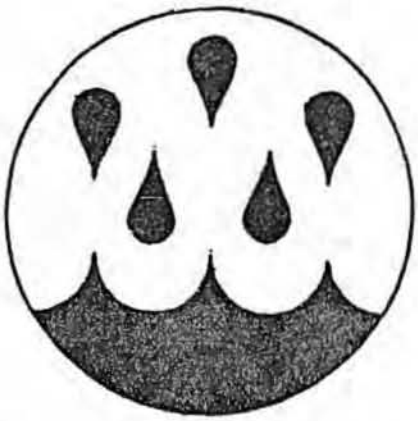
HEXOS PILOT EXPERIMENT

MEETPOST NOORDWIJK, NOVEMBER 1984

FIELD PROJECT REPORT



Wiebe A. Oost, Royal Netherlands Meteorological Institute KNMI

Kristina B. Katsaros, Department of Atmospheric Sciences,

University of Washington

and

Stuart D. Smith, Atlantic Oceanographic Laboratory,

Bedford Institute of Oceanography, DF&O

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Frontispiece (Facing page) North side of MPN, with 17 m boom deployed.

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ACKNOWLEDGEMENTS

The experiment would have been impossible without the readiness and help of a good many people and services. First of all we thank Rijkswaterstaat and more specifically its North Sea Directorate, for putting Meetpost Noordwijk at our disposal. We appreciate very much the way in which its representative, Ing. A.H. Koeman, participated in our deliberations and arranged our stay on MPN. The way in which the caretakers, J.A.M. Goossens, F. van de Velden and J. Harder, handled the situation at the platform and the friendly and productive atmosphere they created there were highly appreciated by the participants and constituted important contributions to the success of the experiment.

We thank those Dutch Customs Officers who helped us to straighten things out after we unexpectedly found ourselves in trouble. We would like to mention especially Mr. van Zuilen of the Inspectie der Invoerrechten en Accijnzen at the Hague who finally cut the knots and enabled us to regain our instruments. Even so we will try to avoid renewed contact! A word of thanks also goes to the people of the directie Luchtverkeersbeveiliging of the Rijksluchtvaartdienst who granted permission to the UK Hercules C-130 aircraft to execute its complete flight pattern.

Finally we mention the people at KNMI who lent support to the experiment by making available supporting data and by giving local forecasts. Though we did not use the forecast facility extensively during HEXPILOT, we thank them and look forward to co-operating with them again in 1986.

1. INTRODUCTION

1.1 The HEXOS (Humidity Exchange over the Sea) Program

This program is intended to develop a better understanding of transport of water from the sea surface to the air. At a NATO-sponsored workshop held at the Bedford Institute of Oceanography in May 1981, the state-of-the-art was reviewed, noting in particular that there are no direct measurements of evaporation over the sea at high wind speeds. Topics requiring research were identified, and a preliminary research proposal was outlined (Smith and Katsaros, 1981). From this and from meetings at the Hague (May 1982) and in Hamburg (August 1983) evolved the HEXOS Scientific Plan (Smith et al., 1983) which poses six questions:

(1) How does the evaporation coefficient depend on wind speed, sea state, and stability?

(2) Can surface-layer bulk formulations be applied at high wind speeds, and, if so, at what height should humidity be measured?

(3) Can we demonstrate experimentally an expected dependence of evaporation on wind stress, stability, wave breaking,and spray droplet distribution?

(4) How well do 'dissipation' measurements from a ship and from a fixed platform estimate evaporation?

(5) Can eddy correlation measurements be satisfactorily corrected for flow distortion by a fixed platform?

(6) Can fast-response humidity sensors be operated in marine conditions for extended periods of time? Which types are most successful, and could they be adapted for longer-term operation on unmanned platforms?

A coordinated, international series of experiments has been planned

to address these questions, taking advantage of existing facilities and expertise. Completion of these experiments will result in major progress toward answering all of the above questions.

The core of the scientific plan is obtaining water vapour flux and aerosol measurements at a Dutch offshore platform, Meetpost Noordwijk (MPN), as well as relevant data from an aircraft and from one or more near-by ships. The series of experiments is as follows:

A. A flow distortion study (Wills, 1984) addressed question 5, finding that at sites 16 m from the west side of MPN, in westerly winds, the platform has only a small effect on the eddy flux of momentum, and hence on other eddy fluxes such as evaporation. This resolved doubts regarding the feasibility of using MPN as a base for eddy flux measurements.

B. Development of a boundary layer model including spray and droplet distribution is ongoing throughout the program.

C. A proposed pilot experiment for U.S. participants at an air-sea interaction study at San Nicolas Island, California, was not carried out due to delays in funding. Instead, efforts were concentrated on experiment D.

D. An international pilot experiment HEXPILOT, at MPN, the subject of this report, addresses all of the above questions.

E. A wave tank/wind tunnel experiment HEXIST will be carried out in the air-sea interaction simulation tunnel at IMST, Marseille, in the spring of 1985, addressing questions 3 and 6.

F. The main experiment HEXMAX will be carried out at MPN in the fall of 1986, taking advantage of experience from the previous experiments, and including ship- and aircraft-based measurements.

G. A longer-term experiment (6 to 12 months) at an unmanned offshore tower will eventually be needed to collect data on humidity exchange in a wide range of conditions on a regular basis. It is anticipated that instrumentation developed and tested during the HEXOS program will make this feasible, but plans for this experiment have not yet been made.

1.2 Summary of Events

Following the recommendations of the flow distortion study, a 17-m boom was constructed at KMNI and mounted at the west side of the platform with the consent of its owner, Rijkswaerstaat (the Dutch Department of Transport and Public Works).

A planning meeting was held at KNMI on May 23-25, 1984, with the major part of travel by non-Dutch participants covered by a grant from the NATO Special Programme Panel on Marine Sciences. The participating agencies were the University of Washington (USA), the Bedford Institute of Oceanography (Canada), the UK Meteorological Office, NMI Ltd. (UK), Rijkswaterstaat (Neth.), TNO-MT (Neth.), FEL-TNO (Neth.), and KNMI (Neth.).

During the meeting, which included a visit to Meetpost Noordwijk, the participants discussed, among other things, the precise dates for the experiment, a scheme for the use of the boom by the various participants, the mutual relations of the various contributions, and the objects to be achieved by this part of the HEXOS program.

The experiment itself took place from October 29 until November 23, 1984, excluding the weekends. Previously, on October 11, the instruments of KNMI as well as a photo/video system for the detection of whitecaps, contributed by University College Galway (Republic of Ireland), were

shipped to the platform. The instruments of the other participants arrived later and had to be taken to the platform at the beginning of the experiment. The weather on that arrival day did not permit landing a ship at the platform, so that the participants and the remaining instruments were transported to the platform by a number of helicopter flights.

The number of HEXOS participants on board the platform was 10 during the whole of the experiment. The numbers of persons from the participating institutes the platform during the four weeks of the experiment are listed in Table 1.1:

TABLE 1.1 Platform Occupancy, 1984 Pilot Experiment

WEEK	FROM	TO	UW	BIO	KNMI	FEL-TNO	TNO-MT
1	OCT 29	NOV 2	2	3	5	0	0
2	NOV 5	NOV 9	2	3	4	1	0
3	NOV 12	NOV 16	2	3	3	1	1
4	NOV 19	NOV 23	2	2	4	1	1

The first week was used for mounting and testing the equipment, and gaining experience in the use of the outrigger. During the second week the measurements were started; most of the results were, however, of restricted value because of a number of technical problems, while furthermore the winds were mainly weak and easterly (the boom, as mentioned before, was at the west side of the platform). During the third week the general weather situation was little different, only the wind speeds were higher, but still from easterly directions. Under these circumstances, it was possible to do a number of intercomparison runs. Also, a test flight was made by the UK C130 Hercules research aircraft. The fourth and final week brought

week brought westerly winds up to gale force. Due to this change in the weather all goals of the experiment were met: flux measurements were made at wind velocities up to 15 m/s, extending significantly the range of wind speeds for which water vapour flux measurements exist, while furthermore the intercomparisons of the various instruments were extended to conditions of high wind, rain, and large amounts of spray. Some limitations of the 20-m boom were discovered under these circumstances. On Wednesday, November 21, the UK Hercules flew a complete mission under favourable circumstances. Mainly because of the results of this last week, the experiment was considered a success by all participants. On Wednesday, December 5, the instruments were brought ashore by boat.

2. UNIVERSITY OF WASHINGTON, DEPARTMENT OF ATMOSPHERIC SCIENCES.

K.B. Katsaros, R.J. Lind

2.1 Goals

The goals of the University of Washinton in the HEXOS pilot experiment were to test our newly developed sensors for measuring turbulent fluctuations of temperature, humidity, and the three components of the wind; reliability of our recording system in a field configuration; and to monitor sea-surface temperature and short- and long-wave irradiances.

Boom-mounted sensors included a modified Gill-type propeller-vane-anemometer and wet- and dry-bulb thermocouples housed within an aspirator unit designed to remove airborne salt and hydrometeors. The K-Gill is a new design and had only been deployed at local field stations. The opportunity to compare spectra and momentum fluxes calculated for measurements made with this instrument to calculations made by our colleagues is valuable. Our aspirator system for measuring temperature and humidity

(using the psychrometric method) was designed to operate in the presence of ocean spray. High winds during the last week of the field program provided a thorough test of the system's operability and effectiveness at keeping liquid water from contaminating thermocouple measurements.

2.2 Instruments and Data Recording

Propeller-vane-anemometer. Our propeller-vane-anemometer (nicknamed the K-Gill due to its shape) has two axial Gill-type helical propeller units (R.M. Young Co.) fixed at 45° above and 45° below horizontal. A standard vane keeps the unit aligned with the wind. An electrical level is mounted horizontally on the axis of rotation. Using the two measured components of the wind, information from the level and the response of the propellers at the deployed angles, an instantaneous estimate of the horizontal and vertical wind components can be made by a short iteration.

Calculations of wind stress using the K-Gill have compared favourably with measurements using a 3-D sonic anemometer. The K-Gill's sensitivity is somewhat lower than that of a standard single propeller-vane anemometer, making stress calculations less accurate in wind speeds below 5 m/s than at higher wind speeds.

Aspirator System and Thermocouple Psychrometry. The following approach was used to remove airborne particles from the air stream without affecting its thermal or moisture properties: an anodized aluminum pipe (4" diameter) was fitted with a rotating fan-and-mesh filter to draw air through the system and remove droplets and particles. This assembly was rotated at 2000 rpm by a dc motor mounted at the exit end of the pipe. The mesh was shaped like a truncated cone wih a nylon mesh filter stretched over it.

Dry- and wet-bulb chromel-constantan thermocouples (0.002" diameter) were mounted within the housing. The wet-bulb thermocouple was wetted by a drip tube fed by gravity flow from a water reservoir. Noise due to the dc motor was minimized by isolating the thermocouples and electronics from the aspirator housing.

Bare dry- and wet-bulb thermocouples were also deployed at the west end of the platform helipad to allow intercomparisons between the two thermocouple systems.

Sea Surface Temperature and Radiation Instruments. A bead thermistor was mounted on a float to measure sea surface temperature at a depth of about 10 cm. This float was deployed from a short boom attached to the SE corner of the understructure of MPN. An infrared radiometer (Barnes Engineering, Model PRT-5) was fixed to a handrail and pointed at the sea surface in the same area.

Upward-looking radiometers were attached to the south edge of the helipad. An Eppley 'PSP' pyranometer measured short-wave irradiance (0.38 to 2.8 μm) and an Eppley 'PIR' pyrgeometer measured long-wave irradiance (3.0 to 50 μm).

Recording System. Outputs from each sensor were sampled at 27.2 samples per second, digitized and serialized using a frequency-shift keying (FSK) unit and recorded on a reel-to-reel tape deck. The data were low-pass filtered at 7 Hz before recording. Additionally, a microprocessor was used to log means for all channels and calculated cross-products of turbulence data. An oscilloscope, chart recorder, and voltmeters were used to evaluate instrument performance during runs.

2.3 Data Obtained

Our flux measuring instruments were operated on the boom on the following dates: November 6,9,13,15,16, and 19-22. During the early runs, the wind blew through the legs of the platform and the data could, at best, be used for intercomparison with measurements by BIO and KNMI. During the week of November 19-22, however, the wind direction became favourable and the instruments and recording systems functioned well. We expect to calculate fluxes of humidity, temperature, and wind stress during this period. The water surface thermistor functioned well after deployment on November 15. The PRT-5 output was erratic. Variations in cloudiness make interpretation of data from this instrument complex. The uplooking radiometers operated well except for some downtime on November 12.

2.4 Problems Encountered

The instruments themselves operated quite well during HEXPILOT. We have not yet seen any problems with the K-Gill anemometer or the psychrometers, although we are not certain about absolute calibrations of the latter. The aspirator exhibited some vibrations due to the motor, which we plan to remedy. It is not terribly significant for our relatively low response instruments, but the vibrations should be minimized before 1986.

Some logistic inconveniences were experienced with the boom. The gravity-fed irrigation system to the wet-bulb thermocouple was lost several times and the exit end of the aspirator unit was directed into the wind while the boom was being raised, allowing spray and rain to enter the tube. These inconveniences will be remedied before the next field phase.

The most significant problem that we see at present is due to interference from the platform-to-shore telephone system. It created

unacceptable noise levels and bias shifts in our data when used. A second minor problem, low ac line voltages on MPN, can be improved for 1986.

2.5 Conclusions

The HEXPILOT was a success for us. We had a proper field test of our equipment and have hopes for some interesting flux data. The main concern from our point of view for 1986 is that we provide adequate instruments (and routine calibration methods) for determining absolute values of quantities to be used in humidity flux parameterization schemes. This question needs to be addressed by the HEXOS participants as a group at the Fall 1985 Workshop.

Another matter, which needs attention before the 1986 main experiment, is sensitivity studies to help us design the measurement scheme (i.e., heights of measurement, duration at each height, sequences, etc.). At the University of Washington, we are taking steps to address this question.

3. BEDFORD INSTITUTE OF OCEANOGRAPHY (BIO), DARTMOUTH, N.S., CANADA

S.D. Smith, R.J. Anderson, D.L. Hendsbee

3.1 Goals of BIO Participation

Our goal in this experiment was to test an eddy flux measuring system using a Lyman Alpha humidiometer in an aspirator designed to remove droplets from the airstream, and to obtain eddy flux measurements where other relevant parameters (spray, aerosol droplets, solar radiation, boundary layer height, standard meteorological parameters, sea state, and ocean currents) are measured.

TABLE 3.1 BIO Data Summary

RUN NO.	START TIME GMT	DAY NOV 1984	LENGTH min.	R.H. (MPN) %	Ta °C	Ts °C	U m/s	DIR'N deg	h m	WEATHER
1	1544	1	45	79	15.9	12.7	9.1	195	4.9	0/10
3	1356	6	47	88	11.4	12.2	7.4	217	4.6	10/10
5	1648		48	86	11.6	12.2	6.0	231	7.5	10/10
9	1027	13	47	87	9.9	11.7	5.7	185	4.7	Fog
10	1245		43	87	10.5	11.8	7.0	223	7.9	Fog
11	1358		37	90	11.0	11.8	5.9	213	5.8	Drizzle
18	1900	19	48	87	9.8	11.2	7.1	206	4.9	Rain
19	2024		49	88	9.4	10.8	6.6	213	5.8	4/10
21	0700	20	49	75	8.6	10.9	8.5	279	5.7	
22	0932		48	72	8.9	10.9	8.2	270	6.7	
23	0951		43	73	8.9	10.8	8.6	274	3.6	
24	1059		40	73	8.7	10.8	8.6	276	3.9	2/10
25	1225		48	72	10.4	11.0	9.2	270	4.5	2/10
26	1400		48	75	10.0	11.1	9.4	264	6.1	8/10
27	1524		48	73	9.8	11.2	8.7	255	7.5	5/10
28	1646		48	74	10.1	11.2	9.6	238	8.6	
29	1810		47	82	9.9	11.0	10.2	211	5.7	10/10
30	1957		48	85	9.4	10.9	10.9	211	5.0	
31	2058		48	85	9.0	10.8	10.2	207	6.2	
32	2228		48	86	9.0	10.8	11.2	195	4.3	
33	0534	21	46	89	10.1	11.1	11.8	221	6.2	10/10
34	0735		48	81	11.8	11.1	12.0	271	5.7	
35	0857		48	80	11.0	10.9	12.8	278	4.7	6/10
36	1018		33	78	11.0	10.9	13.0	288	5.4	
37	1119		21	77	11.0	11.0	12.8	278	5.6	2/10
38	1216		45	76	11.4	11.0	12.2	270	4.2	
39	1325		48	76	11.3	11.1	13.0	260	4.5	
40	1438		48	76	11.4	11.2	11.8	257	4.9	
41	1600		42	77	11.4	11.2	12.1	250	7.3	
42	1708		48	77	11.5	11.2	11.3	247	7.9	7/10
43	1828		48	77	11.7	11.0	11.6	242	7.4	
44	1953		48	84	9.8	11.1	11.4	215	6.8	10/10
45	2114		48	86	9.9	10.8	12.9	216	5.9	10/10
46	0806	22	39	92	12.0	11.1	15.6	226	5.8	10/10
47	0941		40	90	12.2	11.2	15.0	232	8.1	10/10
48	1107		46	90	12.3	11.0	12.5	229	7.6	10/10
49	1217		48	90	12.1	11.2	12.7	227	4.8	10/10
50	1400		46	90	11.9	11.2	13.0	208		10/10

3.2 Instruments Deployed by BIO

An eddy flux measuring system consisting of a Kaijo Denki PAT311 sonic anemometer, a microbead thermistor, and an ERC (Electromagnetic Research Corp.) Lyman Alpha humidiometer was deployed on the south prong of the 20-m boom. This system, with variations, has been used for many years to study wind stress, heat flux, and evaporation at a number of sites including arctic pack ice, the beach of Sable Island (a sand bar in the North Atlantic Ocean), and an unmanned tower 10 km from shore near Halifax, N.S.

During this experiment a second Lyman Alpha humidiometer was mounted in a 'droplet refinery,' an aspirator which was designed to remove droplets onto a collecting surface by directing the inlet air around an abrupt flow reversal. During periods of rain, fog, or salt spray from breaking waves, the first Lyman Alpha humidiometer had to be removed to prevent damage to its soluble MgFl salt windows.

A new thermistor bridge circuit developed at BIO by Dr. N. Oakey was used in this experiment. It linearizes the response to temperature, and is compact enough to be mounted at the tip of the boom so that the signal is no longer subject to the pickup of radio interference along the cable from the boom to the data recorder. The BIO sensors are shown in Fig. 3.1.

3.3 Data Obtained

A total of 50 data runs was recorded with the BIO eddy flux system. After deletion of several runs taken when the wind direction did not have a westerly component and of several which suffered from technical problems, the runs listed in Table 3.1 are suitable for analysis.

The raw data consist of humidity, temperature, and three wind

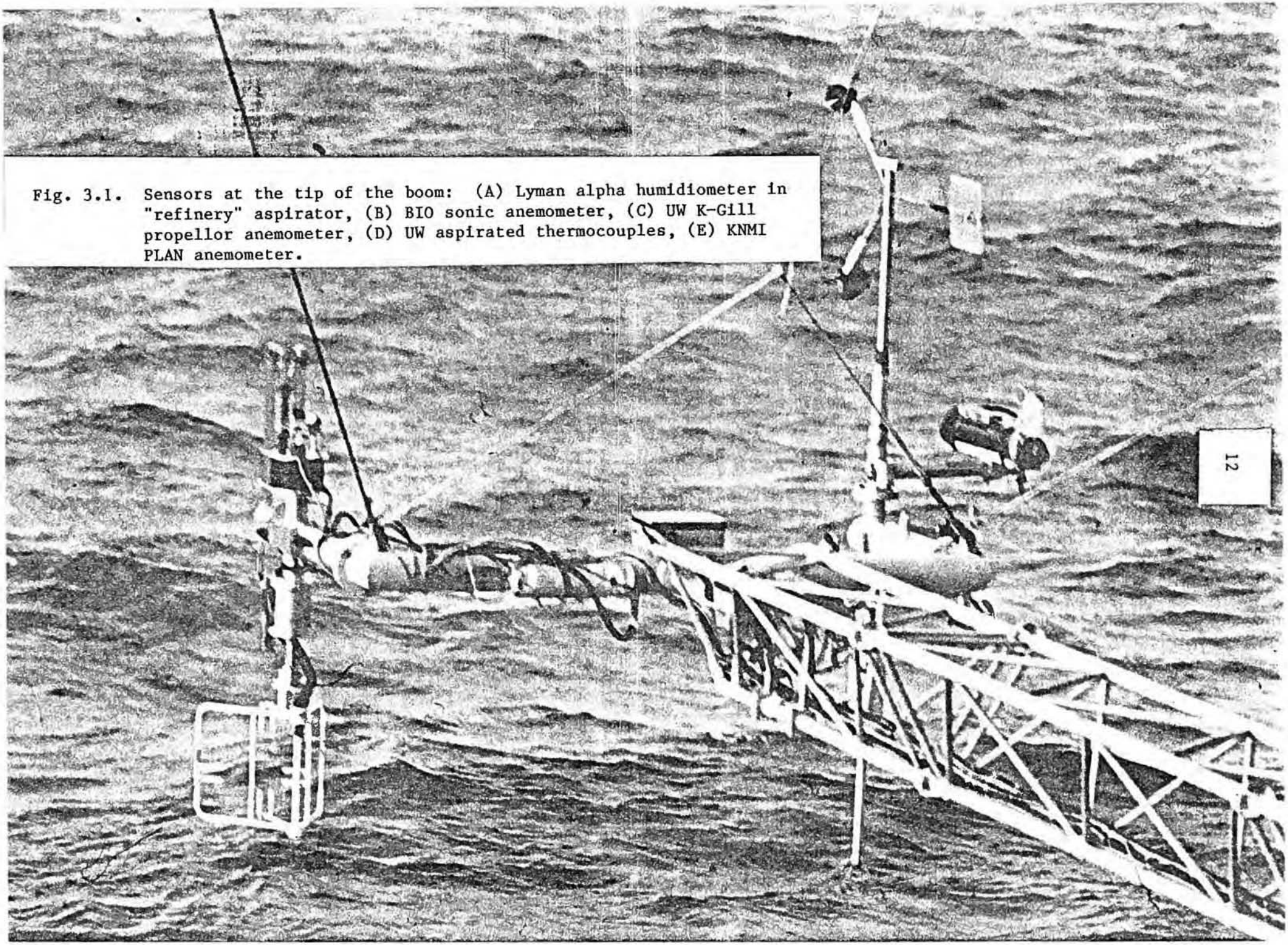


Fig. 3.1. Sensors at the tip of the boom: (A) Lyman alpha humidiometer in "refinery" aspirator, (B) BIO sonic anemometer, (C) UW K-Gill propellor anemometer, (D) UW aspirated thermocouples, (E) KNMI PLAN anemometer.

components sampled 32 times per second, encoded in serial digital form in the range 0 to 2047 (11 bits + parity) and recorded on audio cassette tapes. Data runs are normally about 45 minutes in duration, except that a few are shorter due to rapid meteorological changes or to technical problems. Oscillograph traces were used to monitor sensor performance.

The first stage of analysis consists of decoding the cassette tapes and writing the data to 9-track computer-compatible tape in a buffered format. Calibrations are then applied to generate time series tapes in physical units from which the means and linear trends are removed. Statistical and spectral analyses are then run to obtain turbulent fluxes and statistical properties of the turbulence.

3.4 Problems Encountered

While the newly developed aspirator was highly successful in allowing Lyman Alpha humidiometers to operate in high wind, rain, and mist, the frequency response was noticeably reduced (at and above about 1 Hz) based on comparing oscillographs from the aspirated and bare humidiometers operating simultaneously. Spectral and cospectral analysis will give a more precise measure of the degradation of frequency response. A modified aspirator with a shorter air path is being designed.

On the whole, the installation of equipment from several research groups went very well due to careful preparation by KNMI. Several minor technical problems were part of the process of learning to work on MPN. Intermittent failures of our digital decoder were traced to a dc power supply that was sensitive to low ac line voltages; similar problems were encountered by other groups and were partially solved by adjusting the main power generator. At higher wind speeds there was some motion of the tip of

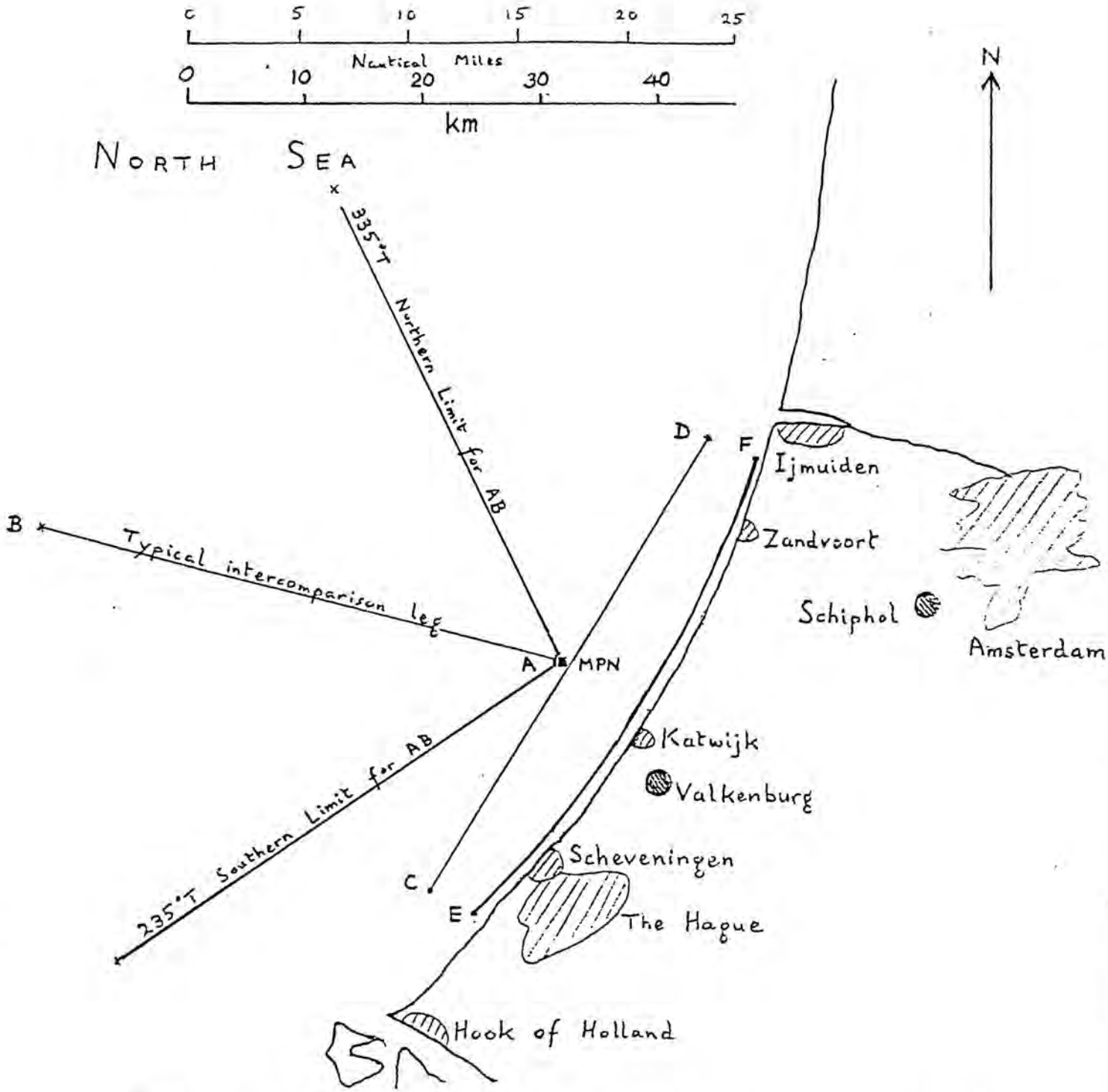


Fig. 4.1. Flight tracks of C130 aircraft on Nov. 21, 1984. The position of MPN is 52°16'26"N, 4°17'46"E.

the boom. We will need a more rigid rotating mount for the sonic anemometer probe, and if possible we should reduce the weight of instruments placed on the boom. A shortage of laboratory space during the Pilot Experiment was due to another project running simultaneously, and during the Main Experiment more space will be available. Occasionally there was interference from radio-telephone transmissions.

3.5 Conclusions

The MPN boom is a suitable site for collecting eddy flux data and other measurements relevant to the HEXOS Programme at wind speeds up to 15 m/s. The Pilot Experiment has demonstrated the feasibility of having several groups operate simultaneously on MPN. Data collected during a period of strong westerly winds are expected to yield significant scientific results.

4. BRITISH METEOROLOGICAL OFFICE

A.L.M. Grant

4.1 Goals

The British Meteorological Office is interested in the structure of atmospheric turbulence in the marine boundary layer. During HEXOS the variation of the turbulent humidity flux with height in the lower half of the mixed layer, and its relationship to the characteristics of the aerosol size distribution, will be investigated, using the Meteorological Research Flight's C130 Hercules aircraft.

4.2 Instruments

The instruments mounted on the C130 for HEXPILOT were those listed

Table 4.1. Aircraft data runs on November 21, 1984.

Run	Times (GMT)	Altitude (m)	Track (Fig. 4.1)	FSSP range	Comments
Profile P1	121521-122254	1500-150	CD	-	Refractometer boom out at 120615. 4 oktas of cumulus cloud present. Bases 600 m, tops 1200 m-1500 m.
$K_{,\gamma}$	122609-123255	150	-	-	Aircraft calibration run.
1	123755-124704	350	DC	3	FSSP working, but see notes. 4 oktas of cumulus cloud overhead, bases 600 m.
2	124939-125654	280	CD	3	3-4 oktas of cumulus cloud overhead, bases 600 m.
3	130049-130921	220	DC	3	FSSP range 3 u/s from 130600. Range 3 only works intermittently for the rest of the flight. Run ended early to avoid a shower.
4	131226-131932	150	CD	3	FSSP range 3 u/s. 1-2 oktas of cumulus cloud overhead.
5	132301-133212	95	DC	3	
6	134016-134921	35	AB	3	Intercomparison run with Meetpost. FSSP range 3 still not working. 3 oktas of small cumulus overhead.
7	135726-140451	35	CD	3	Some spray appears to be reaching the aircraft level. FSSP range 3 appears to be working again.

Table 4.1. Cont'd

Run	Times (GMT)	Altitude (m)	Track (Fig. 4.1)	FSSP range	Comments
8	140840-141716	150	DC	3	FSSP range 3 u/s again.
9	142057-142804	340	EF	3	FSSP u/s until 142330.
10	143122-144008	270	FE	3/2	FSSP on range 2 for most of run. Appears to be working satisfactorily.
11	144259-145012	220	EF	3/2	FSSP on range 2 from 144510. 4 oktas of cumulus cloud overhead, bases 460 m.
12	145339-150230	160	FE	2	4 oktas of small cumulus overhead. Cumulonimbus clouds developing over land. FSSP working.
13	150519-151235	90	EF	3/2	FSSP range 3 u/s. Approximately 4 minutes of data obtained with range 2.
14	151541-152437	35	FE	2/3	2 oktas of small cumulus overhead.
15	152949-153630	160	CD	2/3	Approximately 4 minutes of FSSP data obtained on range 2. Cumulus clouds spreading into stratocumulus overhead.
K,γ	153827-154506	150	-	-	Aircraft calibration run.
Profile P2	154716-155415	140-1500	-	-	4 oktas of cumulus cloud present. Bases 760 m, main tops 910 m with isolated tops to 1450 m. Refractometer boom in at 155511.

in Appendix 3 of the HEXOS Scientific Plan (Smith et al., 1983 except that the Knollenberg ASSP (particle size spectrum probe) has been replaced by a Knollenberg FSSP with particle diameter ranges 0 (2-47 μm), 1 (2-32 μm), 2 (1-16 μm) and 3 (0.5-8 μm). The recording frequencies of some variables have been changed due to the fitting of a new aircraft data recording system (DRS).

4.3 Experimental Flying during HEXPILOT

Because of the unsuitable weather conditions during the first two weeks of the experiment only one flight was made by the C130. The flight, on November 21, took place in a westerly flow behind a cold front. One to four Oktas of small cumulus clouds, with bases between 500 m and 650 m, were present throughout the flight but no precipitation was encountered.

The main part of the flight consisted of horizontal runs along tracks CD and EF in Figure 4.1 at altitudes between 30 m and 350 m above sea level (ASL). A total of 14 runs were carried out, 8 along CD and 6 along EF. In addition to these runs, an intercomparison run along track AB at 30 m ASL, and two vertical soundings, were also carried out (Table 4.1).

When analysis has been completed, the following data will be available:

(a) mean winds (derived from the Doppler radar) for all runs at heights above 60 m;

(b) mean air temperature, specific humidity, and sea surface temperature for all runs;

(c) vertical heat and humidity fluxes;

(d) aerosol size distributions.

Figure 4.2 shows aerosol spectra obtained using ranges 2 and 3 of the FSSP along track EF. The spectra obtained using range 2 are similar in shape to those found by Monahan et al. (1983) in the North Atlantic for wind speeds around 7 ms^{-1}. Compared to the range 2 spectra the range 3 spectra show a marked lack of particles with radii greater than 2 μm. The spectra obtained along track CD using range 3 are similar to the spectrum in the figure. In these spectra the fraction of marine air volume occupied by aerosols is $dV/dr=(4/3)\pi\ r^3 H(r)/\Delta r$ where N(r) is the concentration of particles of radius r to $r + \Delta r$, and Δr is the width of an FSSP channel.

4.4 Instrumental Problems

(i) A hardware fault in the clock of the aircraft data recording system has caused data to be recorded on tape in the wrong order. A tape has been produced with the data in the correct order, and analysis of the data is now underway.

(ii) No data from the inertial navigation system for the northerly component of the aircraft ground speed were recorded because of a wiring fault.

(iii) Some of the data channels are 'noisy.'

(iv) Preliminary analysis of the FSSP data indicates that Range 3 of the instrument was not working properly during some of the runs. (See Comments in Table 4.1).

4.5 Conclusions

The single flight during HEXPILOT proved that the C130 can operate successfully near the Meetpost Nordwijk. Problems with the new DRS on this flight do not affect plans to participate in HEXMAX in 1986.

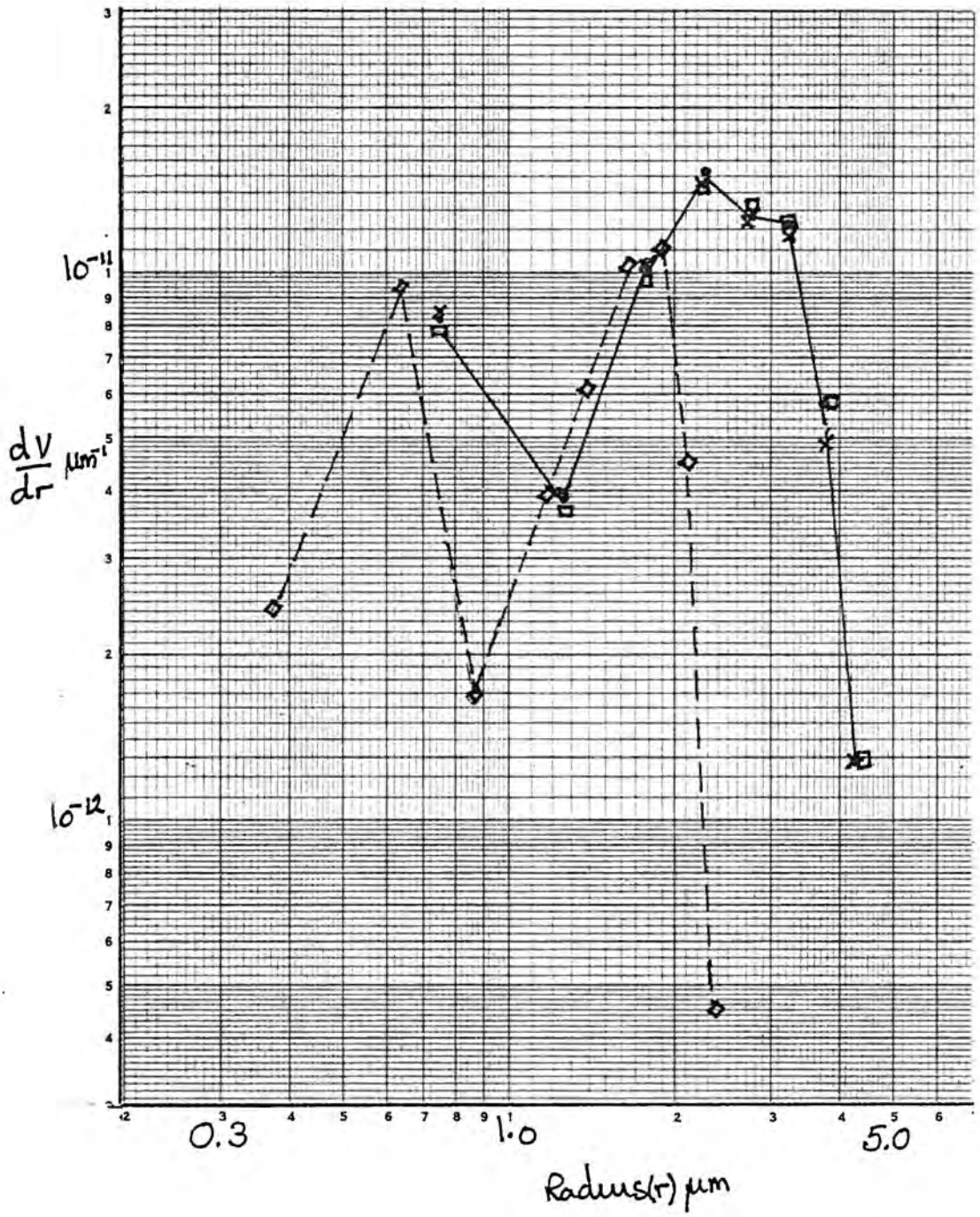


Fig. 4.2. Aerosol spectra along track EF: ● 143250-144000, Range 2;
□ 144510-145000, Range 2; x 145350-150220, Range 2;
◇ 151710-152420, Range 3.

5. ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE, OCEANOGRAPHIC DEPARTMENT (KNMI-00)

W.A. Oost, R. Kraan, J.W. Schaap, E.H.W. Worrell, C. van Oort, R.E. Breemer, and J.H. van der Zweep

5.1 Goals

- Gain experience in the use of some recently developed instruments (pressure anemometer, optical breaking wave detector);
- Gain experience in the properties and in the handling of a 20-m boom;
- Obtain simultaneous momentum flux, wave, and wave-breaking data to check theoretical predictions on their relations;
- Compare moisture flux data, obtained with the pressure anemometer as the wind-sensing device, with those obtained from other instrument combinations;
- Compare the results of the flow distortion study, performed at NMI Ltd. with results obtained in situ; and
- Compare the calculated flow distortion, obtained with a potential flow approximation, with in situ results.

5.2 Instruments Deployed

- Pressure anemometer: a self-cleaning wind-vector sensing device, developed at KNMI for use near the sea surface (Fig. 3.1);
- Sonic anemometer: Kaijo Denki DAT 300. The instrument was mounted 7 m above the heli deck for comparison purposes (see Goals, item 5);
- Nichrome wave wire, resistance type;
- Breaking wave detector: optical system in which the light

reflected from the sea surface right below the instrument is compared with the reflected light from a much larger surrounding area;

- 20 m boom: this 'instrument' consists of two parts connected by a hinge. The second part (i.e., the part not directly connected to the platform) can be positioned at various heights above the sea surface (0 to about 10 m above mean sea level) and can be leveled to within 0.1°; and
- KNMI-00 also made video and photo recordings of whitecaps on behalf of University College Galway, Republic of Ireland.

5.3 Data Obtained

Forty data runs were obtained with a mean duration of 45 minutes each. The first 8 runs will not be analysed because of technical problems and easterly wind directions.

Data were obtained from the following instruments with the indicated data rates and filters:

(1) pressure anemometer, 3 channels, 70.3125 samples/second; low-pass filter at 20 Hz (4-pole Butterworth);

(2) sonic anemometer, 5 channels, 70.3125 samples/second; low-pass filter at 19.4 Hz, single pole;

(3) wave height meter (wave wire), 1 channel, 35.156 samples/second; low-pass filter at 19 Hz, double pole;

(4) breaking wave detector, 1 channel, 17.578 samples/second; low-pass filter at 0.86 Hz; and

(5) wave height meter (waverider), 1 channel, 17.578 samples/second; low-pass filter at 0.86 Hz.

Instruments of the University of Washington that were recorded simultaneously:

(6) protected dry and wet thermocouple, 2 channels, 35.156 samples/second; no (additional) filtering; and

(7) unprotected dry and wet thermocouple, 2 channels, 17.578 samples/second, no (additional) filtering.

Instruments of Bedford Institute of Oceanography that were recorded simultaneously:

(8) protected Lyman-α hygrometer (runs 18-36), 1 channel, 35.156 samples/second, no (additional) filtering; and

(9) unprotected Lyman-α hygrometer (runs 1-17, 37-40), 1 channel, 35.156 samples/second, no (additional) filtering.

KNMI needs our thermistor

Instrument of KNMI-FM that was recorded simultaneously:

(10) CO_2-laser light intensity (runs 14-19, 25-37), 1 channel, 17.578 samples/second, no (additional) filtering.

The following parameters were also recorded:

(11) position of sonic rotor

(12) electronic levels of sonic probe (2 orthogonal directions)

(13) inlet-pressure of pressure anemometer

(14) length of wave wire above the water surface

(15) electronic levels on second part of outrigger (2 orthogonal directions)

(16) inclinometer on first part of outrigger (1 direction)

(17) angle between wave wire and vertical.

(18) A 17.578 Hz time signal was recorded and passed on to the other participants.

A series of 38 video- and photorecordings was made for the University College Galway program on whitecaps.

5.4 Problems Encountered

(i) Probably due to a low mains voltage, the microprocessor controlling the data runs produced spurious pulses on some occasions, which ended a few runs prematurely.

(ii) At strong westerly winds (>20 m/s) the second part of the outrigger boom was not sufficiently heavy to be extended again after it had been brought to a vertical position for the servicing of the instruments at its tip. If an attempt had been made to raise the boom in these conditions, it would have been carried up by the wind force with possibly dangerous or damaging consequences.

(iii) On a number of occasions of strong southerly winds the cables of the outrigger were vibrating; this, on its turn, introduced vibrations in the instruments and a penetrating noise.

(iv) Data of the pressure anemometer are uninterpretable for one run (run 16), due to a defective filter.

(v) Vibrations of the pressure anemometer, caused by an unbalance in the rotor of the UW aspirated psychrometer were visually detected.

(vi) Problems were encountered with Customs authorities, regarding shipment of "foreign" equipment to and from MPN.

5.5 Conclusions

Pressure anemometer: The instrument functioned satisfactorily, especially at high wind velocities. At wind velocities below 8 m/s some problems

during the data anslysis have been attributed to a construction error in the sensing head. The need for relatively frequent zero-point calibrations (at the beginning and end of each run) caused time gaps, which also delayed the other participants. We expect to be able to greatly diminish the number of zero checks by some changes of the main body of the instrument.

Breaking wave detector: A first visual test during the experiment of the performance of this instrument was promising. A further evaluation will be based on a comparison of the breaking wave data and the other wave measurements.

The boom: The behaviour of the boom was more or less as expected. Measures will be taken which will allow us to handle the boom more safely during high wind situations and which will prevent strumming of the cables.

Customs problems: This was a very eduactional experience. A strict adherence to Customs formalities will be required of all participating groups in HEXMAX.

Transport: The late arrival of a great number of instruments necessitated a number of helicopter flights instead of a single trip with a ship. The price difference of several thousand dollars is something to keep in mind when preparing for HEXMAX.

We expect that all goals for this experiment will have been met once the data analysis has been finished. We owe this to a large extent to the strong westerly winds during the final week.

6. ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE, DEPARTMENT OF PHYSICAL METEOROLOGY (KNMI-FM)

W. Kohsiek, D. van der Luit

6.1 Goal

Inferring the moisture flux from observation of the scintillation of a CO_2 laser beam.

6.2 Instruments Deployed

On shore (lighthouse Noordwijk):

- CO_2 laser, output power 2 W, divergence 8 mrad, beam mechanically chopped at 1.6 kHz, height 15 m above mean sea surface level, distance 9.4 km from MPN.

On MPN:

- focussing lens (ϕ = 20 mm, f = 63.5 mm)
- HgCdTe detector (liquid nitrogen cooled)
- electronics for demodulation of the signal, amplification, band-pass filtering (1.5 to 400 Hz), and rms measurement
- The output signal is proportional to log C_n^2, where C_n^2 is the refractive-index structure parameter. Signals are logged on a strip chart recorder and on magnetic tape (KNMI-00).

6.3 Data Obtained

In total, 28 hours of data were obtained on 6 days, of which 11 hours were under favourable conditions, i.e., westerly winds. These 11 hours coincide with 8 runs of BIO/UW/KNMI-00: 3 runs on November 6th, 3 on the 20th, and 2 on the 21st. The scintillation measurement had to be stopped on the 21st because of a shortage of liquid nitrogen.

6.4 Problems Encountered

The CO_2 laser's output showed irregular changes (drift). From time to time the output power was too low to make meaningful measurements. The transport and supply of liquid nitrogen poses some logistical problems.

6.5 Conclusions

Except for the above-mentioned instability of the CO_2 laser, the system worked well, even during periods with high wind speeds. From the strip chart recording of C_n^2, the moisture flux was calculated for the 8 runs mentioned previously. In this calculation the friction velocity (u_*) and the Bowen ratio (B) are needed. u_* was calculated from the observed wind speed assuming $z_0 = 4.9 \times 10^{-5}$ m and neutral stability. B was calcuated from observations of air temperature and humidity, and sea water temperature (bucket), assuming equal transfer coefficients for heat and moisture. Table 6.2 shows the estimated moisture flux E_0, its sensitivity to the Bowen ratio $((dE_0/E_0)/(dB/B))$, and the moisture flux from the bulk aerodynamic method using a transfer coefficient of 1.13×10^{-3}. There is good agreement especially in view of the rather complex route from C_n^2 to the estimated moisture flux, which involves semi-empirical expressions between the fluxes of heat and moisture and their structure parameters in addition to the estimation of u_* and B.

A more definite conclusion on the merits of the scintillation method may be drawn when the eddy correlation data of E_0 are available, and values of the structure parameters of temperature and humidity and the correlation between temperature and humidity from the fast response measurements of these two quantities on the boom.

Table 6.1. Moisture flux E_0, in g m^{-2} s^{-1}, inferred from scintillation and from bulk parameterization. B = Bowen ratio, u_a = wind speed.

Date	Run (BIO)	u_a m/s	B	E_0 scint.	E_0 bulk	$\frac{dE_0/E_0}{dB/B}$
Nov. 6	3	7.3	0.23	13	15	-0.81
	4	6.8	0.21	12	15	-0.79
	5	5.1	0.15	11	12	-0.71
Nov. 20	26	9.5	0.17	31	35	-0.74
	27	8.5	0.17	25	30	-0.74
	28	9.7	0.15	31	33	-0.71
Nov. 21	36	13.0	0	29	32	0
	41	12.1	-0.072	26	27	-0.45

7. PHYSICS AND ELECTRONICS LABAORATORY, TNS

G. De Leeuw

7.1 Objectives of Aerosol and Lidar Measurements

For many years the Physics and Electronics Laboratory (FEL) of TNO has conducted both field trials and theoretical studies of atmospheric scattering and absorption of electromagnetic radiation. Techniques used include lidar measurements and measurements of both the particle-size distribution and chemical composition of the ambient aerosol.

One of the important fields of interest of FEL-TNO is the marine atmosphere. Starting in 1980, data under a variety of conditions were obtained during three cruises in the North Sea and the North Atlantic. Relations have been deduced which eventually will lead to an empirical model describing the marine particle-size distributions both at 10 m above sea level and at lower elevations, from which extinction and scattering properties in this lower layer can be calculated by Mie-theory. The results can be checked against lidar-derived extinction and backscatter coefficients.

The main objective of FEL TNO participation in HEXOS is to extend the data base, particularly at high winds where the number of shipborne measurements is very small and the influence of waves on aerosol production has not yet been clearly established. The number of vertical profiles of particle-size distributions close above sea level is rather limited, and they have all been measured in the North Atlantic in deep water. HEXOS provides an opportunity to obtain data over the North Sea, where these profiles may have different features due to the shorter wave period and the shallow water.

Using vertical profiles, the production rates of aerosol particles

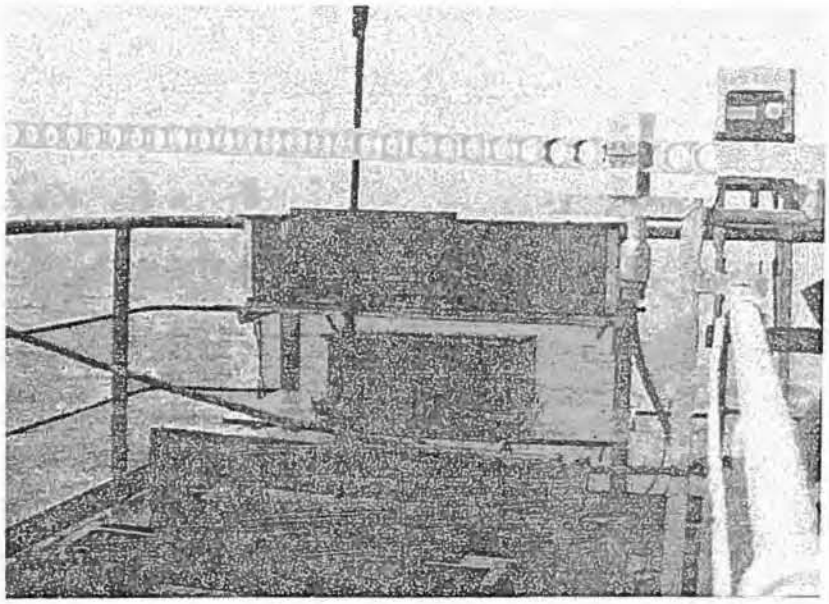
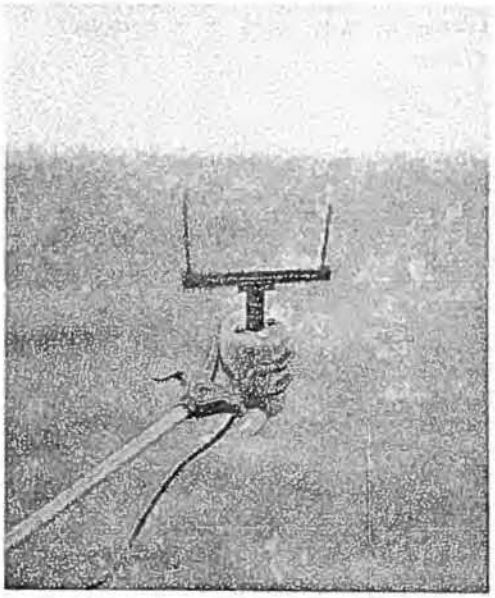


Fig. 7.1. Lidar, optical particle counter and radon counter installed on MPN.



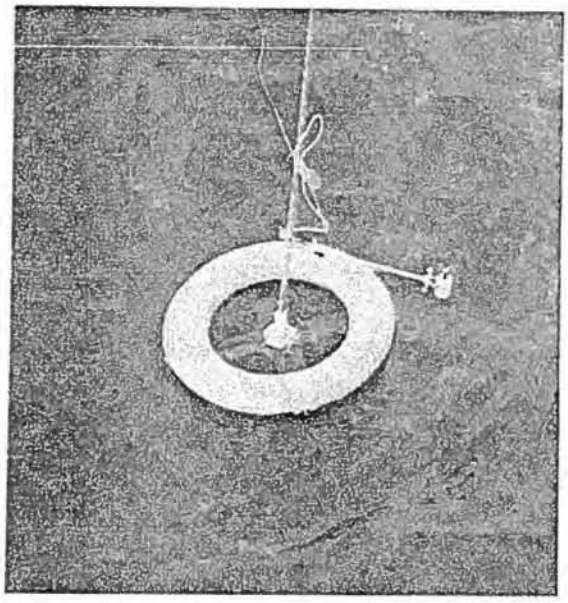


Fig. 7.2. Rotorod mounted on wave float at 50 cm above instantaneous sea level.

and hence the air-sea exchange of both liquid water and water vapour can be estimated. A model of the vertical distribution of aerosols also requires humidity and wind speed, which are measured at various heights by other HEXOS participants. Hence, participation in the HEXOS project fulfills the requirements of FEL TNO while also making an important contribution towards the main goal of HEXOS, i.e., the study of humidity exchange over the sea.

An important parameter for both studies is the evolution of the mixing layer, which has been measured by FEL TNO by using a lidar system. The vertical variation of the backscatter coefficient reveals variations of aerosol concentrations with altitude, and hence the presence of layers such as inversions or clouds. A continuous record of such profiles reveals the dynamic behaviour of the mixing layer.

7.2 Experiments

Lidar. An automatic lidar system (Table 7.1) was used to monitor the dynamic behaviour of the lower 500 m of the atmosphere. The vertical variation of the backscatter coefficient is derived from a horizontal lidar signal and a lidar signal recorded at an elevation of 30°.

The instrument was mounted on a small platform at the SW corner of the lower deck of MPN (Fig. 7.1) at a height of 13 m above sea level, aimed in a westerly direction. The lidar was placed horizontally, with the elevation adjusted by a servo-controlled internal mirror. The system was controlled by an HP-85 mini-computer, which also was used for data processing and storage. The dynamic changes in the atmosphere were made visible by storing the successively recorded signals in a video memory which was read-out on a colour display. The horizontal and vertical axes correspond to time and height, respectively, while colour indicates the

Table 7.1. Lidar parameters

emitter:	Nd glass laser	
	wavelength	1.06 μm
	energy	100 mJ
	pulse time	30 ns
	repetition rate	10/min
	beam diameter	27 mm
	divergence	1 mrad
receiver:		
	cassegrain telescope	
	diameter	74 mm
	field of view	0.3 mrad
detector:		
	Si-avalanche photodiode (RCA C30916E)	
	diameter	1.5 mm
	sensitivity	12 A/W
	quantum efficiency	18%
	amplifier	2500 V/A
	rise time	<30 ns
	decay time	<40 ns
	noise	0.5 mV p-p
	bandwidth	6.3 MHz

value of the backscatter coefficients. Vertical profiles of backscatter were measured day and night with a frequency of one profile each 6.5 minutes.

Optical particle counter. Particle size distributions in the range from 0.5 to 32 μm were measured with a PMS optical particle counter, type CSAS 100 HV. Particles are sized by the intensity of the light they scatter from a HeNe laser beam in a forward cone from 4 to 22°. The dynamic range of the scattered light intensity is so high (several orders of magnitude) that the range of the instrument is divided into two scales: range 0 for diameters from 2 to 32 μm (resolution 2 μm), range 1 for diameters from 0.5 to 8 μm (resolution 0.5 μm). The data are stored in a PMS data acquisition system where they are classified and counted. After each scan the spectra are transferred to a PET personal computer via an interface. The scan time for each range was set to 10 seconds, total integration times of 10 to 20 minutes were chosen. After completion of the measurement, polynomials of degrees 2 and 5

$$N(\log D) = \sum_i P_i * (\log D)^i, \quad i = 0 \text{ to } 2 \text{ or } i = 0 \text{ to } 5 \qquad (1)$$

are fitted to the logarithmic data points. The polynomial of degree 2 yields the parameters C and ν for the Junge distribution:

$$N(D) = CD^{\nu} \qquad (2)$$

The Junge parameters and the polynomial coefficients P_0 to P_5 are stored on magnetic tape, together with meteorological data, but the individual data points of the particle size distribution are not stored.

Rotorod. A Rotorod inertial impactor (Fig. 7.2), used to measure the concentrations of particles with diameters larger than about 10 μm,

consists of two polished stainless steel rods, 8.3 cm apart, mounted on a motor which rotates at 2400 rpm. The linear velocity of the rods is 10 m/s. Due to the rotation velocity, aerosol particles with high inertia stick to the rods. In order to retain the particles, the rods are sprayed with silicon. To prevent the collection of particles before the start of sampling, a retracting collector head was used; when the sampler starts rotating, the rods tip up due to centrifugal forces, and when it stops they are retracted.

The exposed rods are microscopically examined. Five microscopic images, chosen at random over the area of each of the two rods, are photographed. The 10 photographs are later digitized to determine the size distribution of the collected particles by computer.

The Rotorod impaction sampler has two applications. In the first place it complements our optical particle counters by extending the range of the particles that can be measured from 32 μm to about 100 μm. Our experiments in the North Atlantic have shown that in the overlapping size range the spectra determined by both methods are in good agreement, despite the difference in the physical principles on which they are based. Due to its small dimensions and light weight, the Rotorod sampler can be easily mounted in places not readily accessible to more bulky and heavy equipment. Therefore it has been used to measure particle size distributions at various heights above sea level. For this purpose the sampler was mounted on a simple wave follower (Fig. 7.2) consisting of a toroidal buoy which is fastened on gimbals to a tube, which can slide freely up and down a taut rope. The Rotorod was mounted on a 40-cm extension rod to reduce the influence of the buoy on the measured particle size distributions. Particle size distributions were measured at heights of 0.12, 0.2, 0.35, 0.50, 0.75,

1.0, 1.5, and 2.0 m above the instantaneous water level. Measurements at fixed heights of 2, 3, 4, 6, 8,...,20 m above mean sea level were made with the Rotorod mounted on a pole which hung above the buoy. This range of heights was extended to 21 m by measurements from the decks of the platform.

The height variation of the particle size distributions has direct practical applications (e.g., performance predictions of electro-optical equipment, deposition studies, and production estimates of aerosol), as well as more theoretical purposes (e.g., modelling of the marine atmosphere for meteorological optical purposes).

Radon Counter. In a Radon counter developed at the FEL TNO, a constant flow of air is drawn through a glass microfibre filter where aerosol particles are collected. The α activity of decay products of ^{222}Rn attached to the particles on the filter is continuously measured by a detector which is mounted 4 mm above it. The atmospheric Radon concentration is calculated from the α activity. The Radon counter has been calibrated with a source with known α activity. The Radon concentration is a tracer for the residence time of the air mass over sea, and therefore also for the mixing ratio of continental and marine aerosol. A value of less than 10 pC_i/m^3 is indicative of a purely marine air mass; in continental air masses the Radon concentration is often higher than 100 pC_i/m^3.

Whitecapping. Complementary to Monahan's video recordings of whitecapping a limited number of still photos have been taken. In particular, this has been done to investigate the possible influence of observation direction. Monahan's camera was looking in a fixed westerly direction, while our photos were taken in a direction perpendicular to the wind.

7.3 Data Obtained

Aerosol Data. Particle size distributions were measured with the optical particle counter from November 12 to 16, after which the laser tube of the counter failed. In the early mornings of November 13, 15 and 16 data were not recorded due to hardware faults. A total of 127 particle size distributions were recorded. Preliminary results, consisting of polynomial coefficients, Junge parameters, and the upper diameters of the measured particle size distributions, are available.

Vertical Profiles of Particle Size Distributions. Size distributions of particles larger than 10 μm in diameter were measured with the Rotorod at heights from 0.12 m to about 20 m to obtain detailed information on the aerosol dynamics as close as possible above the production zone. A total of 121 samples was collected, resulting in 8 profiles. The dates and times of these measurements are listed in Table 7.2, together with the wind speed and significant wave height. Particle size distributions will be derived from these samples using an image processor.

Table 7.2 Aerosol profiles

Date	Time (GMT)	Heights (m)	Wind Speed (m/s)	h3 (m)
841113	1216-1400	0.2-18.6	6.8	0.58
841114	1003-1052	0.2- 2.0	7.1	0.51
841114	1448-1647	0.12-19.7	6.5	0.42
841115	1426-1632	0.12-20.3	4.1	0.50
841120	1008-1051	0.2- 2.0	8.0	0.96
841120	1430-1645	0.2-21.0	9.1	0.95
841121	0744-1020	0.35-20.9	12.5	1.68
841121	1435-1630	0.5-20.7	12.7	1.71

Vertical Profiles of Backscatter Coefficients. Vertical profiles of backscatter coefficients were continuously recorded by lidar (wavelength 1.06 μm) from November 12 at 1807 until November 16 at 1052, and from November 19 at 1626 until November 22 at 1817 GMT. The measurements were stopped on November 22 because of continuous rain that was blown on the window of the lidar, causing high reflections and erratic signals.

Using the VIDIS video memory and a colour monitor, continuous scans of the vertical backscatter profiles were made visible. An example of such a scan is shown in black and white in Figure 7.3. The dynamic development of the mixing layer is clearly visible. A layer at about 300 m comes down to about 100 m between 1600 and 1800. From 0200 it rises slowly and finally it disappears. The noisy character is in large part due to electromagnetic interference which is probably generated by antennas on the platform. For future experiments both the lidar and connecting cables will have to be shielded more effectively.

Above about 500 m altitude noise dominates and apparently the backscatter coefficients increase. This is due to nonlinearity of the log-amplifier which, for very weak signals (<5 mV), adds a small component to the signal. Hence at altitudes of over about 500 m, the backscatter profiles are not reliable. The profies will be filtered to reduce the noise and so to possibly extend the range over which the data are useful for studies of the dynamics of the mixing layer.

Radon Measurements. Atmospheric radon concentrations were monitored continuously. In the first measuring period in Figure 7.4, from November 12 to 16, the concentrations were very high due to the SE wind which carried continental air. During the following week the concentrations decreased gradually, reflecting a transition toward marine air

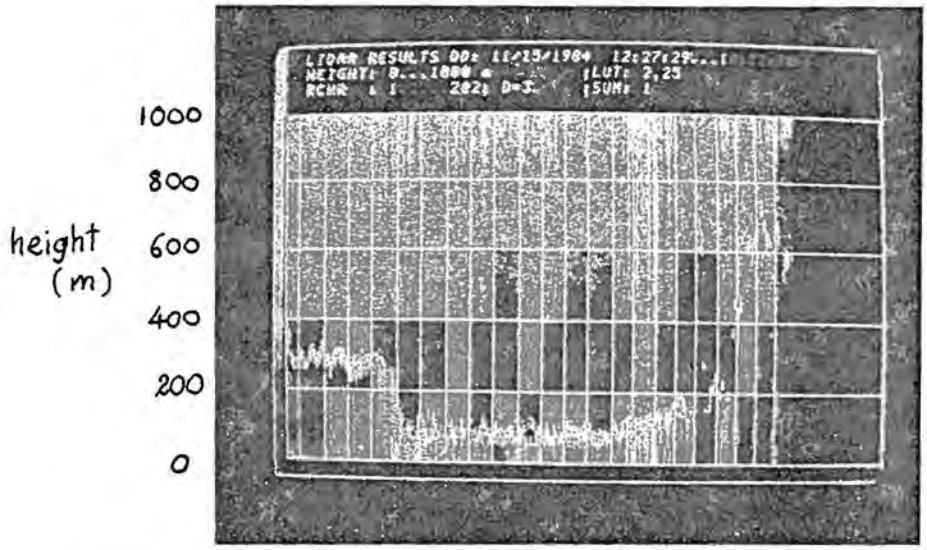


Fig. 7.3. 21 hour sequence of vertical backscatter profiles from November 15 at 1227 until November 16 at 0947 GMT. Time is plotted along the horizontal axis (each white line corresponds to one hour), height (0-1000 m) along the vertical axis. The backscatter coefficient corresponds to the gray level, which in the left hand bar runs from 0.001 to 1/km.

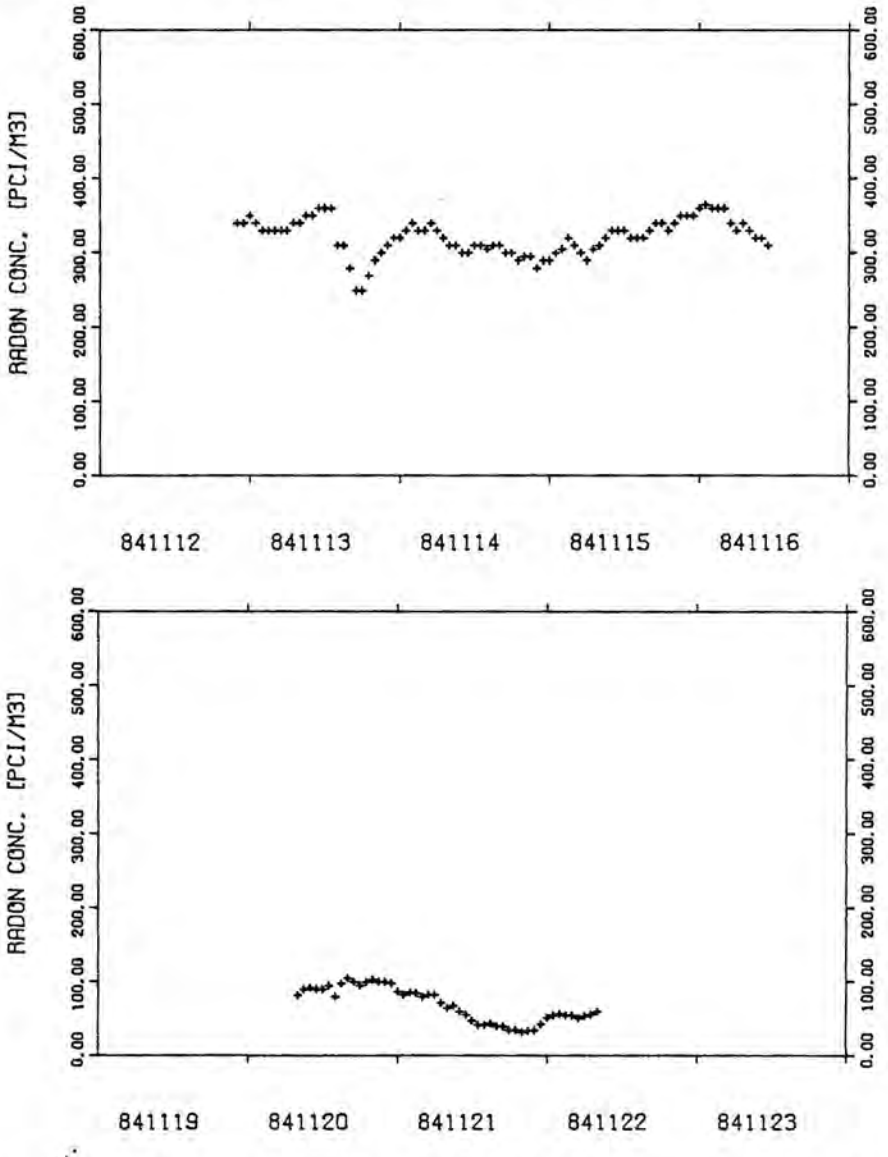


Fig. 7.4. Radon concentrations measured from November 12 to 22, 1984

masses.

Other Data. During the HEXOS pilot experiment data were recorded at the meteorological station and the sodar site at FEL-TNO, 800 m from the beach in the dunes north of The Hague. This establishment is one of the most nearby coastal stations which operated during the HEXOS pilot experiment, the distance to Meetpost Noordwijk being only 16 km. The meteorological observations consist of 10 min running averages of air temperature, dew point, relative humidity, atmospheric pressure, wind speed and direction, visible transmission, visibility, and turbulence.

7.4 Problems Encountered

Apart from the defective laser tube in the particle counter, two major problems were encountered during the HEXOS pilot experiment. The first was electromagnetic interference on the lidar signals caused by other equipment on the platform. Much of this interference was suppressed by a wire-mesh cage around the lidar and shielding of the connecting cables. Further shielding is expected to suppress this interference more satisfactory.

The second problem was associated with interaction of the waves and the platform, producing foam patches and spray, which on some occasions might have been collected with the Rotorod. In particular this was the case on November 15, when foam drifted with the tidal current to the wave follower. This effect was not observed during other measurements. Also, reflected waves came rather close (within a few metres) to the wave follower before they were damped. Collisions between waves travelling in opposite directions result in breaking and hence in enhanced production of spray particles. In most cases, however, the wind direction was such that

the aerosol produced by interference from the platform was not carried to the Rotorod. Measurements with the Rotorod were made at a distance of about 9 m from the legs of the platform. Spray generated by the interaction of the waves and the platform was occasionally detected. The use of a simple boom about 10 m long is recommended so that future experiments will be completely free from influences from the platform.

7.5 Conclusions

The measurements of FEL-TNO were successful, in spite of the problems encountered. The lidar measurements are expected to yield reliable information on the dynamics in the lower 500 m of the mixing layer. Application of a correction for the non-linearity of the detector may extend the value of these measurements to higher altitudes.

Detailed information on the vertical structure of the particle concentrations close above sea level has not been published. To the best of our knowledge, our experiments over the North Atlantic were the first where profiles of size distributions were determined from very close above sea level. The waves on the North Sea are much shorter, however, and it is worthwhile to see whether the features observed over the North Atlantic also apply to the North Sea. Therefore our Rotorod results are a valuable contribution to the data base for modelling of aerosol transport from the sea surface into the mixing layer, and the humidity exchange over the sea.

8. DIVISION OF TECHNOLOGY FOR SOCIETY, NETHERLANDS ORGANIZATION FOR APPLIED SCIENTIFIC RESEARCH (MT-TNO).

J.H. Duyzer

8.1 Goals

The North Sea receives pollutants via several routes, e.g., input by rivers, direct discharges, dumping operations, and deposition of pollutants present in the atmosphere. In a recent TNO study (van Aalst et al., 1982) it was estimated that inputs of metals (e.g., lead and cadmium) and of organic micro pollutants, such as PCB and pesticides from the atmosphere, may be of the same order of magnitude as the other inputs. The estimates of the contribution of dry deposition (i.e., deposition not associated with precipitation) are based on few and uncertain measurements of concentrations of micro pollutants in the air, on one hand, and uncertain estimates of deposition velocities of these pollutants, on the other. Direct measurements of dry deposition fluxes across the air-sea interface have not been carried out over the North Sea, and few are reported in the literature.

In 1984 TNO carried out a research program to explore the feasibility of dry deposition measurements at sea. In a joint effort the National Institute of Public Health and Environmental Hygiene is investigating the technical feasibility of monitoring wet deposition at sea.

The research by TNO is focused on two separate projects:

(1) Investigating the feasibility of measuring fluxes of trace organics at sea; this project falls outside the HEXOS program; and

(2) Measuring dry deposition fluxes of particles as a function of particle size. This information, together with measurements of metal content as a function of particle size, could provide estimates of

dry deposition fluxes of metals into the sea.

TNO's goals in participating in the HEXOS program fall within the second project. Our aim is to establish what equipment is suitable for measuring particle-size-dependent fluxes of aerosols in the marine environment, or, more specifically, whether it is possible to measure these fluxes by eddy correlation techniques using a sonic anemometer and a fast particle counter, and to derive reliable deposition velocities from such measurements.

Technical Objectives. The first objective is to test the usefulness and reliability of the measuring and data acquisition system and the small instrument boom (mounted on the radar platform) exposed to a hostile marine environment. A second objective is to investigate the problems associated with working on a platform (in particular the Meetpost Noordwijk), and to acquire experience with this type of work.

Scientific Objectives. The main objective (bearing in mind the exploratory nature of the project) is to perform reliable measurements of particle-size-dependent deposition velocities. Simultaneous measurements by other participants will allow us to relate the measured deposition velocities to meteorological parameters, such as moisture, heat and momentum fluxes, air and sea temperature, wave breaking, wind speed, etc. Comparison of eddy correlation measurements of the sensible heat flux by instruments mounted on the small TNO boom with simultaneous measurements by instruments mounted on the big 'HEXOS boom' is hoped to provide insight into the disturbing influence of the platform on our measurements.

In addition, some fundamental questions must be looked into:

(a) What is the effect of the vertical gradients of relative humidity over the sea on eddy correlation measurements of hygroscopic

aerosols? These gradients might give rise to apparent upward fluxes of aerosol of a certain particle size, even when the true flux of aerosol of that size is downward. We attempted to overcome this problem by drying the aerosol before detection, and thus measuring, the 'dry' size distribution, which is a conservative property of the aerosol.

(b) What is the effect of surface-generated sea spray on the measurements, and is it possible to quantitatively distinguish an upward flux of a marine aerosol from the downward flux of a continental aerosol? Scavenging of aerosol by sea spray is considered to be one possible mechanism of dry deposition (and therefore interesting only from a mechanistic point of view).

(c) What is the statistical validity of measured deposition fluxes? Measurements of aerosol fluxes (as a function of particle size) by eddy correlation suffer, in the particle size range in question (1 to 5 μm), from the extra complication of poor counting statistics.

8.2 Instruments Deployed

All instruments were mounted at the end of a small boom extending some 3 or 4 m from the radar platform on the NW side of the Meetpost Noordwijk (about 10 m from the main structure). The measuring height was 16 m above mean sea level (MSL). During the third week of HEXOS, with south and southeasterly winds prevailing, the boom was mounted on the SW corner of the lower deck of Meetpost Noordwijk (about 8 m from the main structure, at a height of 12 m above MSL). The following instruments were used:

- Particle Measuring System laser particle counter ASASP-555x-sp. This instrument utilizes the light-scattering properties of

particles for detection. It is capable of measuring particle number concentrations, divided into 16 diameter classes from 0.3 to 15 μm, at a maximum rate of 10 particle size spectra per second. The sampled air was continuously aspirated, at a rate of 500 cm^3/s, into the laser cavity of the particle counter through a 3-m long, 7-mm i.d., copper tube. The tube inlet was placed less than 25 cm from the sonic anemometer. The sampling tube delays the arrival of the sample air in the laser cavity by about 0.4 s. The delay was experimentally verified at the laboratory by measuring the response of the particle counter to a step change in aerosol concentration at the tube inlet.

For the purpose of measuring dry aerosol, the sampling tube could be extended with a diffusion drier just before the sample inlet of the laser cavity. The drier consisted of a double-walled alumina tube, about a metre long, and of 7 mm i.d. The space between the inner wall (made of a porous material) and the outer wall was filled with dry silica gel. The drier was capable of reducing the relative humidity of the sampled air by a factor of at least 1.6.

- One-dimensional (vertical) sonic anemometer.

The sonic anemometer and ancillary electronic equipment were built at TNO. The instrument, which has a path length of 20 cm and a resolution of 0.5 cm/s, performed well in a wind tunnel calibration. It is equipped with a temperature channel (resolution 10^{-3} °C). The instrument responds to frequencies of up to 10 Hz.

- Fast response thermocouple (100 μm diameter copper constantan).

This instrument, including a special amplifier, was built at KNMI,

and responds up to a few hertz with a resolution of 10^{-3} °C.

- The data acquisition system consisted of a Hewlett Packard 9816 micro computer, Hewlett Packard 3497A data acquisition unit, and a Kennedy digital tape unit. Samples were taken at a rate of 5 or 10 per second. The analogue channels were low-pass filtered using 2-pole Bessel filters with selectable cut-off frequencies.

8.3 Data Obtained

During the first week of our participation (second week of HEXOS), the equipment was set up on the radar platform and tested. In view of the unfavourable wind directions at this time, we conducted only a few preliminary measurements.

During the third week of HEXOS, the TNO boom was mounted on the SW corner of the Meetpost Noordwijk, near the equipment of FEL-TNO. The southerly and southeasterly winds allowed us to conduct flux measurements of aerosols of mainly continental origin. Table 8.1 lists our measurements, together with starting times, wind directions, and wind speeds (MPN observations). Each run consisted of about 45 min of recordings of vertical wind velocities, sonic temperatures, and aerosol number concentrations in the 16 size channels. The thermocouple was not mounted during the second week.

During the fourth week we mounted our boom again on the radar platform (this time using the thermocouple) and made recordings simultaneously with the other participants (Table 8.2).

In Figures 8.1 and 8.2 some preliminary results are presented. With moderate winds from the continent (Fig. 8.1) fluxes are small and flux-to-concentration ratios are in the order of ±0.1 cm/s for particles up

Table 8.1 TNO-MT Data runs during the 3rd week

RUN 1)	U (m/s)	D (degrees)
13-10:58	6.1	205
13-11:57*	6.1	205
13-12:43*		
13-13:25	6.2	204
14-09:47	7.5	140
14-10:30	5.8	140
14-11:15	6.2	148
14-15:15*	6.7	150
14-16:03*	5.0	150
14-16:48*	6.8	134
14-18:36*	7.0	134
14-19:22*	6.9	135
14-19:56	6.4	144
14-19:40	6.7	124
14-20:42	7.0	125
15-10:35	6.2	143
15-11:15	5.4	141
15-13:05	5.4	136
15-16:00*	4.0	130
15-16:52*	5.0	127

U = wind speed
D = wind directtion
* - denotes that the aerosol was dried before detection

1) - Run code = Date number in November 1984 and GMT in format DD-HH:MM

Table 8.2 TNO-MT Data runs during the 4th week.

RUN 1)	U (m/s)	D (degrees)
19-15:32	5.9	173
19-16:47*	-	-
19-18:30*	7.1	202
20-09:35	9.0	275
20-10:58	8.0	276
20-12:40	-	-
20-13:56*	9.4	264
20-14:45*	8.5	257
20-16:15	8.6	260
20-18:04	10.3	229
20-19:20	11.2	211
20-20:55*	11.0	206
20-21:52*	11.0	206
21-10:15	13.2	288
21-11:15	12.8	279
21-12:05	12.1	274
21-13:42	13.0	260
21-14:36	11.9	260
21-17:08*	12.1	250
21-18:25*	10.8	241
21-19:54*	11.2	234
21-21:11*	12.6	216

to 5 μm. Flux measurements during westerly winds (Fig. 8.2) show upward turbulent fluxes (sea spray) with flux-to-concentration ratios rapidly increasing with particle size.

During the three weeks of our participation, the influence of the sampling tube on the aerosol spectrum measured by the particle counter was established under various conditions. The results will be used to correct the flux measurements for particle losses in the sampling tube.

8.4 Conclusions

The technical goals of our participation were all met. The measuring equipment and data acquisition system have proved to be reliable and to stand up well to a marine environment. For research of this kind the Meetpost Noordwijk has shown itself to be a very suitable site as regards comfort, logistics, local meteorological data, and reasonable cost. A serious disadvantage of the site is the flow distortion by the platform, necessitating a long instrument boom. Measurements of fluxes of heat or particle concentrations are probably less sensitive than wind stress to flow distortion.

Analysis of the data will afford average particle number concentrations and variances, temperature and vertical wind variances, and average heat fluxes and particle fluxes as a function of particle size. Power spectra and cospectra will be analyzed from the measured data. The data will be interpreted in relation to wind speed, wind direction, air mass history, relative humidity, atmospheric stability, and wave breaking. The results are hoped to extend the meagre knowledge of the subject with some reliable and meteorologically well-documented data on deposition velocities.

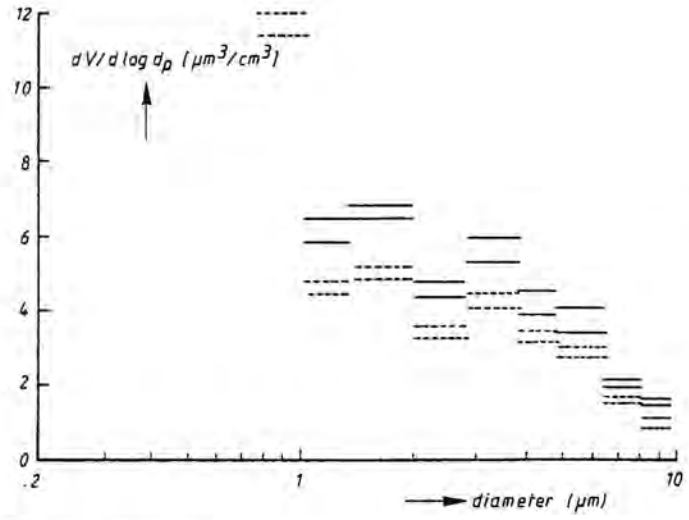


Figure 8.1.a.

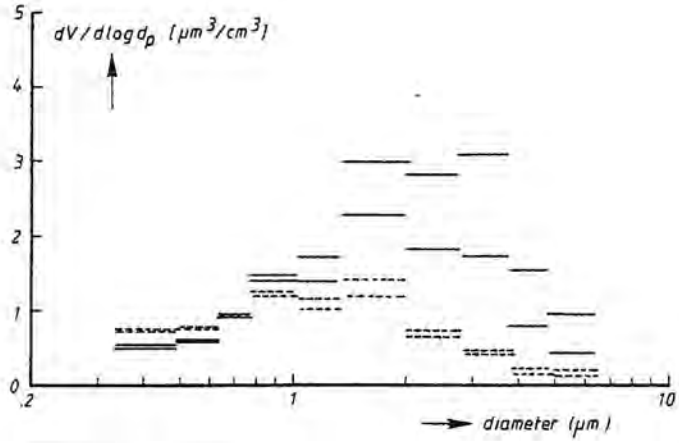


Figure 8.2.a.

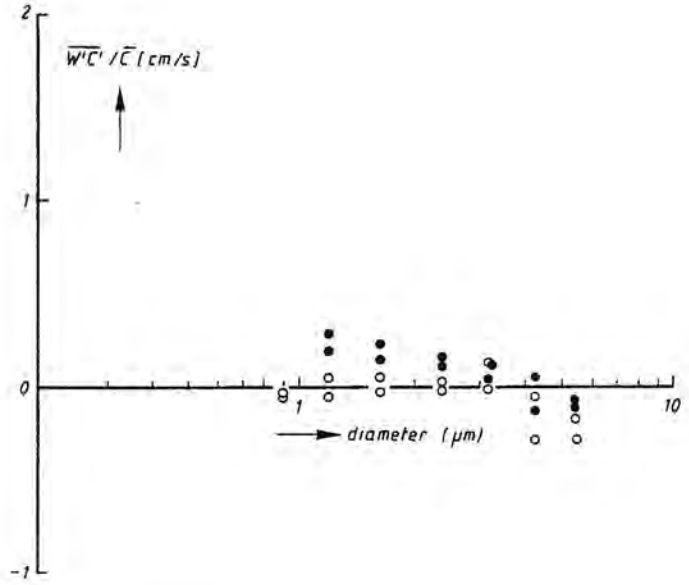


Figure 8.1.b.

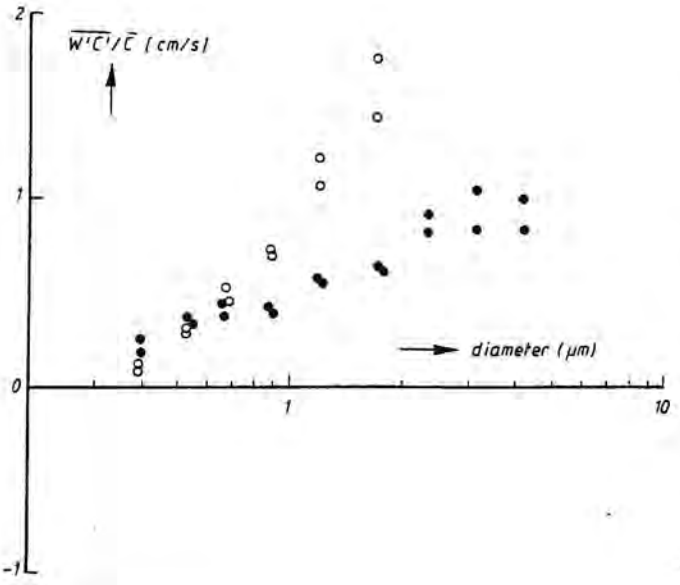


Figure 8.2.b.

Particle volume distribution function (Fig. 8.1.a) and flux-to-concentration ratios (Fig. 8.1.b) versus particle size as measured on November 14, 1984, with southeasterly winds from the continent.
Runs 14-18:36 and 14-19:22: ..., o (dried aerosol)
Runs 14-19:56 and 14-20:42: ——, ●

Particle volume distribution function (Fig. 8.2.a) and flux-to-concentration ratios (Fig. 8.2.b) versus particle size as measured on November 21, 1984, with westerly winds from sea.
Runs 21-21:11 and 21-21:57: ..., o (dried aerosol)
Runs 21-23:42 and 21-14:36: ——, ●

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