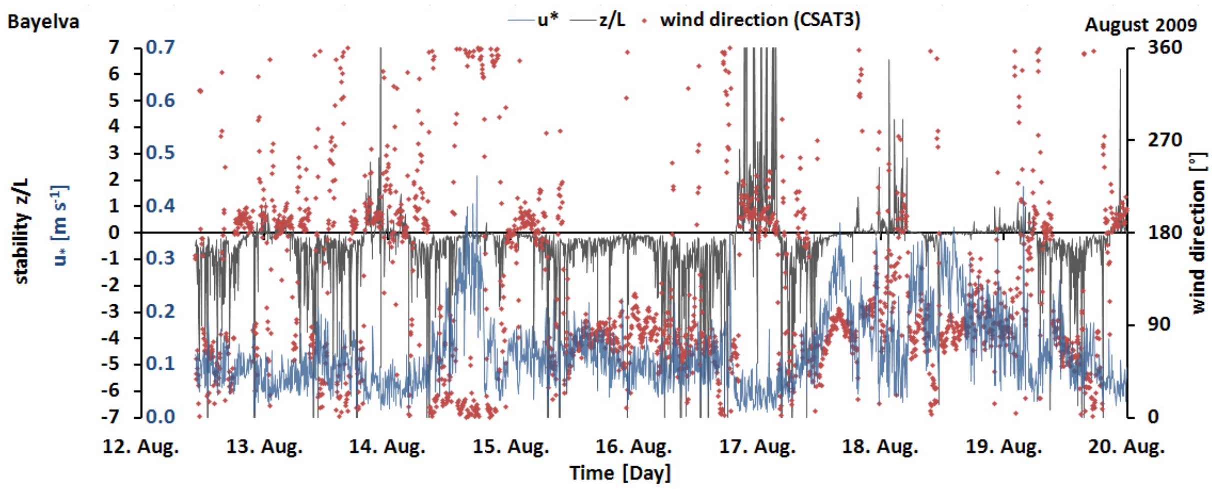
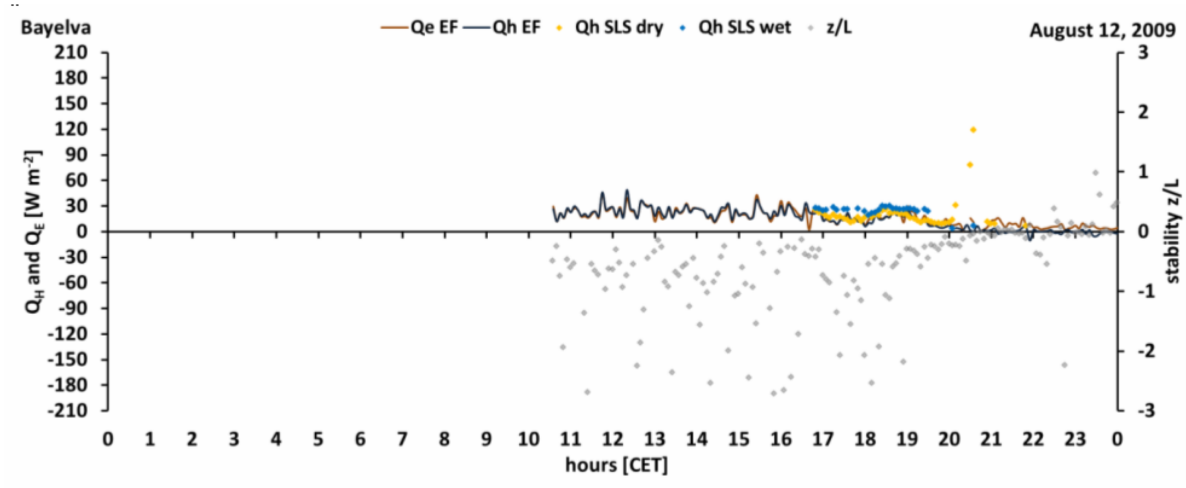
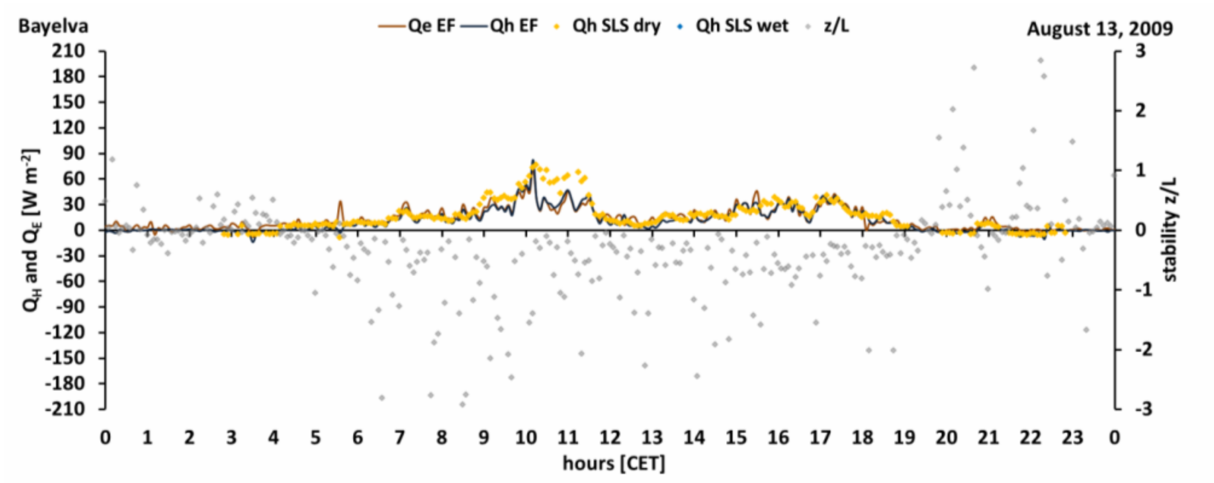


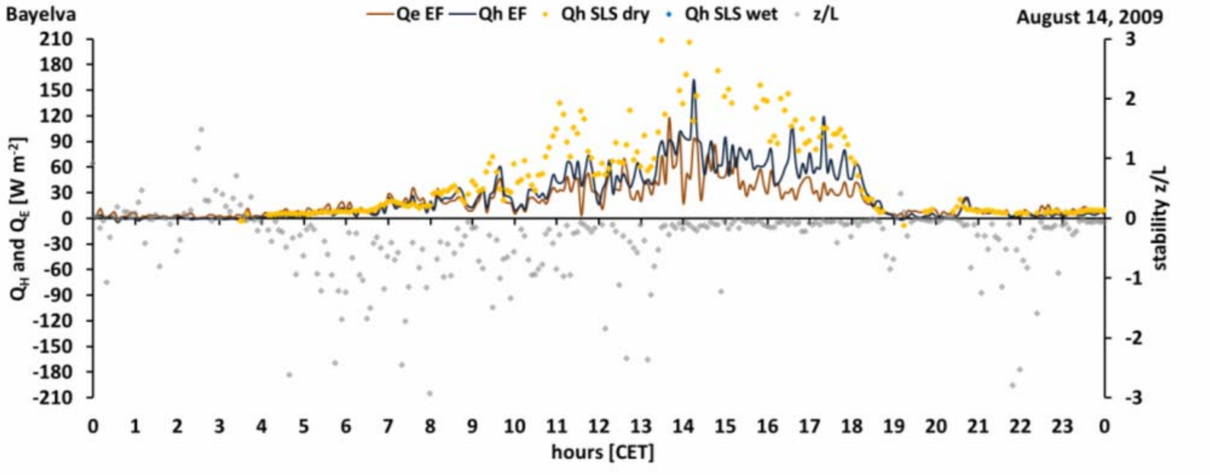
Figure 7.16: Recorded wind direction (red dots) and friction velocity u_* (blue line), and the related atmospheric stability parameter ζ (z/L, dark grey line, pos. values = stable, neg. values = unstable), whereas L is the Obukhov-length and z is the measurement height (2.90 m), all obtained by the eddy covariance complex EF, August 12 to August 20 2009. Bayelva (Svalbard), ARCTEX-2009 campaign.

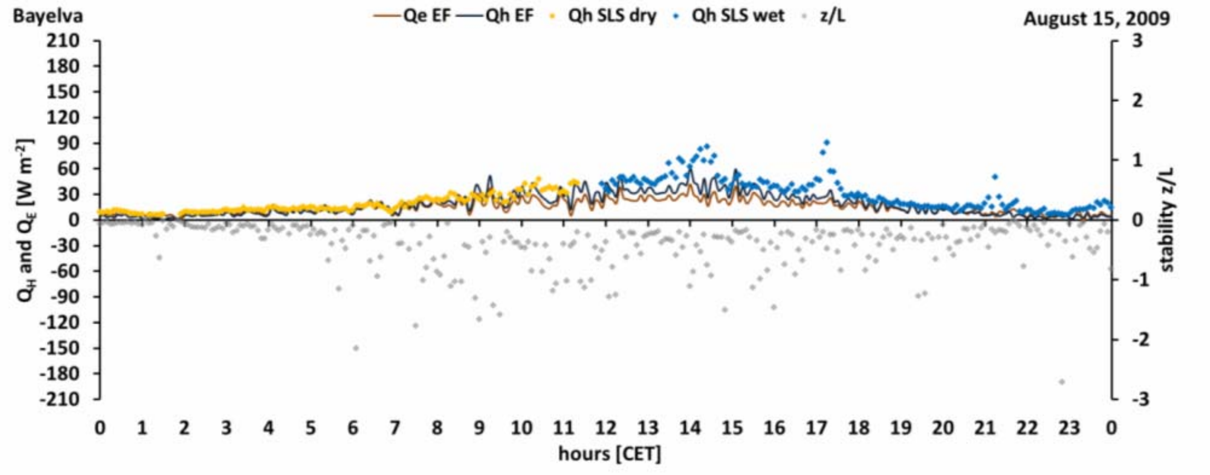
7.3 Daily charts

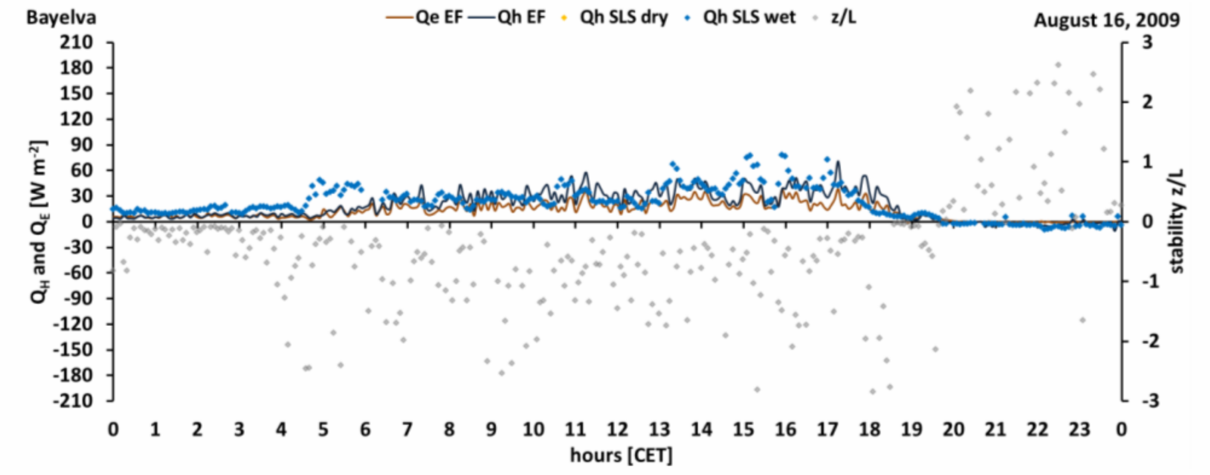
The figures in this chapter present the two independently measured sensible heat fluxes obtained from the eddy-flux complex EF and the laser scintillometer SLS during the ARCTEX-2009 campaign, August 12 to August 20. The graphs include information about a) the atmospheric stability parameter ζ (z/L), the sensible (Qh EF) and latent heat flux (Qe EF) all obtained by the eddy-flux complex (CSAT3, LI-7500) and b) the two laser-scintillometer section (Qh SLS wet tundra and Qh SLS dry tundra). For the analysis of the scintillometer measurements the stability z/L was used to decide the appropriate flux directions instead the usual vertical gradient of air temperature. All values are 5 minute averaged values.

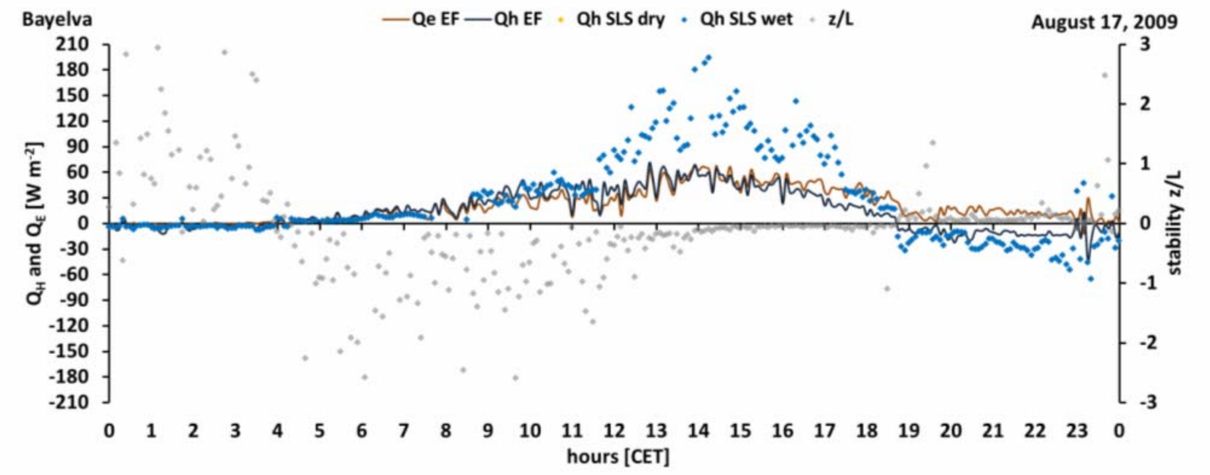


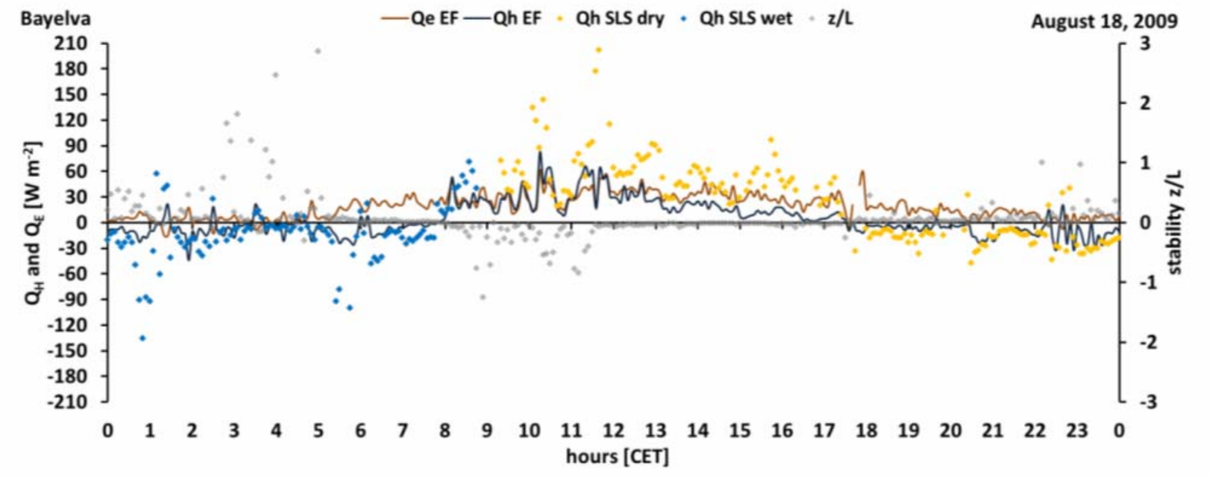


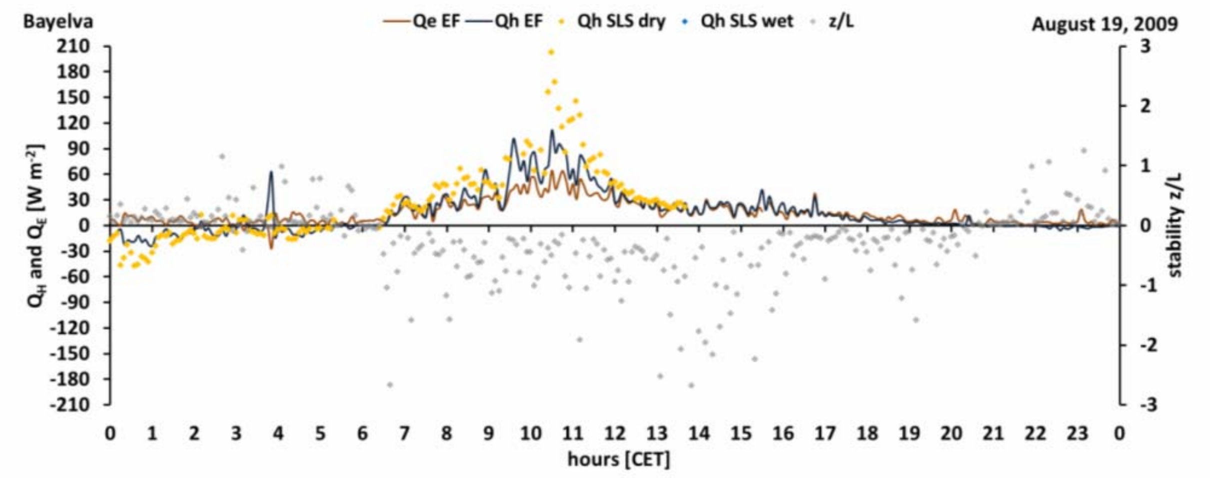

Bayelva
Qe EF
Qh EF
Qh SLS dry
Qh SLS wet
z/L
August 14, 2009
Q_H and Q_E [W m^{-2}]
stability z/L
hours [CET]


Bayelva
Qe EF
Qh EF
Qh SLS dry
Qh SLS wet
z/L
August 15, 2009
Q_H and Q_E [W m^{-2}]
stability z/L
hours [CET]


Bayelva
Qe EF
Qh EF
Qh SLS dry
Qh SLS wet
z/L
August 16, 2009
Q_H and Q_E [W m^{-2}]
stability z/L
hours [CET]


Bayelva
Qe EF
Qh EF
Qh SLS dry
Qh SLS wet
z/L
August 17, 2009
Q_H and Q_E [W m^{-2}]
stability z/L
hours [CET]


Bayelva
Qe EF
Qh EF
Qh SLS dry
Qh SLS wet
z/L
August 18, 2009
Q_H and Q_E [W m^{-2}]
stability z/L
hours [CET]


Bayelva
Qe EF
Qh EF
Qh SLS dry
Qh SLS wet
z/L
August 19, 2009
Q_H and Q_E [W m^{-2}]
stability z/L
hours [CET]

8 Archived Data (CD, DVD, HDD)

CD/DVD-Number	**CD/DVD-content**
DVD-1 **(Nr. 509 Archive Dept. of Micrometeorology, Univ. of Bayreuth)**	Project ARCTEX-2009 - Diploma thesis of Martin Wagner: Raw-data: SLS20, EC-CSAT3, Bayelva-Permafrost-Station, BSRN (Radiation), AWI-Meteo-Tower, Radiosonde; Text, Tables and figures of this documentation and the Diploma theses
DVD-2 **(Nr. 510 Archive Dept. of Micrometeorology, Univ. of Bayreuth)**	Project ARCTEX-2009: Detailed FOOTPRINT Analysis: Land use and roughness matrix Bayelva; TERRAFEX: calculations, tables and figures
DVD-3 **(Nr. 511 Archive Dept. of Micrometeorology, Univ. of Bayreuth)**	Project ARCTEX-2009: Post-processed data SLS20- Scintillometer (corrected) Eddy-Covariance turbulent heat fluxes (TK2-calculations, QA/QC)

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04	Foken et al.	Nachfrostgefährdung des ÖBG	03/1999
05	Hierteis	Dokumentation des Experimentes Dlouhá Louka (CR), 09/1998	03/1999
06	Mangold	Dokumentation des Experimentes am Standort Weidenbrunnen, Juli/August 1998	07/1999
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10	Sodemann	Stationsdatenbank zum BStMLU-Projekt Lufthygienisch-bioklimatische Kennzeichnung des oberen Egertales	03/2000
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