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Baltic Sea Experiment

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The eight BALTIMOS Field Experiments 1998 – 2001 over the Baltic Sea

- Field Reports and Examples of Measurements -

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ISSN 1681-6471

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Hamburg / Helsinki
January 2003

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Contents

1. Introduction

This report summarizes the measurements taken during eight field campaigns over the open and ice-covered water of the Baltic Sea during the period 1998-2001. The overall objective for all eight field experiments was to collect a comprehensive data set suited to validate the coupled model system BALTIMOS (Baltic Sea integrated model system) for the Baltic Sea region. The observations mainly focus on:

- the atmospheric boundary layer structure and processes and the air-sea-ice interaction over areas with inhomogeneous sea ice cover
- the atmospheric boundary layer structure over open water under different synoptic conditions such as cold-air advection, warm-air advection, or frontal passages.

The model system BALTIMOS links existing models for the atmosphere (model REMO "Regional Model"), for the ocean including sea ice (model BSIOM "Baltic Sea Ice Ocean Model"), for the hydrology (model LARSIM "Large Area Runoff Simulation Model") as well as for lakes and vegetation. BALTIMOS is not only the name of the integrated model system but also the name of a research compound in which the coupled model is developed and validated (www.baltimos.de). The research compound is funded by the German Ministry of Research (BMBF) and contributes to the Baltic Sea Experiment (BALTEX). The main objective of the BALTEX research programme is the understanding and realistic modelling of the water and energy budgets of the Baltic Sea and its catchment areas. The model validation of BALTIMOS thus will primarily focus on the water and energy cycle components.

The Baltic Sea itself is a large data-sparse area. Following the recommendations of the BALTEX/BRIDGE Strategic Plan (1997), the eight BALTIMOS field experiments were conducted systematically during all four seasons (two during each season) and over open water and sea ice of the Baltic Sea were otherwise no data are available. Aircraft, ships and surface stations were applied as measurement platforms during the campaigns. The winter experiments were conducted as cooperative effort of the Finnish Institute of Marine Research (FIMR), Helsinki, and the University of Hamburg. The experiments during the other seasons were conducted by the University of Hamburg, only.

2. Experiment times and locations (overview)

The names of the eight BALTIMOS experiments and the experimental times are listed in Table 2.1. The two winter experiments were named BASIS (Baltic Air Sea Ice Study) 1998 and BASIS 2001 and the six experiments during the other seasons over the open water were named Alkor (according to the research vessel Alkor applied) and specified by the month and year of the respective experiment.

Table 2.1: Names and experimental times of the eight BALTIMOS field campaigns

Name	**Time**
BASIS 1998	17 Feb. – 6 March 1998
Alkor 4/2000	5 – 10 April 2000
Alkor 6/2000	14 – 20 June 2000
Alkor 10/2000	25 – 31 October 2000
BASIS 2001	12 – 23 Feb. 2001
Alkor 4/2001	2 – 11 April 2001
Alkor 6/2001	12 – 20 June 2001
Alkor 10/2001	29 Oct. – 7 Nov. 2001

Fig. 2.1 gives an overview of the experiment locations. Since the winters 1998 and 2001 were relatively mild, BASIS 1998 and BASIS 2001 had to be conducted over the northern part of the Gulf of Bothnia, because only that part was ice-covered. The six Alkor campaigns took place always at the location (56.02° N, 18.67° E) (a grid point of the REMO model) in the middle of the Baltic Sea proper where the distances from coasts are longest. Water depth at that place was about 110 m.

Detailed maps of the experimental areas of BASIS 1998 and BASIS 2001 are presented in Figs. 2.2 and 2.3, respectively. The maps show the positions of the various platforms involved: ship, surface meteorological stations, radiosonde stations, automatic ice buoys, and aircraft flight patterns and air base. The platforms are described in detail in Section 3.

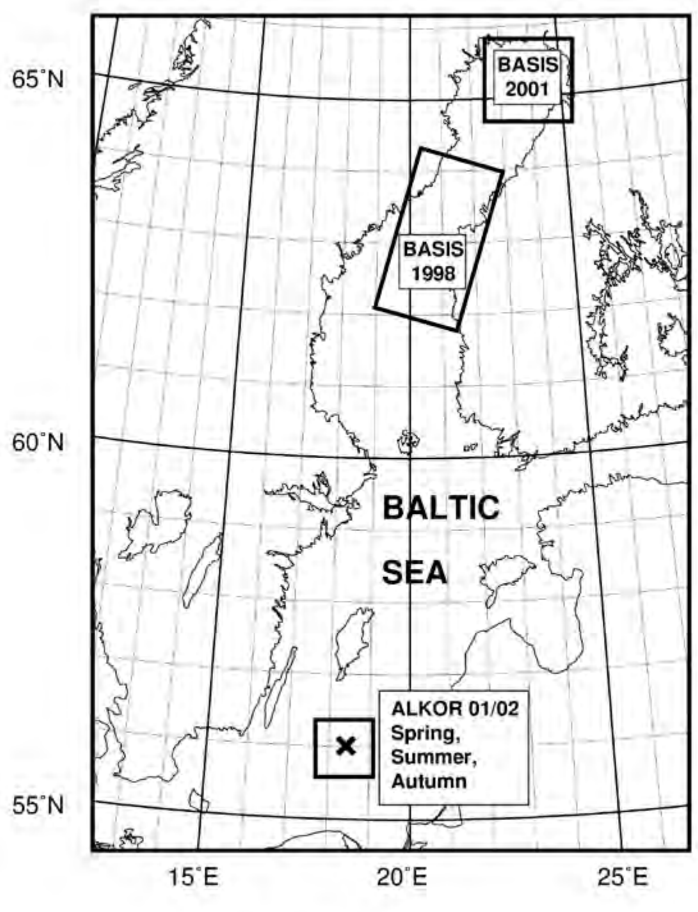


Fig. 2.1: Locations of the eight BALTIMOS field campaigns.

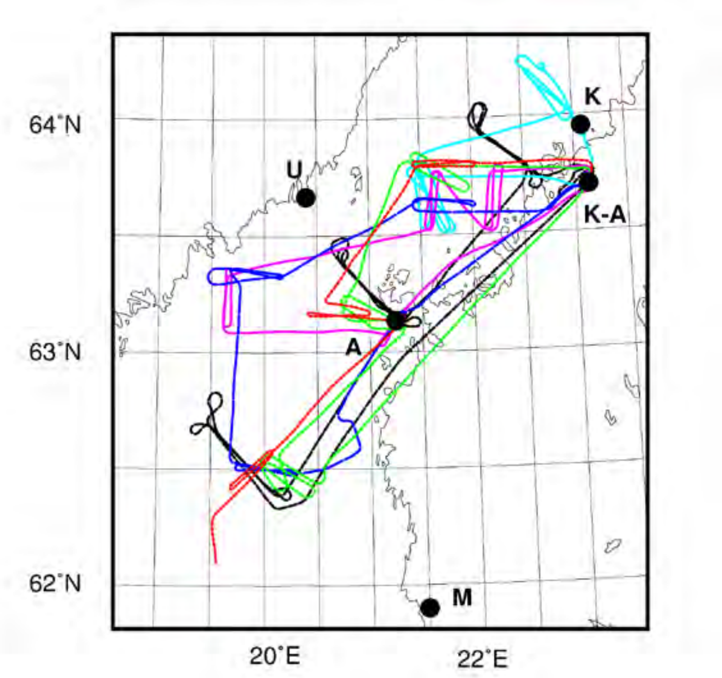


Fig. 2.2: Experimental area of BASIS 1998. Dots mark the measuring stations: A=RV Aranda in the land-fast ice, K=Kokkola on land-fast ice at 100 m distance from the shore. K-A is Kokkola airport used as base for the six flight missions of research aircraft Falcon-20. Flight patterns are indicated.

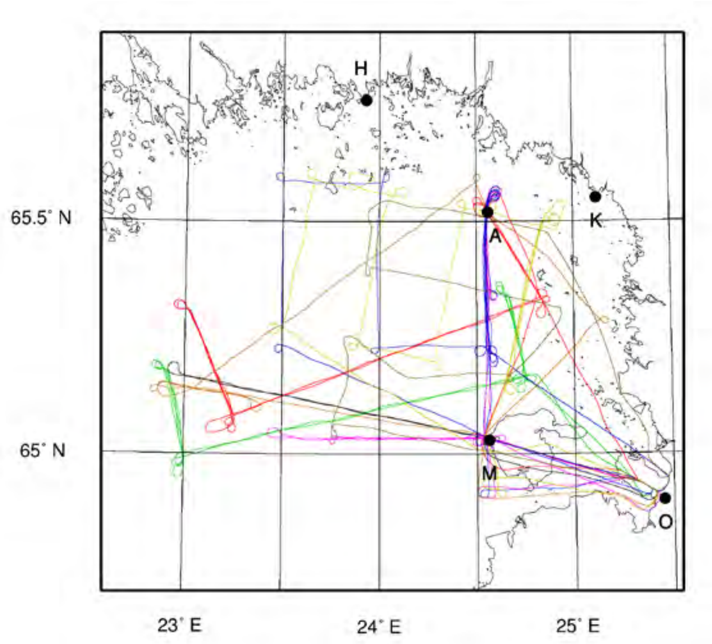


Fig. 2.3: Experimental area of BASIS 2001. Dots mark the measuring stations: A=RV Aranda in the land-fast ice, M=Marjaniemi on land-fast ice at 100 m distance from the shore, K=Kuivaniemi at the shore of land-fast ice, H=Haparanda Hamn at the shore of land-fast ice. O is Oulu airport used as base for the ten flight missions of research aircraft DO-128. Flight patterns are indicated.

3. Platforms and equipment

Table 3.1 lists the various platforms applied in the BALTIMOS field experiments and gives the names of the institutions operating the platform and/or using the data. The equipment installed at the various platforms and the measured quantities together with the sampling frequency or averaging interval are described in detail in Table 3.2. The data availability is summarized in Table 3.3. The data of the eight BALTIMOS campaigns are archived at University of Hamburg and at FIMR. In case of data request, contact the leading author of this report, Burghard Brümmer, at University of Hamburg, Meteorological Institute, Bundesstr.55, 20146 Hamburg, Germany. (E-mail: bruemmer@dkrz.de).

Table 3.1: Platforms applied in the Baltimos field experiments

BASIS 1998		BASIS 2001		Alkor 2000/2001	
Platform	**Operator/User**	**Platform**	**Operator/User**	**Platform**	**Operator/User**
RV Aranda	FIMR, Helsinki	RV Aranda	FIMR, Helsinki	RV Alkor	Univ. Kiel/ Univ. Hamburg
MS Kokkola	Univ. Hamburg	MS Marjaniemi	Univ. Hamburg		
MS Umea	Univ. Uppsala	Ice Buoys	Univ. Hamburg		
MS Merikarvia	Univ. Hannover	RA DO 128	Univ. Braunschweig/ Univ. Hamburg		
RA Falcon	DLR/Univ. Hamburg				
Ice Buoys	FIMR, SMHI, Univ. Hamburg				

FIMR = Finnish Institute of Marine Research; SMHI = Swedish Meteorological and Hydrological Institute;
DLR = Deutsches Zentrum für Luft- und Raumfahrt; RV = Research Vessel; MS = Met. Station; RA = Research Aircraft

Table 3.2: Instrumentation and measured quantities at the various platforms.
Abbreviations: p=pressure; T = temperature; T_d = dew point temperature; RH = relative humidity, FF = wind speed; DD = wind direction; S↓ = shortwave radiation from above; S↑ = shortwave radiation from below; L↓ = longwave radiations from above; L↑ = longwave radiation from below; u'w', v'w' = turbulent momentum fluxes; w'T' = turbulent temperature flux; T_{sfc} = infrared surface temperature; INS = inertial navigation system; GPS = global positioning system

RV Aranda	
- Radiosonde Station: Vaisala p, T, RH, FF, DD	2 – 6 times/day
- Ship-based Met Station: - Pressure p; - Wind Speed FF	10 min average
- Temp. T; - Wind Direct. DD	10 min average
- Humidity RH; - Longwave Rad. L↓	10 min average
- Shortwave Rad. S↓	10 min average
- Ice-based equipment: - Sonic: u'w', v'w', T'w'	10 min average
- Radiation: S↓, S↑, L↓, L↑	10 min average
- 10 m Met. mast: FF (5 x), T (3 x), RH (1 x), DD (1 x)	10 min average
- Ice properties: Temperature profile, Salinity, Thickness	
- Water: Temperature, Salinity, Current	
Met. Station Kokkola	
- Radiosonde Station (Vaisala): p, T, RH, FF, DD	4 – 6 times/day
- Ice-based equipment: - Basic Met Station: p, T, Td, FF, DD	1 min average
- Sonic u' w', v' w', T' w'	5 min average
- Radiation: Shortwave S↓, S↑	1 min average
Longwave L↓, L↑	1 min average
Infrared Sfc Temp. T_{sfc}	1 min average
- Ceilometer	1 min average

Met. Station Umea	
- Radiosonde Station: Vaisala p, T, RH	2 – 4 times/day
Pilot balloon FF, DD	2 – 4 times/day
- Ice-based equipment: - Sonic: u'w', v'w', T'w'	10 min average
- 12 m Met. profile mast: FF (3 x), T (3 x), DD (1 x)	10 min average
- Radiation: S↓, S↑, L↓, L↑	10 min average
Met. Station Merikarvia	
- Radiosonde Station: Vaisala p, T, RH, FF, DD	2 – 4 times/day
Research Aircraft Falcon: 6 Flight Missions	
Turbulence Probe (5 Hole Pressure Probe + INS + GPS): u', v', w'	100 Hz
Temperature T'	100 Hz
Humidity (Lyman α, Humicap, Dewpoint Mirror):	(100 Hz, 10 Hz, 10 Hz)
Pressure	100 Hz
Radio Altitude	100 Hz
Infrared Surface Temperature	10 Hz
Radiation: S↓, S↑, L↓, L↑	10 Hz
Argos Ice Buoys	
Automatic Met. Station (METOCEAN): p, T, RH, FF, DD	1 hourly
Met. Station Marjaniemi	
Ice-based equipment: - Basic Met Station p, T, T_d, FF, DD	1 min average
- Radiation: S↓, S↑, L↓; L↑	1 min average
- Infrared Surface Temp. T_{sfc}	1 min average
- Snow/Ice temperature –2, -6, -10, -19 cm depth	1 min average
- Sonic: u' w', v' w', T' w'	5 min average
- Ceilometer	1 min average
- Rain gauge	droplet counter/min
Research Aircraft DO-128: 10 Flight Mission	
Turbulence Probe (5 Hole Pressure Probe + INS + GPS): u', v', w'	100 Hz
Temperature T'	100 Hz
Humidity (Lyman α, Humicap, Dewpoint Mirror):	(100 Hz, 10 Hz, 10 Hz)
Pressure	100 Hz
Radio Altitude	100 Hz
Infrared Surface Temperature	10 Hz
Radiation: S↓, S↑, L↓, L↑	10 Hz
RV Alkor	
Radiosonde Station (Vaisala): p, T, RH, FF, DD	4 – 8 times/day
Basic Met Station: p, T, T_d, FF, DD	1 min average
Radiation: S↓, L↓	1 min average
Water Temperature: T_{sfc} (infrared), T_{-4m} (intake), bucket	1 min average
Ceilometer	1 min average
Sonic: u' w', v' w', T' w'	5 min average
Tiltmeter: Pitch, Roll of the ship	10 Hz
Rain gauge	1 min
Rain radar: Vertical rain profile	10 sec
Eye Observations (Clouds, Weather)	hourly

Table 3.3: Data availability (overview)

Experiment/Platform	Days with Measurement	Number of radiosoundings
BASIS 1998		
- RV Aranda - Kokkola - Umea - Merikarvia - Ice Buoys - RA Falcon	19 Days 18 Days 21 Days 18 Days 18 Days 6 Flights on 6 Days: 27, 28 Feb., 2, 3, 5, 6 March	71 Radiosondes 72 Radiosondes 50 Radiosondes 65 Radiosondes
Alkor 4/2000	6 Days	17 Radiosondes
Alkor 6/2000	7 Days	22 Radiosondes
Alkor 10/2000	7 Days	19 Radiosondes
BASIS 2001		
- RV Aranda - Marjaniemi - Ice Buoys - RA DO-128	9 Days 12 Days 9 Days 10 Flights on 9 Days: 14 – 22 February	36 Radiosondes
Alkor 4/2001	9 Days	27 Radiosondes
Alkor 6/2001	8 Days	40 Radiosondes
Alkor 10-11/2001	9 Days	40 Radiosondes
Total	76 Days	459 Radiosondes

4. The two winter experiments over the Bay of Bothnia

4.1. BASIS (Baltic Air Sea Ice Study) 1998

BASIS 1998 was a joint field experiment of six institutions: Finnish Institute of Marine Research, University of Hamburg, Germany, University of Hannover, Germany, University of Uppsala, Sweden, Swedish Meteorological and Hydrological Institute, and Chalmers Technical University, Sweden. The project was coordinated by the Finnish Institute of Marine Research and funded to a large extent by the European Commission. A detailed field-data report (Launiainen, 1999) and a scientific summary report (Launiainen and Vihma, 2001) have been published so that only a few examples of measurements during BASIS 1998 are presented here in this report.

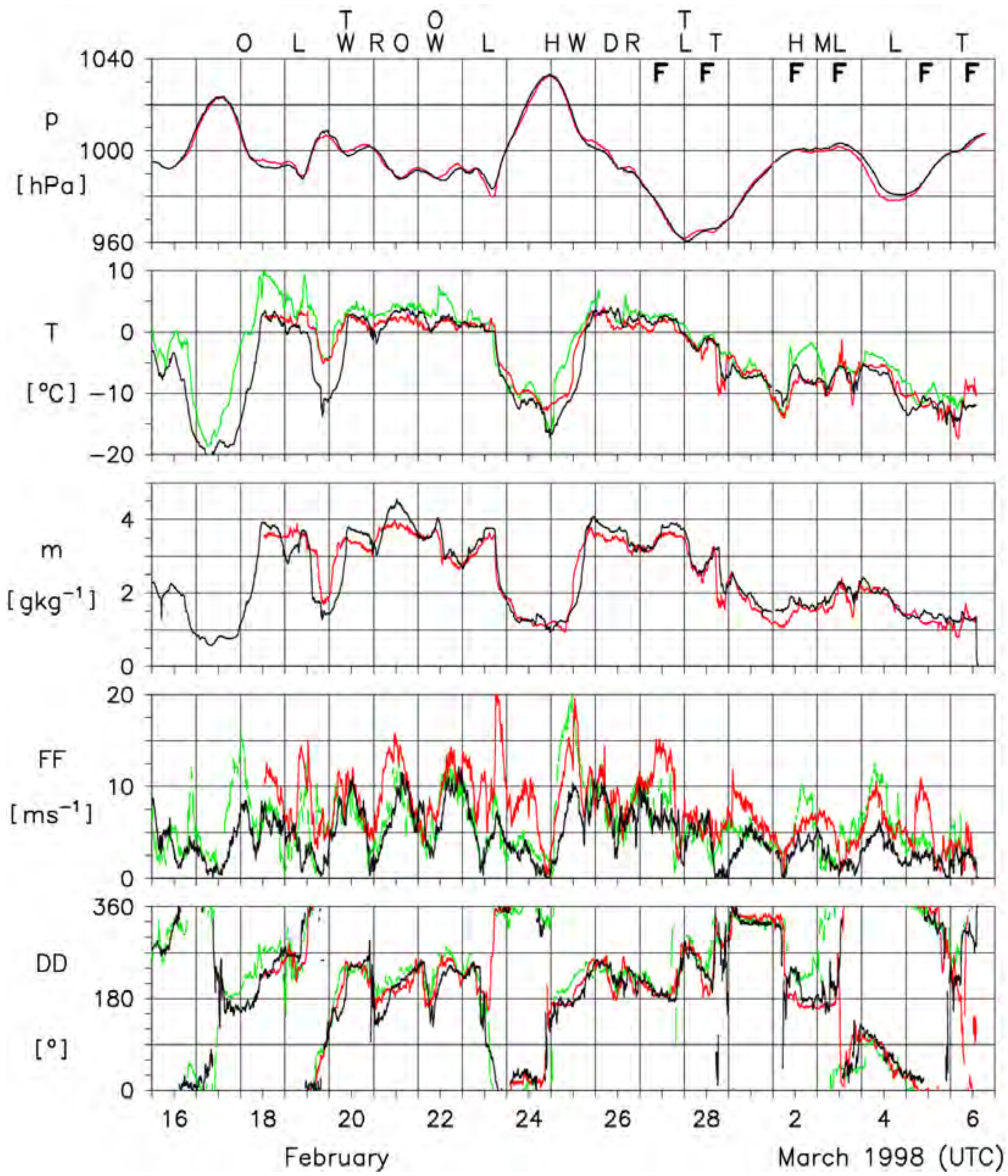


Fig. 4.1: 10 min averages of pressure p, temperature T, water vapour mixing ratio m, wind speed FF, and wind direction DD measured at Aranda (red), Kokkola (black) and Umea (green). Capitals on top mark passage times of synoptic events: high (H), low (L), ridge (R), trough (T), warm front (W), cold front (C), occlusion (O), disturbance (convergence line) (D), and mesoscale low (ML). F indicates times of Falcon flight missions.

The synoptic conditions under which the BASIS 1998 measurements were taken, are represented by the daily 00 UTC weather maps given in Appendix A1. The meteorological conditions were characterized by a rapid sequence of synoptic weather systems. Fig. 4.1 shows the time series of the basic meteorological quantities pressure p, temperature T, water vapour mixing ratio m, wind speed FF, and wind direction DD, measured at the three stations, RV Aranda, Kokkola, and Umea, which had a distance of about 80 km from each other. In spite of the distance between the three stations it is remarkable how close not only the mean basic quantities (Fig. 4.1), but also the small-scale parameters, such as the turbulent fluxes of momentum and sensible heat (Fig. 4.2) as well as the radiation fluxes (Fig. 4.3) are interrelated between the three places. This is due to the fact that the synoptic scale sets primarily the conditions also for the small-scale processes. The high correlation, in addition, underlines the good quality of the measurements.

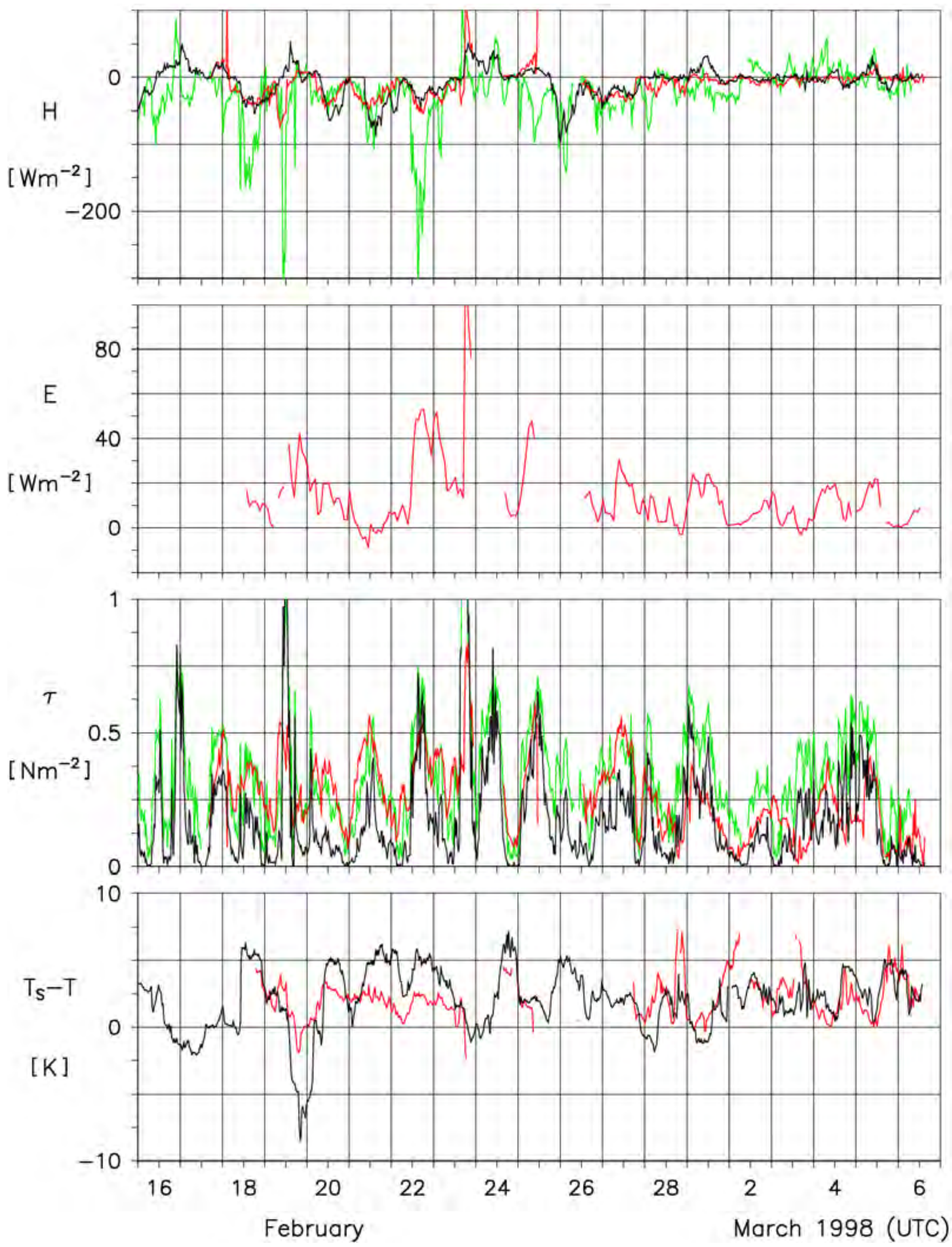


Fig. 4.2: 30 min averages of sensible heat flux H, latent heat flux E, momentum flux τ, and air-surface temperature difference $T\text{-}T_S$ at Aranda (red), Kokkola (black) and Umea (green).

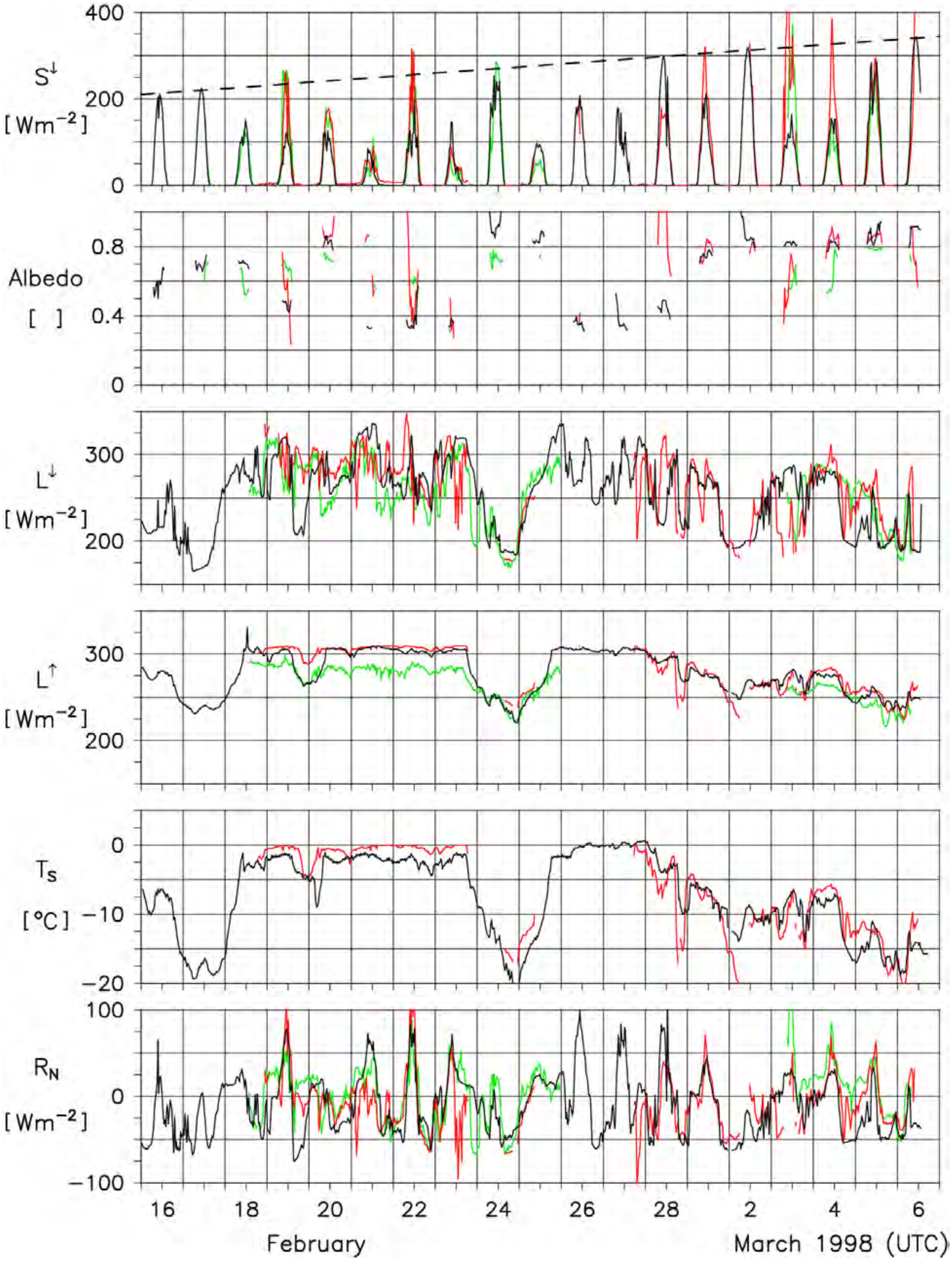


Fig. 4.3: 30 min averages of various radiation quantities: shortwave radiation from above S↓ (dashed line marks daily clear sky maximum), albedo, longwave radiation from above L↓ and below L↑, infrared surface temperature T_S, and net radiation R_N measured at Aranda (red), Kokkola (black), and Umea (green).

As an example for the six-hourly launched radiosondes at RV Aranda, Kokkola, Umea and Merikarvia, the profiles of air temperature T and wind speed FF at Kokkola are presented in Figs. 4.4. to 4.6. The frequent occurrence of stable stratification (often surface-based inversions) in the boundary layer is mentioned; this was mostly accompanied with wind maxima (low-level jets). Fig. 4.6 also shows the frequent loss of the wind data at low levels by the GPS wind finding system of the Vaisala radiosondes, a problem which has been reduced in the meantime but not completely overcome.

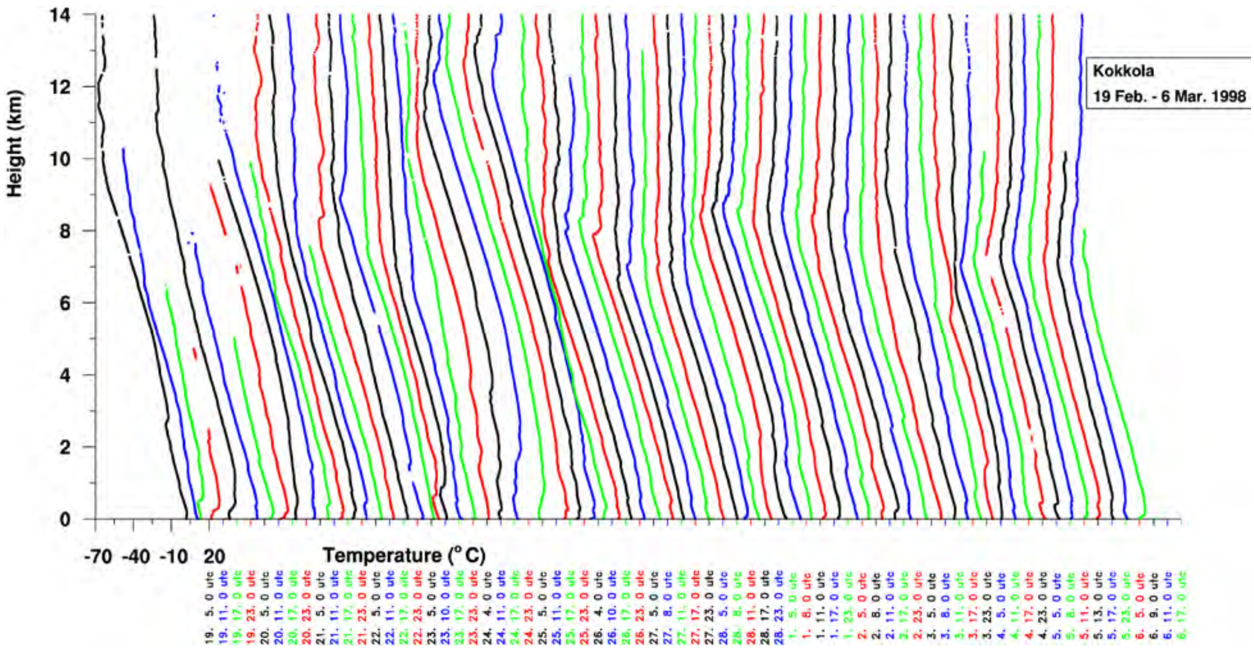
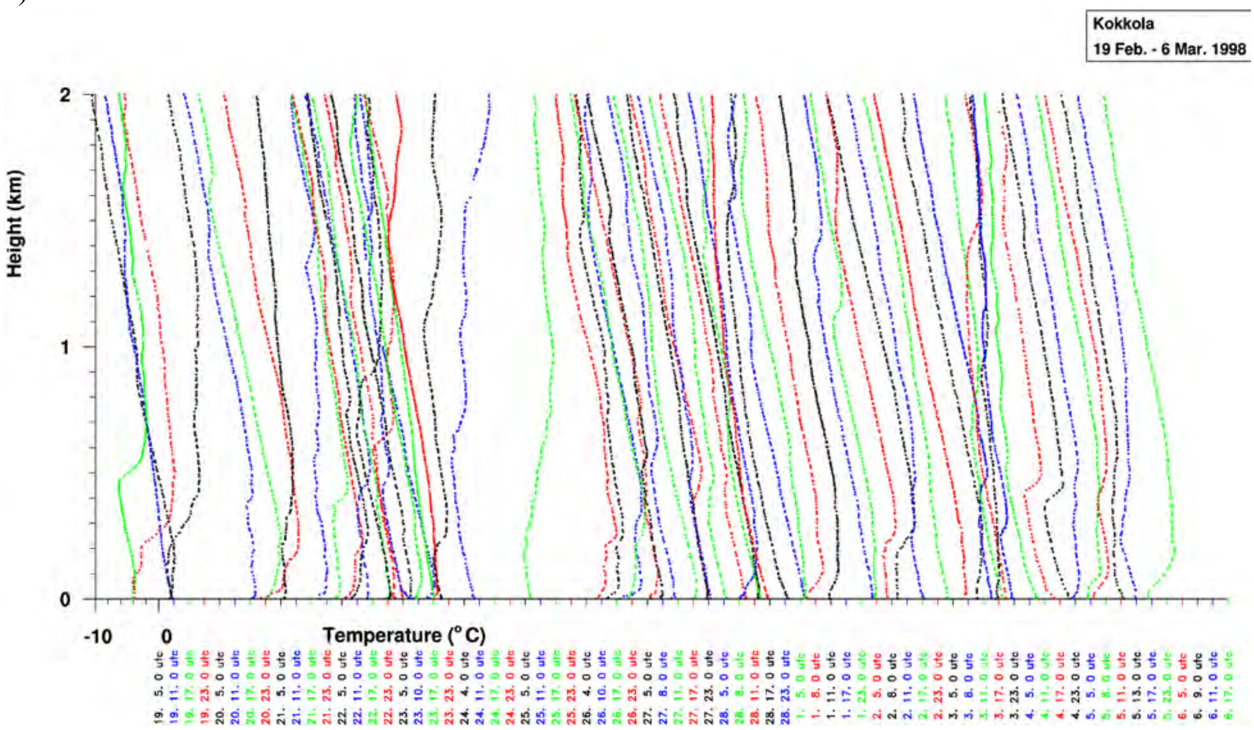


Fig. 4.4: Vertical temperature profiles between surface and 14 km height as measured by 71 Vaisala radiosondes at Kokkola during the period 19 February 1998 05 UT to 6 March 1998 17 UTC. Tick marks at the abscissa indicate the 20°C value of the running temperature scale and the launch time.

a)



b)

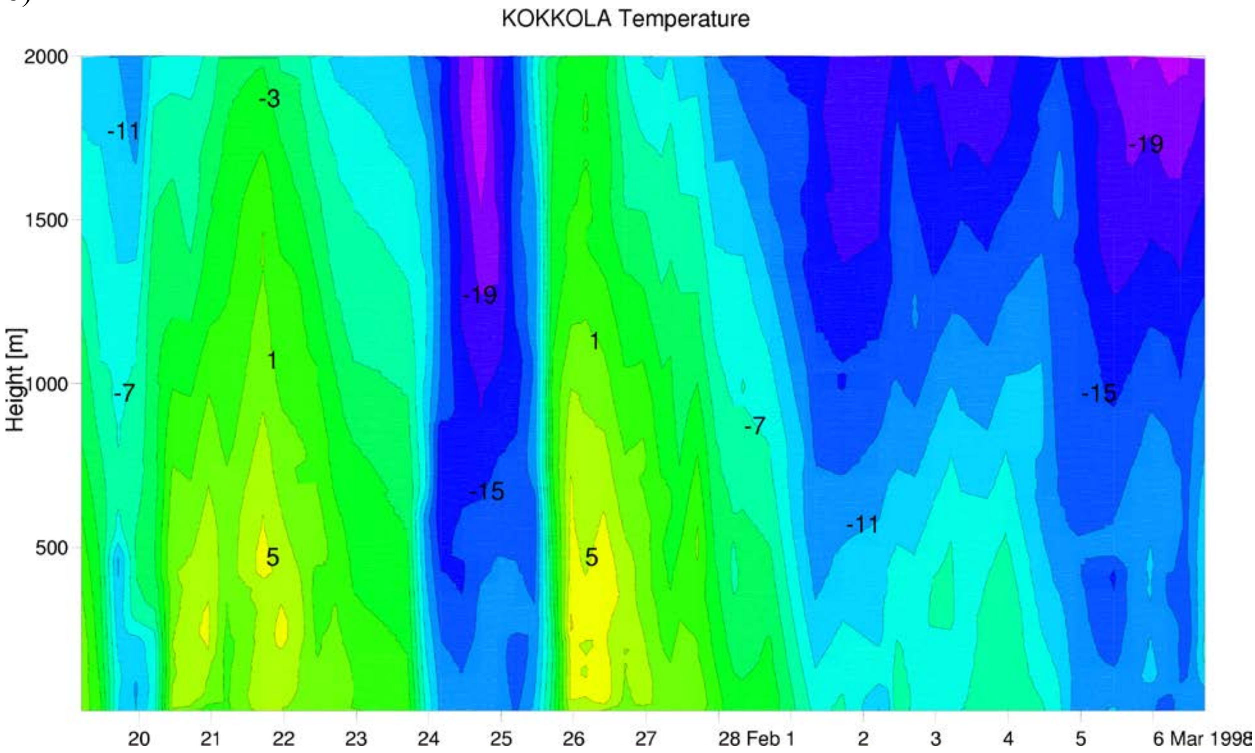
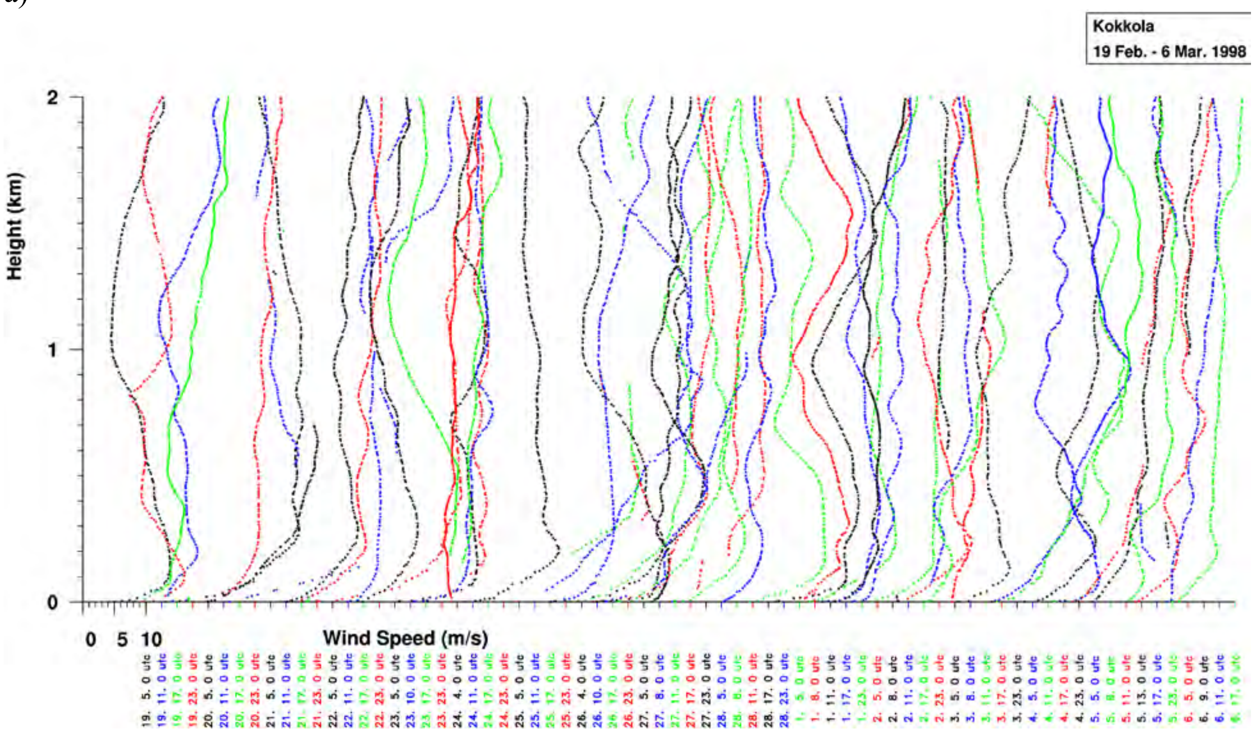


Fig. 4.5: (a) Vertical temperature profiles between surface and 2 km height as measured by 71 Vaisala radiosondes at Kokkola during the period 19 February 1998 05 UTC to 6 March 1998 17 UTC. Tick marks at the abscissa indicate the 5°C value of the running temperature scale and the launch time.
(b) Time height cross section of temperature based on the 71 radiosoundings presented in (a). Temperature isoline difference is 2 K.

a)



b)

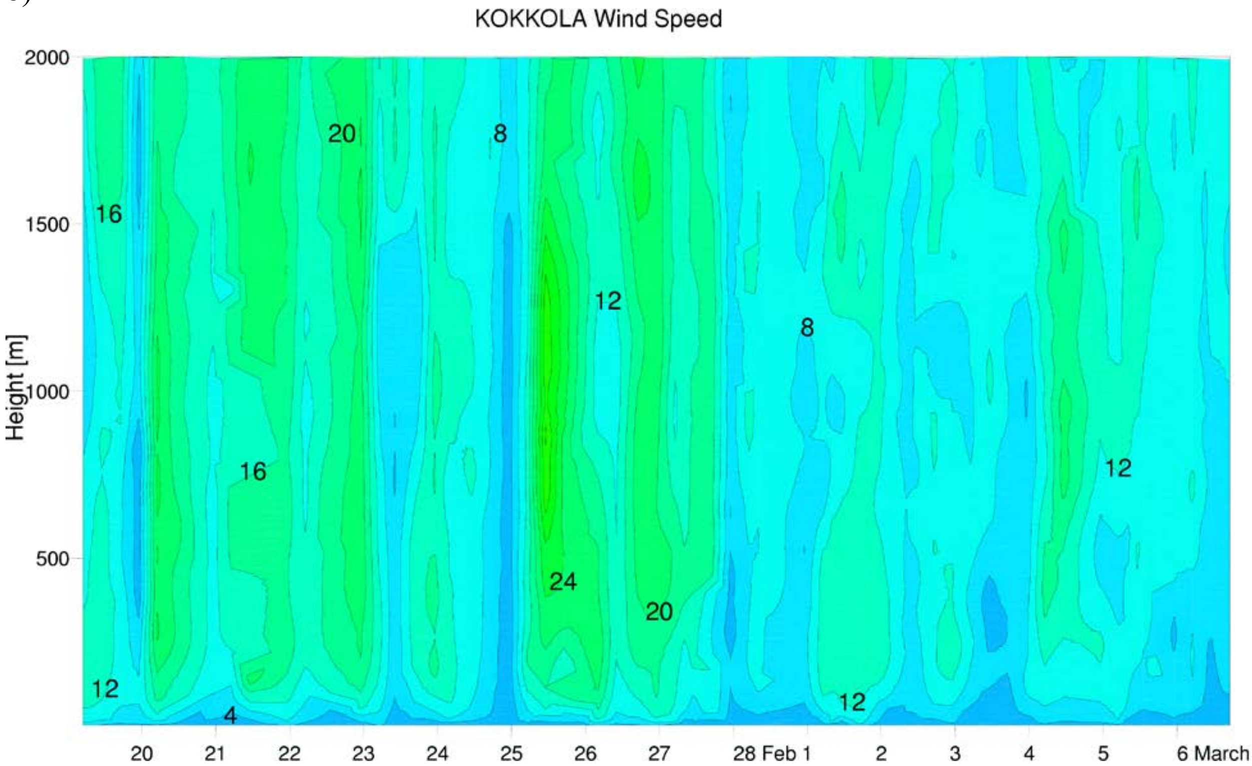


Fig. 4.6: (a) Vertical profiles of wind speed between surface and 2 km height as measured by 71 Vaisala radiosondes at Kokkola during the period 19 February 1998 05 UTC and 6 March 1998 17 UTC. Tick marks at the abscissa indicate the 30 ms^{-1} value of the running wind speed scale and the launch time.
(b): Time height cross section of wind speed based on the 71 radiosoundings presented in (a). Wind speed isoline difference is 4 ms^{-1}.

Flight missions with research Falcon were flown on six days during BASIS 1998 (27, 28 February, 2, 3, 5, 6 March 1998) under different large-scale flow conditions. Two examples are presented below: for the on-ice air flow on 27 February 1998 and the off-ice air flow on 5 March 1998. In the on-ice air flow, the boundary layer is shallow and does not change much along a trajectory from the open water to the ice (Fig. 4.7). In spite of the stable air-sea and air-ice stratification, the relatively strong wind causes some "mixing" in the surface – based inversion layer. When crossing the ice edge at 80 m height during a horizontal flight leg (Fig. 4.8) there is only a small difference between water and ice surface temperature and thus turbulent fluxes of momentum, sensible and latent heat. The same holds for the entire mesoscale area (60 km x 150 km) covered by the flight mission (Fig. 4.9).

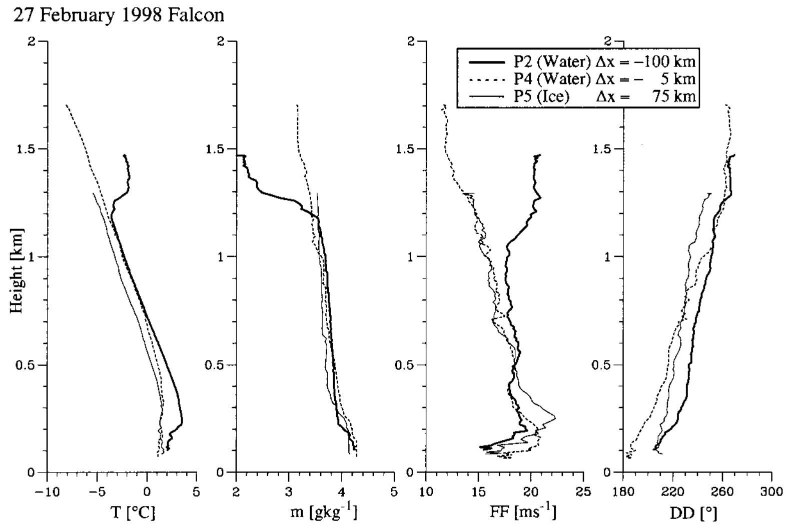


Fig. 4.7: Vertical profile of temperature T, water vapour mixing ratio m, wind speed FF, and wind direction measured by research aircraft Falcon on 27 February 1998 at different distances ∊x from the icedge (∊x=0) during on-ice air flow.

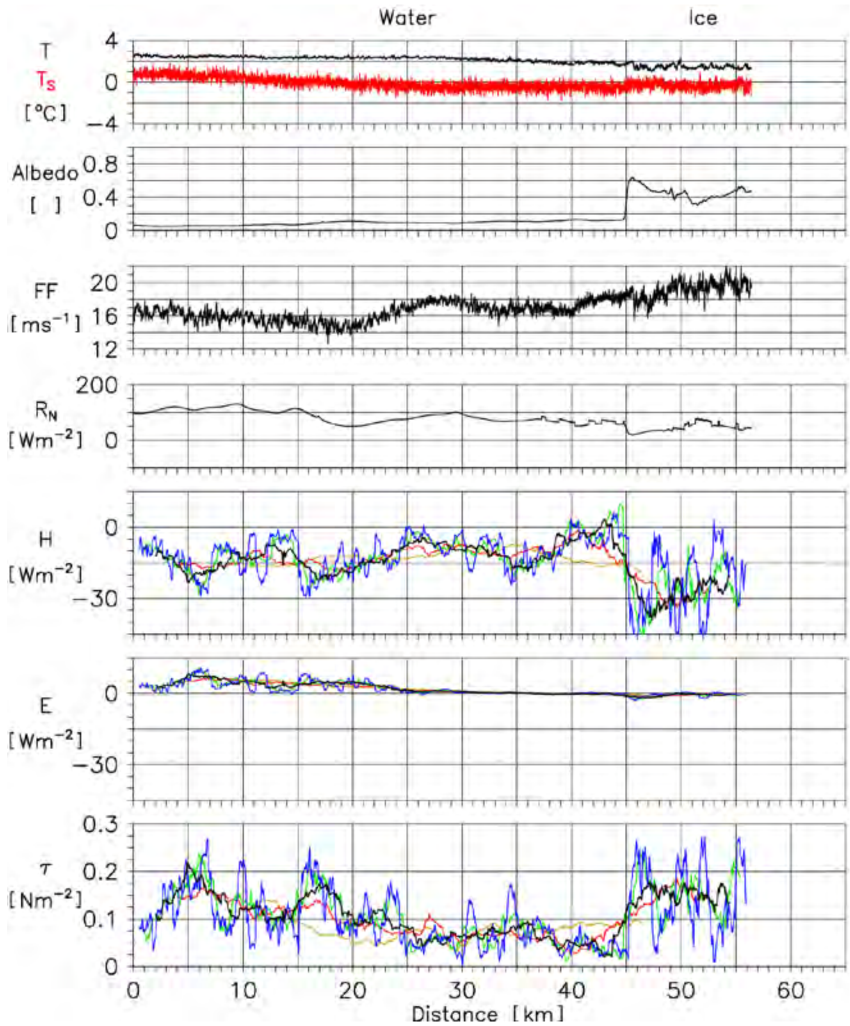


Fig. 4.8: Research aircraft Falcon measurements at 90 m height along a 56 km long leg from the open water to the sea ice during on-ice air flow on 27 February 1998: air temperature T, infrared surface temperature T_S, shortwave albedo, wind speed FF, net radiation flux R_N, sensible heat flux H, latent heat flux E, and momentum flux τ. H, E, τ were calculated for various length intervals: 1 km (blue), 2 km (green), 4 km (black), 8 km (red) and 20 km (yellow).

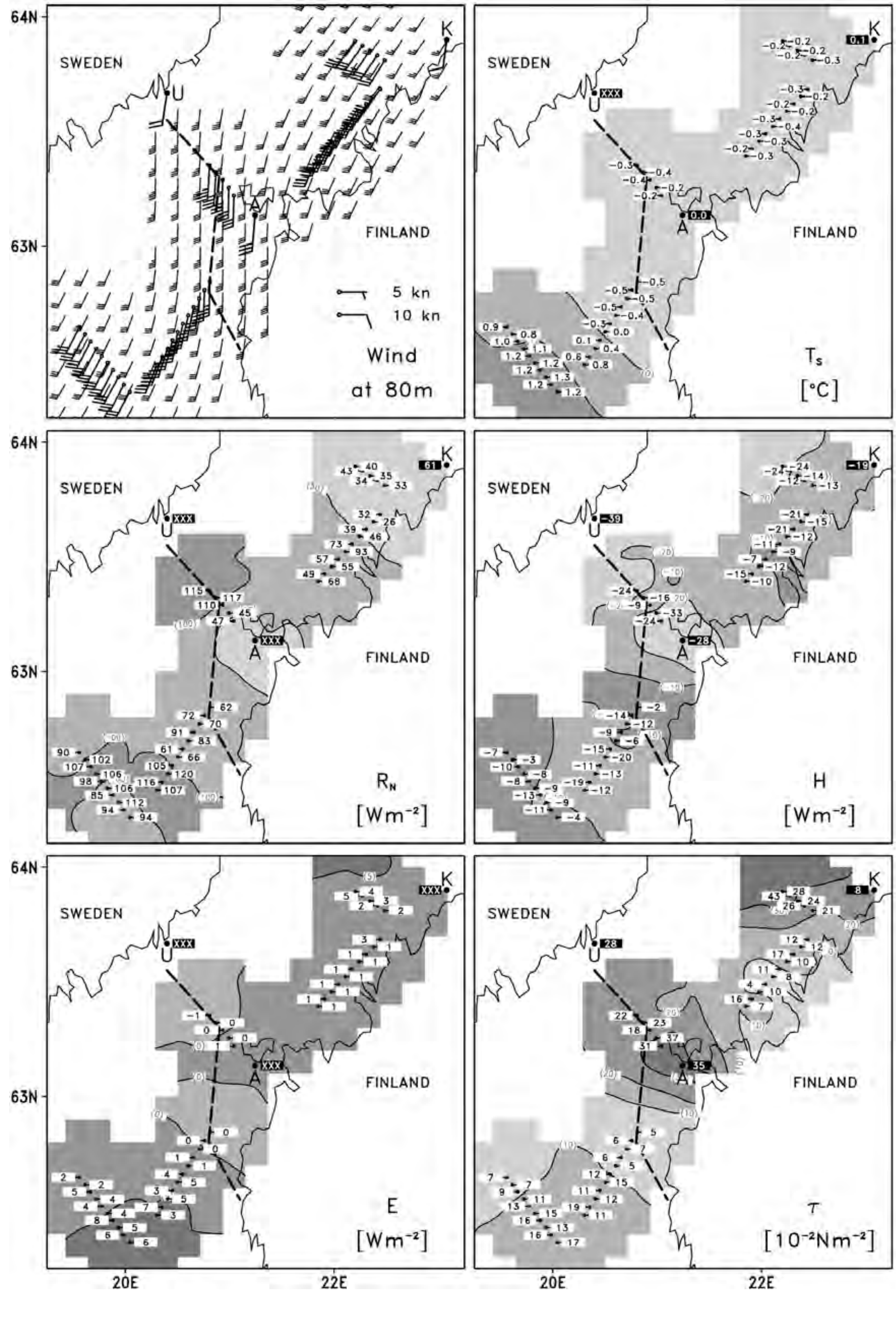


Fig. 4.9: Maps of mesoscale distributions of wind vector, surface temperature T_S, net radiation flux R_N, sensible heat flux H, latent heat flux E, and momentum flux τ based on research aircraft Falcon measurements at 80 m height during on-ice air flow on 27 February 1998 between 9.15 and 11.30 UTC. White rectangles give aircraft 4 km averages, black rectangles give ice stations' 1 hour averages (for comparison). Aircraft 4 km averages were inter- and extrapolated on a regular 10 km grid (grey areas) according to Cressman (1959) for better view of mesoscale distributions. Thick dashed line marks outermost ice edge (from aircraft observation).

The conditions of air-mass modification are completely different during off-ice flow. The depth of the boundary layer is deeper and increased from the closed ice to the broken ice and finally to the open water (Fig. 4.10). A 60 km long horizontal flight leg at 30 m height crossing the ice edge shows large differences in heat fluxes over ice and open water (Fig. 4.11). The heat flux at 30 m height reflects immediately changes of the underlying surface. The reaction is the closer the smaller the length interval for averaging the turbulent flux is chosen. A 4 km length interval appears to be a reasonable compromise between horizontal resolution and statistical significance. The clear transition of the mean quantities and turbulent fluxes from the closed ice to the open water is also obvious in the mesoscale map in Fig. 4.12.

The aircraft measurements during a flight mission delivered a "complete" three-dimensional status of the atmospheric boundary layer over the sea ice and ice-edge region. "Complete" is meant here with respect to the meteorological quantities sampled: The mean quantities (including surface temperature), the turbulent fluxes of momentum, sensible and latent heat (at several vertical levels, called stacks), the shortwave and longwave radiation fluxes, and the cloud situation (base, top, coverage). The aircraft data are therefore particularly suited for validation of the coupled BALTIMOS model or other regional coupled or uncoupled models for the atmosphere and sea ice.

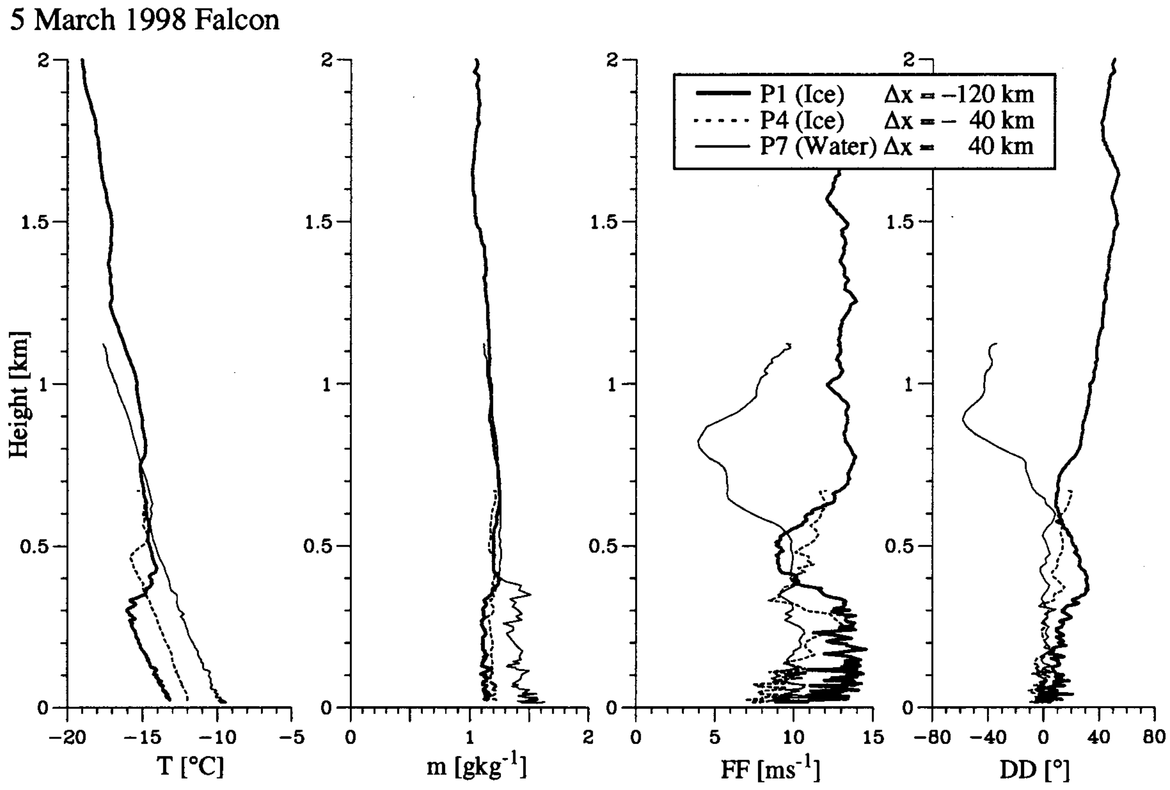


Fig. 4.10: As Fig. 4.7, but measured by research aircraft Falcon on 5 March 1998 during off-ice air flow.

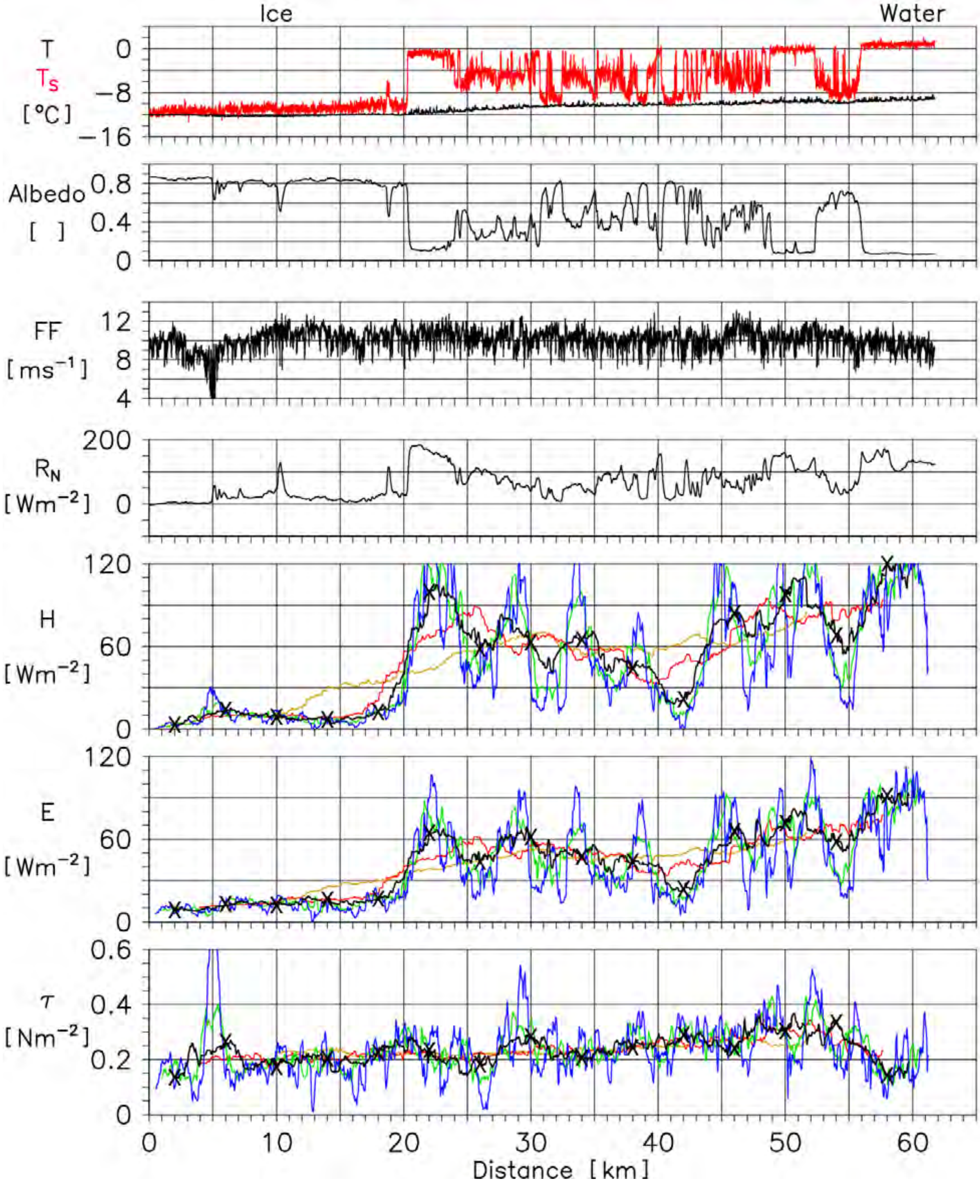


Fig. 4.11: As Fig. 4.8, but measured by research aircraft Falcon at 30 m height along a 62 km long leg from the sea ice to the open water during off-ice air flow on 5 March 1998.

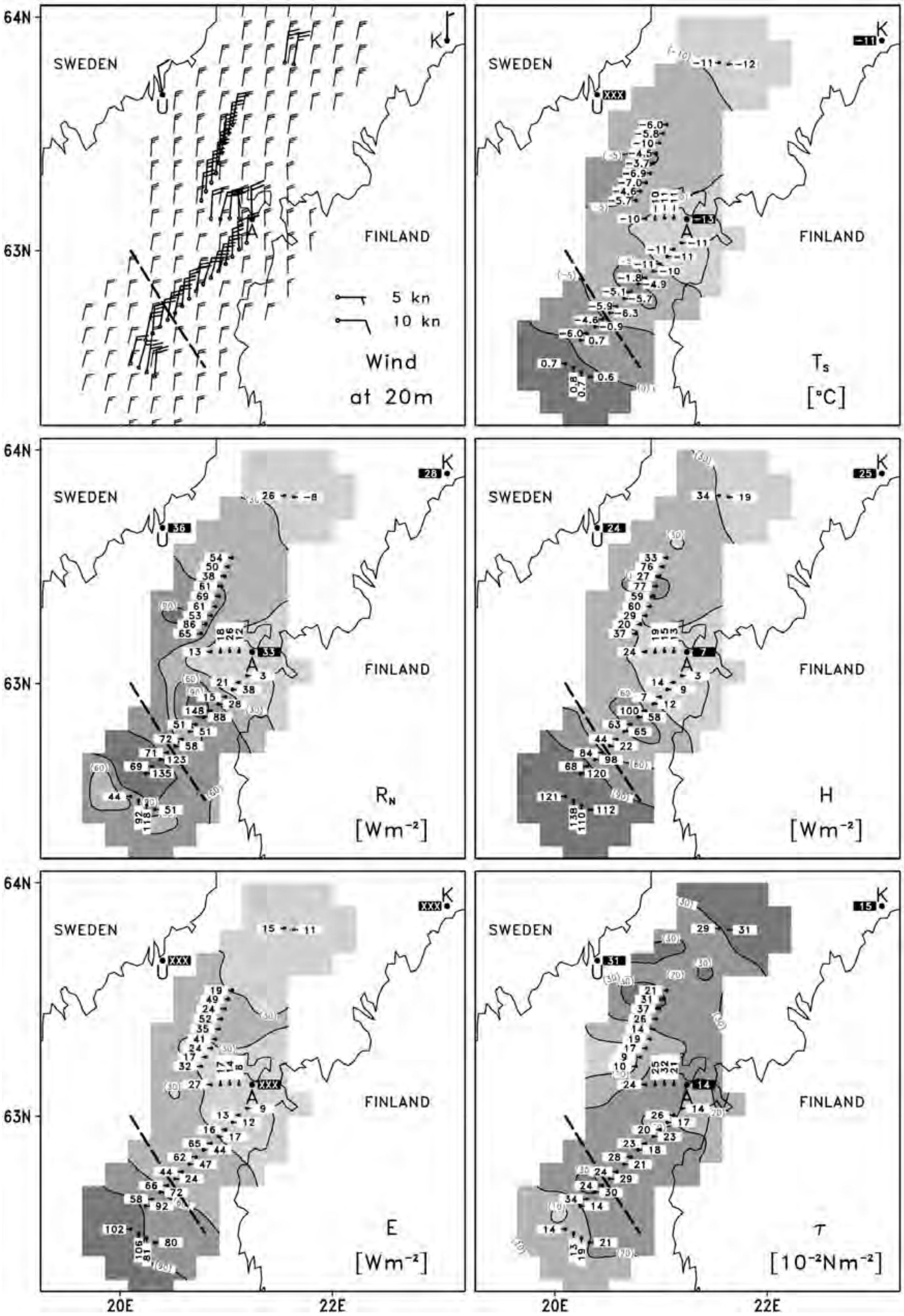


Fig. 4.12: As Fig. 4.9, but measured by research aircraft Falcon at 20 m height during off-ice air flow on 5 March 1998 between 09 und 10.30 UTC.

4.2. BASIS (Baltic Air Sea Ice Study) 2001

Four platforms were involved in BASIS 2001 (see Tables 3.1 –3.3): RV Aranda located in the land-fast ice, meteorological surface station Marjaniemi located at the west side of the Isle of Hailuoto, two automatic meteorological ice buoys deployed at the shore in Kuivaniemi and Haparanda Hamn and the research aircraft DO-128 which operated from the airfield of Oulu. The locations of the platforms and the flight patterns are shown in Fig. 2.3. The synoptic conditions were characterized by frequent passages of weather systems (highs, lows, fronts) as can be seen from the weather maps collected in Appendix A2.

4.2.1. Meteorological surface station Marjaniemi

The meteorological surface station Marjaniemi was deployed on 30-40 cm thick land-fast ice at a distance of about 100 m from the shore line where the water was 0.5 – 1 m deep. Power supply and data registration were made via 300 m long cables to the biological laboratory operated the University of Oulu. Undisturbed air flow was present for winds from 130° to 360°, for the other wind directions the flow was from the island which is 1 to 6 m high and covered mostly by forest; the nearest distance between the ice-station and the forest was about 300 m. The environmental conditions and the instrumentation are illustrated in Figs. 4.13 – 4.19.

The technical responsibility for the Marjaniemi station was in the hands of Rudolf Kapp and Michael Offermann.

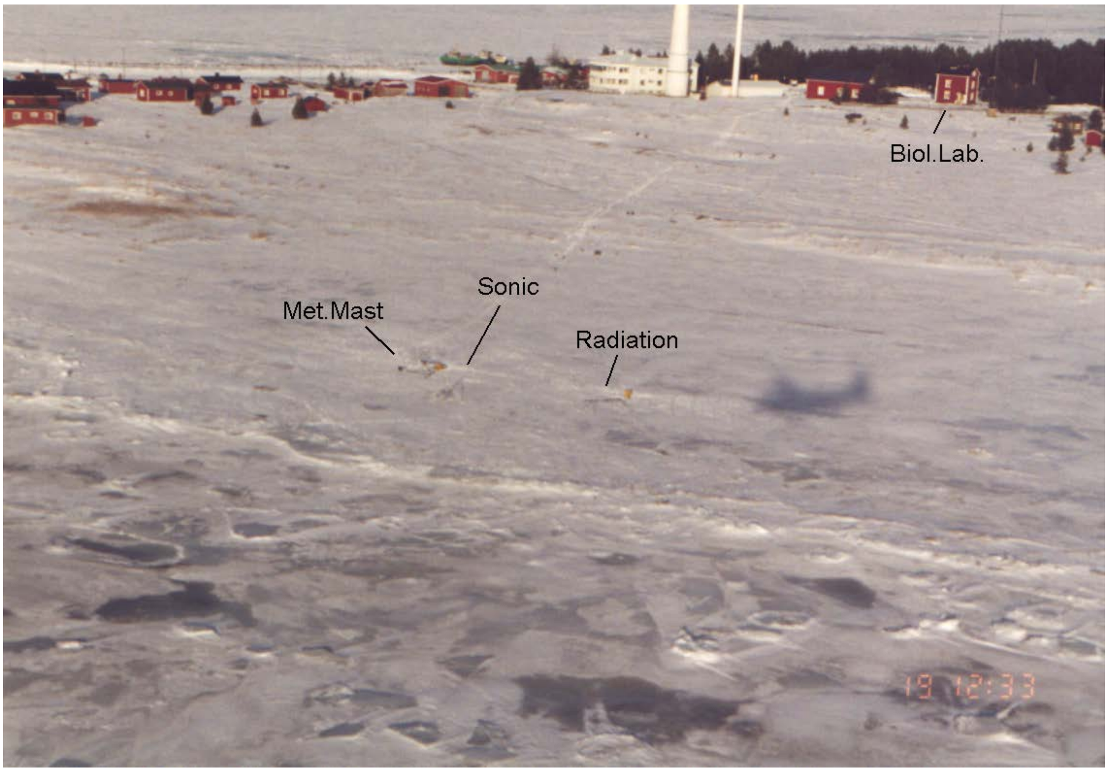


Fig. 4.13: Marjaniemi ice station on the land-fast ice as photographed on 19 February 2001 from research aircraft DO-128 looking towards NE. In the background Marjaniemi village with light house (white) and biological laboratory of Oulu University.

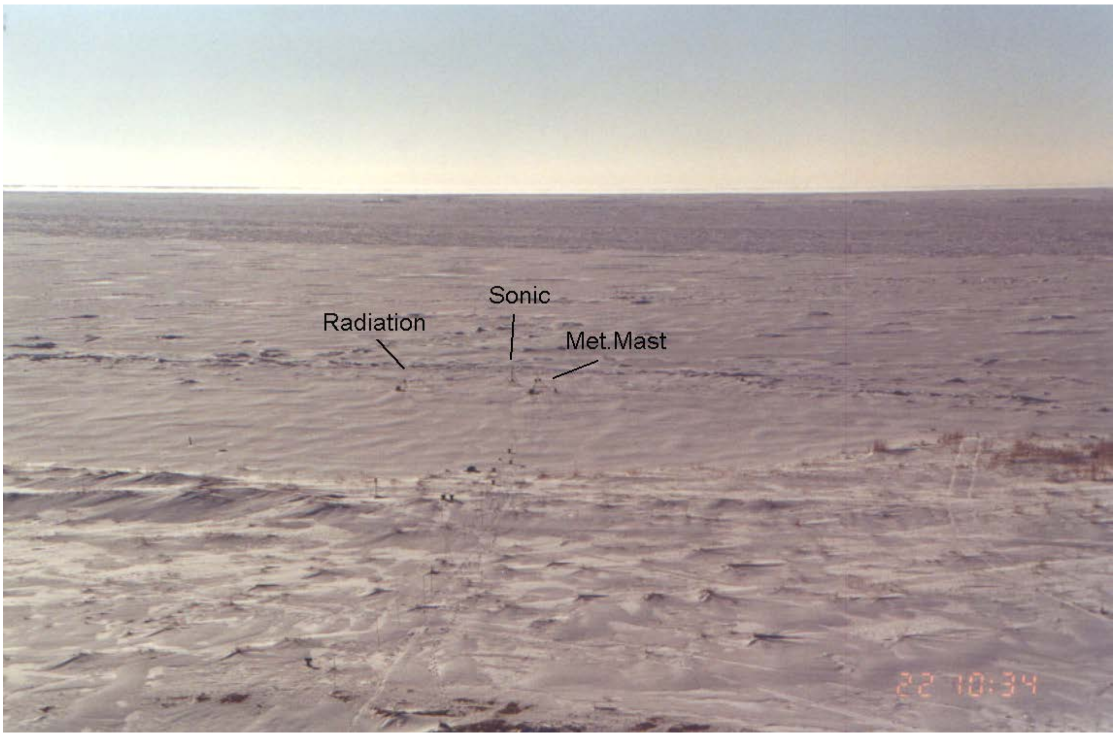


Fig. 4.14: : Marjaniemi ice station on the land-fast ice as photographed on 22 February 2001 from the Marjaniemi light-house looking towards WSW.

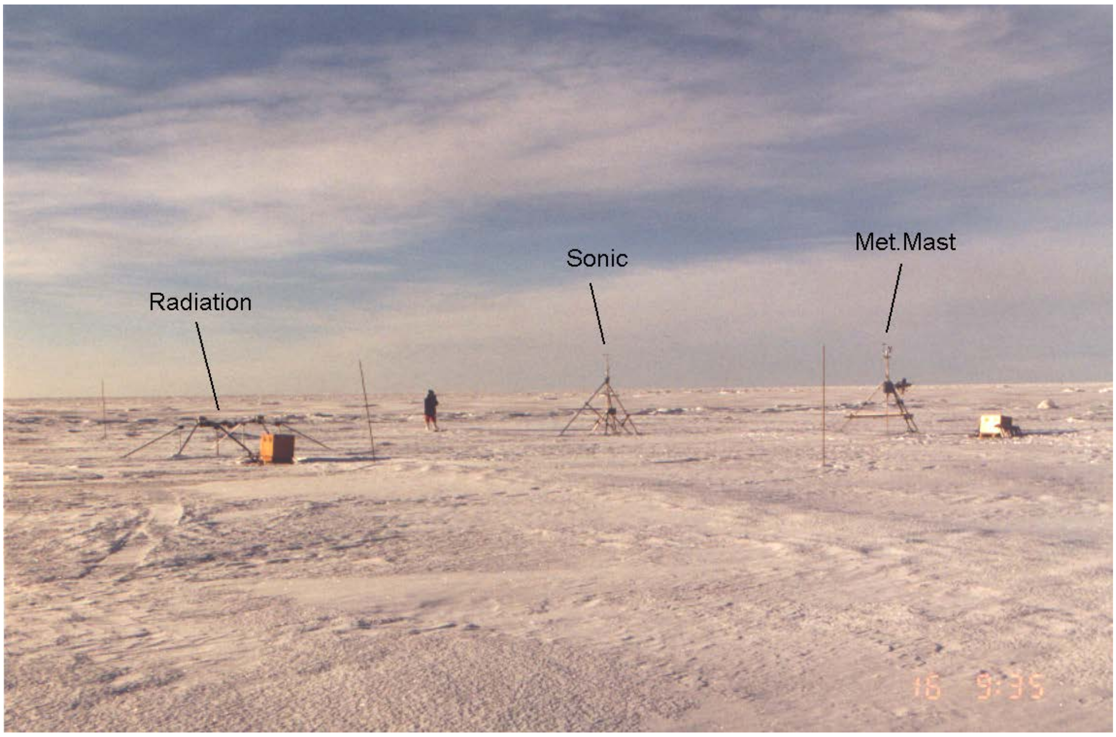


Fig. 4.15: Marjaniemi ice station on the land-fast ice as photographed on 16 February 2001 when looking towards west: meteorological mast (right), Sonic mast (middle), and radiation instruments (left).

The equipment deployed on the land-fast ice consisted of the following components: a meteorological mast (Fig. 4.16), a radiation station (Fig. 4.17), and a turbulence mast (Fig. 4.18). At the meteorological mast wind speed FF (cup anemometer) and wind direction DD (wind vane) were measured at 2.9 m height, air temperature T and air humidity (relative humidity RH and dew point temperature T_d) were measured at 1.55 m height redundantly by a Vaisala humicap and a Kroneis dew point hygrometer. Near the foot of the meteorological mast the surface (ice/snow) temperature T_{sfc} was measured by an infrared radiometer (Heimann KT-19) looking downward from 1.55 m height at a zenith angle of 40°. Close to this point snow/ice temperatures were measured at -0.02, -0.06, -0.10 and -0.19 m depth.

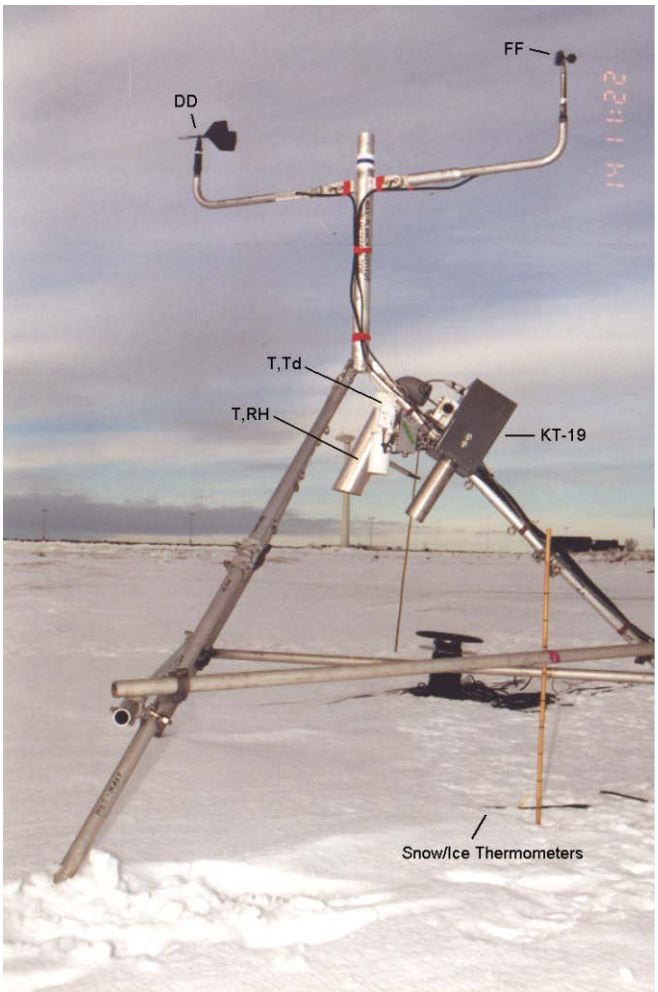


Fig. 4.16: Meteorological mast at Marjaniemi ice station with cup anemometer and wind vane at 2.9 m height, Vaisala humicap (T, RH) and dew point mirror (T, T_d), at 1.55 m, surface temperature radiometer KT-19 and snow/ice thermometers.

The radiation station consisted of a 0,8 m high metal frame at which the radiation instruments were mounted (Fig. 4.17). Shortwave downwelling and upwelling radiation, S↓ and S↑, were measured by Kipp and Zonen instruments and longwave downwelling and upwelling radiation, L↓ and L↑, by Eppley instruments.

The turbulence mast (Fig. 4.18) carried on its top at 3.0 m an ultra sound anemometer/thermometer (Metek USAT) measuring with a frequency of 10 Hz the three wind components u, v, w and the virtual temperature T_v. From these data variances and covariances, such as the turbulent momentum flux τ and the turbulent heat flux H, were calculated over 5 minutes intervals.

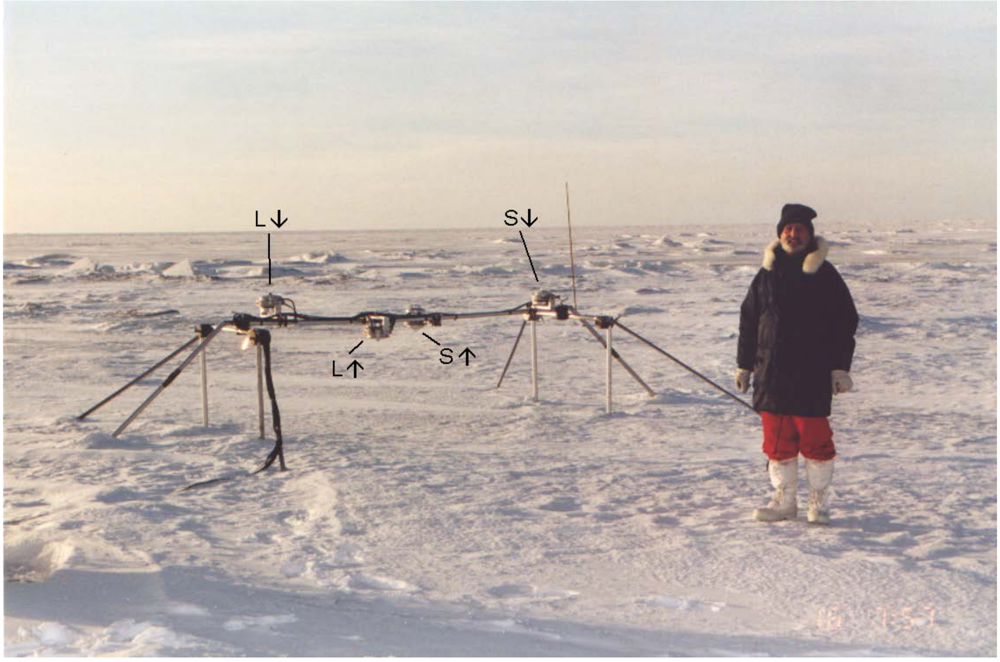


Fig. 4.17: Radiation station at Marjaniemi ice station with pyrgeometers (Eppley) for downwelling (L↓) and upwelling (L↑) longwave radiation (left) and pyranometers (Kipp and Zonen) for downwelling (S↓) and upwelling (S↑) shortwave radiation (right).

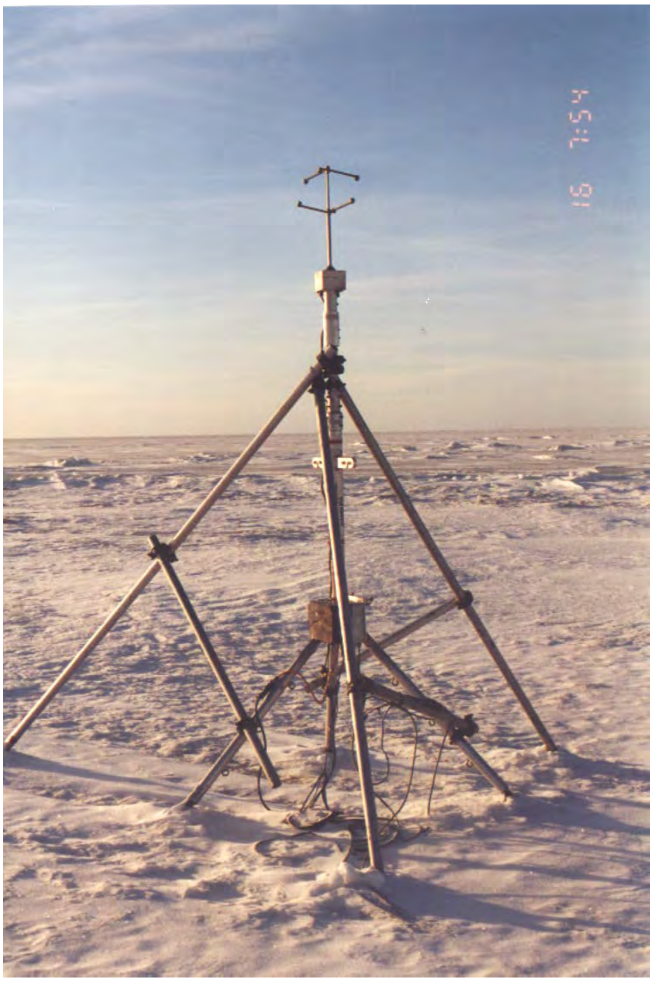


Fig. 4.18: Turbulence mast at Marjaniemi ice station with sonic instrument (Metek USAT) at 3.0 m height.

The instrumentation at the Marjaniemi station was completed by a barometer (Vaisala PTB 200 A at 7 m height), a ceilometer (Impulsphysik LD-WHL) for cloud base height, and a rain/snow gauge (Lambrecht 15188-H) which were placed in or near the biological laboratory (Fig. 4.19).

Fig. 4.19: Ceilometer (Impulsphysik LD-WHL) and precipitation gauge (Lambrecht 15188-H) at Marjaniemi ice station near biological laboratory of Oulu University.

The data from the meteorological mast, the radiation station, the barometer, ceilometer, and rain/snow gauge were sampled every second and recorded as 1-minute averages.

Time series of the basic meteorological parameters, p, T, T_{sfc}, RH, FF, DD, are presented in Fig. 4.20, of the snow/ice temperatures at various depths, T_{sfc}, T_{-2}, T_{-6}, T_{-10} and T_{-19} are presented in Fig. 4.21, of the radiation fluxes, $S\downarrow$, $S\uparrow$, $L\downarrow$, $L\uparrow$, and of the net radiation flux $R_N = S\downarrow - S\uparrow + L\downarrow - L\uparrow$ and albedo $A = S\uparrow / S\downarrow$ are presented in Fig. 4.22, of the sonic mean values, T_v, FF, and DD, and sonic turbulent fluxes, H and τ, and turbulent kinetic energy, $E_{kin,turb} = \frac{1}{2}\left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right)$, are presented in Fig. 4.23, and finally of the ceilometer cloud base and precipitation gauge (all precipitation fell as snow) are presented in Fig. 4.24.

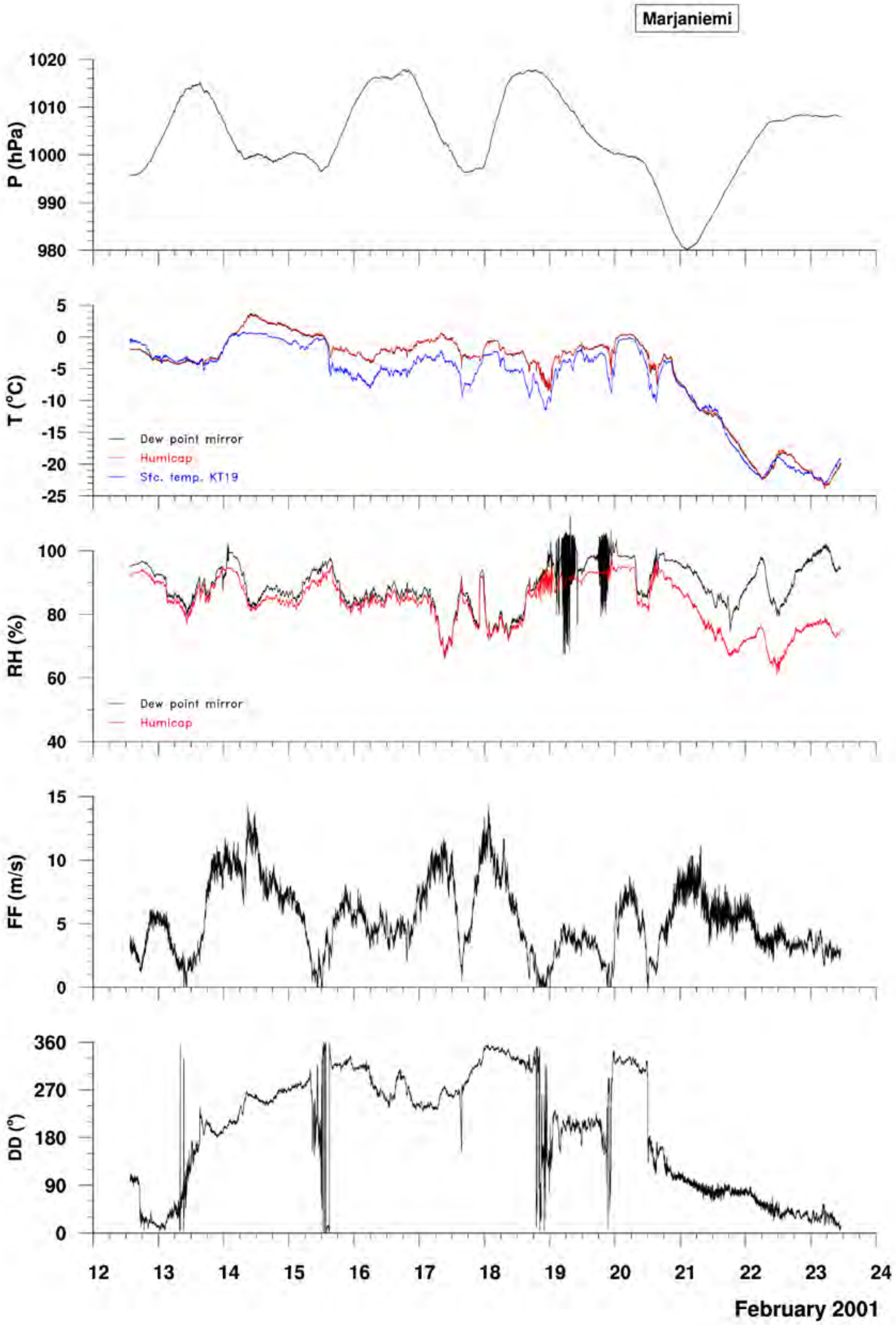


Fig. 4.20: One-minute averages of pressure p, air temperature T from Kroneis dew-point mirror (black) and Vaisala humicap (red) and surface temperature (blue) from Heimann KT-19, relative humidity from dew-point mirror (black) and humicap (red), wind speed FF, and wind direction DD measured at Marjaniemi ice station from 12 to 23 February 2001. Long tick marks at the abscissa indicate 00 UTC of the respective day.

The basic meteorological quantities in Fig. 4.20 show that the weather during BASIS 2001 was characterized by a rapid sequence of high and low pressure systems and passing atmospheric fronts. The winds blew from easterly directions at the beginning and end and from westerly directions in the middle of the campaign. Winds were the strongest (up to 14 ms^{-1} at 2.9 m height) during frontal passages. According to the advection conditions, the highest temperature of 3.7° C was recorded during WSW flow from the open sea on 14 February 2001 and the lowest temperatures of –23.2° C during and at the end of an ENE flow period advecting cold continental air.

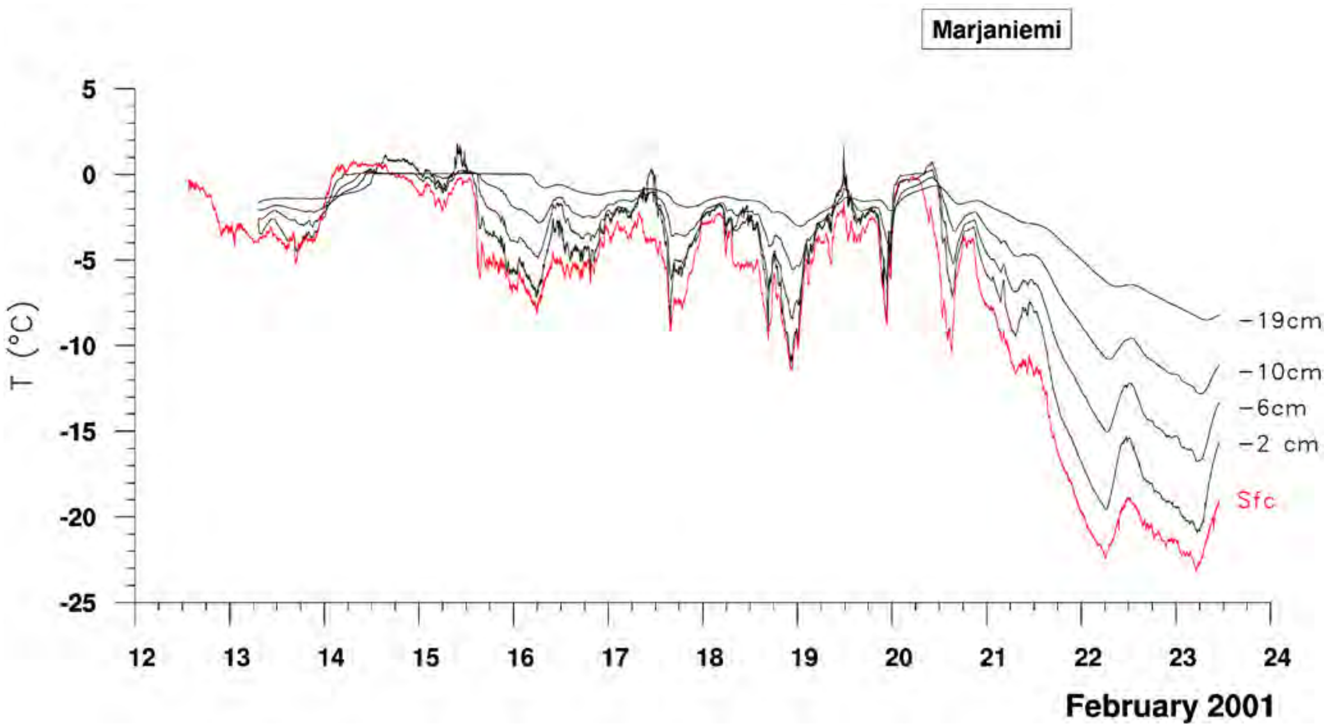


Fig. 4.21: One-minute averages of surface temperature (KT-19 radiometer) and snow/ice temperatures (platinum resistance thermometers) at –0.02, -0.06, -0.10, and –0.19 m depth measured at Marjaniemi ice station from 12 to 23 February 2001. Long tick marks at the abscissa indicate 00 UTC of the respective day.

The surface temperature and the snow/ice temperature at depths down to –0.19 m (Fig. 4.21) changed according to the varying temperature advection and radiation conditions (Fig. 4.22). The largest variations, of course, occurred at the surface, the smallest at 0.19 m depth which was closest to the sea water beneath the ice. The surface temperature T_{sfc} reacted nearly immediately to changes of the surface energy budget and especially the radiation budget. During melting weather periods, like on 14 and 15 February, snow/ice temperatures at all levels were close to 0° C. During cold weather periods, like on 21 to 23 February, there were strong temperature differences of up to 15 K in the ice between the surface (T_{sfc} = -21° C) and -0.19 m depth (T_{-19} = -6° C).

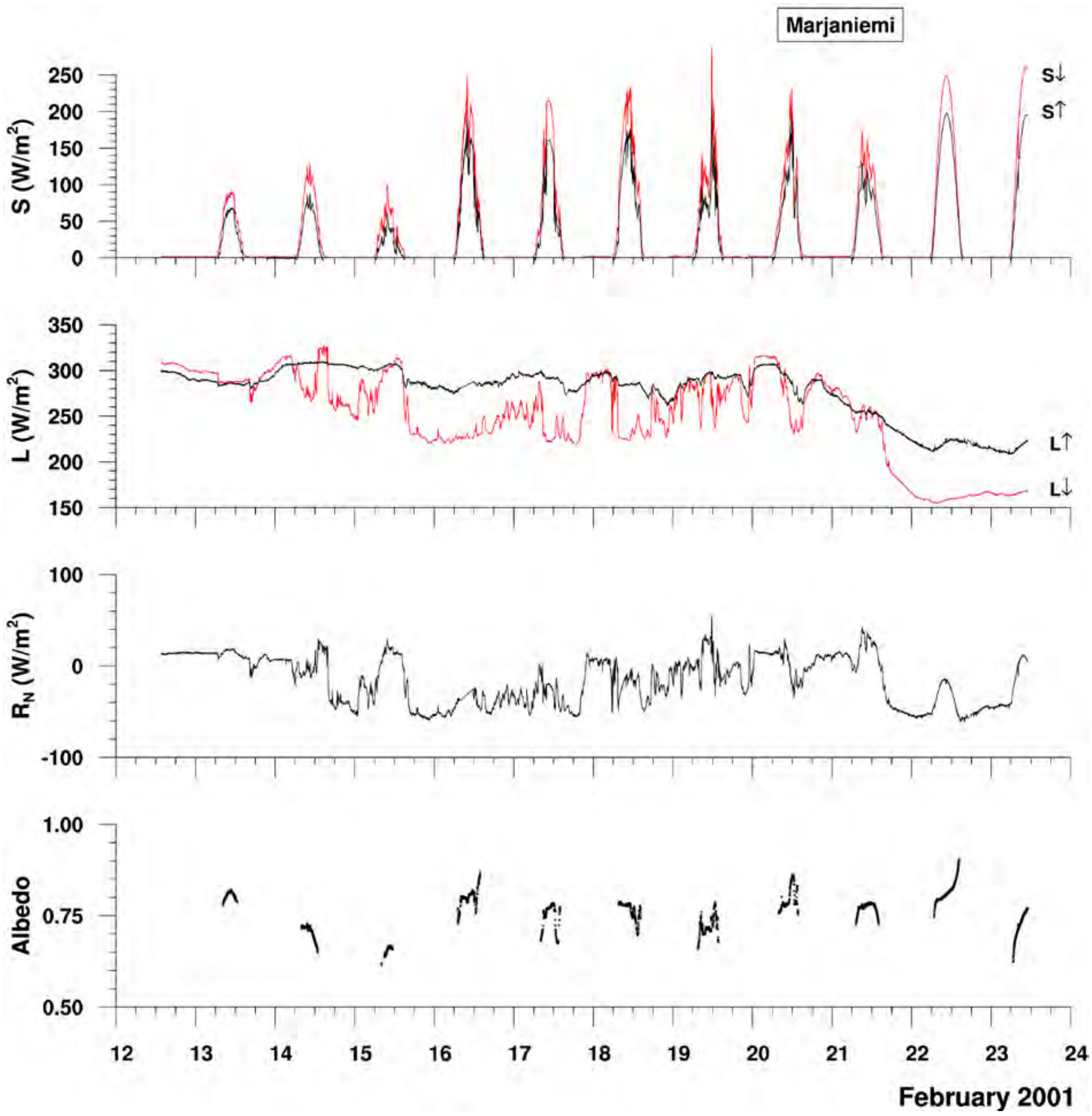


Fig. 4.22: One-minute averages of downwelling (S↓) and upwelling (S↑) shortwave radiation, downwelling (L↓) and upwelling (L↑) longwave radiation, net radiation flux R_N, and shortwave albedo (only computed if S↓ >50 Wm^{-2}) measured at Marjaniemi ice station from 12 to 23 February 2001.

The radiation fluxes (Fig. 4.22) and their variations were closely related to the varying cloud field conditions. On the average over the whole campaign, the negative longwave radiation balance (about –50 Wm^{-2}) dominated the positive shortwave radiation balance (about 13 Wm^{-2}). The albedo A of the land-fast ice at Marjaniemi varied between 60 and 85 % depending on the weather conditions: A was as low as 60 % at the end of the melting period on 15 February and A was higher in cold periods and especially after a snow fall event. The sudden increase of A on 15 February is due to freshly fallen snow.

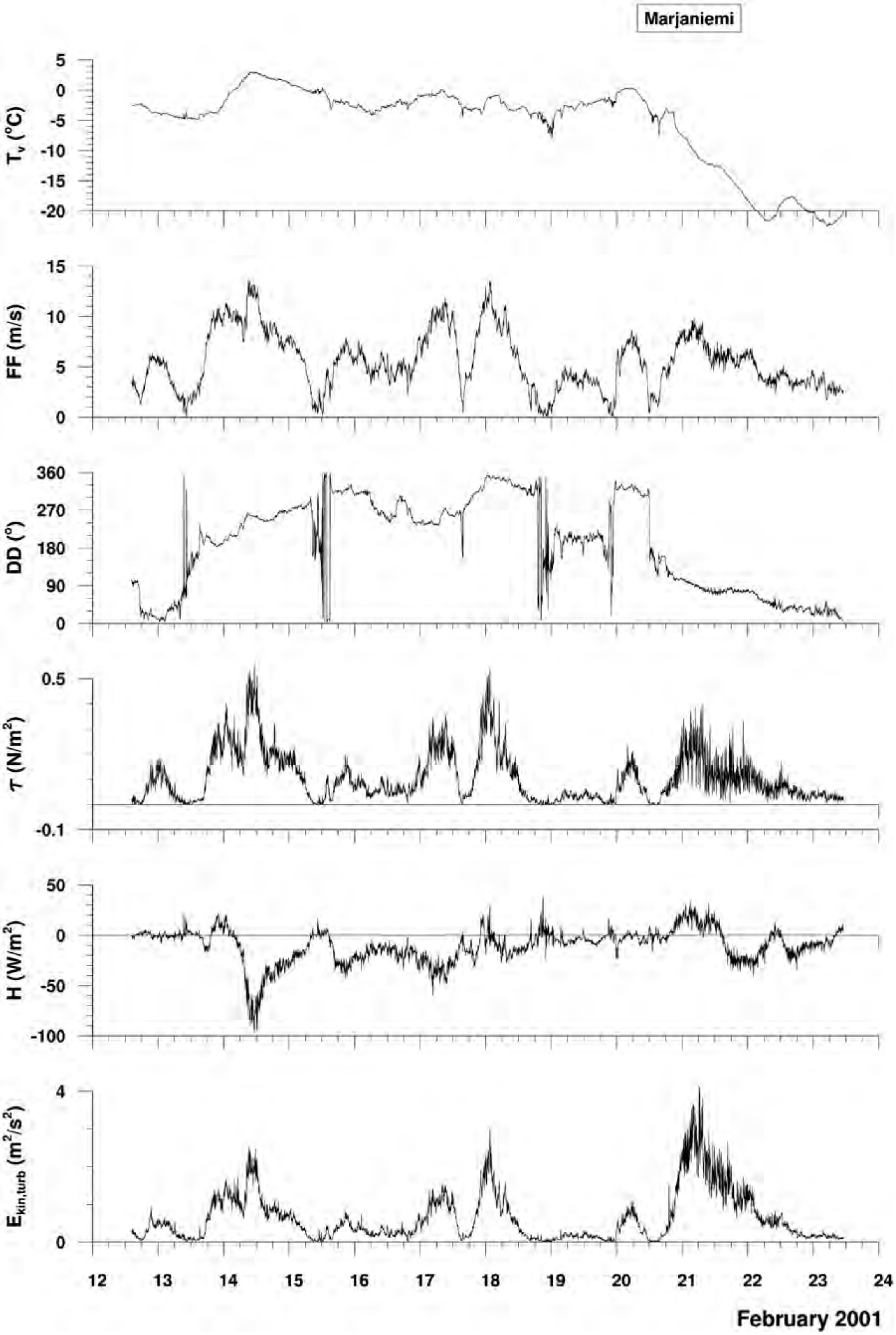


Fig. 4.23: Five-minute averages of Sonic measurements at 3.0 m height at Marjaniemi ice station from 12 to 23 February 2001 virtual temperature $T_{V,}$ wind speed FF, wind direction DD, momentum flux τ, sensible heat flux H, and turbulent kinetic energy $E_{kin,\ turb}$.

The sonic turbulence measurements (Fig. 4.23) are controlled by the synoptic-scale weather variations. The turbulent heat flux H varied between –90 Wm^{-2} on 14 February when the strongest warm air advection occurred and 25 Wm^{-2} on 21 February during the rapid temperature decrease by cold air advection. On the average over the campaign, H was about –15 Wm^{-2} i.e. a sensible heat flux from the air to the surface.

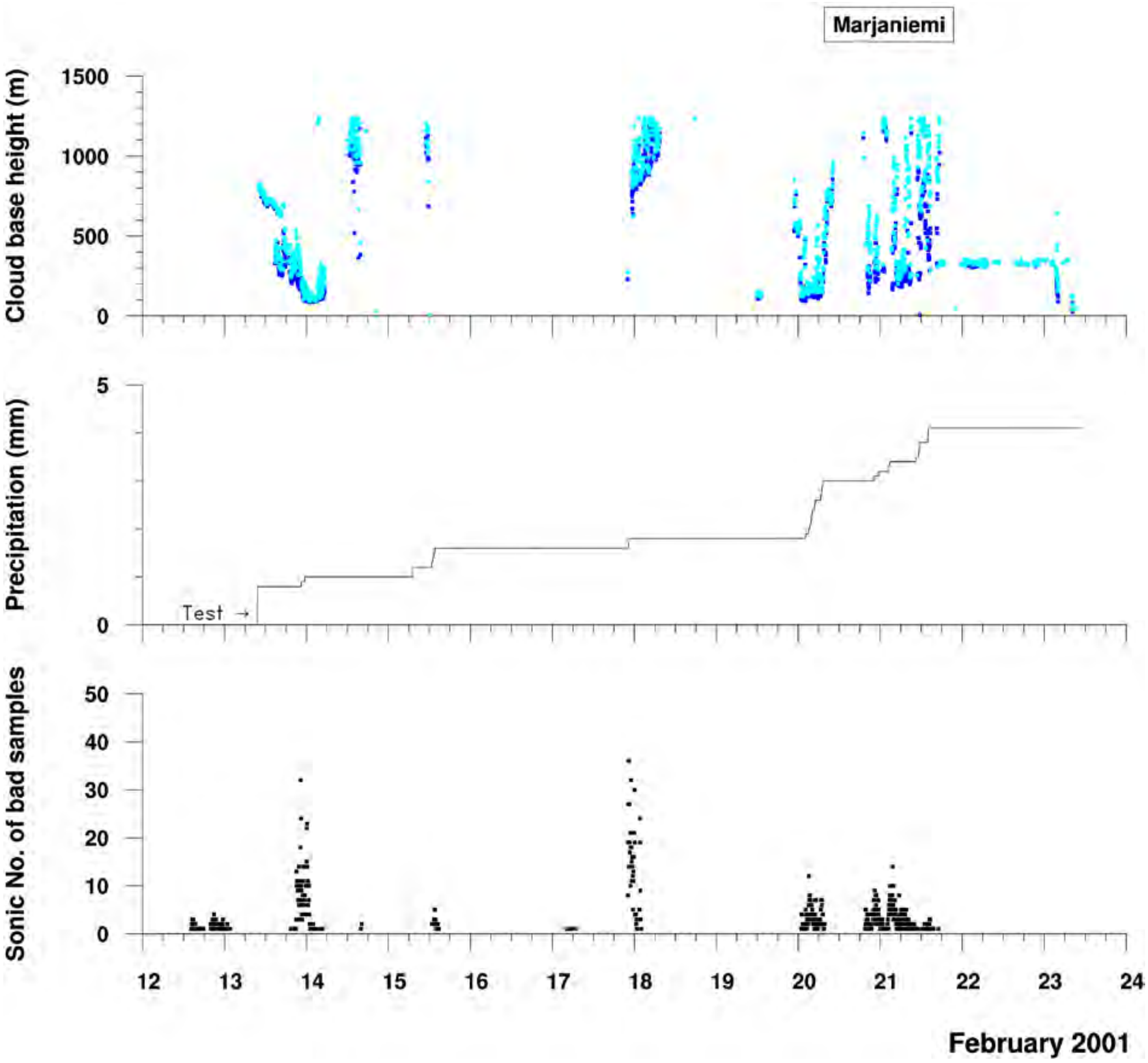


Fig. 4.24: Time series of cloud base height (ceilometer Impulsphysik LD-WHL) and precipitation (Lambrecht 15188-H) measured every minute at Marjaniemi ice station from 12 to 23 February 2001. All precipitation fell as snow. The lowest panel shows the number of bad samples of the Sonic instrument (Metek USAT) within a five minutes interval (maximum number of samples: 3000). A bad sample occurs if a snow flake is in the sound path. From the good agreement between the direct precipitation measurement and the number of bad samples the Sonic appears to be at least a snowfall indicator (if not even a quantitative snowfall sensor if calibration is possible).

Cloud base and precipitation conditions (Fig. 4.24) show no spectacular events. All precipitation fell as snow and amounted to only 3 mm for the entire 10 days period. The precipitation events are also reflected in the number of "bad samples" in the sonic measurements. For the 10 Hz sampling frequency and the 5 minutes averaging period the maximum number of good samples is 3000. A bad sample is defined when a snow flake is between the sound transmitter and receiver. Thus, the sonic is also suited to be used as a snow fall indicator at least, or even as a quantitative snow fall sensor.

Cloud bases were low during frontal passages and in precipitation events, but cloud base never decreased below 80 m. Fog did not occur. The phases of low-level cloud occurrences generally agree with the periods where the net longwave radiation, $L_N = L\downarrow - L\uparrow$, is close to zero or even positive (compare Fig. 4.22).

4.2.2. The automatic meteorological ARGOS stations at Kuivaniemi and Haparanda Hamn and the meteorological station at Oulu airport

Measurements at a single location (such as the metorological surface station at Marjaniemi) do not allow to draw conclusions on the representativeness of the data and on mesoscale field distributions of wind, pressure, temperature etc. In order to be able to do that and to calculate e.g. the geostrophic and thermal wind for the experimental area, data from three additional stations (in addition to the continuous measurements at Marjaniemi (Section 4.2.1.) and at RV Aranda (Section 4.2.3.) were used.

One station was the official weather station at the airport of Oulu (at 64.93°N, 25.36°E) from which the DO-128 aircraft operations (Section 4.2.4.) started and which is about 2 km away from the Bay of Bothnia. The other two additional stations were especially installed for the BASIS 2001 experiment and were placed directly at the shore of the Bay of Bothnia near to the villages of Kuivaniemi (65.55°N, 25.12°E) and Haparanda Hamn (65.77°N, 23.90°E). The latter station was on Swedish territory. At both places the Bay of Bothnia was covered with land-fast ice. The locations of all three stations are indicated in Fig. 2.3.

The two stations at Kuivaniemi and Haparanda Hamn were identical. They were portable automatic meteorological stations fabricated by METOCEAN company in Canada. They were driven by Battery power and transmitted their data via the ARGOS satellite system to the ground station at Toulouse from where the data were collected on-line and off-line. Usually, such automatic stations are used for autonomous measurements on drifting sea ice. The data transmission was not regularly, depending on the availability of ARGOS satellites, but was typically on the order of 1 hour.

The two ARGOS stations were equipped with a barometer, a thermometer and humicap mounted within a radiation shield, a coupled wind propeller and wind vane. In addition, the stations carried a thermometer inside the bottom plate of the buoy housing for "estimate" of the ice surface temperature, and an ARGOS navigation system for the position. Figs. 4.25 and 4.26 show the two ARGOS stations as deployed on stoney ground at the shores of Kuivaniemi and Haparanda Hamn, respectively.

Time series of the basic meteorological parameters, p, T, RH, FF, and DD, recorded at Oulu, Kuivaniemi, and Haparanda Hamn are displayed in Fig. 4.27. All three stations reflect the synoptic variations in a same way as in the time series recorded at Marjaniemi (Fig. 4.20) and at RV Aranda (Fig. 4.37). Details in the time series at the various stations are, of course, different and caused by the local conditions (shore station, land station or ice station) and by the passage of differently oriented fronts or by the passage of high and low pressure centres right through the experimental area. The latter can be seen e.g. on 15 February when a small low passed through the area and in the night from 19 to 20 February when a warm front passed the area.

Fig. 4.25: The automatic meteorological ARGOS buoy at the shore (at appr. 2 m height) of Kuivaniemi (looking towards WSW) after deployment on 14 February 2001. The wind mast is 2 m long.

Fig. 4.26: The automatic meteorological ARGOS buoy at the shore (on a stone mole at appr. 1.3 m height) of Haparanda Hamn (looking towards SSE) after deployment on 15 February 2001. The wind mast is 2 m long.

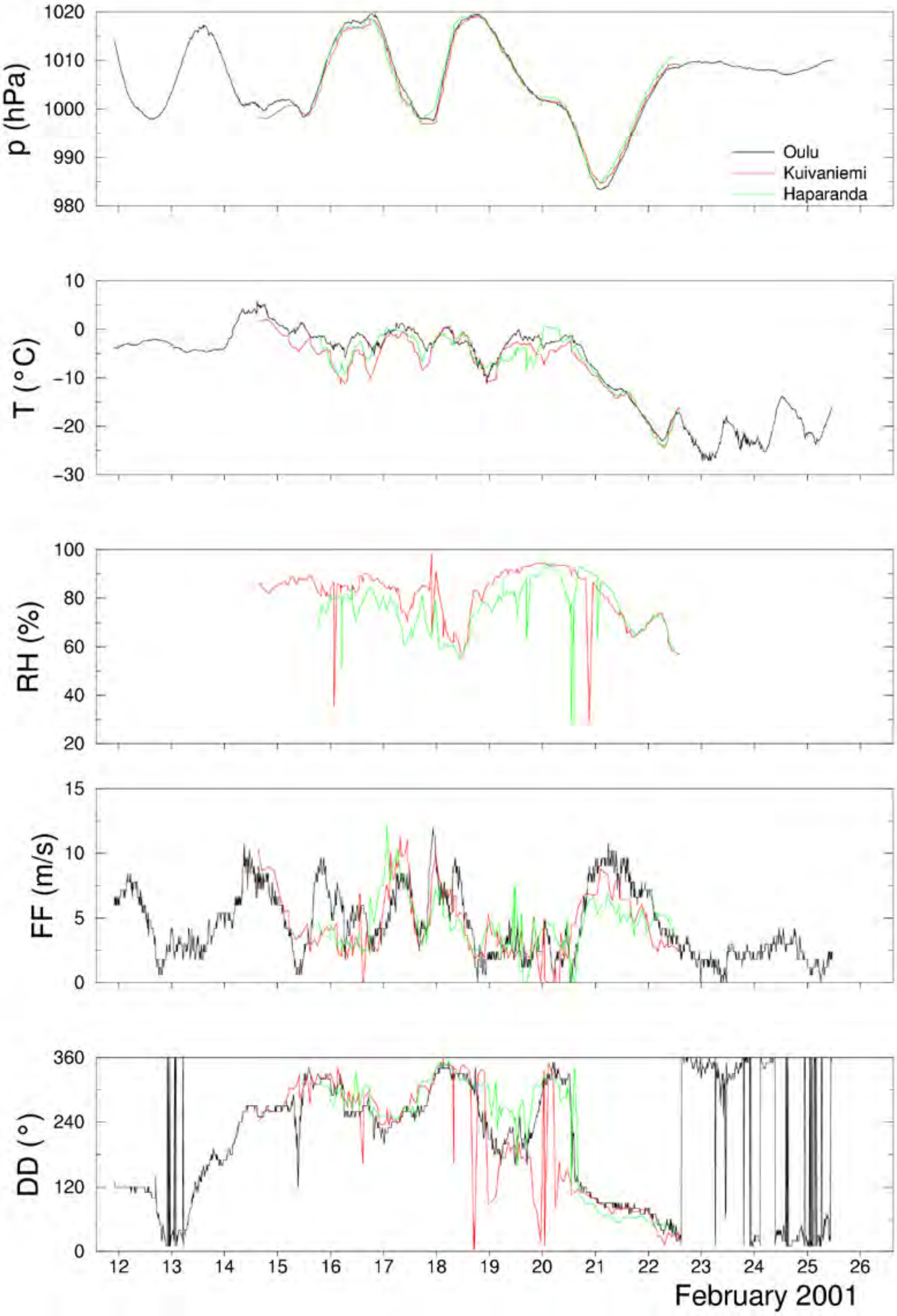


Fig. 4.27: Time series of pressure p, air temperature T, relative humidity RH, wind speed FF, and wind direction DD as measured at Oulu airport (black), Kuivaniemi (red), and Haparanda Hamn (green).

4.2.3. Measurements at RV Aranda

The Finnish RV Aranda, operated by the Finnish Institute of Marine Research (FIMR), was the only station in the BASIS 2001 field campaign, which was placed in the ice-covered Bay of Bothnia (Fig. 4.28). It was located at 65° 31.5'N, 24° 33.8'E near the edge, but inside the land-fast ice. The nearest coast was 15 km apart: land-fast ice was present to the south, east and north of RV Aranda and fractured drifting ice in the west/southwest. The ice was about 0.40 m thick and the water below was about 32 m deep. Figs. 4.29 and 4.30 show RV Aranda in the land-fast ice, as photographed from the research aircraft DO-128, and present the varying conditions of the snow cover (and thus albedo) on the land-fast ice. Fig. 4.29 taken on 16 February still shows the track of RV Aranda when it had moved on 13 February through the land-fast ice. The ice on 16 February was covered by "snow dunes" - patterns which develop by snow drift or in case of melting conditions. Fig. 4.30 shows RV Aranda at the same position on 22 February after freshly fallen snow and during a cold temperature period. RV Aranda's participation in the BASIS 2001 campaigns lasted from 12 to 24 February 2001.

The following persons participated in the cruise: as scientists Hannu Grönvall, Milla Johansson, Roberta Pirazzini, and TimoVihma and as technicians Pekka Kosloff, Henry Söderman, and Hannu Vuori.

Fig. 4.28: RV Aranda in the land-fast ice in the Bay of Bothnia as photographed from research aircraft DO-128 on 19 February 2001.

Fig. 4.29: RV Aranda in the land-fast ice as photographed towards east direction from research aircraft DO-128 on 16 February 2001. The track of Aranda when it moved into the land-fast ice on 13 February is still visible. On 16 February the land-fast ice was covered by “snow dunes” which develop by snow drift or/and under melting conditions.

Fig. 4.30: RV Aranda in the land-fast ice as photographed towards northeast direction from research aircraft DO-128 on 22 February 2001. The ice is totally covered with snow which fell one day before and the air temperature is around –20°C. At the horizon the Finnish coast of a distance of about 20 km is visible.

A comprehensive set of instrumentation was installed on the land-fast ice in the vicinity of RV Aranda. It was arranged along an about 300 m long measurement line oriented approximately from West to East (Fig. 4.31). The installed instrumentation consisted of the following components: a profile mast (Fig. 4.32), a turbulence mast (Fig. 4.33), a radiation station (Fig. 4.34), and a thermistor stick in the snow and ice (Fig. 4.35). These instruments were energy-supplied by autonomous wind/solar energy generators (Fig. 4.36). In addition, the ice and snow thickness was measured once a day at five sites situated around a circle with a radius of about 15 m.

Furthermore, the following measurements were made in the vicinity of RV Aranda: six-hourly balloon soundings with the Vaisala RS-80 GPS radiosondes, continuous (every 10 min) current measurements (speed and direction) between 3 and 32 m depth using an ADCP (Acoustic Doppler Current Profiler), and once-a-day water temperature and salinity profile measurement with a CTD instrument. Meteorological data were also recorded by the automatic weather station of the ship.

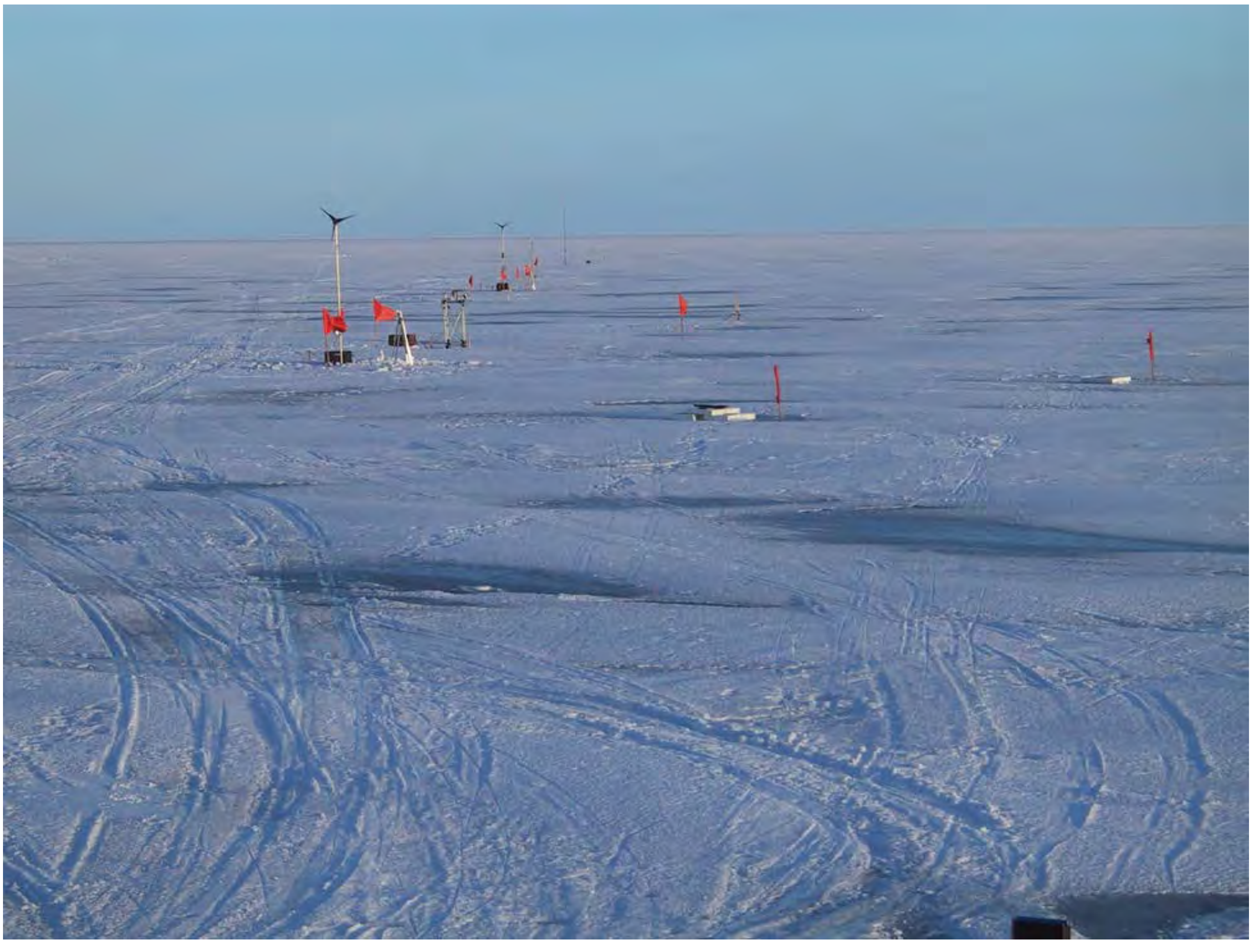


Fig. 4.31: Measuring equipment deployed on the land-fast ice close to RV Aranda. The instruments are arranged along an about 300 m long line oriented from west to east.

The profile mast (Fig. 4.32) was 10 m high and equipped with cup anemometers (for wind speed) at 0.4, 1.3, 2.6, 4.6 and 10 m height, with a wind vane (for wind direction) at 10 m height, and with platinum resistance thermometers at 0.4, 1.3, 4.6 and 10 m height. The turbulence mast (Fig. 4.33) carried on its top at 3.3 m height an ultrasonic anemometer/thermometer (Metek USAT) measuring with a frequency of 10 Hz the three wind components u, v, w and the virtual temperature T_V. From these data, variances and covariances (momentum flux τ and sensible heat flux H) were calculated as 10 minute averages.

The radiation station on the ice (Fig. 4.34) consisted of a 1.5-m-high frame, at which the radiation instruments were mounted. Shortwave downwelling radiation, S↓, was measured by a Kipp & Zonen CM-5 pyranometer and the longwave downwelling and upwelling radiation, L↓ and L↑, were measured by Kipp & Zonen CG-2 pyrgeometers. A thermistor stick (Fig. 4.35) was drilled into the ice to continuously measure the air-snow-ice temperatures at 0.04 m vertical intervals. During daytime, the meteorological measurements were completed by hourly cloud and weather observations.

Fig. 4.32: 10 m-mast at RV Aranda ice-station: with cup anemometers (wind speed) at 0.4, 1.3, 2.6, 4.6, and 10 m height, a wind vane (wind direction) at 10 m height, and with thermometers at 0.4, 1.3, 4.6, and 10 m height.

Fig. 4.33: Turbulence mast at RV Aranda ice station with sonic instrument (Metek USAT) at 3.3 m height.

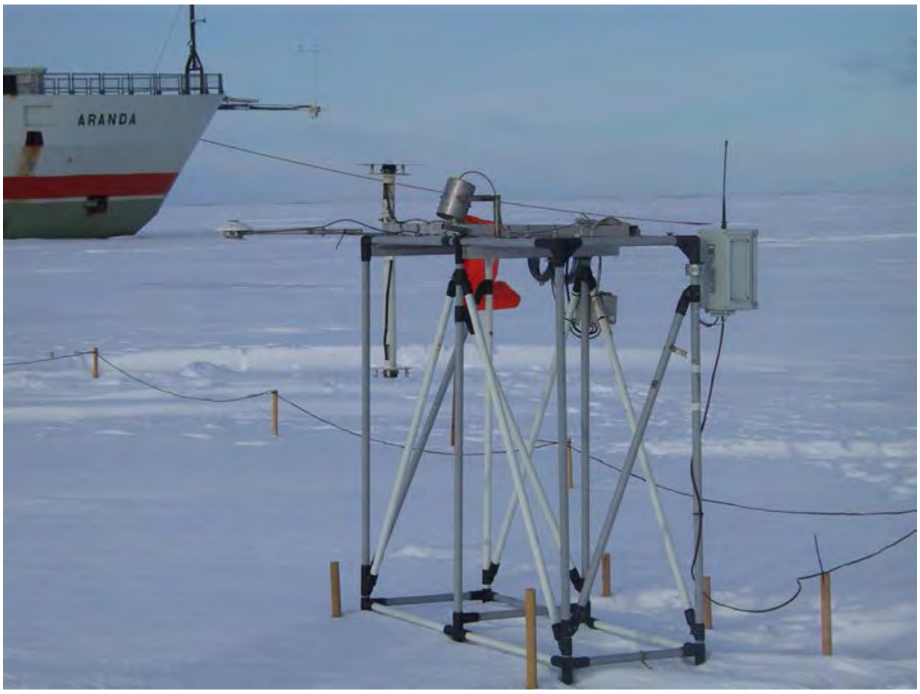
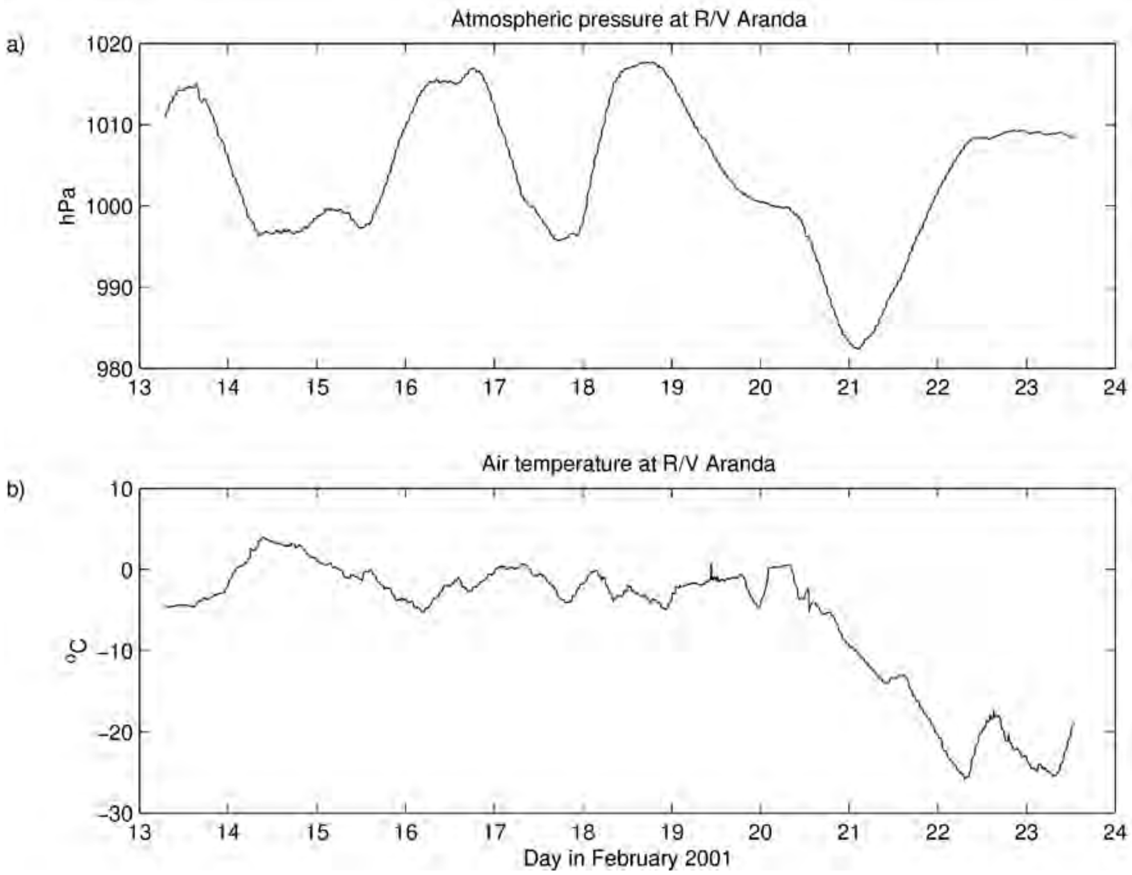


Fig. 4.34: Radiation station at RV Aranda ice station with pyrgeometers (Kipp & Zonen CG-2) for downwelling (L↓) and upwelling (L↑) longwave radiation and with pyranometers (Kipp & Zonen CM-5) for downwelling (S↓) shortwave radiation.

Fig. 4.35: Thermistor stick for snow, ice, and water temperature measurement at 10 levels with a distance of 0.1 m (right). The left part shows the data recording equipment.

Fig. 4.36: RV Aranda ice station instrumentation had a ship-independent power supply from wind/solar energy generators.

In the following, measurements taken with the various instruments are presented. Time series of the basic meteorological quantities, pressure p, temperature T, relative humidity RH, wind speed FF, and wind direction DD, measured at RV Aranda's ship station are displayed in Fig. 4.37. The longer-period (synoptic) variations were very similar to those measured at Marjaniemi (Fig. 4.20) and at Oulu, Kuivaniemi and Haparanda harbour (Fig. 4.27). The 11 days long experimental period was characterized by a rapid sequence of passing highs, lows and fronts. The wind speeds reached values up to 18 ms^{-1}. In general, FF measured at RV Aranda was higher than at the other surface stations for two reasons: (1) FF measurements at RV Aranda were taken at a higher level and (2) the surface roughness of the land-fast ice was lower.



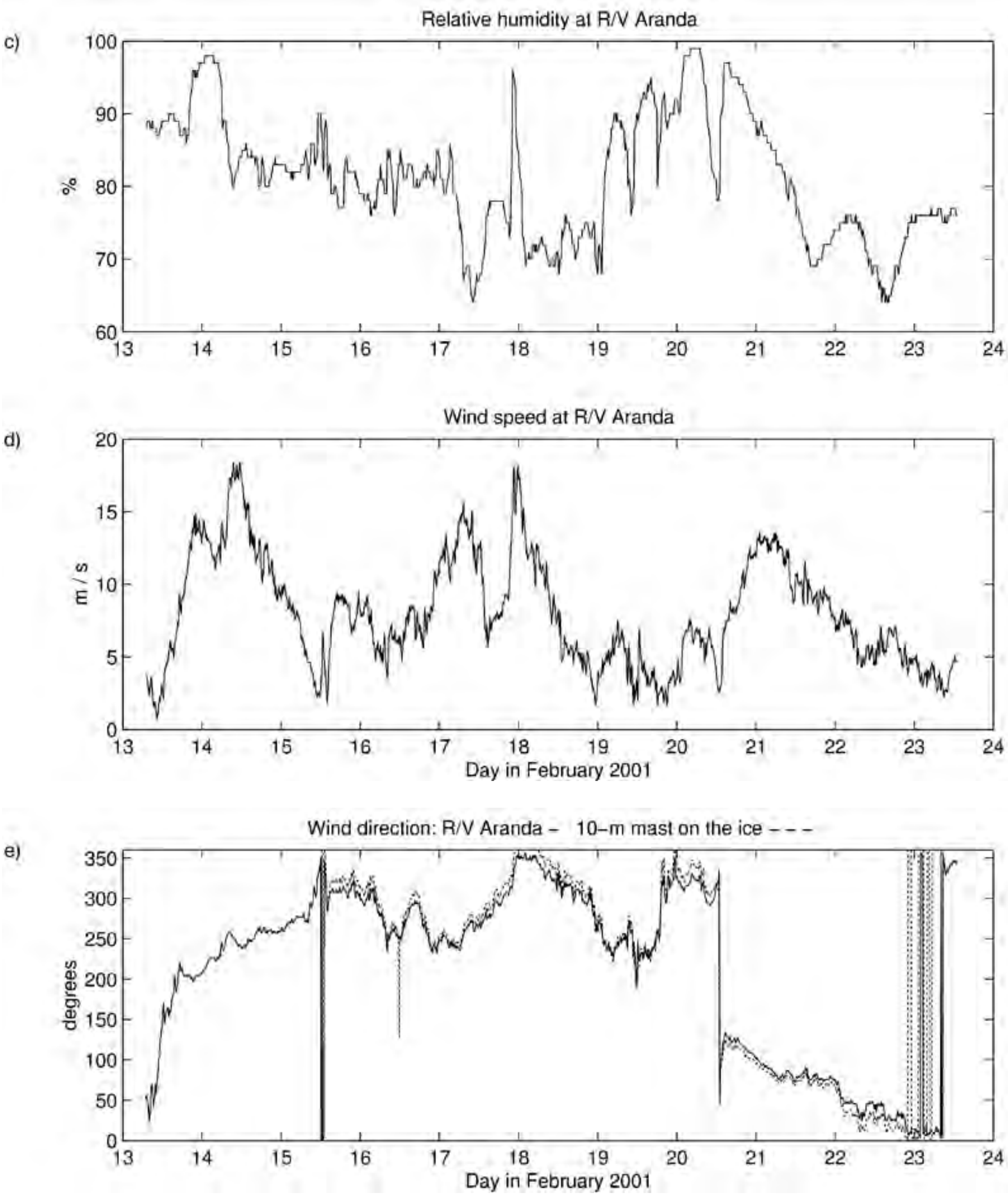


Fig. 4.37: Time series of pressure (a), air temperature (b), relative humidity (c), wind speed (d), and wind direction (e) measured on board the RV Aranda from 13 to 23 February 2001. The tick mark indicates 00 UTC of the respective day.

The wind and temperature measurements at the profile mast are given in Fig. 4.38. The mean variations naturally follow those measured at RV Aranda (Fig. 4.37), but in addition the measurements show the varying temperature stratification and vertical wind shear. A particularly strong stratification occurred on the last day under cold, clear sky, and low wind conditions.

The turbulent surface fluxes of momentum τ and sensible heat H, measured at 3.3 m height by the sonic instrument, are shown in Fig. 4.39. The two periods of high momentum fluxes (17-18 February and 21 February) correlate well with the periods of high wind speeds (Figs. 4.37 and 4.38). However, they were accompanied with different stratification conditions: stable during the period 17-18 February and unstable during the period 21 February. Consequently, the momentum flux during the second period was nearly as high as during the first period although the wind speed in the second period was only 80 % of that in the first period. During the entire BASIS 2001 campaign, a negative sensible heat flux dominated; the minimum value was close to $-80\ Wm^{-2}$.

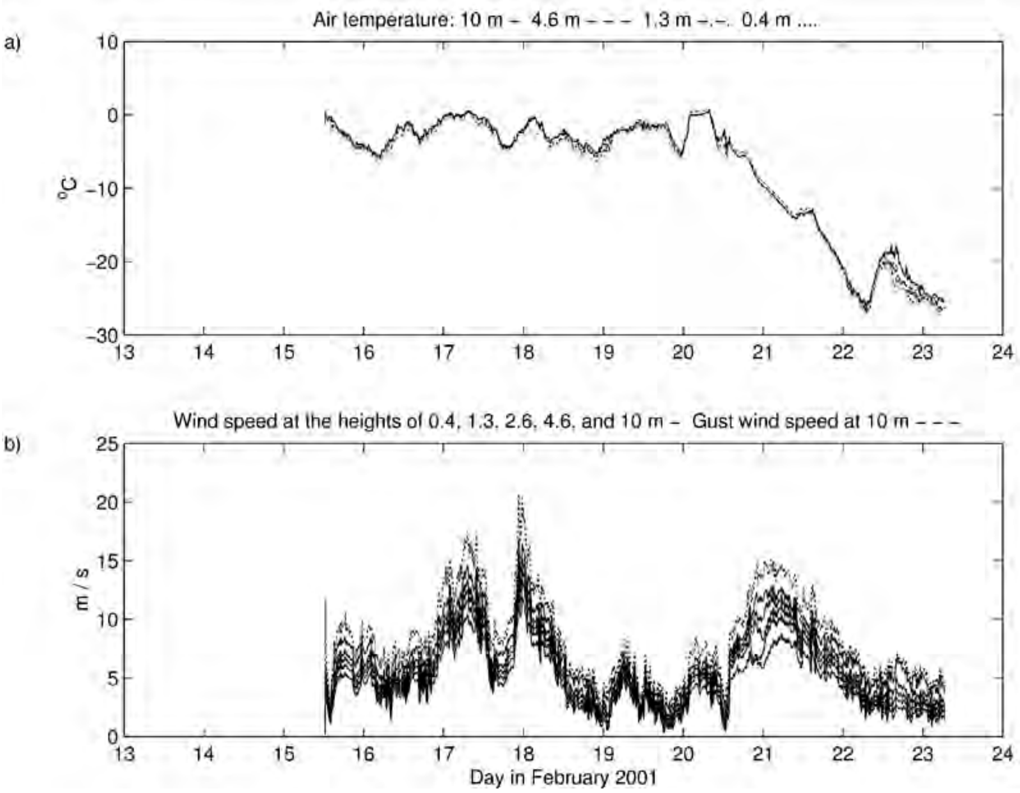


Fig. 4.38: Time series of (a) air temperature measured at 10, 4.6, 1.3, and 0.4 m height, and (b) wind speed measured at 10, 4.6, 2.6, 1.3, and 0.4 m height at the 10 m-mast deployed on the land-fast ice near RV Aranda during the period 15 to 23 February 2001.

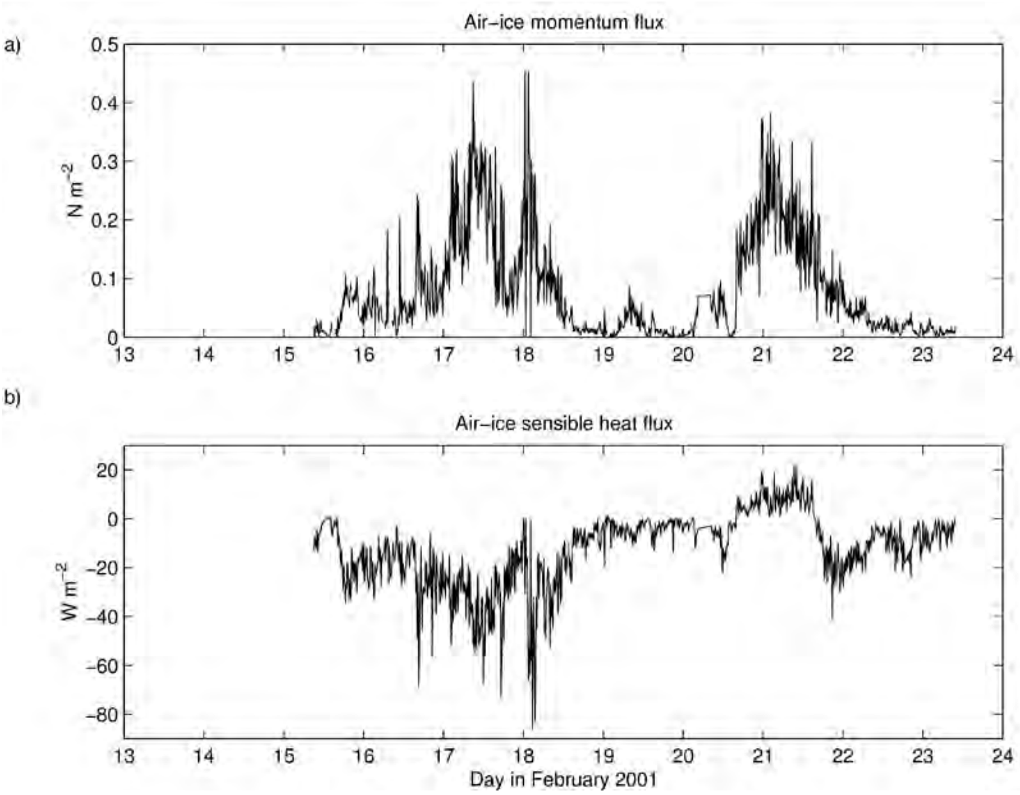


Fig. 4.39: Time series of 10-minutes averages of (a) momentum flux and (b) sensible heat flux measured at 3.3 m height by a sonic instrument (Metek USAT) deployed on the land-fast ice near RV Aranda during the period 15 to 23 February 2001.

The radiation fluxes (Fig. 4.40) and their variations are closely related to the varying cloud conditions. The longwave radiation balance was negative (about –50 Wm^{-2} on the average). Only during frontal events with low-level clouds the net longwave radiation increased to values close to zero Wm^{-2}. This is particularly obvious during the warm front event on 14 February (which was accompanied with the warmest temperatures observed during the campaign) and also during the cold front event on the night of 20 February (later on 20-21 February the data quality was not good due to snow accumulation on the sensors). In both cases, a warmer cloudy air mass was lying on top of the colder near-surface air mass.

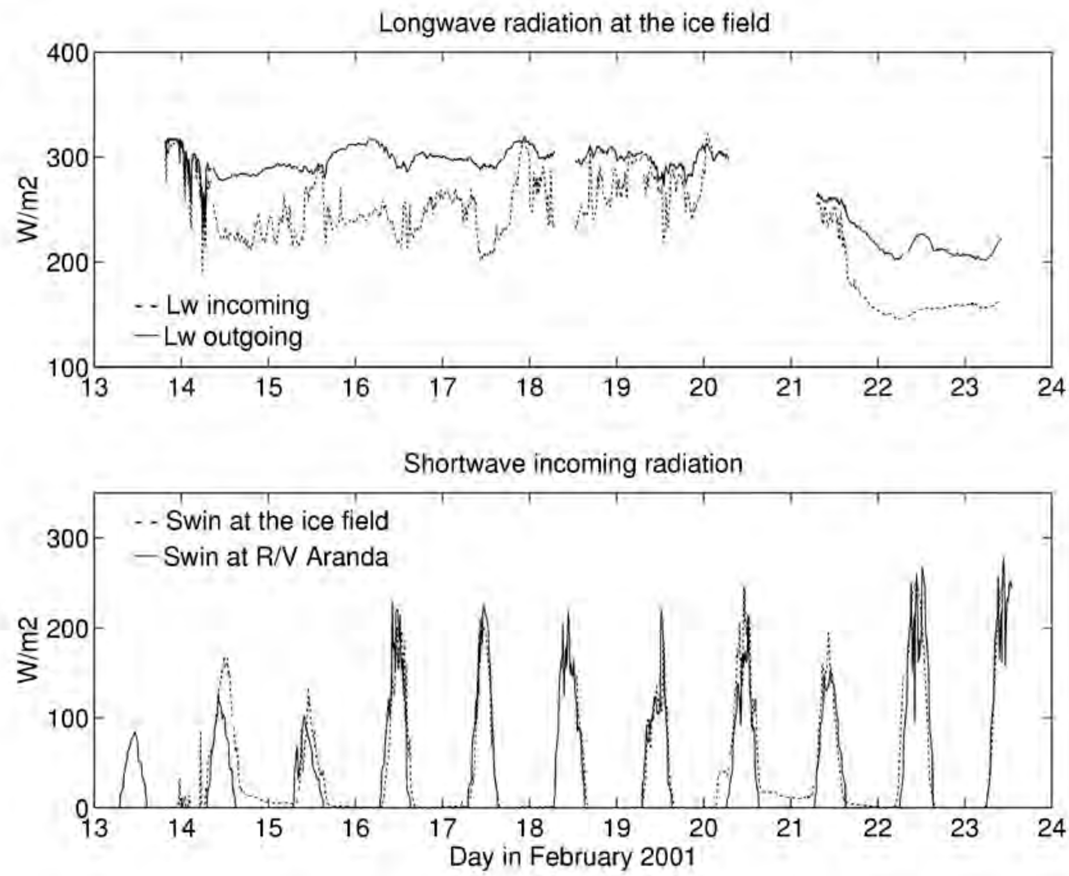


Fig. 4.40: Time series of incoming (dashed line) and outgoing (solid line) longwave radiation measured at the ice station and incoming shortwave radiation measured at RV Aranda (solid line) and at the ice station (dashed line) during the period 13 to 23 February 2001.

The varying phases of warm and cold air temperature during the period 13-20 February also show up in the snow, and ice temperatures (Fig. 4.41). The largest temperature variations naturally occurred at the uppermost snow layer. Surface melting was observed particularly on 14 February, and some liquid water remained around the lower parts of the thermistor stick. A large temperature gradient formed in the snow and ice during the cold-air advection phase from 20 to 23 February.

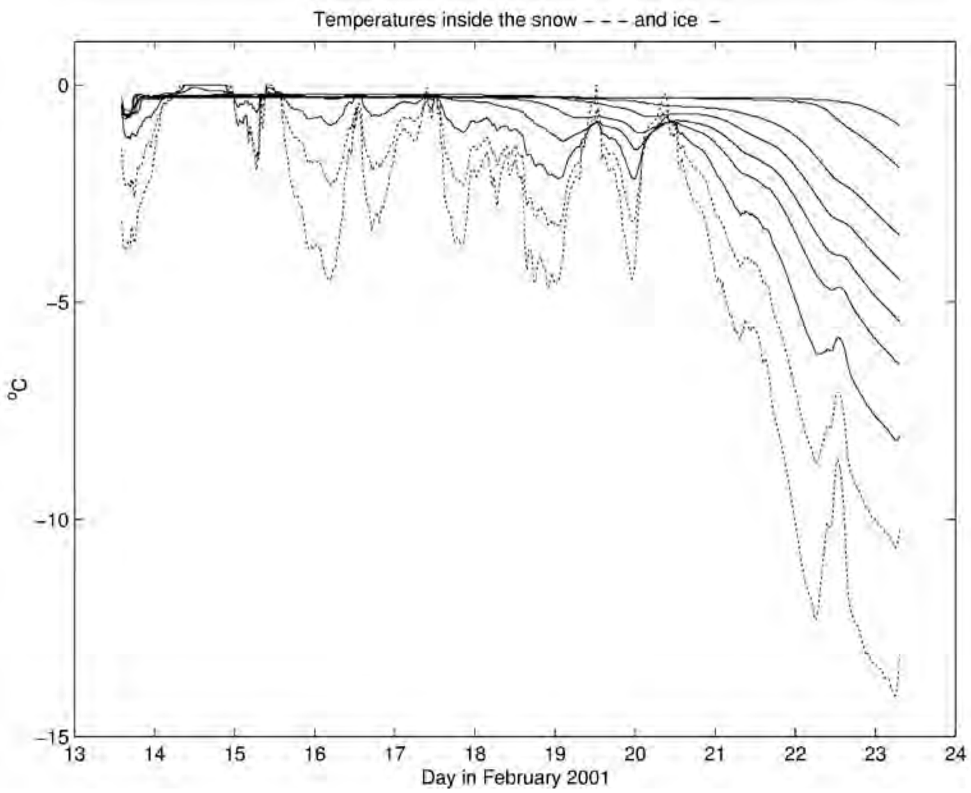
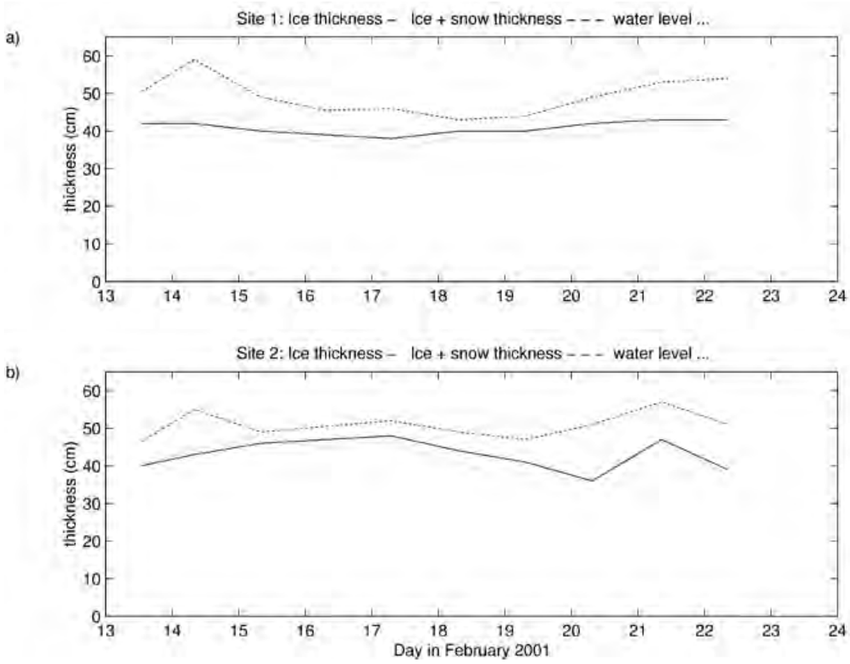


Fig. 4.41: Time series of snow (dashed) and ice (solid) temperatures measured using a stick with thermistors at 0.04 m vertical intervals in the land-fast sea ice near RV Aranda during the period 13 to 23 February 2001

The results from the daily measurements of the ice thickness, snow thickness, and water level at five different sites of the land-fast ice near RV Aranda are presented in Fig. 4.42 a-e. The ice thickness varied between 0.36 and 0.48 m. Although the measurement sites were less than 30 m apart from each other, the differences in ice thickness were up to 0.10 m. The snow cover on the land-fast ice also varied from site to site and also with time. The full range in snow cover was from 0 to 0.18 m. The water level was very close to the sea ice top, sometimes even above it. These cases were related to snow melt at the surface rather than flooding of sea water.



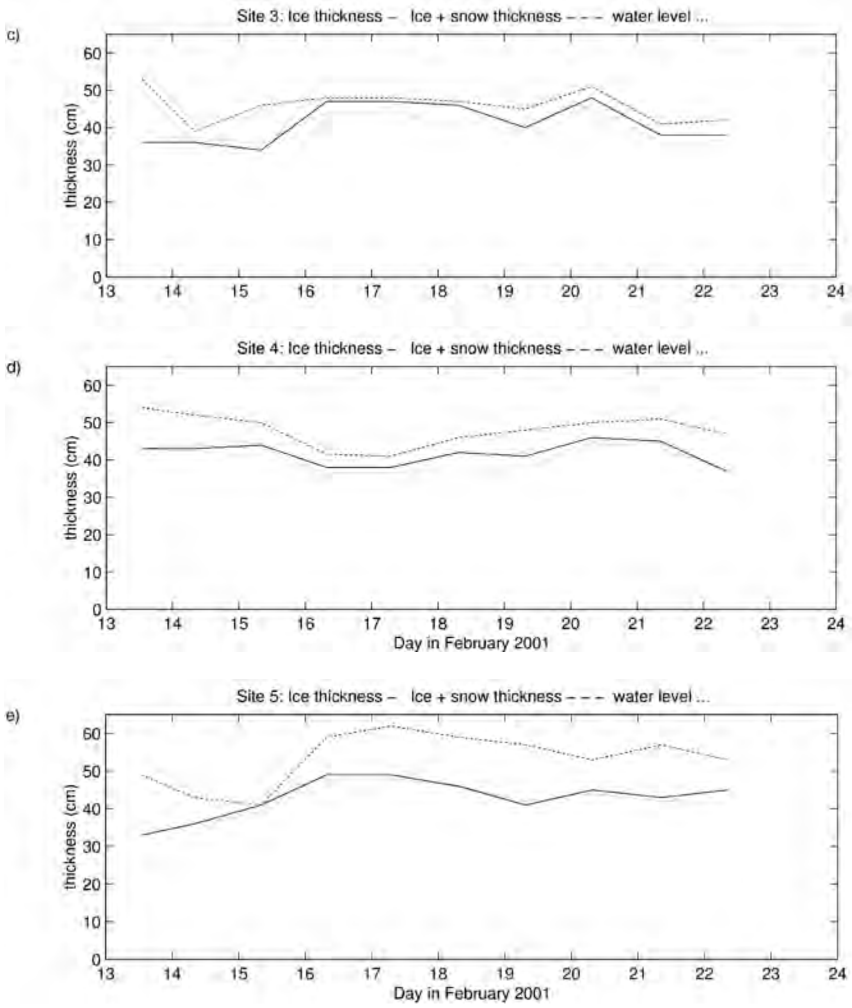


Fig. 4.42: Time series of daily measurements of ice thickness (solid), ice plus snow thickness (dashed), and water level (dotted) at 5 sites along a 15 m diameter circle at the RV Aranda land-fast ice station during the period 13 to 22 February 2001.

The water temperature and salinity profiles below the land-fast ice are shown in Fig. 4.43. The uppermost water layer (> 3 m) had a low salinity and was cold (around 0°C). A strong halocline was present between 3 and 10 m depth. Within it, a layer of warm water centred around 4 m depth was observed. Below 10 m depth, the temperature increased again with increasing depth. The salinity controls the density stratification.

The current below the land-fast sea ice (Fig. 4.44) shows a high degree of temporal variability. Speeds were generally between 0 and 0.20 ms^{-1} with a short exception at 7 m depth on 17 February. It was probably due to the high wind speed and a simultaneous presence of larger areas of open water in the upwind direction. The current direction frequently changed between easterly and westerly directions. The changes mostly hold for the entire water column.

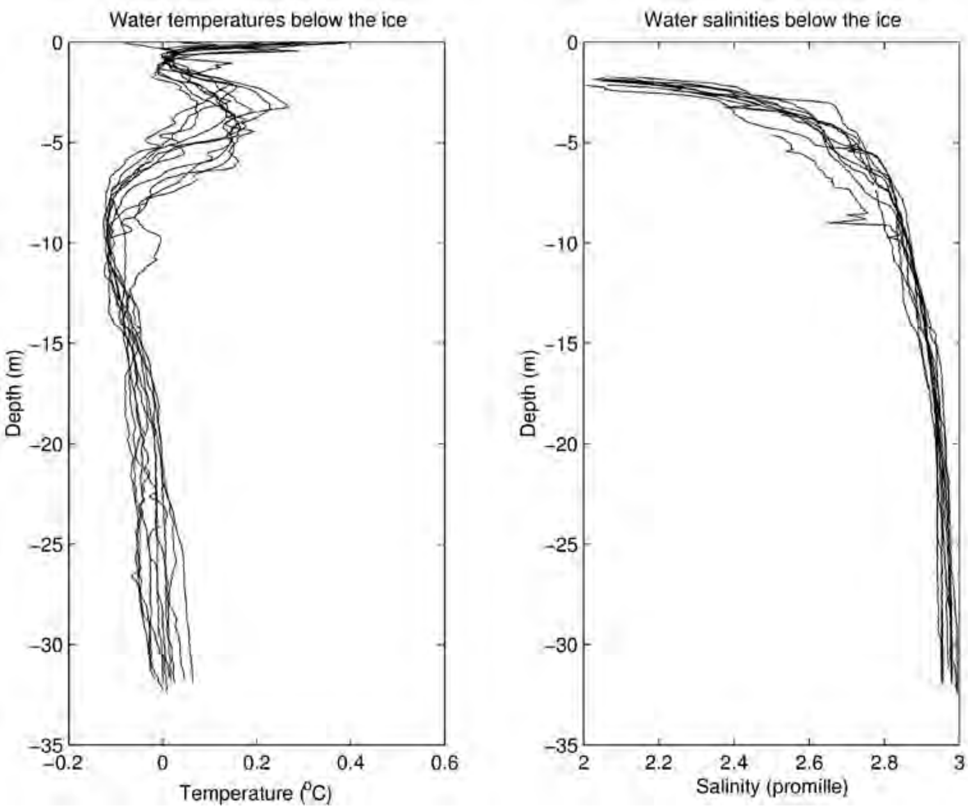


Fig. 4.43: Ten vertical profiles of water temperature (left) and water salinity (right) measured below the land-fast ice near RV Aranda during the period 13 – 22 February 2001

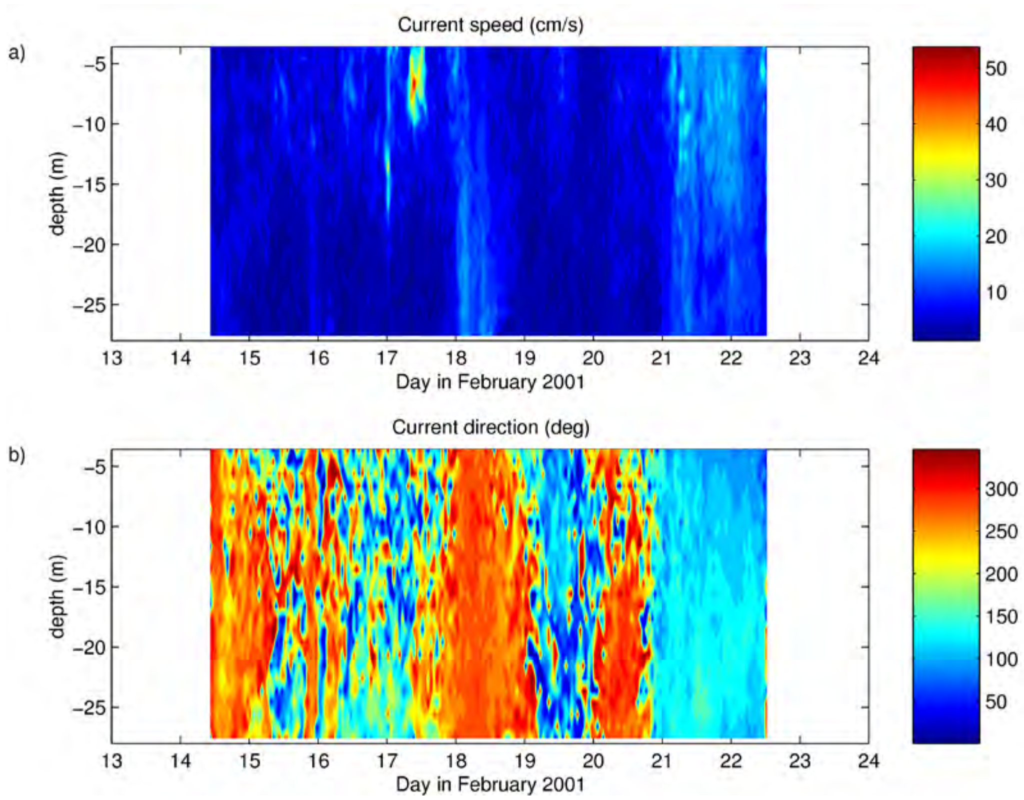


Fig. 4.44: Time-depth cross-section of acoustic doppler current profiler (ADCP) measurements (every 10 min) of (a) current speed and (b) current direction at RV Aranda during the period 14 to 22 February 2001.

A total of 36 radiosondes were launched from the deck of RV Aranda during the period 13-23 February 2001. The temperature profiles in Fig. 4.45 for the height range 0-14 km show that substantial changes of the tropopause level occurred. The height range was from 6 to 11 km. On 17 February, the tropopause level decreased from 9 to 6 km within only six hours (from 06.11 UTC to 11.51 UTC). This was accompanied with a low passage (see Appendix A2). The temperature and wind profiles in the atmospheric boundary layer are given in more detail in Figs. 4.46 and 4.47, respectively. The striking feature is, that a low-level inversion (below 600 m) was permanently present and that in about 70 % of the time the inversion or a stable layer was surface-based. Nearly each inversion was accompanied with a low-level jet.

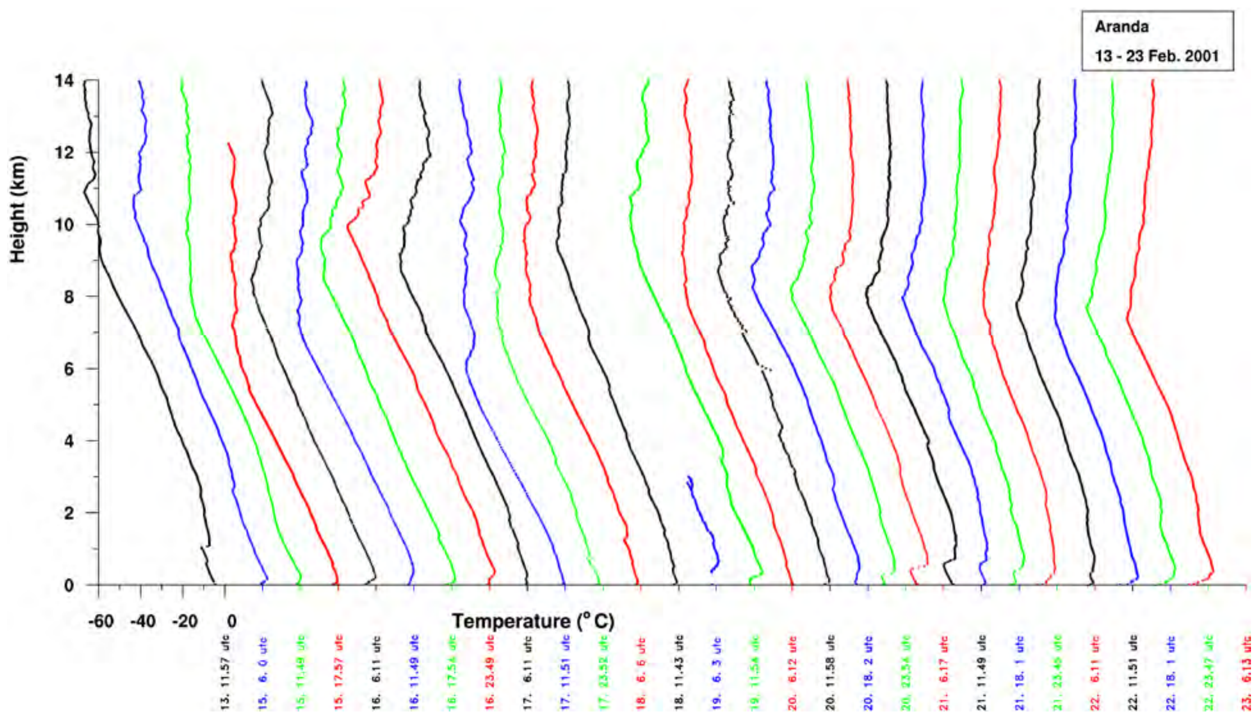
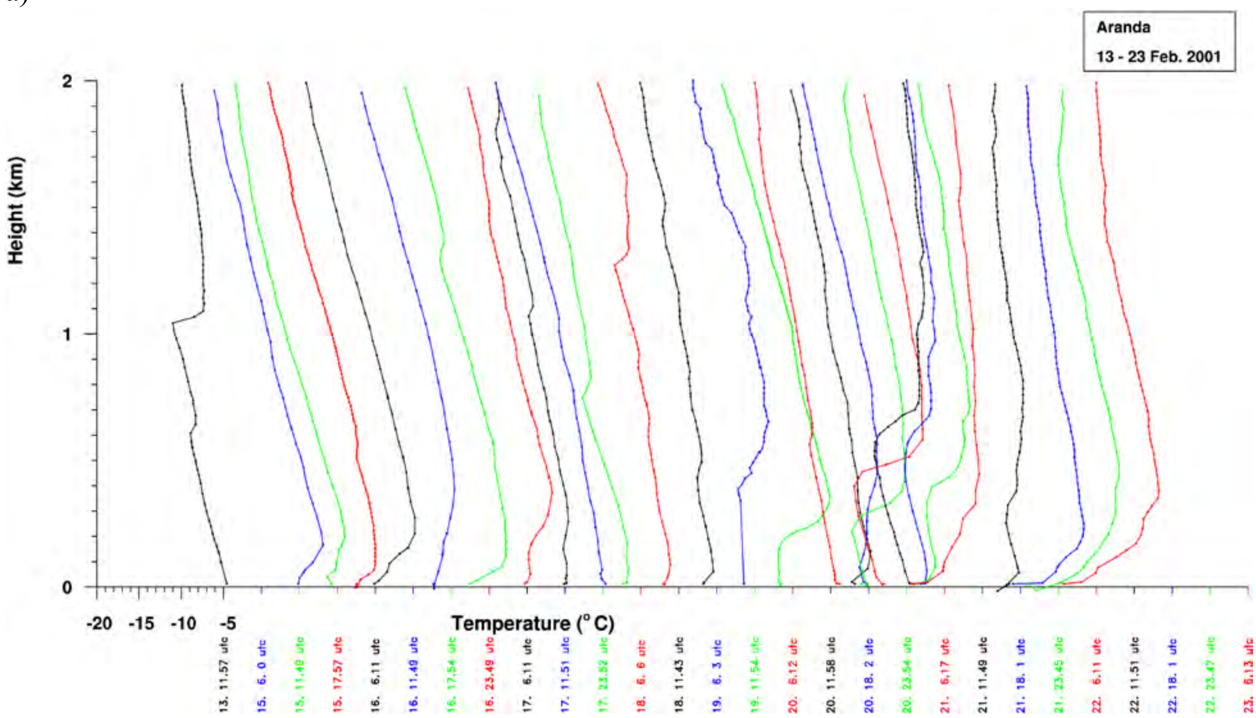


Fig. 4.45: Vertical temperature profiles between surface and 14 km as measured by 36 Vaisala radiosondes at RV Aranda during the period 13 February 2001 11.57 UTC to 23 February 2001 06.13.UTC. Tick marks at the abscissa indicate the 0°C value of the running temperature scale and the launch time.

a)



b)

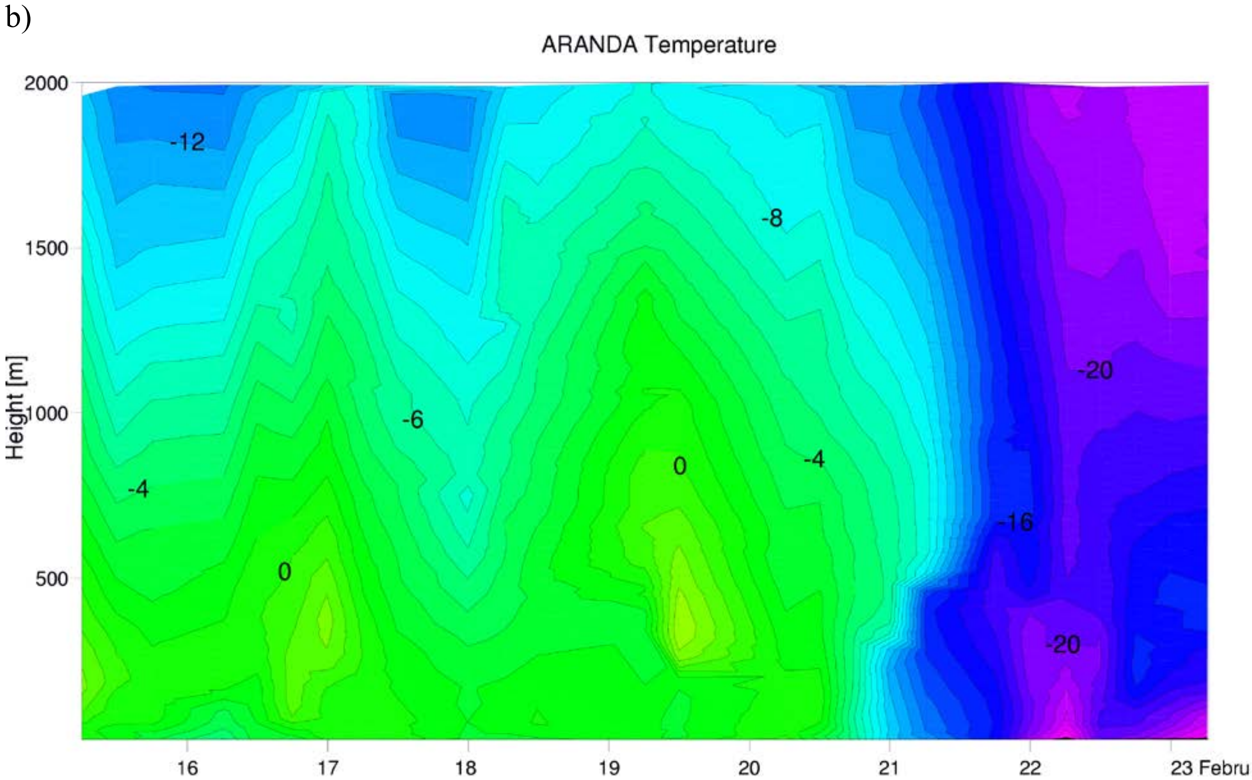
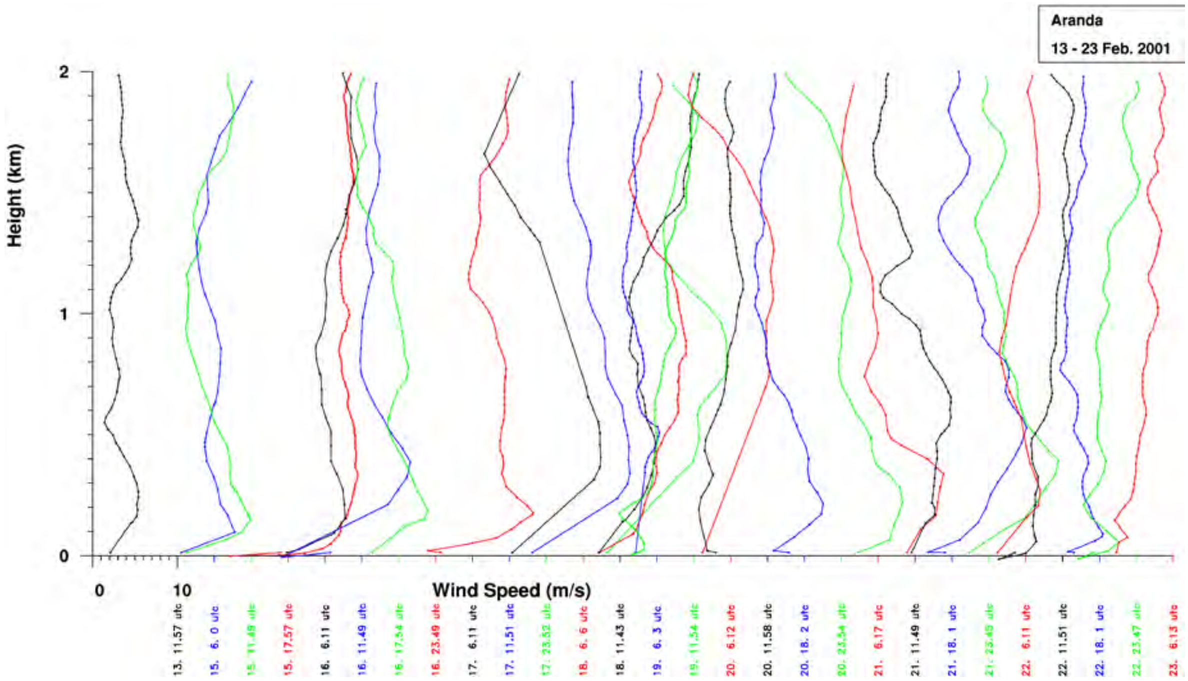


Fig. 4.46: (a) Vertical temperature profiles between surface and 2 km height as measured by 28 Vaisala radiosondes at RV Aranda during the period 13 February 2001 11.57 UTC to 23 February 2001 06.13 UTC. Tick marks at the abscissa indicate the –5 °C value of the running temperature scale and the launch time.
(b) Time-height cross section of temperature based on the 28 radiosoundings presented in (a). Temperature isoline difference is 1 K.

a)



b)

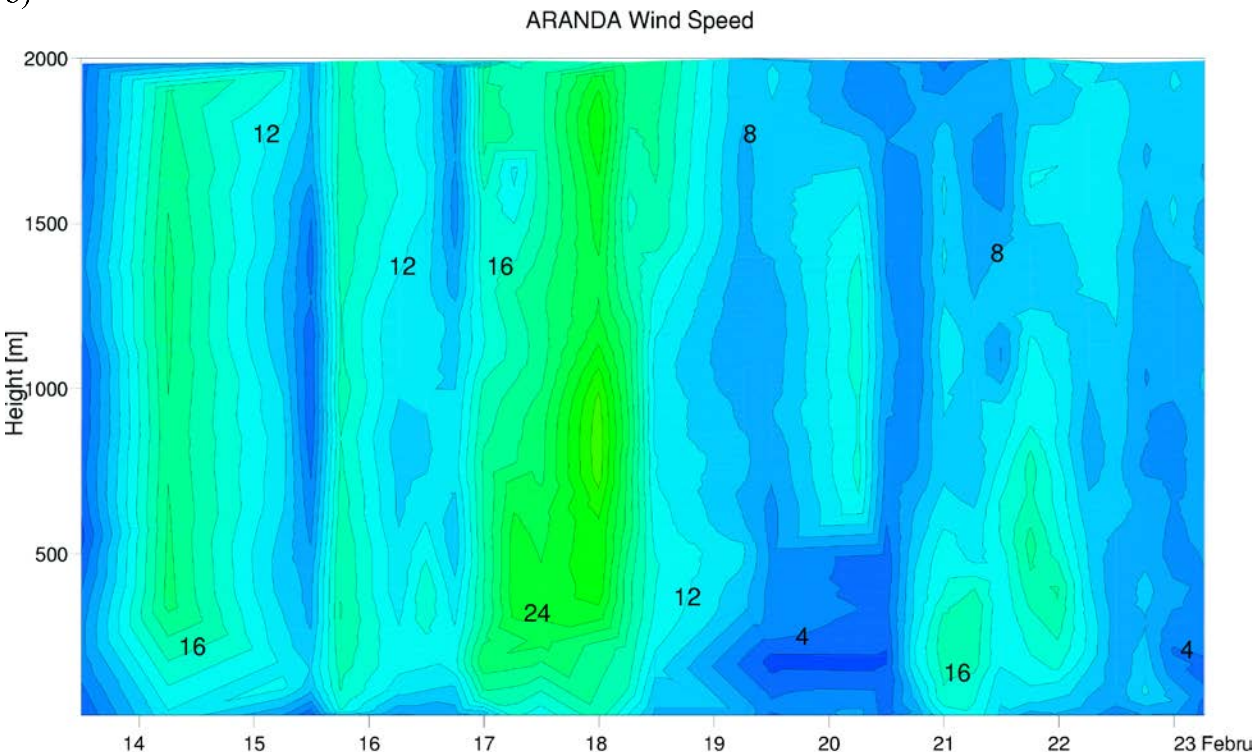


Fig. 4.47: (a) Vertical profiles of wind speed between surface and 2 km height as measured by 28 Vaisala radiosondes at RV Aranda during the period 13 February 2001 11.57 UTC to 23 February 2001 06.13 UTC. Tick marks at abscissa indicate the 10 ms^{-1} value of the running wind speed scale and the launch time.
(b) Time-height cross-section of wind speed based on the 28 radiosoundings presented in (a). Wind speed isoline difference is 2 ms^{-1}.

4.2.4. Research aircraft DO-128

The task of the research aircraft (RA) DO-128, call-sign D-IBUF, during BASIS 2001 was to document the spatial variability within the experimental area. This concerned the mean and the turbulent properties and the radiation fluxes in the atmospheric boundary layer over the inhomogeneous surface of the Bay of Bothnia: land-fast ice, drifting sea ice, and open water. RA DO-128, owned by the University of Braunschweig, operated from the airport of Oulu at 64.93° N, 25.36° E. It arrived on 13 February in Oulu and left Oulu on 23 February 2001. On the nine days between one flight mission per day was flown, on 19 February even two missions, resulting in a total of 10 flight missions during BASIS 2001.

The following persons were involved in the DO-128 aircraft measurements: Burghard Brümmer, Gerd Müller, and David Schröder from the University of Hamburg and Rolf Hankers, Thomas Feuerle, Helmut Schulz, and Gerko Wende from the University of Braunschweig.

Figs. 4.48 and 4.49 show RA DO-128 on the airfield Oulu before the first mission and after returning from its first flight mission on 14 February. The DO-128 is a two engine turbo-prop aircraft with a length of 11.71 m (14.29 m including the noseboom and a wing-span of 15.55 m . It has a duration of 4.5 hours and its typical flight speed during boundary layer operations is 65 m s^{-1}. Beside the two pilots, RA DO-128 had place for three scientists. The equipment installed at the aircraft during the BASIS 2001 campaign is summarized in Table 4.1. The noseboom with the 5-hole pressure probe for measurement of the three wind components, the temperature sensor housing and the moisture inlet are shown in Fig. 4.50.

Fig. 4.48: Research aircraft DO-128 at the airfield Oulu before the start to the first flight mission on 14 February 2001.

Fig. 4.49: Research aircraft DO-128 and crew at the airfield Oulu after return from the first flight mission on 14 February 2001.

Fig. 4.50: The head of the 3.5 m long noseboom of the DO-128 with the 5-hole-probe (right) for measurement of the three wind components, the Rousemount housing for the temperature sensor (left), and the air inlet (below) for the moisture sensors.

Table 4.1 Instrumentation of research aircraft DO-128 (D-IBUF) during BASIS 2001

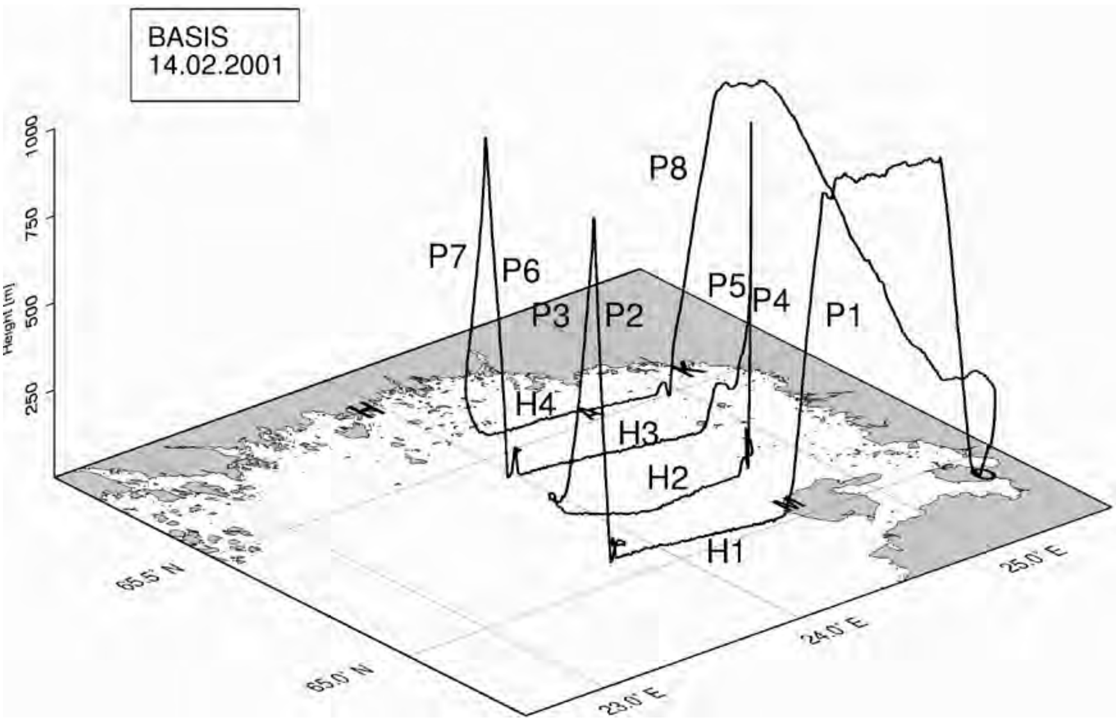
Research Aircraft D-IBUF, Dornier 128-6						
Data Group		Accuracy	Resolution	Data Rate	Sensor	Remarks
Air Data	Static Press.	0,05 hPa	0,02 hPa	100 Hz	Setra	Rosemount 5-Hole-Probe
	Dynamic Press.	0,1 hPa	0,005 hPa	100 Hz	Setra	
	Static Temp. slow	0,5°C	0,01° C	100 Hz	Rosemount	
	Static Temp. fast	0,5°C	0,01° C	100 Hz	Rosemount	
	Altitude	5 m	0,2 m	100 Hz	computed	based on ISA at 2000 m MSL
	Airspeed	0,3 m/s	0,01 m/s	100 Hz	computed	
Humidity	Capacitive	2% rel.	0,01 %	100 Hz	HumiCap HMP 233	
	Dewpoint	0,25	0,05	variable	Meteolabor TP3	
	Optical	-	0,01 %	100 Hz	Buck Research	
GPS Data	Position	10 m	1 m	1 Hz	Novatel Millenium	Stand alone Mode
	Speed	0,5 m/s	0,01 m/s	1 Hz		
INS Data	Speed	12 kt	0,125 kt	10 Hz	Honeywell LaserNav	Serial Digital Data via ARINC-429
	Heading	0,4	0,1	20 Hz		
	Accelleration	10 %	0,001 g	50 Hz		
	Rate	1 %	0,015° s	50 Hz		
Wind	Direction	2°	0,1 %	100 Hz	Computed	In level flight at wind speed of 10 m/s time resolution dependent to INS data rate
	Speed	0,5 m/s	0,08 m/s	100 Hz		
	Vertical	0,2 m/s	0,04 m/s	100 Hz		
Additional	Radio Alt.	1 m	0,1 m	100 Hz	Sperry AA-300	
Radiation	Shortwave up and down	5 Wm^{-2}	0,1 Wm^{-2}	10 Hz	Kipp and Zonen	
	Longwave up and down	5 Wm^{-2}	0,1 Wm^{-2}	10 Hz	Eppley	
	Surface Temp.	0,5° C	0,03° C	10 Hz	Heimann KT 19	

Nearly all quantities, except the radiation fluxes and the GPS (Global Positioning system) and INS (Inertial Navigation System) data, were sampled with 100 Hz, corresponding to a horizontal distance of 0.65 m.

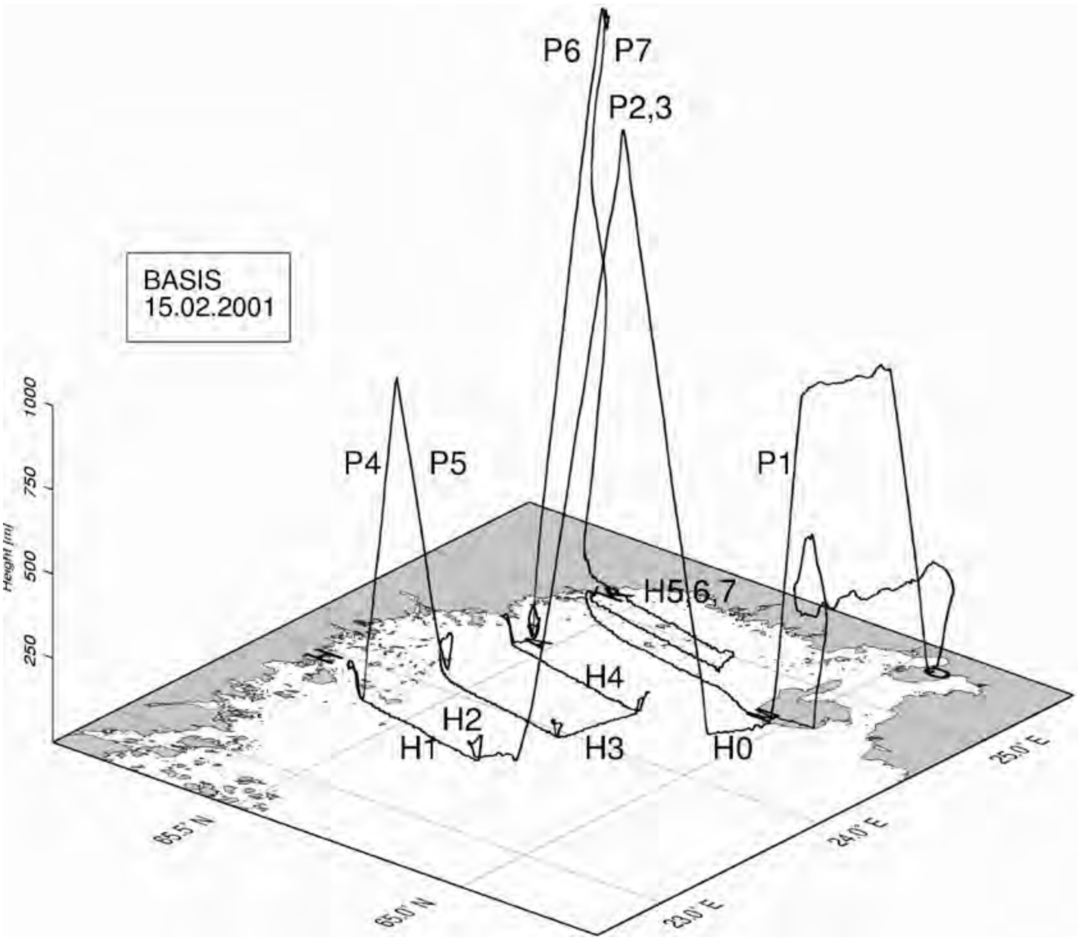
The flight pattern during each mission was composed of vertical profiles (abbreviated by "P") and horizontal flight legs (abbreviated by "H"). In many flight missions so-called vertical stacks were flown, i.e. H-legs located one upon the other at different altitudes. If possible the flight pattern was oriented with the mean wind direction, resulting in alongwind and crosswind flight orientations. In order to measure the surface fluxes, the lowest legs were flown at altitudes around 10 m height. The engaged work of the pilots is particularly mentioned here.

The RA DO-128 flight patterns including the locations of the horizontal legs, stacks, and vertical profiles during the ten flight missions are shown in Figs. 4.51 a-j. They are also summarized in Fig. 2.3. A typical flight mission covered an area of about 50 km x 50 km and reached up to 3 km height. Whenever possible, the ice station Marjaniemi and RV Aranda were incorporated in the flight missions. Figs. 4.52 to 4.54 show low level passages of DO-128 at the Majaniemi ice station.

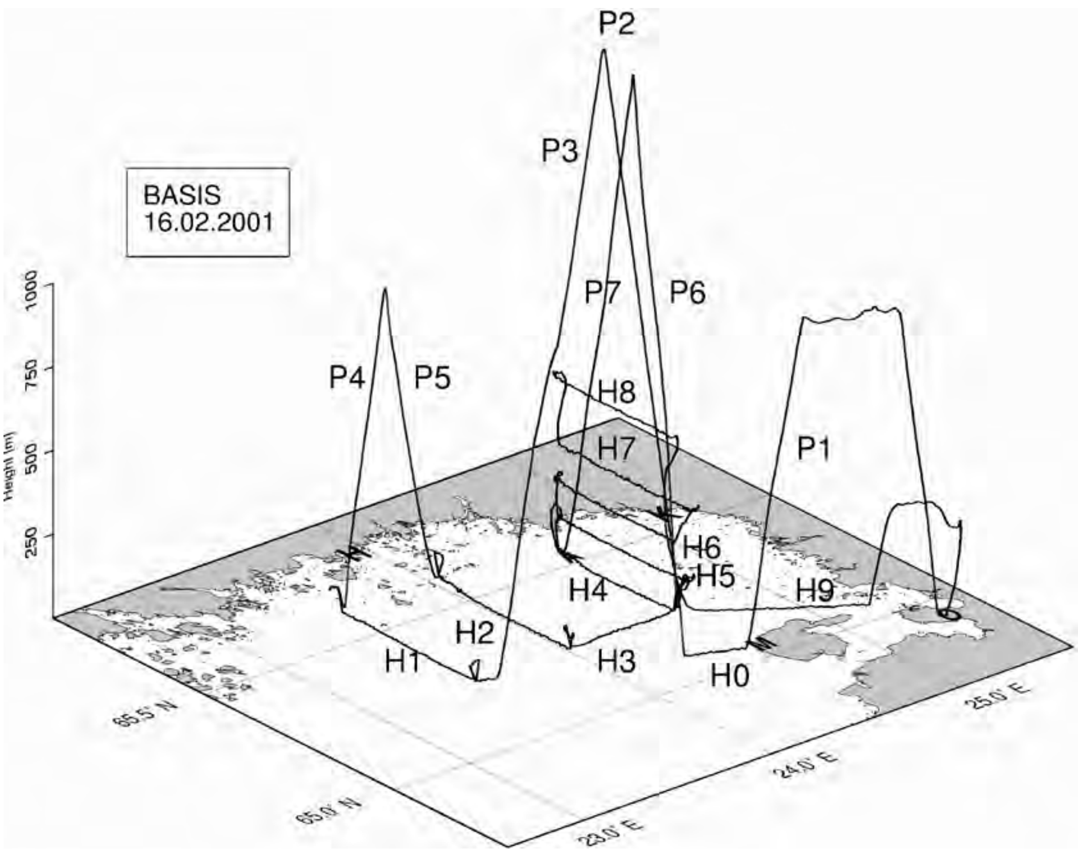
a)



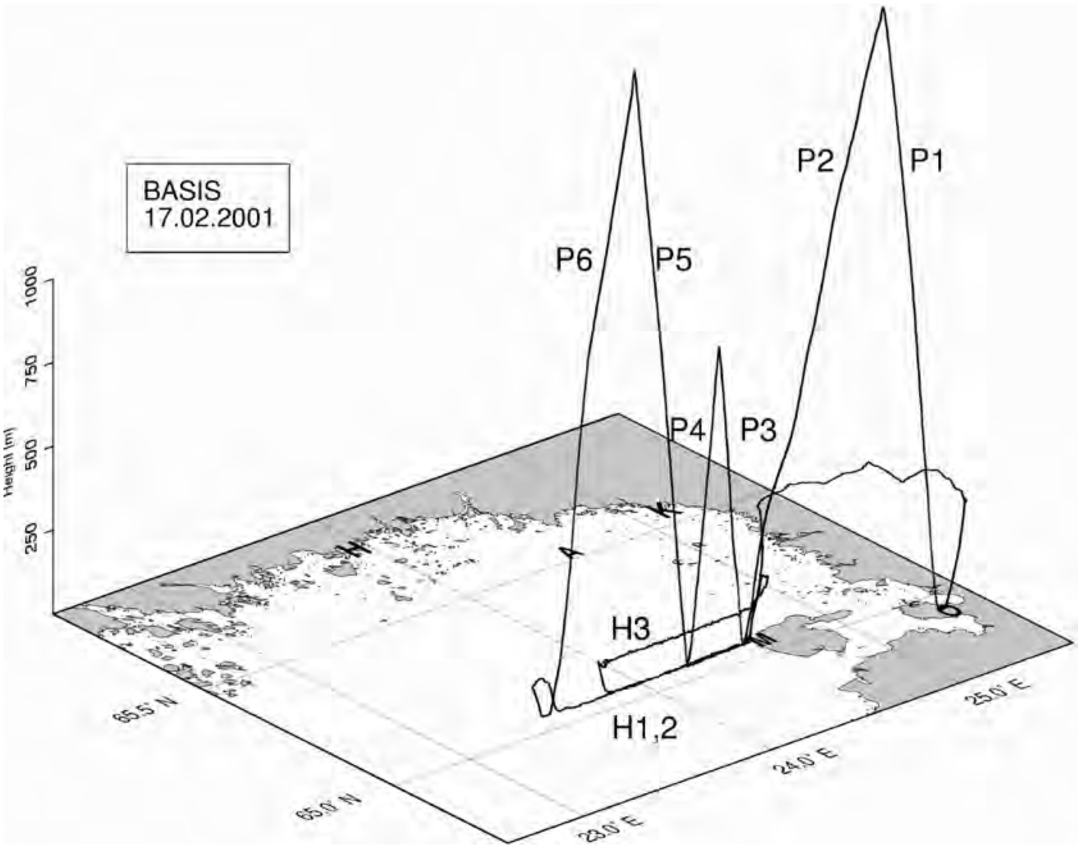
b)


P6
P7
P2,3
BASIS
15.02.2001
Height [m]
1000
750
500
250
P4
P5
P1
H5,6,7
H4
H2
H1
H3
H0
65.5° N
65.0° N
23.0° E
24.0° E
25.0° E

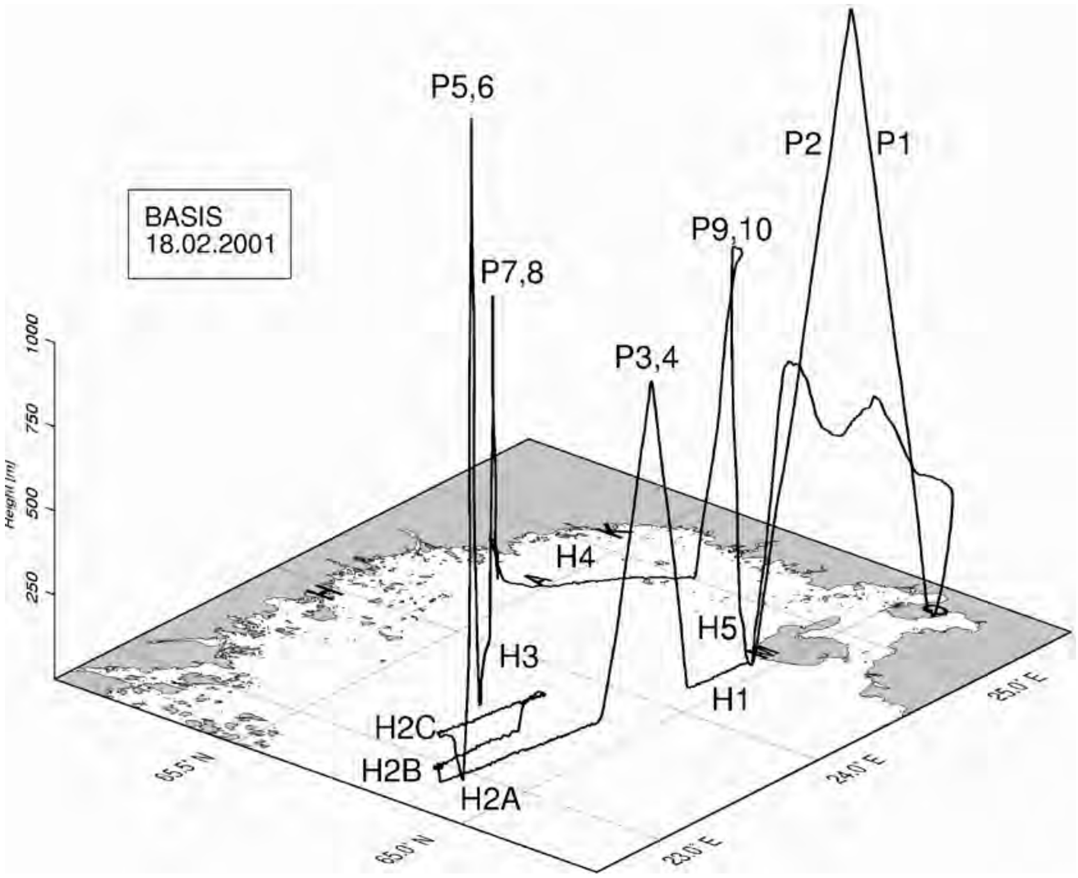
c)


P2
P3
BASIS
16.02.2001
P7
P6
Height [m]
1000
750
500
250
P4
P5
H8
H7
P1
H6
H5
H4
H9
H2
H1
H3
H0
65.5° N
65.0° N
23.0° E
24.0° E
25.0° E

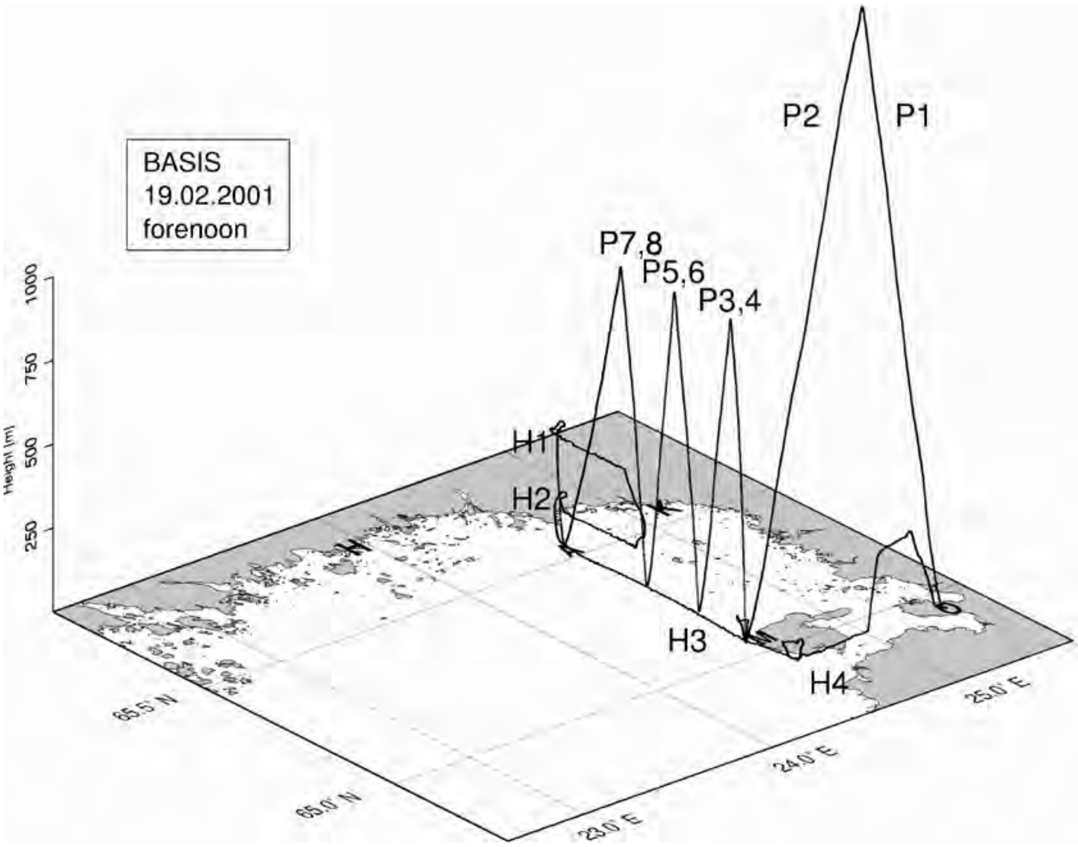
d)


BASIS
17.02.2001
P2
P1
P6
P5
P4
P3
H3
H1,2
Height [m]
1000
750
500
250
65.5° N
65.0° N
23.0° E
24.0° E
25.0° E

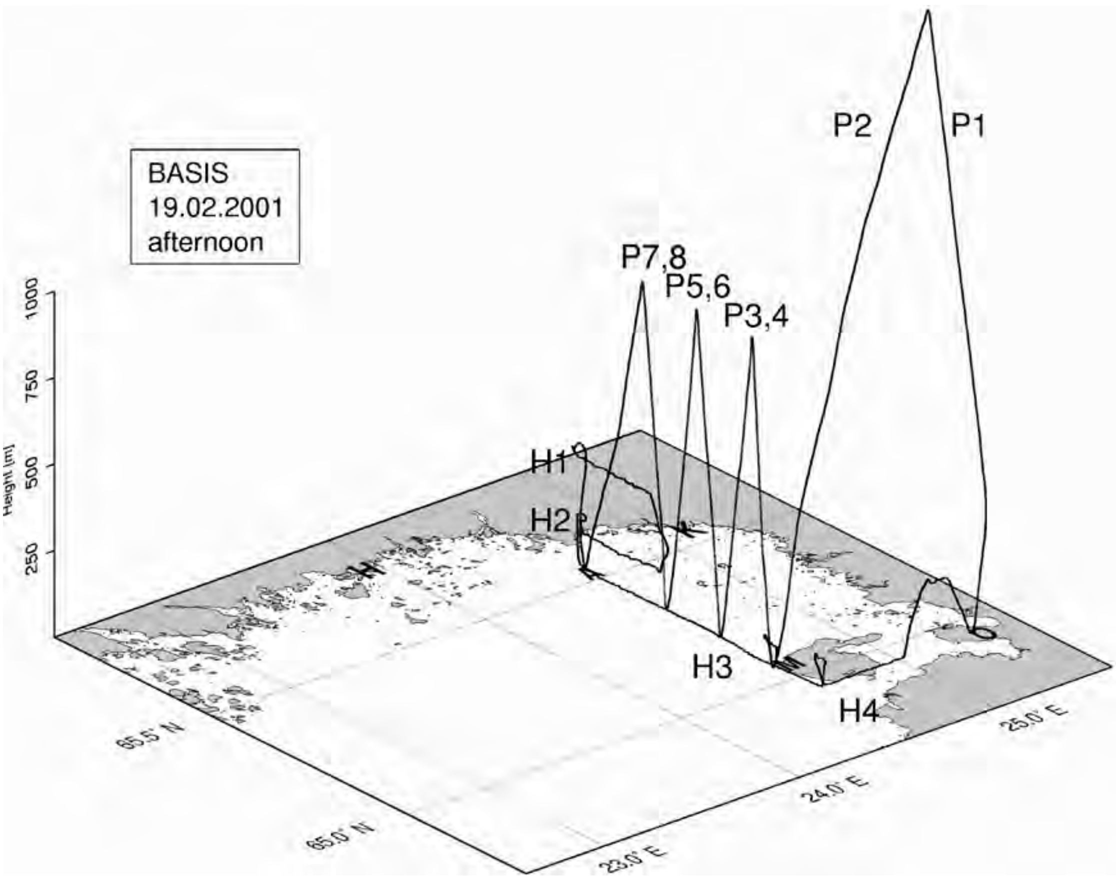
e)


BASIS
18.02.2001
P5,6
P2
P1
P9,10
P7,8
P3,4
H4
H5
H3
H1
H2C
H2B
H2A
Height [m]
1000
750
500
250
65.5° N
65.0° N
23.0° E
24.0° E
25.0° E

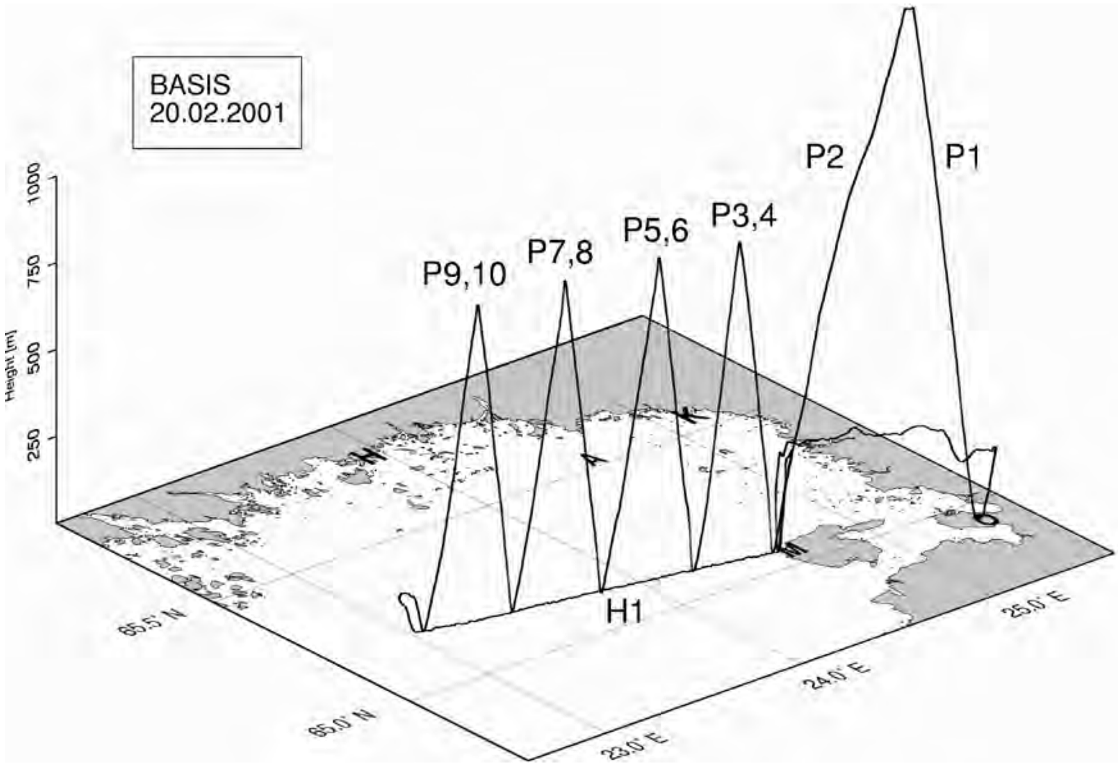
f)


BASIS
19.02.2001
forenoon
P2
P1
P7,8
P5,6
P3,4
H1
H2
H3
H4
Height [m]
1000
750
500
250
65.5° N
65.0° N
23.0° E
24.0° E
25.0° E

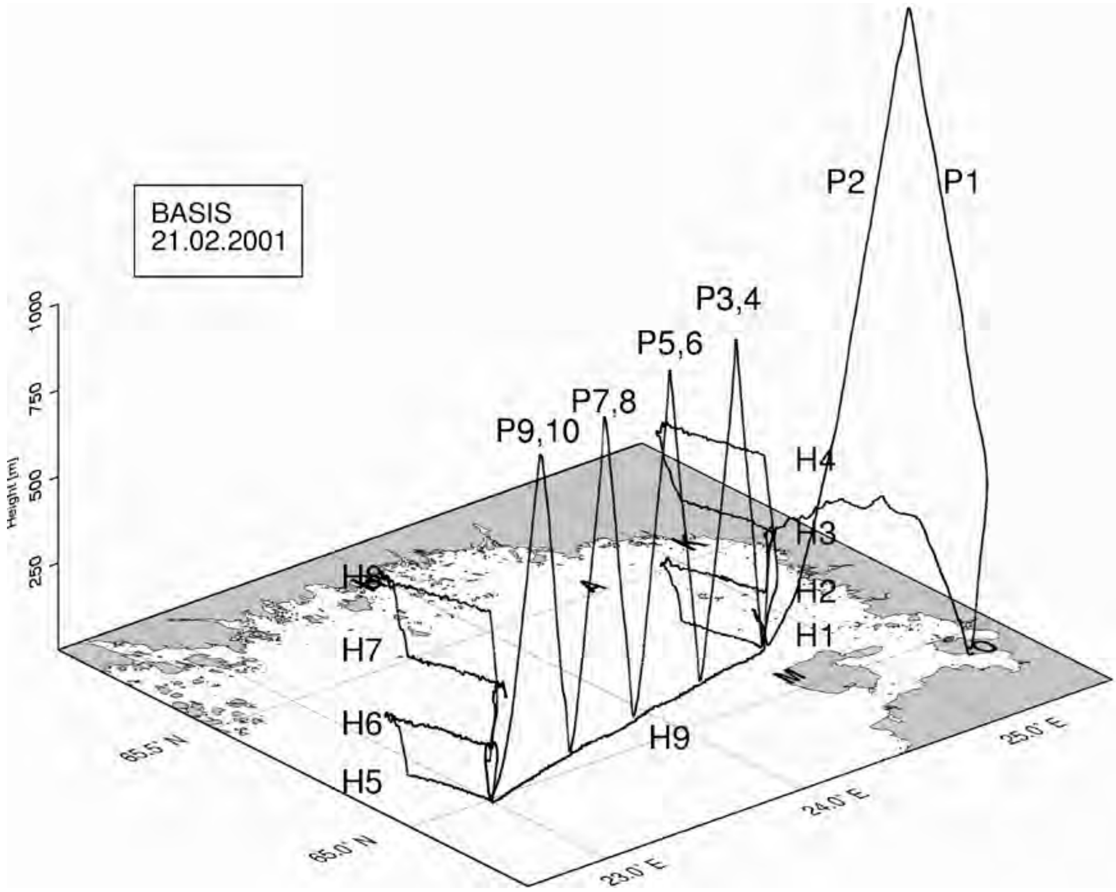
g)


BASIS
19.02.2001
afternoon
P2
P1
P7,8
P5,6
P3,4
H1
H2
H3
H4
Height [m]
1000
750
500
250
65.5° N
65.0° N
23.0° E
24.0° E
25.0° E

h)


BASIS
20.02.2001
Height [m]
250
500
750
1000
P9,10
P7,8
P5,6
P3,4
P2
P1
H1
65.5° N
65.0° N
23.0° E
24.0° E
25.0° E

i)


BASIS
21.02.2001
Height [m]
250
500
750
1000
P9,10
P7,8
P5,6
P3,4
P2
P1
H4
H3
H2
H1
H8
H7
H6
H5
H9
65.5° N
65.0° N
23.0° E
24.0° E
25.0° E

j)

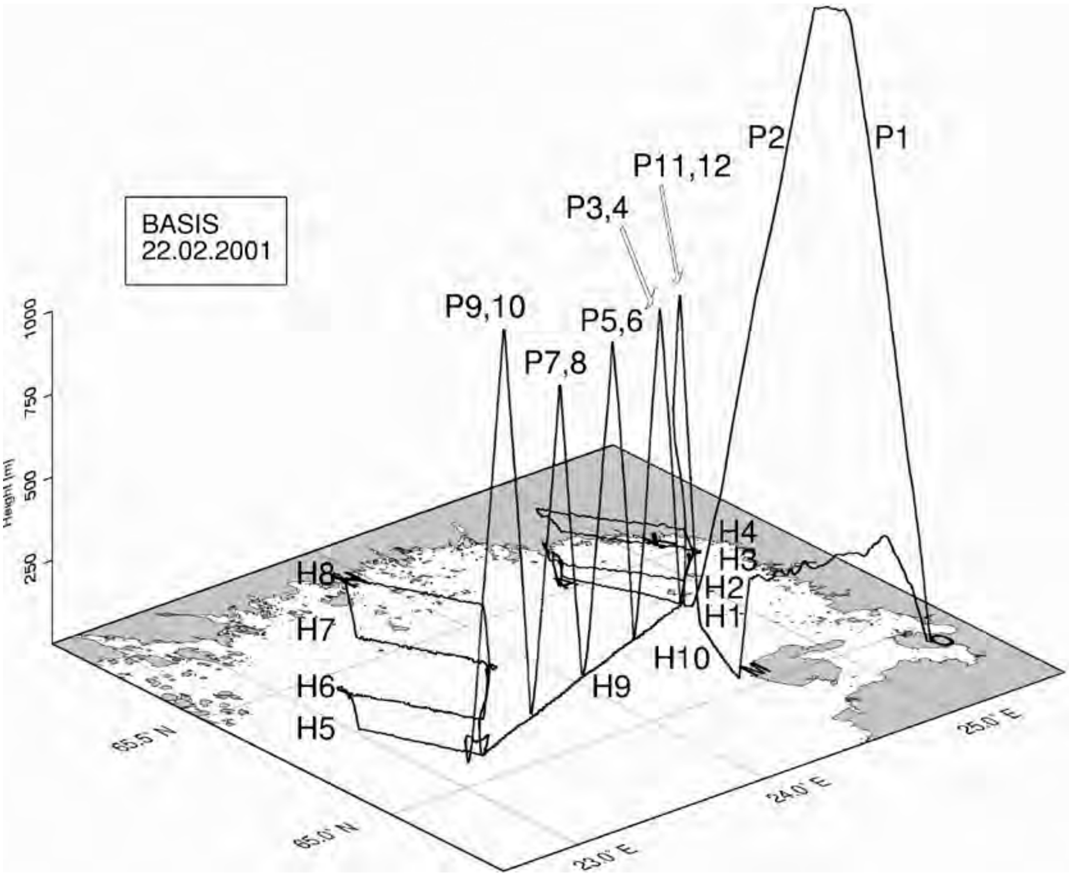


Fig. 4.51 a-j: Three dimensional flight pattern for each of the ten DO-128 flight missions during BASIS 2001. P1, ….and H1, … mark the vertical profiles and horizontal legs, respectively. Capital letters in the surface plane indicate the airfield Oulu (O), RV Aranda (A), ice station Marjaniemi (M), and automatic meteorological buoys at Kuivaniemi (K) and Haparanda Hamn(H).

Fig. 4.52: Low-level passage of research aircraft DO-128 at the Marjaniemi ice station on 18 February 2001 09.02 UTC (view towards east).

Fig. 4.53: Low-level passage of research aircraft DO-128 at Marjaniemi ice station on 19 February 2001 10.32 UTC (view towards west).

Fig. 4.54: Low-level passage of research aircraft DO-128 at Marjaniemi ice station on 20 February 2001 13.50 UTC (view towards west-southwest).

Details of the ten flight missions such as times, locations, altitudes/height intervals, headings etc. of all H-legs and all P-profiles are summarized in the flight reports (Tables 4.2 a-j). Visual observations (cloud base, cloud top, cloud cover, sea ice cover etc.) made by the aircraft scientists and needed for the future evaluation and interpretation of the data are also listed.

Table 4.2a: Mission 1 14 February 2001

Time (UT)	Pattern	Height (’)	Comment
11:58:37			Start at Oulu.
12:09:47-12:12:12	Transit		Very good visibility, below 7/8 Sc. Hailuoto is enclosed by land-fast ice.
12:09:47-12:12:12	P1	3000’-40’	Descent starts above Hailuoto, below 7/8. 12:11:50 Marjaniemi station on starboard (aircraft altitude 343’), no clouds have been crossed.
12:12:47-12:22:57	H1	30’-40’	Below 7/8 Sc. Ice fraction: 80%-90% with leads.12:12:50 rough ice. 12:13:27 small water patches.12:17:00 snow coverage of ice completely water-soaked.12:22:40 Open water.
12:25:22-12:27:38	P2	40’-3000’	No clouds.
12:27:47-12:31:37	P3	3000’-40’	
12:31:37-12:39:37	H2	30’-40’	Below 7/8 Sc, very good visibility. Ice flows frozen together and covered by snow.12:34:40 grey ice with 10% snow coverage and 5% open water.
12:41:38-12:43:52	P4	40’-3000‘	Clouds above, but not reached.
12:43:57-12:48:47	P5	3000’-40’	Completely closed ice with 80%-90% snow coverage.
12:48:47-12:59:27	H3	30’-40’	12:52:00 ice with ridges. 12:56:00 ice breaker on starboard.
13:01:27-13:03:47	P6		Cloudless. Ice fraction: 80%-90% with dry snow, ridges and leads.
13:03:49-13:06:27	P7	3000’-40’	
13:06:37	H4	30’-40’	High ridges and leads. 13:11:30 Aranda on starboard. Ci fr at W. 13:13:19 smooth ice completely covered by snow.
13:14:47-13:17:17	P8	40’-3000’	
13:32:00			Landing at Oulu.

Comment Flight 1 (14.02.2001)

- Measurement area in strong westerly flow inside warm core of a low pressure system centered near Faroer Islands.
- Clouds: 8/8 Sc in southern part (cloud bases higher than the 900 m profiles), cloudless in the northern part.
- Very good horizontal visibility (unusual in warm air advection).
- Ice conditions: extremely variable over short distances: rough, smooth, white, grey, old, new, open fractures, ridges, drift ice with water soaked snow and landfast ice with with dry snow.
- Melting conditions prevailed in the measurement area with ice temperature 0° C and T(10m) 3-3.5 °C.
- In the southern part two inversions were present: the lower one below 80 – 140 m (tops) with stably stratified layer underneath down to the surface, the upper one below 150 – 320 m (tops); in the northern part only one inversion of 3 – 3.5 K below 150 – 320 m (tops).
- Humidity: dryer below inversion than above.
- Strong westerly winds with maxima of FF 22 – 27 m/s from DD 240 – 270° between 150 and 300 m have been observed.

Table 4.2b: Mission 2 15 February 2001

Time (UT)	Pattern	Height (’)	Comment
09:24:22			Start at Oulu.
09:31:00-09:33:28	Transit		Flight over the eastern coast of Hailuoto, land-fast ice.
09:34:22-09:37:07	P1		Below 8/8 St. Descent over the island to the Marjaniemi station.
09:37:07-09:40:12	H0	30’-40’	Rough ice with ridges. At the end slight snowfall.
09:40:12-09:45:22	P2	40’-6000’	8/8 St, CB 4000’. Low ground visibility due to clouds. CT not reached.
09:45:32-09:50:57	P3	6000’-40’	Weak turbulence. Ice 5% covered by snow.
09:55:22-10:04:02	H1	30’-40’	Shower on the left. 09:56:30 open water pond. 8/8 St. 09:59:00 open water pond. 10:02:11 smooth and solid ice. 10:04:02 ice completely closed.
10:05:54-10:08:07	P4	40’-6000’	10:06:30 above an island.
10:08:10	Start P5		P5 is broken off because of problems with the computer.
10:13:08-10:15:59	New Start P5	6000’-40’	8/8 St above the aircraft, profile does not reach the clouds. On the right: haze, on the left: good visibility, 95% ice with leads.
10:17:45-10:26:40	H2	30’-40’	10:18:58 shower in front of us. Quite smooth ice. 10:24:00 big water area. Almost completely free of turbulence.
10:28:20-10:32:37	H3	30’-40’	Below 8/8 St. Quite smooth ice. Later, the ice is more rough. Either, the snow is blown away, or it is completely soaked.
10:34:00-10:43:11	H4	30’-40’	The ice becomes more smooth and solid. Good visibility. Slight snow showers in front of us on the right side. No turbulence.
10:44:00-10:49:20		30’	Intercomparison with Aranda. 10:46:03 Aranda passed on the left side in W-E direction. 10:49:00 Aranda passed on the right side in N-S direction.
10:49:20	P6	30’-6000’	CB 4800’, CT not reached, 8/8 Sc.
10:59:00-11:08:00	H5	400’-430’	11:02:00 over land-fast ice, quite smooth ice. 11:07:00 open water pond.
11:10:25-11:20:14	H6	200’	In N direction, the ice becomes more smooth and solid, up to point H, the ice is completely snow-covered. Quite turbulent.
11:22:18-11:38:25	H7	25’	Below 8/8 Sc. No turbulence. Closed ice, 50% snow. 11:30:35 water below, increased turbulence. 11:33:36 large fraction of open water, flight over a large area open water. 11:36:00 Marjaniemi station in front of us. 11:37:44 this leg ends inside fog that reaches to the ground.
11:52:50			Landing at Oulu.

Comment Flight 2 (15.02.2001)

- Experimental area in weak NW flow with temperatures at 10 m slightly below freezing point.
- Position of Aranda: 65° 30.5’ N, 24° 23.8’ E.
- Very good horizontal visibility.
- Clouds: 8/8 St/Sc with CB 4000’ - 4800’, CT not reached.
- Ice conditions: as during the preceding mission extremely variable over short distances: rough, smooth, white, grey, old, new, open fractures, ridges, drift ice and landfast ice with with snow.
- Inversion of 1 –3 K at 100 – 220 m (tops).
- Humidity: dryer (2.2 g/kg) above inversion than below (3.5 g/kg) (vice versa as during mission 1).
- Wind: moderate winds with maxima of FF 5 – 7 m/s from DD 320 - 350º between 40 and 180 m.

Table 4.2c: Mission 3 16 February 2001

Time (UT)	Pattern	Height (’)	Comment
09:20:40			Start at Oulu. Transit to Hailuoto at 3000’, cloudless and sunshine. 09:21:00 6/8 Ci.
09:29:00-09:32:10	P1	3000’-20’	Ice is completely covered by new snow after snowfall in night, almost 100% ice with 80% snow coverage, sunny. 09:32:10 Marjaniemi station in front, inversion at 330’ and 990’.
09:32:20-09:36:00	H0	20’	Open water with a thin new ice pile, first grey ice, later a 100 m wide lead. 09:36:00 90% thin, new ice snow-covered, black leads and patches, no clouds apart from 1/8 Ci.
09:36:00-09:41:25	P2	20’-6000’	Some small leads, ice almost completely covered by snow.
09:41:25-09:46:59	P3	6000’-50’	No clouds below 6000’, big water pond (width of 200 m). 09:46:59 cloudless.
09:49:53-09:59:31	H1	50’	Intermittent smooth and rough ice, black ponds with a thin ice pile. 09:52:56 big open water area (without thin ice), clouds in the West. 09:55:22 very big open water area with 50% new ice (very thin, black). 09:57:11 closed ice.
10:00:40			10:00:40 100% ice (80% snow-covered), small leads. Ac far away in the North.
10:01:23-10:03:47	P4	50’-3000’	On the right smooth, land-fast ice, almost cloudless (thin Ci).
10:03:47-10:06:00	P5	3000’-30’	
10:08:15-10:18:34	H2	20’	Fields of smooth ice with ridges, isolated fissures. Very good visibility.
10:20:08-10:25:58	H3	20’	A small fraction of fissures.
10:27:45-10:31:43	P6	20’-5000’	Turbulence at 2000’. No clouds.
10:31:43-10.37:11	P7	5000’-30’	
10:37:11-10:48:40	H4	30’	10:39:53 Aranda passed, quite rough ice without open water. 10:45:07 frozen lead. Sunny. 3/8 Ci in the East
10:54:35-11:01:00	H5	330’	2/8 As on the western horizon. 10:57:23 from now on over land-fast, smooth ice. Less turbulence. Run ends at Aranda.
11:02:33-11:10:52	H6	660’	More turbulence than at 30’ and 330’. Clouds with frontal character in W.
11:12:15-11:23:44	H7	1000’	Intermittent rough and smooth ice.
11:25:00-11:34:00	H8	1600’	
11:36:32-11:44:40	H9	30’	Maximum of turbulence, rough ice with open water ponds. 11:43:40 the eastern top of Hailuoto passed.
11:51:00			Landing at Oulu.

Comment Flight 3 (16.02.2001)

- Westerly flow and high pressure ridge centered above S- Sweden.
- Cloudless and good visibility.
- Ice conditions: after snowfall during night the ice is more white than during the preceding missions, formerly water-soaked grey snow and black new ice is now covered by fresh snow.
- Temperature: air temperature of about -2° C at 10 m is between ice temp. (about -4 C) and water temp.
- Inversion of 1-3 K at 140-450 m (tops).
- Humidity: dryer above inversion (here about 1.7 g/kg) than below (increase towards surface up to 2.7 g/kg).
- Wind: FF 7-9 m/s at 10 m increases near the inversion up to 13-17 m/s, DD shows veering with height of about 50° up to the inversion.

Table 4.2d: Mission 4 17 February 2001

Time (UT)	Pattern	Height (’)	Comment
08:22:00			Start at Oulu.
08:23:00-08:28:22	P1	30’-6000’	Below 8/8 Sc (slightly transparent). Clouds not reached, cloud base clearly higher than 6000’.
08:28:22-08:38:00	P2	6000’-30’	Cloudless zone in the West. Turbulence in 4500’. 08:32:00 over the eastern coast of Hailuoto. 08:33:00 2970’-3670’ isothermal, turbulence 0-990’. 08:37:25 station across, strong turbulence.
08:38:00-08:40:25	P3	30’-3000’	Ice: white and fewer open ponds than on the days before, but more new ridges. Sun shines through the clouds. 5/8 medium-altitude and high clouds. 99% ice.
08:40:25-08:43:50	P4	3000’-50’	
08:43:50-08:49:31	P5	50’-6000’	Turbulence 0-330’. Sunny. Clear cloud edge (25° over the horizon). 4/8 As, 4/8 Ci, 5/8 total coverage. No clouds below 6000’.
08:49:31-08:55:00	P6	6000’-30’	08:51:00 ice edge in front of us. 08:53:00 ice: 90%. P6 ends directly at the ice edge. 6/8 medium-altitude clouds (As, Ac).
08:58:18-09:08:00	H1	30’-40’	Very few open water ponds. For about 30 sec. problems with the computer. Ice is more rough than on the days before (new ridges). 4/8 clouds. 95% ice. 09:04:00 30 sec malfunction of computer.
09:11:20-09:23:50	H2	30’	More turbulence than at H1. Sunny. 4/8 clouds, clouds clear off from NW.
09:25:24-09:33:10	H3	30’	Sunshine through high Ci. Run ends about 300 m in the South of the Marjaniemi station.
09:45:35			Landing at Oulu.

Comment Flight 4 (17.02.2001)

- Experimental area in W-flow with +2º C at 10 m. The area has been passed by a weak cold front of a low centered W of N-Norway during the begin of flight.
- Clouds: thin Sc (8/8) higher than 1800 m at the eastern part, otherwise cloudless.
- No surface inversion but isotherm conditions (+2º C) and increasing humidity towards the surface below 200m, above 200 m well mixed layer below an inversion at 1000 m.
- Ice temperature (-4º C) clearly below air temperature (+ 2º C) due to radiative cooling below cloudless sky.
- Wind shear of 10 m/s below 200 m.
- Ice conditions: strongly compressed ice with new ridges and only a few open ponds, open water starts W of the western point of the flight pattern.

Table 4.2e: Mission 5 18 February 2001

Time (UT)	Pattern	Height (’)	Comment
08:50:00			Start at Oulu.
08:50:00-08:57:09	P1	6000’	Experimental area is completely cloudless.
08:57:09-09:02:30	P2	6000’-30’	In the Southeast over land a flat layer of haze. At 800’ turbulence.
09:02:30-09:07:00	H1	30’	Big water lakes in the ice, ice relatively free of snow, on the right a big lead.
09:07:00-09:09:51	P3	30’-3000’	No clouds.
09:09:51-09:13:30	P4	3000’-30’	
09:13:30-09:24.41	H2a	30’	09:15:00 lead, 10% of the time over open lakes. 09:18:59 ice edge, from now on 100% water and streaks of ice pulp.
09:26:37-09:31:32	H2b	230’	Just before the ice edge flexible ice pulp that moves on the waves. More turbulence than at H2a.
09:34:50-09.40:21	H2c	500’	Open water with 3% ice pulp streaks. In the West high clouds (approaching front).
09:42:20-09:47:28	P5	30’-6000’	No clouds.
09:47:28-09:52:49	P6	6000’-30’	
09:52:49-10:01:10	H3	30’	Over closed ice with open fissures. Up to now always sunshine. Ice is quite rough with many ice ridges. On the left side the ice edge is 2 km away. The heading is parallel to the ice edge.
10:01:10-10:03:39	P7	30’-3000’	Over open water. No clouds. Aranda on the right in front. Compared to the previous days, the ice edge moved nearer to the Aranda (up to about. 5 km).
10:03:39-10.08.43	P8	3000’-30’	P8 over ice.
10:10:13-10:18:51	H4	30’	Aranda passed in ca. 300 m distance on the left side. Very smooth, land-fast ice with dry snow. 10:18:50 ice with thick snow.
10:18:51-10:21:18	P9	30’-3000’	Profile over land-fast, smooth, snow-covered ice. Ci in the West.
10:21.18-10:25:27	P10	3000’-30’	
10:25:27-10:32:16	H5	30’	Above closed ice with small leads. Marjaniemi station reached at the endpoint.
10:32:16-10:34:31	P11	30’-3000’	No clouds.
10:47:56			Landing at Oulu..

Comment Flight 5 (18.02.2001)

- Experimental area inside moderately cold (3-4º C) NW-flow at the rear of a low centered above Lithuania.
- Cloudless conditions and good visibility.
- Complex structure of inversions (some soundings show 3 inversions) with strongest inversion (1.5-3 K) at 400-500 m.
- Wind: 8-12 m/s at z = 10 m shows a maximum of 16 - 21 m/s at the main inversion.
- Ice conditions: strong NW winds caused a lot of new open ponds and the ice edge has moved towards E; near Aranda, the ice edge is eroded and ends now only 5 km W of it.

Table 4.2f: Mission 6 19 February 2001 forenoon

Time (UT)	Pattern	Height (')	Comment
07:55:30			Start at Oulu.
07:56:10-08:02:24	P1	6000'	In 990' very thin haze layer (1/8 Sc). 07:57:00 2/8 Cu in 825', CB with 7/8 As higher than 6000'. 07:59:00 on the right under the plane 2/8 thin Sc, cloud base at 5700', CT at 6500'.
08:02:24-08:09:00	P2	6000'-30'	Below 4/8 Ac, half sun shine, half shadow, 3/8 Ci.
08:10:22-08.12:40	P3	30'-3000'	Below 3/8 medium-altitude clouds, no clouds in the profile level. 98% ice with 80% snow-coverage, ice is quite closed.
08:12:40-08:14:55	P4	3000'-30'	Below 6/8 Ac, no low clouds. Water ponds with thin black new ice.
08:14:55-08:17:16	P5	30'-3000'	
08.17:16-08:19:12	P6	3000'-30'	Below 6/8 Ac. White ice in the East, thin new ice in the West.
08:19:12-08.21:37	P7	30'-3000'	Jet in 1815', below 7/8 Ac/As, CB is higher than 3000'.
08:21:37-08:26:14	P8	3000'-30'	The area free of ice near RV Aranda seen during mission 5 is closed today.
08:28:59-08:34:12	H1	1000'	Below 7/8 thin Sc.
08:36:05-08:41:18	H2	300'	In the Northeast quite compact clouds, below 8/8 medium-altitude Sc.
08:43:35-09:02:25	H3	30'	Aranda is starting point. Almost no open water below. 08:47:00 sunny, larger ice floes. 08:48:00 grey ice, 20% snow-covered. 08:52:13 for a short time open water, the medium-altitude clouds decrease in the South. 08:56:34 2/8 thin Sc. 08:57:30 7/8 As/Ac, 2/8 Cu over Hailuoto. 08:58:56 Marjaniemi station across.
09:04:48-09:09:46	H4	30'	Thin cloud shreds about 1000'.
09:14:10			Landing at Oulu.

Comment Flight 6 (19.02.2001) forenoon

- Experimental area in moderate SW-flow (FF (10 m) = 5.5–6.5 m/s) behind a warm front with temperatures at 10 m between –2 and –3º C.
- Very good visibility.
- Clouds at about 1700 m (not reached by the profile soundings) with northward increasing coverage: 3/8 (South), 7/8 near Aranda.
- Inversion at 500/550m with ΔT =3 to 4.5 K and a wind maximum of 8-10.5 m/s at 120-220 m.
- Ice conditions: the new open water ponds observed on the preceding day are now closed, new open ridges have formed in the southern section. New black ice and grey ice covers now most of the open water which was observed near Aranda the day before .

Table 4.2g: Mission 7 19 February 2001 afternoon

Time (UT)	Pattern	Height (’)	Comment
12:20:26			Start at Oulu.
12:20:26-12:25:48	P1	0’-6000’	Industrial smoke marks very low inversion. 7/8 thin Sc, CB at 7000’, Hailuoto is covered with low, thin, transparent Sc layer. No clouds in the area of measuring.
12:25:48-12:34:00	P2	6000’-30’	2/8 Sc, CT in 600’, CB in 400’ (only over the island).
12:35:58-12:38:20	P3	30’-3000’	No clouds at flight level and above.
12:38:20-12.40.24	P4	3000’-30’	
12.40:25-12:42:34	P5	30’-3000’	Pool with thin black ice below, ice is completely closed.
12:42:34-12:44:46	P6	3000’-30’	
12:44:46-12:47:03	P7	30’-3000’	
12:47:03-12:51:14	P8	3000’-30’	Old lead from yesterday near RV Aranda is closed completely with white ice.
12:53:45-12:59:00	H1	1000’	Start over land-fast ice, change from complete white ice into half white/half grey ice.
13:01:00-13.06.20	H2	300’	Below 2/8 thin Sc, compact clouds in the North over the land.
13:08:23-13:27:50	H3	30’	Start over land-fast ice with thick snow coverage. 13:11:50 ridge of height 2m. Diffuse sunshine. 13:14:00 ice becomes more free of snow. 13:17:04 pool with thin, black new ice. 13:17:50 the ice shows a few open ponds. 13:21:00 at this place, there are more ridges than in average. 13:23:36 flight over Marjaniemi station.
13:29:40-13:34:00	H4	30’	Run to Oulu.
13:38:35			Landing at Oulu.

Comment Flight 7 (19.02.2001) afternoon
The temperature at 10 m increased by about 1 K, otherwise the conditions in the experiment area are similar to those observed during the forenoon mission.

Table 4.2h: Mission 8 20 February 2001

Time (UT)	Pattern	Height (’)	Comment
12:55:33			Start at Oulu.
12:55:33-12:59:50	P1	0’-5000’	8/8 Sc, a few cloud scraps in 800’, second cloud layer between 1400’and 1500’, third cloud layer between 2300’ and 2500’, sharply marked CT, 1/8 Ci above. Clouds end at the east edge of Hailuoto, experimental area seems to be free of low clouds, but shows some haze.
12:59:50-13:07.16	P2	5000’-30’	13:06:30 6/8 Cs and 2/8 As, no low clouds. 95% of the sea surface is ice-covered, 10% grey ice. 13:07:03 Marjaniemi station below, descent profile did not go through clouds, fresh snow covers the ice, about 10% of the ice shows black spots due to new ice, soaked snow, and snow pulp.
13:07:16-13:09:50	P3	30’-3000’	No clouds are crossed.
13:09:50-13:12:17	P4	3000’-30’	Lots of changes between diffuse and direct sun shine, 2/8 transparent, medium-altitude clouds.
13:12:17-13:14:46	P5	30’-3000’	
13:14:46-13.18:12	P6	3000’-30’	Ice is almost closed now.
13:18:12-13:21:28	P7	30’-3000’	Big sun spots and shadow spots on the ice.
13:21:28-13:23:42	P8	3000’-30’	13:22:45 broken sea ice under the plane. 13.23:14 ice edge crossed, the water is completely free of ice. Waves are recognizable.
13:23:42-13:26:09	P9	30’-3000’	Compact clouds in direction of Sweden. Streaks of ice pulp or new ice in the water.
13:26:09-13:29:18	P10	3000’-30’	The sun is behind clouds over Sweden. 70% grey ice, 5% white ice, 25% water. Profile ends over 80% thin and black new ice.
13:31:45-13:50:00	H1	30’	Still a thin, black new ice skin covers 80% of the water. 13:32:45 only 10% new-ice streaks and 90% open water. Waves are very low. Hardly turbulence. 13:35:00 good horizontal visibility, no clouds above. 13:36:50 broken sea ice and then the ice edge. 13:37:56 from now on compact ice with single water ponds. 13:38:00 the sun comes out again, completely closed ice, 2/8 Ci over us. 13:41:00 6/8 clouds: 2/8 As and 5/8 Ci. 13:42:51 small water pond, ice is completely covered with fresh snow. 13:49:00 pool with thin new ice below. Up to now, it is the low level run with the weakest turbulence of the campaign. End at Marjaniemi station.
13:52:30			Second flight over Marjaniemi station in E-W direction.
14:02:03			Short flight through clouds.
14:05:20			Landing at Oulu.

Comment Flight 8 (20.02.2001)

- Flight W of an occlusion line located along Kemi-Oulu. Experimental area in weak W-flow (FF (10 m) = 2-4 m/s) with temperatures at 10 m between –0.5 and 0.1ºC above water and –1 to –3ºCabove ice. The ice temperature is 2 to 7 K below air temperature.
- Good visibility.
- Clouds: 2/8 Sc at medium height (not reached by the profile soundings).
- Hardly any turbulence.
- Surface-based boundary layer below 70-200 m.
- Two temperature inversions at 100-260 m and 400-480 m.
- The wind shows a maximum (3.5 – 7 m/s) at 70-220 m.
- Ice conditions: the ice is covered very uniformly by fresh white snow. A lot of new open water ponds covered by very thin black new ice (coverage 80 %) have formed. The ice edge is not sharply marked (a smooth decrease in ice floe coverage).

Table 4.2i: Mission 9 21 February 2001

Time (UT)	Pattern	Height (’)	Comment
09:57:17			Start at Oulu.
09:57:17-10:02:36	P1	0’-6000’	Haze around Oulu. CT reached at 6000’.
10:02:36-10:07:45	P2	6000’-40’	
10:10:15-10:15:56	H1	30’	Moderate visibility (3-4 km), 7/8 clouds, but no precipitation. It is very turbulent, the ice edge is parallel to the flight path.
10:17:57-10:23:33	H2	500’	The visibility is better in 500’. Haze or weak snowfall reaches to the ground. The sun shines slightly through it. The ice is mostly free of snow.
10:25:31-10:31:00	H3	1050’	The flight is still in haze, but the ground can be seen clearly. The ice edge is still parallel to the flight path. Begin of weak snowfall.
10:32:40-10:39:05	H4	1650’	The measurement of humidity broke down. 8/8 clouds and weak snowfall. 10:35:30 snowfall ends, still 8/8 clouds. 10:37:00 7/8 clouds and diffuse sunlight now. The measurement of the humidity works again. Direct sunshine at endpoint of H4.
10:41:33-10.43:50	P3	40’-3000’	P3 begins over ice, flight over the ice edge, open water under the plane (in the water 50% ice pulp streaks aligned in wind direction). At 1400’ 2/8 Cu/Sc.
10:43:50-10:46:15	P4	3000’-40’	From now on, the flight is over broken sea ice.
10:46:15-10:48:48	P5	40’-3000’	10:47:20 flight over solid ice now. 10:47:53 snowfall begins again, lead below and low cloud scraps below the plane.
10.48:48-10:50:50	P6	3000’-40’	Snowfall continues.
10:50:50-10.52:35	P7	40’-3000’	4/8 Cu below us, cloud in 2000’-2300’. The ice is compact here.
10:52:35-10:54:54	P8	3000’-40’	Snowfall reaches to the ground.
10:54:54-10:57:59	P9	40’-3000’	8/8 clouds. 100% ice and snowfall.
10:57:59-11:00.48	P10	3000’-40’	The snowfall is moderate to strong.
11:02.00			Snowfall ends.
11:03:10-11:09:07	H5	30’	The run starts over open water with 20% broken sea ice. Over us all is grey, sea smoke.
11.10:52-11.16:00	H6	500’	In this level the flight with good horizontal visibility is more turbulent than at 30’. Over open water without broken sea ice.
11.17:59-11.25:13	H7	1050’	Again snowfall. 11:21:45 flying closely underneath the CB. 11:22:00 snowfall ends. 11:22:22 flying through the clouds now. 11:23:00 flying closely underneath the CB again.
11.27.25-11:32:44	H8	1500’	The flight goes through the clouds with temporary ground visibility.
11.33:23			Snowfall again.
11:34:57-12:00:26	H9	30’	11:36:20 on the left side there is sea smoke. 11.38:19 up to now, open water areas always changed with ice areas. 11:39.50 snowfall ends and it becomes brighter, the visibility is between 800 m and 1000 m, the ice has less open ponds now. 11:42:00 moderate turbulence over closed ice. 11:44:56 the visibility is about 500 m. 11:46:27 the sun is seen through the clouds as weak disk. 11:48:40 flight over open water for a short time.

			11:49:45 small water pond below. 11:52:03 it becomes darker again. 11:52:10 open water, then ice again. 11:55:45 ice is very thin or it is ice pulp without waves. 11:57.40-11:59:20 a zone with open water (50% ice pulp) begins. 12:00:26 the first ridges appear and the flight becomes more turbulent. The sun shines weakly through haze.
12:13:36			Landing at Oulu.

Comment Flight 9 (21.02.2001)

- Small low centered above Bothnian Bay, a N-S moving cold front separating cold air in the N from warm air in the S has passed the experimental area shortly before the flight, a N-E flow (FF (10 m) = 2-4 m/s) advects cold air with temperatures at 10 m between –12 and -13º C into the area. The ice temperature is 1 to 6 K above air temperature.
- Bad visibility (down to 500 m).
- Clouds: 7-8/8 Sc with tops at 1800 m, 4/8 near the western leg, snow showers, haze and sea smoke.
- Well mixed boundary layer below 550 m.
- Inversion (ΔT = 8 to 9 K) at 600 to 800 m.
- Ice conditions: due to the strong easterly wind an N-S oriented open lead has formed between the landfast ice and the drift ice.

Table 4.2j: Mission 10 22 February 2001

Time (UT)	Pattern	Height (’)	Comment
09:54:00			Start at Oulu.
09:54:00-09:58:46	P1	0-6000’	Cloudless sky and a good visibility, the new lead ahead of Hailuoto seems to be covered with new ice.
10:00:38-10:06.53	P2	6000’-30’	Low haze in the West.
10:06:53-10:14:39	H1	30’	Sea smoke on the left at the horizon. The ice at Aranda is covered by fresh snow.
10:19:25-10:25:35	H2	230’	Flight over completely closed, snow-covered, smooth ice.
10.28.00-10.34:54	H3	500’	Ice edge can be seen in a distance of ca. 5 km. Sea smoke begins directly behind the ice edge.
10:37:10-10:44:21	H4	660’	The whole flight is nearly without turbulence. The ice is smooth and snow-covered here. Over the water sea smoke with a low haze layer over it is discernable.
10.46.07-10.48:12	P3	30’-3000’	Start over solid ice. P3 ends where yesterday open water had been that is now covered by a thin, white new ice layer. 10% of the area show round, open water ponds.
10:48:12-10.50:39	P4	3000’-30’	
10:50:39-10:52:55	P5	30’-3000’	
10:52:55-10:55:39	P6	3000’-30’	
10:55:39-10:58:16	P7	30’-3000’	Up to now always new ice.
10:58.16-11:00:05	P8	3000’-30’	There are cloud scraps with a CB at 1100’ and a CT at 1600’. Low clouds in front of us.
11:00:50-11:03:51	P9	30’-4000’	
11:03:51-00:00:00	P10	4000’-30’	CT at 1700’ and CB at 1390’.

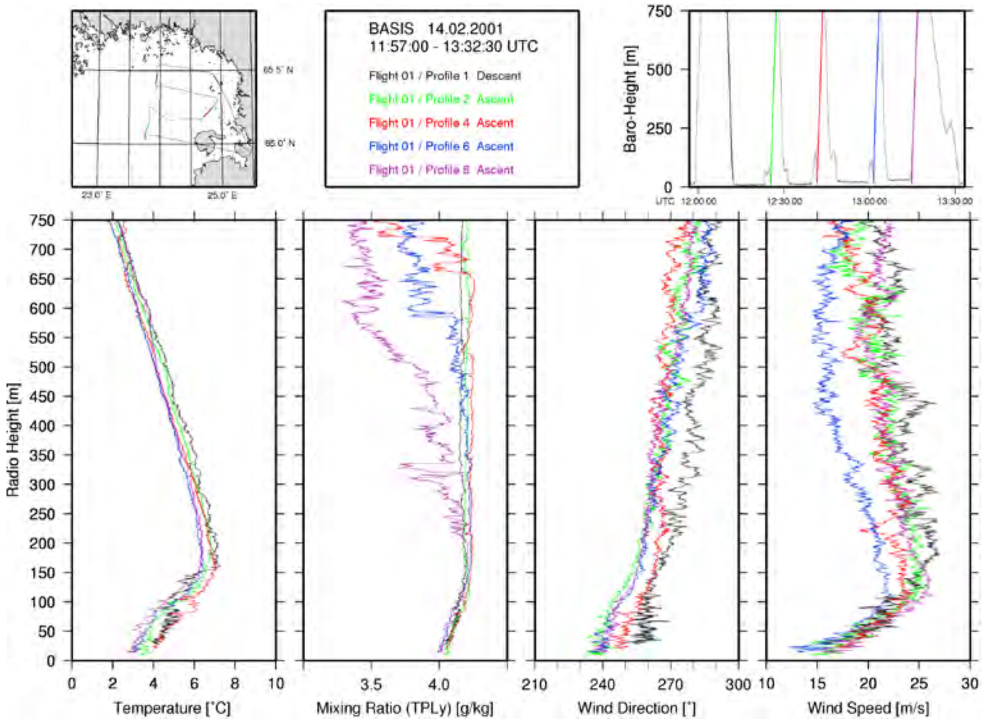
11:10:13-11:17:30	H5	30’	Ice with snow and sea smoke is at the weather side. 11:12:40 flight over an open water pond. After that sea smoke shreds over us.
11:19:48-11:26:59	H6	330’	Run is very turbulent. Cloud scraps are above.
11:29:05-11:36:31	H7	840’	Closely below sporadic cloud scraps. 11:34:30 for a short time inside the cloud scraps.
11:39:22-11:45:52	H8	1320’	Closely above the CT. 11:43:45 shortly through clouds, compact low clouds in the Southwest.
11:48:03-12:11:22	H9	30’	Below 2/8 low Cu/Sc. 11:53:26 ice breaker across. 11:53:26 it is cloudless. 11:54:22-11:57:45 a very smooth and large new ice area with hoarfrost is below us. 11:54:22 a smooth new ice area with hoarfrost below us again. 12:07:00 from now on flight over old ice.
12:11:22-12:13:41	P11	30’-3000’	
12:13:41-12:16:16	P12	3000’-30’	
12:16:16-12:22:51	H10	30’	‘Bay’ with open water is 300m away.
12:35:00			Landing at Oulu.

Comment Flight 10 (22.02.2001)

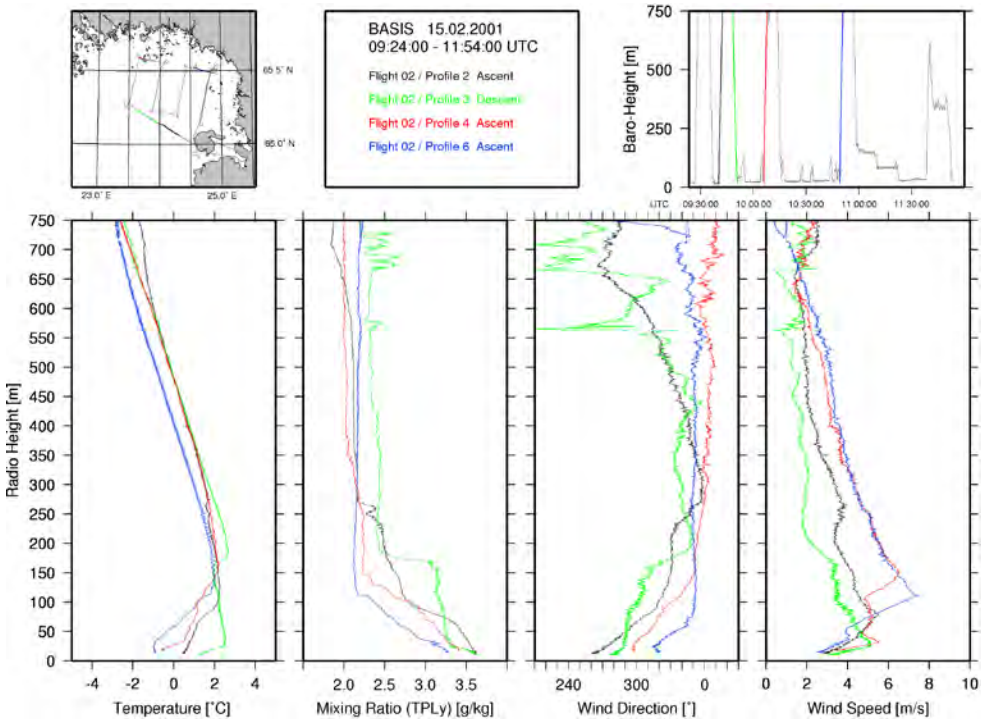
- Strong low over W-Russia, flat ridge over N-Finland, a moderate N-E flow (FF (10 m) = 7.5-12 m/s) causes advection of very cold air with temperatures at 10 m between –17 and -23º C into the experimental area.
- Very good visibility.
- Clouds: 2/8 Cu only at the western part, otherwise cloudless.
- A boundary layer is present, its thickness increases downstream from 200 to 400 m.
- Inversion (ΔT = 1 to 3 K) at 350 to 500 m.
- Ice conditions: from E to W 4 different zones are discernable: 1) landfast ice in the E, 2) N-S oriented stripe of open water (width 50 m), 3) large area of very smooth new ice with white hoarfrost, 4) old ice with 30 % open water.

Data were recorded continuously during the entire flight mission. After the flight, separate data files were generated for the vertical profile (P) sections and the horizontal leg (H) sections. The profile data sets, identified by date, flight number and profile P number contain the following parameters as 0.1 second averages: time, latitude, longitude, height, pressure, temperature, water vapour mixing ratio, and horizontal wind components. The data sets from the horizontal flight legs, identified by date, flight number and leg H number, contain at 0.01 and 0.1 second intervals: time, latitude, longitude, height, pressure, temperature, water vapour mixing ratio, horizontal and vertical wind components, upward and downward shortwave and longwave radiation fluxes, and surface temperature. For control reasons and for simple and quick inspection of the data, all profiles and horizontal legs were plotted. Examples of vertical profiles (temperature, water vapour mixing ratio, wind speed, and wind direction) which represent the vertical stratification of the atmospheric boundary layer during each flight mission are displayed in Figs. 4.55 a-j.

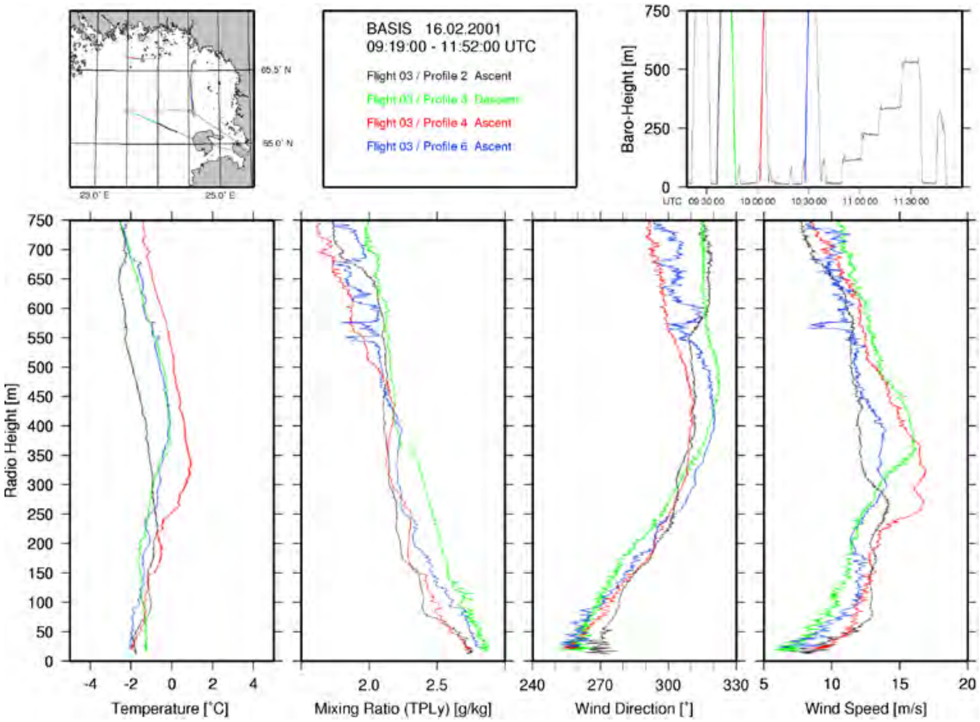
a)


BASIS 14.02.2001
11:57:00 - 13:32:30 UTC
Flight 01 / Profile 1 Descent
Flight 01 / Profile 2 Ascent
Flight 01 / Profile 4 Ascent
Flight 01 / Profile 6 Ascent
Flight 01 / Profile 8 Ascent
Baro-Height [m]
Radio Height [m]
Temperature [°C]
Mixing Ratio (TPLy) [g/kg]
Wind Direction [°]
Wind Speed [m/s]

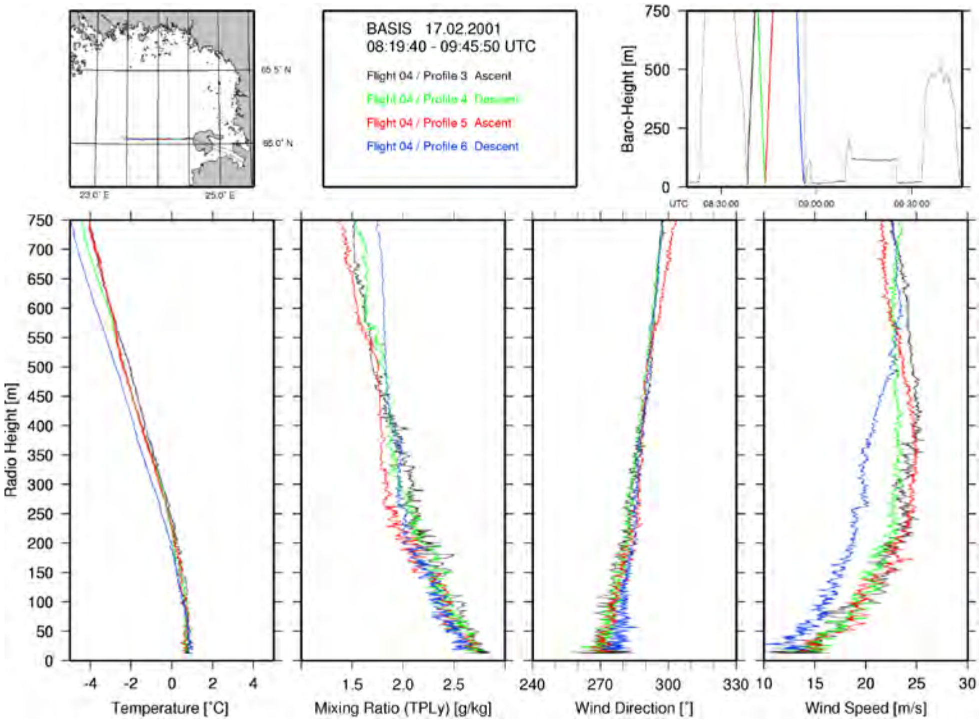
b)


BASIS 15.02.2001
09:24:00 - 11:54:00 UTC
Flight 02 / Profile 2 Ascent
Flight 02 / Profile 3 Descent
Flight 02 / Profile 4 Ascent
Flight 02 / Profile 6 Ascent
Baro-Height [m]
Radio Height [m]
Temperature [°C]
Mixing Ratio (TPLy) [g/kg]
Wind Direction [°]
Wind Speed [m/s]

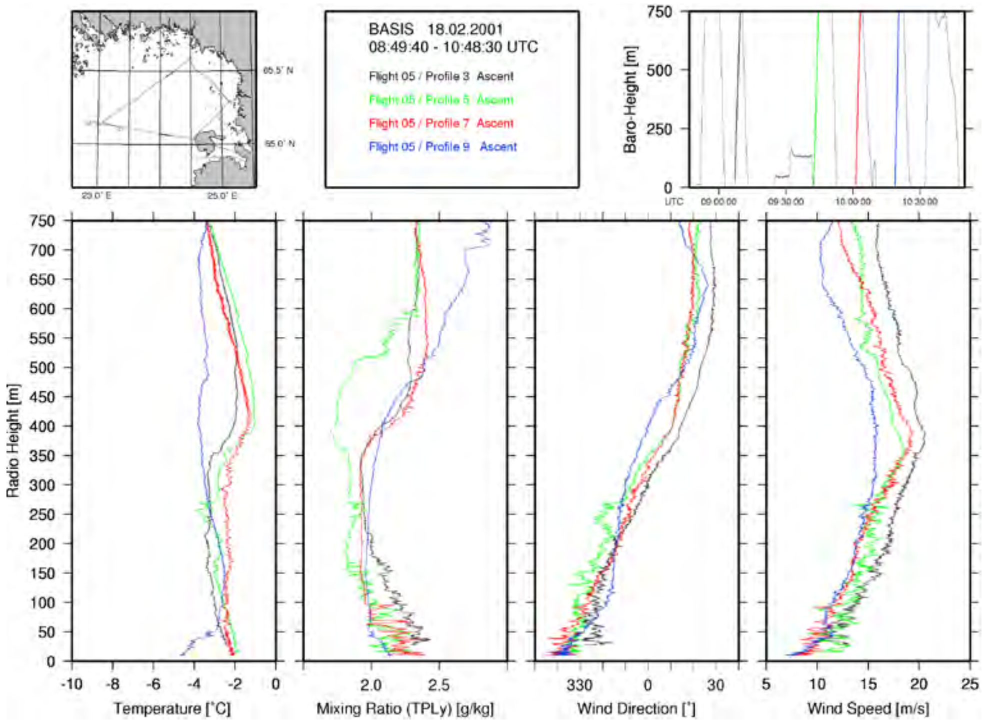
c)


BASIS 16.02.2001
09:19:00 - 11:52:00 UTC
Flight 03 / Profile 2 Ascent
Flight 03 / Profile 3 Descent
Flight 03 / Profile 4 Ascent
Flight 03 / Profile 6 Ascent
Baro-Height [m]
Radio Height [m]
Temperature [°C]
Mixing Ratio (TPLy) [g/kg]
Wind Direction [°]
Wind Speed [m/s]

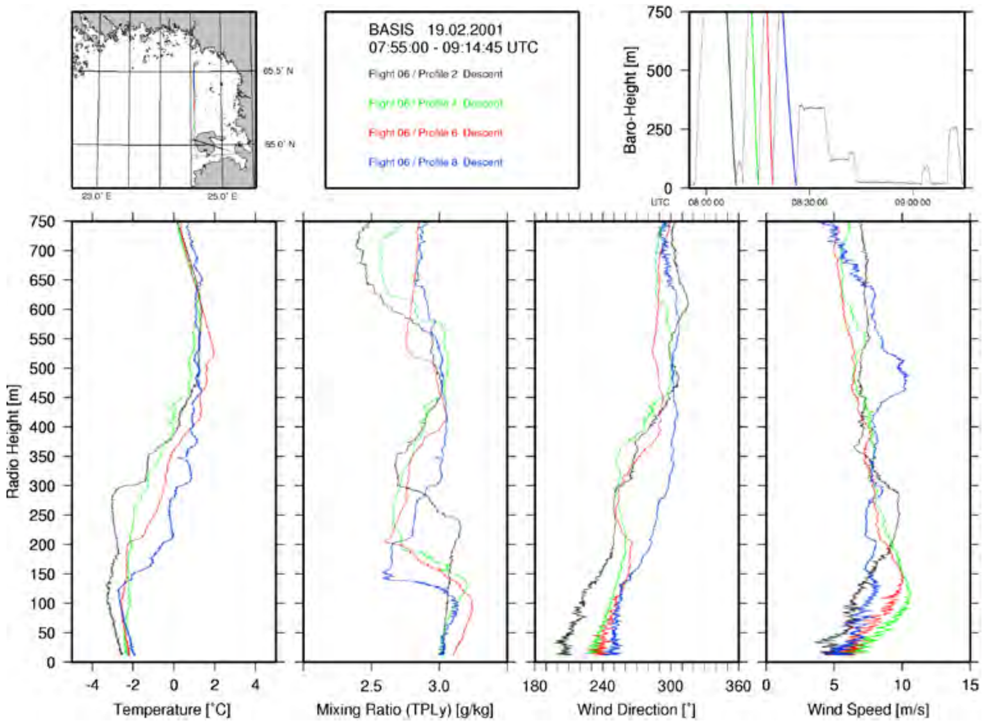
d)


BASIS 17.02.2001
08:19:40 - 09:45:50 UTC
Flight 04 / Profile 3 Ascent
Flight 04 / Profile 4 Descent
Flight 04 / Profile 5 Ascent
Flight 04 / Profile 6 Descent
Baro-Height [m]
Radio Height [m]
Temperature [°C]
Mixing Ratio (TPLy) [g/kg]
Wind Direction [°]
Wind Speed [m/s]

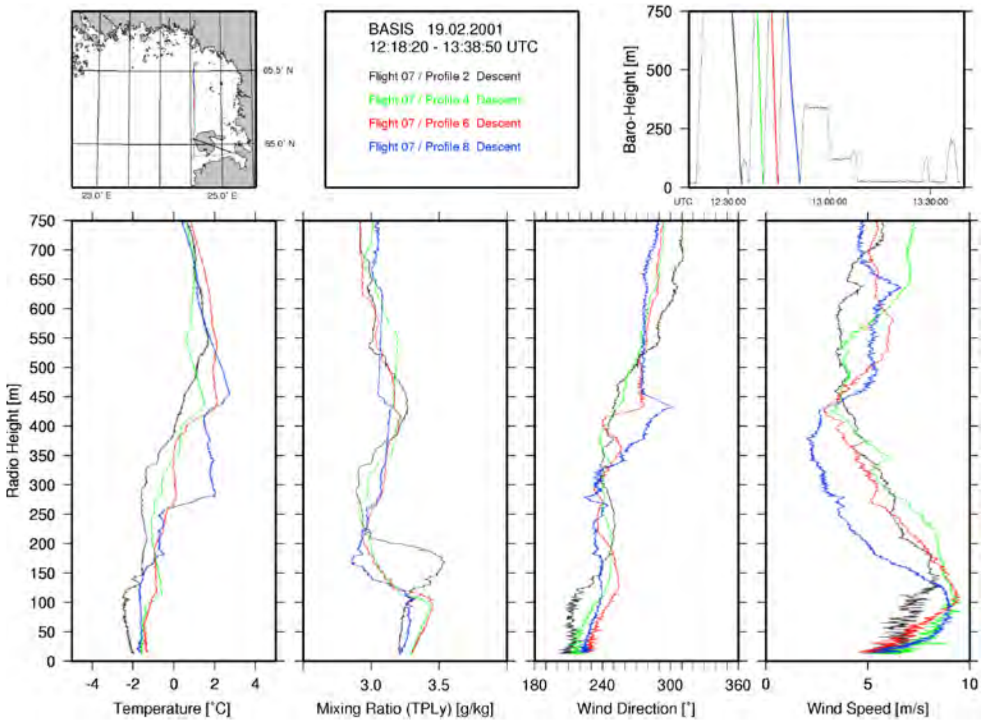
e)


65.5° N
65.0° N
23.0° E
25.0° E
BASIS 18.02.2001
08:49:40 - 10:48:30 UTC
Flight 05 / Profile 3 Ascent
Flight 05 / Profile 5 Ascent
Flight 05 / Profile 7 Ascent
Flight 05 / Profile 9 Ascent
Baro-Height [m]
UTC 09:00:00 09:30:00 10:00:00 10:30:00
Radio Height [m]
Temperature [°C]
Mixing Ratio (TPLy) [g/kg]
Wind Direction [°]
Wind Speed [m/s]

f)

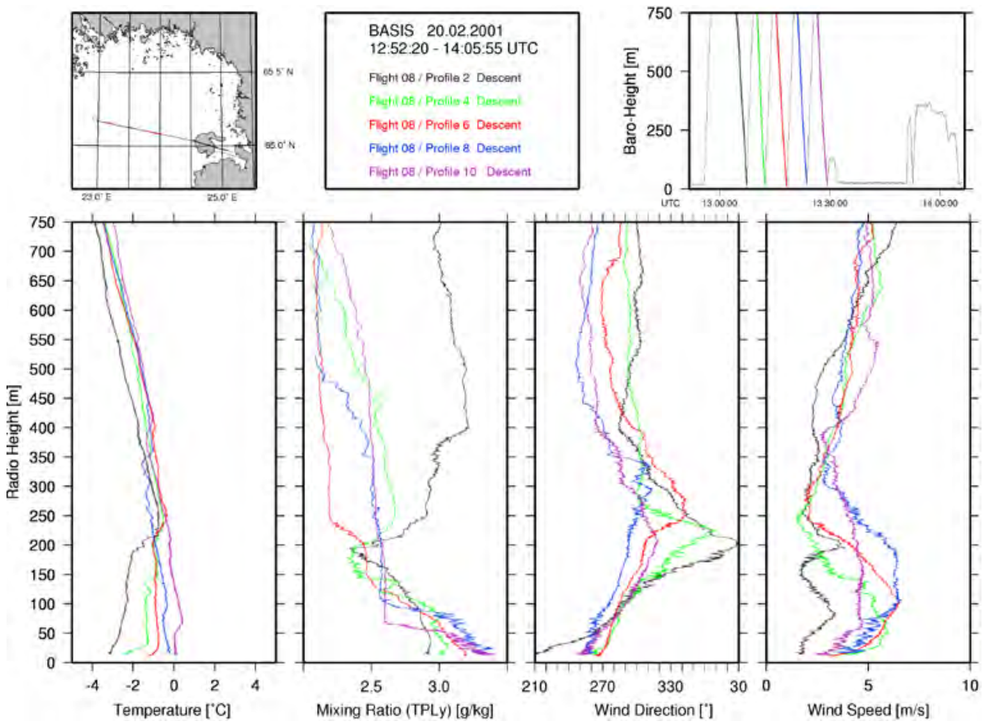

65.5° N
65.0° N
23.0° E
25.0° E
BASIS 19.02.2001
07:55:00 - 09:14:45 UTC
Flight 06 / Profile 2 Descent
Flight 06 / Profile 4 Descent
Flight 06 / Profile 6 Descent
Flight 06 / Profile 8 Descent
Baro-Height [m]
UTC 08:00:00 08:30:00 09:00:00
Radio Height [m]
Temperature [°C]
Mixing Ratio (TPLy) [g/kg]
Wind Direction [°]
Wind Speed [m/s]

g)



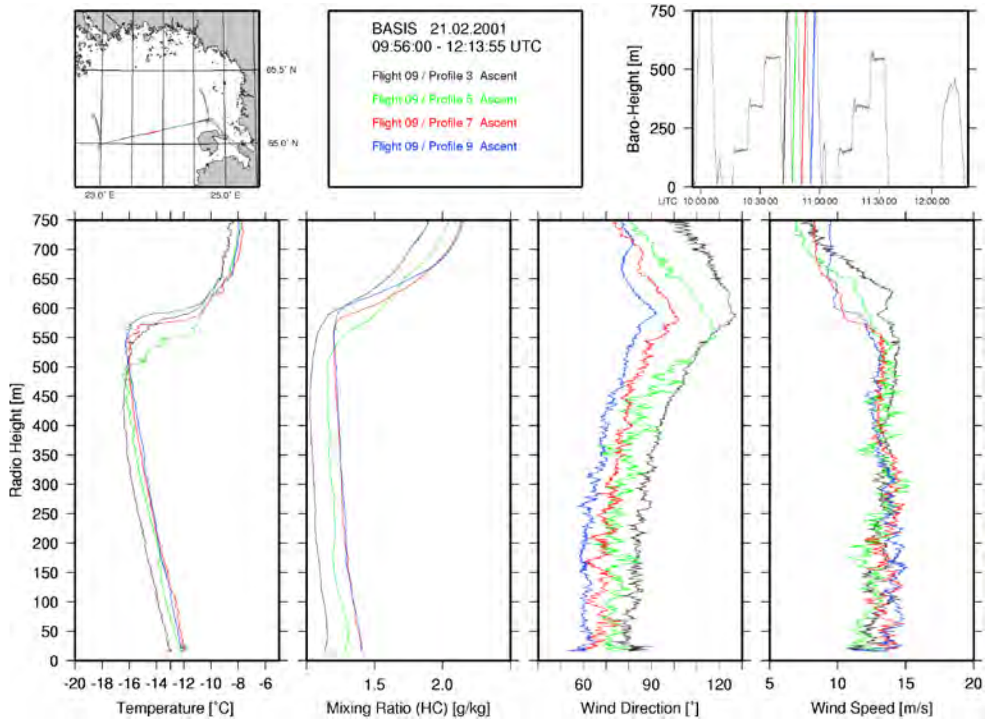
BASIS 19.02.2001
12:18:20 - 13:38:50 UTC
Flight 07 / Profile 2 Descent
Flight 07 / Profile 4 Descent
Flight 07 / Profile 6 Descent
Flight 07 / Profile 8 Descent
Baro-Height [m]
Radio Height [m]
Temperature [°C]
Mixing Ratio (TPLy) [g/kg]
Wind Direction [°]
Wind Speed [m/s]

h)



BASIS 20.02.2001
12:52:20 - 14:05:55 UTC
Flight 08 / Profile 2 Descent
Flight 08 / Profile 4 Descent
Flight 08 / Profile 6 Descent
Flight 08 / Profile 8 Descent
Flight 08 / Profile 10 Descent
Baro-Height [m]
Radio Height [m]
Temperature [°C]
Mixing Ratio (TPLy) [g/kg]
Wind Direction [°]
Wind Speed [m/s]

i)



j)

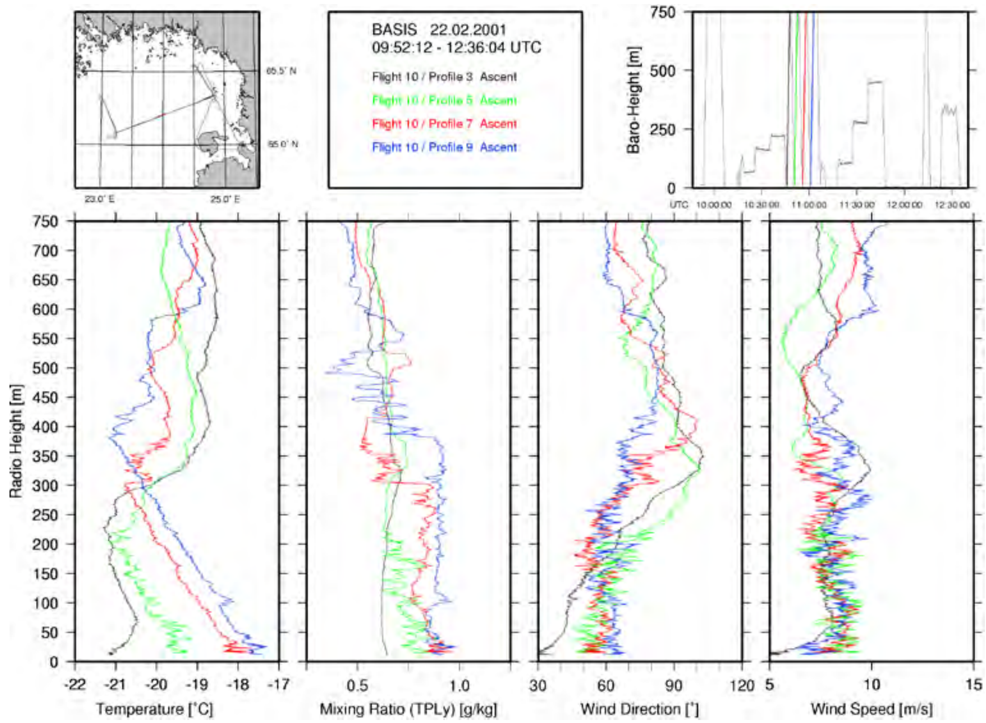


Fig. 4.55 a-j: Selected vertical profiles of temperature, water vapour mixing ratio, wind speed and wind direction in the boundary layer for each of the ten DO-128 flight missions during BASIS 2001. The geographical location of the profiles is given in the map (upper left) and the measurement times in the time-height plot (upper right).

Table 4.3 gives a summary of all 10 flight missions in terms of parameters which characterize the atmospheric boundary layer. These parameters are (a) the mean meteorological conditions near the surface, i.e. temperature T_{10m}, moisture m_{10m}, wind speed FF_{10m} and direction DD_{10m} at 10 m height and the surface temperature T_{sfc}, and (b) the vertical boundary layer structure, i.e.

Table 4.3: BASIS 14 - 22 February 2001: Research aircraft DO-128 (D-IBUF) flights over Bay of Bothnia

Flight No.		1	2	3	4	5	6	7	8	9	10
Date	Febr.	14	15	16	17	18	19	19	20	21	22
Depth of near sfc bound. layer, h	m	50 (Iso)	50	50	50/200 (Iso)	200/500	110/220	80/120	70/200	550 (ML)	80 (Inv., over fast ice)
Top of Inv. h_t	m	150/200	140/220	250/450	850/1100	400/680	500/550	480/700	100/260 (1.) 400/480 (2.)	600/800	350/500
ΔT across Inv.	K	3.0/3.5	1.8/3.0	1.0/3.0	0/0.5	0.1/2.0	3.0/4.5	3.5/5.0	0.7/2.5 ice 0.3 water	8.0/9.0	1.0/3.0
T_{10m}	°C	3.0/4.0	-0.8/1.8	-2.3/-1.0	0.0/1.5	-2.0/-4.5	-2.0/-3.0	-1.3/-2.2	-0.5/0.1 water -1.0/-3.0 ice	-11/-13	-17/-23
T_{sfc} water ice	°C	-0.2/0.5 0/-0.2	-0.3 -1.0/-2.5	-0.3 -3/-5	-0.3 -2/-4	-0.3/ -3/-7	-0.3/ -2.5/-4.0	-0.3/ -2.0/-3.5	0/-0.5 -2/-10	-4/-12 -0.2	-0.2 -6/-26
ΔT air-water air-ice	K	3.0/3.5 3.0/3.5	0/0.5 1.0/1.5	-1/-1.5 -1.5/3.0	1.0/1.5 2.5/3.5	-1.0/-2.5 1.0/3.0	-1.5 0.5/1.5	-1.0 1.0/2.0	-2.0/0.5 2.0/7.0	-10/-11 -1.0/-6.0	-16/-18 3.0/-8.0
m_{10m}	g/kg	4.0/4.1	3.2/3.6	2.7/2.8	2.6/2.8	2.1/2.4	3.0/3.1	3.2/3.3	2.9/3.4	1.1/1.4	0.6/0.9
Δm/Δz	sign	> 0	< 0	< 0	< 0	< 0	> 0	> 0	< 0	< 0 in ML; > 0 in Inv.	< 0, > 0, = 0
FF_{10m}	m/s	13/18	2.9/3.5	6/8	12/14	8/12	5.5/6.5	5.0/6.5	2/4	12/15	4/9
FF_{Max}	m/s	22/27	5.2/7.1	13/17	22/25	16/21	8/10.5	8/9	3.5/7.0	14/16	7/12 (LLJ over fast ice)
$h_{FF\ Max}$	m	120/200	40/180	130/400	400/550	350/470	120/220	110/180	70/220	600/700 fast ice 200 over ice	100 (1. Inv.) 400 (2. Inv.)
DD_{10m}	deg	240/255	260/310	250/270	270/280	320/345	210/250	210/230	230/270	60/80	20/60
$\Delta D_{10m\text{-}Inv.}$	deg	10/20	40/70	35/65	30/40	25/30	10/20	15/30	35/150	30/45	15/80

the depth h of boundary layer (or base of lowest inversion), top h_t of lowest inversion (or stable layer), the temperature increase ΔT across it, the sign of the vertical moisture gradient in the layer below h, the height $h_{FF_{Max}}$ and magnitude FF_{Max} of the lowest wind maximum and the wind direction change ΔDD between 10 m height and inversion top h_t. The most extreme days were 14 February when the warmest (3-4°C) and 22 February when the coldest (-18 to –22°C) 10 m air temperatures occurred. Inversion bases h varied between 50 and 550 m height with temperature differences ΔT_{inv} across the inversion of 0.5 to 9.0 K. Low-level jets were present in nearly all flight missions below 500 m height, particularly extreme during the warm air advection event on 14 February with 27 m s^{-1} at 200 m height. In that case and in a few others the moisture increased ($\Delta m/\Delta z > 0$) with height in the subinversion layer. This is unusual for the typical boundary layer, but is a consequence of the warm and moist air advection in this situation.

Examples of the turbulent flux measurements along horizontal legs at low level are given in Fig. 4.56 for the strong warm-air advection on 14 February and in Fig. 4.57 for the strong cold-air advection on 22 February. On 14 February ice and water surface have about the same temperature and, thus, the horizontal variation of the downward (negative) sensible and latent heat fluxes are small. In contrast to that, ice and water surface temperature have differences of up to 15 K on 22 February and, thus, the upward (positive) sensible and latent heat fluxes show large differences over open water and sea ice which can have different surface temperatures. The fluxes are even close to zero over the cold land-fast ice between 60 and 70 km distance in Fig. 4.57.

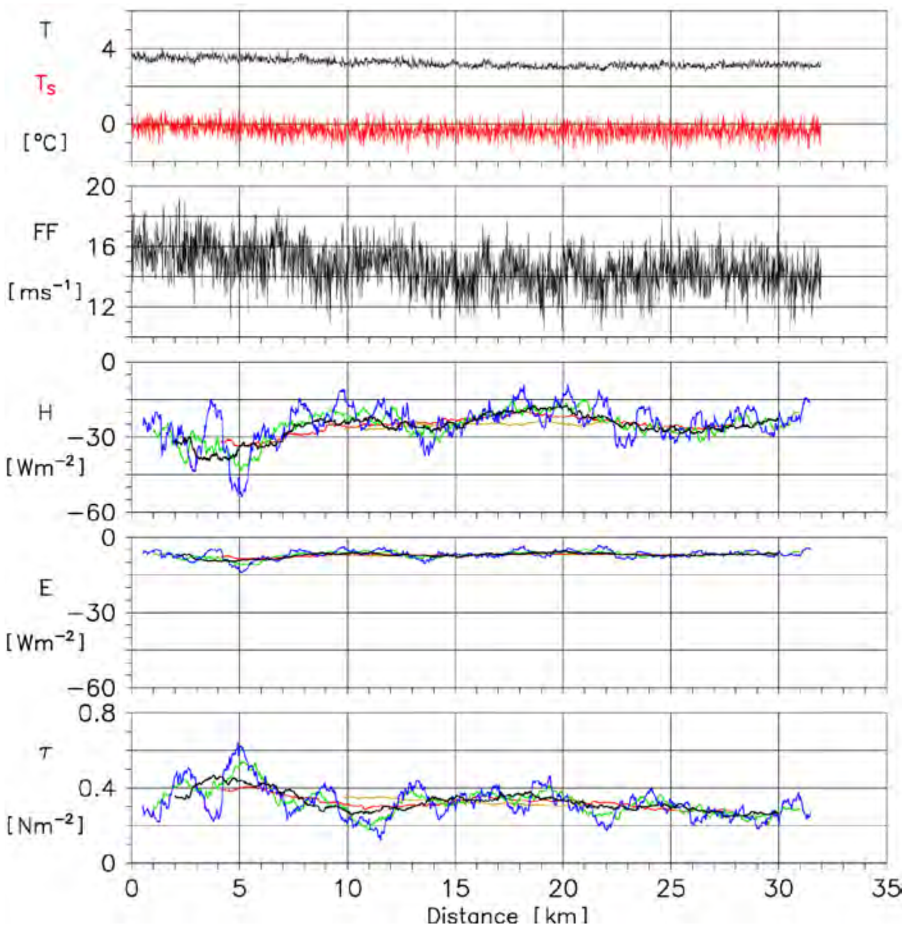


Fig. 4.56: Research aircraft DO-128 measurements at 13 m height along the 32 km long leg H3 over sea ice and open water during strong warm-air advection on 14 February 20001: air temperature T, infrared surface temperature T_S, wind speed FF,

sensible heat flux H, latent heat flux E, and momentum flux τ. H, E, τ were calculated for various length intervals: 1 km (blue), 2 km (green), 4 km (black), 8 km (red), and 20 km (yellow).

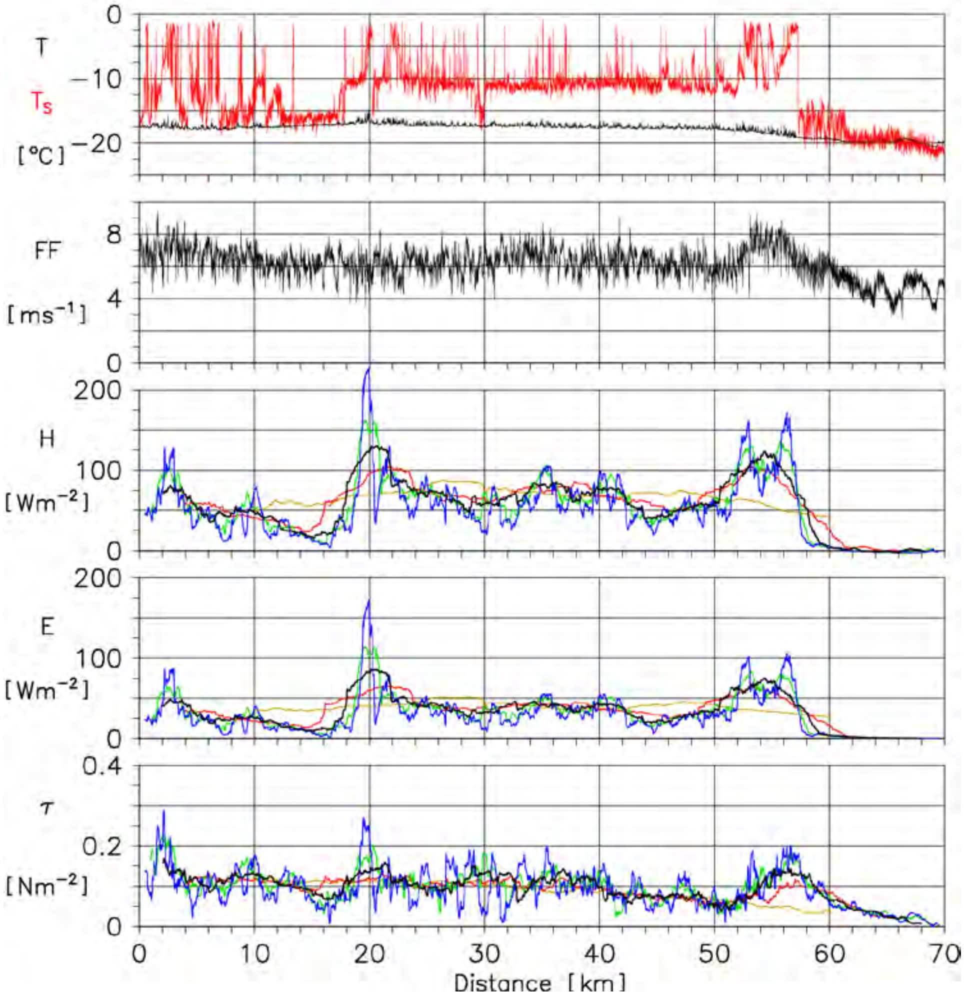


Fig. 4.57: Research aircraft DO-128 measurements at 12 m height along the 70 km long leg H9 over sea ice and open water during strong cold-air advection on 22 February 2001: air temperature T, infrared surface temperature T_S , wind speed FF, sensible heat flux H, latent heat flux E, and momentum flux τ. H, E, τ were calculated for various length intervals: 1 km (blue), 2 km (green), 4 km (black), 8 km (red), and 20 km (yellow).

5. The six RV Alkor cruises to the central Baltic Sea

5.1 General

The scientific aim of the six Alkor cruises was to sample data and to make detailed studies of the atmosphere, particular the atmospheric boundary layer and the surface layer at a clearly marine location in the BALTEX region from which otherwise no data are available. As position for the measurements the point 56.02° N, 18.67° E in the central Baltic Sea was chosen (Fig. 2.1). This location is also a grid point of the REMO model and has farest distances from all coast lines; the nearest coast (southern tip of the isle of Gotland) is at a distance of 110 km. For winds from SW or NE the fetch is even longer than 300 km.

In order to study a wide parameter range of atmospheric boundary layer conditions, cruises took place during each season (except winter) and were repeated in the years 2000 and 2001. The expedition times were:

Alkor 4/2000: 05-10 April 2000
Alkor 6/2000: 14-20 June 2000
Alkor 10/2000: 25-31 October 2000
Alkor 4/2001: 02-11 April 2001
Alkor 6/2001: 12-20 June 2001
Alkor 10-11/2001: 29 Oct. – 07 Nov. 2001

In this way, the seasonally and synoptically caused variability of the atmospheric boundary layer was covered. This will also increase the significance of the results for the planned comparisons of the observations with the REMO and BALTIMOS model.

RV Alkor is owned by the University of Kiel, where also its home harbour is, and was chartered by the University of Hamburg for the six cruises. RV Alkor is 55.2 m long and has a size of 999.08 BRT (Fig. 5.1). It was equipped with instruments which are permanently installed and instruments which were installed especially for the campaigns.

Fig. 5.1: RV Alkor at the pier in Kiel harbour.

The permanent meteorological instrumentation encloses: air pressure at 13.9 m, temperature and wet bulb temperature at 13.9 m, wind speed and wind direction on the left and right side of the main mast at 18.5 m height, shortwave radiation mounted at 11.6 m height on the ship's foremast, water temperature taken at 4 m depth. This is supplemented by ship's data: latitude, longitude, heading, along-ship and cross-ship motion. The latter three quantities are needed to calculate the wind velocity with respect to the ground and to choose the proper side for the wind sensors.

The following additional instrumentation was installed. At the foremast (Fig. 5.2) a Kroneis dew-point sensor, measuring air temperature and dew-point temperature, was mounted at 11.6 m height. Also at the foremast, a pressure sensor (Vaisala PTB 200A) at 11.6 m height, an upward looking shortwave pyranometer (Kipp and Zonen) and a longwave pyrgeometer (Eppley) were mounted. For turbulence test measurements an ultra-sound anemometer/thermometer (METEK USAT) was mounted at 10.1 m height on a 1.0 m long boom directed to the front of the ship. In case of air flow from the front, the wind at the sonic is not disturbed by the ship, but of course all ship motions are included in the sonic data.

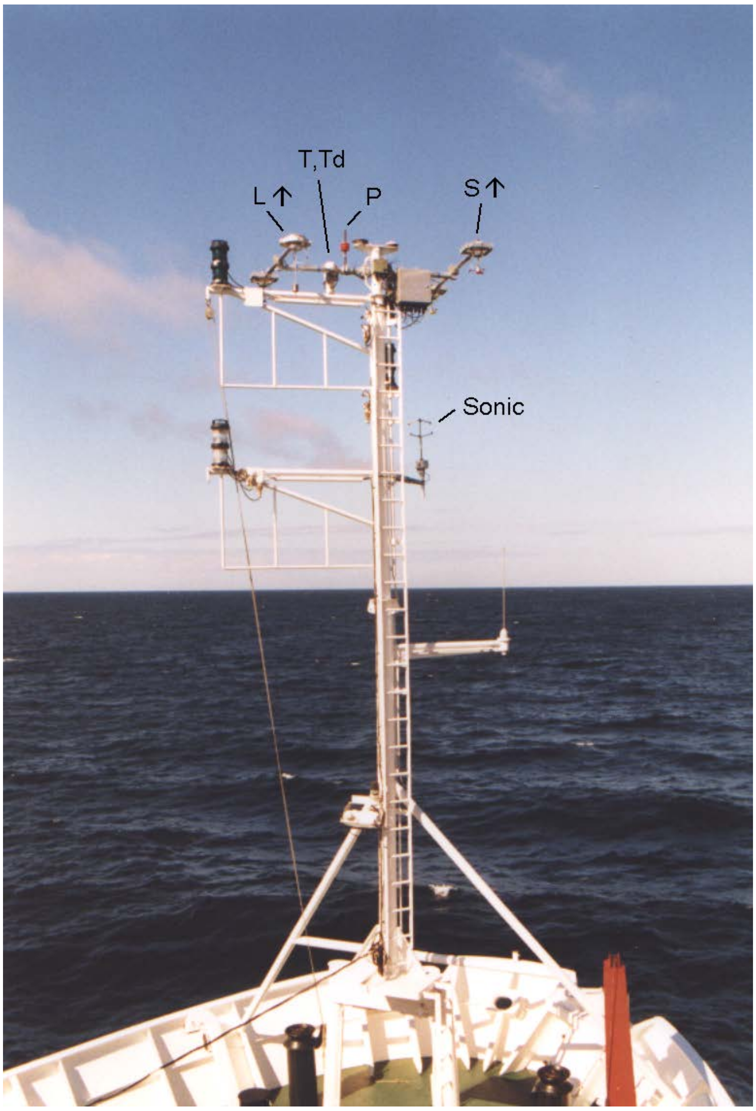


Fig. 5.2.: Meteorological instruments at the foremast of RV Alkor (top of foremast 11.6 m): pressure inlet (p), temperature (T), dew-point (T_d), downwelling shortwave radiation (S) and longwave radiation (L), and Sonic.

On the highest deck of the ship three remote sensing instruments were installed: a ceilometer (Fig. 5.3) to measure cloud base height, an infrared radiometer (Heimann KT 19) (Fig. 5.4) to measure the sea surface temperature, and an upward looking rain radar (METEK MRR) (Fig. 5.3) to measure rain intensity at different levels above the ship. The rain radar is a recently developed rain device which appears to be especially suited for rain measurements on ship which itself is an obstacle for the air flow and thus affects the true rainfall.

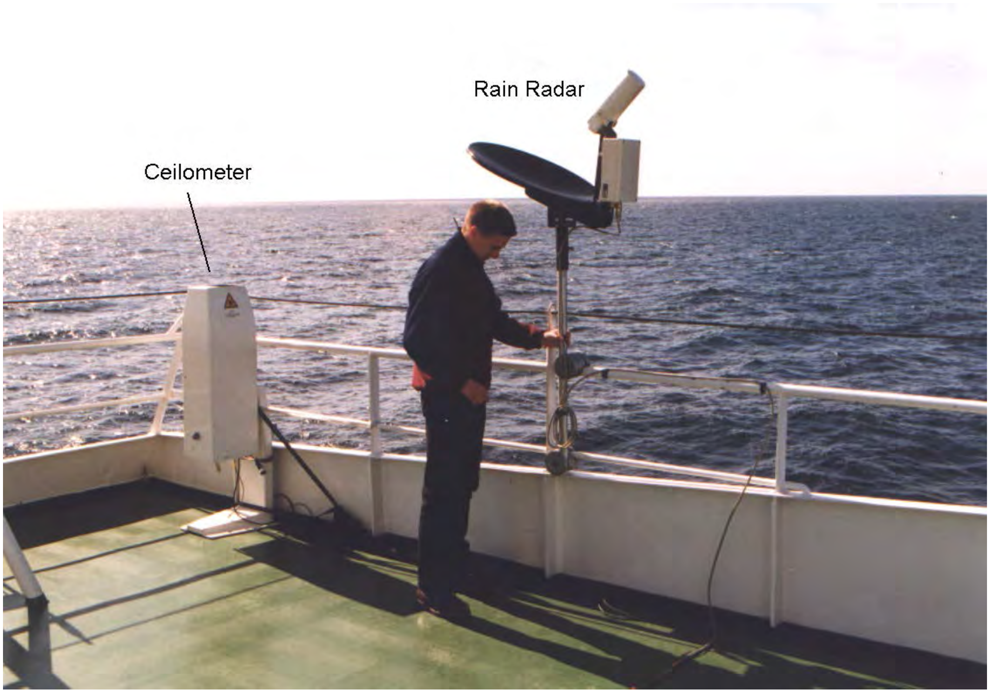


Fig. 5.3: Ceilometer and rain radar at the upper deck of RV Alkor.

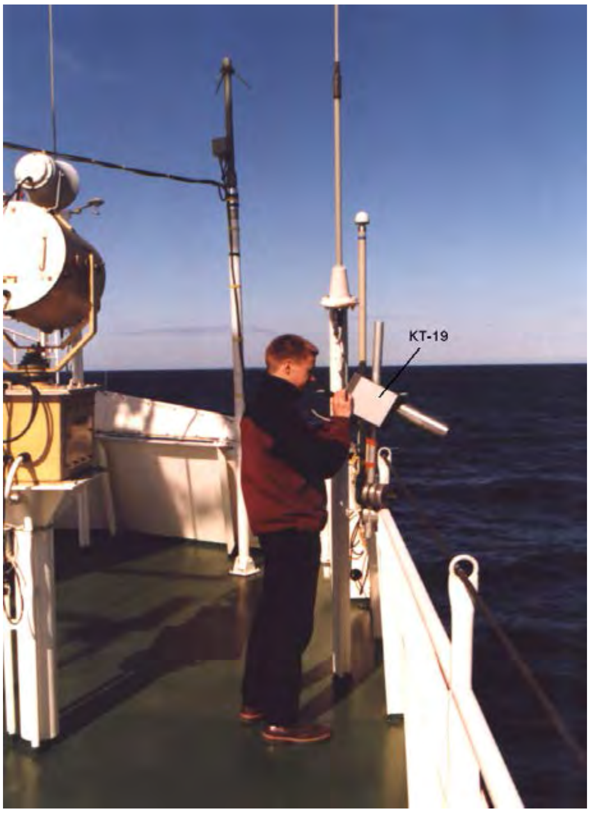


Fig. 5.4: Infrared radiometer KT-19 for water surface temperature measurement at the upper deck of RV Alkor.

In addition, regular radiosoundings with the Vaisala Digi-Cora-2 system and RS-80-15G. radiosondes with GPS wind finding were made (Fig. 5.5). During the first four Alkor cruises radiosondes were launched every 6 hours and during the last two Alkor cruises every 3 hours. With only a few exceptions radiosondes reached levels higher than 14 km. Eye-observations of clouds, weather events, frontal passages etc. were made every hour.

Fig. 5.5: Launching a Vaisala radiosonde from the upper deck of RV Alkor.

Daily weather maps for the six campaigns are given in Appendices A3-A8. Generally, the synoptic weather conditions were very variable, causing frequent changes between unstable and stable stratification in the surface layer. Inspite of frontal passages, there was astonishingly little rainfall in the central Baltic Sea. Details of the meteorological measurements taken during the six Alkor cruises are given in the following subsections 5.2-5.7. As particularly outstanding events we mention already here the strong surface-based inversions with a temperature increase of up to 7 K and low-level jets encountered during Alkor 4/2001 and the gale low event with wind speeds of up to 25 $m\ s^{-1}$ and 8 to 10 m high waves encountered during Alkor 10/2001.

5.2. The cruise Alkor 4/2000

RV Alkor left Kiel harbour on 5 April 2000 at 10 UTC. It arrived at the destination point 56.02°N, 18.67°E in the central Baltic Sea on 6 April 16.45 UTC and left on 10 April 06.45 UTC. Kiel harbour was reached on 11 April 14 UTC. Cruise leader was Dr. Gerd Müller. Michael Offermann was responsible for the technical installation and functioning of the sientific equipment. In addition, six students of the Meteorological Institute of the University of Hamburg were involved in the measurements.

The 00 UTC weather maps for the cruise period are given in Appendix A3. After the passage of a gale low from SW to NE on 5 April, the first phase (6 to 8 April) in the experimental area was governed by anticyclonic conditions due to a high over England/Netherlands and later a ridge over Scandinavia. During the second phase (9-10 April) a low over Belarussia extended its influence westward even into the experimental area.

The standard meteorological quantities (p, T, T_{sfc}, RH, FF, DD) together with ship's heading and speed are presented in Fig. 5.6 and the radiation fluxes S↓, L↓ and cloud base height in Fig. 5.7. During the anticyclonic phase northerly winds and mostly cloudless conditions prevailed. Clouds of the occlusion associated with the Belarussian low reached the experimental area and led to overcast conditions on 9 and 10 April.

The water temperature was around 4°C. There were relatively large temperature differences, $T_{sfc} - T_{-4\ m}$, of ± 1 K between the radiometer surface temperature T_{sfc} and the intake water temperature $T_{-4\ m}$ at 4 m depth. T_{sfc} was determined on the basis of $\varepsilon = 1$ for the longwave emissivity of water. Since ε is on the order of $\varepsilon \approx 0.96$, the true T_{sfc} will be higher especially in clear sky conditions when L↓ is small. The correction of T_{sfc} with the correct ε will be small during overcast conditions, and even zero, when L↓ is equal to L↑. The air temperature varied around the water temperature. Weakly stable stratification, $T - T_{sfc}$, occurred on 7 April when a small cyclonic disturbance passed in the SW of the experimental area from NW to SE, accompanied by closed altocumulus clouds (Fig. 5.7) and weak winds (Fig. 5.6). Unstable stratification prevailed afterwards during cold-air advection from northerly direction. Shallow cloud streets with 2 octas cloud cover occurred in the afternoon of 8 April. During the unstable and overcast conditions caused by the Belarussian low cloud bases occurred at different levels; weak showers were observed in the vicinity of RV Alkor on 9 April and only light rain between 04 and 05 UTC on 10 April.

As mentioned above, the sonic measurements at the ship's foremast were made as a test. Results are presented in Fig. 5.8 for the mean quantities, wind speed FF, wind direction DD, and virtual temperature T_v and for the turbulent quantities, sensible heat flux H, momentum flux τ and turbulent kinetic energy $E_{Kin,turb}$. The mean quantities FF, DD, T_v agree well with the corresponding quantities measured by the standard meteorological equipment (see Fig. 5.6). The ship's motion particularly affects the turbulent quantities, however, it contributes to H and τ only if the appearent fluctuations w' and T_v' or w' and u' (or v'), caused by the ships motion, are correlated. This appears to be unlikely in case of H but to be realistic in case of τ and the variances of the wind components. On the other hand, ship's pitch and roll motions have periods of 5 to 10 seconds, whereas the true turbulent fluctuations have their spectral maximum at shorter periods and are accounted for by the sonic sampling frequency of 20 Hz.

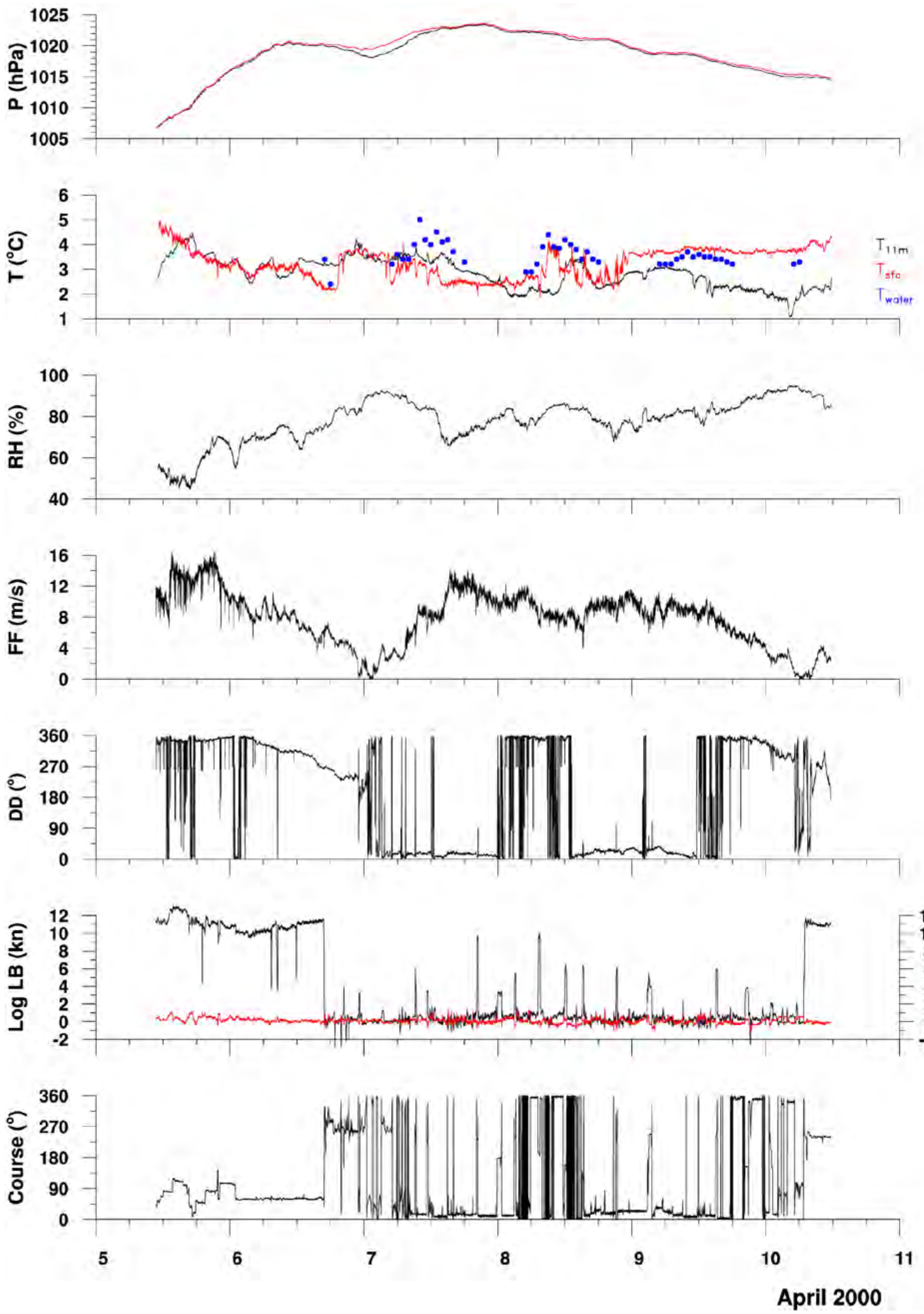


Fig. 5.6: One-minute averages of pressure p (from ship's permanent station (red) and foremast station (black)), air temperature T, and infrared surface temperature T_{sfc} (KT-19), and bucket water temperature T_{water}, relative humidity RH, wind speed FF, wind direction DD, ship's velocity component in along-ship (Log LB) and cross-ship (Log QB) direction, and ship's heading (course) measured at RV Alkor from 5 to 10 April 2000. Long tick marks indicate 00 UTC of the respective day.

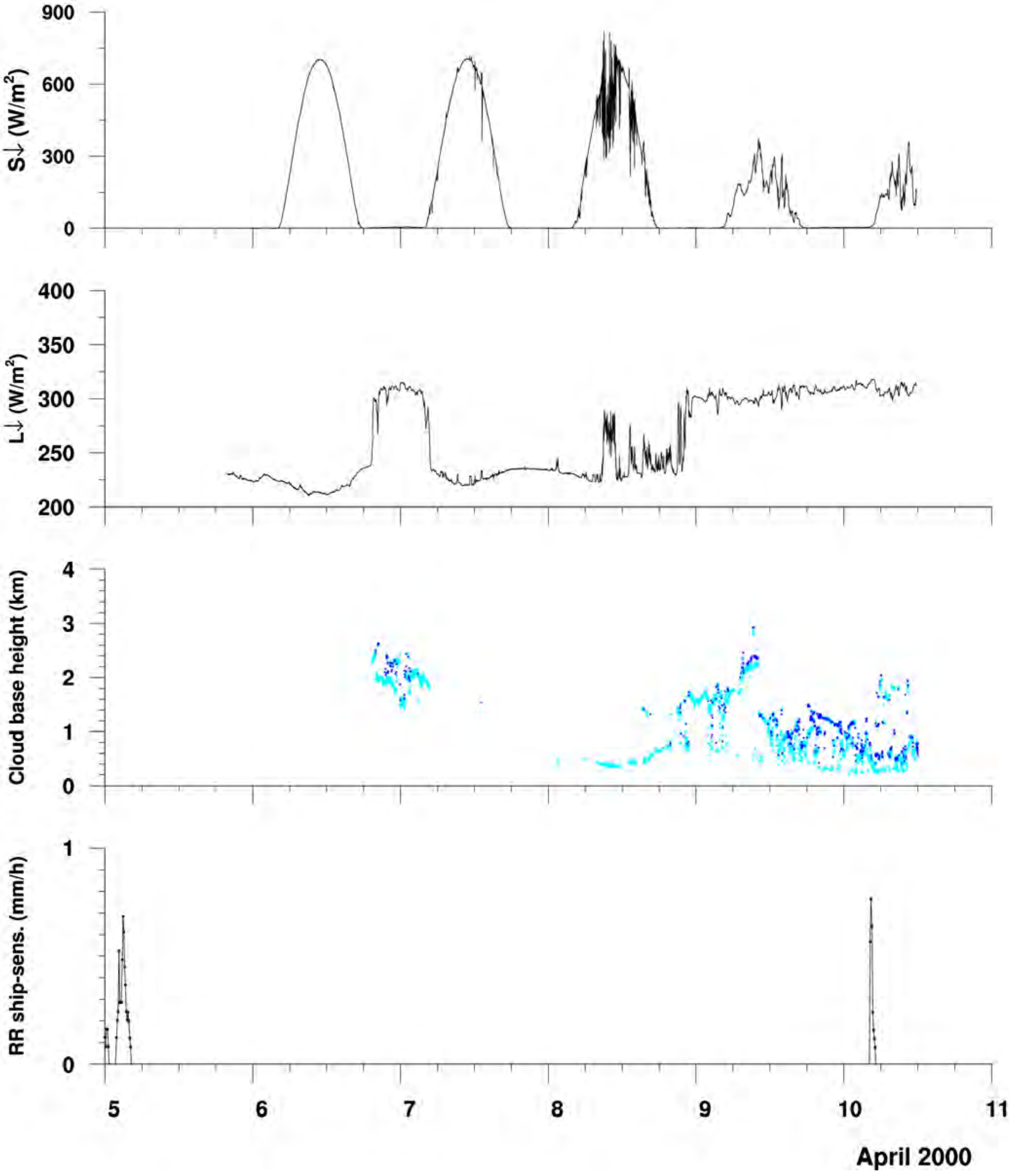


Fig. 5.7: Time series of downwelling shortwave radiation S↓, longwave radiation L↓, and cloud base height, and rain rate measured at RV Alkor from 5 to 10 April 2000.

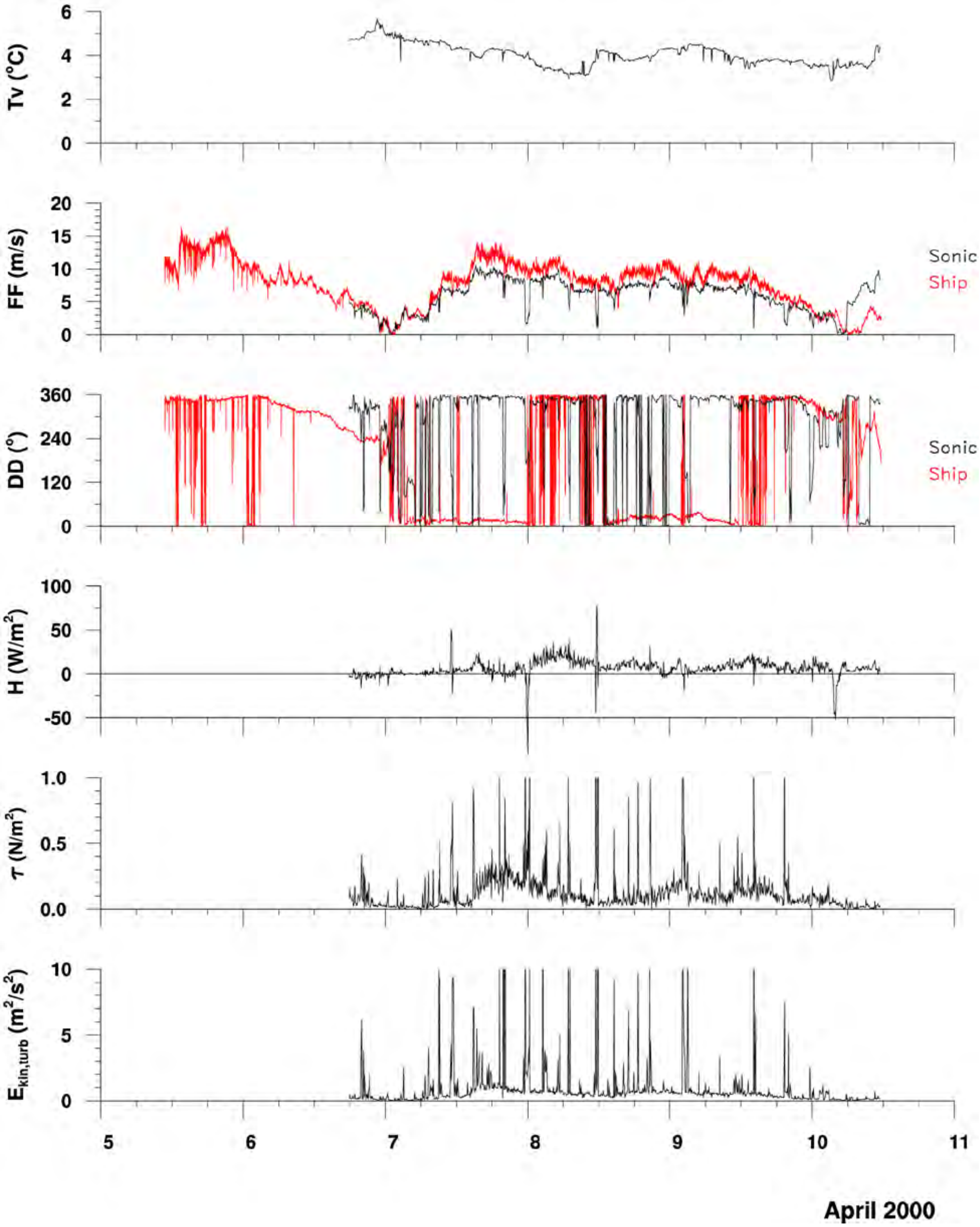


Fig. 5.8:Time series of 5-minute averages of uncorrected (for ship's motion) sonic measurements at the foremast of RV Alkor from 5 to 10 April 2000: virtual temperature T_V, wind speed FF, wind direction DD, sensible heat flux H, momentum flux τ, and turbulent kinetic energy $E_{kin,turb}$.

Again, the sonic measurements were made as a test, but when looking at the time series of H in Fig. 5.8 and the air-sea temperature difference ΔT and wind speed in Fig. 5.6 there is a high degree of correspondence. For example, the sonic based H was small or negative (downward H-flux) in the evening of 6 April and morning of 7 April when ΔT was small or positive. On the other hand, the sonic based H had the largest positive values (upward) when ΔT was negative (unstable) and FF was high. Of course, this comparison is rather qualitative, but is encouraging for future sonic test on board a ship. Note that such qualitative comparisons only make sense when, at least, the ship is not cruising (thus, see ships speed in Fig. 5.6).

In total 17 radiosondes were launched during the campaign, regularly every six hours when RV Alkor was on station. Overviews on the radiosonde measurements are given in Fig. 5.9 which shows the temperature profiles in the lowest 14 km and in Figs. 5.10 and 5.11 which present the temperature and wind structure, respectively, in the lowest 2 km. The height of the tropopause did not exhibit large variations and was mostly in the range between 9 and 10 km height.

The different phases of stable and unstable air-sea temperature stratification, $T - T_{sfc}$, are well reflected in the vertical structure of the boundary layer. A surface-based inversion was present up to 200 m height during the stable phase of warm-air advection when the weak cyclonic disturbance passed (in the night from 6 to 7 April). In the following cold-air advection phase between 00 and 12 UTC on 8 April a well-mixed layer below a relatively shallow inversion with bases between 300 and 400 m occurred. Later on, when the influence of the Belarussian low strengthened, the low-level inversion disappeared and the boundary layer depth increased to more than 1 km height with clouds embedded (see Fig. 5.7). Fig. 5.11 shows that the radiosonde GPS wind measurements had a lot of gaps and often even total failures in the boundary layer. The reason for that became not clear during this cruise. During a later cruise it was found that the ship's radar was the reason and thus was switched off for a few minutes before and after the radiosonde launch. Also pendulum motions of the radiosonde and its antenna can lead to GPS signal losses.

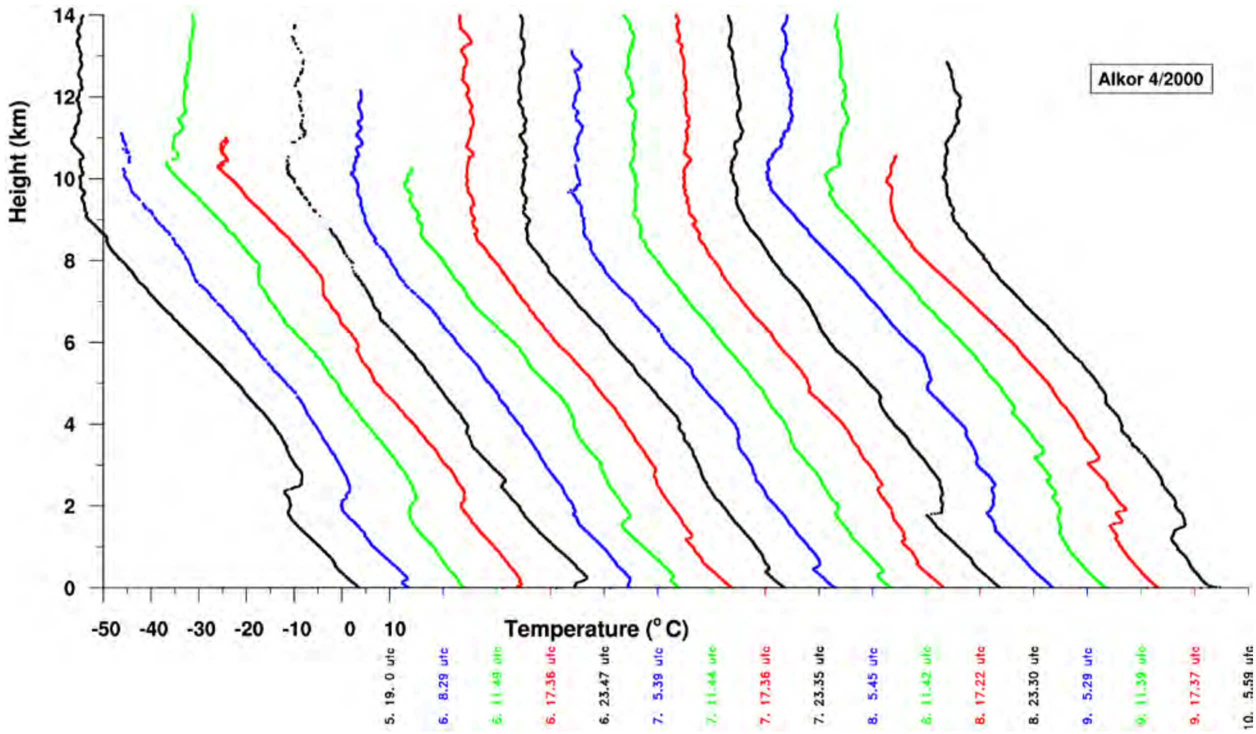
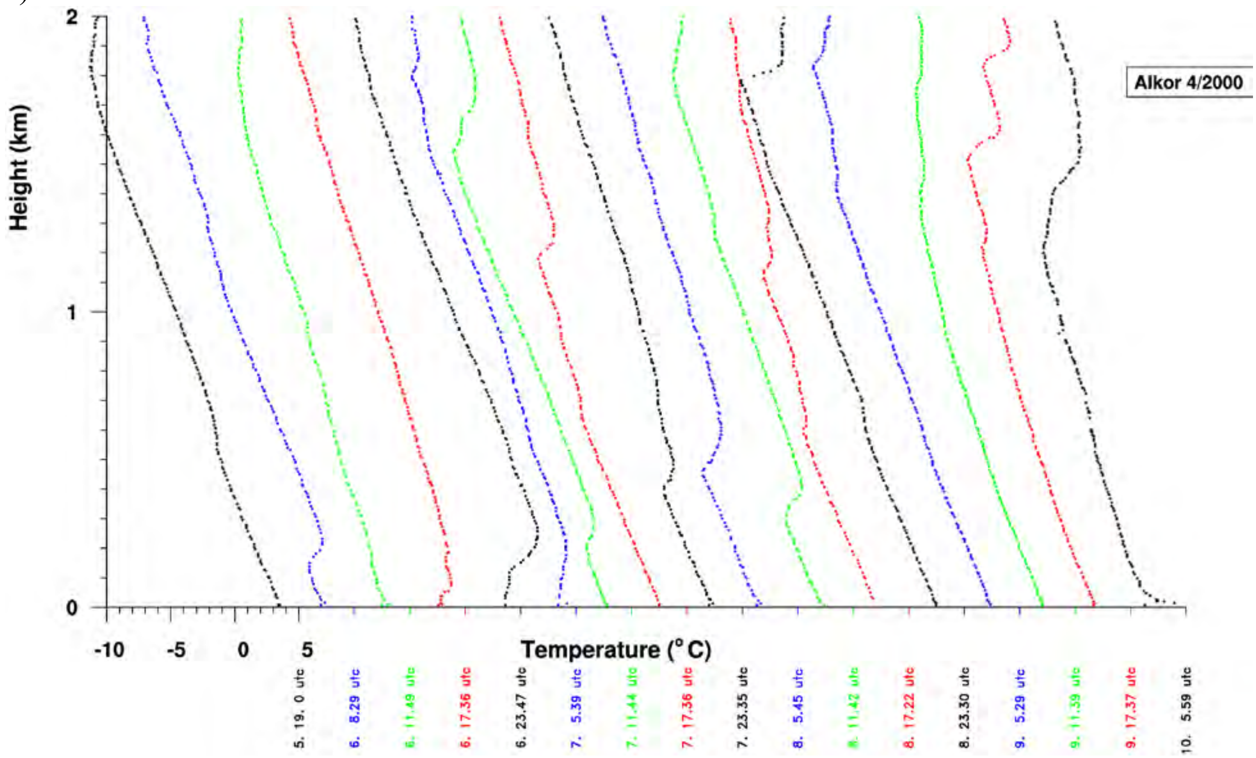


Fig. 5.9: Vertical temperature profiles between surface and 14 km height as measured by 17 Vaisala radiosondes at RV Alkor during the period 5 April 19 UTC to 10 April 2000 05.59 UTC. Tick marks at the abscissa indicate the 10° C value of the running temperature scale and the launch time.

a)



b)

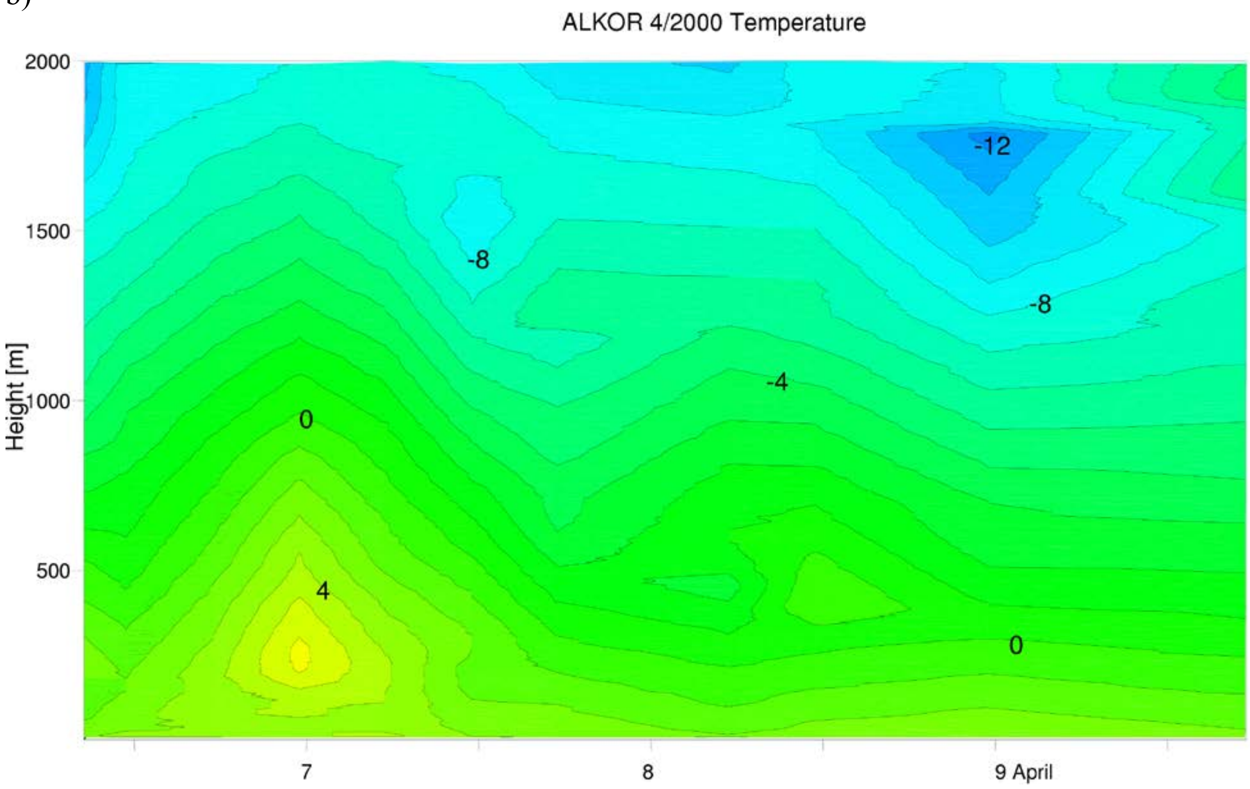
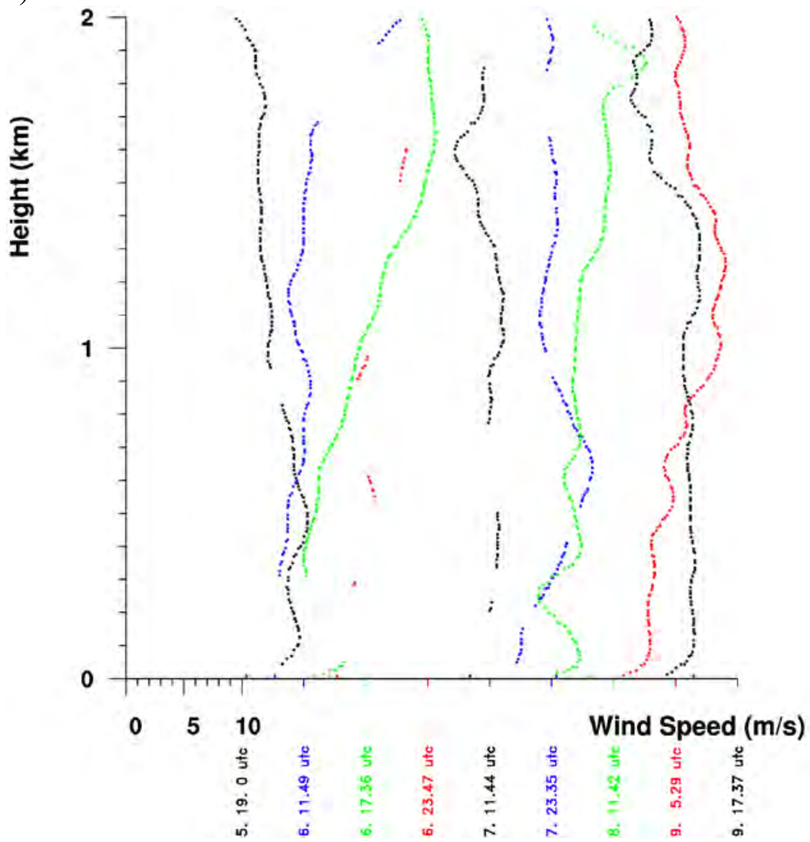


Fig. 5.10: (a) Vertical temperature profiles between surface and 2 km height as measured by 17 Vaisala radiosondes at RVAlkor during the period 5 April 2000 19 UTC to 10 April 2000 05.59 UTC. Tick marks at the abscissa indicate the 5° C value of the running temperature scale and the launch time.
(b) Time-height cross-section of temperature based on the 17 radiosoundings presented in (a). Temperature isoline difference is 1 K.

a)



b)

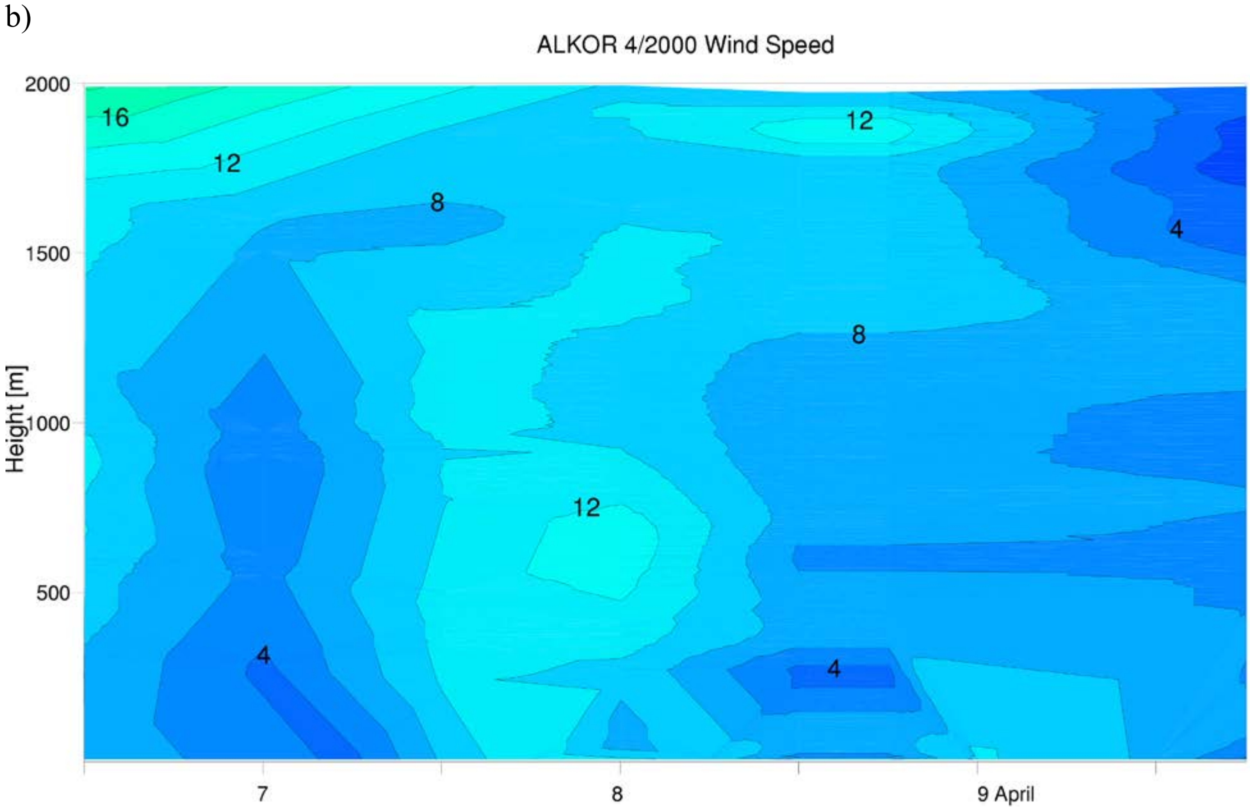


Fig. 5.11: (a) Vertical wind speed profiles between surface and 2 km height as measured by Vaisala radiosondes at RV Alkor during the period 5 April 19 UTC to 10 April 2000 05.59 UTC. Tick marks at the abscissa indicate the 10 ms^{-1} value of the running wind speed scale and the launch time.
(b) Time-height cross-section of wind speed based on the radiosoundings presented in (a). Wind speed isoline difference is 2 ms^{-1}.

5.3. The cruise Alkor 6/2000

RV Alkor left Kiel harbour on 14 June 2000 at 10 UTC. The ship arrived the destination point 56.02°N, 18,67°E in the central Baltic Sea on 15 June 15.30 UTC and stayed there until 19 June 18 UTC. The home harbour Kiel was reached on 20 June 09 UTC. Cruise leader was Dr. Stefan Thiemann and the technical responsibility for the meteorological equipment had Michael Offermann. They were supported by five students of the Meteorological Institute of the University of Hamburg.

The 00 UTC weather maps for the cruise period are given in Appendix A4. At the beginning (14-15 June) a high pressure zone extended from the Biscaya Sea to Central Europe and a low system moved from the Norwegian Sea towards Northern Scandinavia so that the experimental area was in a westerly air flow between both systems. On the next two days (16-17 June) the high pressure zone weakened in the eastern part and strengthened in the western part with a ridge now extending to the area of the Shetland islands. On the eastern side of this high pressure zone the air flow turned to northerly directions in the experimental area. The high and its ridge moved slowly eastward. The ridge passed the experimental area in the morning of 18 June. After a short period of weak winds, the air flow turned back to south/southwest so that increasingly warmer air was advected from Central Europe.

The water temperature at the experimental site (56.02°N, 18.67°E) was around 13°C and about 3 K colder than the water further to the west (Fig. 5.12). Except for the beginning and end of the experimental period (which is marked by the abrupt change in ship's speed), the air-sea temperature difference was mostly slightly unstable. The radiation curves of S↓ and L↓ show that there was predominantly little cloud cover (Fig. 5.13). With only a few exceptions cloud bases were above 1.5 km height. There was no rain during the entire period, neither at the ship nor in its vicinity.

The sonic measurements (Fig. 5.14) show a good agreement concerning the mean quantities FF, DD, T_v with standard meteorological instruments. The uncorrected (for ship's motion) turbulent heat flux H, however, appears to be useless; it even does not agree with the changing sign of the air-sea temperature difference, $T - T_{sfc}$.

In total 22 radiosondes were launched during Alkor 6/2000. The vertical structure of the atmosphere as measured by the radiosondes is given in Fig. 5.15 for the height range 0-14 km

and in Figs. 5.16 and 5.17 for the boundary layer height range 0-2 km. The tropopause height decreased from 11.5 km in the westerly air flow on 15 June to nearly 8 km in the cold northerly air flow on 16 June. With the approaching and passing high pressure zone the tropopause increased again from 17 to 19 June to a level around 12 km. The depth of the boundary layer (defined here as the layer between the surface and the lowest stable layer) seldomly reached higher than 1 km. Often the lowest stable layer was below 500 m height even during the cold northerly air flow period. In the southerly air-flow period at the end of the campaign increasingly warmer air arrived. This led to a stable layer from the surface up to 300 m height (18 June 18 UTC) and later to a surface-based inversion. On 19 June 18 UTC the temperature increased by $\Delta T = 9$ K between the surface (16°C) and 300 m height (25°C). This was accompanied by a shallow low-level jet at about 50 m height.

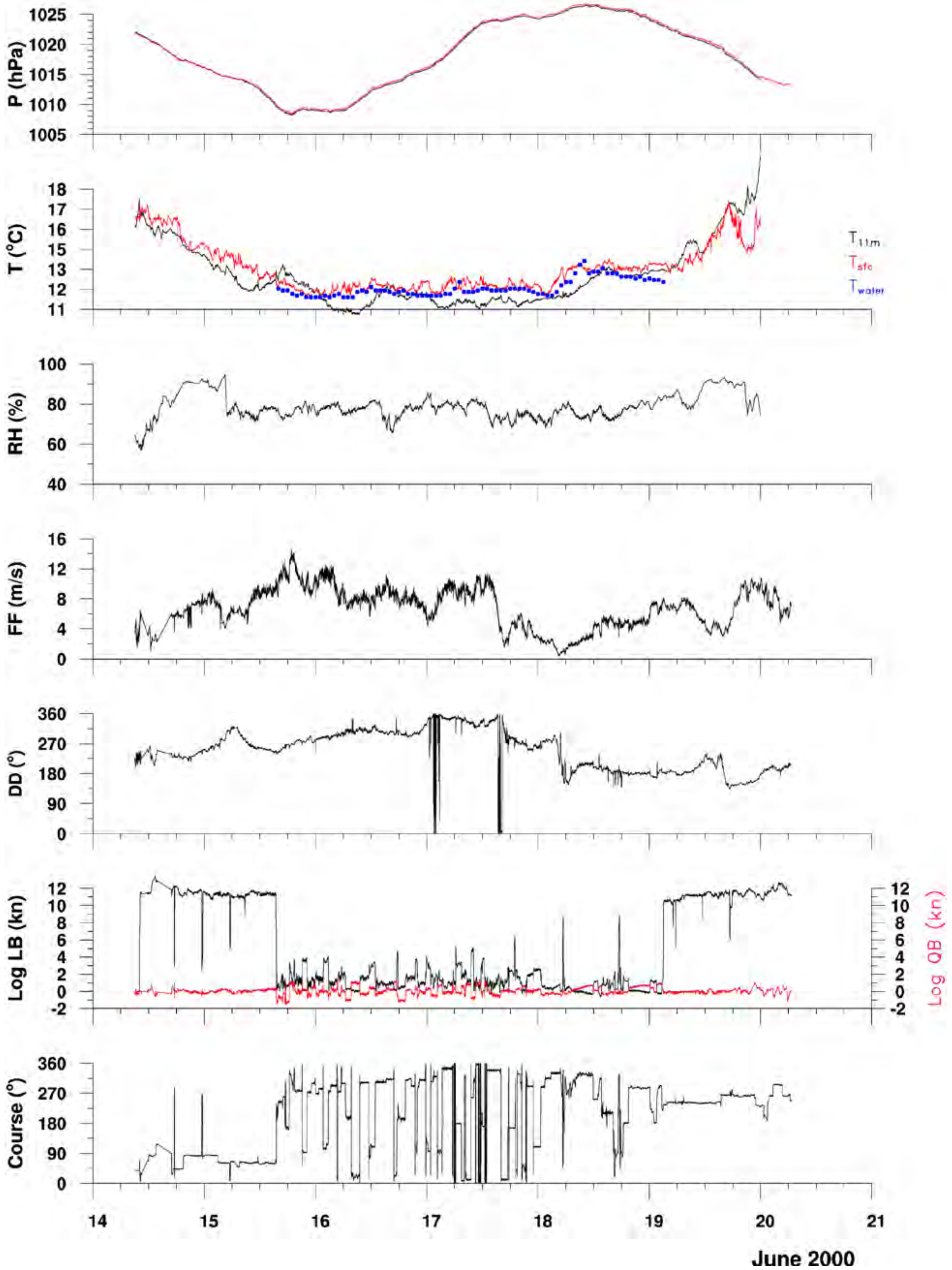


Fig. 5.12: One-minute averages of pressure p (ship's permanent station (black), foremast station (red)), air temperature T, infrared surface temperature (KT-19), and bucket temperature, relative humidity RH, wind speed FF, wind direction DD, ship's velocity component in along-ship (Log LB) and cross-ship (Log QB) direction, and ship's heading (cruise) measured at RV Alkor from 14 to 20 June 2000. Long tick marks indicate 00 UTC of the respective day.

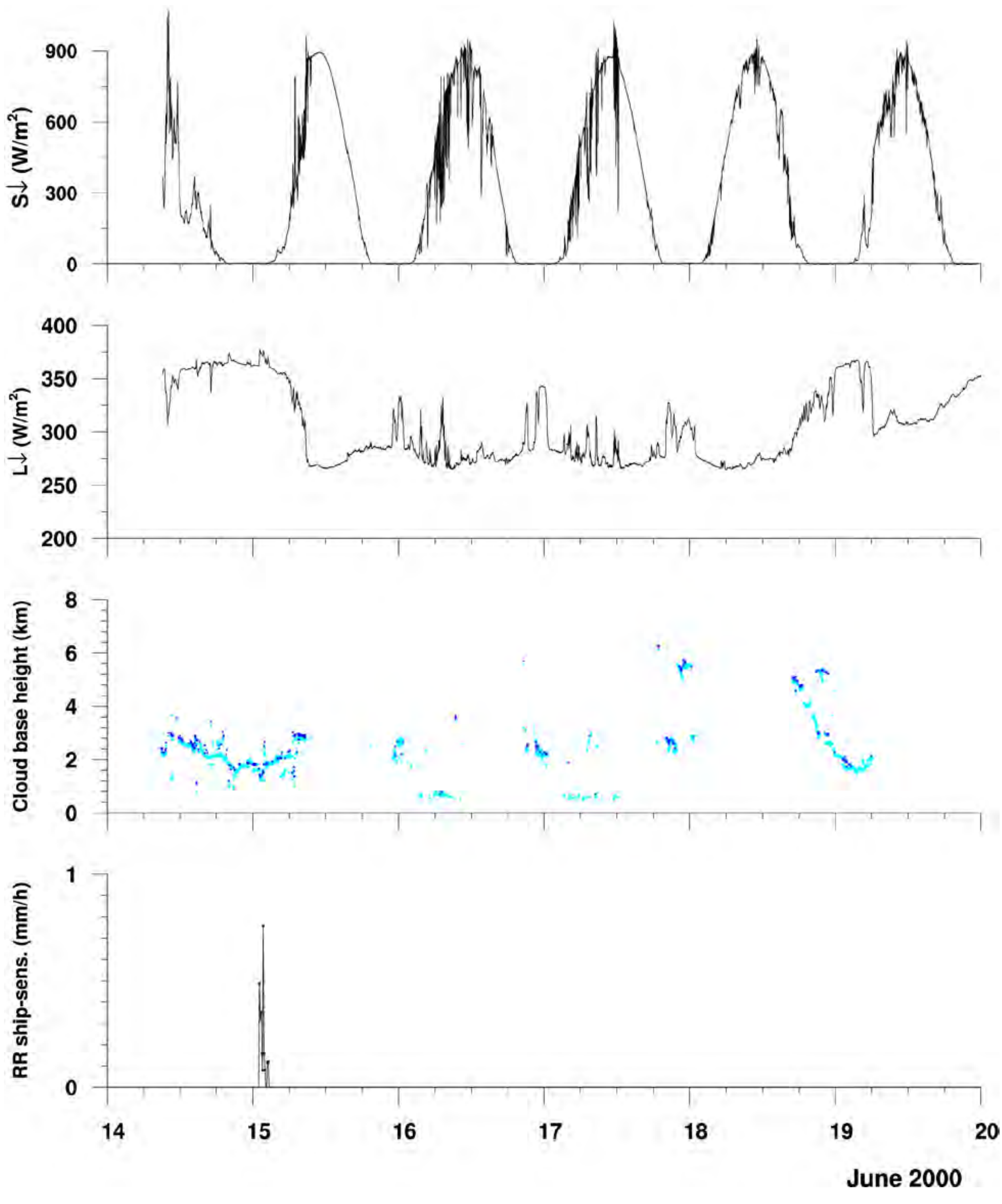


Fig. 5.13: Time series of downwelling shortwave (S↓) and longwave (L↓) radiation, cloud base height, and rain rate measured at RV Alkor from 14 to 20 June 2000.

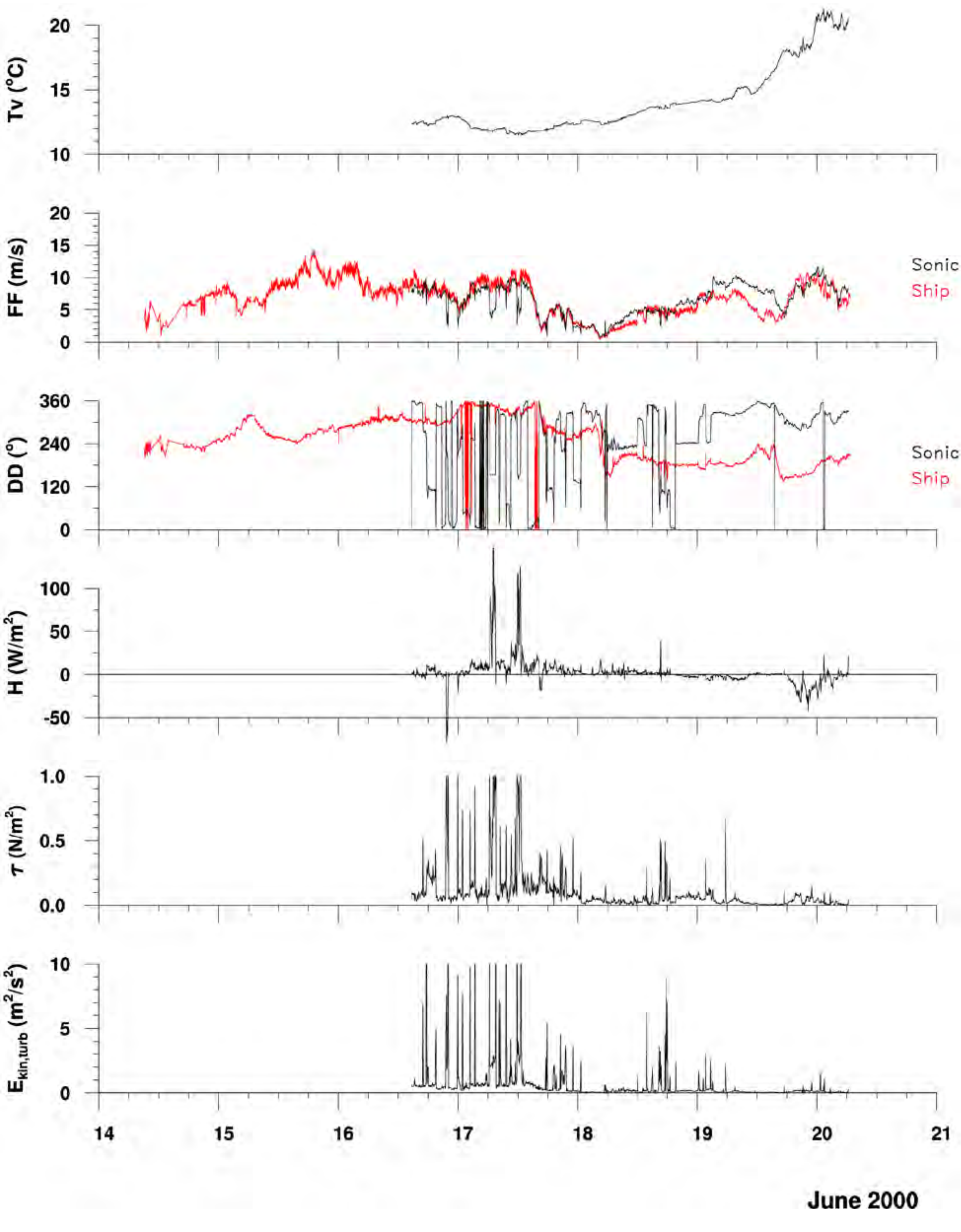


Fig. 5.14: Time series of 5 minute averages of uncorrected (for ship's motion) sonic measurements at the foremast of RV Alkor from 14 to 20 June 2000: virtual temperature T_V, wind speed FF, wind direction DD, sensible heat flux H, momentum flux τ, and turbulent kinetic energy $E_{kin,turb}$.

The problem with the radiosonde GPS wind finding at low levels also occurred in this campaign. 13 out of the 22 radiosondes delivered no wind information in the lowest 300 m.

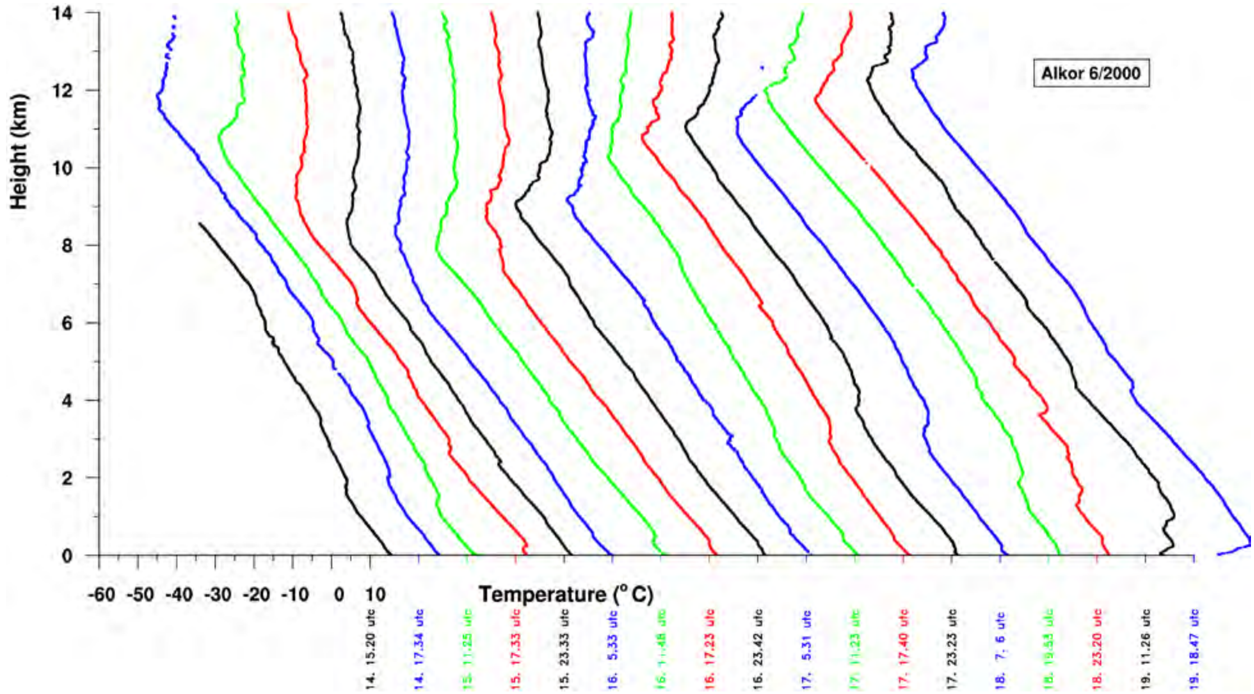
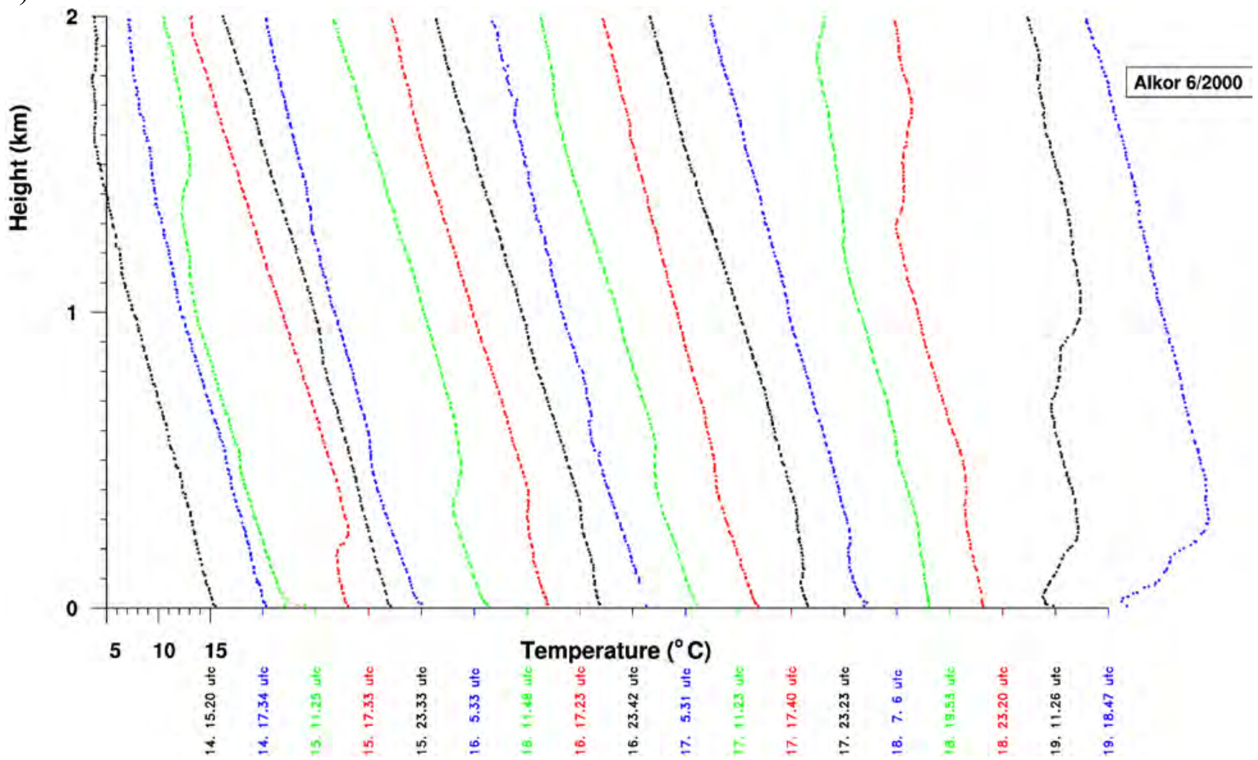


Fig. 5.15: Vertical temperature profiles between surface and 14 km height as measured by 18 Vaisala radiosondes at RV Alkor during the period 14 June 2000 15.20 UTC to 19 June 2000 18.47 UTC. Tick marks at the abscissa indicate the 10°C value of the running temperature scale and the launch time.

a)



b)

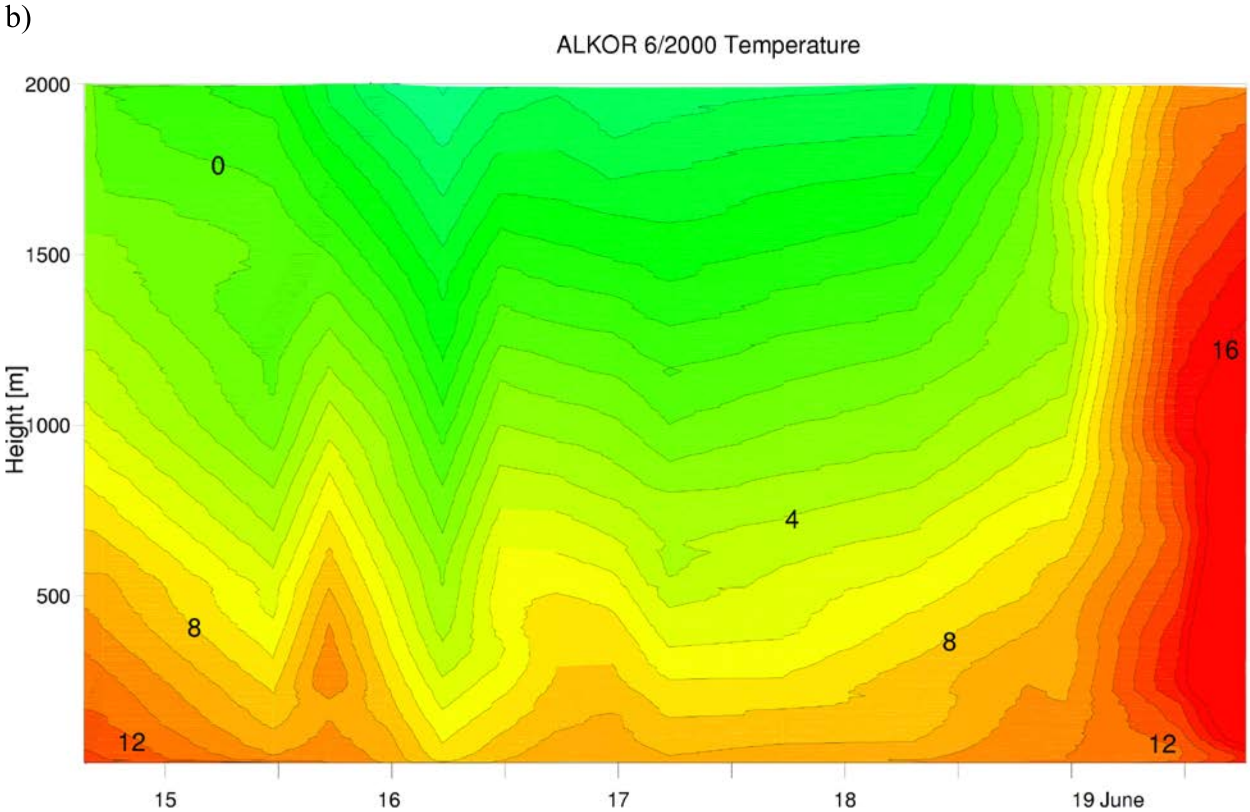


Fig. 5.16: (a) Vertical temperature profiles between surface and 2 km height as measured by 18 Vaisala radiosondes at RV Alkor during the period 14 June 2000 15.20 UTC to 19 June 2000 18.47 UTC. Tick marks at the abscissa indicate the 15°C value of the running temperature scale and the launch time.
(b) Time-height cross section of temperature based on the 18 radiosoundings presented in (a). Temperature isoline difference is 1 K.

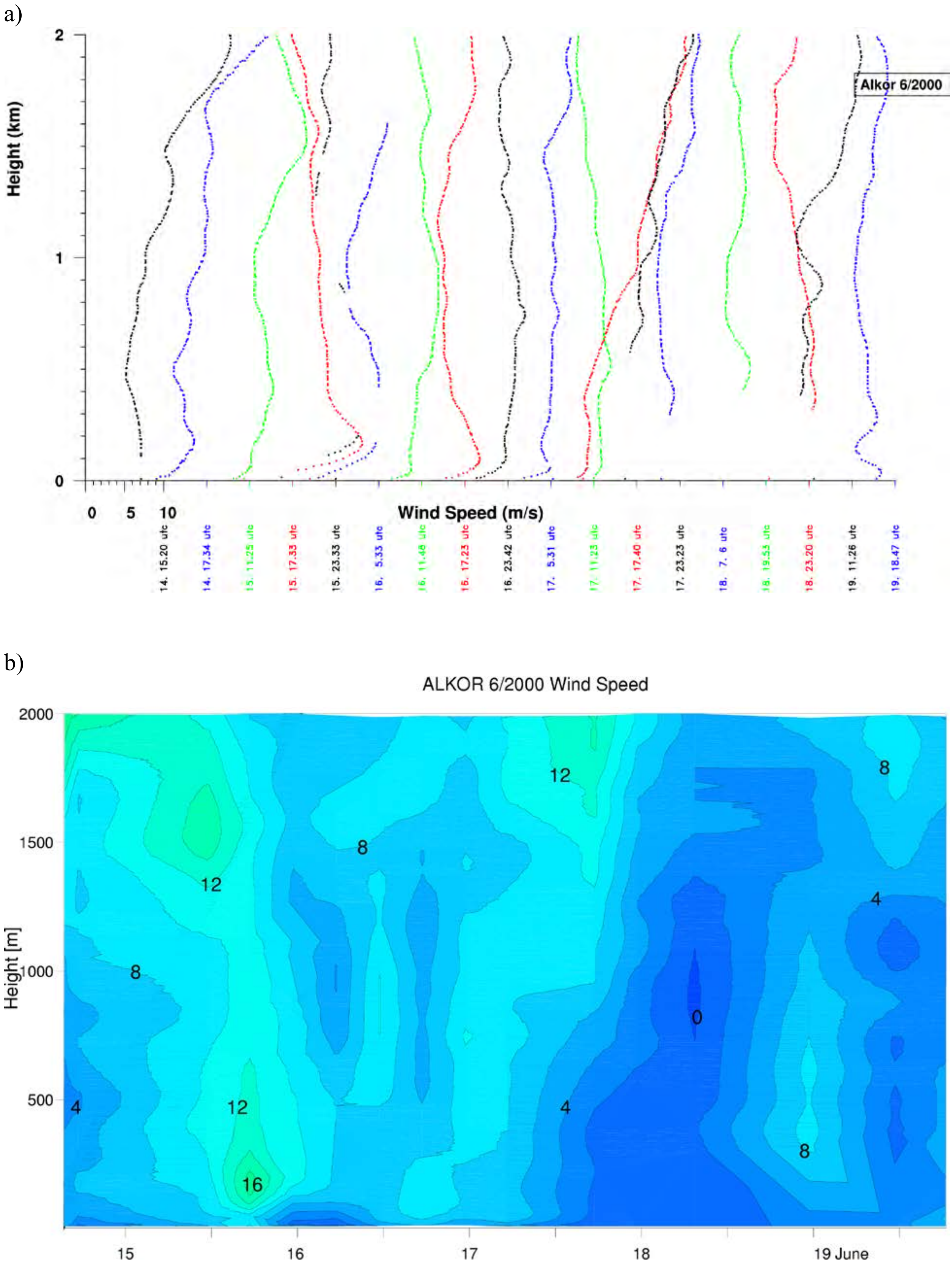


Fig. 5.17: (a) Vertical wind speed profiles between surface and 2 km height as measured by 18 Vaisala radiosondes at RV Alkor during the period 14 June 2000 15.20 UTC to 19 June 2000 18.47 UTC. Tick marks indicate the 10 ms^{-1} value of the running wind speed scale and the launch time.
(b) Time-height cross-section of wind speed based on the 18 radiosoundings presented in (a). Wind speed isoline difference is 2 ms^{-1}

5.4. The cruise Alkor 10/2000

RV Alkor left Kiel harbour on 25 October 2000 08.30 UTC. The ship arrived at the destination point (56.02°N, 18.67°E) in the central Baltic Sea and stayed there until 29 October 08.30 UTC. The experimental area had to be left about one day earlier than planned in order to avoid the southwest storm up to Beaufort 10-11 forecasted for the journey back. The home harbour Kiel was reached on 31 October 08 UTC. Cruise leader was Dr. Gerd Müller and the technical responsibility had Michael Offermann. The meteorological observations were headed by Ingo Oldeland supported by five students of the Meteorological Institute of the University of Hamburg.

The daily 00 UTC weather maps for the cruise period are given in Appendix A5. The synoptic situation was characterized by a low pressure zone extending from the North-Atlantic to Northeast-Scandinavia. The experimental area was situated to the south of this zone in which individual lows passed from west to east. The cyclone chain was shortly interrupted in the afternoon of 27 October when the cold front on the rear side of a passing low crossed the area from north and a weak ridge followed (28 October). Thereafter, a gale low over Scotland and the North Sea attained increasing influence in the experimental area with increasing southwesterly wind with embedded shower fronts (29 and 30 October).

The basic meteorological quantities (p, T, T_{sfc}, RH, FF, DD) and ship's speed and course are displayed in Fig. 5.18. The water temperature in the experimental area as well as west of it (measured during the cruise forth and back) was around 12°C. Southwesterly wind directions dominated, except for the 27 October when the cold front passed and the wind turned to north. This was accompanied by a temperature decrease of –3 K so that the air-sea temperature differences changed from neutral/weakly unstable to clearly unstable. This cold-air advection period lasted only until the early morning hours of 28 October. Thereafter the center of the high pressure ridge (accompanied with weak winds) passed and warmer air was advected from SW leading on 29 October to neutral to slightly stable air-sea temperature differences. Wind speed FF was high (18 ms^{-1}) on the way to the experimental site and back. In the warm-frontal system belonging to the gale low over the North Sea a gust front was embedded and crossed on 29 October 19.20 UTC at 55.15°N, 15.83°E. Within a few minutes the wind turned from 180° to 240° and increased from 12 ms^{-1} to 25 ms^{-1}. This was accompanied with an air temperature drop of 3.5 K in the shower and a pressure rise of 1.5 hPa. After about one hour all meteorological quantities returned to their normal levels.

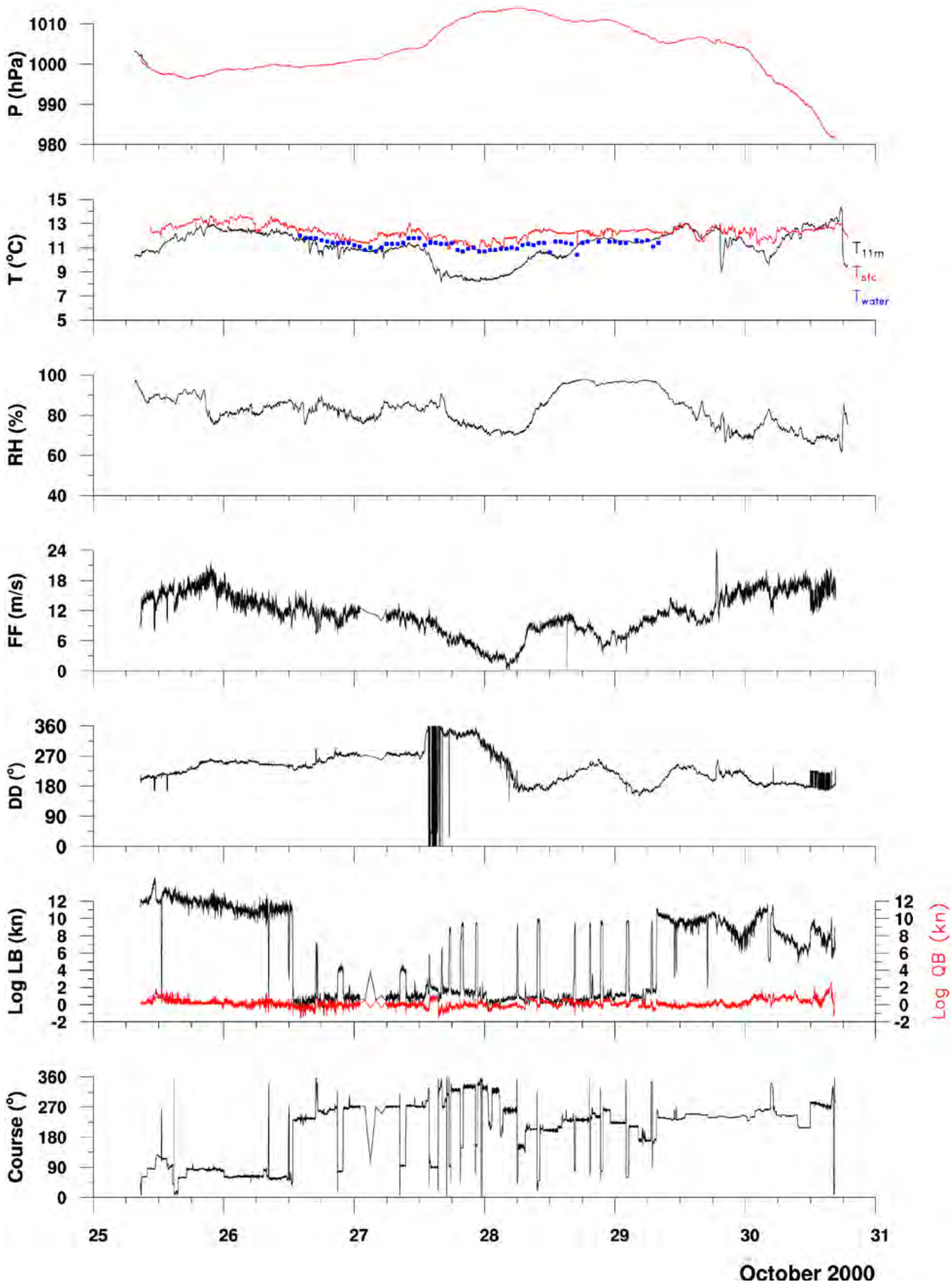


Fig. 5.18: One-minute averages of pressure p (ship's permanent station (black), foremast station (red)), air temperature T, infrared surface temperature (KT-19), and bucket temperature, relative humidity RH, wind speed FF, wind direction DD, ship's velocity component in along-ship (Log LB) and cross-ship (Log QB) direction, and ship's heading (cruise) measured at RV Alkor from 25 to 31 October 2000. Long tick marks indicate 00 UTC of the respective day.

The radiation fluxes S↓ and L↓ and the ceilometer cloud base are presented in Fig. 5.19. All three quantities indicate a high amount of cloud cover during the entire cruise. It was overcast at the beginning (25 October) and end (30 October). Only a few cloud gaps occurred during daytime, some larger gaps during the night hours. Lowest cloud bases were seldomly above 2 km height. Most frequently cloud base was below 1 km . The lowest cloud bases around 100 m height were observed in the afternoon (13-17 UTC) of 28 October in the warm southwesterly air flow. This was accompanied with continuous drizzle.

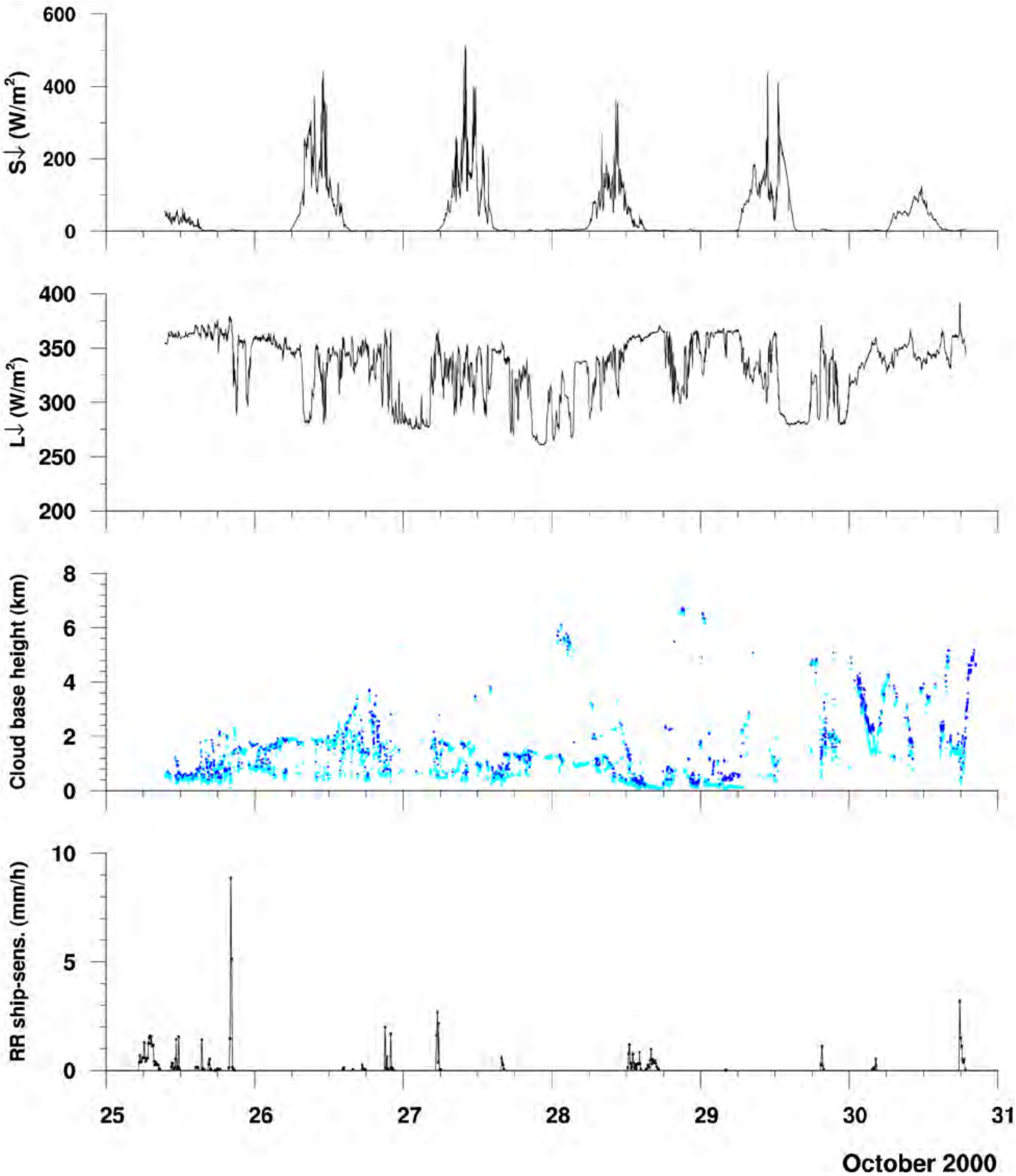


Fig. 5.19: Time series of downwelling shortwave (S↓) and longwave (L↓) radiation, cloud base height, and rain rate measured at RV Alkor from 25 to 31 October 2000.

The sonic measurements are displayed in Fig. 5.20. It is mentioned here again that the sonic data are not corrected for the ship's motion. This affects all wind quantities. Nevertheless the general course of the sensible heat flux curve (during the period when Alkor was on station) appears to be reasonable: large positive fluxes during the cold-air period (27 October noon to 28 October noon) and heat fluxes close to zero during the warm air advection and drizzle period on 28 October afternoon and night.

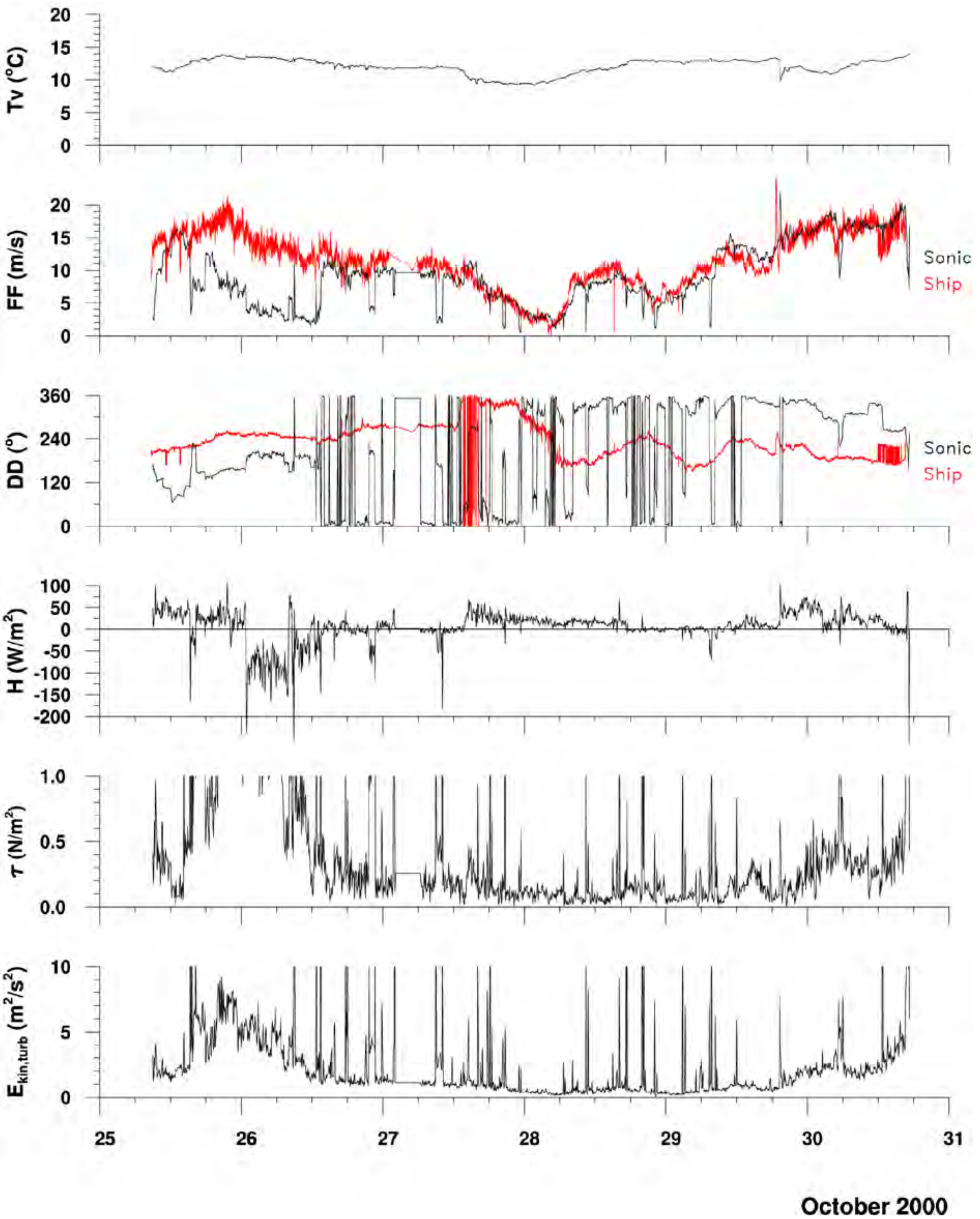


Fig. 5.20: Time series of 5 minute averages of uncorrected (for ship's motion) sonic measurements at the foremast of RV Alkor from 25 to 31 October 2000: virtual temperature T_V, wind speed FF, wind direction DD, sensible heat flux H, momentum flux τ, and turbulent kinetic energy $E_{kin,turb}$.

In total, 19 radiosondes were launched at 6 hours intervals on 26 and 27 October and at 3 hours intervals on 28 and 29 October. The temperature profiles for the height range 0-14 km are displayed in Fig. 5.21. To see the structure in the boundary layer in more detail, the temperature and wind profiles for the height range 0-2 km are given in Fig. 5.22 and Fig. 5.23, respectively. The tropopause level shows substantial height variations ranging from less than 8 km (26 October 23.42 UTC) to more than 12 km (29 October 0536 UTC). This is in agreement with the general well-known tropopause height differences between cold and warm air masses. Temperature and wind in the boundary layer (Figs. 5.22. and 5.23) show no spectacular structures. Inversions in the lowest km were nearly absent. Most temperature profiles show a well-mixed layer at least in the lowest 500 m above the surface.

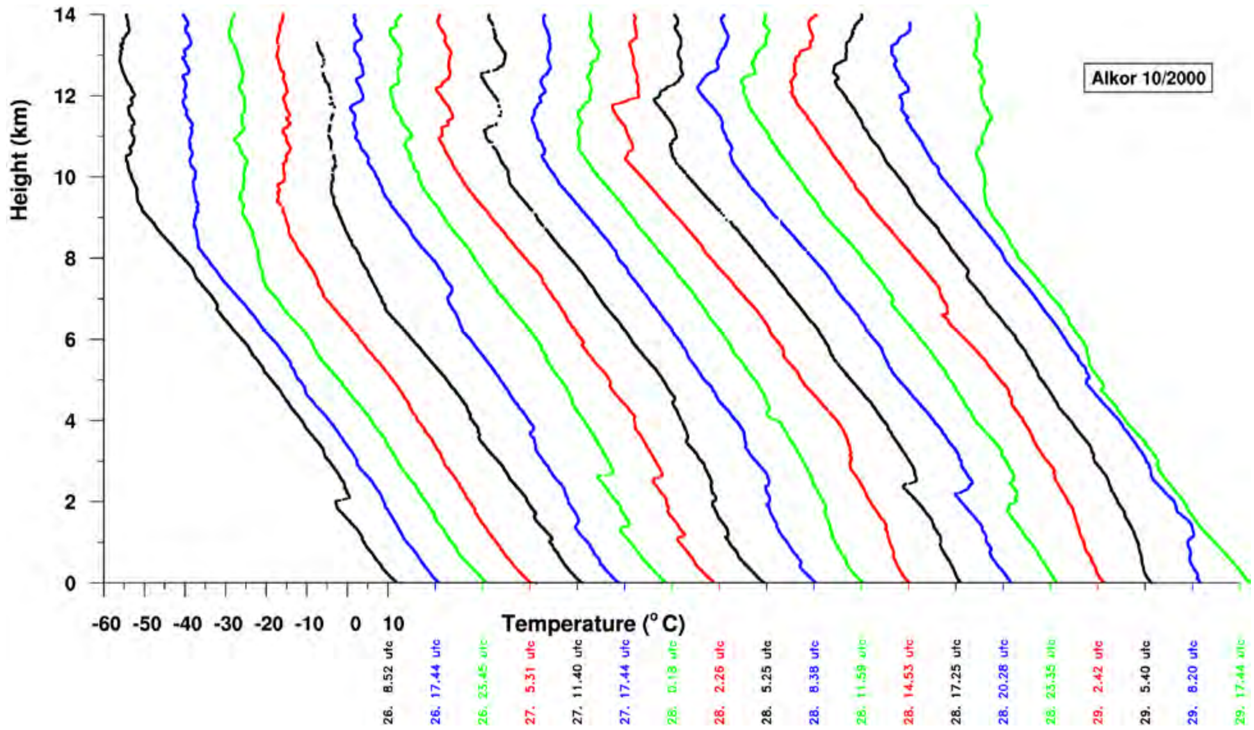
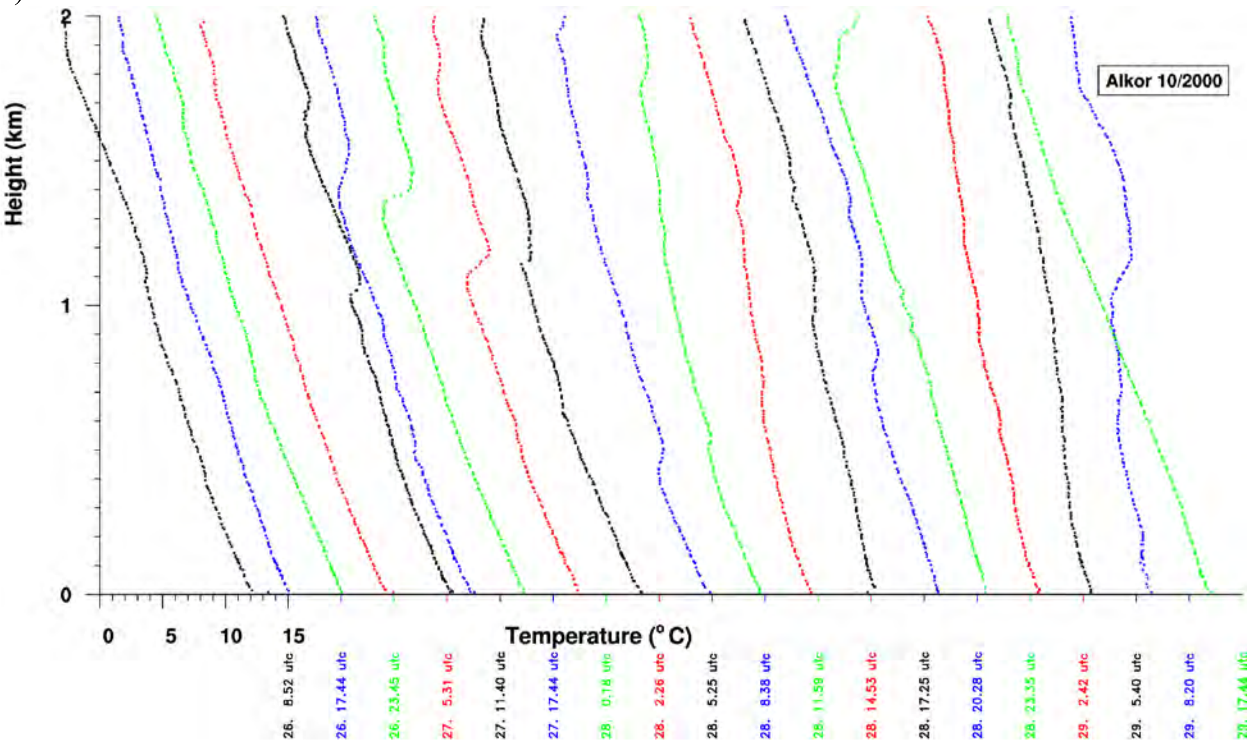


Fig. 5.21: Vertical temperature profiles between surface and 14 km height as measured by 19 Vaisala radiosondes at RV Alkor during the period 26 October 2000 8.52 UTC to 29 October 2000 17.44 UTC. Tick marks at the abscissa indicate the 10°C value of the running temperature scale and the launch time.

a)



b)

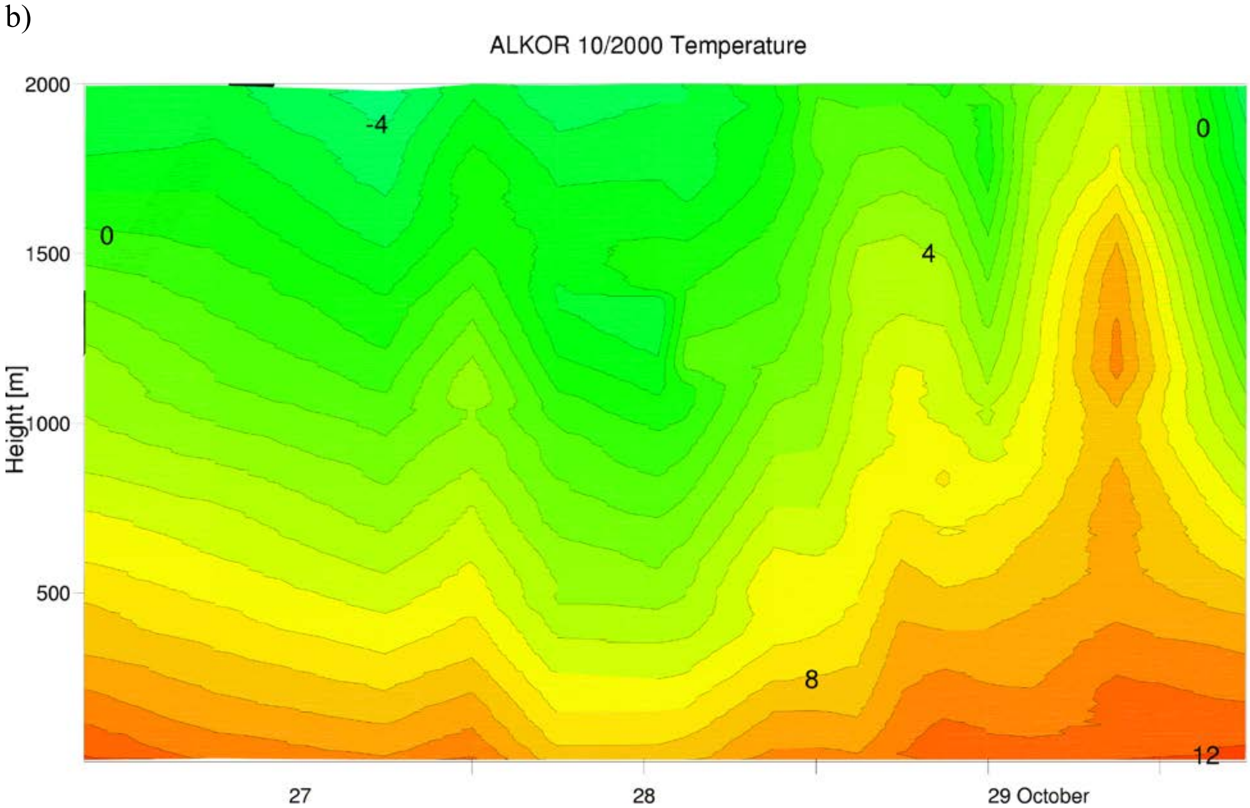
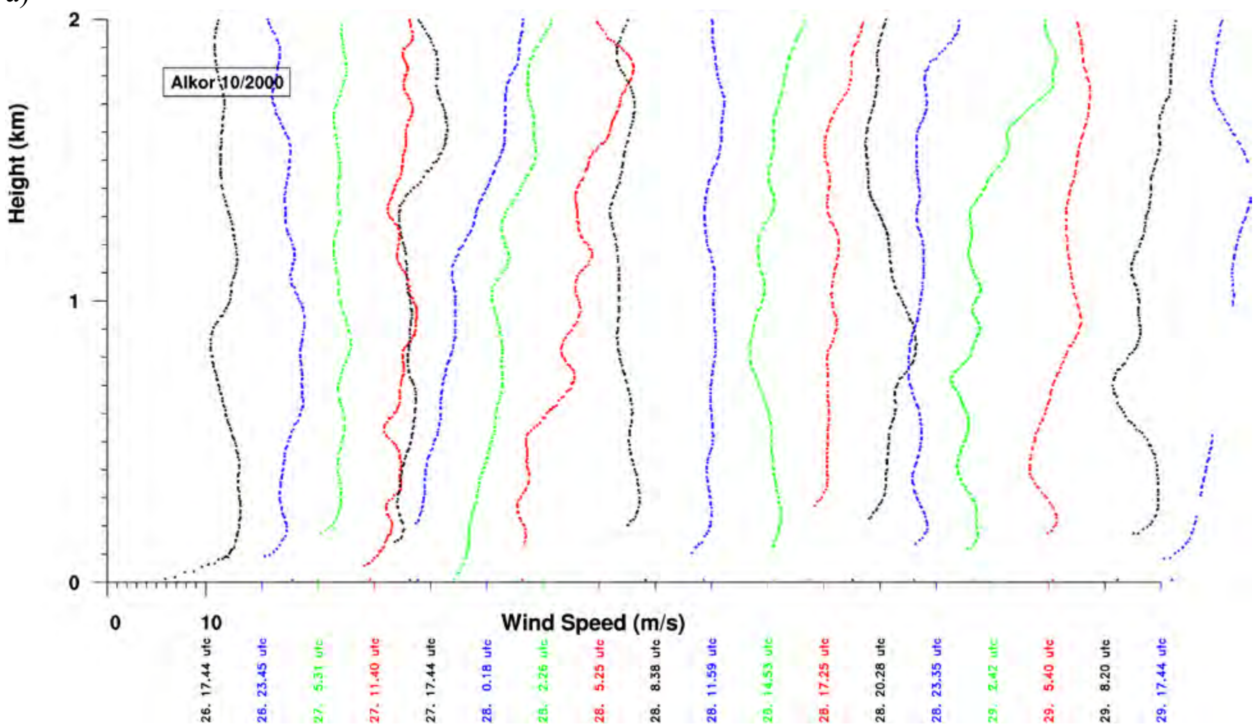


Fig. 5.22: (a) Vertical temperature profiles between surface and 2 km height as measured by 19 Vaisala radiosondes at RV Alkor during the period 26 October 2000 08.52 UTC to 29 October 2000 17.44 UTC. Tick marks at the abscissa indicate the 15°C value of the running temperature scale and the launch time.
(b) Time-height cross section of temperature based on the 19 radiosoundings presented in (a). Temperature isoline difference is 1 K.

a)



b)

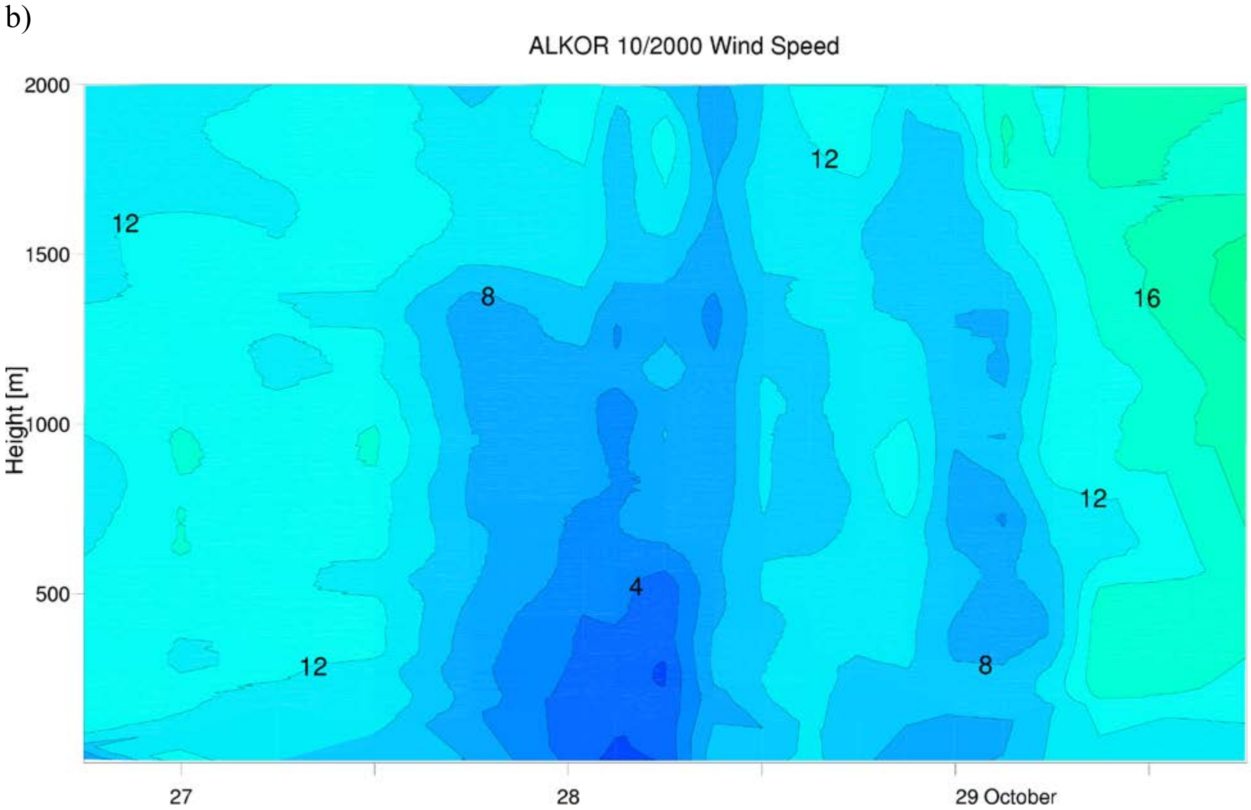


Fig. 5.23: (a) Vertical wind speed profiles between surface and 2 km height as measured by 19 Vaisala radiosondes at RV Alkor during the period 26 October 2000 08.52 UTC to 29 October 2000 17.44 UTC. Tick marks indicate the 10 ms^{-1} value of the running wind speed scale and the launch time.
(b) Time-height cross-section of wind speed based on the 19 radiosoundings presented in (a). Wind speed isoline difference is 2 ms^{-1}

5.5. The cruise Alkor 4/2001

RV Aranda left Kiel harbour on 2 April 2001 11.30 UTC. It reached the central Baltic Sea (56.02°N, 18.67°E) on 3 April 19.15 UTC and stayed there until 10 April 03 UTC. The ship returned to Kiel harbour on 11 April 08 UTC. Cruise leader was Dr. Gerd Müller. Michael Offermann was responsible for the technical equipment. They were supported by nine students from the Meteorological Institute of the University of Hamburg.

The daily 00 UTC weather maps for the period of Alkor 4/2001 are given in Appendix A6. The synoptic conditions during the first part of the cruise (2-7 April) were determined by a high pressure system over Southeast-Europe and a low pressure zone extending from England towards North-Scandinavia. In this time period the experimental area was alternately under high or low pressure influence but always in a southerly to southwesterly air flow. During the second part (8-10 October) of Alkor 4/2001 a low moving from southwest to northeast over South-Sweden affected the weather in the experimental area. This low had a more southern track than the lows before.

The basic meteorological quantities (p, T, T_{sfc}, RH, FF, DD) and ship's speed and course are displayed in Fig. 5.24. The pressure curve reflects the variable influences of the high pressure zone over Southeast Europe and the low-pressure systems over Scandinavia. The water temperature had still wintertime values and was around 4°C. Except for a few hours the air-sea temperature difference was stable or neutral due to the predominating winds from south to west advecting warm air from the land.

In the noon hours of 4 April fog occurred at the Alkor station. The fog was formed in the warm and moist air flow from the land. The low-level air cooled at the cooler sea surface until the dew point was reached. Afterwards, the foggy air was further cooled radiatively even below the sea surface temperature. Increasing winds and thus fog-top entrainment mixing led to fog dissolution. The increasing winds were caused by an approaching cold front belonging to an edge low over the Skagerak Sea. The cold front with thunderstorm winds of up to 16 m s^{-1} ahead, and rain rates of up to 20 mm/h reached RV Alkor at about 00 UTC on 5 April. The outstanding

temperature peak of 10°C is not a measurement error, but due to the pre-frontal downdraft pushing warm air from above the inversion down to the surface.

The radiation fluxes S↓ and L↓ and the ceilometer cloud base are presented in Fig. 5.25. Except for 8 April, there were relatively few clouds during daytime; S↓ often reached values of 700 W m^{-2}. The fog on 4 April was less than 100 m deep and did not reduce S↓ much. More clouds occurred during the night as can be seen from L↓. The ceilometer did not work properly. It showed clouds whenever there were clouds, but it also showed clouds in some case when there were surely no clouds (as in the night 5/6 April). Four major rain events occurred: 3 April 18-22 UTC, 4/5 April 23-01 UTC, 6/7 April 22-03 UTC, 8 April 13-19 UTC. All were connected with frontal passages.

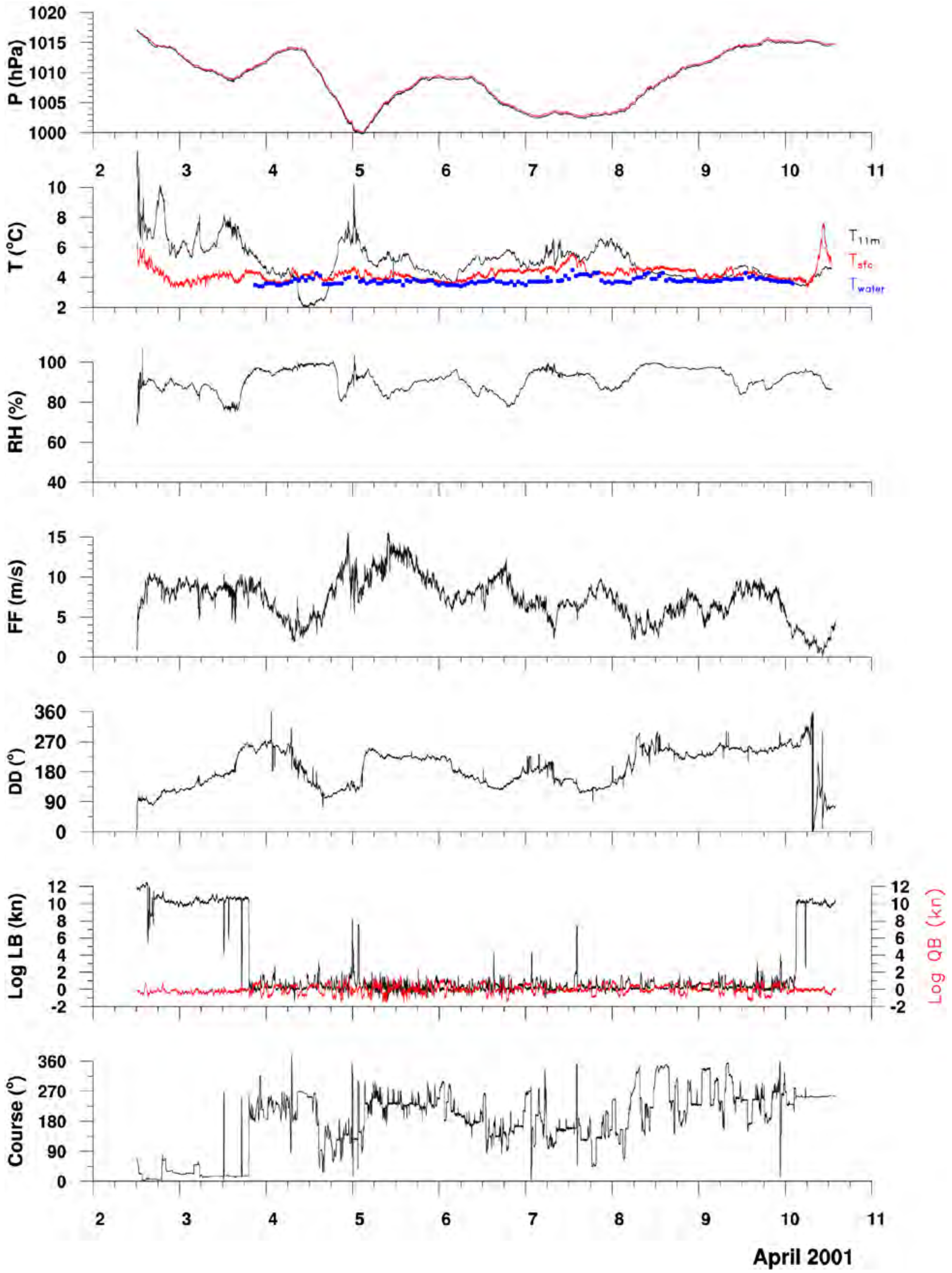


Fig. 5.24: One-minute averages of pressure p (ship's permanent station (black), foremast station (red)), air temperature T and infrared surface temperature (KT-19), relative humidity RH, wind speed FF, wind direction DD, ship's velocity component in along-ship (Log LB) and cross-ship (Log QB) direction, and ship's heading (cruise) measured at RV Alkor from 2 to 10 April 2001. Long tick marks indicate 00 UTC of the respective day.

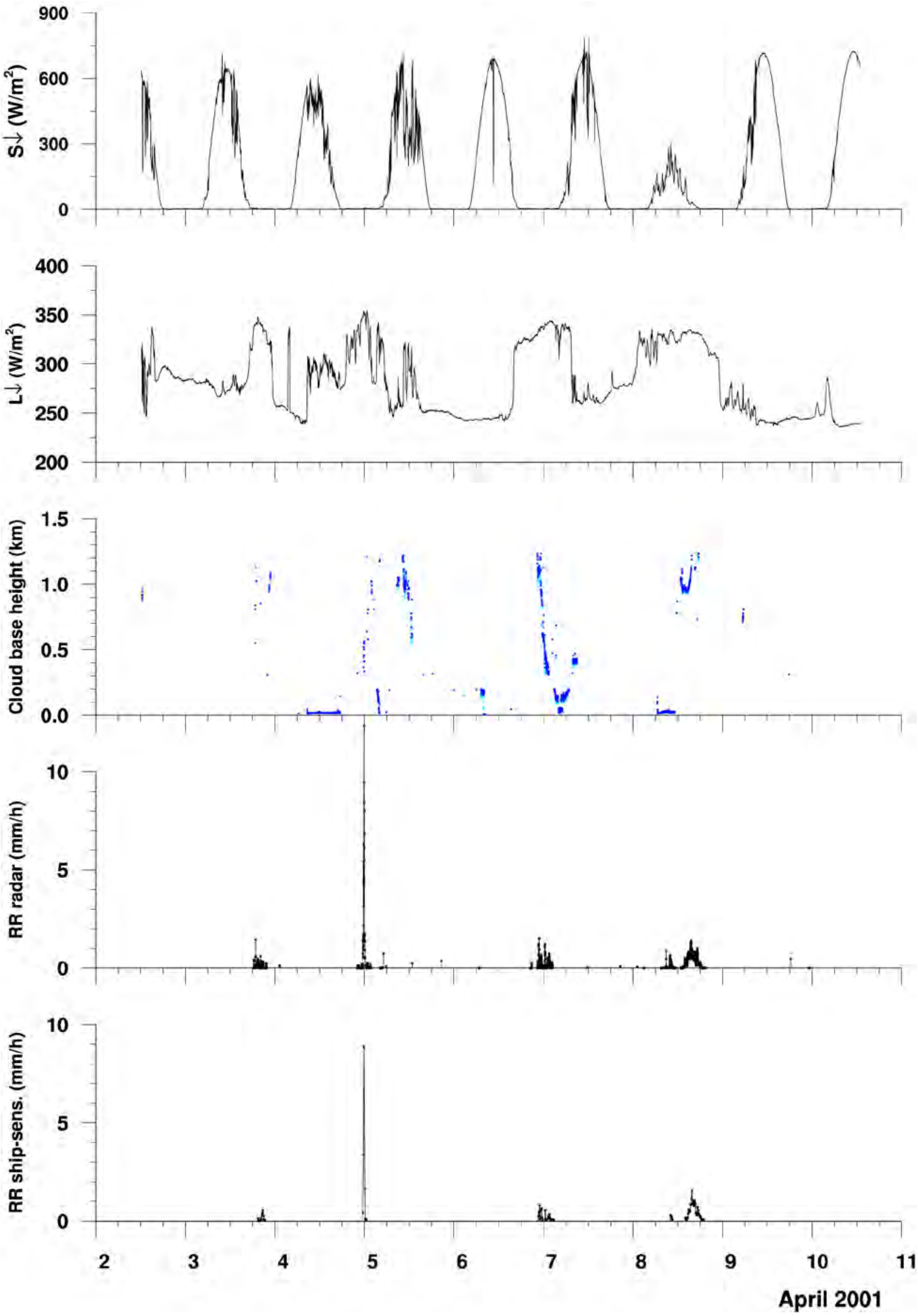


Fig. 5.25: Time series of downwelling shortwave (S↓) and longwave (L↓) radiation, cloud base height, and rain rate (radar and gauge) measured at RV Alkor from 2 to 10 April 2001.

The sonic measurements are displayed in Fig. 5.26. The presented data are not corrected for ship's motion. Nevertheless, the heat flux is negative (downward) most of the time in accordance with the stable air-sea temperature difference and is positive (upward) during the unstable fog hours on 4 April. Also the thunderstorm shows up as a special event: increasing negative heat flux ahead of the storm is concident with the increasing warm air advection and wind speed FF and extreme positive heat flux values during the storm. At least, this encourages to proceed further with sonic measurements on board a ship.

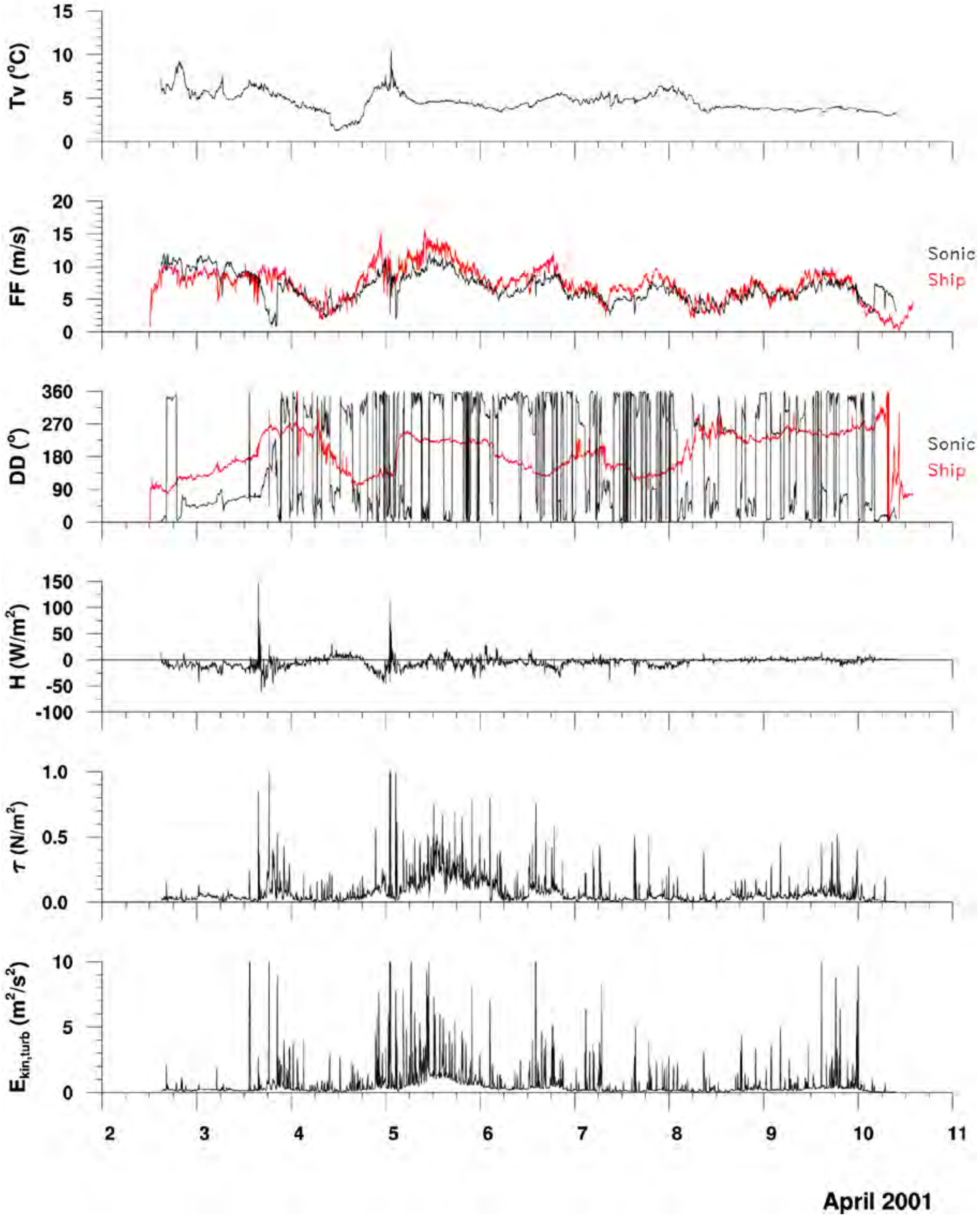


Fig. 5.26: Time series of 5 minute averages of uncorrected (for ship's motion) sonic measurements at the foremast of RV Alkor from 2 to 10 April 2001: virtual temperature T_V, wind speed FF, wind direction DD, sensible heat flux H, momentum flux τ, and turbulent kinetic energy $E_{kin,turb}$.

In total 28 radiosondes were launched during the Alkor 4/2001 cruise. The temperature profiles in Fig. 5.27 for the height range 0-14 km show a rather constant tropopause level between 9 and 23 km height during the entire cruise. The temperature and wind speed profiles in the boundary layer are given in more detail in Figs. 5.28 and 5.29, respectively. The striking feature in the temperature profiles is that there was a low-level inversion nearly all the time. Often, the inversion was surface-based and its top reached to levels between 100 and 300 m. The temperature increase between inversion base and top was up to 7 K (4 April 17.35 UTC and 7 April 17.24 UTC). The wind profile in the low-level inversion often showed a low-level jet. The temperature profiles taken during the fog on 4 April (11.28 UTC and 17.35 UTC) show that the fog layer top was below 100 m height.

The effect of the thunderstorm on 5 April 00 UTC can be seen by comparison of the radiosonde profile before it (4 April 23.31 UTC) and after it (5 April 05.16 UTC). The boundary layer inversion was removed by the storm: the air temperature in the height range of the inversion (100-400 m) dropped by about 7 K, whereas the temperature dropped by only 1 K at ship's level (11 m).

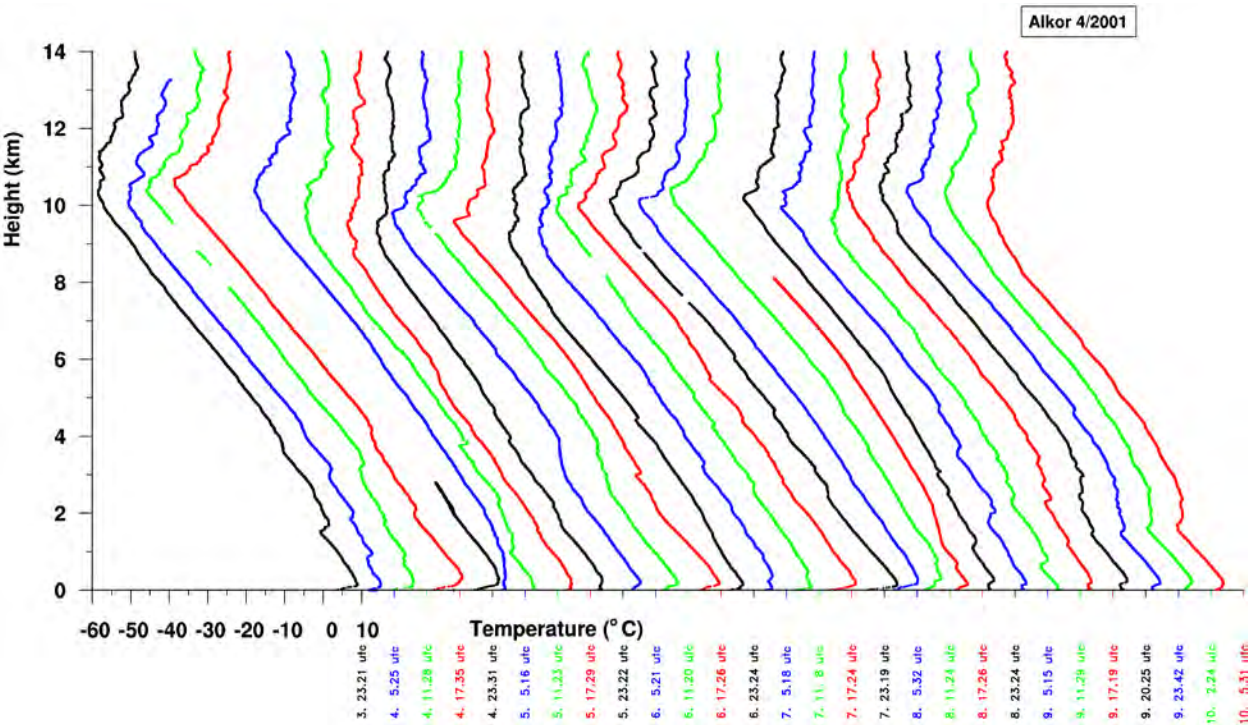
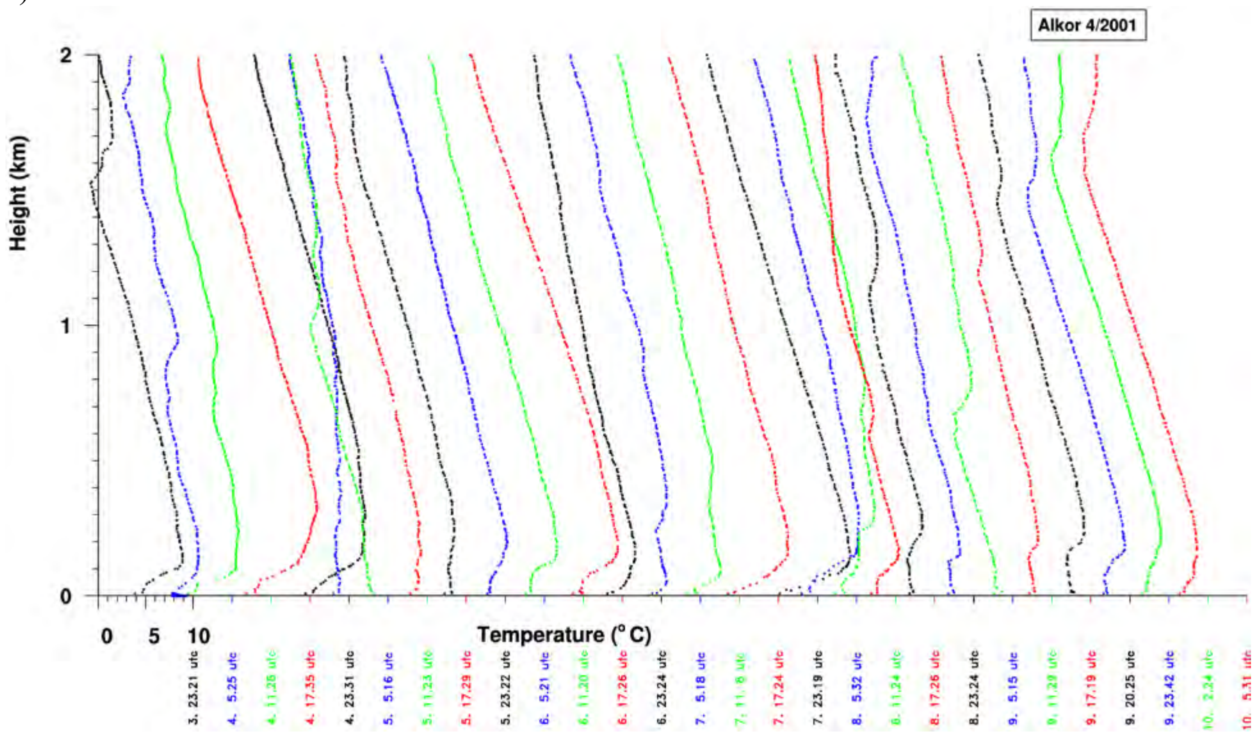


Fig. 5.27: Vertical temperature profiles between surface and 14 km height as measured by 28 Vaisala radiosondes at RV Alkor during the period 3 April 2001 23.21 UTC to 10 April 2001 05.31 UTC. Tick marks at the abscissa indicate the 10°C value of the running temperature scale and the launch time.

a)



b)

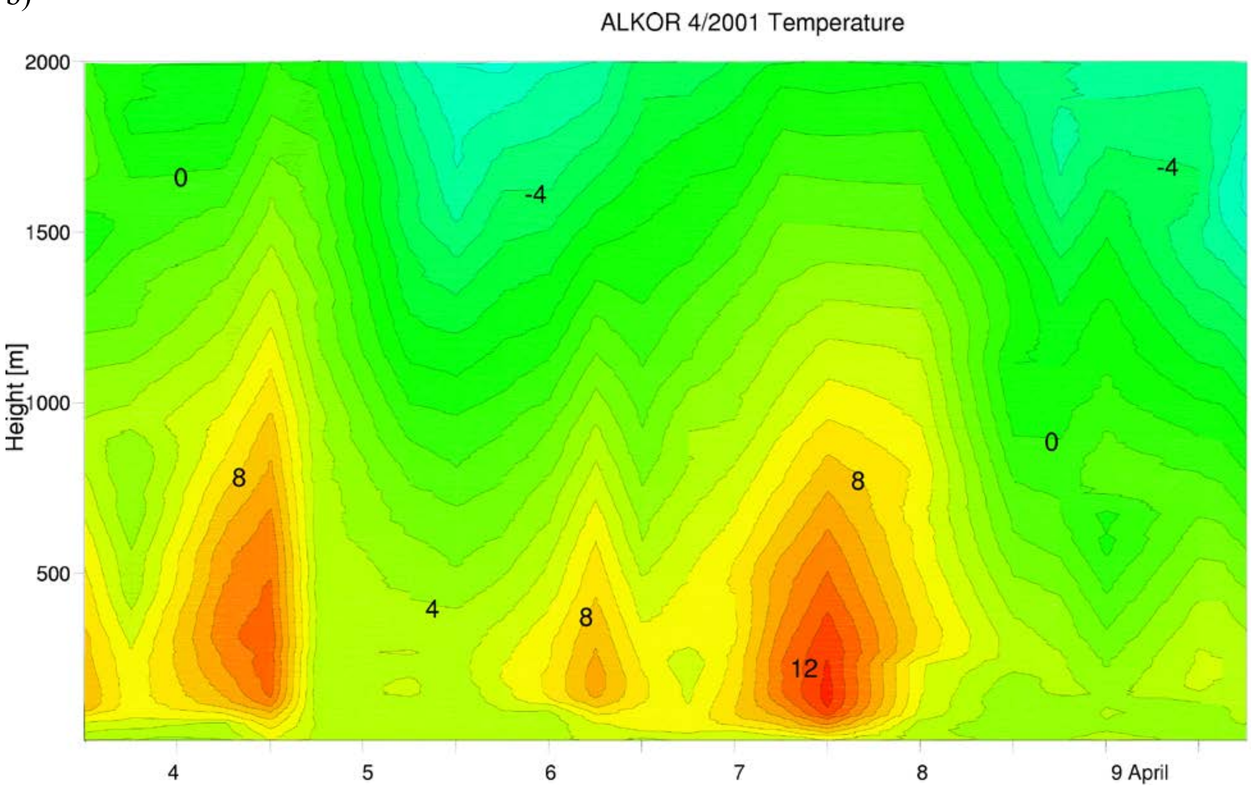
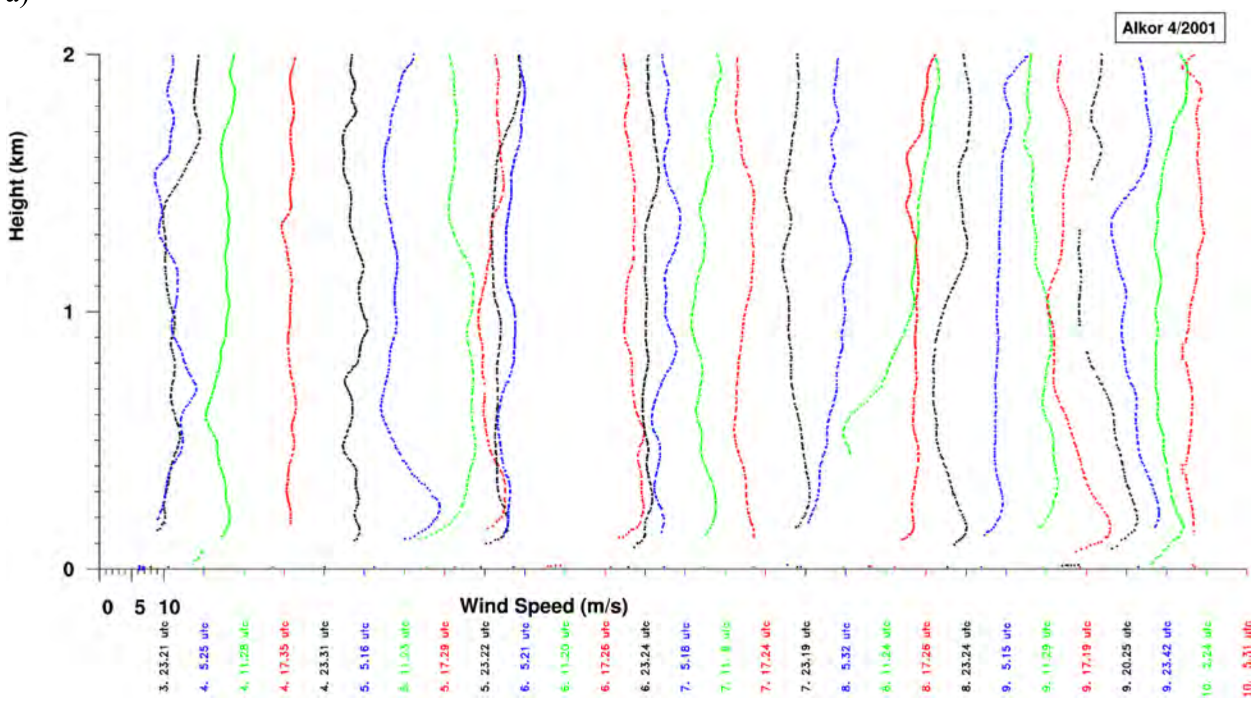


Fig. 5.28: (a) Vertical temperature profiles between surface and 2 km height as measured by 28 Vaisala radiosondes at RV Alkor during the period 3 April 2001 23.21 UTC to 10 April 2001 05.31 UTC. Tick marks at the abscissa indicate the 10°C value of the running temperature scale and the launch time.

(b) Time-height cross section of temperature based on the 28 radiosoundings presented in (a). Temperature isoline difference is 1 K.

a)



b)

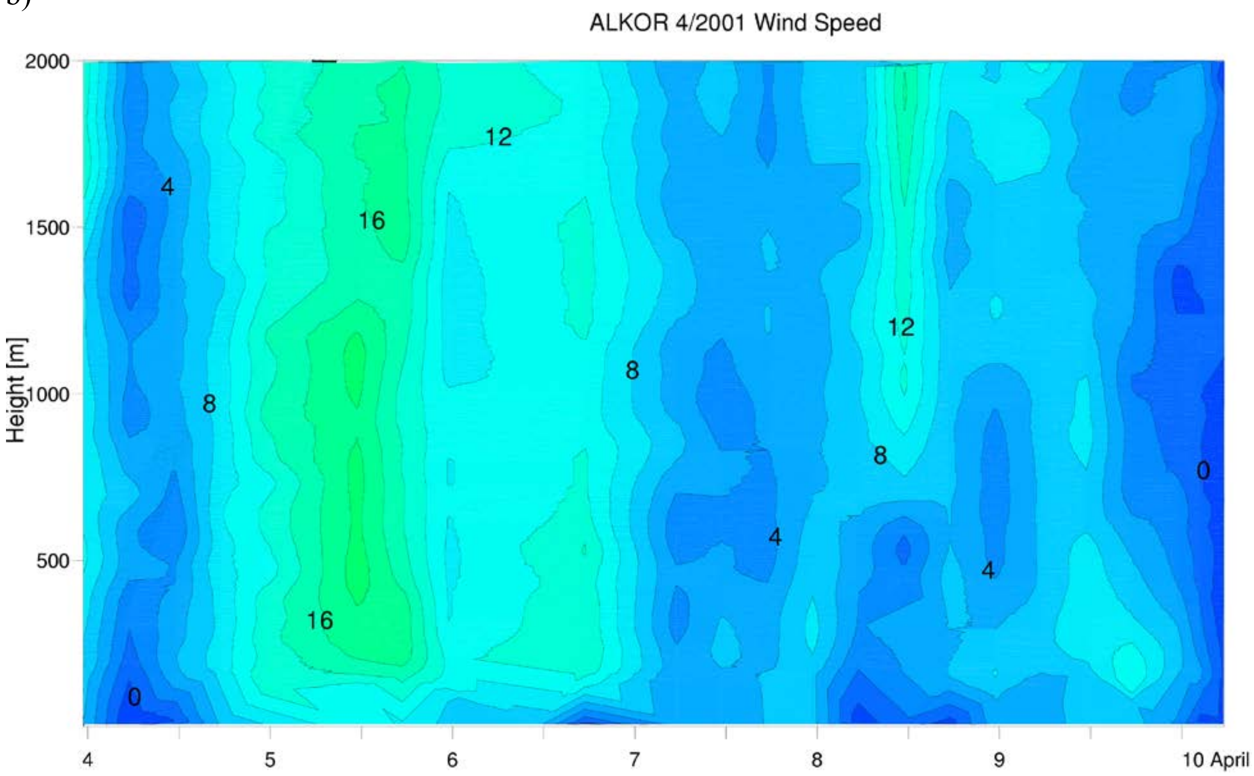


Fig. 5.29: (a) Vertical wind speed profiles between surface and 2 km height as measured by 28 Vaisala radiosondes at RV Alkor during the period 3 April 2001 23.21 UTC to 10 April 2001 05.31 UTC. Tick marks indicate the 10 ms^{-1} value of the running wind speed scale and the launch time.
(b) Time-height cross-section of wind speed based on the 28 radiosoundings presented in (a). Wind speed isoline difference is 2 ms^{-1}

5.6. The cruise Alkor 6/2001

RV Alkor left Kiel harbour on 12 June 2001 10 UTC. It reached the central Baltic Sea (56.02°N, 18.67°E) on 13 June 14 UTC and stayed there until 19 June 02 UTC. The home harbour Kiel was reached again on 20 June 08 UTC. Cruise leader was Dr. Gerd Müller. Michael Offermann was responsible for the meteorological instrumentation. The measurement work was supported by eight students from the Meteorological Institute of the University of Hamburg.

The daily 00 UTC weather maps for the Alkor 6/2001 cruise are given in Appendix A7. The synoptic situation during the cruise was characterized by unstationarity. On 13 and 14 June a low pressure system over Finland affected the area with westerly winds. At the edge of this system a weak disturbance developed and moved from west over the Central Baltic Sea on late 14 June. After its passage a flat high pressure bridge followed from SW on 15 June. On 16 June an edge low developed over the experimental area. Ahead of it easterly wind occurred. After the passage of the occlusion and the entire low, winds turned to SW and the highest air temperature (14°C) of the campaign was observed. Later on, the low filled up north of Gotland and another low formed over Poland which overtook the weather influence at the Alkor station with north/northeasterly winds.

The basic meteorological quantities (p, T, T_{sfc}, RH, FF, DD) measured at Alkor and ship's course and speed are displayed in Fig. 5.30. Water temperature was between 12 and 13°C. The air temperature was close to that. Clear stable stratification in the surface only occurred on 16 June after the occlusion passage. Winds were moderate (7 m s^{-1} on the average). Higher winds occurred only on 13 June under the influence of the Finnish low and on 16 June ahead of the small low in the western Baltic Sea.

The radiation fluxes S↓ and L↓ as well as the cloud base height and the rainfall are presented in Fig. 5.31 . There were relatively often cloudfree conditions. Longer periods with cloud cover only occurred with the low/occlusion event on 16 June and the frontal system of the Poland low on 18 June. The ceilometer shows the decreasing cloud base on 16 June with the occlusion approach. Rainfall at RV Alkor occurred between 09 and 11 UTC. The frontal system of the Poland low on 18 June was accompanied with low-level nimbostratus clouds with bases below 100 m height and continuous rainfall of varying intensity between 09 UTC on 18 June and 05 UTC on 19 June.

The sonic data are displayed in Fig. 5.32 . They are not yet corrected for the ship's motion. The heat flux H is weakly positive, except for the second half of 16 June when the occlusion passed with air from south/southwest being warmer than the water. The preliminary sonic data encourage further working with the data. At first, periods of ship's cruise and periods of air flow from directions other than the front of the ship have to be removed. Further corrections are possible with the data from a pitch and roll tiltmeter and high frequency (1 Hz) pressure data which were also recorded in parallel.

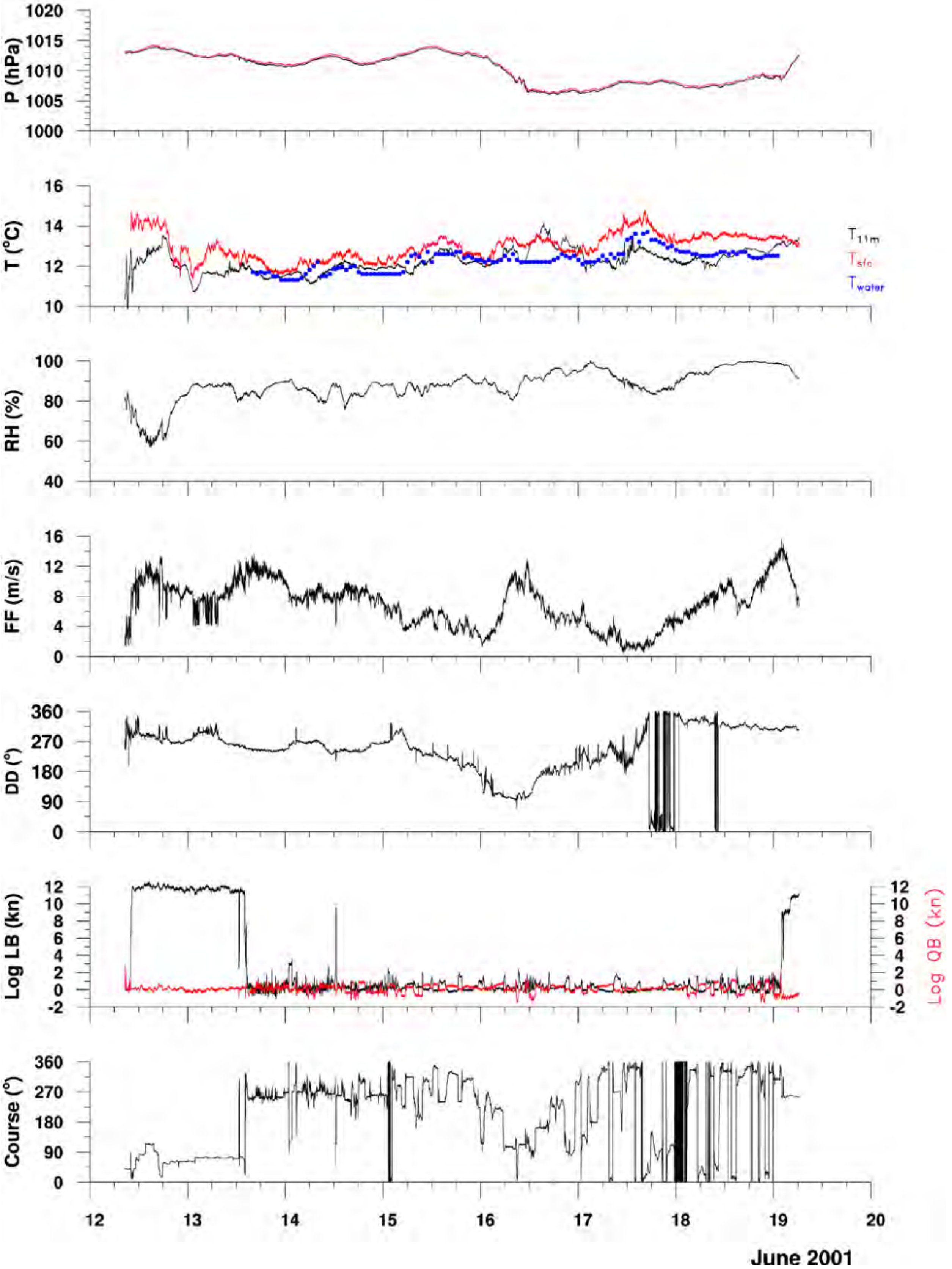


Fig. 5.30: One-minute averages of pressure p (ship's permanent station (black), foremast station (red)), air temperature T, infrared surface temperature (KT-19), and bucket temperature, relative humidity RH, wind speed FF, wind direction DD, ship's velocity component in along-ship (Log LB) and cross-ship (Log QB) direction, and ship's heading (cruise) measured at RV Alkor from 12 to 19 June 2001. Long tick marks indicate 00 UTC of the respective day.

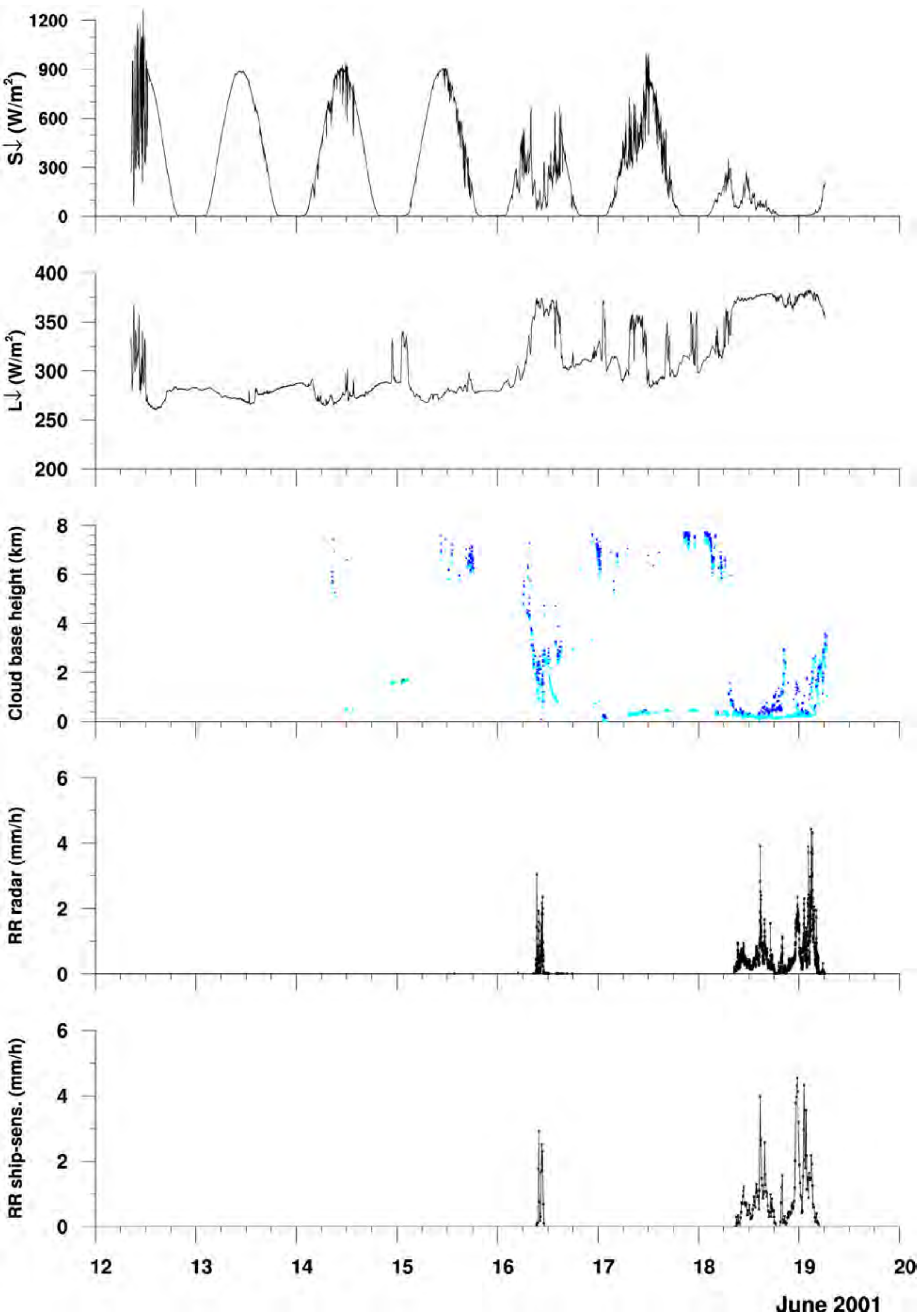


Fig. 5.31: Fig. 5.13: Time series of downwelling shortwave (S↓) and longwave (L↓) radiation, cloud base height, and rain rate (radar and gauge) measured at RV Alkor from 12 to 19 June 2001.

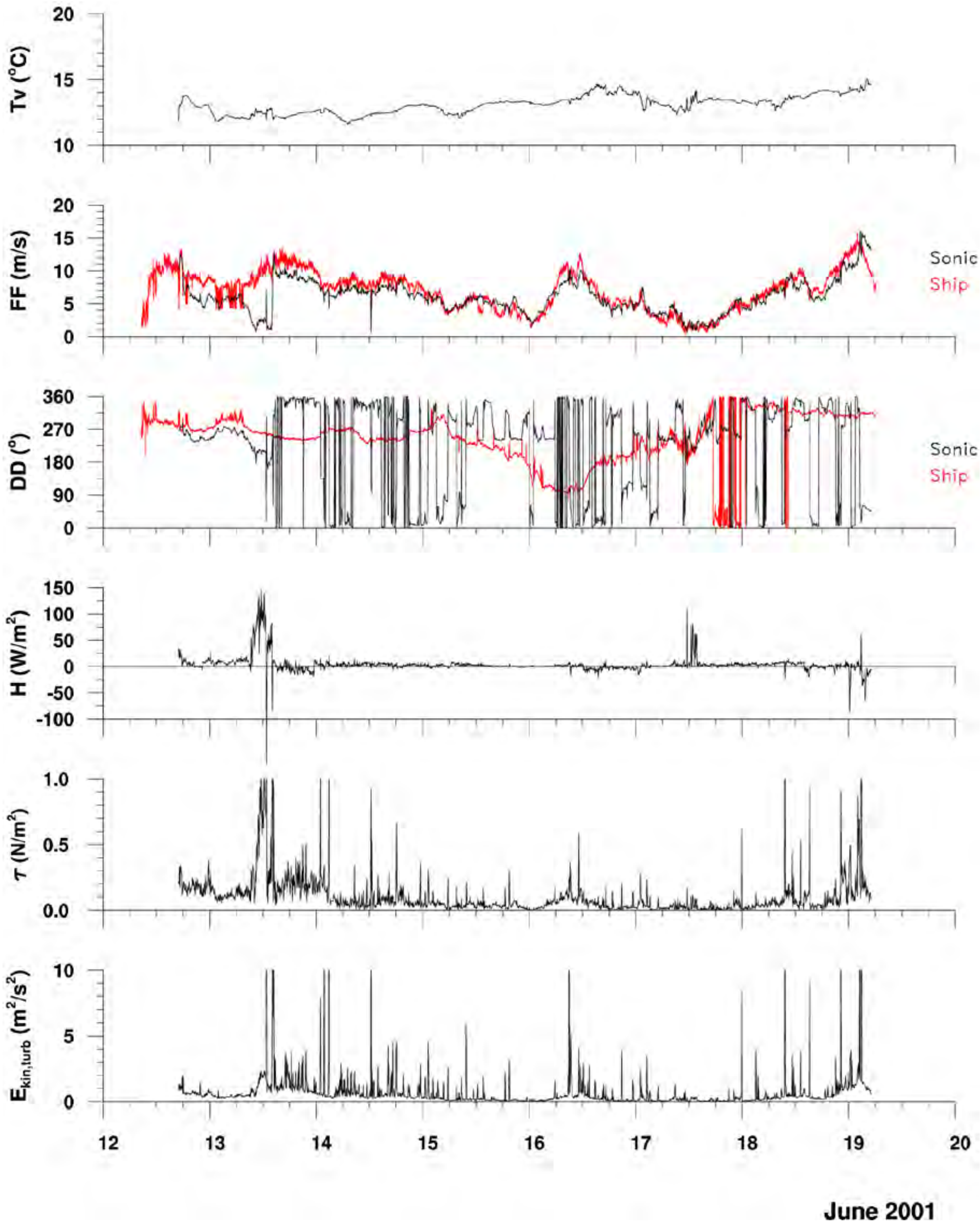


Fig. 5.32: Time series of 5 minute averages of uncorrected (for ship's motion) sonic measurements at the foremast of RV Alkor from 12 to 19 June 2001: virtual temperature T_V, wind speed FF, wind direction DD, sensible heat flux H, momentum flux τ, and turbulent kinetic energy $E_{kin,turb}$.

In total, 40 radiosondes were launched every 3 hours during the Alkor 6/2001 cruise. The temperature profiles for the height range 0-14 km are presented in Fig. 5.33 . The tropopause level varied between 9 and 11 km. The atmosphere between 2 km height and the tropopause level did not show up remarkable inversion layers. Inversions only occurred in the layer below 2 km height. This layer is shown in more detail in Figs. 5.34 and 5.35 for the temperature and wind profiles, respectively. The boundary layer structure was very variable in the central Baltic Sea. An elevated shallow inversion with bases at 200 m was present in the night from 13 to 14 June on the back side of the Finnish low. The weak low pressure disturbance on 14 June advected warm air into the area; the base of this layer formed an inversion which lowered in the course of the time from 1000 m (12 UTC) to 150 m (24 UTC). The warm-air advection inversion disappeared on the back side of the disturbance where the temperature stratification was close to neutral. Ahead of the northeastward moving low over the western Baltic Sea and the occlusion, again warm-air advection formed a slowly downward coming low-level inversion on 16 June between 09 and 24 UTC. This inversion immediately disappeared when the air flow turned on the back side to northerly directions. Now an unstably stratified shallow mixed layer of a few hundred meters was established which was capped by an inversion around 400-500 m height. At the end of the campaign during the rain period caused by the low over Poland the inversion structure disappeared in the boundary layer and was replaced by a weakly stable stratification in the lowest 500 m.

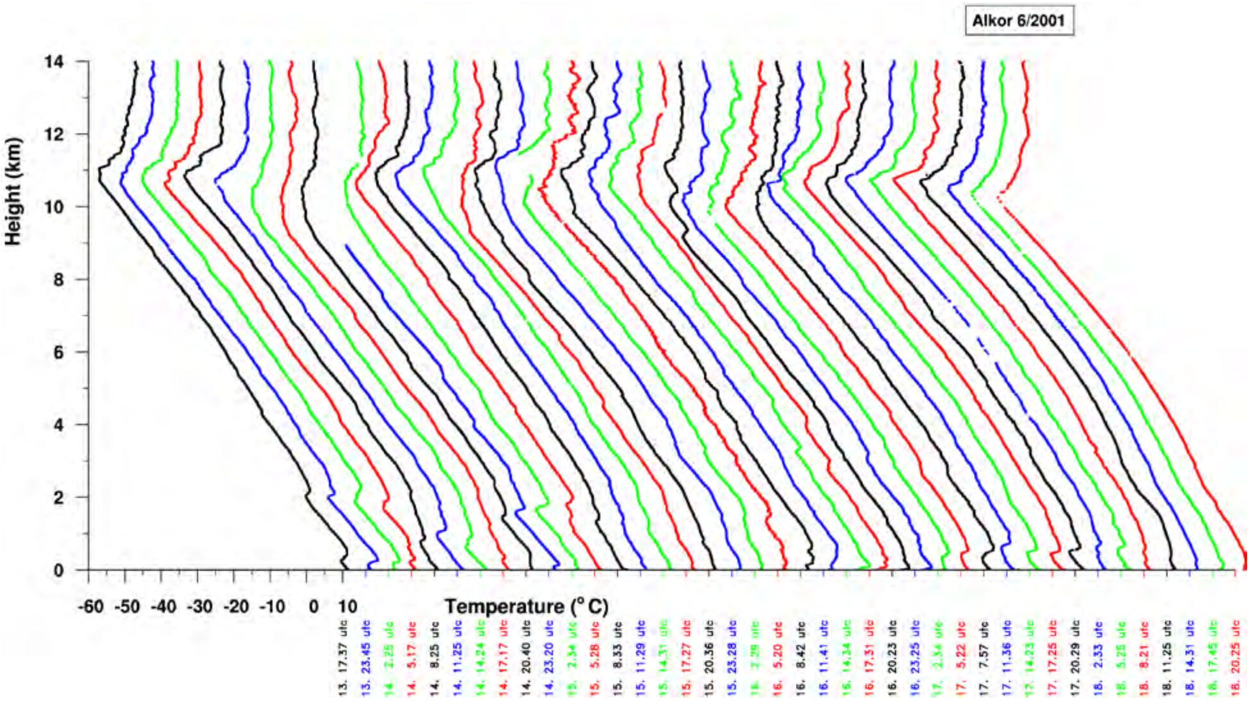
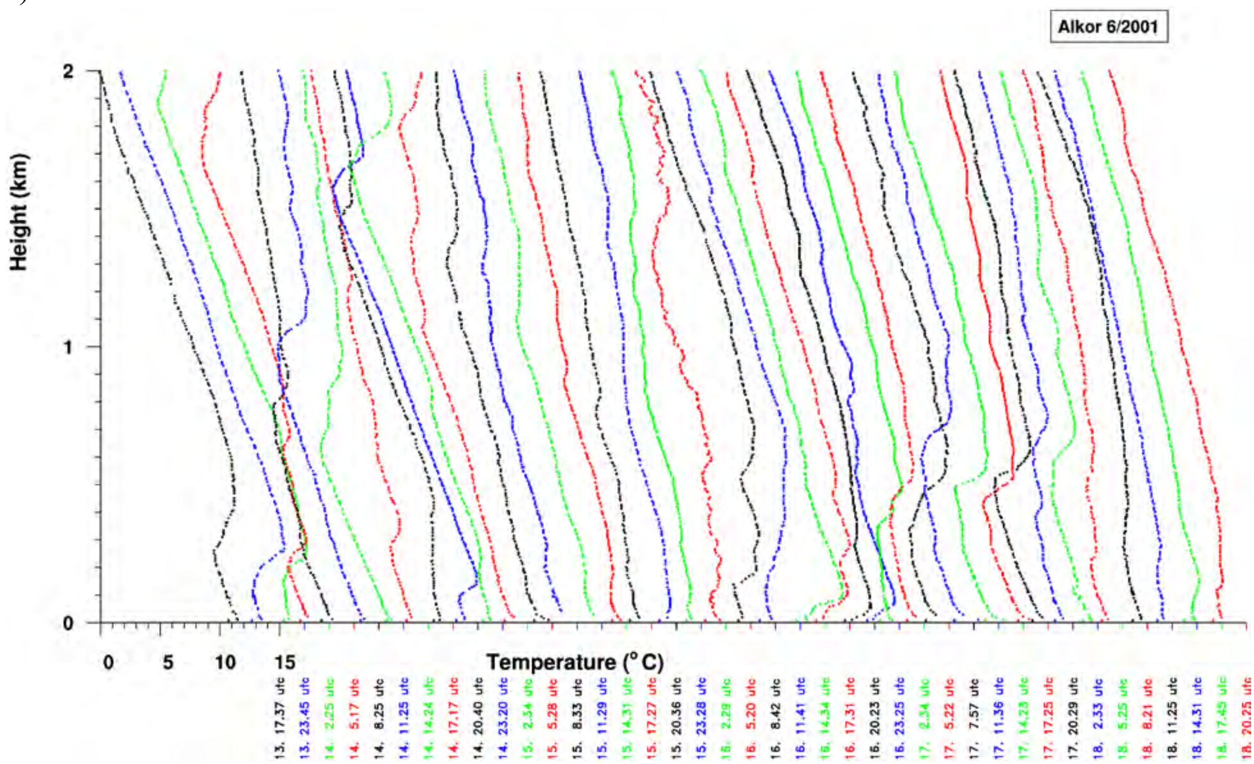


Fig. 5.33: Vertical temperature profiles between surface and 14 km height as measured by 40 Vaisala radiosondes at RV Alkor during the period 13 June 2001 17.37 UTC to 18 June 2001 20.25 UTC. Tick marks at the abscissa indicate the 10°C value of the running temperature scale and the launch time.

a)



b)

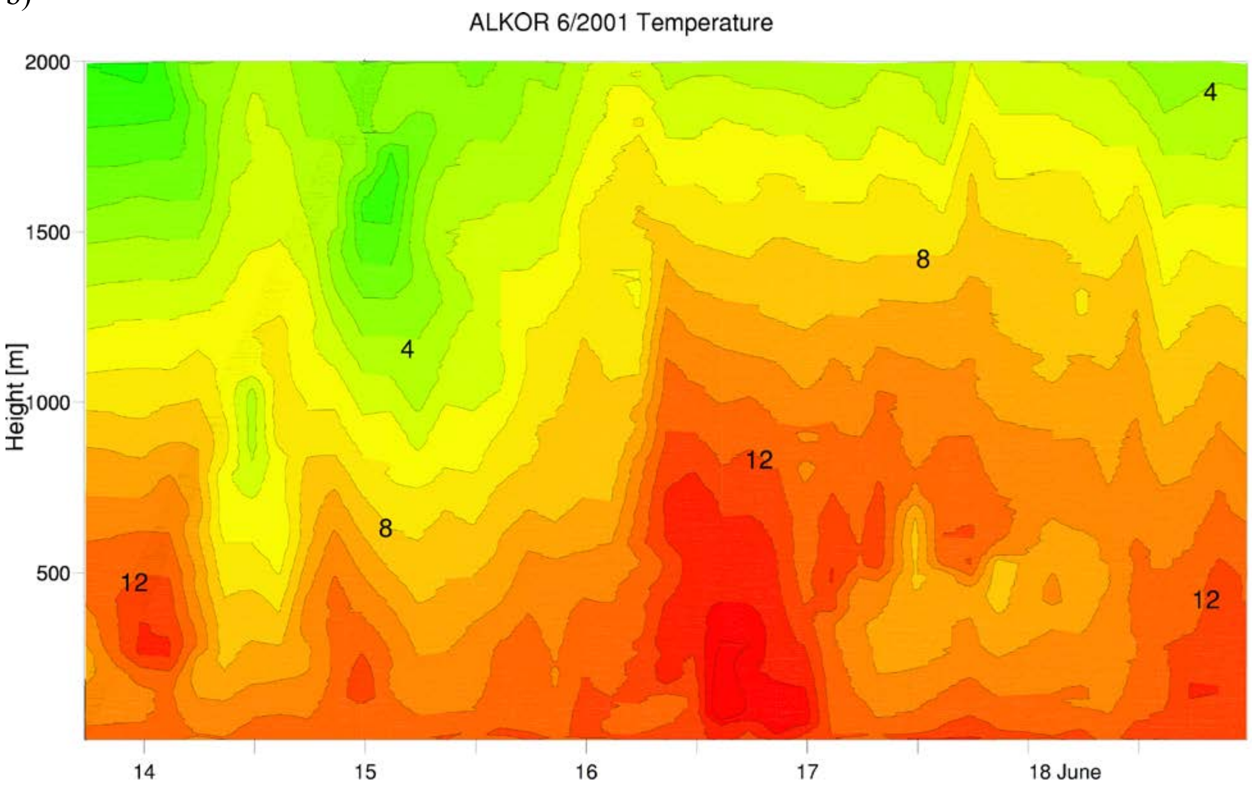
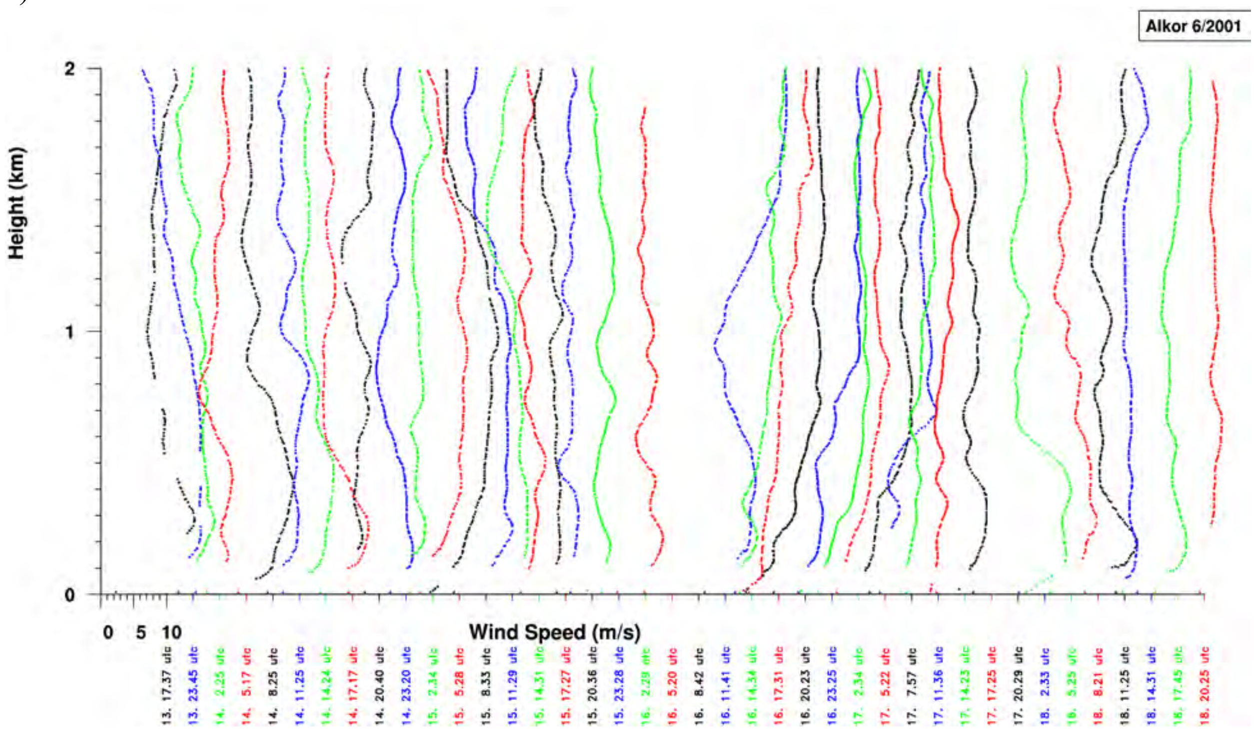


Fig. 5.34: (a) Vertical temperature profiles between surface and 2 km height as measured by 40 Vaisala radiosondes at RV Alkor during the period 13 June 2001 17.37 UTC to 18 June 2001 20.25 UTC. Tick marks at the abscissa indicate the 15°C value of the running temperature scale and the launch time.
(b) Time-height cross section of temperature based on the 40 radiosoundings presented in (a). Temperature isoline difference is 1 K.

a)



b)

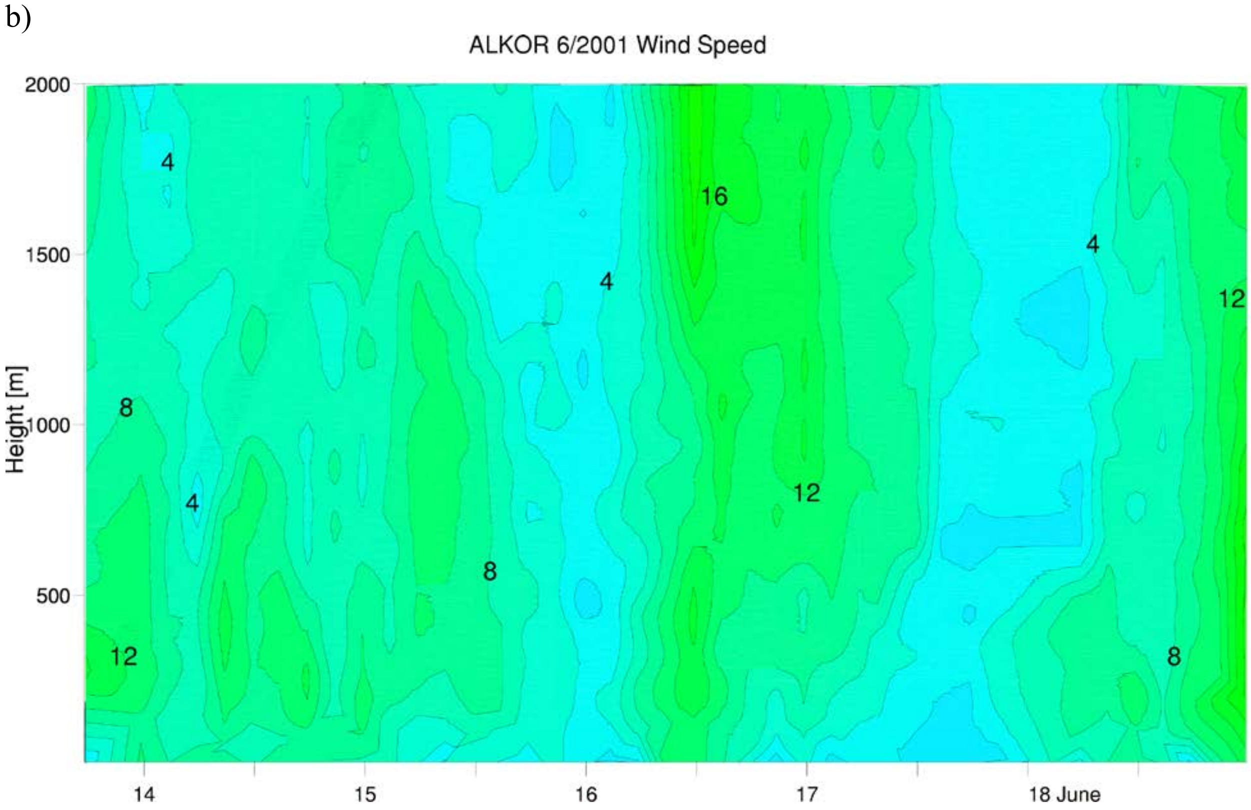


Fig. 5.35: : (a) Vertical wind speed profiles between surface and 2 km height as measured by 40 Vaisala radiosondes at RV Alkor during the period 13 June 2001 17.37 UTC to 18 June 2001 20.25 UTC. Tick marks indicate the 15 ms^{-1} value of the running wind speed scale and the launch time.

(b) Time-height cross-section of wind speed based on the 40 radiosoundings presented in (a). Wind speed isoline difference is 2 ms^{-1}

5.7. The cruise Alkor 10/2001

RV Alkor left Kiel harbour on 29 October 2001 12 UTC. It reached the central Baltic Sea (56.02°N, 18.67°E) on 30 October 16.30 UTC and stayed there until 5 November 18 UTC. The ship looked with its bow always into the wind and operated always within a radius of three nautical miles from the center point. The home harbour Kiel was reached on 7 November 10 UTC. Cruise leader was Dr. Gerd Müller. Michael Offermann was responsible for the meteorological instrumentation. The meteorological observations were headed by Amélie Kirchgäßner supported by eight students of the Meteorological Institute of the University of Hamburg.

The daily 00 UTC weather maps for the Alkor 10/2001 cruise are given in Appendix A8. The synoptic situation was characterized by a strong cyclone activity over Scandinavia and the Norwegian Sea. Nearly every second day a new cyclone influenced or passed the experimental area. The first cyclone with its frontal system crossed with rain in the morning hours on 30 October when RV Alkor was still steaming to its destination. On 31 October, the warm front of another eastward morning cyclone passed the ship in the early morning hours. This cyclone deepened to a gale low. Its cold front and trough crossed the experimental area in the afternoon and late evening. Winds of up to 28 m s^{-1} were measured (Fig. 5.36) leading to waves of up to 8 m height. The gale low was followed on 1 and 2 November by a rapidly intensifiying high pressure ridge entending from a high over the British Channel area. On 3 November the fronts of a new (third) cyclone over the Greenland Sea reached the Alkor position. The cyclone moved eastward over North-Scandinavia on 3 and 4 November. On its south-side a disturbance developed into an edge low (fourth low) which moved over South-Scandinavia on 3/4 November. The cold front and the trough crossed RV Alkor in the morning hours of 5 November. This was followed on 6 November by a flat transient high pressure zone.

The basic meteorological quantities (p, T, T_{sfc}, RH, FF, DD) measured at RV Alkor and ship's speed and course are presented in Fig. 5.36. Water surface temperature was between 11 and 9°C and decreased in the course of the time. The pressure curve reflects clearly the passage of the four lows and their fronts and troughs. The average wind speed during the Alkor 10/2001 cruise was 15 m s^{-1}; the wind was never below 7 m s^{-1}. The maximum wind speeds were reached during the passages of the first, second, and fourth low. The third low on 3 November passed too far north to result into a clear wind peak. Compared to the preceding Alkor cruises the air temperature varied a lot, between 12 and 5°C. The highest temperatures were measured ahead of the gale low in southwesterly air flow on 31 October so that the air was up to 2 K warmer than the water temperature. On the rear side of the gale low on 1 November and with further wind turning to northerly directions caused by the high pressure ridge on 2 November the coldest temperatures were observed with unstable air-sea temperature differences of up to –4 K. More or less neutral stratification occurred for about 2.5 days lasting from the evening of 2 November until the very early morning on 5 November. The edge low on 5 November passed closely north of RV Alkor and caused a rapid (within one hour) temperature decrease of 4 K.

The radiation fluxes S↓ and L↓ as well as the cloud base height and the rainfall are presented in Fig. 5.37. In spite of the high cyclone activity the shortwave radiation S↓ reached the maximum possible values every day. Most of the fronts and associated cloud fields passed during nighttime as can be concluded from L↓ and from the ceilometer measurements of cloud base. On 31 October at 22.30 UTC the Eppley sensor (for L↓ measurements) broke off from the foremast of the ship during the period of the highest wind speeds around 28 m s^{-1} (it should be mentioned again that these values represent 1 min-averages and not the individual gusts). Fortunately, the Eppley fell on the foredeck, but due to the ongoing high sea it could not be saved and remounted earlier than on 2 November 14 UTC. The rain-radar was a very useful sensor during this Alkor

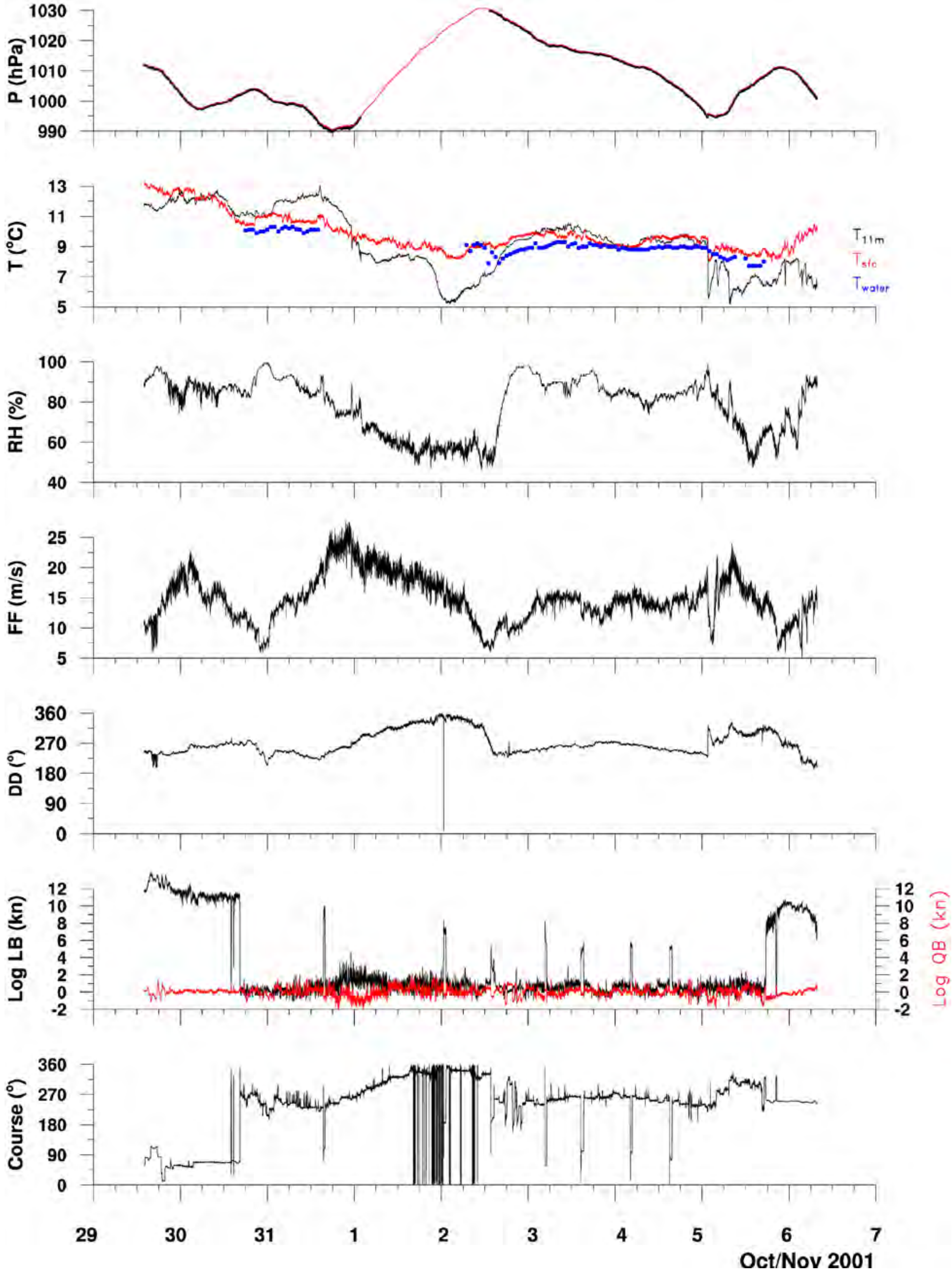


Fig. 5.36: : One-minute averages of pressure p (ship's permanent station (black), foremast station (red)), air temperature T, infrared surface temperature (KT-19), and bucket temperature, relative humidity RH, wind speed FF, wind direction DD, ship's velocity component in along-ship (Log LB) and cross-ship (Log QB) direction, and ship's heading (cruise) measured at RV Alkor from 29 October to 6 November 2001. Long tick marks indicate 00 UTC of the respective day.

cruise with the continuously high winds. Rain was connected with front passages and there were also some showers on the rear side of the first low (30 October) and fourth low (5 November).

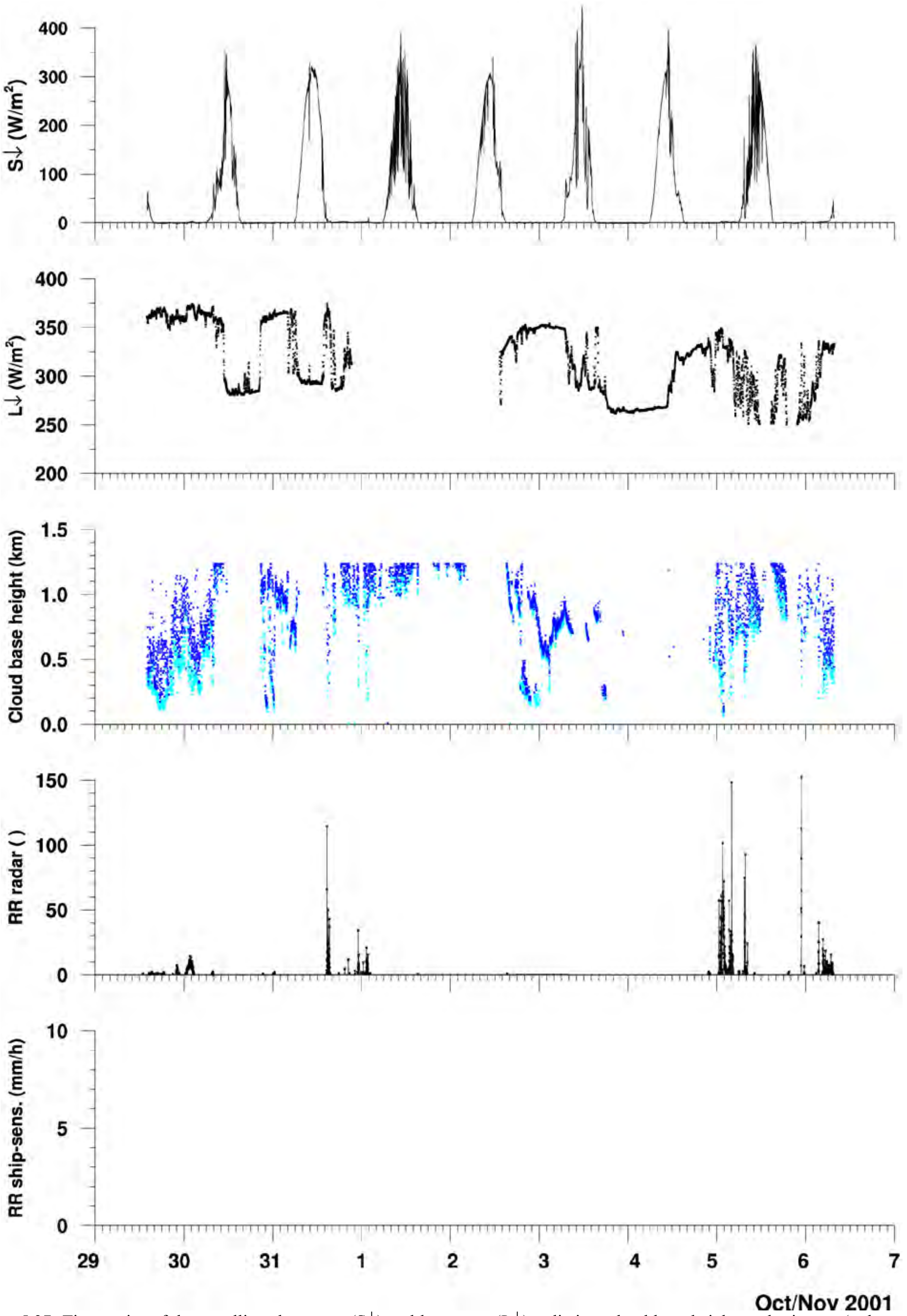


Fig. 5.37: Time series of downwelling shortwave (S↓) and longwave (L↓) radiation, cloud base height, and rain rate (radar and gauge) measured at RV Alkor from 29 October to 6 November 2001.

The sonic measurements of wind speed FF, wind direction, virtual temperature T_v, sensible heat flux H, momentum flux τ, and turbulent kinetic energy $K_{kin,\ turb}$ are displayed in Fig. 5.38. It is mentioned again, that these data are not corrected for the ship's motion. Nevertheless, the preliminary data encourage further investigations. The sensible heat flux H follows the above-mentioned air-sea temperature difference by and large: H is negative (downward) during the warm-air advection period ahead of the gale low on 31 October and it is extremely positive (upward) after the passage of the gale low and the following pressure ridge from late 31 October to early 2 November and is again clearly positive on the rear side of the edge low on 5 November.

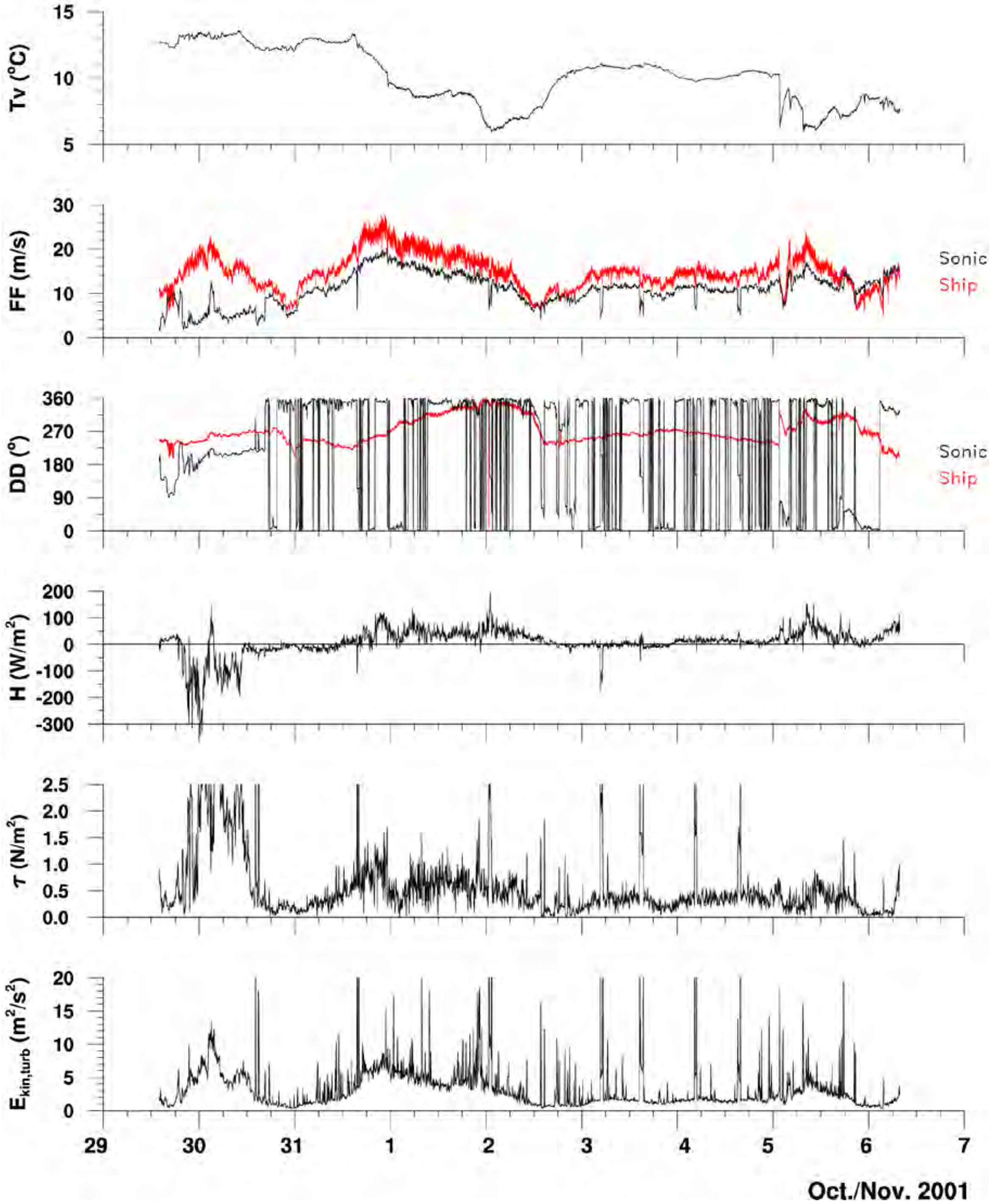


Fig. 5.38: Time series of 5 minute averages of uncorrected (for ship's motion) sonic measurements at the foremast of RV Alkor from 29 October to 6 November 2001: virtual temperature T_V, wind speed FF, wind direction DD, sensible heat flux H, momentum flux τ, and turbulent kinetic energy $E_{kin,turb}$.

In total, 40 radiosondes were successfully launched at 3-hourly intervals. Due to the strong strom, no radiosonde ascents could be made during the period 31 October 18 UTC to 1 November 21 UTC and on 5 November 06 UTC. The temperature profiles for the height range 0-14 km are presented in Fig. 5.39. The tropopause level varied largely during the Alkor 10/2001 cruise. The highest tropopause levels were measured on 2 November in the high pressure ridge and the lowest levels on 5 November after the passage of the edge low. The temperature and wind structure in the lowest 2 km and, thus, boundary layer are shown in Figs. 5.40 and 5.41, respectively. Surface-based inversions, as they were often observed during the summer and spring cruises of RV Alkor, were totally absent during this cruise. During the periods of warm air advection stable surface-based stratification was observed in the boundary layer, as for example on 31 October ahead of the gale low and on early 3 November connected with the passing warm front of the North-Scandinavian low. In the surface-based stable layers low-level jets were embedded. The maximum winds occurred at levels between 200 and 400 m. A GPS wind measurement gap below 100 m occurred in one half of the radiosondes. On the rear side of the passing lows deep mixed layers occurred. The deepest one of 1600 m was observed on 2 November 00 UTC in the strong high pressure ridge under strong northerly winds and –4 K air-sea temperature difference. This was also the period with the highest sensible heat fluxes. Deep well-mixed layers were also observed after the passage of the edge low on 5 November. strong elevated boundary layer inversions with temperature increases of up to 6 K in the inversion were observed in the night 2/3 November during the period of the removing high pressure ridge and approaching warm front.

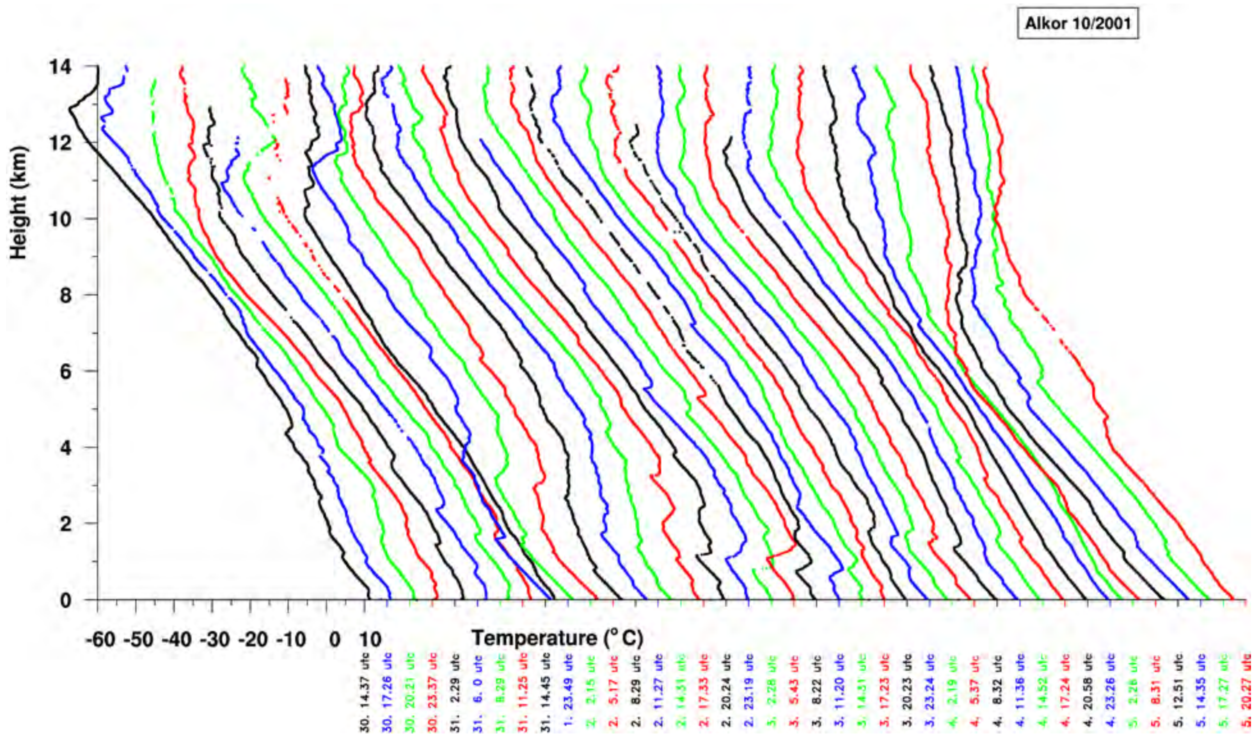


Fig. 5.39: Vertical temperature profiles between surface and 14 km height as measured by 40 Vaisala radiosondes at RV Alkor during the period 30 October 2001 14.37 UTC to 5 November 2001 20.27 UTC. Tick marks at the abscissa indicate the 10°C value of the running temperature scale and the launch time.

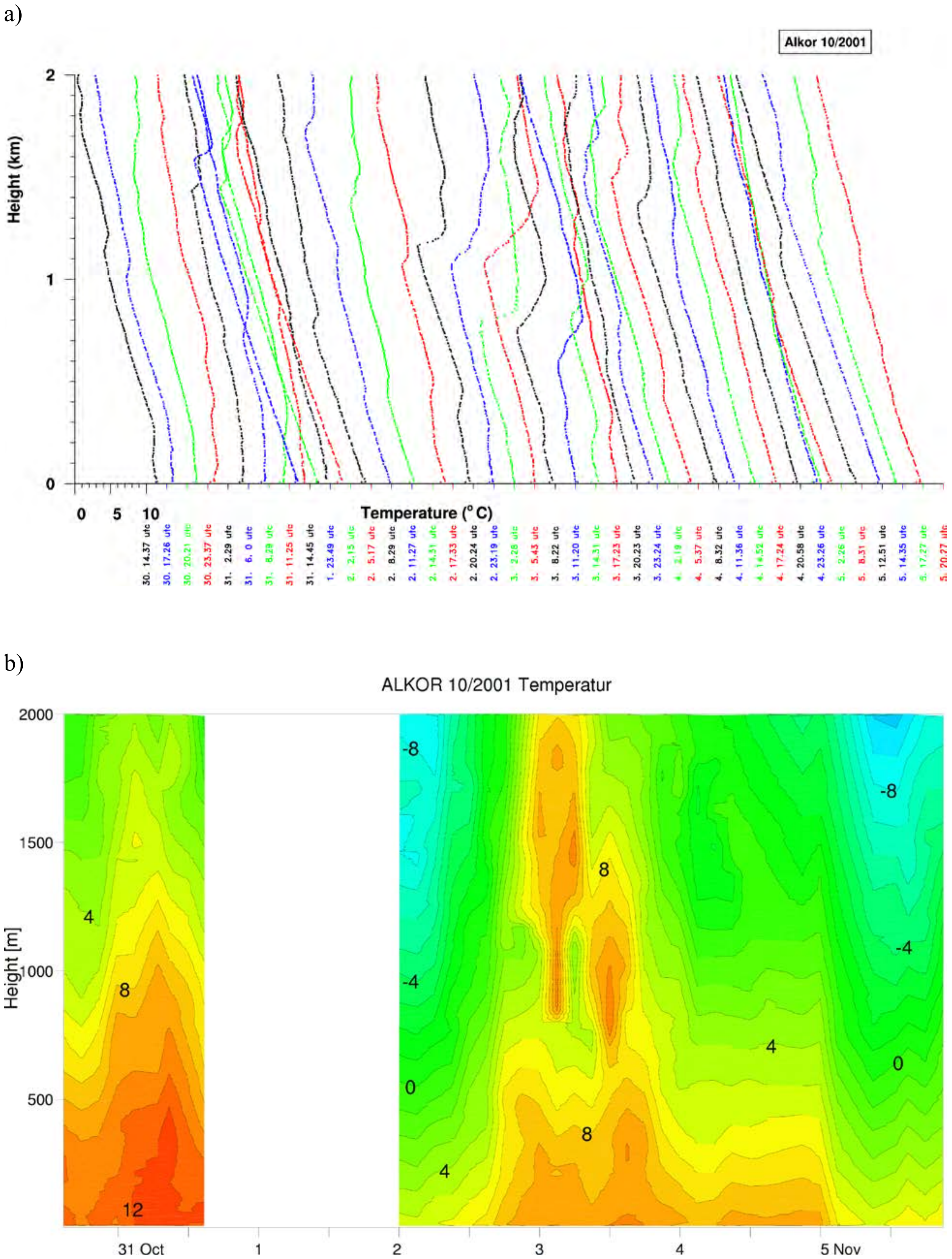
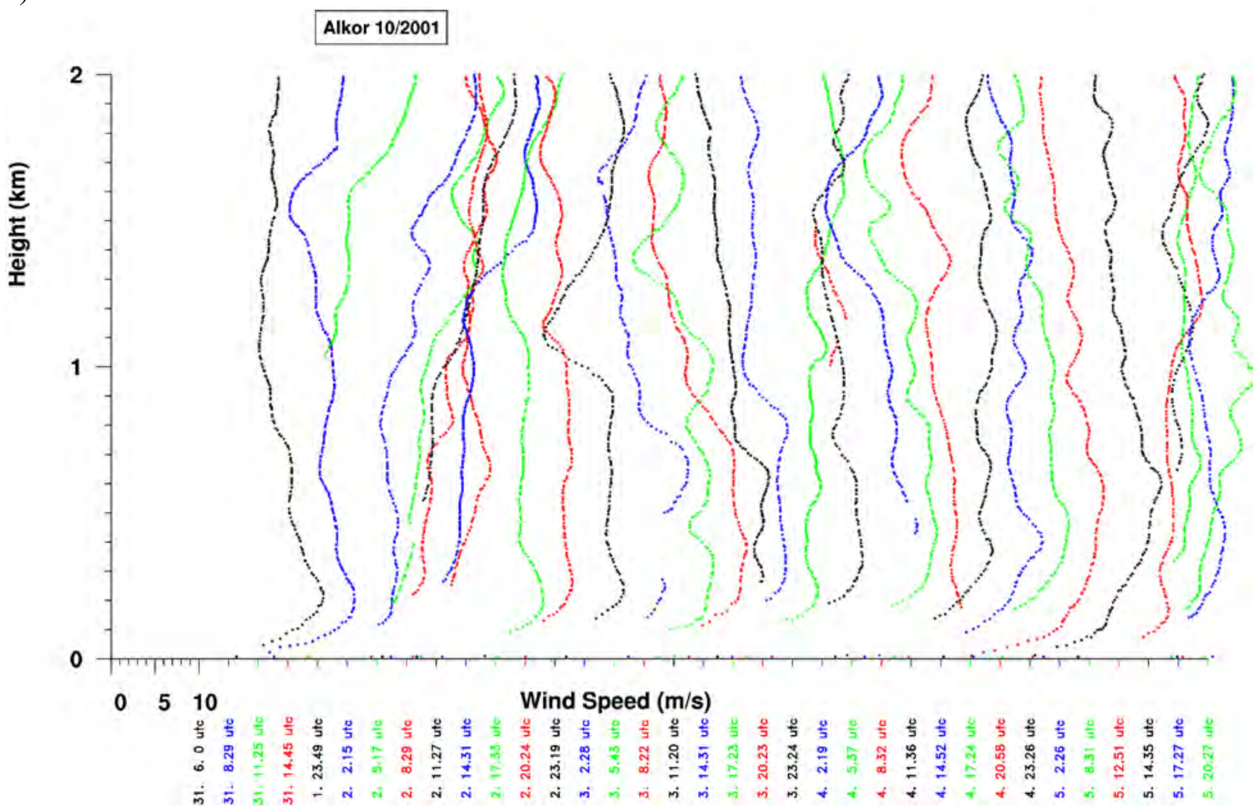


Fig. 5.40: (a) Vertical temperature profiles between surface and 2 km height as measured by 40 Vaisala radiosondes at RV Alkor during the period 30 October 2001 14.37 UTC to 5 November 2001 20.27 UTC. Tick marks at the abscissa indicate the 10°C value of the running temperature scale and the launch time.
(b) Time-height cross section of temperature based on the 40 radiosoundings presented in (a). Temperature isoline difference is 1 K.

a)



b)

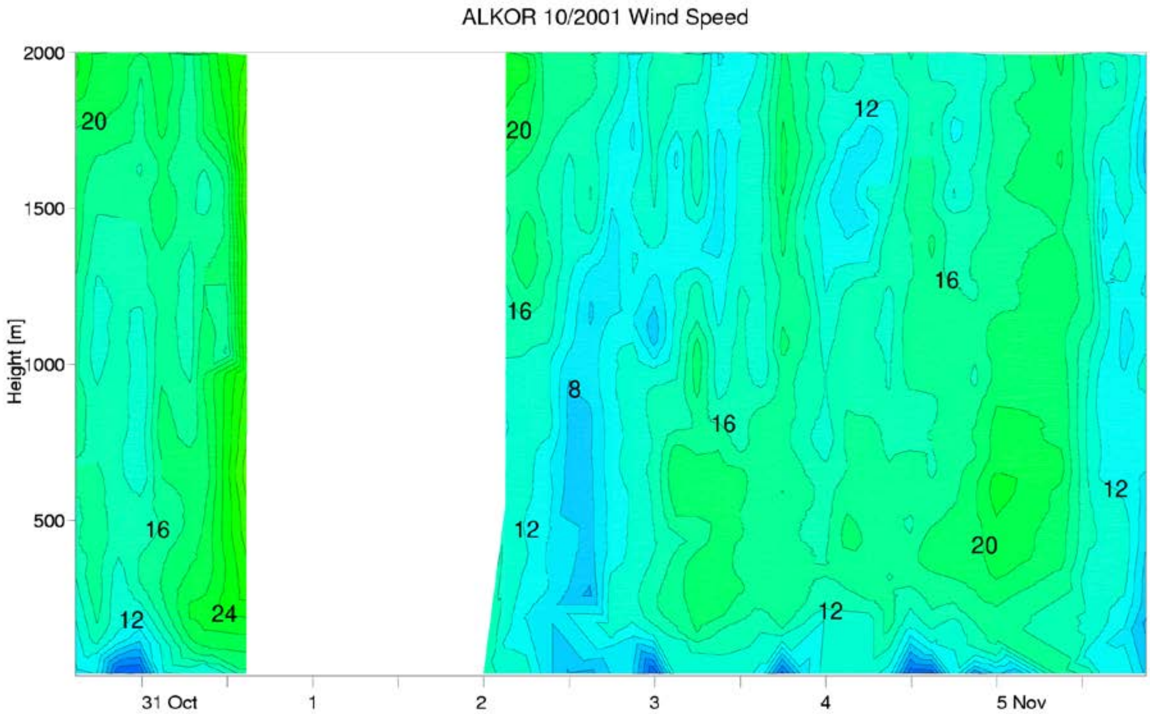


Fig. 5.41: (a) Vertical wind speed profiles between surface and 2 km height as measured by 40 Vaisala radiosondes at RV Alkor during the period 30 October 2001 14.37 UTC to 5 November 2001 20.27 UTC. Tick marks indicate the 10 ms^{-1} value of the running wind speed scale and the launch time.
(b) Time-height cross-section of wind speed based on the 40 radiosoundings presented in (a). Wind speed isoline difference is 2 ms^{-}

6. Concluding remarks

A comprehensive meteorological data set could be sampled during eight field experiments over the Baltic Sea at places where otherwise no data are available. The data were measured over sea ice and open water in the Bay of Bothnia and the Central Baltic Sea, respectively, systematically in all four seasons in the time period 1998 to 2001. As measurement platforms research ships, research aircraft, surface stations and radiosonde stations were applied. According to the platforms the measurements basically followed two strategies:

(a) measurements at a fixed place over a long time period
(b) measurements in a mesoscale three-dimensional box at special times

Following strategy (a) the vertical structure in the atmosphere from the surface up the 15 km height could be sampled on about 75 days distributed over all four seasons. Following strategy (b), 16 times the three-dimensional atmosphere boundary layer structure could be documented.

The complete data set of all eight field campaigns is archived at the Meteorological Institute of the University of Hamburg and at the Finnish Institute of Marine Research in Helsinki. So far only a few scientific evaluations were made based on the data of the BASIS 1998 experiment. We mention here only some publications: Launiainen et al. (2001), Brümmer et al. (2002), Vihma and Brümmer (2002), Schröder et al. (2003).

Although the data cover a wide height range, they focus on the atmospheric boundary layer including the most relevant properties of the underlying surface (surface temperature, sea ice coverage, and albedo). Concerning the atmospheric boundary layer, the following quantities which give a rather complete description of the boundary layer were measured:

- surface radiation budget
- surface energy budget
- mean vertical structure of temperature, humidity, wind speed and direction
- turbulent fluxes of momentum, sensible and latent heat (at the surface and at different levels in the boundary layer)
- cloud base and amount
- precipitation.

Looking at the meteorological conditions covered by the data set, the relatively high amount of situations with stable stratification in the boundary layer is striking both over open water and sea ice. Over sea ice, the stable stratification was even the dominating stratification type caused by warm-air advection and radiational cooling. The latter process of generating a stable boundary layer does not occur over the open sea. The stable stratification was accompanied with either surface-based or low-level inversions and mostly with a low-level jet at the inversion. This can result in very sensitive conditions which may just lead or lead not to turbulence generation. It is known that atmospheric models still face problems concerning the realistic simulation of the stable boundary layer.

Thus, in the forthcoming validation of the coupled model system BALTIMOS, special attention will be given to the validation in situations of stable stratification; i.e. in particular the height and strength of the inversion and the low-level jet and the turbulent vertical fluxes of momentum and heat.

A further point of special attention in the future BALTIMOS validation work will be the comparison of modelled and observed moisture structure and processes. This covers the mean vertical moisture structure, the turbulent moisture flux, cloud base and amount, and precipitation. It will be interesting to separate these comparisons with respect to frontal passages and non-frontal situations, because the quality of models in forecasting precipitation under these two different synoptic conditions is still under discussion.

The data set gathered during the eight field campaigns and presented here, may also be of interest for other research projects and for validation of other models inside or outside the BALTEX research programme community. In such a case, we encourage potential users to contact the leading author: Prof. Burghard Brümmer, Meteorological Institute, University of Hamburg, Bundesstrasse 55, D-20146 Hamburg, Germany (Tel.: 0049-40-42838-5083, Fax: 0049-40-42838-5452 or E-Mail: bruemmer@dkrz.de).

References:

BALTEX, 1997: The main BALTEX experiment 1999-2001: BRIDGE Strategic Plan, International BALTEX Secretariat, No 9, Geesthacht, Germany, October 1997, 78 pp.

Brümmer, B., D. Schröder, J. Launiainen, T. Vihma, A. Smedman, and M. Magnusson, 2002: Temporal and spatial variability of surface fluxes over the ice edge zone in the northern Baltic Sea. J. Geophys. Res. 107, No. C8, 10.1029/2001JC00884, 2002.

Cressman, G.P., 1959: An operational objective analysis system. Mon. Weather Rev., 87, 367-374.

Launiainen, J. (Ed.), 1999: BALTEX-BASIS: Data Report 1998. International BALTEX Secretariat, No. 14, Geesthacht, Germany March 1999, 95 pp.

Launiainen, J. and T. Vihma (Eds.), 2001: BALTEX-BASIS: Final Report. International BALTEX Secretariat, No. 19, May 2001, 219 pp.

Launiainen, J., B. Cheng, J. Uotila, and T. Vihma, 2001: Turbulent surface fluxes and air-ice coupling in the Baltic Air-Sea-Ice Study (BASIS). Annals of Glaciology, 33, 237-242.

Schröder, D., T. Vihma , B. Brümmer, and A. Kerber, 2003: On the parameterization of turbulent surface fluxes over heterogeneous sea ice surfaces. J. Geophys. Res. (Oceans), in print.

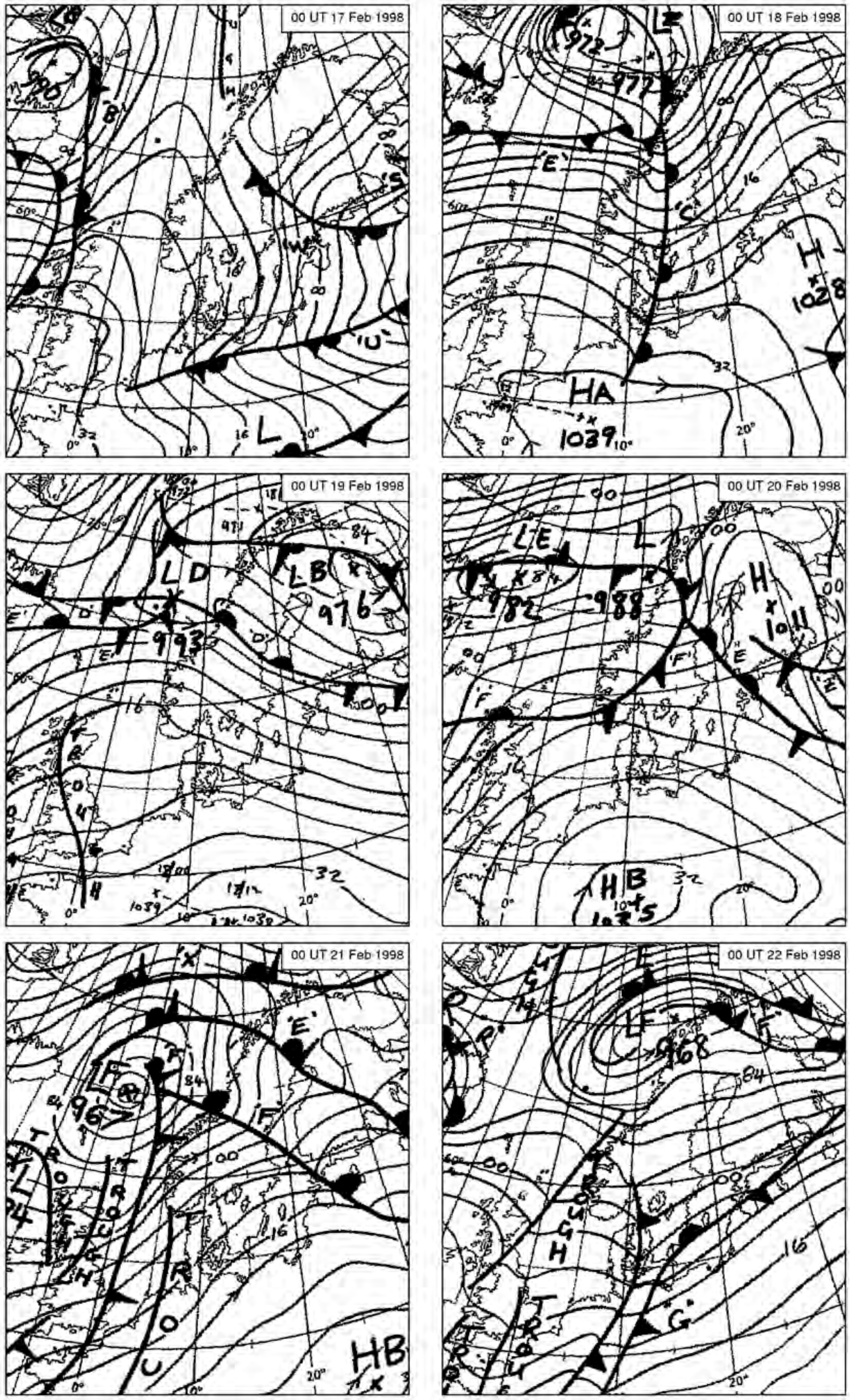
Vihma, T., and B. Brümmer, 2002: Observations and modelling of the on-ice and off-ice air flow over the northern Baltic Sea. Bound. Layer Meteorol., 103, 1-27.

Acknowledgements

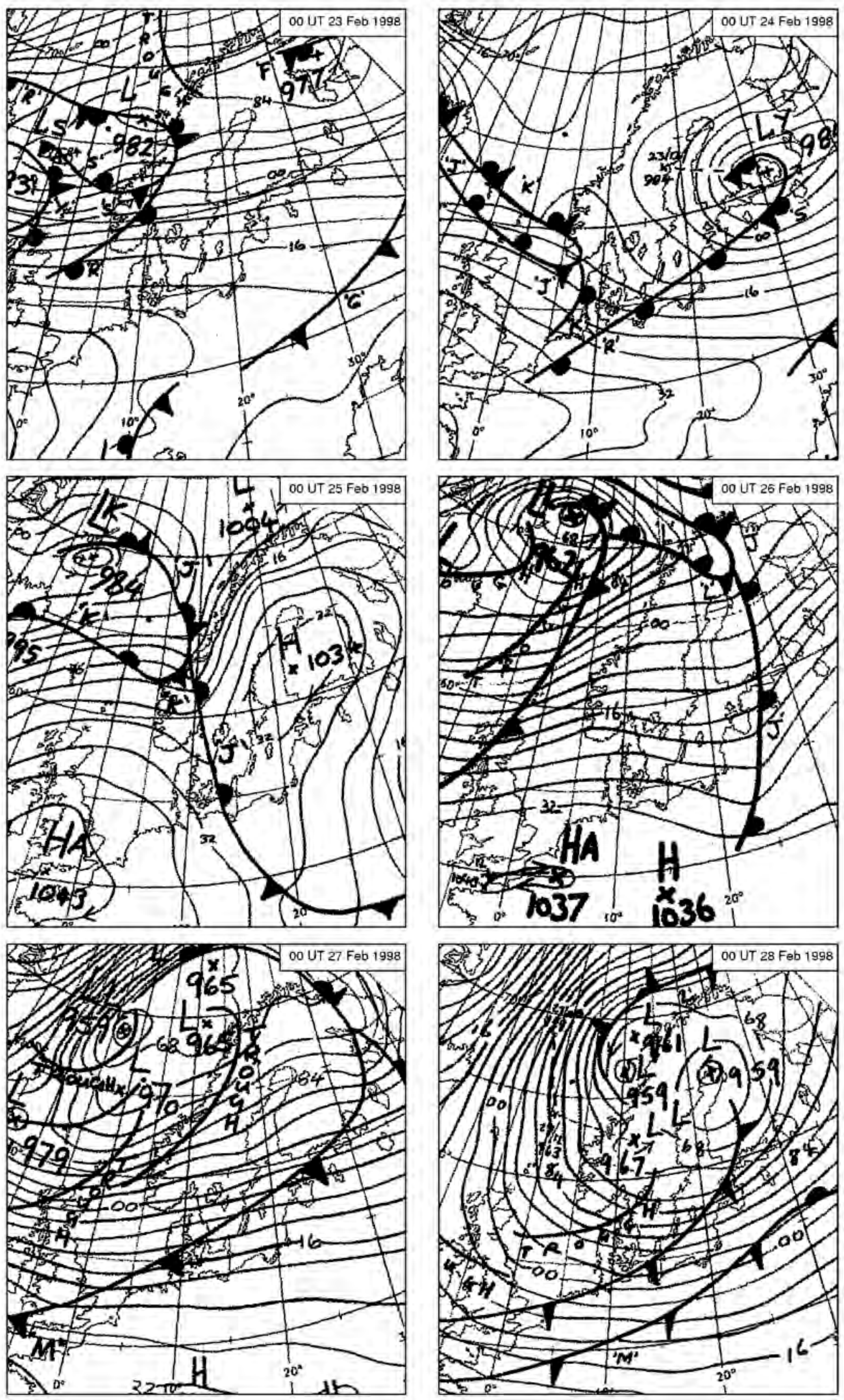
We particularly thank the crews and technicians of the research vessels Aranda (Helsinki) and Alkor (Kiel) and of the research aircraft Falcon-20 (Oberpfaffenhofen) and DO-128 (Braunschweig) for their great engagement. We are grateful to Björn Affeld for preparing the figures with the DO-128 research aircraft results and to Sabine Bartols for typing the manuscript and making the figure layout.

We thank the EU Commission Bruxelles (Contract MAST3-CT97-0117), the Ministry for Education and Research, BMBF, Germany (Grant: BALTIMOS 01LD0027), the Finnish Institute of Marine Research, FIMR, Helsinki, and the University of Hamburg for their financial support of the experimental field work.

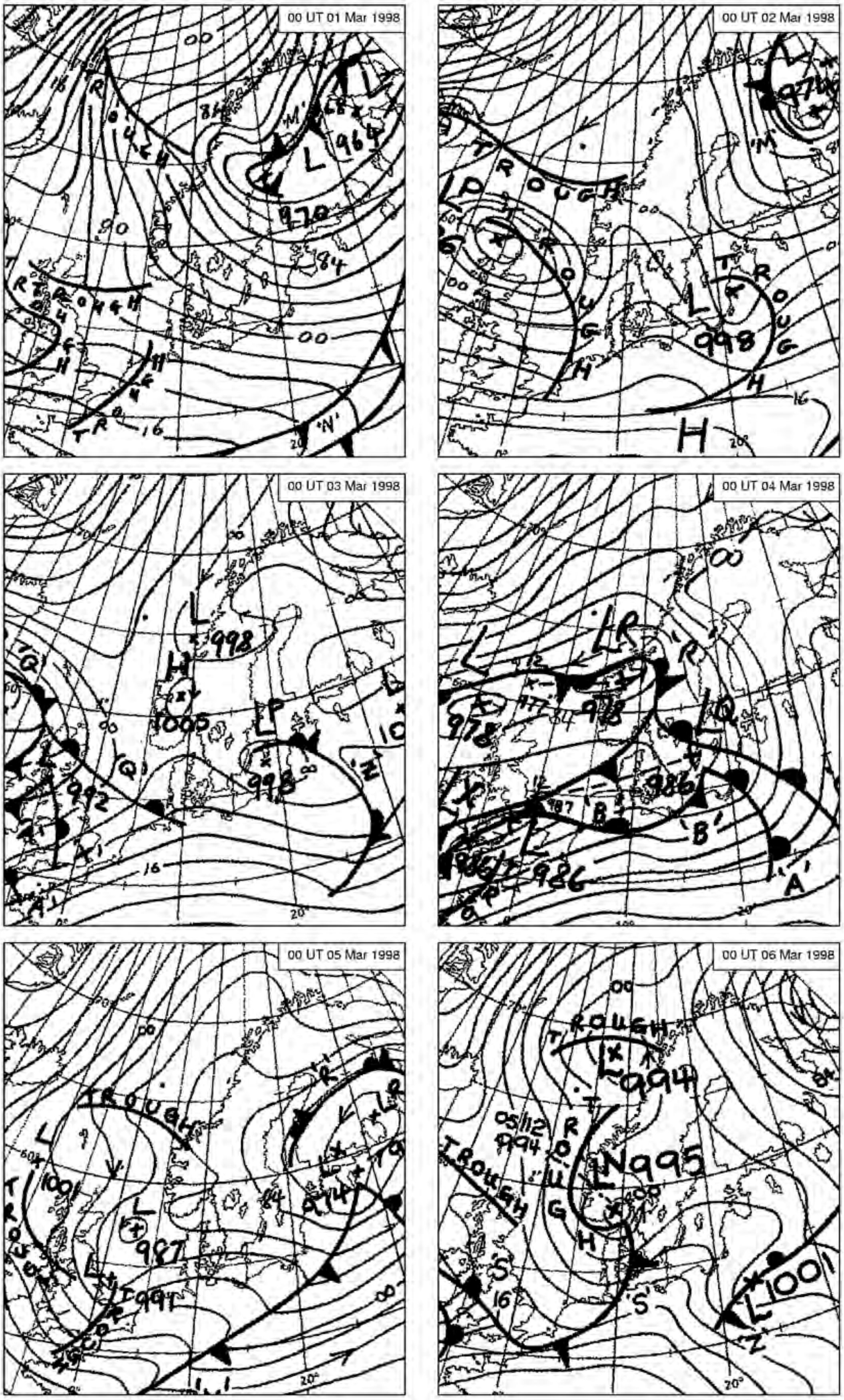
Appendix A1: Daily weather maps during BASIS 1998



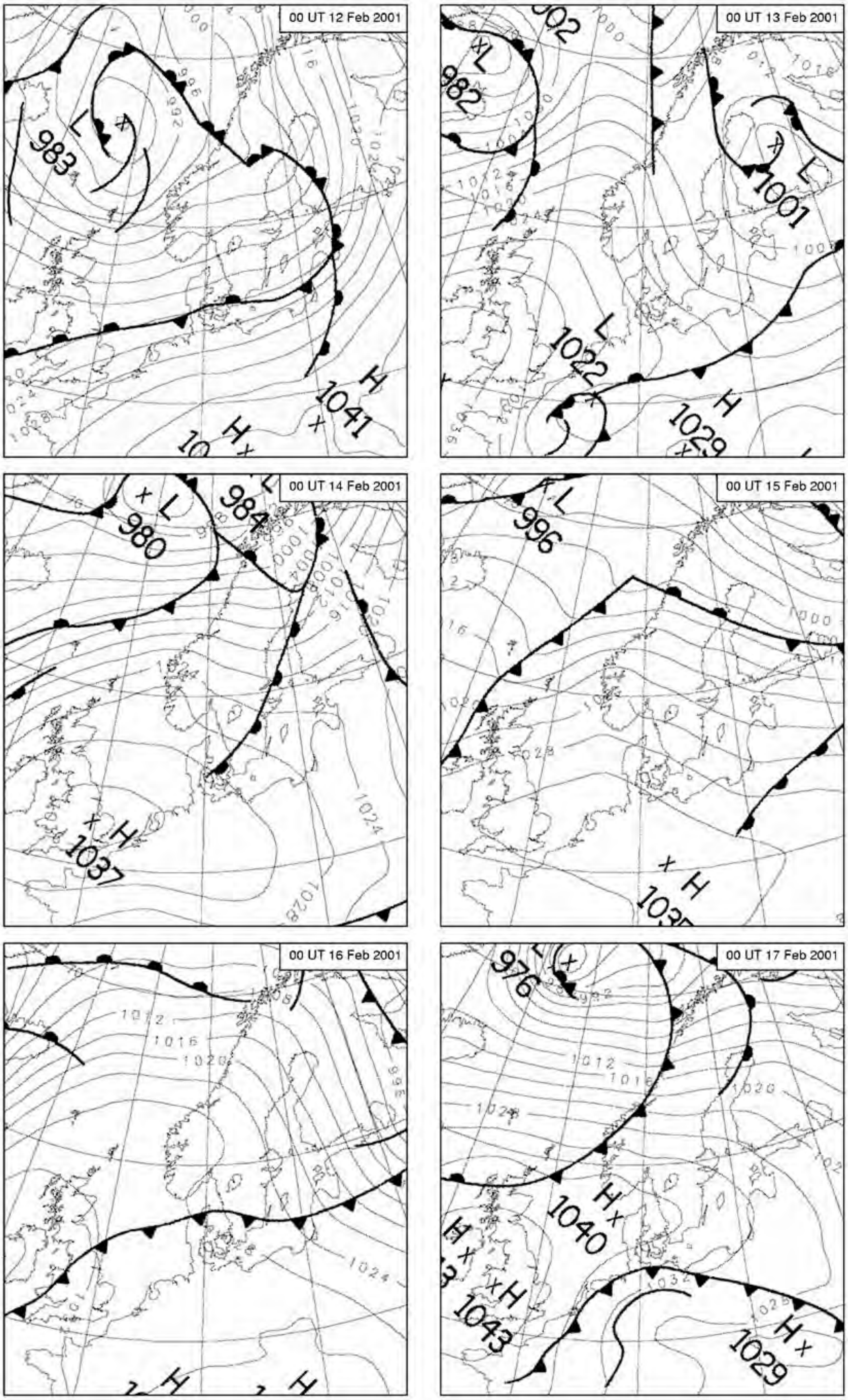
Appendix A1: Daily weather maps during BASIS 1998



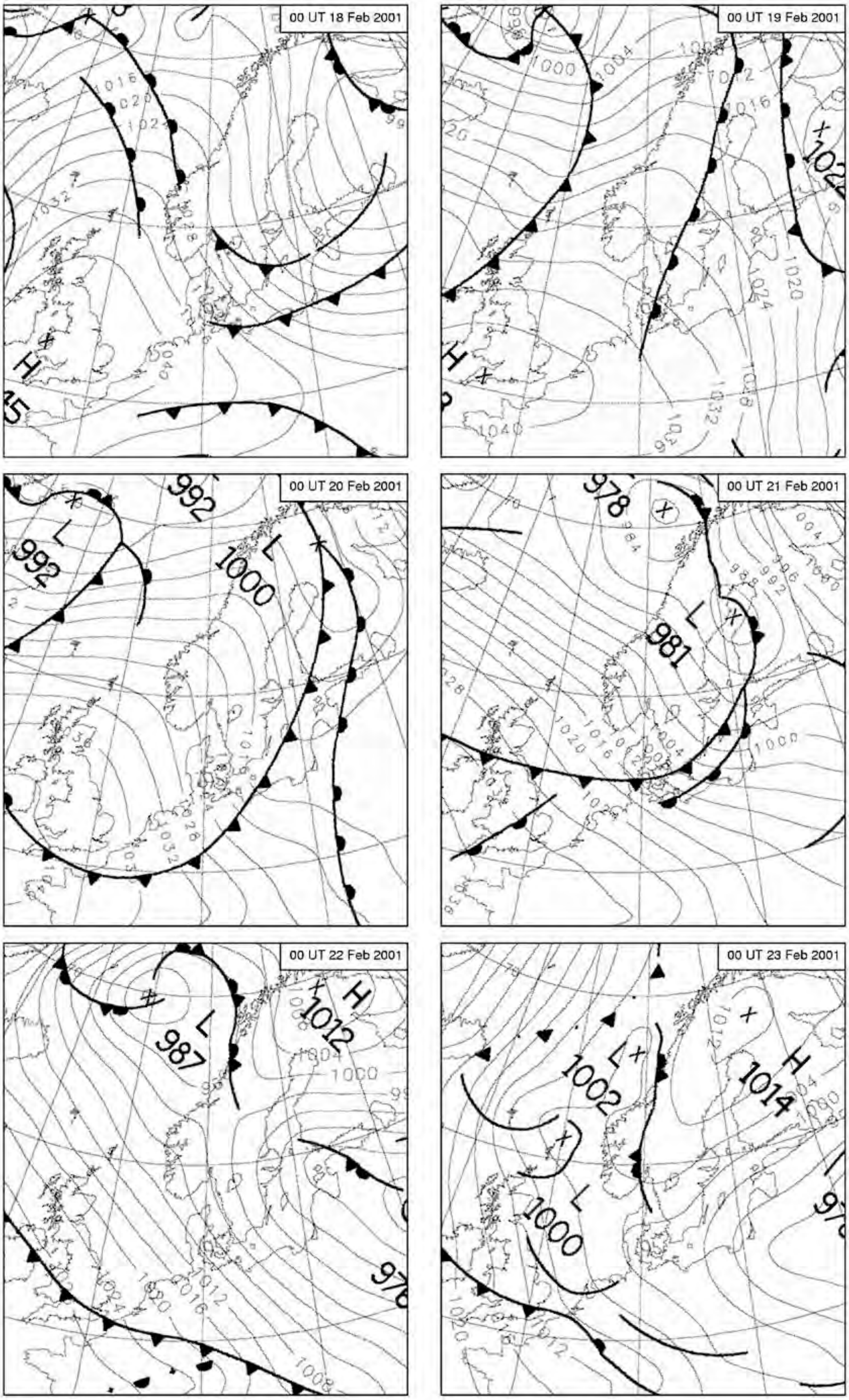
Appendix A1: Daily weather maps during BASIS 1998



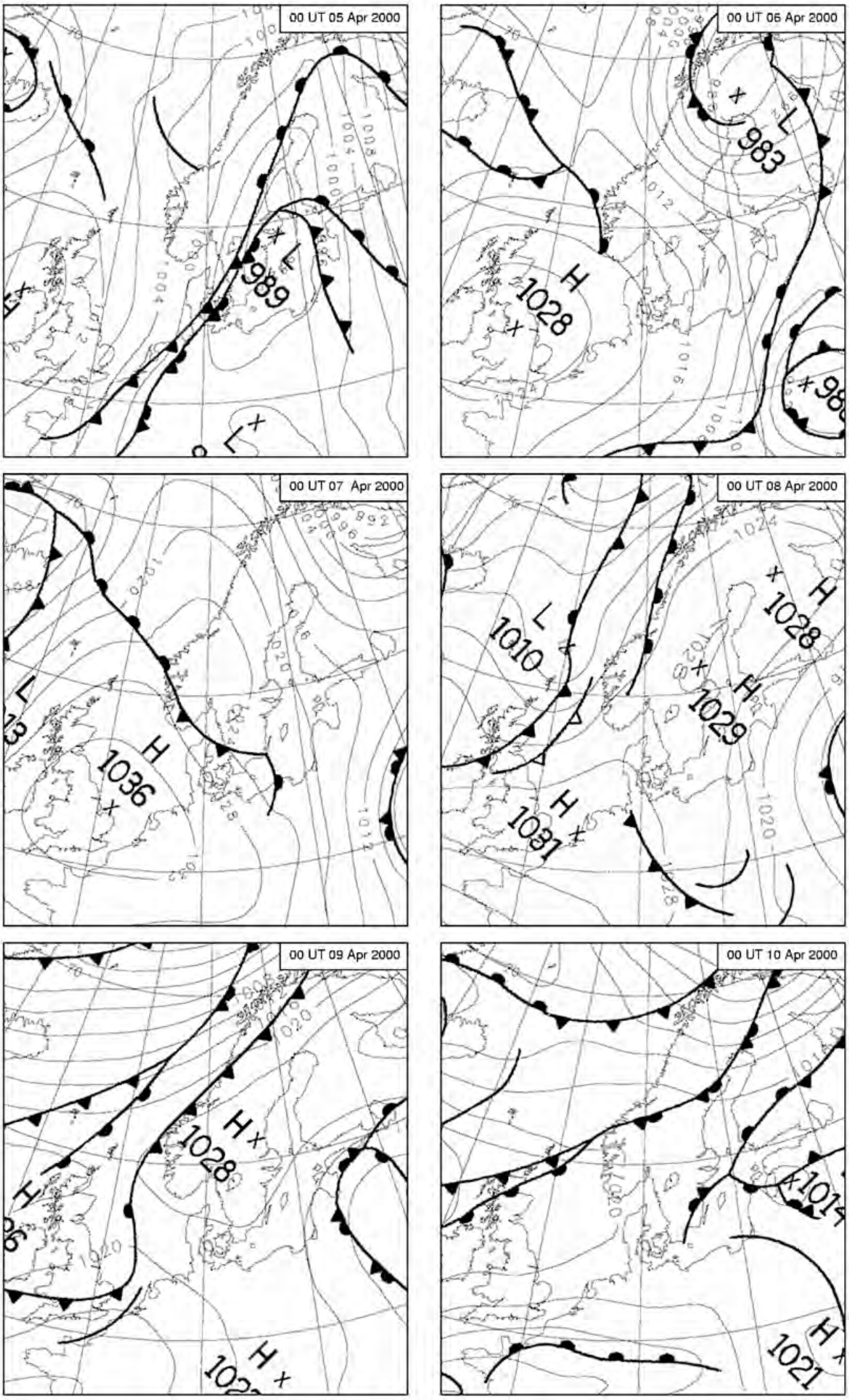
Appendix A2: Daily weather maps during BASIS 2001



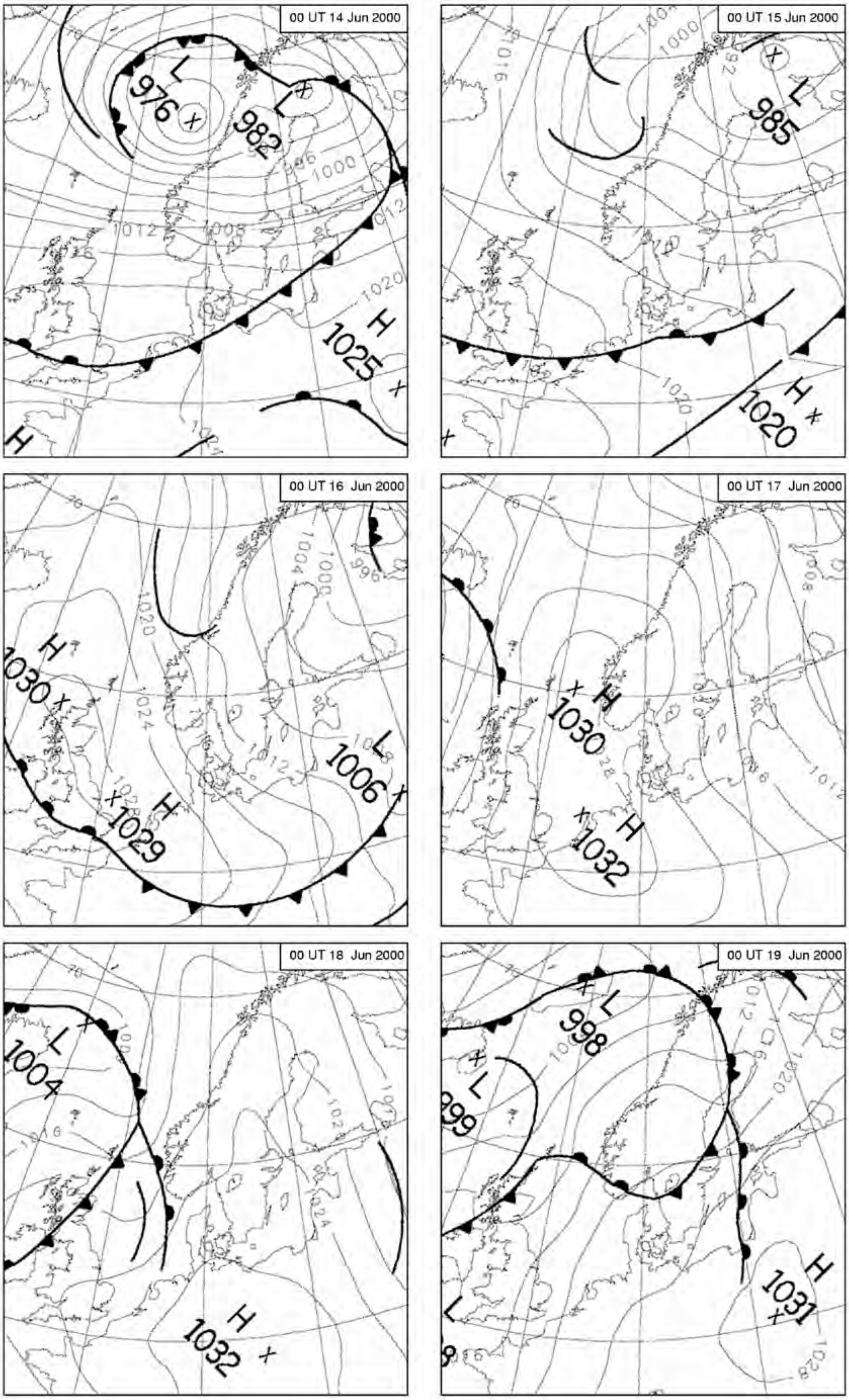
Appendix A2: Daily weather maps during BASIS 2001



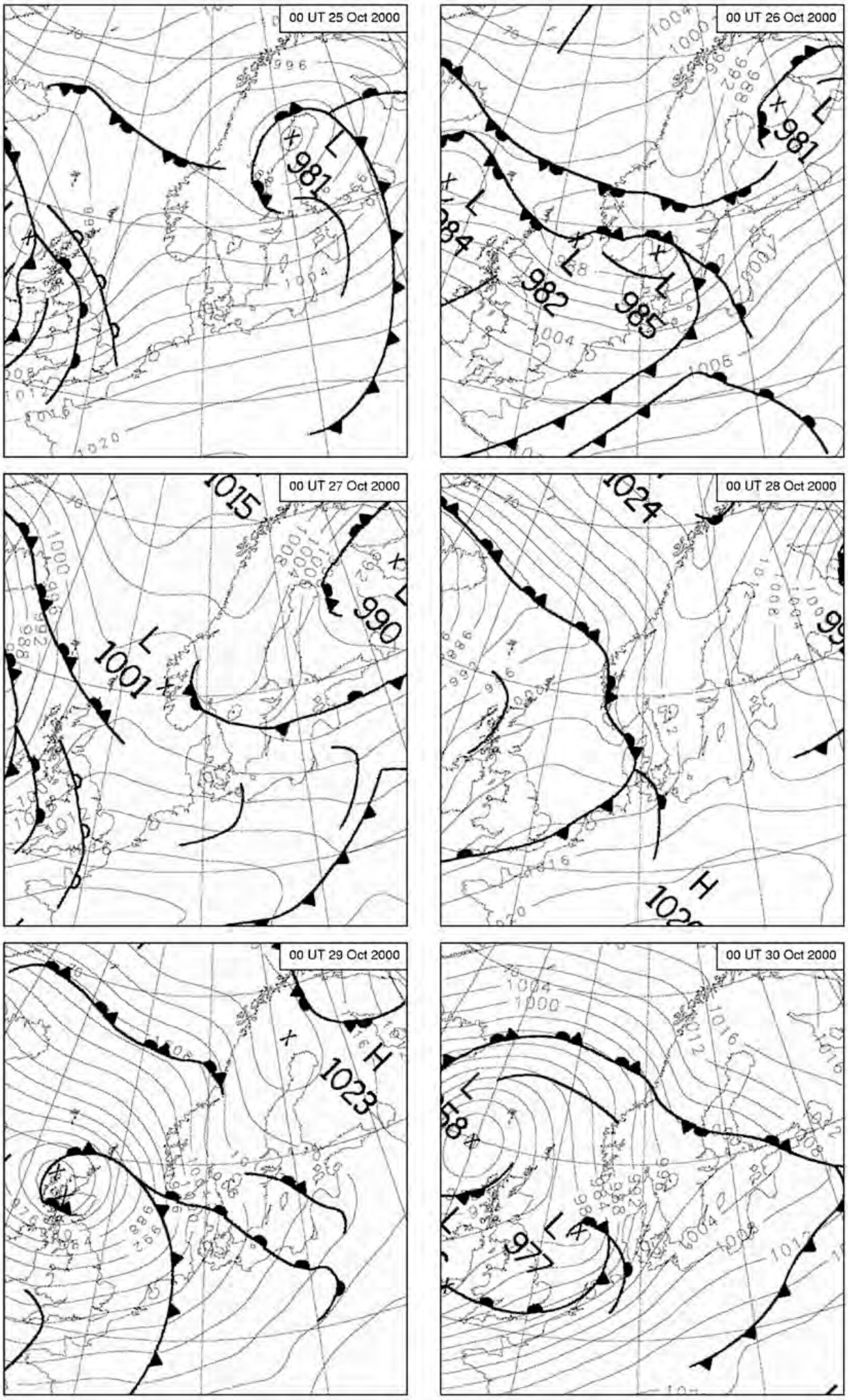
Appendix A3: Daily weather maps during Alkor 4/2000



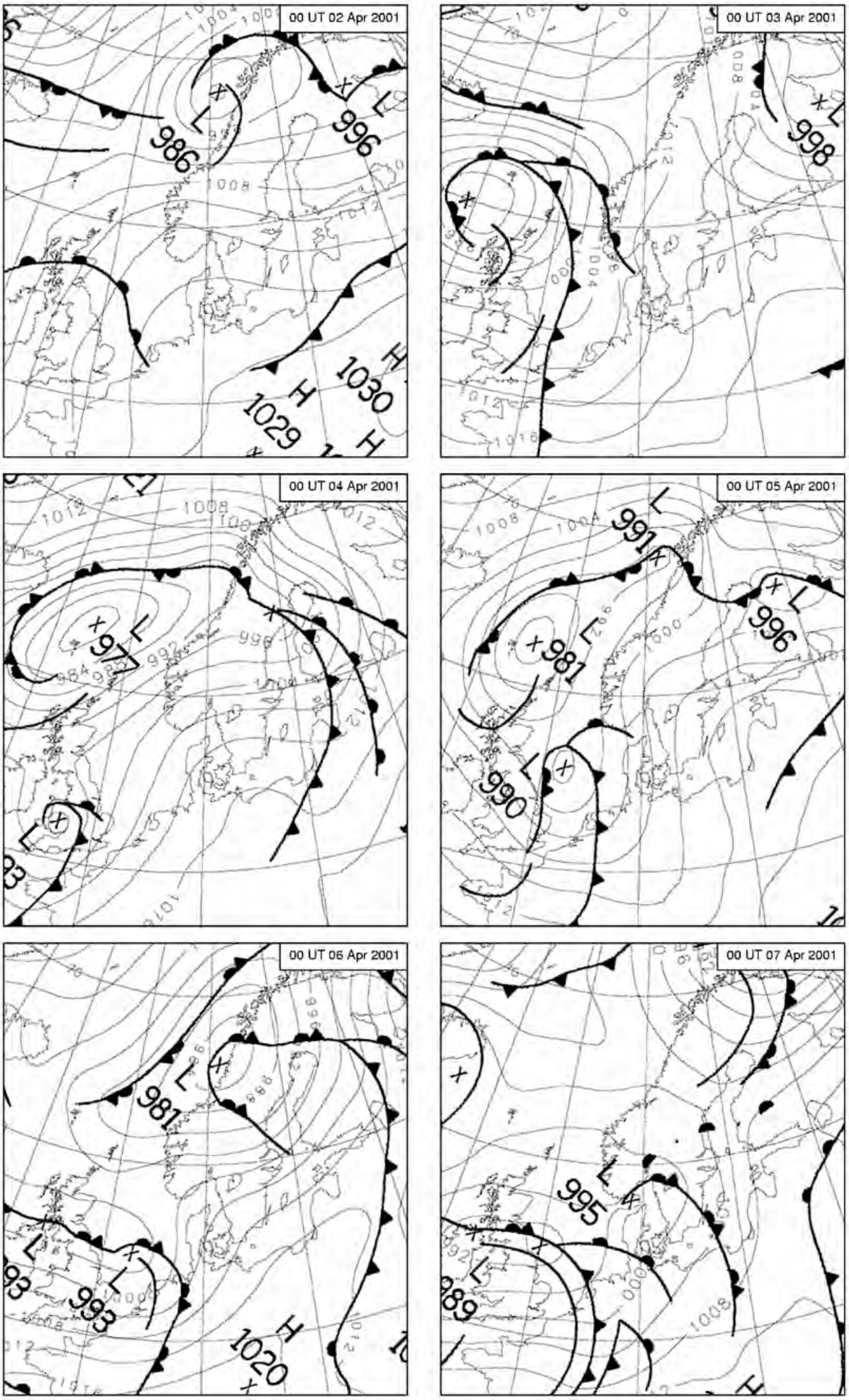
Appendix A4: Daily weather maps during Alkor 6/2000



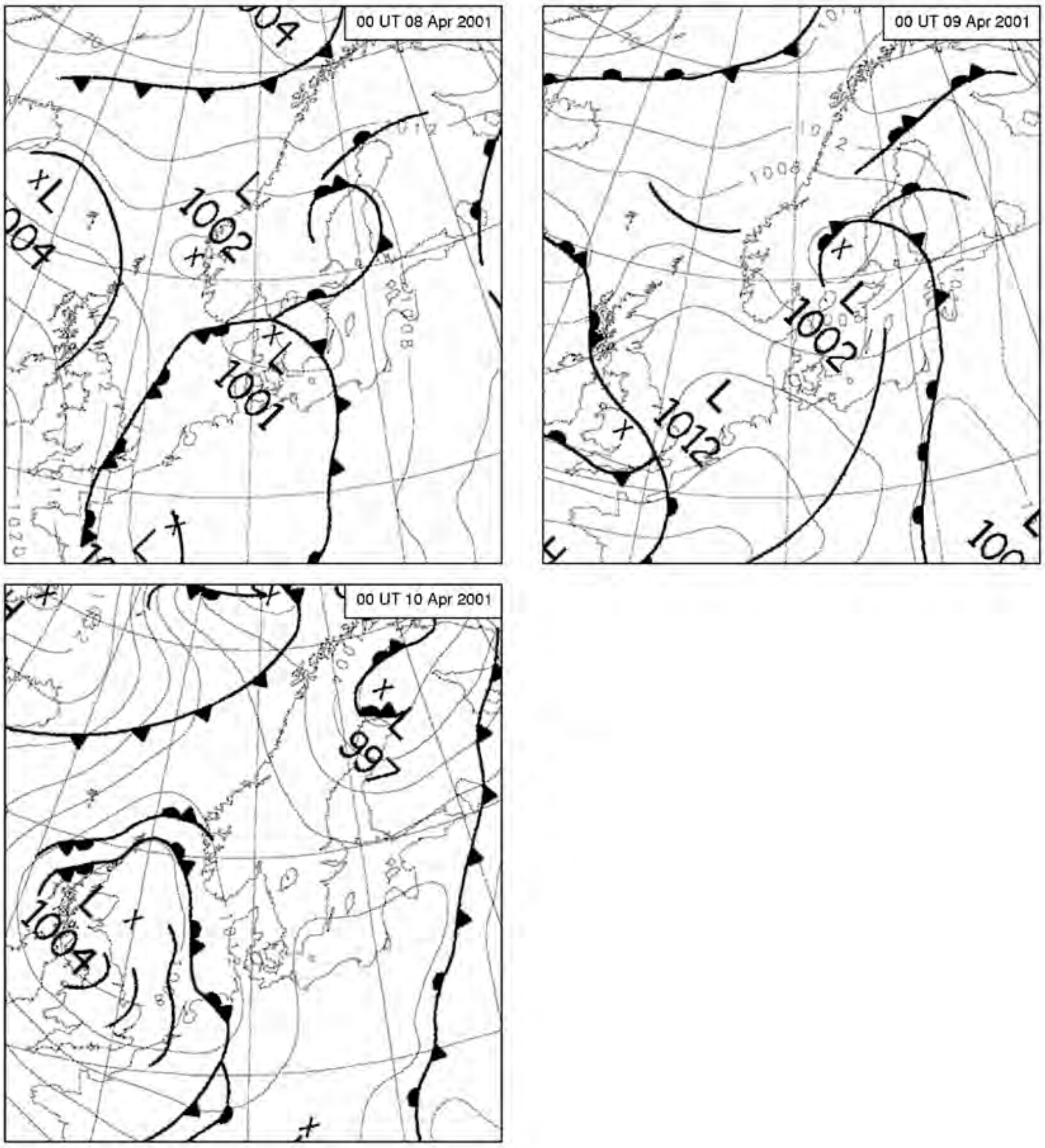
Appendix A5: Daily weather maps during Alkor 10/2000



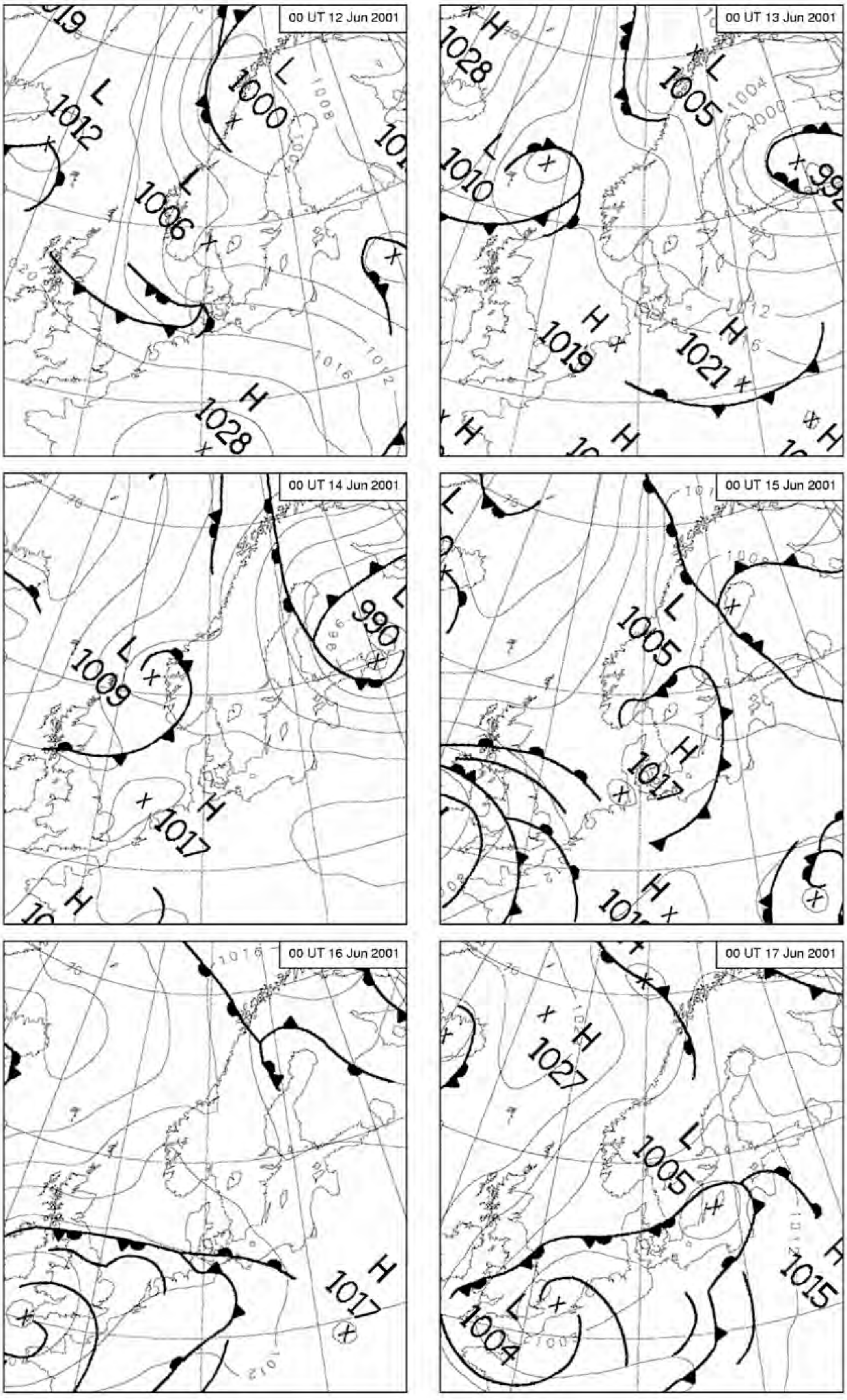
Appendix A6: Daily weather maps during Alkor 4/2001



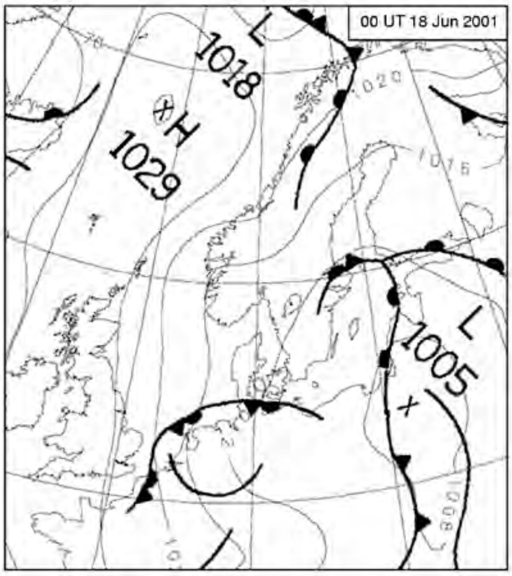
Appendix A6: Daily weather maps during Alkor 4/2001

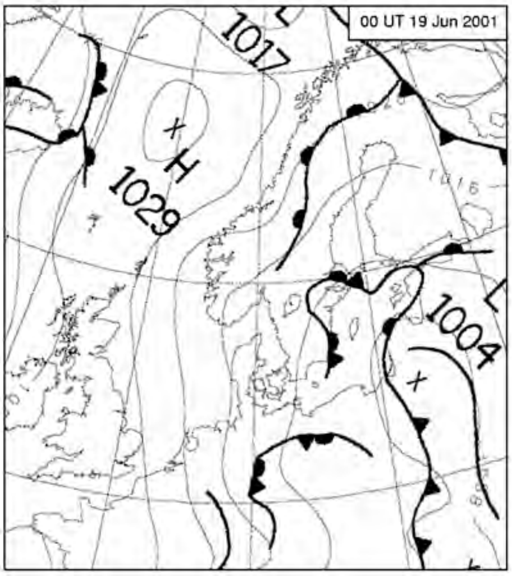


Appendix A7: Daily weather maps during Alkor 6/2001

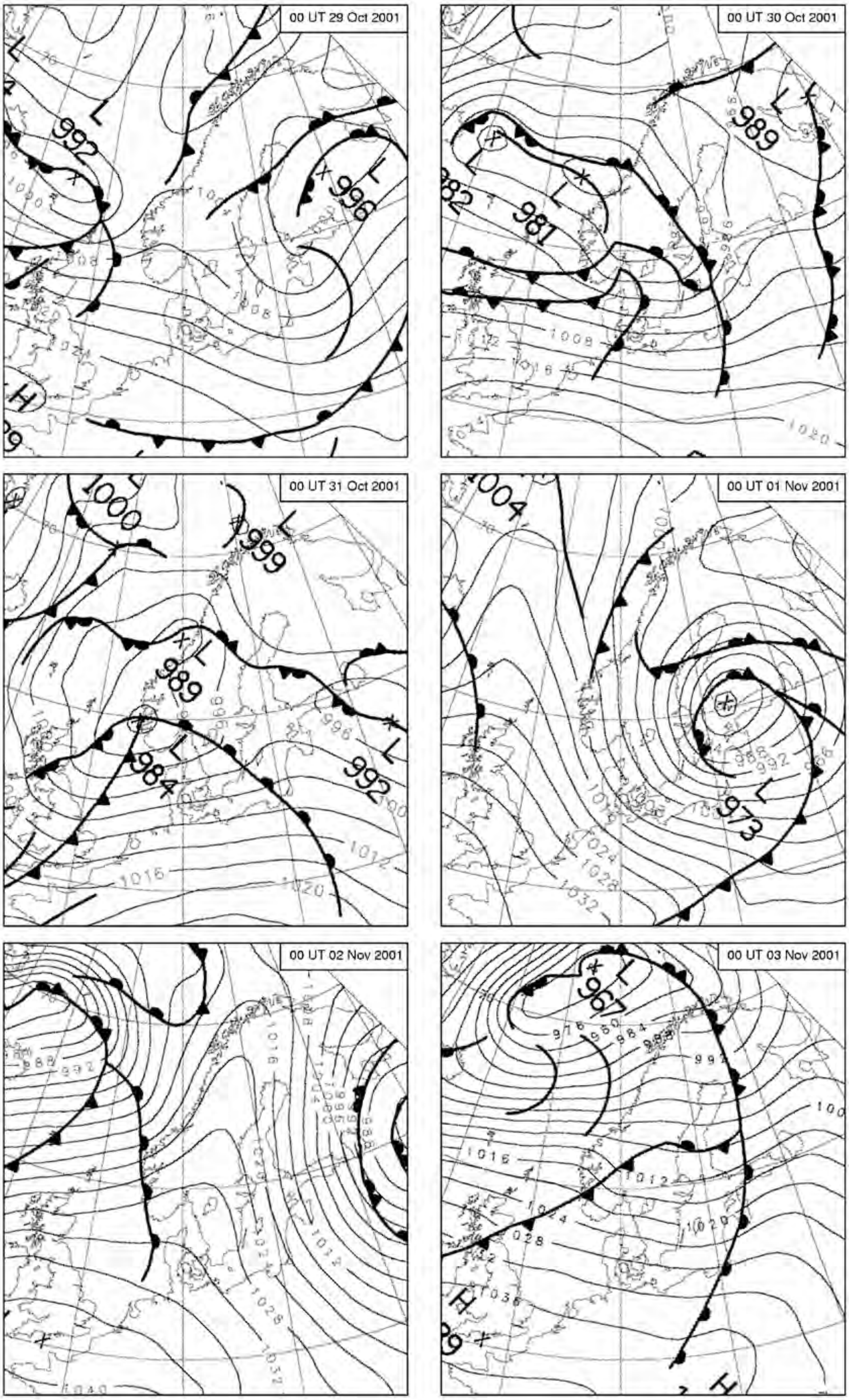


Appendix A7: Daily weather maps during Alkor 6/2001

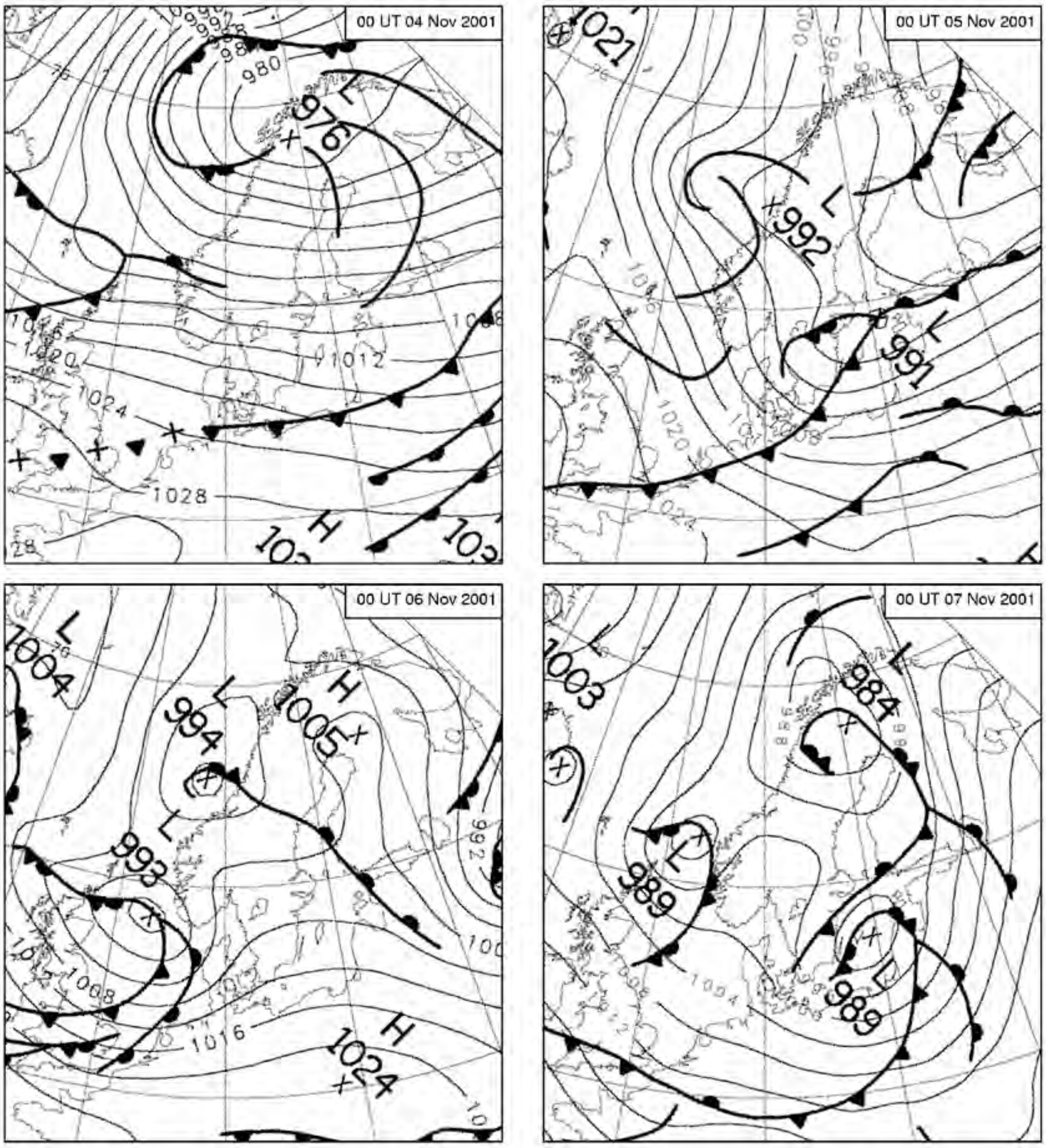




Appendix A8: Daily weather maps during Alkor 10/2001



Appendix A8: Daily weather maps during Alkor 10/2001



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No. 15: Minutes of 8th Meeting of the Science Steering Group held at Stockholm University in Stockholm, Sweden, 8-10 December 1998. May 1999

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No. 17: Parameterization of surface fluxes, atmospheric planetary boundary layer and ocean mixed layer turbulence for BRIDGE – What can we learn from field experiments? Editor: Nils Gustafsson. April 2000

No. 18: Minutes of 10th Meeting of the BALTEX Science Steering Group held in Warsaw, Poland, 7-9 February 2000. April 2000

No. 19: BALTEX-BASIS: Final Report, Editors: Jouko Launiainen and Timo Vihma. May 2001

No. 20: Third Study Conference on BALTEX, Mariehamn, Island of Åland, Finland, 2-6 July 2001, Conference Proceedings. Editor: Jens Meywerk, 264 pages. July 2001

No. 21: Minutes of 11th Meeting of the BALTEX Science Steering Group held at Max-Planck-Institute for Meteorology in Hamburg, Germany, 13-14 November 2000. July 2001.

No. 22: Minutes of 12th Meeting of the BALTEX Science Steering Group held at Royal Netherlands Meteorological Institute (KNMI), De Bilt, The Netherlands, 12-14 November 2001. April 2002

No. 23: Minutes of 13th Meeting of the BALTEX Science Steering Group held at Estonian Business School (EBS), Centre for Baltic Studies, Tallinn, Estonia, 17-19 June 2002. September 2002

No. 24: The eight BALTIMOS Field Experiments 1998-2001. Field Reports and Examples of Measurements. Editors: Burghard Brümmer, Gerd Müller, David Schröder, Amélie Kirchgäßner, Jouko Launiainen, Timo Vihma. April 2003, 138 pages.

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International BALTEX Secretariat Publication
ISSN 1681-6471