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THE ØRESUND-EXPERIMENT -
METEOROLOGICAL MEASUREMENTS (MASTS, TURBULENCE, MINI-SONDES) PERFORMED BY RISØ NATIONAL LABORATORY

Sven-Erik Gryning and Niels Gylling Mortensen

Abstract. This report describes the measurements carried out by Risø National Laboratory as part of the Øresund experiment. Measurements were made of 1) turbulence at the Gladsaxe mast during tracer releases, 2) profiles of wind and temperature at four small masts and at the Risø mast; by application of current flux profile relationship estimates of the momentum and sensible heat flux can be calculated, and 3) profiles of temperature, wet-bulb temperature and pressure by a mini-radiosonde-system (AIRSONDE), the sondes were launched from a fishing boat at various positions in Øresund during tracer releases. The report also describes measurements of temperature with a so-called Sprenger-radiosonde-system. All radiosonde measurements described in this report were carried out by the Swedish Meteorological and Hydrological Institute. The Sprenger-sondes were launched from the fishing-boat in between the AIRSONDES. The report contains a technical description of the instruments that were used and of their position and performance during the experiment. Most of the measurements are illustrated in figures and tables.

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PREFACE

The planning of the Øresund-experiment was carried out by institutions from the Nordic countries with NORDFORSK (Nordic cooperative organization for applied research) acting as project co-ordinator. The authors thank the members of the "managing staff" for smooth and constructive co-operation before, during and after the experiment. We especially thank Mari-Mai Lagus of NORDFORSK for her excellent handling of the project. We acknowledge the help of persons from Risø who took part in the experiment, especially Morten Frederiksen, Arent Hansen and Gunnar Jensen. Birthe Skrumsager is acknowledged for her typing of the manuscript. Furthermore, the assistance of the Danish Post and Telecommunication is appreciated.

1. INTRODUCTION

The atmospheric dispersion processes and the modifications in the wind field across the 20-km wide strait of Øresund between Denmark and Sweden was studied in an experimental campaign called the Øresund-experiment. The project was coordinated by NORDFORSK. The campaign took place from May 15 to June 14, 1984. Conditions with cold water and warm land surfaces were of specific interest in the experiment. The meteorological observational network extended over a 80-km wide cross section through the Øresund. A large proportion of the meso- and micrometeorological instrumentation in the Nordic countries were used in the experiment. A thorough description of the project is given in Gryning (1985).

As a part of the Øresund-experiment Risø National Laboratory carried out meteorological measurements at a number of masts in Denmark and performed measurements of turbulence at the mast in Gladsaxe during tracer releases. In cooperation with the Swedish Meteorological and Hydrological Institute Risø performed measurements with a mini-sonde system that was operated from a fishing-boat in Øresund. The mini-sonde equipment (AIRSONDE) belonged to Risø and was operated by personnel from the Swedish Meteorological and Hydrological Institute. Also a Sprenger radio-sonde system which belonged to the Swedish Defense Weather Service was operated on the fishing-boat. During the campaign Risø carried out an intercomparison of the pressure sensors, which were operated as a part of the Øresund-experiment. This report describes the measurements in which Risø was involved as well as the measurements with the Sprenger radio-sonde system. For use in the subsequent technical description Fig. 1 shows some of the measuring positions of the Øresund-experiment.

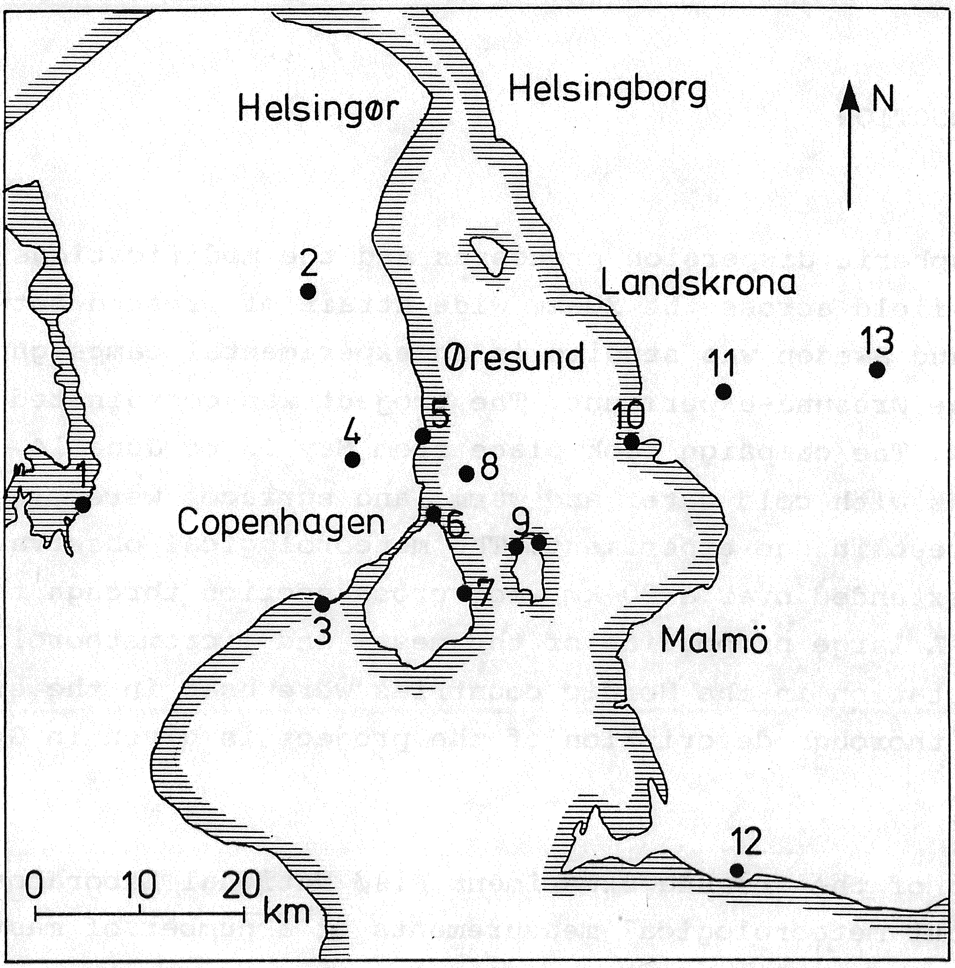


Fig. 1. The geographical location where the meteorological measurements were carried out. The positions refer to 1) Risø, 2) Sjælsmark, 3) Avedøre, 4) Gladsaxe, 5) Charlottenlund, 6) Margretheholm, 7) Kastrup Airport, 8) Middelgrunden, 9) Saltholm, 10) Barsebäck, 11) Furulund, 12) Maglarp and 13) Borlunda. Some of the cities in the area are shown.

2. TURBULENCE MEASUREMENTS AT THE GLADSAXE MAST

During releases of the tracer, measurements were carried out of the turbulent wind fluctuations at the height of release (115 m) at the mast at Gladsaxe. These measurements were carried out using an instrument package that consists of a fast responding light-weight cup-anemometer, a wind vane and a vertical propeller.

The signals (analogue or pulsed) from these instruments were recorded continuously on an analogue recorder during the tracer experiments and were later digitized with a sampling frequency of 1 Hz. The continuous signals from the instruments are used for the computation of the fluctuating three-dimensional wind velocity vector, taking into account the appropriate angular response functions of the instruments. A detailed description of the technique is given in Gryning (1981). A short description of the light-weight instruments is given below.

2.1. Cup-anemometer

A Risø model 70 cup-anemometer was used as wind speed sensor. It is a light-weight, strong instrument with cups made of carbon-reinforced plastic. The distance constant is about 1.5 m and the starting speed is 0.2 ms^{-1}. The version of the Risø 70 anemometer used here is a light chopper type, producing 30 pulses per rotation. The number of pulses can be counted and converted into wind speed. The cup-anemometer is individually calibrated in order to obtain the relationship to be used to convert the pulse frequency to wind speed. The calibration is given by $u = 0.26 + 0.042\ n$, where u is wind speed in ms^{-1} and n the cup-anemometer pulse frequency.

Ideally, the angular response of a cup-anemometer is the so-called cosine response. With this response, the angular velocity will be independent of the wind velocity component parallel to the axis. The angular response of the Risø 70 cup-anemometer is, like that of most similar instruments, not symmetrical with respect to a horizontal plane. Due to the anemometer shaft and body, the angular response for sub-horizontal wind attack angles departs measurably from a cosine response; for super-horizontal attack angles up to ~ 20^{o}, the angular response is approximated well by a cosine function. The angular response of the cup-anemometer used is shown in Figure 2. Corrections have been made in the analysis of the data for the lack of cosine response. The correction is especially important for light winds, and strong surface heating conditions.

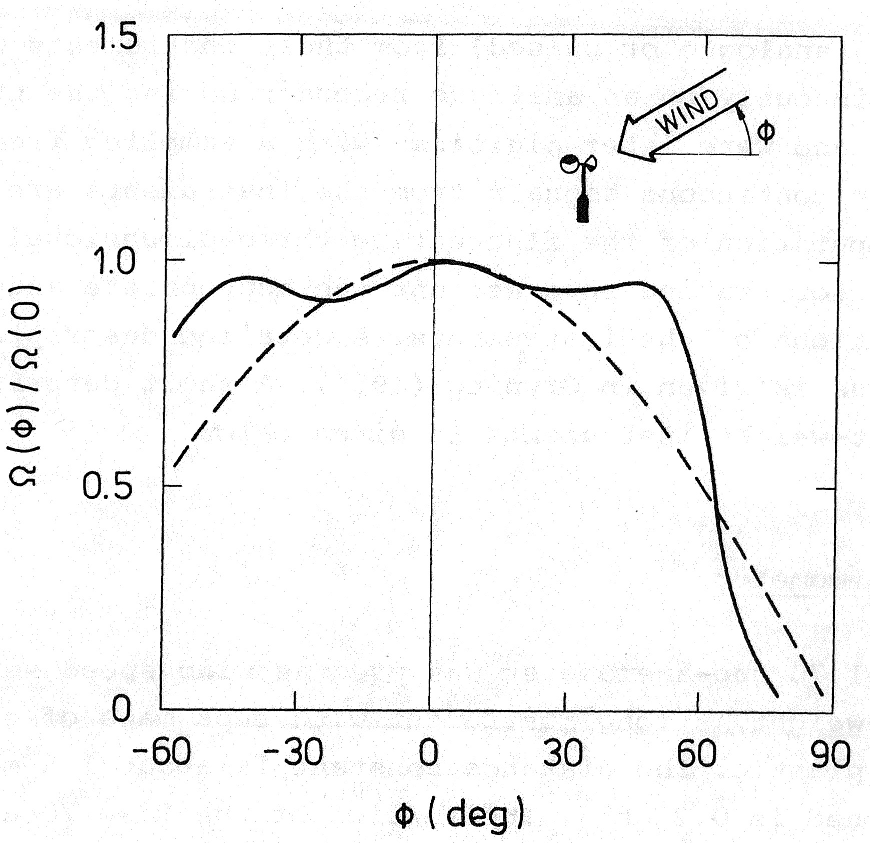


Fig. 2. Angular response of the Risø 70 cup-anemometer. Positive angles indicate that the wind attacks from above. The full line is the directly measured angular response; the dashed line is the ideal cosine response (from Busch et al., 1979). The ordinate shows the angular response, $\Omega(\phi)/\Omega(0)$, where $\Omega(\phi)$ is the angular velocity of the cup-anemometer for an angle of attack ϕ, and $\Omega(0)$ is the angular velocity for horizontal flow of an equal speed.

A Risø 70 cup-anemometer is accurate to within ± 1 per cent of the actual wind speed reading above 5 m/s, and to ± 5 cm/s below (Busch et al. 1979).

2.2. Wind vane

The horizontal wind direction was sensed using a light-weight vane, also developed at Risø and described in detail by Larsen and Busch (1974). In the vane design considerable attention was paid to the proper response characteristic at relatively high

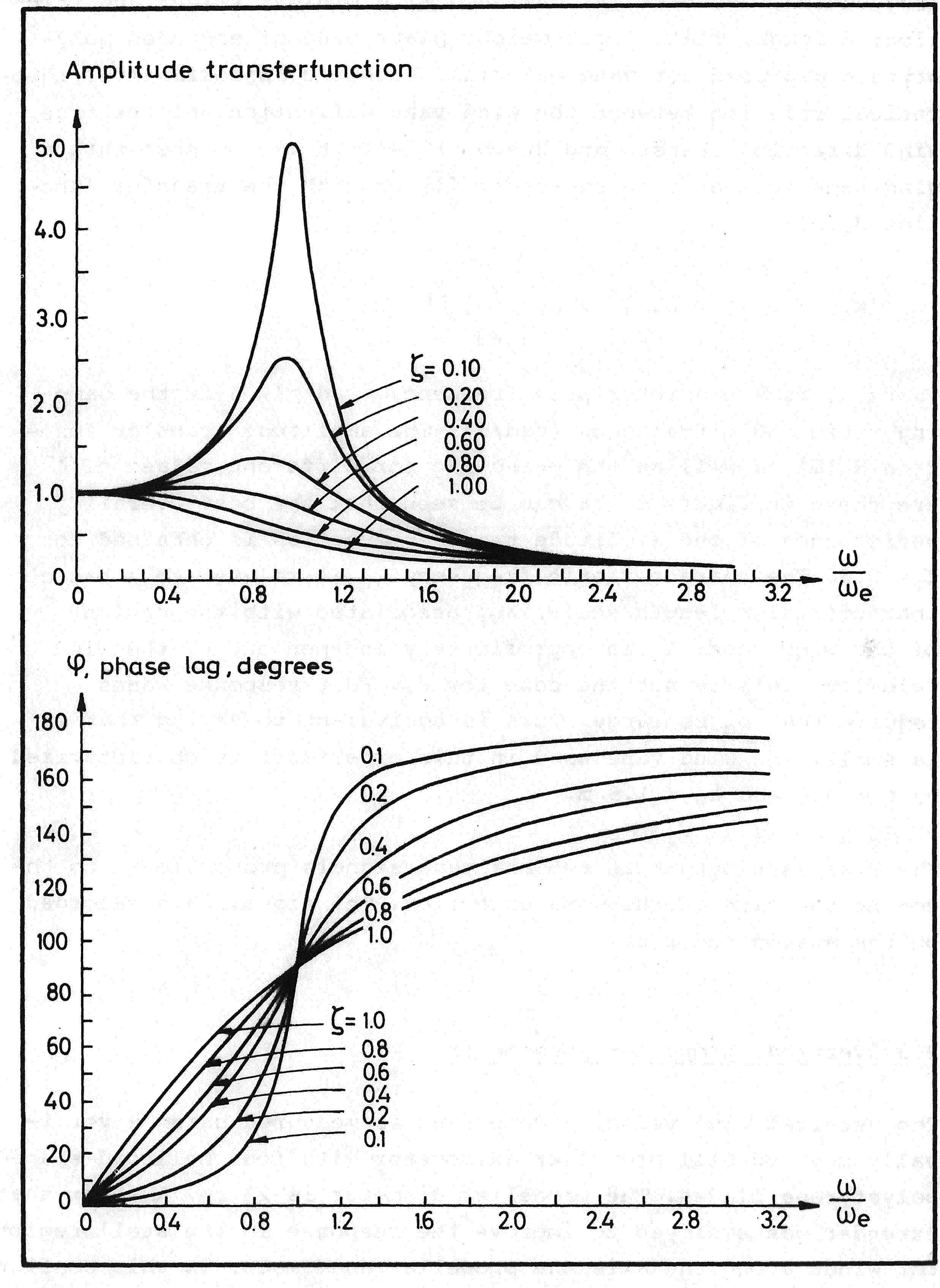


Fig. 3. Amplitude transfer function and phase lag for a number of values of the damping ratio, ζ, (Busch et al., 1979).

frequencies. The vane was designed with minimal weight and friction; a rough, flat, light-weight plate made of expanded polystyrene was used for vane material. From the approximative, theoretical relation between the wind vane deflection and the true wind direction (Larsen and Busch, 1974), it can be seen that a wind vane acts as a second-order filter with the transfer function $H_v(\omega)$:

$$H_v(\omega) = [1 - (\frac{\omega}{\omega_e})^2 - 2i\zeta(\frac{\omega}{\omega_e})]^{-1}$$

where ω_e is a characteristic frequency (rad/s), ζ is the damping ratio and ω frequency (rad/s). The amplitude transfer function $H_v(\omega)$ as well as the phase lag for different values of ζ are shown in Figure 3. It can be seen that the best overall performance of the amplitude transfer function is obtained for $\zeta \simeq 0.6$. The characteristic frequency ω_e is related to a basic characteristic length scale, λ_v, associated with the design of the wind vane; λ_v is approximately independent of the wind velocity. This is not the case for ω_e. Fast response vanes require that ω_e be large. This is equivalent to saying that λ_v is small. The wind vane used in this experiment is characterized by $\zeta \simeq 0.6$ and $\lambda_v \simeq 1.5$ m.

The Risø vane output is two analogue signals proportional to the cosine and sine of the wind direction. The signals are recorded on the analog recorder.

2.3. Vertical propeller anemometer

The vertical wind velocity component is measured using a vertically mounted Gill propeller anemometer with four helicord-shaped polystyrene blades. The propeller diameter is 23 cm. A 10 cm shaft extender was employed to improve the response in the stall region. For winds along the axis the propeller anemometer in this configuration is reported to have a distance constant of approximately 1 m. The distance constant for the propeller, λ_p, is usually measured by releasing a propeller from rest in a steady wind (wind tunnel) and observing the time necessary for 63% of the change towards stable rotation to occur. The distance constant is a function of the angle of attack, γ, of the wind vector (the angle between the wind vector and the propeller axis) and λ_p is fairly well approximated by

$$\lambda_p(\gamma) = \lambda_p(0) \cos^{1/2}\gamma.$$

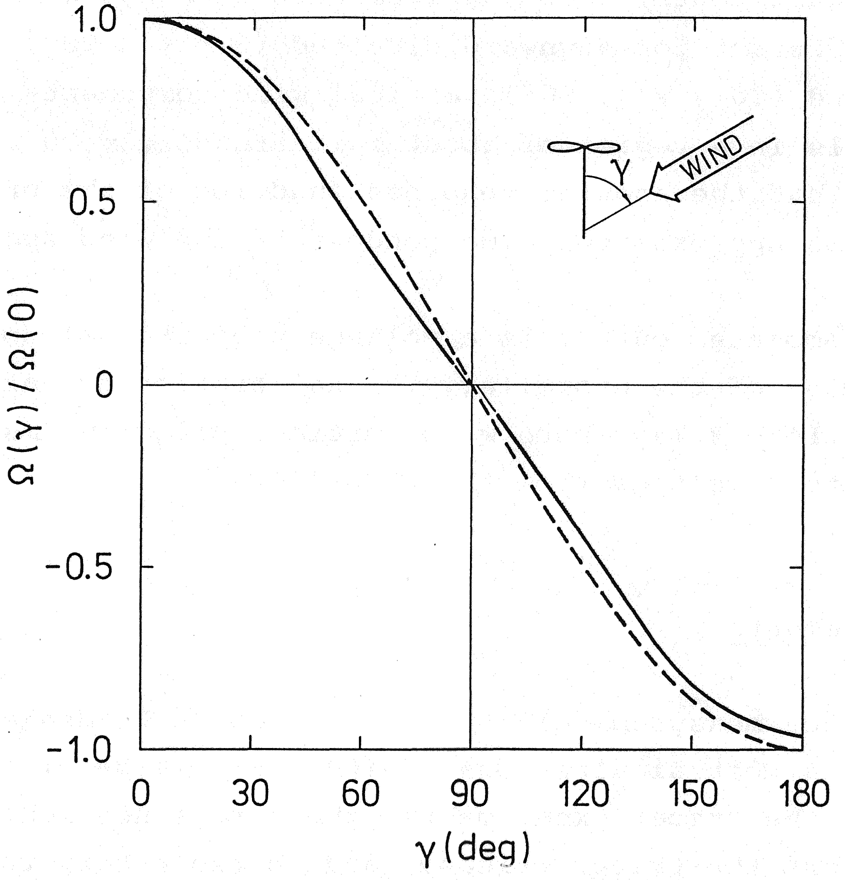


Fig. 4. Steady-state angular response of the Gill-propeller. For $0 < \gamma < 90^0$, the wind attacks from above; for $90 < \gamma < 180^0$ the wind attacks from below. The full line is the directly measured angular response, the dashed line the ideal cosine response. The ordinate shows the angular response $\Omega(\gamma)/\Omega(0)$, where $\Omega(\gamma)$ is the angular velocity of the propeller anemometer for an angle of attack γ, and $\Omega(0)$ is the angular velocity for axial flow of an equal speed.

As a consequence, as γ approaches 90^0 the distance constant becomes infinitesimal, and the time constant $\lambda_p(\gamma)/w$ becomes infinite. Thus, the frequency response of the propeller anemometer depends on the instantaneous vertical wind speed and γ, so the response time will always be changing.

Like the cup-anemometer, the angular response of the propeller anemometer is not ideal. Thus, the output signal is not a simple linear function of the vertical velocity component. The steady state angular response of the propeller anemometer used here was measured in a wind tunnel and is shown in Figure 4. The response deviates significantly from the ideal cosine response, it is also markedly different for downward directed ($0 < \gamma < 90^0$) and upward directed ($90 < \gamma < 180^0$) vertical wind components. The propeller stalls in a region of about $\pm 1^0$ around $\gamma = 90^0$. Measurements show that the angular response function of the propeller anemometer is approximately independent of the wind speed.

The Gill anemometer output is a voltage proportional to the angular velocity of the propeller. The calibration for axial flow reads $w = 0.14 + 3.8 \cdot v$ where w is vertical velocity (ms^{-1}) and v is the output voltage from the propeller.

2.4. Measurements

The turbulence measurements at 115 m height at Gladsaxe were carried out almost simultaneously with the release of the tracer. In seven of the tracer experiments, the turbulence measurements started before the tracer release, and in two others turbulence measurements began a little (3 and 11 min) after the start of tracer release. The turbulence measurements were stopped at the time when tracer release was stopped or later, Table 1. The data exist in the data bank as time series of one sec averages of wind speed, wind direction and vertical wind velocity. Table 2-10 lists 10-min averaged values of wind speed, vertical wind velocity and wind direction, and the standard deviations of these.

Unfortunately, the cup-anemometer did not function throughout the last part of the experiment on June 12, and during the entire experiment on June 14. In order to calculate the vertical wind velocity, taking into account the angular response function of the cup anemometer and vertical propeller, the wind speed must be known. For the experiment on June 12, the wind speed was assumed to be 5.34 m/s in the period where the cup-anemometer was out of function. For the experiment on June 14, the wind speed was assumed to be 9.9 m/s, the value is taken from the measurements by the Doppler acoustic sounder at Gladsaxe.

Table 1. Starting and stopping times for the turbulence measurements at Gladsaxe.

Day	Start	Stop
16 May	9:02	14:34
18 May	8:00	13:29
22 May	9:11	12:10
29 May	8:03	12:04
30 May	8:00	12:06
4 June	8:30	12:09
5 June	8:00	12:11
12 June	8:30	12:50
14 June	9:00	14:14

Table 2. Meteorological measurements of wind speed, direction, vertical velocity and the standard deviations of these at 115 m above ground from the mast at Gladsaxe May 16, 1984.

time (CET)	wind speed		wind direction		vertical velocity	
from to	mean (m/s)	st.dev. (m/s)	mean (deg)	st.dev. (deg)	mean (m/s)	st.dev. (m/s)
09:02-09:10	4.81	0.58	164.3	5.9	-0.20	0.43
09:10-09:20	4.06	0.75	152.3	7.4	-0.07	0.60
09:20-09:30	4.79	0.69	152.4	5.1	-0.17	0.42
09:30-09:40	4.16	0.76	153.1	7.8	0.02	0.61
09:40-09:50	4.03	0.65	154.3	6.2	-0.37	0.41
09:50-10:00	3.76	0.65	154.8	6.9	-0.24	0.51
10:00-10:10	4.96	0.84	160.1	9.6	-0.14	0.67
10:10-10:20	5.23	0.76	155.2	5.1	-0.14	0.64
10:20-10:30	3.57	0.79	143.9	6.7	0.06	0.50
10:30-10:40	4.14	0.87	146.3	7.1	0.01	0.65
10:40-10:50	4.29	0.85	148.7	8.2	0.17	0.92
10:50-11:00	4.50	0.96	142.6	10.8	0.10	0.85
11:00-11:10	4.67	0.82	142.1	6.6	-0.16	0.79
11:10-11:20	3.80	0.86	125.0	7.9	0.21	0.72
11:20-11:30	4.10	0.86	133.5	9.0	0.19	0.78
11:30-11:40	3.86	0.64	128.3	6.8	-0.10	0.61
11:40-11:50	3.83	0.85	130.7	10.5	0.34	0.78
11:50-12:00	3.43	0.79	130.0	9.9	0.59	0.72
12:00-12:10	3.80	0.58	126.8	7.4	-0.10	0.47
12:10-12:20	3.49	0.63	129.6	10.5	0.02	1.09
12:20-12:30	3.56	0.74	123.7	8.7	0.05	0.78
12:30-12:40	3.94	0.91	123.6	9.1	0.40	1.10
12:40-12:50	3.97	0.66	122.9	6.6	0.06	0.72
12:50-13:00	3.98	0.75	127.1	7.6	-0.01	0.77
13:00-13:10	3.87	0.91	122.6	9.2	0.13	0.84
13:10-13:20	4.27	0.95	119.5	7.5	-0.39	0.71
13:20-13:30	3.95	0.87	117.4	8.3	-0.40	0.74
13:30-13:40	5.24	1.29	109.6	7.7	-0.36	0.85
13:40-13:50	5.53	1.16	107.4	7.3	-0.48	0.81
13:50-14:00	5.49	1.14	106.5	8.4	-0.20	0.80
14:00-14:10	4.96	1.23	110.2	7.3	-0.36	0.74
14:10-14:20	4.62	1.18	109.9	8.2	-0.35	0.72
14:20-14:30	3.83	1.12	115.9	7.9	-0.78	0.71
14:30-14:34	4.66	1.46	110.3	12.8	0.38	0.98
09:02-14:34	4.26	1.05	132.6	18.6	-0.07	0.79
13:30-14:30	4.94	1.33	109.9	8.4	-0.42	0.80

Table 3. Meteorological measurements of wind speed, direction, vertical velocity and the standard deviations of these at 115 m above ground from the mast at Gladsaxe May 18, 1984.

time	wind speed		wind direction		vertical velocity	
(CET) from to	mean (m/s)	st.dev. (m/s)	mean (deg)	st.dev. (deg)	mean (m/s)	st.dev. (m/s)
08:00-08:10	9.20	1.00	231.9	5.8	-0.13	1.00
08:10-08:20	9.06	0.69	232.2	4.6	-0.61	0.63
08:20-08:30	8.10	1.27	232.7	6.9	-0.17	0.87
08:30-08:40	8.51	1.00	225.3	4.3	-0.47	0.76
08:40-08:50	7.43	0.86	222.1	6.4	0.16	0.78
08:50-09:00	8.51	0.93	226.9	6.4	-0.44	0.96
09:00-09:10	9.00	0.87	230.6	4.8	-0.12	0.72
09:10-09:20	8.60	0.87	227.9	5.6	-0.32	0.76
09:20-09:30	8.11	0.84	226.0	7.2	-0.08	0.98
09:30-09:40	8.14	1.11	222.7	7.6	-0.08	0.92
09:40-09:50	8.17	1.09	221.1	5.8	-0.32	0.92
09:50-10:00	5.82	0.91	219.7	9.0	0.23	0.97
10:00-10:10	6.94	0.79	212.6	8.8	-0.48	0.85
10:10-10:20	7.18	0.77	207.9	7.4	0.02	0.77
10:20-10:30	6.51	1.14	216.6	10.2	0.19	0.74
10:30-10:40	7.29	1.16	217.4	9.5	0.29	0.86
10:40-10:50	8.32	0.83	224.6	6.9	-0.36	0.77
10:50-11:00	7.69	0.80	228.4	6.5	-0.64	0.89
11:00-11:10	7.59	1.10	225.4	7.7	-0.30	0.92
11:10-11:20	7.87	1.05	225.0	6.2	-0.39	0.93
11:20-11:30	7.61	1.05	217.9	8.1	-0.16	1.00
11:30-11:40	7.90	1.06	220.7	6.0	-0.41	1.05
11:40-11:50	7.03	1.18	224.1	9.9	-0.16	1.19
11:50-12:00	6.68	1.01	215.7	9.4	-0.07	1.21
12:00-12:10	6.39	1.39	222.0	8.1	-0.30	1.20
12:10-12:20	6.84	1.31	223.4	11.0	-0.55	1.27
12:20-12:30	7.23	0.75	218.9	5.6	-0.78	0.78
12:30-12:40	7.16	1.07	217.6	11.2	-0.41	0.94
12:40-12:50	6.50	0.96	225.2	10.4	-0.23	1.00
12:50-13:00	7.07	1.57	223.7	11.2	-0.04	1.32
13:00-13:10	6.31	1.36	222.4	14.5	-0.24	1.04
13:10-13:20	5.88	0.99	225.9	16.9	0.19	1.00
13:20-13:29	6.99	1.06	211.1	7.5	-0.20	1.11
08:00-13:29	7.50	1.37	222.6	10.3	-0.22	0.99
12:20-13:20	6.69	1.25	222.3	12.5	-0.25	1.07

Table 4. Meteorological measurements of wind speed, direction, vertical velocity and the standard deviations of these at 115 m above ground from the mast at Gladsaxe May 22, 1984.

time (CET) from to	wind speed mean (m/s)	wind speed st.dev. (m/s)	wind direction mean (deg)	wind direction st.dev. (deg)	vertical velocity mean (m/s)	vertical velocity st.dev. (m/s)
09:11-09:20	10.36	1.86	91.6	7.1	0.57	1.09
09:20-09:30	10.65	1.78	95.8	6.3	0.31	0.98
09:30-09:40	11.25	1.45	92.4	5.8	0.23	1.04
09:40-09:50	10.19	1.27	87.7	7.2	0.25	1.05
09:50-10:00	11.07	1.36	85.7	6.9	0.14	1.02
10:00-10:10	12.03	1.93	82.7	6.9	0.25	1.12
10:10-10:20	11.43	1.69	85.8	6.4	0.41	1.12
10:20-10:30	11.40	1.80	85.1	8.1	0.56	1.20
10:30-10:40	12.15	1.63	86.0	7.7	0.34	1.23
10:40-10:50	12.37	2.17	90.9	7.1	0.52	1.40
10:50-11:00	13.75	1.89	90.0	6.4	0.41	1.16
11:00-11:10	13.21	1.44	91.7	6.9	0.23	1.26
11:10-11:20	12.26	1.93	91.8	6.7	0.31	1.32
11:20-11:30	12.50	1.75	90.1	5.8	0.20	1.06
11:40-11:50	10.19	2.14	91.1	8.2	0.40	1.36
11:50-12:00	10.93	1.99	92.5	8.4	0.30	1.35
12:00-12:10	12.98	1.89	91.2	7.1	0.45	1.32
12:10-12:10	14.79	1.72	89.4	6.2	-0.26	0.96
09:11-12:10	11.68	2.06	89.6	7.8	0.34	1.19
11:00-12:00	11.70	2.10	91.3	7.3	0.28	1.24

Table 5. Meteorological measurements of wind speed, direction, vertical velocity and the standard deviations of these at 115 m above ground from the mast at Gladsaxe May 29, 1984.

time	wind speed		wind direction		vertical velocity	
(CET)	mean	st.dev.	mean	st.dev.	mean	st.dev.
from to	(m/s)	(m/s)	(deg)	(deg)	(m/s)	(m/s)
08:03-08:10	9.27	0.83	60.4	3.8	0.29	0.57
08:10-08:20	8.76	1.13	66.8	4.9	0.31	0.65
08:20-08:30	8.36	0.99	75.3	5.6	0.32	0.72
08:30-08:40	7.76	1.04	76.6	6.5	0.24	0.73
08:40-08:50	7.73	0.88	77.8	6.9	0.14	0.78
08:50-09:00	8.21	1.20	78.0	5.7	0.11	0.68
09:00-09:10	7.59	1.43	79.1	7.2	0.21	0.87
09:10-09:20	6.87	0.93	86.9	7.6	0.04	0.92
09:20-09:30	6.45	0.86	84.3	8.6	0.46	0.99
09:30-09:40	5.54	1.00	81.9	11.4	0.94	1.00
09:40-09:50	7.41	1.26	81.9	7.3	0.49	0.90
09:50-10:00	6.95	1.13	83.3	8.3	0.43	1.04
10:00-10:10	7.87	1.17	83.4	7.6	0.26	0.90
10:10-10:20	7.83	1.12	84.4	8.1	0.19	1.04
10:20-10:30	6.43	1.25	84.2	10.5	0.77	1.07
10:30-10:40	8.18	1.16	85.2	6.6	0.08	0.75
10:40-10:50	8.11	1.05	85.7	7.0	-0.13	0.83
10:50-11:00	8.12	1.41	90.4	7.4	0.31	1.07
11:00-11:10	6.75	1.22	89.2	10.0	0.94	0.99
11:10-11:20	6.68	1.33	91.1	9.3	0.56	1.09
11:20-11:30	8.19	1.10	93.0	7.9	-0.04	1.08
11:30-11:40	8.80	1.17	98.0	7.3	-0.02	0.95
11:40-11:50	8.16	2.00	97.1	9.9	0.22	1.09
11:50-12:00	9.09	1.53	96.3	6.8	0.07	1.11
12:00-12:04	9.60	1.46	96.1	6.9	-0.40	1.11
08:03-12:04	7.73	1.52	84.3	11.5	0.29	0.98
11:00-12:00	7.94	1.70	94.1	9.2	0.29	1.11

Table 6. Meteorological measurements of wind speed, direction, vertical velocity and the standard deviations of these at 115 m above ground from the mast at Gladsaxe May 30, 1984.

time	wind speed		wind direction		vertical velocity	
(CET)	mean	st.dev.	mean	st.dev.	mean	st.dev.
from to	(m/s)	(m/s)	(deg)	(deg)	(m/s)	(m/s)
08:00-08:10	7.67	1.73	109.9	5.2	-0.31	0.86
08:10-08:20	7.40	1.30	108.5	5.6	-0.27	0.81
08:20-08:30	6.85	1.78	110.2	6.4	-0.22	0.84
08:30-08:40	7.63	1.50	105.6	4.7	-0.21	0.86
08:40-08:50	7.15	1.19	94.8	5.9	0.25	0.73
08:50-09:00	7.06	1.05	88.5	7.7	0.19	0.75
09:00-09:10	7.71	0.81	85.9	6.9	0.04	0.80
09:10-09:20	6.77	1.14	89.4	8.0	0.46	1.00
09:20-09:30	7.27	1.20	95.8	6.2	-0.07	0.82
09:30-09:40	6.10	1.55	101.0	8.5	0.04	0.85
09:40-09:50	5.64	1.30	106.9	5.8	-0.02	0.87
09:50-10:00	5.73	0.88	106.2	4.3	-0.05	0.60
10:00-10:10	5.27	0.91	108.8	4.3	-0.38	0.48
10:10-10:20	4.26	1.31	109.6	8.8	0.24	0.75
10:20-10:30	3.88	0.94	114.8	4.1	-0.67	0.34
10:30-10:40	3.67	0.97	114.8	6.5	-0.32	0.64
10:40-10:50	4.07	0.99	112.3	6.0	-0.41	0.52
10:50-11:00	3.04	0.50	125.9	9.0	-0.08	0.50
11:00-11:10	3.60	0.68	136.0	6.8	0.08	0.68
11:10-11:20	3.28	0.47	130.6	5.8	-0.08	0.39
11:20-11:30	3.13	0.53	129.2	6.1	0.08	0.47
11:30-11:40	3.04	0.63	140.9	8.7	0.15	0.54
11:40-11:50	3.18	0.86	147.7	11.2	0.11	0.50
11:50-12:00	4.26	0.62	155.9	6.8	-0.01	0.56
12:00-12:06	3.55	0.48	153.2	9.9	0.68	0.42
08:00-12:06	5.27	2.04	114.8	20.3	-0.04	0.74
11:00-12:00	3.41	0.77	140.0	12.3	0.05	0.54

Table 7. Meteorological measurements of wind speed, direction, vertical velocity and the standard deviations of these at 115 m above ground from the mast at Gladsaxe June 4, 1984.

time (CET) from to	wind speed		wind direction		vertical velocity	
	mean (m/s)	st.dev. (m/s)	mean (deg)	st.dev. (deg)	mean (m/s)	st.dev. (m/s)
08:30-08:40	10.29	1.51	89.4	7.0	0.14	1.05
08:40-08:50	9.87	1.20	89.8	7.0	0.25	0.91
08:50-09:00	9.29	1.58	88.3	7.7	0.30	1.00
09:00-09:10	9.93	1.35	89.2	6.6	0.33	1.06
09:10-09:20	9.87	1.35	87.5	6.3	0.30	0.98
09:20-09:30	9.84	1.37	87.7	7.3	0.33	1.02
09:30-09:40	10.14	1.58	88.6	6.8	0.45	1.13
09:40-09:50	11.15	1.36	85.8	6.1	0.26	0.98
09:50-10:00	10.17	1.68	86.9	6.1	0.45	1.14
10:00-10:10	10.49	1.28	87.4	7.1	0.45	1.11
10:10-10:20	10.92	1.60	86.9	6.1	0.36	1.12
10:20-10:30	10.72	1.35	85.2	7.1	0.30	1.15
10:30-10:40	10.94	1.67	87.2	7.3	0.23	1.04
10:40-10:50	10.17	1.49	85.3	7.3	0.71	1.10
10:50-11:00	11.05	1.64	86.2	7.0	0.16	1.22
11:00-11:10	12.18	1.32	84.2	5.6	0.21	1.10
11:10-11:20	12.11	1.54	85.6	5.7	0.29	1.10
11:20-11:30	12.19	1.33	85.4	6.7	0.47	1.11
11:30-11:40	11.72	1.44	87.8	6.5	0.47	1.06
11:40-11:50	12.18	1.41	88.3	5.4	0.23	0.91
11:50-12:00	11.63	1.49	90.6	5.8	-0.03	0.97
12:00-12:09	10.41	1.56	89.3	8.2	0.57	1.23
08:30-12:09	10.78	1.70	87.4	6.9	0.33	1.08
11:00-12:00	12.00	1.44	87.0	6.3	0.27	1.06

Table 8. Meteorological measurements of wind speed, direction, vertical velocity and the standard deviations of these at 115 m above ground from the mast at Gladsaxe June 5, 1984.

time	wind speed		wind direction		vertical velocity	
(CET)	mean	st.dev.	mean	st.dev.	mean	st.dev.
from to	(m/s)	(m/s)	(deg)	(deg)	(m/s)	(m/s)
08:00-08:10	9.80	1.33	76.7	6.3	0.44	0.88
08:10-08:20	9.91	1.08	79.7	4.9	0.31	0.73
08:20-08:30	8.28	1.09	80.7	7.5	0.41	0.90
08:30-08:40	8.78	1.21	76.5	7.4	0.27	0.87
08:40-08:50	8.79	1.15	75.4	6.1	0.28	0.87
08:50-09:00	9.85	1.36	73.2	6.9	0.25	1.04
09:00-09:10	9.05	1.39	71.2	7.3	0.33	1.02
09:10-09:20	8.25	1.82	73.1	6.8	0.72	0.99
09:20-09:30	8.61	1.64	74.9	8.3	0.51	1.18
09:30-09:40	9.81	1.40	79.8	7.7	0.43	1.10
09:40-09:50	10.94	1.26	78.5	5.2	0.33	0.95
09:50-10:00	10.06	1.25	81.3	5.3	0.28	1.02
10:00-10:10	10.35	1.28	82.0	7.4	0.02	1.01
10:10-10:20	9.48	1.58	83.9	9.5	0.69	1.29
10:20-10:30	9.23	1.50	84.3	7.6	0.47	1.14
10:30-10:40	9.66	1.62	87.2	8.6	0.65	1.42
10:40-10:50	10.14	1.68	87.3	9.3	0.46	1.35
10:50-11:00	10.23	1.62	88.2	7.3	0.32	1.12
11:00-11:10	10.28	1.59	84.7	6.6	0.24	1.10
11:10-11:20	10.72	1.13	85.5	7.2	0.07	1.04
11:20-11:30	10.87	1.29	88.2	6.3	0.09	0.89
11:30-11:40	10.75	1.60	88.7	6.9	0.17	1.08
11:40-11:50	10.95	1.54	89.3	6.8	0.26	1.28
11:50-12:00	11.78	1.27	90.4	5.3	0.13	1.01
12:00-12:10	10.74	1.66	92.7	9.7	0.53	1.09
12:10-12:11	11.24	1.25	90.9	7.2	0.26	1.05
08:00-12:11	9.90	1.69	82.2	9.4	0.35	1.08
11:00-12:00	10.89	1.48	87.8	6.9	0.16	1.08

Table 9. Meteorological measurements of wind speed, direction, vertical velocity and the standard deviations of these at 115 m above ground from the mast at Gladsaxe June 12, 1984.

time (CET) from to	wind speed mean (m/s)	 st.dev. (m/s)	wind direction mean (deg)	 st.dev. (deg)	vertical velocity mean (m/s)	 st.dev. (m/s)
08:30-08:40	5.25	0.53	256.3	7.6	-0.48	0.79
08:40-08:50	5.76	0.67	243.5	5.6	-0.49	0.73
08:50-09:00	5.07	1.02	239.8	12.2	-0.32	1.06
09:00-09:10	5.17	0.87	245.6	10.4	0.16	0.98
09:10-09:20	6.02	0.52	256.5	5.8	-0.83	0.78
09:20-09:30	6.23	0.67	259.0	6.4	-0.42	0.73
09:30-09:40	4.72	1.28	248.6	9.7	0.08	1.18
09:40-09:50	4.42	0.88	249.7	17.7	0.31	1.06
09:50-10:00	5.34	1.48	259.3	6.8	-0.61	1.03
10:00-10:10	-	-	255.4	15.9	0.10	1.18
10:10-10:20	-	-	245.7	11.3	-0.21	1.20
10:20-10:30	-	-	246.6	14.6	0.13	0.89
10:30-10:40	-	-	266.8	6.6	-0.22	0.77
10:40-10:50	-	-	250.6	11.7	0.14	0.96
10:50-11:00	-	-	249.1	18.0	0.24	1.18
11:00-11:10	-	-	282.7	11.0	0.19	1.01
11:10-11:20	-	-	269.5	12.4	0.06	1.19
11:20-11:30	-	-	266.2	17.5	0.85	0.95
11:30-11:40	-	-	271.0	7.8	0.23	1.11
11:40-11:50	-	-	264.3	11.8	0.16	1.15
11:50-12:00	-	-	278.6	9.0	-0.16	1.15
12:00-12:10	-	-	262.1	16.0	0.20	1.05
12:10-12:20	-	-	270.8	8.6	-0.10	0.97
12:20-12:30	-	-	268.5	13.3	-0.28	1.12
12:30-12:40	-	-	260.8	12.9	-0.10	1.29
12:40-12:50	-	-	256.4	13.9	-0.64	1.48
12:50-12:50	-	-	249.9	6.0	-0.56	0.98
08:30-12:50	-	-	258.6	16.1	-0.08	1.11
11:45-12:45	-	-	267.7	13.6	-0.02	1.14

Table 10. Meteorological measurements of wind speed, direction, vertical velocity and the standard deviations of these at 115 m above ground from the mast at Gladsaxe June 14, 1984.

time (CET) from to	wind speed mean (m/s)	wind speed st.dev. (m/s)	wind direction mean (deg)	wind direction st.dev. (deg)	vertical velocity mean (m/s)	vertical velocity st.dev. (m/s)
09:00-09:10	-	-	323.0	10.2	0.08	0.79
09:10-09:20	-	-	324.3	10.6	0.36	1.00
09:20-09:30	-	-	319.7	10.6	0.40	0.98
09:30-09:40	-	-	329.0	10.2	0.11	1.03
09:40-09:50	-	-	317.4	9.8	-0.43	0.77
09:50-10:00	-	-	315.7	9.3	0.04	0.86
10:00-10:10	-	-	321.8	12.3	-0.10	0.91
10:10-10:20	-	-	319.7	12.9	0.27	1.08
10:20-10:30	-	-	301.6	6.5	0.30	0.91
10:30-10:40	-	-	329.6	16.4	1.04	1.11
10:40-10:50	-	-	309.4	10.3	-0.20	0.98
10:50-11:00	-	-	303.8	12.1	-0.19	1.10
11:00-11:10	-	-	302.3	16.5	0.03	0.83
11:10-11:20	-	-	317.0	5.6	-0.40	0.82
11:20-11:30	-	-	310.3	10.4	0.30	1.02
11:30-11:40	-	-	306.5	9.6	0.17	0.96
11:40-11:50	-	-	295.5	4.8	-0.38	0.62
11:50-12:00	-	-	291.0	9.8	-0.18	0.80
12:00-12:10	-	-	296.8	8.6	0.13	1.10
12:10-12:20	-	-	298.5	9.5	0.07	1.13
12:20-12:30	-	-	298.1	7.9	-0.09	0.81
12:30-12:40	-	-	296.0	4.9	-0.54	0.68
12:40-12:50	-	-	290.9	6.5	-0.08	0.80
12:50-13:00	-	-	285.6	5.5	-0.26	0.73
13:00-13:10	-	-	285.0	5.9	0.01	0.83
13:10-13:20	-	-	292.3	7.8	-0.09	0.86
13:20-13:30	-	-	293.2	5.8	-0.25	0.88
13:30-13:40	-	-	298.8	4.8	-0.18	0.91
13:40-13:50	-	-	287.6	10.3	0.45	1.29
13:50-14:00	-	-	292.1	7.9	-0.18	1.03
14:00-14:10	-	-	287.3	9.0	0.12	1.13
14:10-14:14	-	-	291.0	3.9	-0.54	0.72
09:00-14:14	-	-	304.3	16.6	0.00	0.99
13:00-14:00	-	-	291.5	8.5	-0.04	1.01

3. PROFILE MEASUREMENTS AT MASTS

3.1. Small masts

Measurements of wind speed and direction, temperature and temperature difference were carried out at Avedøre, Margretheholm, Saltholm and Sjælsmark. Humidity and pressure were measured at Avedøre, Saltholm and Sjælsmark. The instrumental set-up differs from mast to mast; however, the same types of instruments were employed at all of the masts. The measurements were taken every 5 min, except for the masts at Risø, where the measurements were taken every 10 min. Wind direction, temperature, temperature difference, humidity and pressure are instantaneous values at the time of scanning. The wind speed was averaged over the five- or ten-minute sampling period.

3.1.1. Instruments

Wind speed was measured with a cup-anemometer identical to the Risø model 70 type described in Chapter 2, except that it outputs two electric pulses per rotation of the cups. The pulses are counted and the numbers are converted to wind speed. All of the cup-anemometers are calibrated individually.

Wind direction was measured by a wind vane (Aanderaa Instruments, wind direction sensor 2750). It consists of a light wind vane turning on a vertical pivot. The vane is coupled magnetically to an accompanying device inside the housing. The accompanying device is clamped when the direction is read. In order to damp the vane movements the space between the pivot and the surrounding shaft is filled with silicone oil. The oil damping permits the vane to line up at even very light wind, but effectively damps the influence of rapid fluctuations in the wind direction.

The temperature and temperature differences were measured by platinum-resistance thermometers fitted inside a radiation screen (Aanderaa Instruments, air temperature sensor 1289 and radiation screen 4011). The radiation screen, being ventilated solely by the wind, protects the temperature probe effectively from the incoming and outgoing radiation. Measurements of temperatures, in which the probes were shielded by various types of screens, have been carried out at Risø. The screen used here turned out to be equally good as the ventilated screens at moderate and high wind speeds (say more than 1-2 ms^{-1}).

A Stevenson screen was placed at some of the masts. Inside the screen measurements of temperature, humidity and pressure were carried out. The temperature sensors were of the type described above. Pressure was measured by a sensitive aneroid barometer (Yellow Spring Instruments, Sostman model 2014 barometric pressure transducer). The long-term accuracy of the instrument is ±0.4 mb. In order to improve the short-term accuracy of the measurements, allowing for the determination of the pressure gradient in the area, all instruments measuring pressure at fixed positions as a part of this experiment, were intercompared (see chapter 5 for details).

Humidity was measured by a hair hygrometer (Lambrecht, Pr No. 800). Each humidity sensor was calibrated, using an Assmann psychrometer as reference. This was done by measuring the humidity each time the mast was serviced. After a number of maintenance visits the relevant humidity range was covered, enabling us to construct the regression line between air humidity measured by a hair hygrometer and Assmann psychrometer. Thus, each hair hygrometer was individually calibrated at the measuring position.

The registration was carried out by a datalogger (Aanderaa DL-1); it contains a mechanical scanner that reads the contents of the channels every five min. Each reading of all the channels takes less than one min. The results are stored on magnetic tape.

3.1.2. Avedøre

The meteorological mast at Avedøre is situated on a 4-m high embankment looking directly to the sea. The embankment runs 90-270°. The measurements at the lowest part of the mast are likely to be influenced by the embankment, but the upper measurements will be outside the influenced zone. The influence will vary as function of the wind direction, being smallest at northerly and largest at southerly winds. Figure 5 shows the mast. Instrumentation and position are given in Table 11.

Measurements at the mast were carried out continuously in the period May 15 to June 11 at 00:55. Data from the remaining part of the measuring period lack due to technical problems with the datalogging system.

Table 11. Instrumentation and position of the mast at Avedøre.

sensor height above mast base (m)					
wind speed	wind direction	temperature	temperature difference	pressure	humidity
3.53		2.04	7.57- 2.04	1*	1*
4.97			14.26- 7.57		
7.97	7.97		19.09-14.26		
11.95			30.88-19.09		
14.66					
19.49					
24.32					
31.58	31.58	30.88			

Position UTM-33 E 339580 m N 6165180 m
Base of mast is 4 m above mean sea level.

* Stevenson screen.

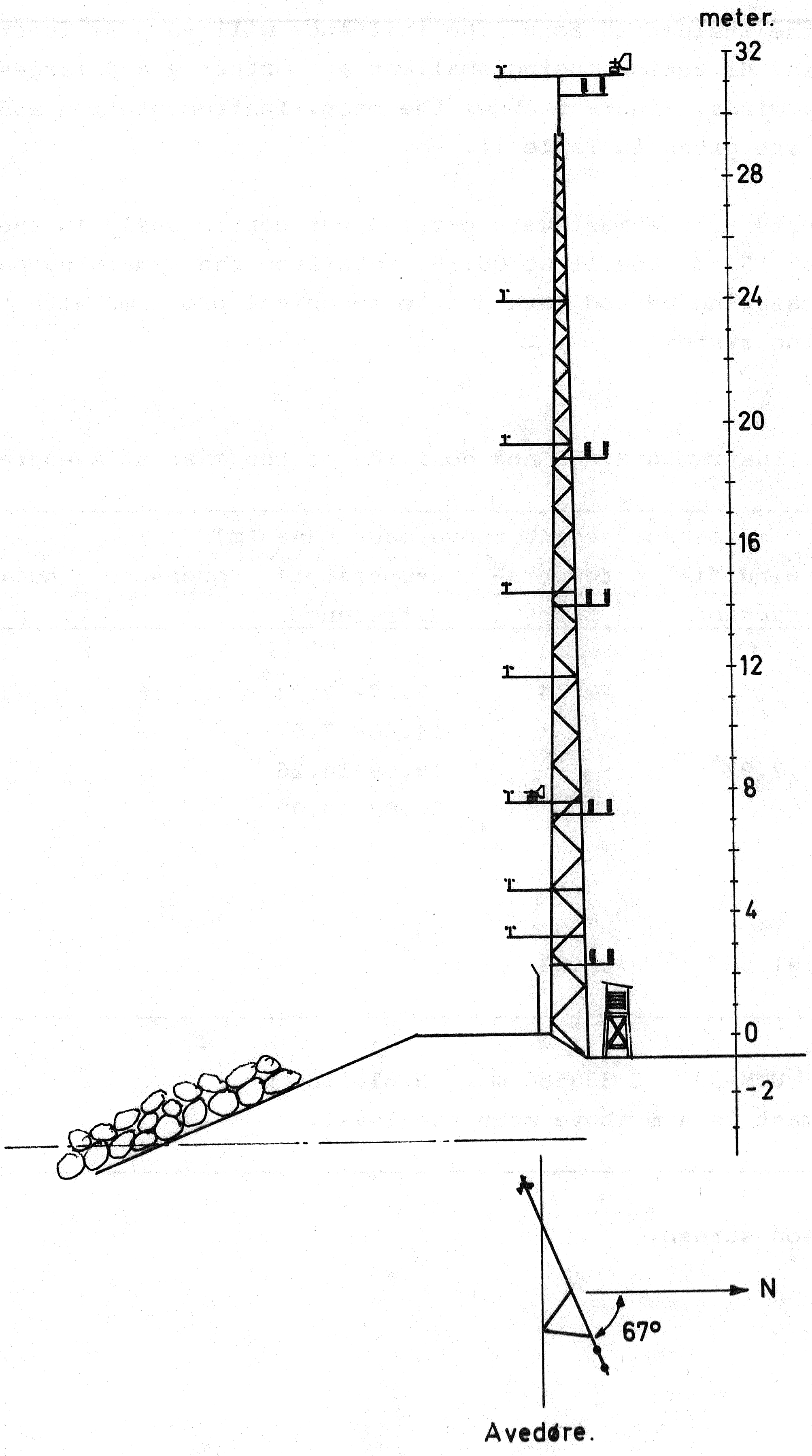


Fig. 5. Sketch and geographical orientation of the Avedøre mast.

3.1.3. Saltholm (east)

The meteorology mast at Saltholm operated by Risø is situated at the eastern part of Saltholm about 10 m from the coast line. The position was chosen such that the measurements reflect the over-water condition over Øresund at easterly winds.

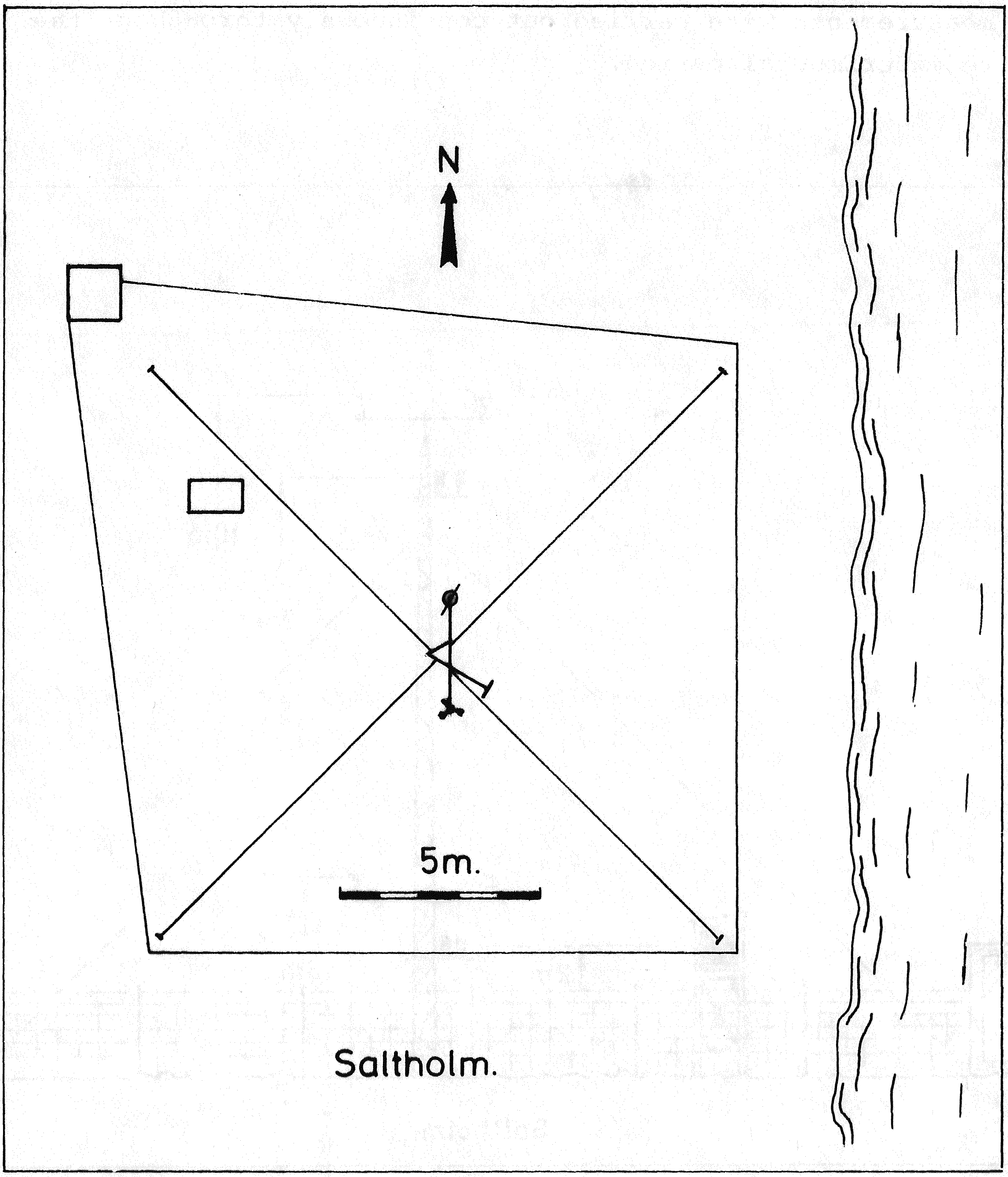


Fig. 6. Surroundings and geographical orientation of the Saltholm mast.

The surrounding area consists of grassland. The grass around the mast was kept short in the experimental period. In order to keep an abundance of cattle - which are at pasture on Saltholm during the summer - away from the mast, a fence 1½ m in height was put around it, see Fig. 6. Figure 7 shows the mast. Instrumentation and position of the mast are given in Table 12.

The measurements were carried out continuously throughout the entire experimental period.

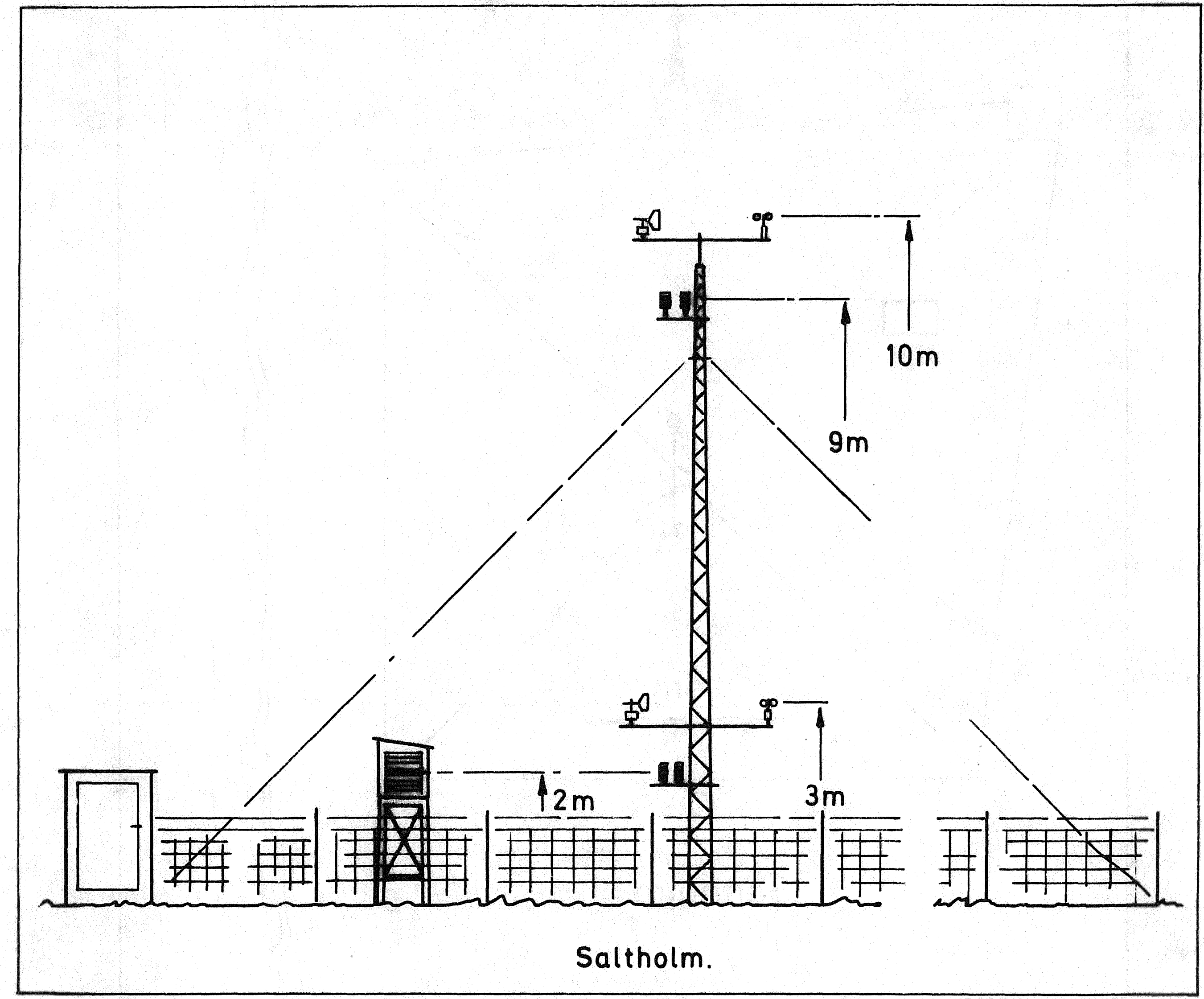


Fig. 7. Sketch of the Saltholm mast.

Table 12. Instrumentation and position of the mast at Saltholm.

Sensor height above mast base (m)					
wind speed	wind direction	temperature	temperature difference	pressure	humidity
3.0	3.0	2.0	9.0 - 2.0	2*	2*
10.0	10.0	9.0			

Position UTM-33 E 360330 m N 6170560 m
Base of mast is 1 m above mean sea level.

* Stevenson screen.

3.1.4. Sjælsmark

The meteorology mast at Sjælsmark was situated in a military training area on a flat plateau on top of a small hill in a generally undulating terrain. The area is covered with grass, but with large parts lacking vegetation due to excessive terrain driving of military equipment. The mast is situated 8 km west of the Øresund coast. Figure 8 shows a sketch of the mast. Instrumentation and position are given in Table 13.

Measurements were carried out continuously throughout the experimental period.

Table 13. Instrumentation and position of the mast at Sjælsmark.

Sensor height above mast base (m)					
wind speed	wind direction	temperature	temperature difference	pressure	humidity
3.0		3.0	10.0-3.0	2*	2*
10.0	10.0	10.0			

Position UTM-33 E 338670 m N 6195650 m
Base of mast is 30 m above mean sea level

*Stevenson screen.

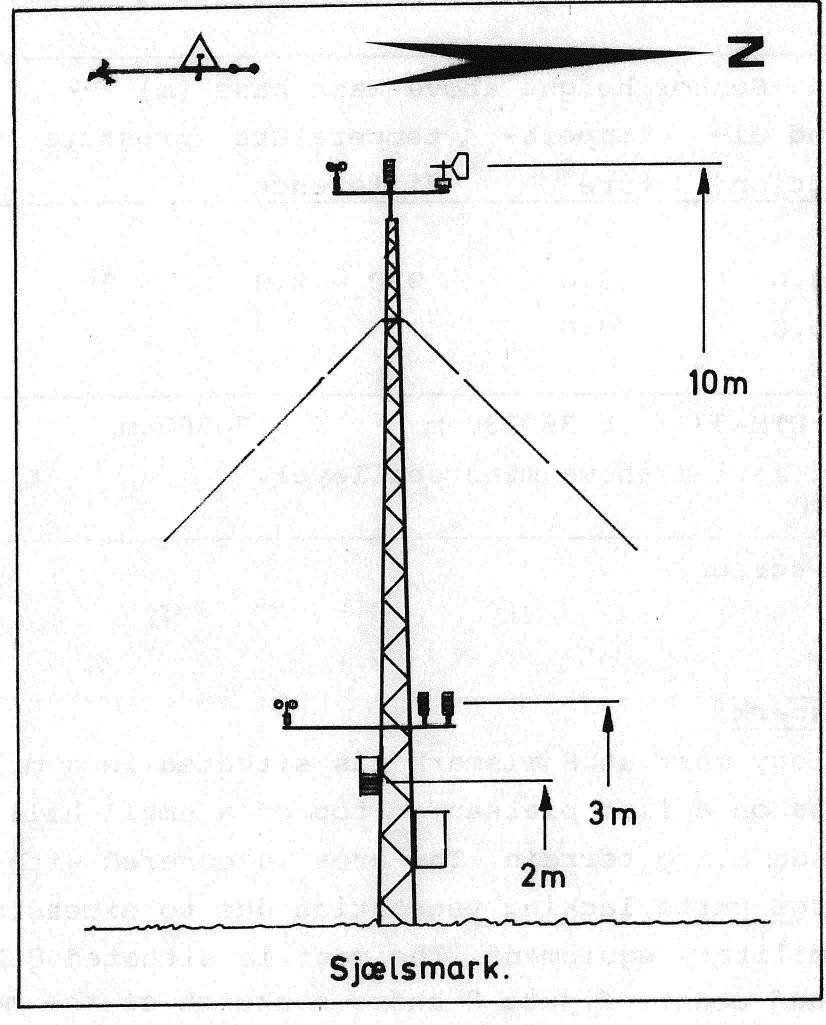


Fig. 8. Sketch and geographical orientation of the Sjælsmark mast.

3.1.5. Margretheholm

The meteorological mast at Margretheholm is situated in a mixed industrial and office area. One or two storage buildings lie to the west, south and east about 50 m from the mast. To the north the fetch is unobstructed for about 500 m, looking over a harbour mainly used for small sailing boats. Figure 9 shows the mast; its instrumentation and position are given in Table 14. The mast was in continuous operation throughout the experimental period.

Table 14. Instrumentation and position of the mast at Margretheholm.

Sensor height above mast base (m)			
wind speed	wind direction	temperature	temperature difference
		2.0	38.8 - 2.0
38.9	38.9	38.8	

Position UTM-33 E 350020 m N 6173980 m

Base of mast is 3 m above mean sea level.

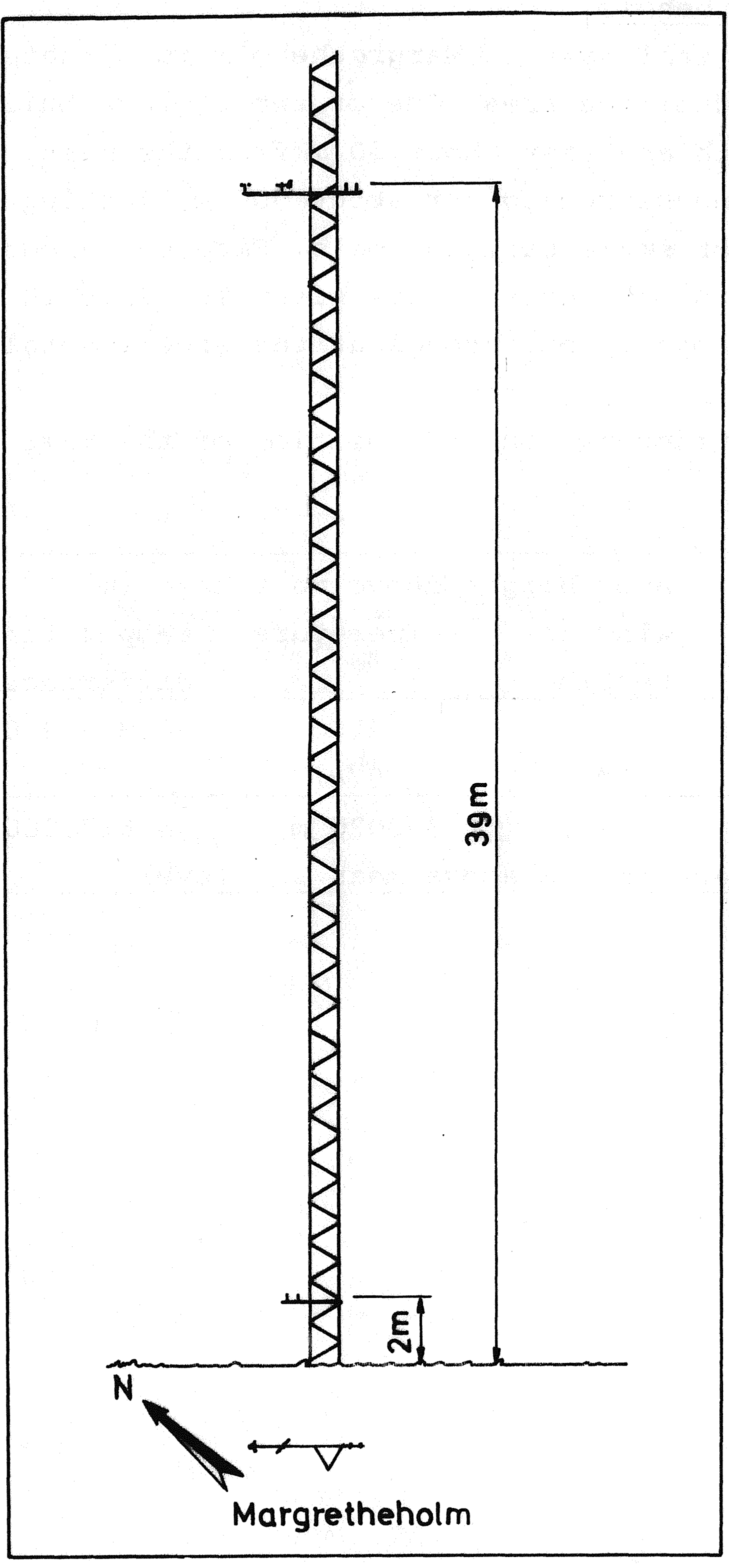


Fig. 9. Sketch and geographical orientation of the Margretheholm mast.

3.2. The Risø Mast

The 117-m mast is situated at the Risø Peninsula, Fig. 10. At the western tip of the peninsula the coast forms a rather steep slope which rises to about 10 m above mean sea level. The western half of the peninsula is gently rolling land with the meteorological tower erected on a 6-m hill. East of the mast is a meadow, bordered to the south by a road with 10-m high trees along the road.

The measurements that were carried out at the Risø mast (Fig. 11), differ somewhat from the measurements at the small masts. The

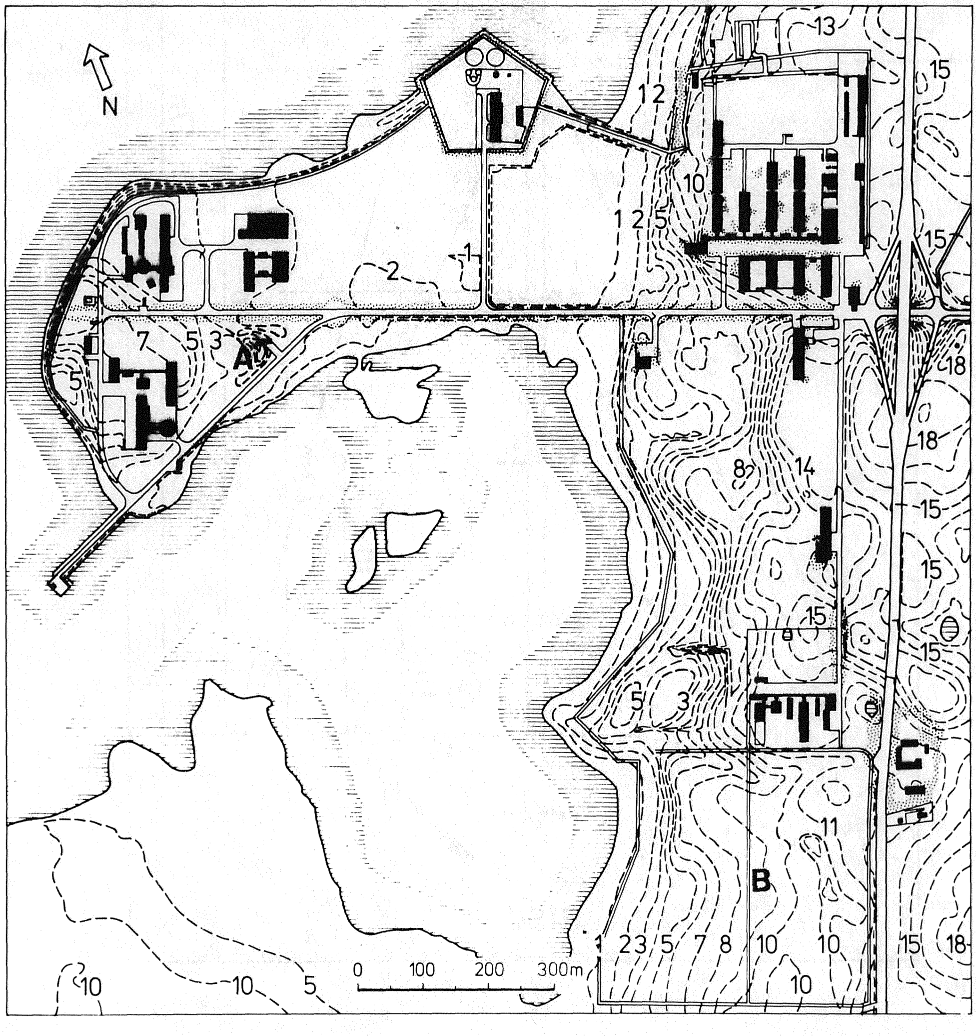


Fig. 10. Surroundings and location of the meteorological masts at Risø; A) indicates the position of the 117-m mast, and B) the position of the 33-m mast.

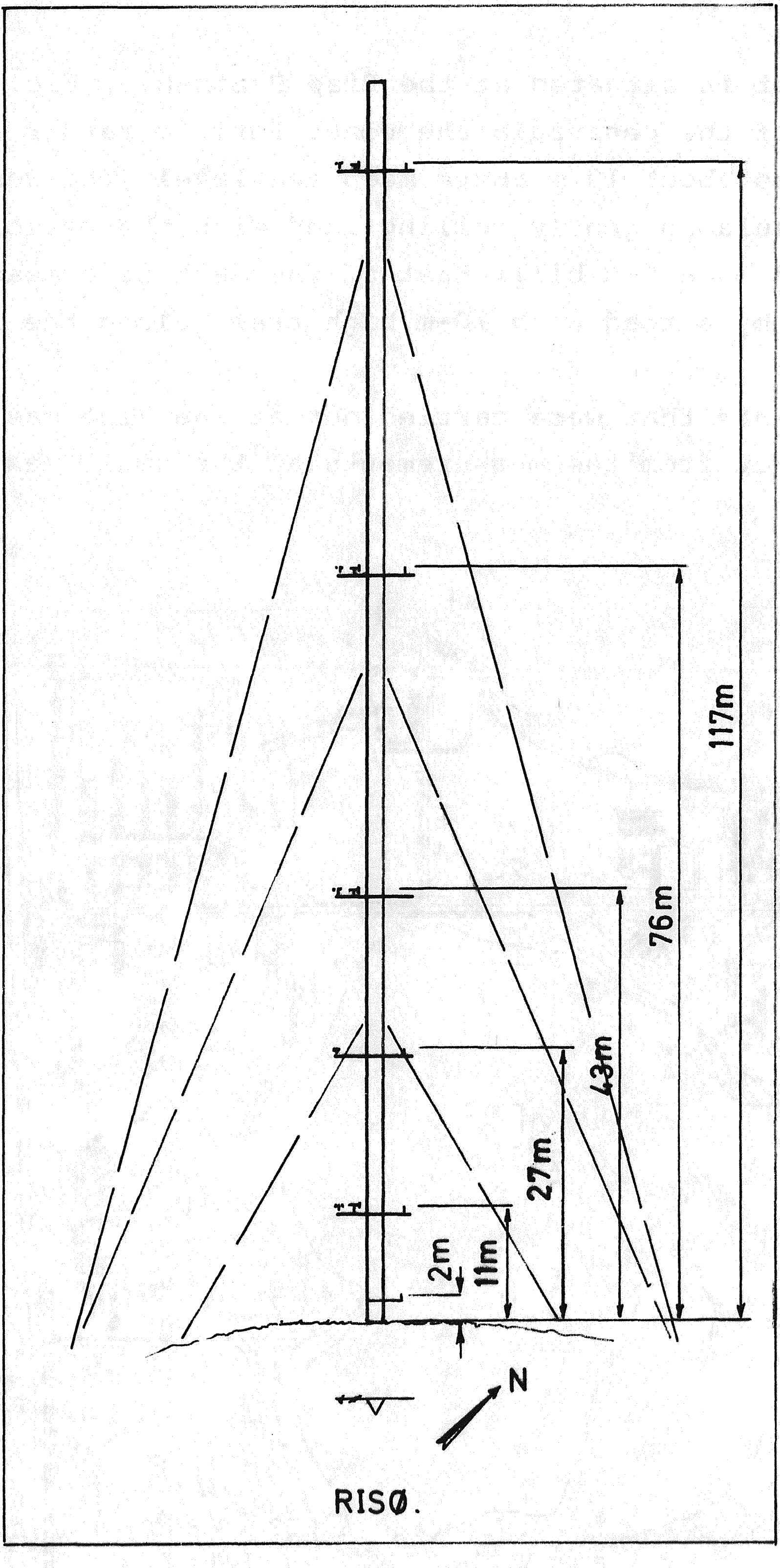


Fig. 11. Sketch of the 117-m meteorological mast at Risø.

reason is that some of the facilities lacking at the small masts are available at the Risø mast, the most important being access to electrical power. Table 15 gives the measuring levels of the instrumentation. Wind speed is measured with Risø model 70

Table 15. Instrumentation and position of the Risø mast.

Sensor height above mast base (m)			
wind speed	wind direction	Wind direction variance	temperature
			2.0
11.0	11.0	11.0	11.0
27.0			27.0
43.0	43.0	43.0	
76.0	76.0	76.0	76.0
117.0	117.0		117.0

Stevenson screen 2 m above ground: temperature and pressure.

Precipitation: pluviograph with weekly chart

Radiation measurements: net radiation, global radiation and direct-beam short-wave radiation.

Position of mast: UTM-33 E 317070 m N 6176090 m

Base of mast is 6 m above mean sea level

cup-anemometers. The wind direction is measured with light-weight wind vanes similar to the one used at the Gladsaxe mast. From the wind vane signals the lateral standard deviation of the wind direction fluctuations are computed. Temperature and temperature difference are measured by quartz thermometers shielded in ventilated screens. These instruments are mounted 1-4 m from the lattice of the tower on booms directed to the southwest. All measurements are averaged over 10 min. A Stevenson screen is located close to the tower, in this measurements of temperature, wet-bulb temperature and pressure are carried out. All measurements from the mast are recorded consecutively as 10-min averages. However, the measurements at Risø are displaced 5 min relative to what was agreed upon for the Øresund-experiment. This time shift could not be changed because the mast acts as a climatological station and consequently must retain its characteristics.

Direct-beam short-wave radiation was measured using a Eppley pyrheliometer (mod. NIP) and the global radiation using an Eppley pyranometer (mod. PSP). Both instruments are temperature compensated. They were mounted on the roof of a 15-m high building, 200 m southwest of the Risø mast with an almost unobscured horizon. As judged from the night-time values of shortwave radiation, the pyrheliometer and pyranometer have a bias of -0.7 Wm^{-2} and $+6.7$ Wm^{-2}, respectively. The net radiation was determined with a Middleton (CSIRO) net pyrradiometer (mod. CN2), 1 m above long grass vegetation. The characteristics of the three instruments are summarized in Table 16.

Table 16. Characteristics of radiation measurements

	resolution Wm^{-2}	accuracy* %	response time* sec.
pyrheliometer	2.3	-	-
pyranometer	2.1	1	1
net pyrradiometer	1.4	-	90

*according to manufacturer's specifications.

The radiation instruments have been compared earlier with reference instruments as a general check on their performance. The measurements at Risø were carried out without interruption throughout the experimental period.

The terrain within 1 km of the 117-m mast is rather inhomogeneous due to the varying patterns of land and water surfaces, and the Risø peninsula itself comprises a complex mixture of buildings and trees. Consequently, the lower measurement levels of the mast are strongly influenced by these inhomogeneities. Therefore, we have included the measurements of another mast at Risø, situated in a less obstructed landscape. The small meteorological mast (33 m) is situated 1100 m SSE of the Risø mast, and is the reference mast of the Test Station for Windmills. The distance to the water is 200 m in a westerly direction, and the elevation of the mast is 8.5 m above sea level. The ground surface around the mast consists of corn fields. The exposure is generally good, though for northerly and southerly winds the mast will be in the wake of the windmills, and from N to NE there are some one-storeyed buildings at a distance of about 200 m.

The instrumentation and data acquisition system is similar to that of the small masts described in paragraph 3.1.1, whereas the scanning times are synchronous with the Risø mast. The averaging time is thus 10 min.

The mast was in continuous operation throughout the experimental period. Fig. 12 shows a sketch of the mast, and the instrumentation and position are given in Table 17.

Table 17. Instrumentation and position of the small mast at Risø.

Sensor height above mast base (m)			
wind speed	wind direction	temperature	temperature difference
3.0	3.0	2.0	9.0 - 2.0
10.0	10.0		32.0 - 9.0
20.0			
33.0	33.0	32.0	

Position UTM-33 E 317620 m N 6175140 m

Base of mast is 8.5 m above mean sea level.

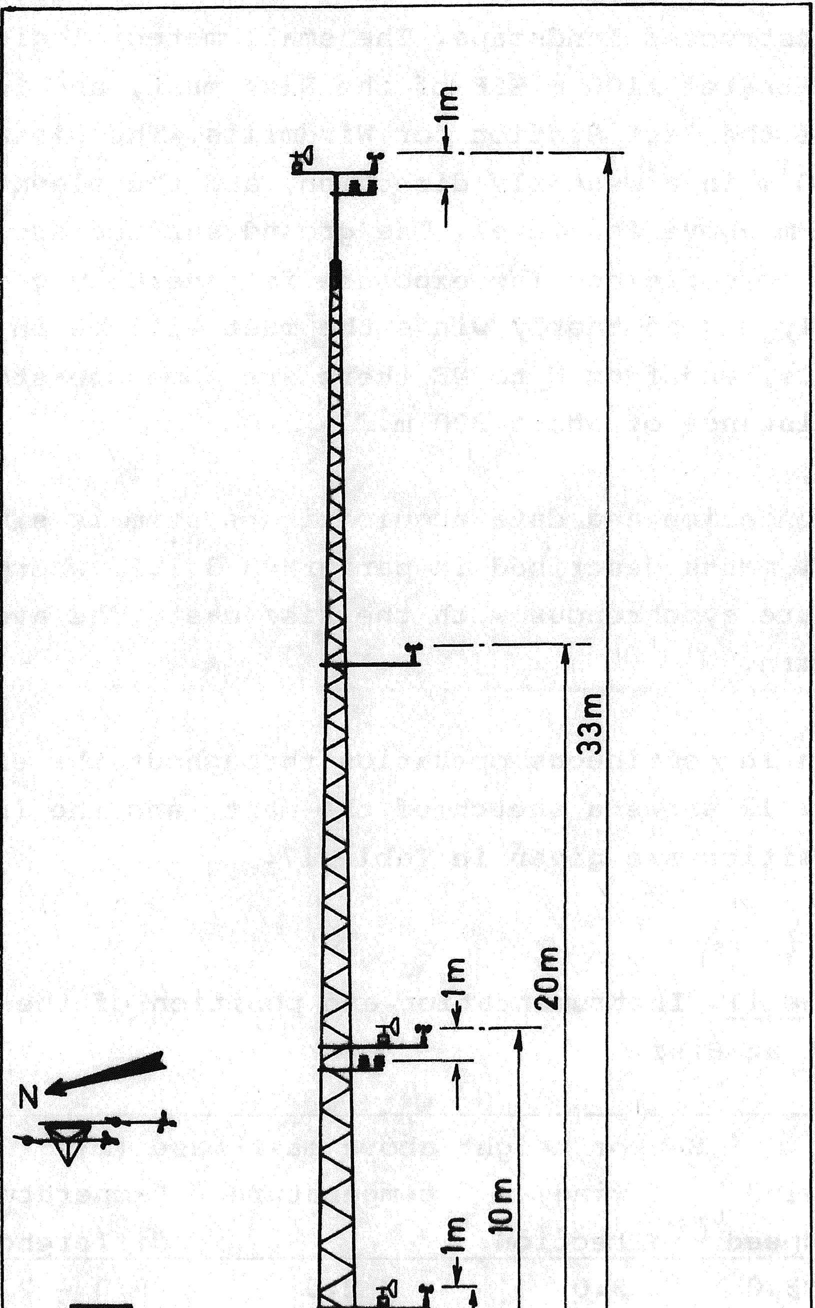


Fig. 12. Sketch of the 33-m mast at Risø.

4. PROFILE MEASUREMENTS BY MINI RADIOSONDES

During tracer releases so-called mini-sondes were launched from a fishing boat at various positions in Øresund. The mini-sondes used were of two types, one system (AIRSONDE) belongs to Risø National Laboratory, and the other one of type A. Sprenger is owned by the Swedish Defence Weather Service. Both systems were operated by Kjell Ericson from the Swedish Meteorological and Hydrological Institute.

4.1. The AIRSONDE system

This mini-sonde system consists of a sensor package (mini-sonde) transmitting data to a ground station every six sec. The system used here is the AIRSONDE^{TM} Model AS-1A which is manufactured by Atmospheric Instrumentation Research Incorporated, Boulder, USA. The sensors and electronics in the mini-sonde are contained in a styrofoam package that has the form of a helicord propeller, Fig. 13. The total mass of a mini-sonde is 130 g. As the mini-sonde rises, its spinning aspirates two bead thermistors mounted in radiation shields at the tips of the propeller. One of these

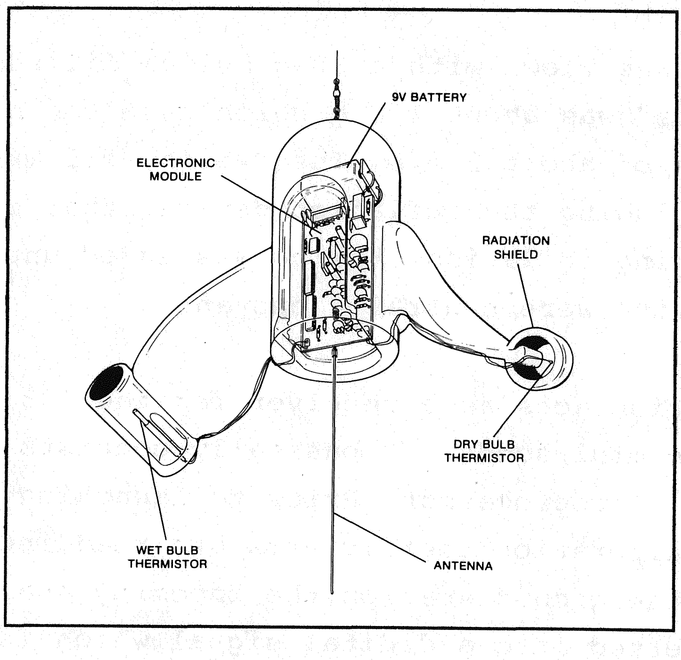


Fig. 13. Schematic showing of an AIRSONDE.

is covered with a wick wetted by water that is contained in a small reservoir, and the two form a psychrometer. The bead thermistors are epoxy-coated and each of them is mounted in its own radiation shield. The shield, a tube of molded styrofoam, has a small thermal capacity and is a good thermal insulator. The dry bulb thermistor has a time constant of 10 seconds in still air and 3-5 seconds with the rotational aspiration that occurs at nominal ascent rates (2-4 m/sec). The wet bulb response time is believed to be about three times that of the dry bulb.

Pressure is sensed by a variable capacitance aneroid cell. It consists of a square ceramic substrate with the aneroid capsule bonded symmetrically to both sides. The ceramic substrate has a metalized area that forms one plate while the capsule forms the other plate of the sensing capacitor. Each aneroid cell is calibrated individually by the manufacturer. The calibration yields a curve of pressure versus capacitance that can be fitted adequately by a second-order polynominal. The calibration coefficients are supplied with each mini-sonde. These are read into a computer at the ground station prior to launching of the mini-sonde. This technique gives pressure readings with a characteristic absolute accuracy of ± 3 mb from 1000 to 300 mb, without performing baseline corrections. The system specifications are given in Table 18.

The mini-sonde was flown with a 30-g Helium filled balloon. The "weight-off mass" was about 170 g which gave the mini-sonde an ascent velocity of about 2 m/s. The "weight-off mass" is the total mass, including the inflation device, that is suspended on the balloon during inflation. Helium was added until the balloon and filling device were neutrally buoyant.

The ground station acts as a receiver for the 403.500 MHz radio signal from the mini-sonde. It basically consists of a UHF-receiver and a microprocessor. Prior to launching of the mini-sonde, seven calibration coefficients are read into the microprocessor. In the ground station the incoming analogue telemetry signal is converted into a digital signal which is calibrated by the microprocessor. Several possibilities exist to store the digital data. Here, the data were converted into a serial frequency-shift-keyed tone that were recorded on a standard cassette recorder. In the laboratory the data are played back into the ground station where they are converted into digital data that are transmitted to a Hewlett-Packard 85 computer for further analysis.

Table 18. System specifications for the sensors in the minisonde according to the manufacturer.

Parameter	Sensor	Range	Precision	Resolution
AIRSONDE				
Dry bulb temperature	bead thermistor	-70 to 50°C	± 0.5°C	0.1°C
Wet bulb temperature	bead thermistor	-70 to 50°C	± 0.5°C	0.1°C
Pressure	aneroid capacitance	1050-300 mb	± 3 mb	0.1 mb
Sprenger-sonde	thermistor	-20 to 20°C (linear)	± 1°C*	0.2°C

*Including uncertainties in the reading of the temperature and the height determination.

4.2. The Sprenger system

The Sprenger system consists of a temperature sonde, a radio receiver, antenna and a recorder, manufactured by Albin Sprenger KG, St. Andreasberg, West Germany. This rather old-fashioned equipment uses a sonde with a thermistor without any radiation shield. Battery and radio transmitter are contained in a styrofoam box and the total mass is 80 g. It was flown with a 30-g helium-filled balloon and an ascent velocity of 2 m/s was aimed at.

The receiver transforms the FM (150-155 Hz) radio signal to temperature and displays this on a chart recorder. The temperature profile is plotted as a function of time and the height must be deduced from the elapsed time after launch of the sonde. Consequently, we must assume that the ascent velocity is known (from how bouyant the balloon is) and constant during each sounding. Neither of these assumptions are strictly fulfilled, but to approximate this we used the following procedure.

1. Sprenger sondes were always launched alternately with the AIRSONDES (except on May 29).

2. Above the boundary layer over the sea (usually below 1000 m) we assume that the temperature has not changed significantly (less than the accuracy of the two devices) during the time elapsed between the two AIRSONDE launches (two hours at most).

Practically, we determine a height where the tempeatures from all three sondes coincide. This height divided by the elapsed time then gives the approximate ascent velocity of the balloon and a temperature versus height profile can be derived. Table 18 summarizes the estimated system performance taking into account the evaluation procedure.

4.3. Analyses of AIRSONDE data

Based on the measurements of temperature, wet-bulb temperature and pressure, the height of the mini-sonde above the sea level and some derived parameters were calculated.

When the wet-bulb is not frozen, we have with good approximation:

$$e_s = 6.1078 \cdot 10^{\left(\frac{7.5\ T}{237.3+T}\right)}$$

where e_s (mb) is the saturation vapour pressure over water at temperature T (°C). If we substitute the wet-bulb temperature, T', the saturation vapour pressure at the wet-bulb temperature, e_{sw} (mb), is obtained. The actual vapour pressure in the air, e, is given by

$$e = e_{sw} - 0.00066(1+0.00115\ T')p\ (T-T')$$

where p is ambient pressure (mb). Knowing e, an approximation for the dew-point temperature, T_d (°C), is given by

$$T_d = \frac{237.3 \log\ (e/6.1078)}{7.5 - \log\ (e/6.1078)} \quad .$$

When the wet-bulb is frozen, which typically happens at -5 to -10°C, the above formulas are no longer valid. Denoting the temperature of the frozen wet-bulb by T_i', then the sublimation vapor pressure over ice, e_{si} (mb) at that temperature is given by

$$e_{si} = 6.1078 \cdot 10^{\left(\frac{9.321\ T_i'}{261.24+T_i'}\right)} \quad ,$$

the vapour pressure, e, is then approximately given as

$$e = e_{si} - 0.00066(1+0.00115\ T_i')p(T-T_i').$$

Then we can derive the dew-point (frost-point) temperature, $T_{D,i}$ (°C) when the wet-bulb is frozen as

$$T_{D,i} = \frac{261.24 \log\ \left(\frac{e}{6.1078}\right)}{9.321 - \log\ \left(\frac{e}{6.1078}\right)} \quad .$$

Knowing e, the mixing ratio w is given as

$$w = \frac{0.622\ e}{p-e}$$

irrespective of whether the wet-bulb is frozen or not. The virtual temperature, T*(°K), can be calculated from

$$T^* = \frac{(273.15+T)(1+1.609\ w)}{(1+w)} \quad .$$

The height, ΔH (m), between a level with pressure p_1 and virtual temperature T_1^*, and a level with pressure p_2 and virtual temperature T_2^* is given by the hypsometric equation

$$\Delta H = 14.636(T_1^* + T_2^*)\ln\left(\frac{p_1}{p_2}\right)$$

from which the height of the minisonde above the sea level can be determined. The dry potential temperature, θ, is given as

$$\theta = (T+273.15)\left(\frac{1000}{p}\right)^{0.286}$$

where θ, T and p are in units of K, °C and mb, respectively.

4.4. Characteristics of the mini-sonde launches

Experiment on May 16

During this tracer experiment five AIRSONDES were launched. Figure 14 and Table 19 give times and positions for the launches, in addition to other parameters describing the measurements. The soundings are illustrated in Fig. 15. The sounding at 10:58 has not been analysed because the cassette recorder was not activated until 5 min after launching.

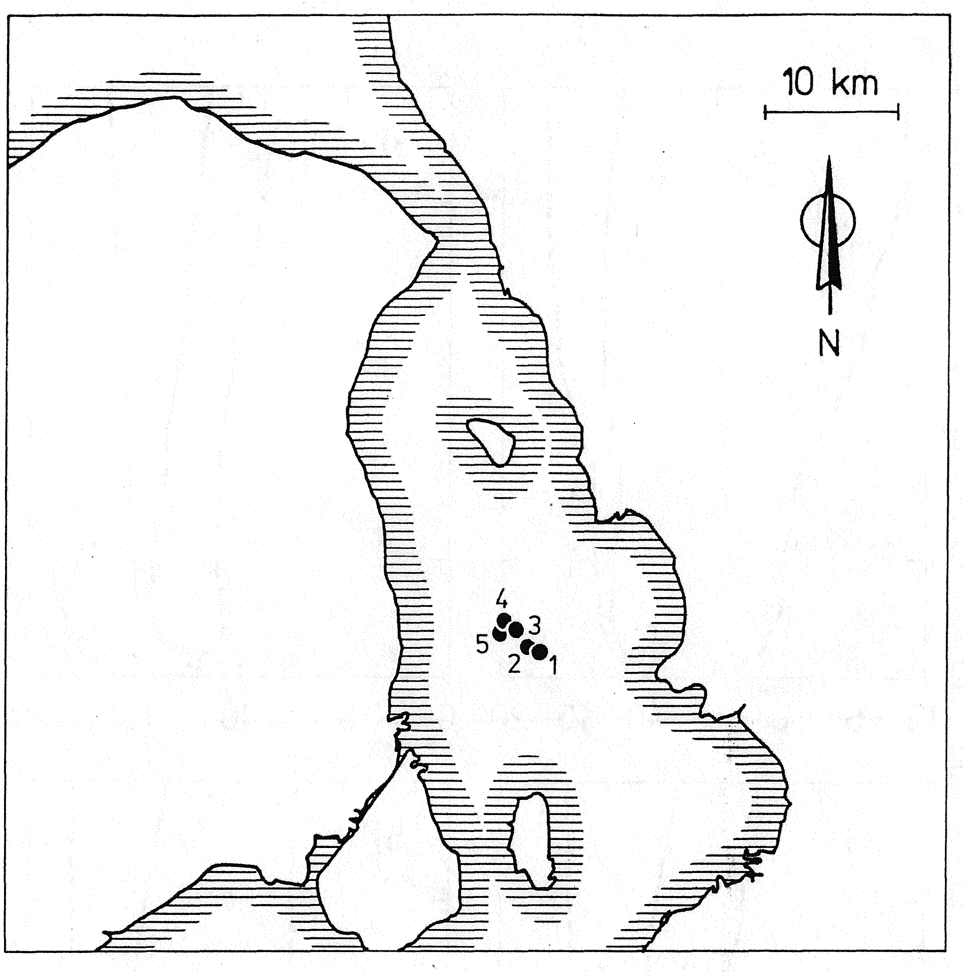


Fig. 14. Positions where AIRSONDES were launched during the experiment on 16 May. The numbers indicate the order of the launchings.

Table 19. Characteristic parameters for the AIRSONDE launches on May 16.

launch time	UTM-coordinates of launch pos. (m)	pressure at sea surface (mb)	max. height (m)	pressure at max. height (mb)
9:55	E359900 N6182290	996	2012	780
10:58	E359050 N6182650	-	-	-
12:23	E358070 N6183910	1000	2954	697
13:28	E357240 N6184600	996	6398	443
14:43	E356990 N6183750	1005	4424	584

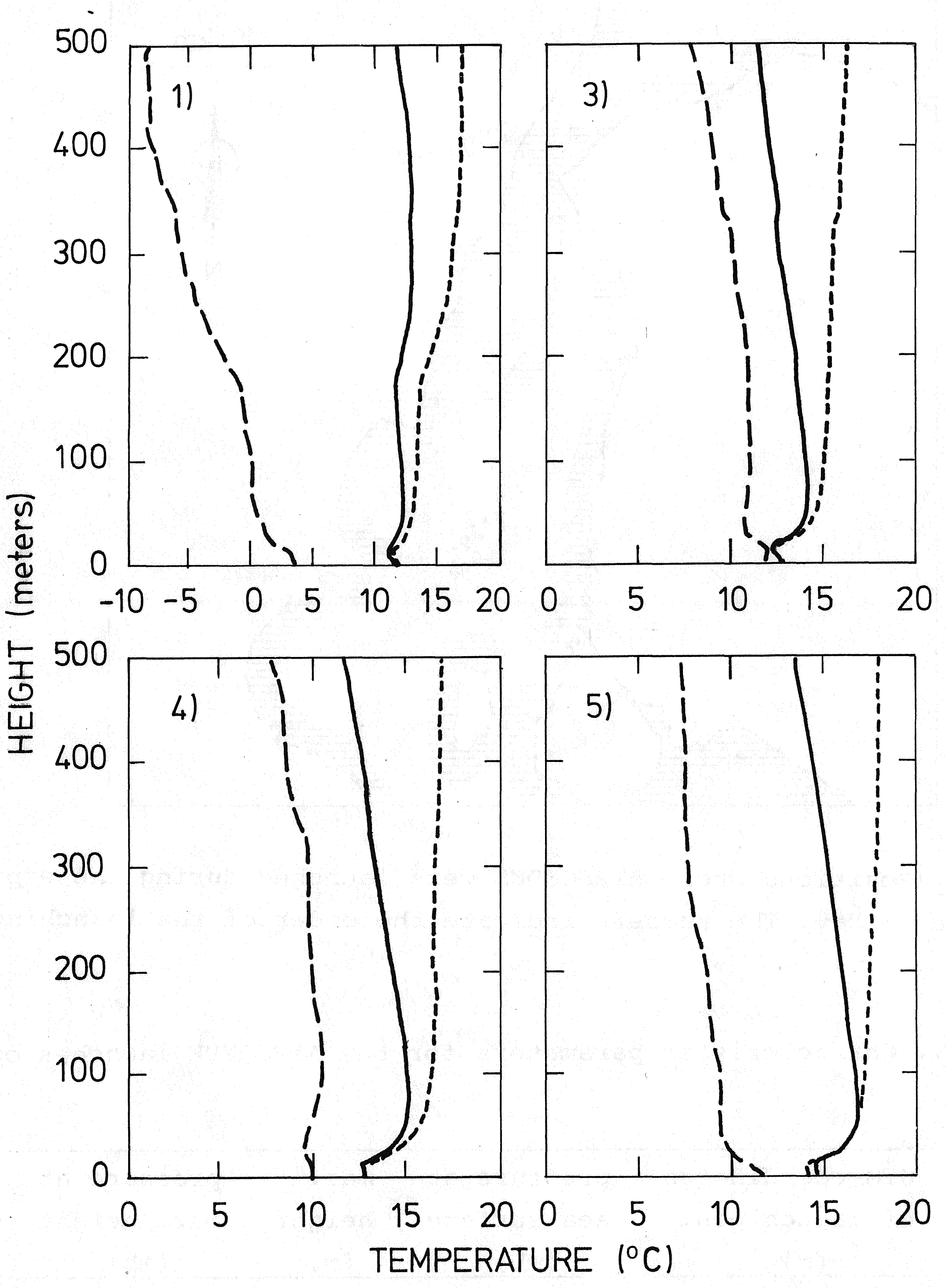


Fig. 15. Temperature profiles measured by AIRSONDES launched during the experiment on 16 May. The temperature is indicated by the solid line; the dew-point temperature is shown by a coarse dashed line, and the potential temperature by a fine dashed line. The numbering of the figures indicates the order of the launchings.

Experiment on May 18

During this tracer experiment three AIRSONDES were launched. Figure 16 and Table 20 give times and positions for the launches, in addition to other parameters that describe the measurements. The soundings are illustrated in Fig. 17.

Table 20. Characteristic parameters for the AIRSONDE launches on May 18.

launch time	UTM-coordinates of launch pos. (m)	pressure at sea surface (mb)	max. height (m)	pressure at max. height (mb)
9:23	E353860 N6177680	1004	7211	394
11:02	E358710 N6184490	1006	6814	417
12:33	E358710 E6184490	1006	7023	405

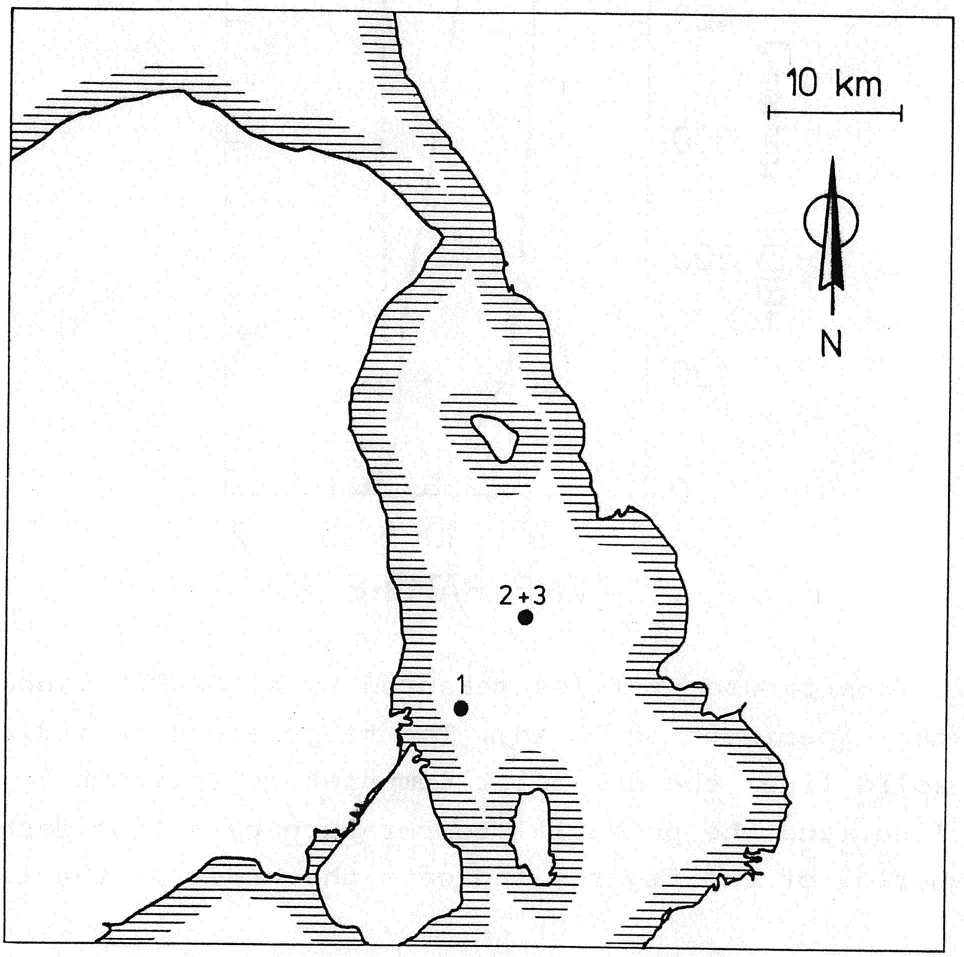


Fig. 16. Positions where AIRSONDES were launched during the experiment on 18 May. The numbers indicate the order of the launchings.

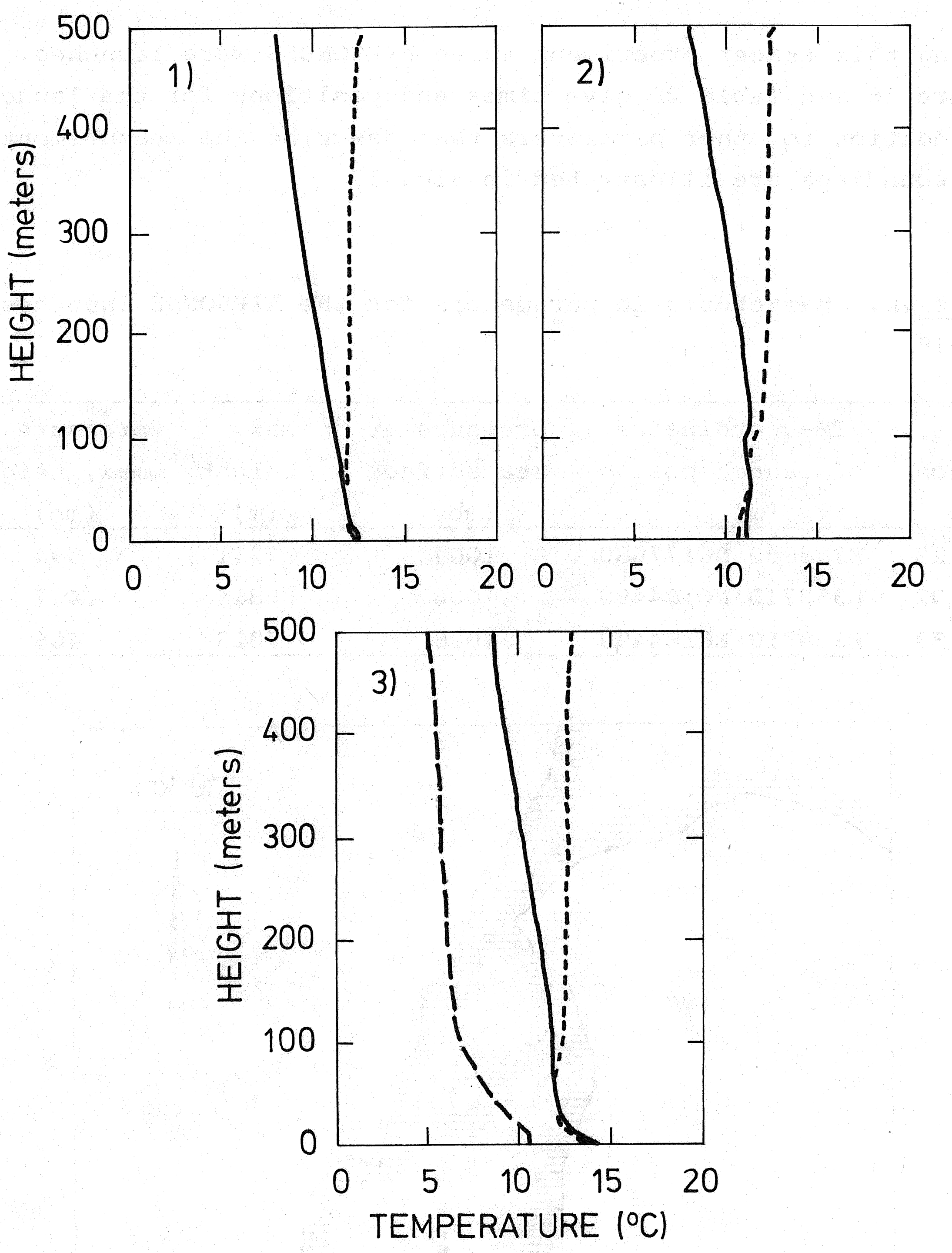


Fig. 17. Temperature profiles measured by AIRSONDES launched during the experiment on 18 May. The temperature is indicated by the solid line; the dew-point temperature is shown by a coarse dashed line, and the potential temperature by a fine dashed line. The numbering of the figures indicate the order of the launchings.

Experiment on May 22

No mini-sondes were launched. This was due to the high wind speed that characterized this experiment, and which excluded handling of mini-sondes on a fishing boat.

Experiment on May 29

During this tracer experiment two AIRSONDES and two Sprenger-sondes were launched. Figure 18 and Table 21 give times and positions for the launches in addition to other parameters that describe the measurements. The soundings are illustrated in Fig. 19.

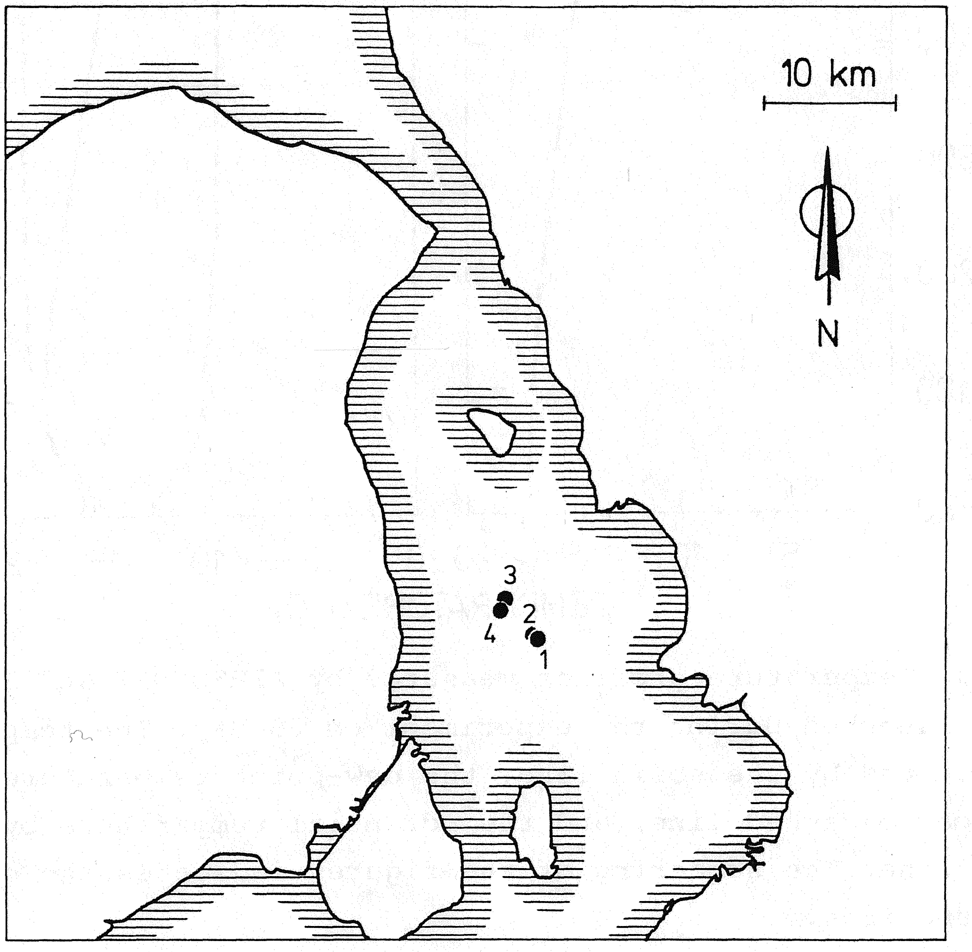


Fig. 18. Positions where AIRSONDES and Sprenger-sondes were launched during the experiment on 29 May. The numbers indicate the order of the launchings.

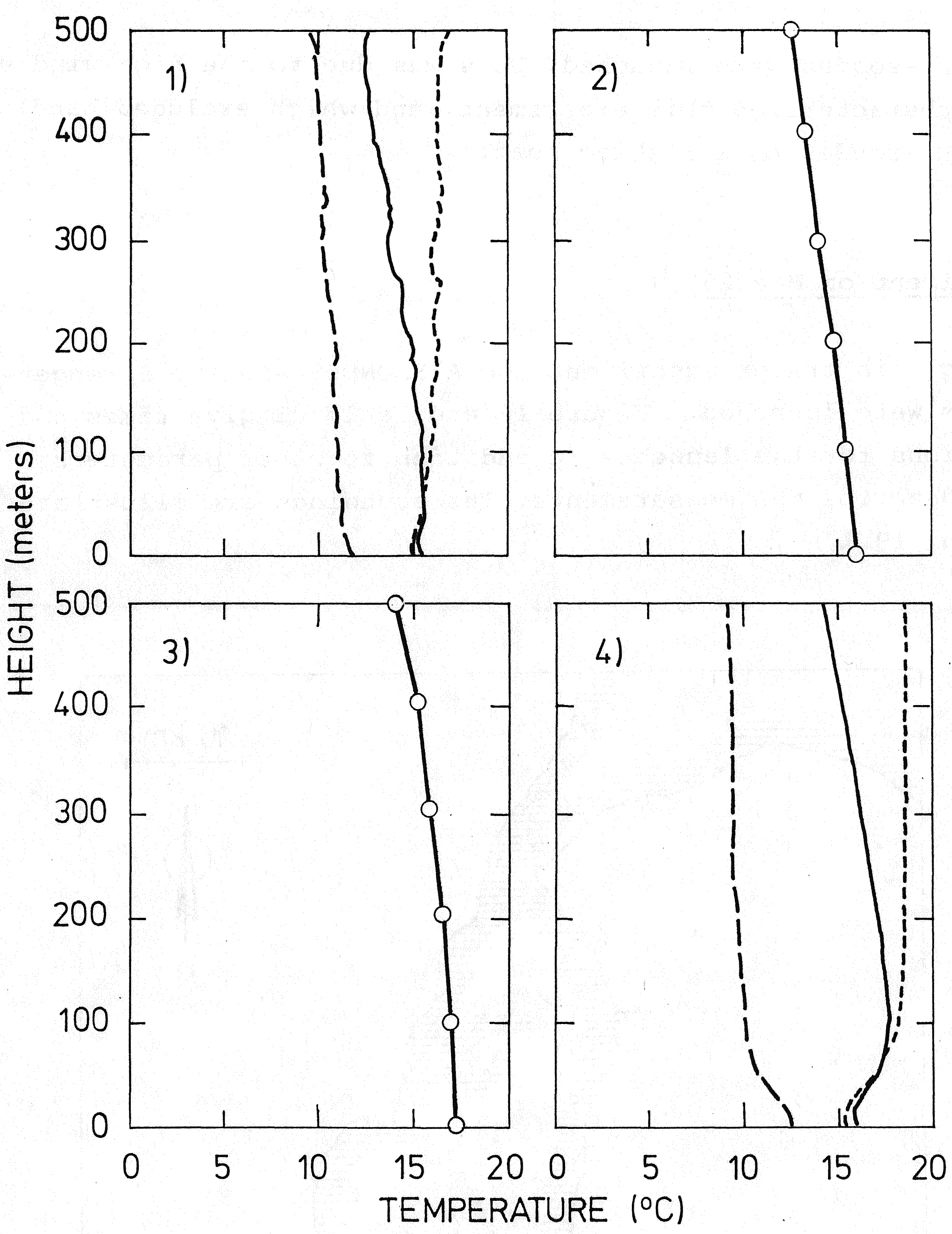


Fig. 19. Temperature profiles measured by AIRSONDES and Sprengersondes launched during the experiment on 29 May. The temperature is indicated by the solid line; the dew-point temperature is shown by a coarse dashed line, and the potential temperature by a fine dashed line. The numbering of the figures indicates the order of the launchings.

Table 21. Characteristic parameters for the mini-sonde launches on May 29.

launch time	UTM-coordinates of launch pos. (m)	pressure at sea surface (mb)	max. height (m)	pressure at max. height (mb)
9:10	E359810 N6182400	1006	2145	778
9:30	E359730 N6182550	Sprenger-sonde	2200	-
10:23	E357200 N6185600	Sprenger-sonde	1400	-
10:55	E357050 N6184550	1006	3569	651

Experiment on May 30

During this tracer experiment two AIRSONDES and two Sprenger-sondes were launched. Figure 20 and Table 22 give times and positions for the launches in addition to other parameters that describe the measurements. The soundings are illustrated in Fig. 21.

Table 22. Characteristic parameters for the mini-sonde launches on May 30.

launch time	UTM-coordinates of launch pos. (m)	pressure at sea surface (mb)	max. height (m)	pressure at max. height (mb)
9:00	E356990 N6183780	1010	7081	409
10:09	E362350 N6181050	Sprenger-sonde	1800	-
11:00	E358470 N6184500	1005	6213	457
11:25	E358550 N6183450	Sprenger-sonde	2200	-

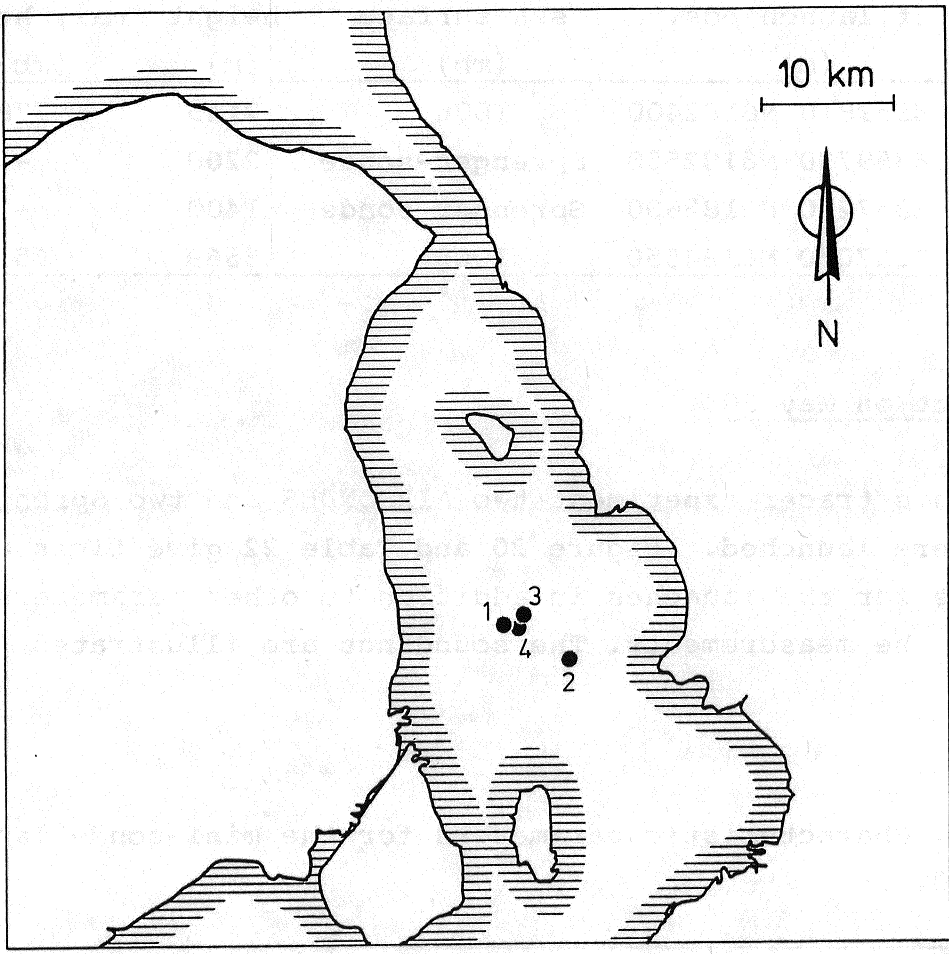


Fig. 20. Positions where AIRSONDES and Sprenger-sondes were launched during the experiment on 30 May. The numbers indicate the order of the launchings.

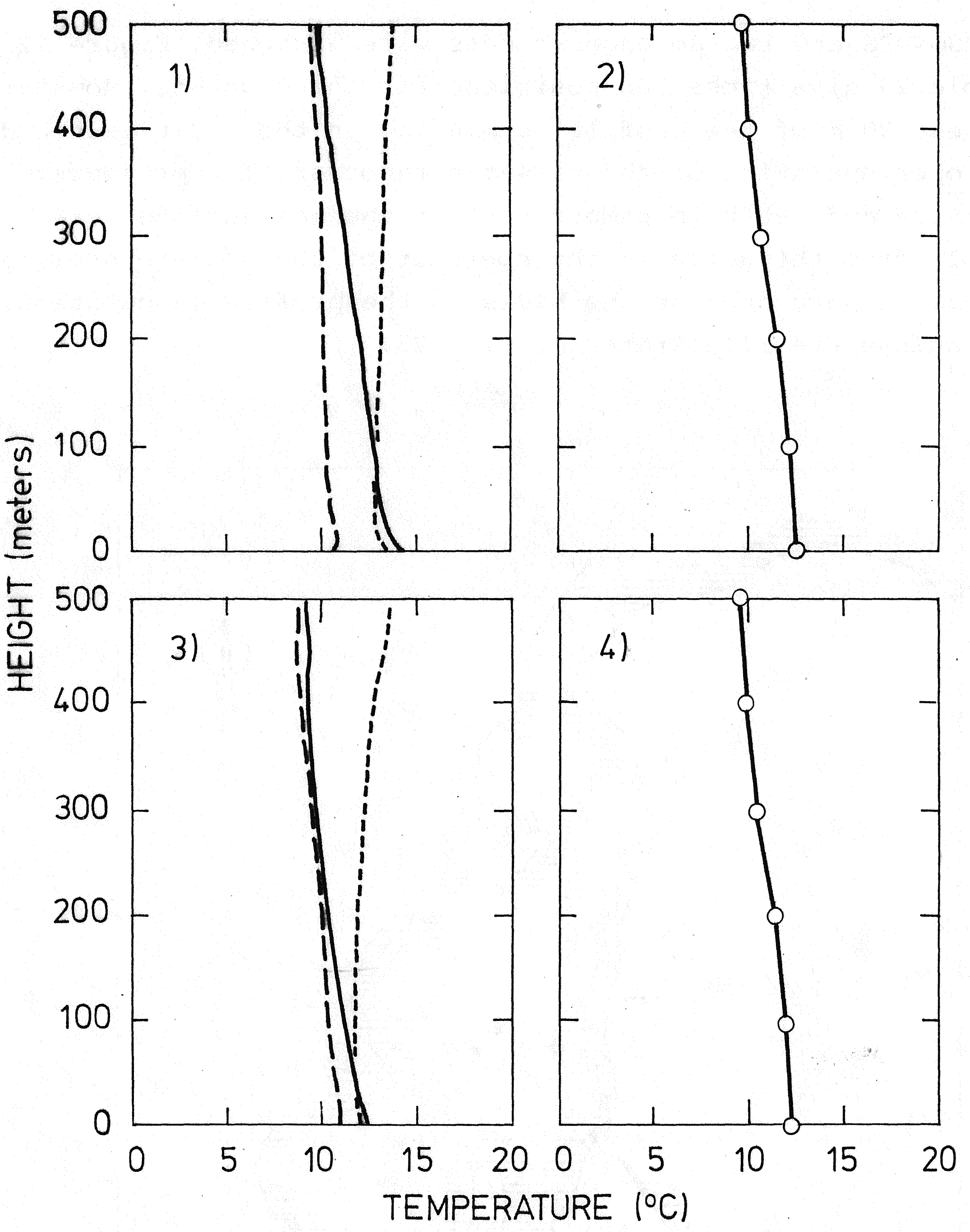


Fig. 21. Temperature profiles measured by AIRSONDES and Sprenger-sondes launched during the experiment on 30 May. The temperature is indicated by the solid line; the dew-point temperature is shown by a coarse dashed line, and the potential temperature by a fine dashed line. The numbering of the figures indicates the order of the launchings.

Experiment on June 4

Two AIRSONDES and two Sprenger-sondes were launched. Figure 22 and Table 23 give times and positions for the launches. However, the lowest 90 m of the profile is missing in the first launch due to improper operation of the cassette recorder. The pressure, temperature and wet-bulb temperature at the sea surface were available from the notes of the operator of the sonde system, and these values were used as the basis of the profile calculation. The soundings are illustrated in Fig. 23.

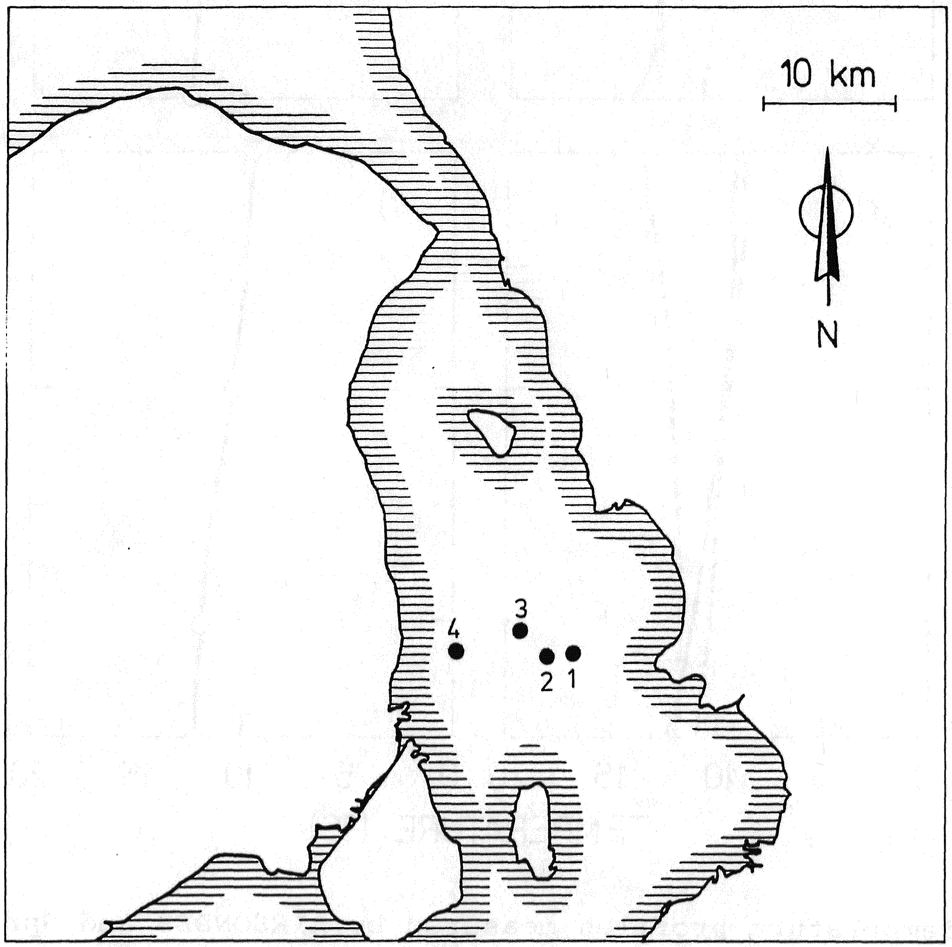


Fig. 22. Positions where AIRSONDES and Sprenger-sondes were launched during the experiment on 4 June. The numbers indicate the order of the launchings.

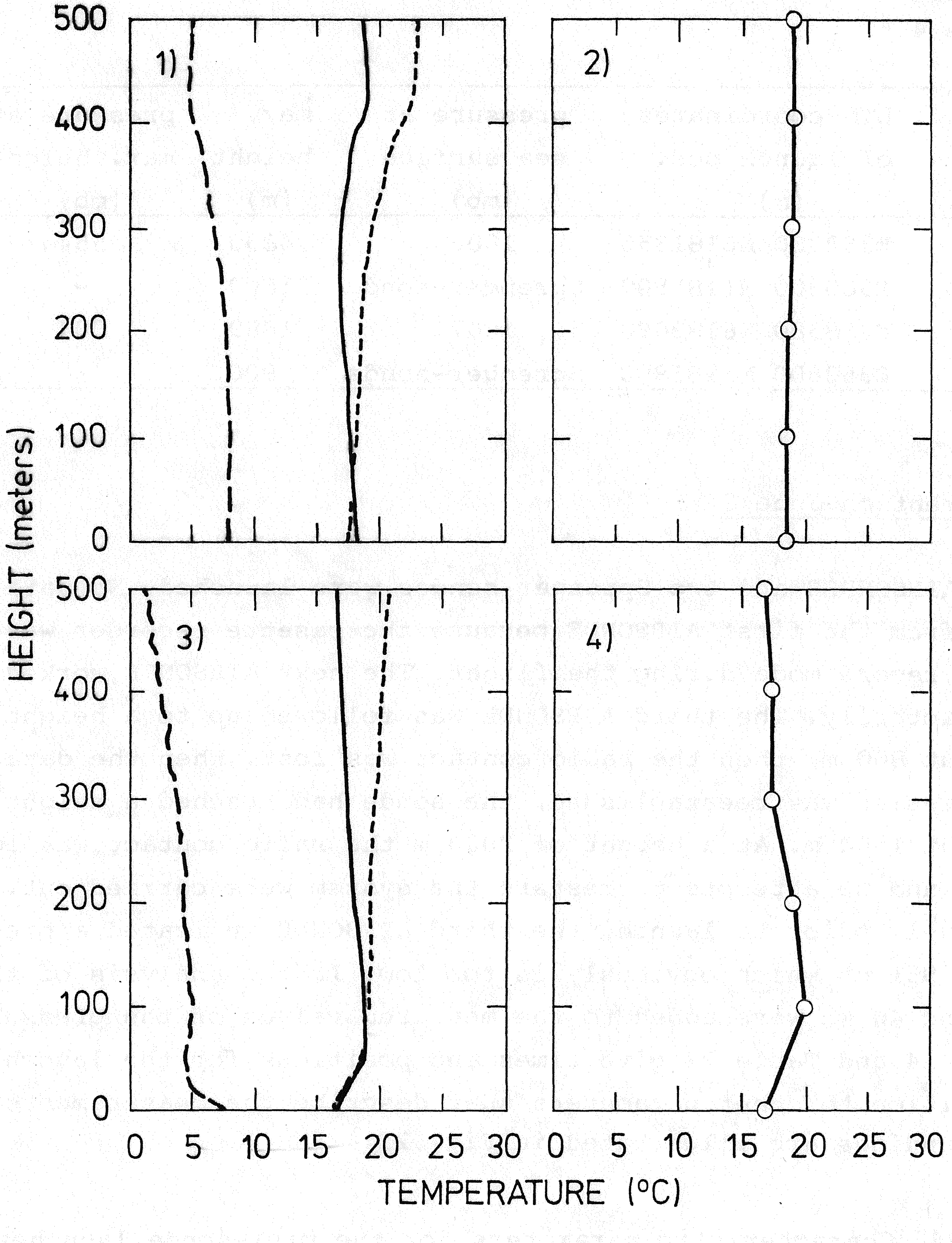


Fig. 23. Temperature profiles measured by AIRSONDES and Sprengersondes launched during the experiment on 4 June. The temperature is indicated by the solid line; the dew-point temperature is shown by a coarse dashed line, and the potential temperature by a fine dashed line. The numbering of the figures indicates the order of the launchings.

Table 23. Characteristic parameters for the mini-sonde launches on June 4.

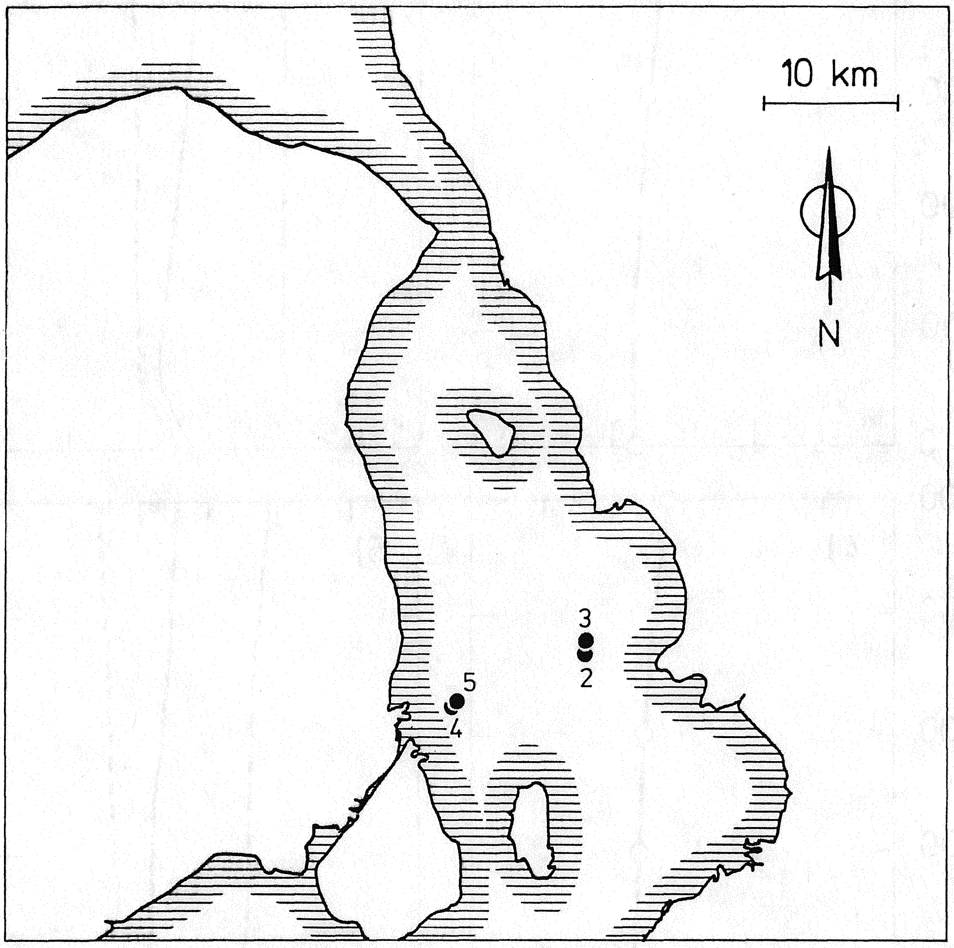
launch time	UTM-coordinates of launch pos. (m)	pressure at sea surface (mb)	max. height (m)	pressure at max. height (mb)
8:12	E362360 N6181350	1006	4890	554
9:16	E360300 N6181500	Sprenger-sonde	1800	-
10:38	E358380 N6183090	1007	1889	804
11:12	E353500 N6181900	Sprenger-sonde	900	-

Experiment on June 5

Three AIRSONDES and two Sprenger-sondes were launched. No data exist from the first AIRSONDE because the casette recorder was not in record mode during the flight. The next AIRSONDE worked satisfactorily. The third AIRSONDE was followed up to a height of about 800 m, then the radio contact was lost. When the data transmission was reestablished, the sonde had reached a height of about 1500 m. At a height of 2000 m the radio contact was lost again, and no attempts to restart the system were carried out. At sea level, prior to launch, the third AIRSONDE indicated a pressure of 951 mb which obviously is too low. In the analysis of this sounding 40 mb were added to the measured values of the pressure. Figure 24 and Table 24 give times and positions for the launchings in addition to other parameters that describe the measurements. The soundings are illustrated in Fig. 25.

Table 24. Characteristic parameters for the mini-sonde launches on June 5.

launch time	UTM-coordinates of launch pos. (m)	pressure at sea surface (mb)	max. height (m)	pressure at max. height (mb)
8:06	-	-	-	-
9:02	E363300 N6181530	Sprenger-sonde	1500	-
9:29	E363260 N6182280	991	3574	639
10:35	E353550 N6177630	Sprenger-sonde	1300	-
12:02	E353650 N6177760	951	2013	738



<u>Fig. 24.</u> Positions where AIRSONDES and Sprenger-sondes were launched during the experiment on 5 June. The numbers indicate the order of the launchings.

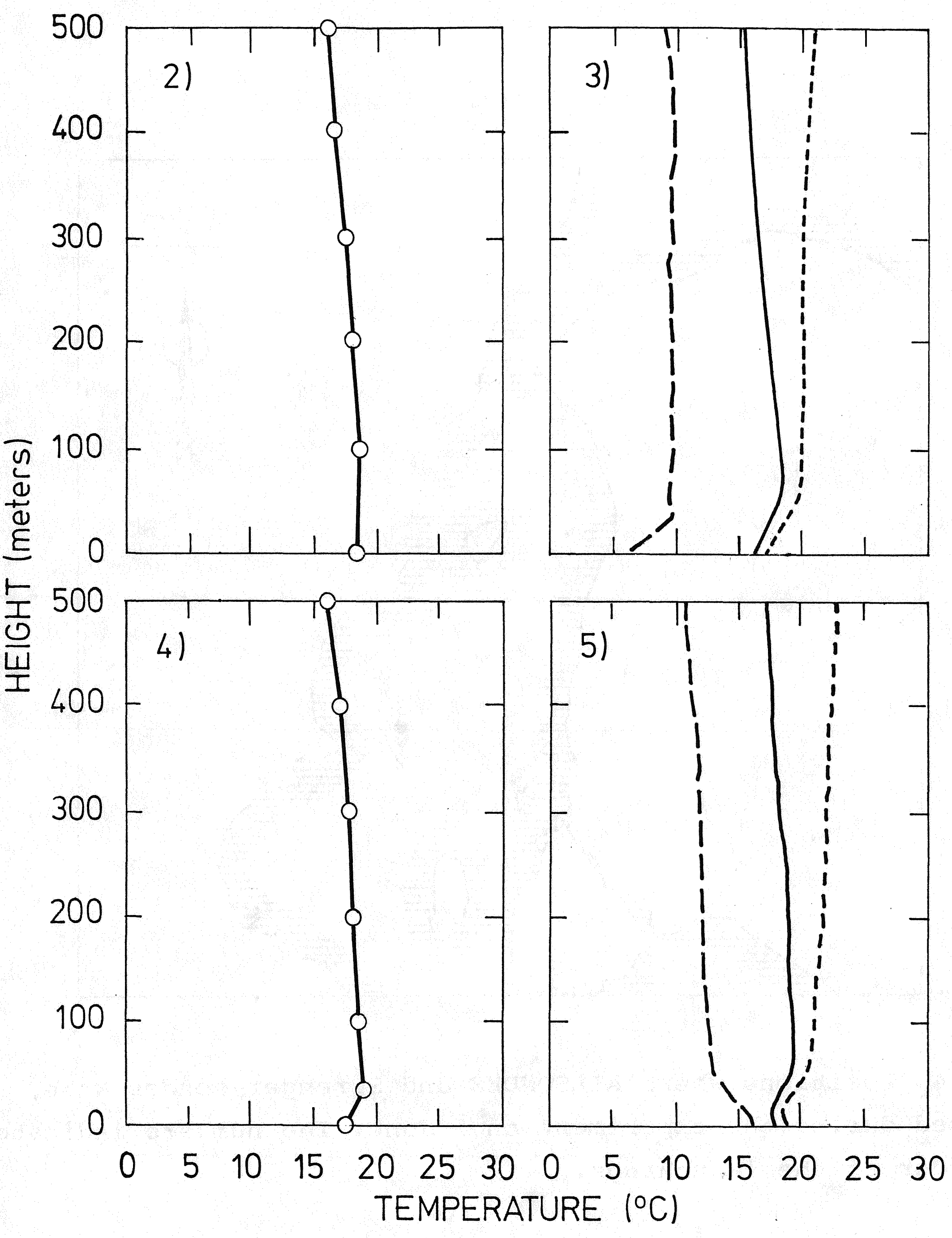


Fig. 25. Temperature profiles measured by AIRSONDES and Sprenger-sondes launched during the experiment on 5 June. The temperature is indicated by the solid line; the dew-point temperature is shown by a coarse dashed line, and the potential temperature by a fine dashed line. The numbering of the figures indicates the order of the launchings.

Experiment on June 12

Four AIRSONDES were launched during this experiment. When the data from the third AIRSONDE were analysed, 13 mb were added to the measured values of the pressure, to be in accordance with the other sea level pressures measured on that day. Figure 26 and Table 25 give times and positions for the launchings in addition to the other parameters describing the measurements. The soundings are illustrated in Fig. 27.

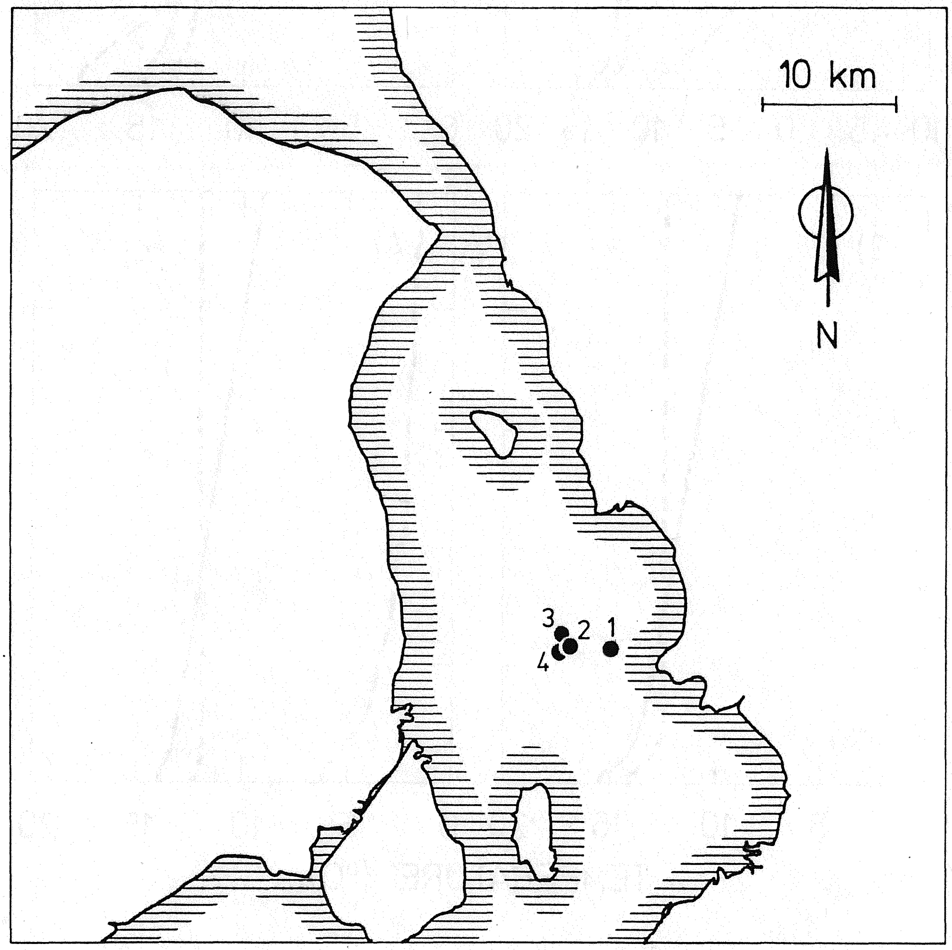


Fig. 26. Positions where AIRSONDES were launched during the experiment on 12 June. The numbers indicate the order of the launchings.

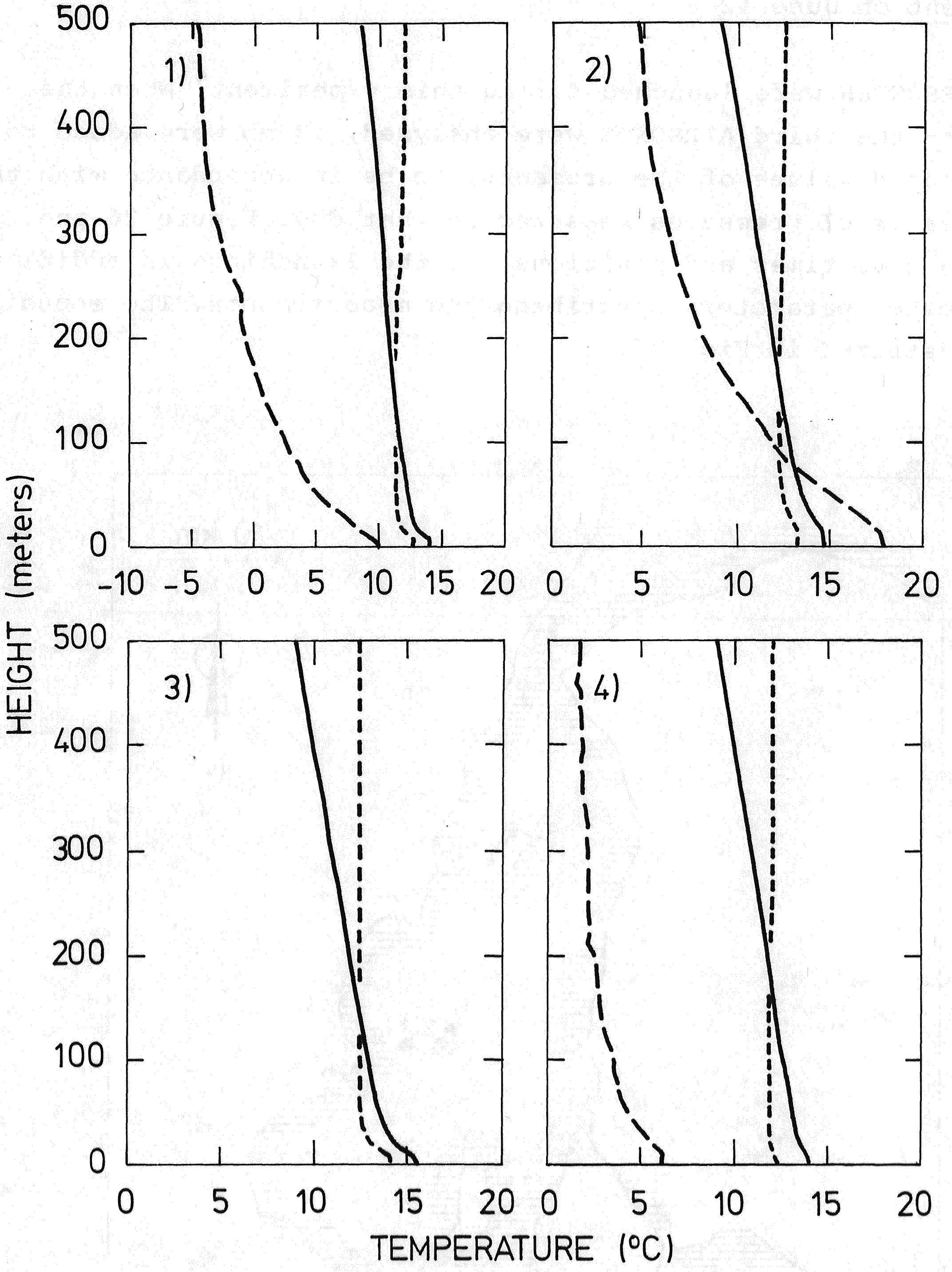


Fig. 27. Temperature profiles measured by AIRSONDES launched during the experiment on 12 June. The temperature is indicated by the solid line; the dew-point temperature is shown by a coarse dashed line, and the potential temperature by a fine dashed line. The numbering of the figures indicates the order of the launchings.

Table 25. Characteristic parameters for the AIRSONDE launches on June 12.

launch time	UTM-coordinates of launch pos. (m)	pressure at sea surface (mb)	max. height (m)	pressure at max. height (mb)
8:30	E364890 N6181780	1017	8070	353
9:40	E361860 N6182040	1017	5105	534
10:30	E361140 N6182940	1005	8682	311
11:50	E361050 N6181530	1023	4504	581

Experiment on June 14

Four AIRSONDES were launched during this experiment. At the first launch, data are missing at the lowest 10 mb. Figure 28 and Table 26 give times and positions for the launchings in addition to other parameters describing the measurements. The soundings are illustrated in Fig. 29.

Table 26. Characteristic parameters for the AIRSONDE launches on June 14.

launch time	UTM-coordinates of launch pos. (m)	pressure at sea surface (mb)	max. height (m)	pressure at max. height (mb)
9:52	E364720 N6181090	999	4954	536
11:07	E364420 N6179730	1004	7470	382
12:30	E363510 N6177640	1008	4351	585
13:42	E353800 N6177420	1003	5833	477

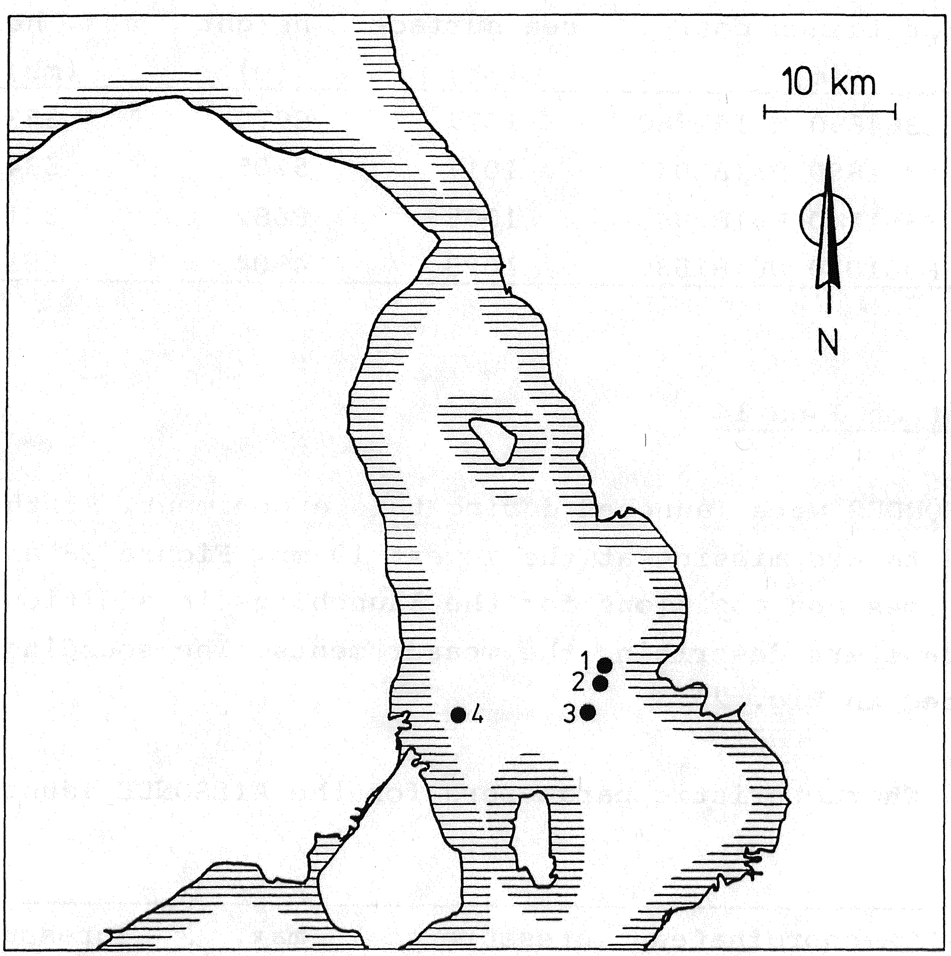


Fig. 28. Positions where AIRSONDES were launched during the experiment on 14 June. The numbers indicate the order of the launchings.

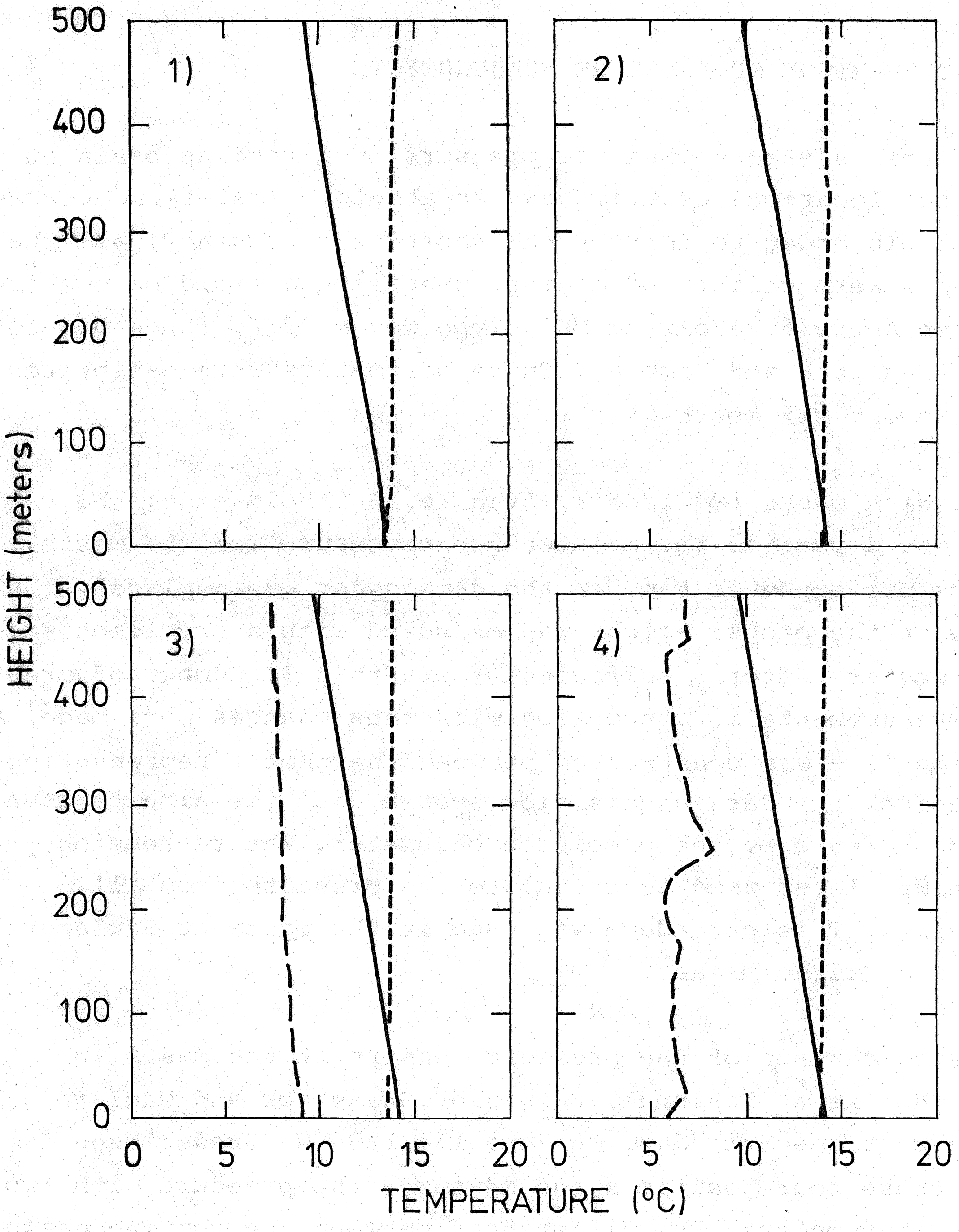


Fig. 29. Temperature profiles measured by AIRSONDES launched during the experiment on 14 June. The temperature is indicated by the solid line; the dew-point temperature is shown by a coarse dashed line, and the potential temperature by a fine dashed line. The numbering of the figures indicates the order of the launchings.

5. INTERCOMPARISON OF PRESSURE MEASUREMENTS

The instruments used to measure pressure on a routine basis at the various locations usually have an absolute long-term accuracy of 0.4 mb. In order to improve the short-term accuracy, all the instruments were calibrated against precision aneroid barometers (Precision Aneroid Barometer MK2, Type No. M 2236, range 900-1050 mb, make Negritta and Zambra). These barometers were calibrated at least every six months.

At the Danish masts (Sjælsmark, Avedøre, Saltholm east) the calibration was a part of the maintenance procedure for the masts. Each time the magnetic tape on the datalogger was replaced, the pressure at the proper height was measured with a precision aneroid barometer. After a sufficient (more than 3) number of precision measurements in connection with tape changes were made, a regression line was constructed between the number representing pressure from the data acquisition system, and the simultaneously measured pressure by the precision barometer. The regression equation was later used to calculate the pressure from all measurements. This procedure was used at the masts at Sjælsmark, Avedøre and Saltholm east.

The intercomparison of the pressure sensors at the masts in Sweden, that is at Borlunda, Furulund, Barsebäck and Maglarp, was done on a specific day. On June 15, 1984 M. Frederiksen visited these four positions and measured the pressure with two precision barometers. The differences between the routine measurements and the ones made by the precision barometer were always of the order of a few tenths of a millibar. The differences were later accounted for in the data.

6. METAR OBSERVATIONS AT KASTRUP AIRPORT

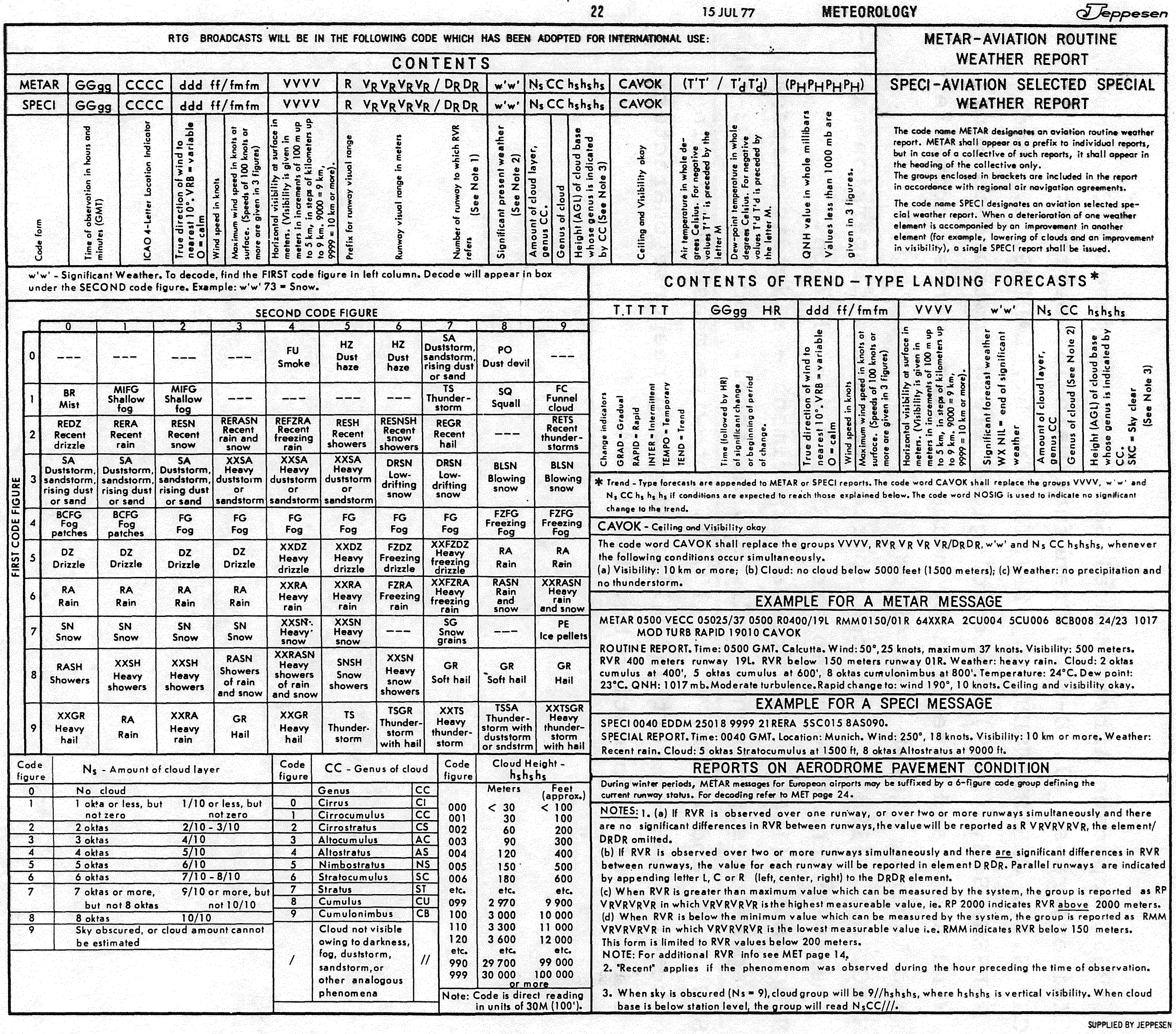
The code name METAR designates an aviation routine weather report. Among other things, the METAR reports contain information about wind speed and direction, air- and dewpoint temperature, amount, types and heights of cloud layers as well as pressure. All the METAR reports that were produced at Kastrup Airport during the experimental period were kept for this experiment. METAR observations are routinely collected every 30 minutes. The wind speed and direction in the METAR from Kastrup Airport are measured at 10-m height about 100 m west of the Øresund coastline. Figure 30 gives an example of METAR observations from Kastrup Airport. The translation from code to meteorology is given in Fig. 31, taken from AIR (1985).

METAR/SPECI

5. juni 1984 STATION: Københavns Lufthavn

CCCC	GGgg	ddd	ff	$/f_mf_m$	VVVV	$R\left(\frac{P}{mm}\right)$	$V_RV_RV_RV_R$	$/D_RD_R$	w'w'	N_s	CC	$h_sh_sh_s$	N_s	CC	$h_sh_sh_s$	N_s	CC	$h_sh_sh_s$	N_s	CC	$h_sh_sh_s$	(M)	T'T'	(M)	$T'_dT'_d$	$P_HP_HP_HP_H$
EKCH	1150	090	18						CAVOK														22		12	1006
EKCH	1220	090	15		9999					1	cu	040	3	ac	100								23		13	1006
EKCH	1250	090	17	27	9999					1	cu	040											22		12	1005
EKCH	1320	090	16		9999					1	cu	040											23		13	1005
EKCH	1350	090	20		9999					1	cu	040											22		12	1005
EKCH	1420	090	16		9999					1	cu	040											22		12	1005
EKCH	1450	090	16		9999					1	cb	040	4	ac	120								21		11	1005
EKCH	1520	080	17		9999					1	cu	040	3	ac	120								21		11	1005
EKCH	1550	080	14		9999					1	cu	040	5	ac	100								20		11	1005
EKCH	1620	090	19		9999					1	cu	040	5	ac	100								20		10	1005
EKCH	1650	090	14		9999					1	cu	040	5	ac	080								19		10	1005
EKCH	1720	100	14						CAVOK														19		10	1005

Fig. 30. Example of METAR observations from Kastrup Airport 5 June 1984.



RTG BROADCASTS WILL BE IN THE FOLLOWING CODE WHICH HAS BEEN ADOPTED FOR INTERNATIONAL USE:

METAR-AVIATION ROUTINE WEATHER REPORT

SPECI-AVIATION SELECTED SPECIAL WEATHER REPORT

CONTENTS

METAR	GGgg	CCCC	ddd ff/fmfm	VVVV	R $V_RV_RV_RV_R$ / D_RD_R	w'w'	N_s CC $h_sh_sh_s$	CAVOK	(T'T' / $T'_dT'_d$)	($P_HP_HP_HP_H$)
SPECI	GGgg	CCCC	ddd ff/fmfm	VVVV	R $V_RV_RV_RV_R$ / D_RD_R	w'w'	N_s CC $h_sh_sh_s$	CAVOK		
Code form	Time of observation in hours and minutes (GMT)	ICAO 4-Letter Location Indicator	True direction of wind to nearest 10°. VRB = variable O = calm Wind speed in knots Maximum wind speed in knots at surface. (Speeds of 100 knots or more are given in 3 figures)	Horizontal visibility at surface in meters. (Visibility is given in meters in increments of 100 m up to 5 km, in steps of kilometers up to 9 km. 9000 = 9 km, 9999 = 10 km or more).	Prefix for runway visual range Runway visual range in meters Number of runway to which RVR refers (See Note 1)	Significant present weather (See Note 2)	Amount of cloud layer, genus CC. Genus of cloud Height (AGL) of cloud base whose genus is indicated by CC (See Note 3)	Ceiling and Visibility okay	Air temperature in whole degrees Celsius. For negative values T'T' is preceded by the letter M Dew-point temperature in whole degrees Celsius. For negative values T'd T'd is preceded by the letter M.	QNH value in whole millibars Values less than 1000 mb are given in 3 figures.

The code name METAR designates an aviation routine weather report. METAR shall appear as a prefix to individual reports, but in case of a collective of such reports, it shall appear in the heading of the collective only.
The groups enclosed in brackets are included in the report in accordance with regional air navigation agreements.

The code name SPECI designates an aviation selected special weather report. When a deterioration of one weather element is accompanied by an improvement in another element (for example, lowering of clouds and an improvement in visibility), a single SPECI report shall be issued.

w'w' - Significant Weather. To decode, find the FIRST code figure in left column. Decode will appear in box under the SECOND code figure. Example: w'w' 73 = Snow.

FIRST CODE FIGURE	SECOND CODE FIGURE 0	1	2	3	4	5	6	7	8	9
0	---	---	---	---	FU Smoke	HZ Dust haze	HZ Dust haze	SA Duststorm, sandstorm, rising dust or sand	PO Dust devil	---
1	BR Mist	MIFG Shallow fog	MIFG Shallow fog	---	---	---	---	TS Thunder-storm	SQ Squall	FC Funnel cloud
2	REDZ Recent drizzle	RERA Recent rain	RESN Recent snow	RERASN Recent rain and snow	REFZRA Recent freezing rain	RESH Recent showers	RESNSH Recent snow showers	REGR Recent hail	---	RETS Recent thunder-storms
3	SA Duststorm, sandstorm, rising dust or sand	SA Duststorm, sandstorm, rising dust or sand	SA Duststorm, sandstorm, rising dust or sand	XXSA Heavy duststorm or sandstorm	XXSA Heavy duststorm or sandstorm	XXSA Heavy duststorm or sandstorm	DRSN Low-drifting snow	DRSN Low-drifting snow	BLSN Blowing snow	BLSN Blowing snow
4	BCFG Fog patches	BCFG Fog patches	FG Fog	FG Fog	FG Fog	FG Fog	FG Fog	FG Fog	FZFG Freezing Fog	FZFG Freezing Fog
5	DZ Drizzle	DZ Drizzle	DZ Drizzle	DZ Drizzle	XXDZ Heavy drizzle	XXDZ Heavy drizzle	FZDZ Freezing drizzle	XXFZDZ Heavy freezing drizzle	RA Rain	RA Rain
6	RA Rain	RA Rain	RA Rain	RA Rain	XXRA Heavy rain	XXRA Heavy rain	FZRA Freezing rain	XXFZRA Heavy freezing rain	RASN Rain and snow	XXRASN Heavy rain and snow
7	SN Snow	SN Snow	SN Snow	SN Snow	XXSN Heavy snow	XXSN Heavy snow	---	SG Snow grains	---	PE Ice pellets
8	RASH Showers	XXSH Heavy showers	XXSH Heavy showers	RASN Showers of rain and snow	XXRASN Heavy showers of rain and snow	SNSH Snow showers	XXSN Heavy snow showers	GR Soft hail	GR Soft hail	GR Hail
9	XXGR Heavy hail	RA Rain	XXRA Heavy rain	GR Hail	XXGR Heavy hail	TS Thunder-storm	TSGR Thunder-storm with hail	XXTS Heavy thunder-storm	TSSA Thunder-storm with duststorm or sndstrm	XXTSGR Heavy thunder-storm with hail

Code figure	N_s - Amount of cloud layer	
0	No cloud	
1	1 okta or less, but not zero	1/10 or less, but not zero
2	2 oktas	2/10 - 3/10
3	3 oktas	4/10
4	4 oktas	5/10
5	5 oktas	6/10
6	6 oktas	7/10 - 8/10
7	7 oktas or more, but not 8 oktas	9/10 or more, but not 10/10
8	8 oktas	10/10
9	Sky obscured, or cloud amount cannot be estimated	

Code figure	CC - Genus of cloud	
	Genus	CC
0	Cirrus	CI
1	Cirrocumulus	CC
2	Cirrostratus	CS
3	Altocumulus	AC
4	Altostratus	AS
5	Nimbostratus	NS
6	Stratocumulus	SC
7	Stratus	ST
8	Cumulus	CU
9	Cumulonimbus	CB
/	Cloud not visible owing to darkness, fog, duststorm, sandstorm, or other analogous phenomena	//

Code figure	Cloud Height - $h_sh_sh_s$	
	Meters	Feet (approx.)
000	< 30	< 100
001	30	100
002	60	200
003	90	300
004	120	400
005	150	500
006	180	600
etc.	etc.	etc.
099	2 970	9 900
100	3 000	10 000
110	3 300	11 000
120	3 600	12 000
etc.	etc.	etc.
990	29 700	99 000
999	30 000 or more	100 000

Note: Code is direct reading in units of 30M (100').

CONTENTS OF TREND – TYPE LANDING FORECASTS*

T.T T T T	GGgg HR	ddd ff/fmfm	VVVV	w'w'	N_s CC $h_sh_sh_s$
Change indicators GRAD = Gradual RAPID = Rapid INTER = Intermittent TEMPO = Temporary TEND = Trend	Time (followed by HR) of significant change or beginning of period of change.	True direction of wind to nearest 10°. VRB = variable O = calm Wind speed in knots Maximum wind speed in knots at surface. (Speeds of 100 knots or more are given in 3 figures)	Horizontal visibility at surface in meters. (Visibility is given in meters in increments of 100 m up to 5 km, in steps of kilometers up to 9 km. 9000 = 9 km, 9999 = 10 km or more).	Significant forecast weather WX NIL = end of significant weather	Amount of cloud layer, genus CC Genus of cloud (See Note 2) Height (AGL) of cloud base whose genus is indicated by CC. SKC = Sky clear (See Note 3)

* Trend - Type forecasts are appended to METAR or SPECI reports. The code word CAVOK shall replace the groups VVVV, w'w' and N_s CC h_s h_s h_s if conditions are expected to reach those explained below. The code word NOSIG is used to indicate no significant change to the trend.

CAVOK - Ceiling and Visibility okay

The code word CAVOK shall replace the groups VVVV, RV_R V_R V_R V_R/D_RD_R, w'w' and N_s CC $h_sh_sh_s$, whenever the following conditions occur simultaneously.
(a) Visibility: 10 km or more; (b) Cloud: no cloud below 5000 feet (1500 meters); (c) Weather: no precipitation and no thunderstorm.

EXAMPLE FOR A METAR MESSAGE

METAR 0500 VECC 05025/37 0500 R0400/19L RMM0150/01R 64XXRA 2CU004 5CU006 8CB008 24/23 1017
MOD TURB RAPID 19010 CAVOK

ROUTINE REPORT. Time: 0500 GMT. Calcutta. Wind: 50°, 25 knots, maximum 37 knots. Visibility: 500 meters. RVR 400 meters runway 19L. RVR below 150 meters runway 01R. Weather: heavy rain. Cloud: 2 oktas cumulus at 400', 5 oktas cumulus at 600', 8 oktas cumulonimbus at 800'. Temperature: 24°C. Dew point: 23°C. QNH: 1017 mb. Moderate turbulence. Rapid change to: wind 190°, 10 knots. Ceiling and visibility okay.

EXAMPLE FOR A SPECI MESSAGE

SPECI 0040 EDDM 25018 9999 21RERA 5SC015 8AS090.
SPECIAL REPORT. Time: 0040 GMT. Location: Munich. Wind: 250°, 18 knots. Visibility: 10 km or more. Weather: Recent rain. Cloud: 5 oktas Stratocumulus at 1500 ft, 8 oktas Altostratus at 9000 ft.

REPORTS ON AERODROME PAVEMENT CONDITION

During winter periods, METAR messages for European airports may be suffixed by a 6-figure code group defining the current runway status. For decoding refer to MET page 24.

NOTES: 1. (a) If RVR is observed over one runway, or over two or more runways simultaneously and there are no significant differences in RVR between runways, the value will be reported as R $V_RV_RV_RV_R$, the element/ D_RD_R omitted.
(b) If RVR is observed over two or more runways simultaneously and there are significant differences in RVR between runways, the value for each runway will be reported in element D_RD_R. Parallel runways are indicated by appending letter L, C or R (left, center, right) to the D_RD_R element.
(c) When RVR is greater than maximum value which can be measured by the system, the group is reported as RP $V_RV_RV_RV_R$ in which $V_RV_RV_RV_R$ is the highest measureable value, ie. RP 2000 indicates RVR above 2000 meters.
(d) When RVR is below the minimum value which can be measured by the system, the group is reported as RMM $V_RV_RV_RV_R$ in which $V_RV_RV_RV_R$ is the lowest measurable value i.e. RMM indicates RVR below 150 meters.
This form is limited to RVR values below 200 meters.
NOTE: For additional RVR info see MET page 14.
2. "Recent" applies if the phenomenom was observed during the hour preceding the time of observation.

3. When sky is obscured (N_s = 9), cloud group will be 9//$h_sh_sh_s$, where $h_sh_sh_s$ is vertical visibility. When cloud base is below station level, the group will read N_sCC///.

SUPPLIED BY JEPPESEN

Fig. 31. Translation of the code used in METAR.

REFERENCES

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Title and author(s)

The Øresund-Experiment -
Meteorological Measurements (Masts,
Turbulence, Mini-Sondes) Performed
by Risø National Laboratory

Sven-Erik Gryning and Niels Gylling Mortensen

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Pages 70 **Tables** 26 **Illustrations** 31 **References** 5

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Abstract (Max. 2000 char.)

This report describes the measurements carried out by Risø National Laboratory as part of the Øresund experiment. Measurements were made of 1) turbulence at the Gladsaxe mast during tracer releases, 2) profiles of wind and temperature at four small masts and at the Risø mast; by application of current flux profile relationship estimates of the momentum and sensible heat flux can be calculated, and 3) profiles of temperature, wet-bulb temperature and pressure by a mini-radiosonde-system (AIR-SONDE), the sondes were launched from a fishing boat at various positions in Øresund during tracer releases. The report also describes measurements of temperature with a so-called Sprenger-radiosonde-system. All radiosonde measurements described in this report were carried out by the Swedish Meteorological and Hydrological Institute. The Sprenger-sondes were launched from the fishing-boat in between the AIR-SONDES. The report contains a technical description of the instruments that were used and of their position and performance during the experiment. Most of the measurements are illustrated in figures and tables.

Descriptors

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