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A study under the Uranium Project, performed by Risø National Laboratory and the Air Follution Laboratory of the National Agency of Environmental Protection

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A TRACER INVESTIGATION OF THE ATMOSPHERIC DISPERSION IN THE DYRNÆS VALLEY, GREENLAND

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Abstract. Mining at Kvanefjeld, Greenland, will result in releases of air polluting gases. In order to measure the dilution of these gases tracer experiments were carried out in July-August 1981. Results from these experiments are described. The Kvanefjeld constitutes the northwestern side of a valley. The tracer was released at the Kvanefjeld during the night and sampled in the valley. The measured tracer concentrations were compared with those calculated by use of a conventional model of the dispersion of plumes. The dilution of the tracer was found to correspond to the dilution at ground level of a plume from a stack of 100-200 m height in atmospheric neutral conditions
(continue on next page)

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(wind speed 5 m/s). General aspects of the flow-field in the valley are discussed. It was observed that the flow direction in the valley shifts between downvalley and upvalley with a period of approximately 1 hour. It is suggested that this behaviour is caused by the interplay of a drainage flow and a sea-breeze.

INIS-descriptors: AIR POLLUTION; DILUTION; DISPERSION; ENVIRONMENTAL IMPACTS; GASES; GREENLAND; METEOROLOGY; MINING; SULFUR FLUORIDES; TEMPERATURE INVERSIONS; TRACER TECHNIQUES; URANIUM ORES; WIND

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PREFACE

The investigation was carried out jointly by the Physics Department at Risø National Laboratory and the Air Pollution Laboratory of the National Agency of Environmental Protection, under contract for the Uranium Project, Risø. The objective of the investigation was, by tracer experiments, to study the atmospheric dispersion of releases from uranium mining at Kvanefjeld, Greenland. The tracer experiments require meteorological and tracer instrument systems.

The Physics Department at Risø has since 1979 performed meteorological measurements on two masts in the area. One of these masts was during this investigation equipped with instruments for turbulence measurements.

The Air Pollution Laboratory has developed and maintained the tracer instrument system for dispersion studies. A special electron capture gas chromatograph for tracer analysis was designed for this investigation by Erling Lund Thomsen. The authors greatly appreciate his work.

A number of people at the two institutions have taken part in the experimental campaign in Greenland. Bjarne Breiting and Arent Hansen from the Physics Department and Hans Ahleson from the Air Pollution Laboratory are acknowledged for skilled technical assistance during the experiments.

The authors thank Torkild Lundgaard and Arne Sørensen from the Uranium Project for valuable assistance in the planning of the investigation. We also thank Kim Pilegaard for comments on the report. During the experimental campaign we benefitted much from the assistance given by The Geological Survey of Greenland and The Greenland Technical Organization. We direct special thanks to Ivan Bohm, Narssaq, for help and advises that made life in Greenland a great deal easier for us.

1. INTRODUCTION

Ongoing experimental work with extraction of uranium from the ore at Kvanefjeld, Greenland, has the purpose of investigating whether industrial extraction from the deposits of the uranium ore can be justified from a technical, economical and environmental point of view. A description of the project can be found in (Risø, 1980).

Mining at Kvanefjeld will result in releases of ore dust particles containing various elements. Among these are uranium, thorium, and their respective progenies. In addition, there will be releases of the noble gas radon. The purpose of the meteorological part of the investigation, of which this project is a subpart, is to produce knowledge of the local meteorology in the area at Kvanefjeld in order to evaluate characteristics of the dispersion of particles and gases that will be released by mining activities in the area. Some of these meteorological investigations have been described in Kristensen (1980), Kristensen (1980), and Kristensen (1982) in the status report form.

As the potential mining area is situated in a very complex area from a meteorological point of view, a detailed mapping of the wind field will require a prohibitive number of meteorological measuring stations. As the wind field is a very important parameter in mathematical modelling of the dispersion process, the modelling approach is troublesome. Alternatively, tracer experiments have been carried out in order to measure directly the dilution of gases released at Kvanefjeld. This report describes results from 6 tracer experiments carried out in a 4-week period of July-August 1981 at Kvanefjeld. The report describes the experimental set-up and lists the measured data from the campaign. Characteristics of the dispersion process in the area are discussed, and data are given that describes the dilution in the valley of gases released at Kvanefjeld.

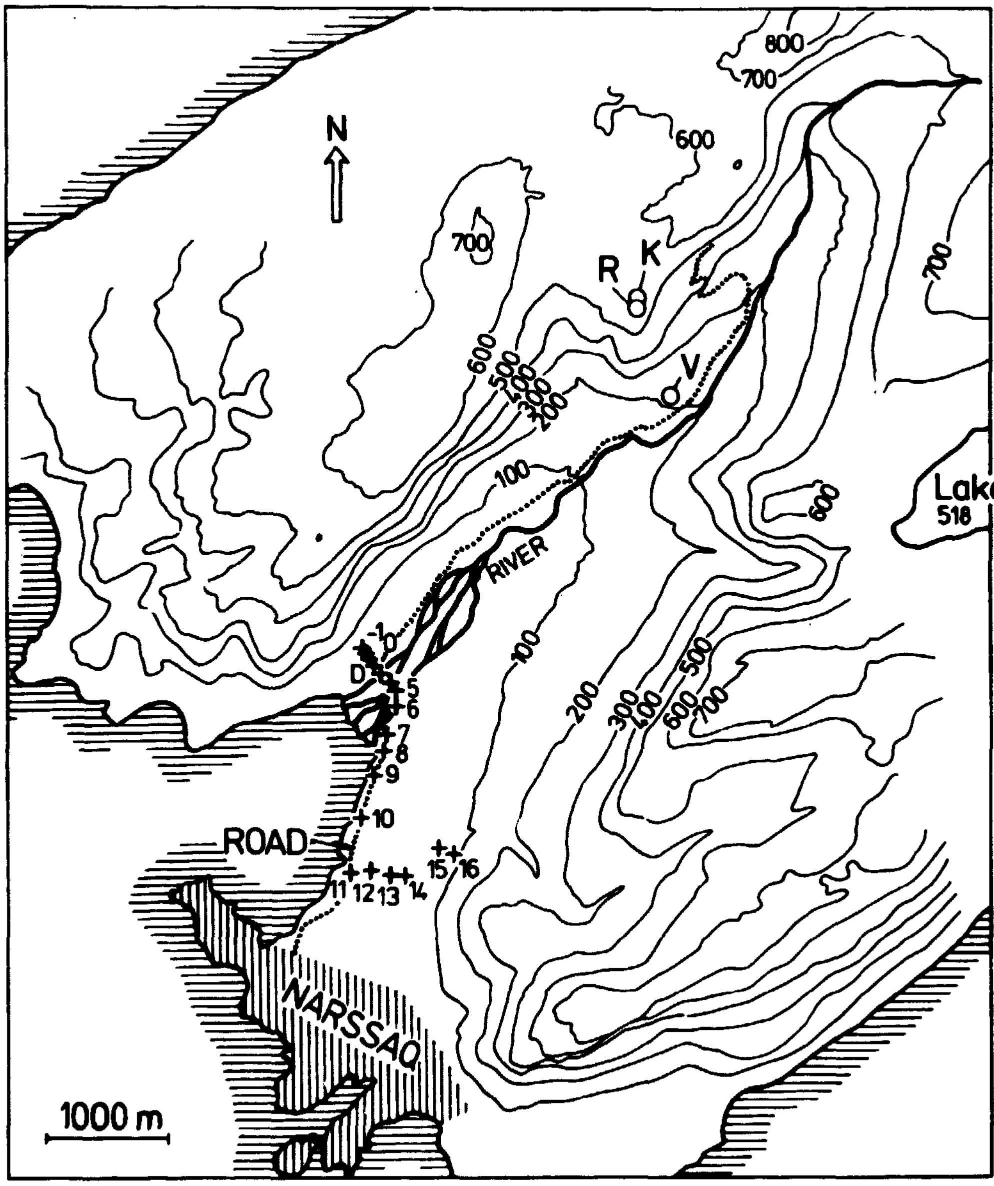

Fig. 1. Map of the area with positions of main points indicated. The position of the meteorological mast at Kvanefjeld is indicated by K, the mast in the valley is shown by V, the tracer release point by R, the Dyrnæs camp by D and the numbered crosses near the fjord shows the positions of the tracer sampling units. The town of Narssaq is situated at the fjord south of the Dyrnæs valley outlet.

2. SITE DESCRIPTION

A map of the area is shown in Fig.1. The valley that extends southwest-northeast is the Dyrnæs valley. On the northwestern slope of this valley, about 4 km from the outlet of the valley into the fjord, the nearly 600-m high Kvanefjeld is situated; a mountain with uranium ore deposits. The valley has a total length of roughly 8 km, over which it descends from about 700 m above sea level down to sea level; thus it has a mean

Fig.2. Picture taken at the tracer release point in the direction to the fjord. The winding Narssaq river is seen at the bottom of the valley. Narssaq is situated at the fjord partly behind the edge of the mountain to the left, and partly around the little inlet that can be found on the picture about 2 cm to the left of the river delta. The meteorological mast in the valley cannot be seen here; it is situated further up in the valley than covered by this picture.

Fig.3. The Dyrnæs valley seen from the Dyrnæs camp close to the fjord. Kvanefjeld is the dark mountain in the left part of the picture. Tne tracer release was carried out near the top as seen from this picture of the Kvanefjeld. The position of the meteorological mast in the valley is indicated by a circle. The Narssaq glacier that forms the bottom of the valley is seen slightly to the left of the center of the picture. In the foreground are seen a tracer sampling unit and one of the sticks that were used to mark out the positions where sampling was carried out.

inclination of about 5 deg. The highest part of the valley (the Narssaq glacier) was snow covered in the experimental period, and at the outlet the fjord contained a substantial amount of icebergs very close to the land (about 100 m). The valley surface is rather irregular, consisting mainly of areas partly covered with grass and partly without vegetation.

About 2 km from the outlet of the valley into the fjord, the Narssaq river forms a rather flat delta. The valley broadens further at the outlet and extends to the south where the town

Narssaq is situated. Seen from the Kvanefjeld a major part of this town is hidden behind the mountains that form the southern slope of the valley (Fig.2). In Fig.3 the valley is seen from a position close to the fjord, about 100 m northwest of the Dyrnæs camp.

3. GENERAL DESCRIPTION OF THE WIND FIELD IN A VALLEY

The local winds in a valley are created by differences in the radiation heating of the ground. The interplay during the course of a day of the valley winds are shown in Fig.4. The white arrows are the slope winds (winds along the slopes of the valley), and the black ones the valley winds (winds along the valley). As seen in Fig.4, there is a double system of mountain winds; during the day there are upslope and upvalley winds; at

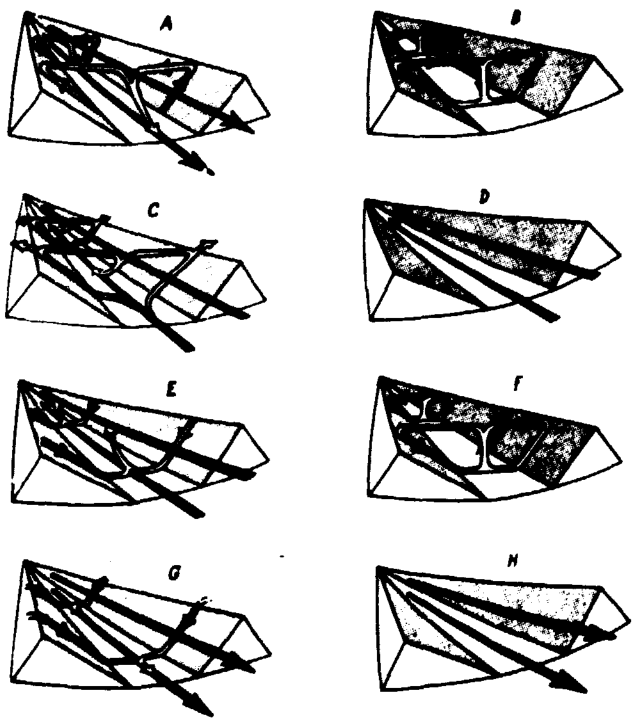

Fig.4. The interplay of slope and valley winds during the course of a day, (Geiger, 1966).

night downslope and downvalley winds. The slope winds are always initiated first and the valley winds follow. During the course of one day and night there is a change taking place, but with a phase difference between slope and valley winds, this also is illustrated in Fig.4. In A the flow is shown shortly after sunrise. The upslope winds have started, but the air in the bottom of the valley is still relatively cold forcing a downvalley wind, which also is fed by the return flow from the upslope circulation. In B, the downvalley wind, due to heating of the bottom of the valley, have died out and only upslope winds exists. The transition from down- to upvalley wind has taken place in C, occurring around noon. This is the situation which can lead to the formation of cumulus clouds above the slopes of the valley while the air remains clear over the center of the valley where the air is sinking. In late afternoon, D, the upslope wind ceases and the upvalley wind continues for some time. Later during the evening, E, the downslope wind sets in, the transition between upvalley and downvalley wind, F, takes place and G illustrates the flow situation during a night with substantial cooling. In H the situation around sunrise is illustrated. The valley wind is on a larger scale than the slope wind, and most often stronger than the slope wind.

It must be kept in mind, however, that the periodic variation in the wind system can be disturbed by outside influences. The winds described above will be influenced by the elevation of the sun, the cloud cover, the albedo of the surface, and special effects of the individual localities.

4. THE WIND FIELD IN THE DYRNÆS VALLEY

Here we will discuss some general characteristics on the type of local wind pattern that develops in the Dyrnæs valley. We will restrict the description to summer and winter conditions, as the spring and autumn represent transitional stages between these conditions.

In summer a circulation of the type generally described in the foregoing chapter occurs. At night radiational cooling of the sloping surface causes the air adjacent to the surface to cool more than the free air at the same elevation. This results in a pressure gradient which drives the cool air down the slopes. These winds, called drainage winds, will be relatively strong during clear nights, because a substantial radiational cooling of the ground will take place under these circumstances. Under overcast conditions the development of drainage winds will be slow or nonexistent. The drainage winds will exist as long as the radiational cooling is able to maintain the necessary cooling of the flow. Around sunrise the radiation from the sun starts to heat the ground and initiate winds that blow up through the valley. These winds are stronger than the drainage winds because the radiational exchange is greater. They will continue the whole day until sunset, when radiation cooling of the ground again initiates drainage winds, and the cycle is repeated. In summer the fjord is typically colder than the surface of the valley. This influences the circulation in a way which will be discussed later.

In winter the incoming radiation during the day will be smaller compared with summer because of the lower elevation of the sun. The meteorological measurements in the Dyrnæs valley show that in winter, the flow direction nearly always is downvalley, indicating that the incoming radiation during the day cannot establish an upvalley flow. It should be noted, however, that in the part of the winter where the fjord is warmer than the snow in the valley, this temperature difference will also force a circulation with downvalley flow.

5. EXPERIMENTAL

5.1. Description of meteorological masts

Two masts, on which standard meteorological parameters are measured, have been in operation in the area since 1979. One is situated at the Kvanefjeld plateau close to a 400-m steep slope to the valley, the position is indicated by K on Fig.1. The other mast is situated in the middle of the Dyrnæs valley about 800 m SE of the former mast, indicated by V in Fig.1. Due to the irregularity of the surrounding terrain and the anticipated complex air flow in the area the two masts will only reflect the flow in their nearest surroundings. The mast at Kvanefjeld will reflect the meteorological conditions at the potential mining area, whereas the mast in the valley will reflect the various types of valley winds that exist in the area.

The instrumentation of the two 20-m high masts are identical, see Fig.5. The following meteorological parameters are measured

wind speed at 5,10,21 meters height
wind direction at 10 and 21 meters height
temperature at 2 and 20 meters height
temperature difference between 2 and 20 meters height

These parameters are at each mast measured by two systems that are completely independent what concerns instruments and registration. On each of the masts a Stevenson screen for measurements of temperature, humidity and pressure is mounted. All measurements are taken every 10 minutes, wind direction, temperature, temperature difference and the measurements in the Stevenson screen are instantaneous values at the time of scanning. The wind speed is averaged over a period of 10 min. The registration is carried out by a datalogger, manufactured by Aanderaa; it contains a mechanical scanner that reads the contents of 12 channels every 10 min; each reading of the channels takes about 1 min. The results are stored on magnetic

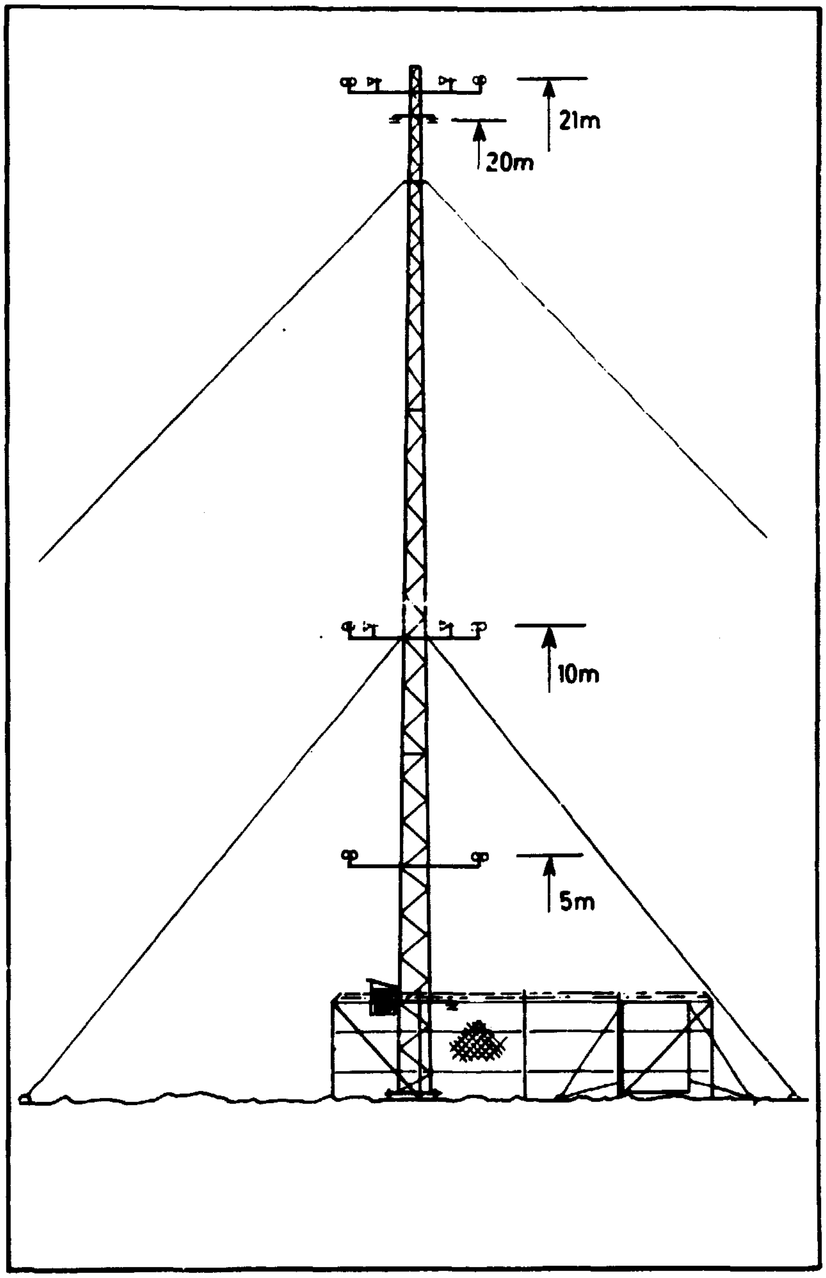

Fig.5. Mast with instruments for measurements of routine meteorological parameters. The instrumentation was doubled at both the valley and the mountain mast. Both instruments systems functioned well during the whole campaign, and both system-outputs were identical for all practical purposes. Therefore, this report contains only data from one of the systems. The instruments for measurements of wind- and temperature fluctuations are not shown on this drawing.

tape. Measurements of the wind speed are carried out with Risø-model 70 cup-anemometers that outputs two electric pulses per rotation of the cups which are then counted. Wind direction is sensed by wind vanes of the potentiometer type and with oil-damped wind-vanes manufactured by Aanderaa. Temperature is measured by platinum-resistance thermometers shielded in a screen of Risø design. The screen is ventilated by the wind alone. In the Stevenson screen, humidity is measured by a hair hygrometer and air pressure with an aneroid barometer.

5.2. Instrumentation for measuring fluctuations in wind velocity and temperature

Measurements of mean and fluctuating wind velocity and fluctuating temperature were carried out on a boom at the valley mast at a height of 23 m. This boom was mounted specially for these experiments; Fig.6 shows the instrumented boom. The turbulence instrumentation is described in detaill in Gryning and Thomson (1979) and Gryning (1981). A short description is given below.

A Risø-model 70 cup-anemometer is used as a wind-speed sensor. It is a light-weight, strong anemometer with cups formed of carbon-reinforced plastic. The distance constant is 1.5 m and the starting speed is 0.26 m/s. The anemometer is a light chopper type producing 30 pulses per rotation.

Wind direction is sensed using a light-weight vane also developed at Risø. The vane is of the resolver type and outputs two signals, proportional to sine and cosine of the wind attack angle. The vane's natural wavelength is 1.5 m; its damping ratio is 0.5.

Vertical wind velocities are sensed using a helicord Gill-type propeller. However, the vertical velocities encountered during these experiments were so small that this vertical propeller was inappropiate for measuring these fluctuations; therefore, a description of this instrument is left out.

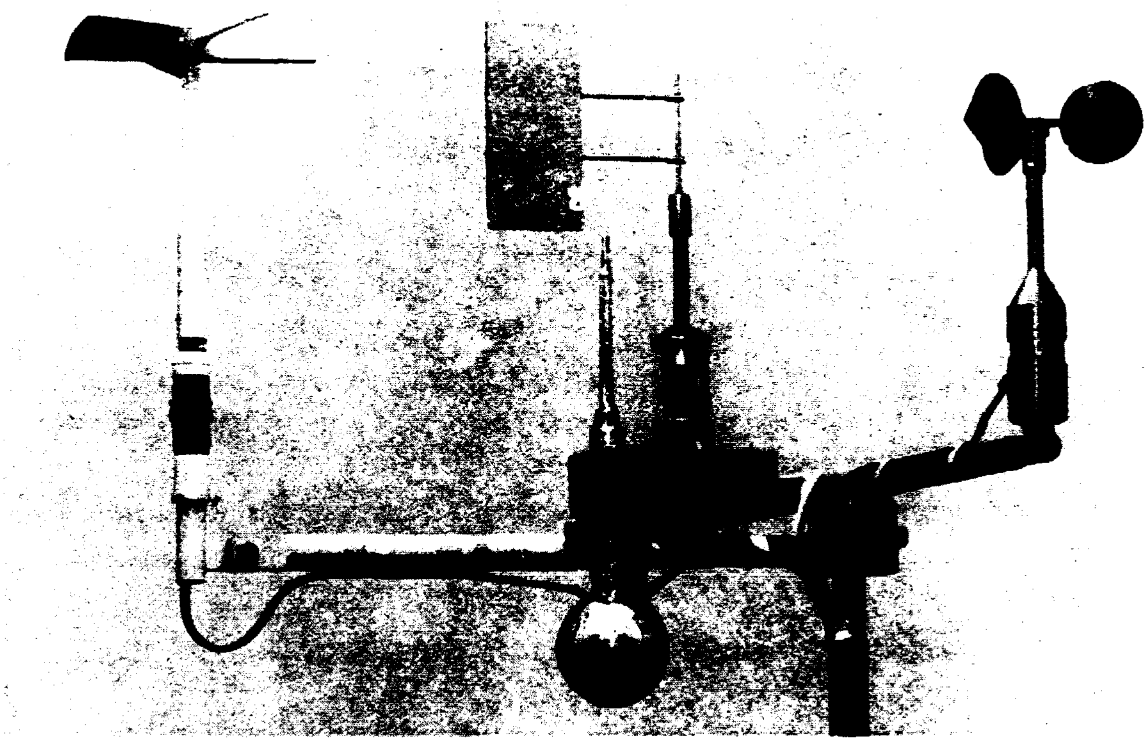

Fig.6. Instruments that were used to measure the wind- and temperature fluctuations. The fluctuating lateral wind speed was sensed by the cup anemometer, the vertical wind speed by the vertical propeller, wind direction by the vane, and the temperature by the instrument with the sphere.

Temperature fluctuations are derived from a single pair of copper-constantan thermocouples. The fluctuations are derived from the instantaneous temperature difference between a thermocouple junction extending 5 mm into the air stream and a reference junction imbedded in the center of a 10-cm acrylic sphere. The result of this design is that the air-temperature fluctuation measurements are effectively bandpass filtered with an upper frequency characterized by a time constant of about 1 s, owing to the size of the thermocouple wires, and a lower frequency corresponding to a time constant of about 75 min controlled primarily by the diameter of the acrylic sphere. The low-level thermocouple emf is amplified in a closely situated thermally stabilized dc-amplifier before the electric signal is transmitted to the recording instruments.

The analog or pulsed signals from these instruments were recorded continuously during the experiments on a HP-3968A FM-recorder, and were later digitized with a sampling frequency of 1 Hz.

During each experiment, a radiosonde (Atmospheric Instrumentation Research, Inc.) was launched that measures pressure, air temperature, and wet-bulb temperature. This gives information about the vertical structure of temperature and humidity in the atmosphere. The sonde was flown with a free balloon in such a way that the ascent velocity was about 1.5 m/s. Data was transmitted from the sonde to a receiver on the ground every 3 sec. On the ground the data were calibrated and then recorded in semi-digital form on a cassette-recorder, and later replayed into a HP-85 computer for analysis.

The power to run the instruments was supplied by a 3 kW gasoline generator.

5.3. System for tracer release

The tracer, sulphur hexafluoride, SF_6, is a chemically inert and non-toxic gas that is available in cylinders. A total number of 15 cylinders each of which weighted 50 kg in gross were brought to the point of release about 150 m south of the meteorological mast at Kvanefjeld. Due to helicopter-strike the cylinders were carried by hand about 1 km (height difference 200 m) up to the point of release. A picture of the release system is shown in Fig.7. The tracer was released near ground level at rates ranging from 2.3 to 3.2 g/s in the various experiments. A constant flow rate was assured by observing a flow-meter through which the tracer was led. The tracer release rate was calculated from the weight of the cylinders before and after each experiment and from the time of release.

Fig.7. Tracer release system at the Kvanefjeld. Two cylinders of sulphur hexafluoride connected with tubes to a flowmeter can be seen. The antenna was used for radio communication with the person releasing the tracer and for transmitting the coded radiosignals for start of the tracer sampling units.

5.4. Tracer sampling units

Automatic radio-controlled air-sampling units, based on sampling in plastic bags, were used. Figure 8 shows the interior of a unit. Air was sucked in through an intake tube by a small diaphragm pump and let to one of three plastic bags which are inflated with a flow rate of about 300 ml/min; the inflation of the bags is regulated by magnetic valves. The units inflate the three plastic bags in sequence, each having a sampling time of 20 min. The sampling procedure is controlled by signals to a radio-reciever in each unit. The power to the units is supplied by a battery in each unit that was recharged in the Dyrnæs camp after each experiment. The units were started by transmitting a coded signal from a 6-watt transmitter positioned at the point of tracer release to the sampling units. The radios were operated at the goverment-assigned frequency of 447.150 MHz; the signals were always properly received by the sampling-units. A total number of 24 units were used. The tracer sampling system is in detaill described in Gryning et al. (1978) and in Gryning (1981).

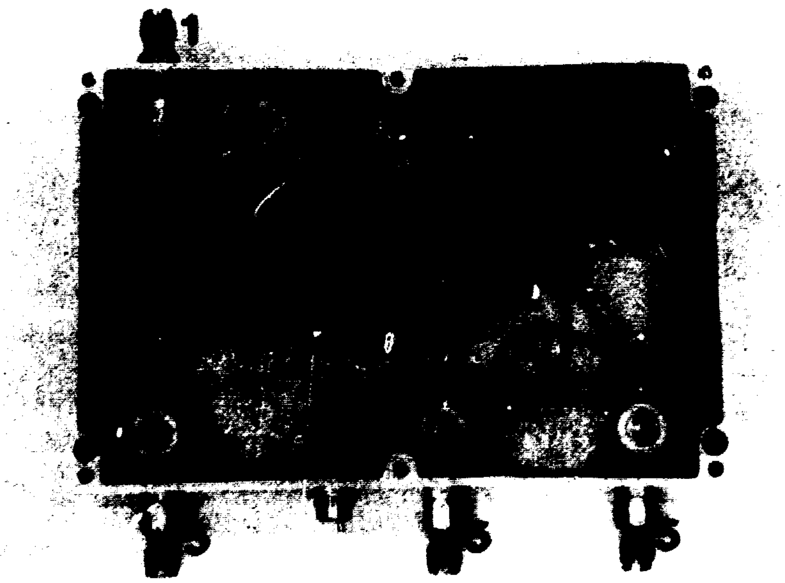

Fig.8. Interior of radio-controlled tracer sampling unit. 1) fitting for mounting of the intake tube, 2) diaphragm pump, 3) magnetic valves, 4) NiCd battery, 5) fittings for mounting of the plastic bags, 6) radio receiver for the start of the sampling.

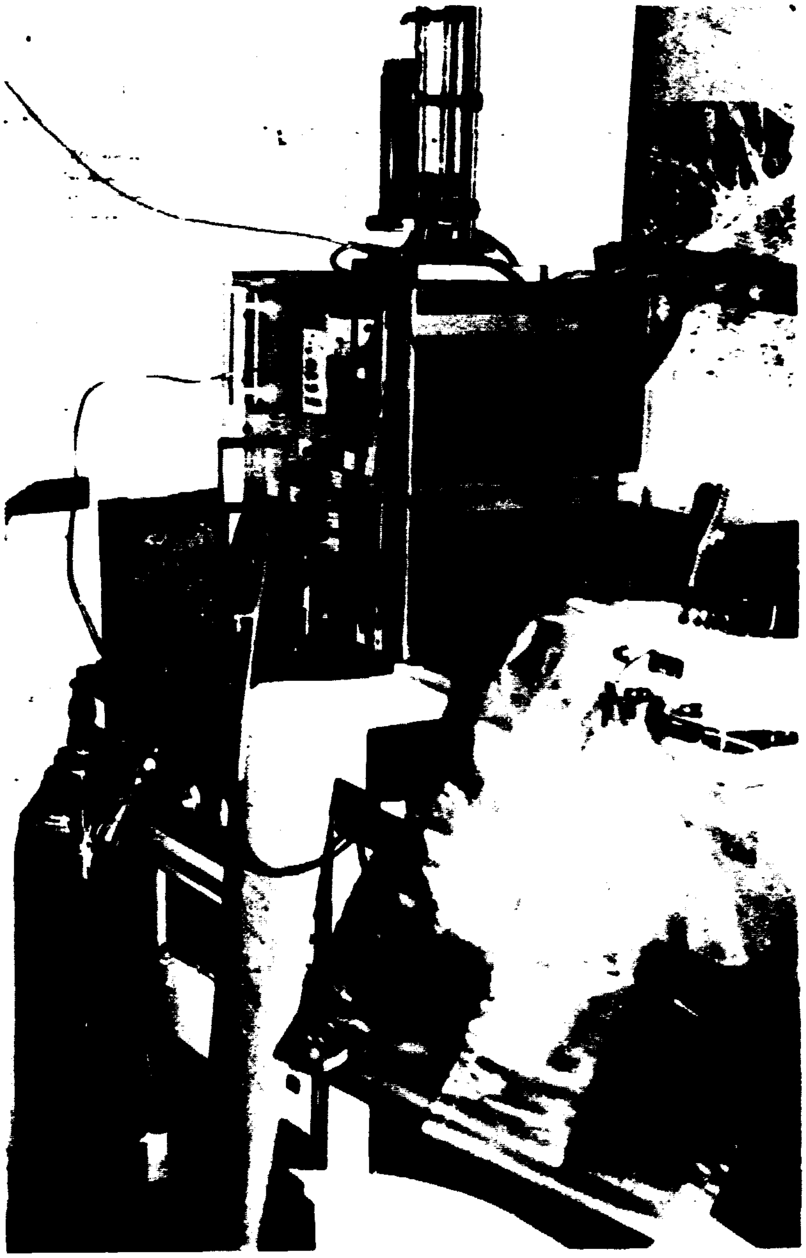

Fig.9. Gas chromatograph for analysis of tracer content in the air samples that are collected by the tracer sampling units. On the right-hand side a tracer sampling unit mounted with plastic bags is seen. The gas chromatograph was installed in the Dyrnæs camp, and this picture gives an impression of the primitive conditions under which all work was done in this campaign.

5.5. Tracer analysis

All air samples were brought to the Dyrnæs camp immediately after each experiment and analysed for their content of sulphur hexafluoride. The tracer concentrations were measured by means of a pulsed electron capture detector gas chromatograph equipped with a molecular sieve column. Figure 9 shows the instrument installed in the camp. The gas chromatograph was calibrated by means of tracer standards prepared at Risø. The detection limit is about 15 ng/m^3. The tracer concentration in these standards is believed to be known with an uncertainty of 20%. This uncertainty leads to a systematic error that influences all concentrations identically during the experimental campaign. The reproducibility of the tracer standards within the time necessary to analyse the measurements from one experiment was about 4%; this uncertainty affects the measured concentrations randomly. After the analysis the plastic bags were flushed with filtered air and reused.

6. EXPERIMENTS

The experimental campaign took place during the summer of 1981. The incoming radiation during the day is strong enough during most days to initiate a strong upvalley daytime flow during this part of the year. The upvalley flow only failed to appear during very overcast conditions, in which the wind in the valley was calm. An upvalley flow prevents the tracer from being transported in the direction of Narssaq. Only transport carried out by large-scale meteorological circulations would be able to bring the tracer to Narssaq under these circumstances, and this is believed to result in very small concentrations of the tracer in the town. Therefore, from an air pollution point of view the most severe conditions during the summer, except for such special weather conditions as the Pitorak, is believed to be associated with well-developed slope and drainage winds. This type of flow is developed by the radiation cooling of the ground and is only present at night during the sumner. Therefore all experiments were made at night, and most of them intentionally under clear sky conditions.

A total number of 6 tracer dispersion experiments were carried out during the July 20 to August 14 period, 1981. The occurrence of nights with drainage winds was observed to be the same as the number of experiments in this period. The tracer was released at ground level 539 meters above the sea level at the geodetic point (number 50777) about 150 m south of the meteorological mast at Kvanefjeld. Tracer sampling units, separated by about 2 deg as seen from the release position were positioned at the outlet of the valley prior to an experiment, (see Fig.1 for an indication of the positions). These positions were marked out in advance in order to facilitate the experimental procedure. About 20 tracer sampling units were used in each experiment. The sampling was radiocontrolled from the point of tracer release. During the experiments the wind velocity fluctuations were recorded at the meteorological mast in the valley. Table 1 shows characteristic parameters for the 6 experiments. It can be seen that all experiments were carried out under night conditions with tracer sampling initiated in the 0200 to 0430 period for the various experiments. It was intended to release the tracer so much in advance of the sampling that the plume would have had time to spread down the valley to the outlet into the fjord. In the first 4 experiments the tracer-release was started 2 hours before the sampling was initiated. The experience from these experiments led us to extend the time between the start of release and sampling to about 5 hours in the succeeding 2 experiments. The reason for doing so will be discussed in the next chapter. Measurements of the fluctuating wind velocity and temperature were carried out on the mast in the valley. These measurements were started typically 1/2 hour before the tracer sampling units were initiated. During each experiment, usually 1/2 hour after the start of the tracer sampling, a radiosonde was launched at the valley mast. In most experiments, radio contact with the radiosonde was lost when the sonde reached a height corrresponding to 800-700 mb, which is about 1.5 to 2 km.

Table 1. Characteristic times and tracer release rates for the experiments.

Experiment	start of: tracer release	start of: meteorological measurements	start of: tracer sampling units	time of radiosonde launches	stop of: tracer sampling units	stop of: tracer release	stop of: meteorological measurements	tracer release rate (g/s)	tracer release rate: flowmeter (%)
26 July	0001	0128	0201	0230[2)] 0445[3)]	0301	0301	0334	2.3	30
30 July	0124	0255	0330	abortion	0430	0430	0455	2.3	30
1 Aug.	0012	0140	0214	0230	0330[5)]	0330	0410	3.2	40
4 Aug.	0225	0330	0425	0430	0525	0525	0549	3.2	40
7 Aug.	2148[1)]	0252	0330	0350	0430	0430	0445	3.2	40
10 Aug.	2225[1)]	0220	0330	0345[4)] 0445	0430	0430	0510	3.2	40

1) the previous day. 2) abortive attempt because sonde was damaged by mast-wire.
3) launched from the Dyrnæs-camp. 4) radio-contact lost 10 min. after launch due to brief power fall-out.
5) run 1: 0214-0234; run 2: 0234-0254; run 3: 0310-0330.

As we are interested mainly in data in the range of 0 to 1 km height, the difficulties with the data transmission did not bother us.

6.1. Experiment on July 26, 1981 (KVANE 1)

On July 25 the sky was completely covered with low clouds; about 1800 o'clock the clouds started to disappear, and the clearing up was complete about 2200. It was dark during the entire experimental period and the sky was completely clear. Sunrise occured about 1/2 hour after the closing of the experiment. A radiosonde was launched during the experiment; however, the line connecting the radiosonde to the balloon was twisted into one of the wires of the mast, and the sonde was damaged in attempts of disengaging. Another radiosonde was released from the Dyrnæs camp after the experiment.

The set-up of the tracer sampling units is represented by the positions from 0 to 11 in Fig.1. In this experiment positions from 12 to 15 were in a series that was extended into the town of Narssaq. Unfortunately, during the experiment, one tracer sampling unit in Narssaq was stolen and another was seriously damaged by vandals. This led us to give up sampling directly in the town. In the succeeding experiments the series was altered to the positions shown in Fig.1, and then the sampling took place without further problems. Results from this experiment are shown in Appendix KVANE 1.

6.2. Experiment on July 30, 1981 (KVANE 2)

On July 29 a weak Pitorak swept over the area, resulting in relatively high temperatures (15-20 deg C) and wind speeds. The sky was mainly cloudless during the day. During the experiment the sky was slightly overcast with a cloud cover judged to be 2/8. At the meteorological mast at Kvanefjeld, the wind was relatively strong and blowing in the direction of Narssaq; inspection of the measurements at the valley-mast reveals that here the wind direction was mainly uphill, and thus in the opposite direction. A tentative explanation of this feature might be found in the heating the foregoing day of the ground caused by the Pitorak. The night temperature at the mast in the valley was about 12 deg C which maintained a nearly permanent sea-breeze during the night. Results from this experiment are shown in Appendix KVANE 2.

6.3. Experiment on August 1, 1981 (KVANE 3)

During the whole experiment the sky was completely covered with clouds. The clouds moved in a south-westerly direction, that is along the valley in the direction of the outlet into the fjord. Results from this experiment are shown in Appendix KVANE 3. The measured tracer concentrations in this experiment are all below the detection limit for the tracer analysis, and therefore are not illustrated.

6.4. Experiment on August 4, 1981 (KVANE 4)

During the experiment the sky was completely clear with plentiful stars and northern lights. A balloon was released about 0450, and it slowly moved in the direction of the Dyrnæs camp; another balloon released about 0505 ascended nearly vertically. Results from this experiment are shown in Appendix KVANE 4.

6.5. Experiment on August 7, 1981 (KVANE 5)

During the foregoing day, the whole area was covered by a thick cloud cover; during the evening the clouds started to disappear, and the clearing up was completed about 2000, and was maintained throughout the night. In this experiment, the tracer release was started 2148 (August 6), that is about 6 hours prior to the tracer sampling. Results from this experiment are shown in Appendix KVANE 5.

6.6. Experiment on August 10, 1981 (KVANE 6)

On the foregoing day the sky was clear and it maintained clear during the night. A radiosonde that was launched 0345 ascended nearly vertically. In this experiment tracer release was started about 5 hours before tracer sampling was initiated. Results from this experiment are shown in Appendix KVANE 6.

7. DATA ANALYSIS

The greater part of the time spent on this analysis has been devoted to digitizing analog signals, calibrating, presentating data, making intercomparisons, etc. This has resulted in the plots of the fluctuating wind speed, directions and temperature, plots of data from the radiosonde launches, plots of the tracer concentrations, and tables of the routine measurements every 10 min along the meteorological masts.

An interesting feature was observed. The measurements at the valley mast show that the wind direction changes between up- and downhill flow. In the evaluation of this feature it should be recalled that wind speed and wind direction is undefined for wind speeds lower than 0.26 m/s.

As a typical example of the type of flow field that was found under clear sky, night conditions, we have chosen the measurements from the experiment on August 7, shown in Fig.10. The fluctuating wind-vector has been divided into cross- and downvalley components. Positive downvalley wind velocities represents descending flow. The direction of a descending flow with no crosswind component corresponds to a wind direction of 60 deg, similarly, positive crossvalley wind velocities represents a wind direction of 150 deg. Also shown are the fluctuating temperature and temperature differences (instantaneous value every 10 min) between the 20- and 2-meter heights.

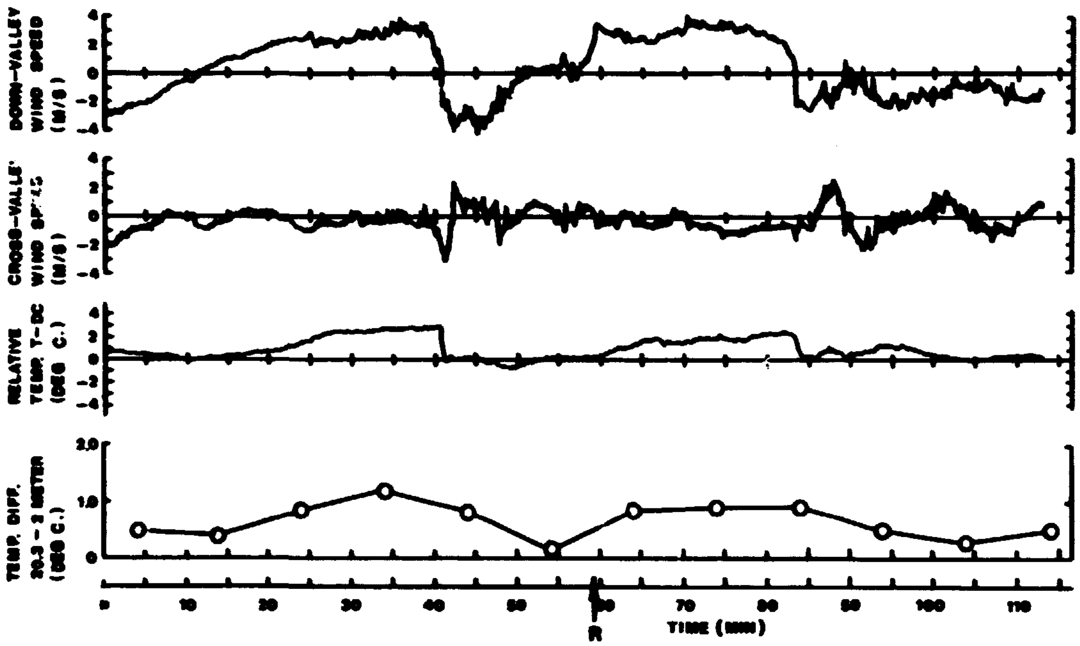

Fig.10. Measurements at the valley mast of the fluctuating downvalley and crossvalley wind velocity and temperature for the experiment on August 7, 1981. The relative temperature are bandpass filtered with an upper frequency that can be characterized by a time constant of 1 s and a lower frequency of roughly 75 min; the temperature differences are instantaneous values, taken every 10 min. The record starts at 0252 local time. The time for launch of the radiosonde is indicated by R.

The flows encountered in these experiments are of the drainage type. Drainage flow consists of cooled air moving down the mountain slopes. Radiation cooling of a sloping surface causes the air adjacent to the surface to cool more than the free air at the same elevation. This results in a pressure gradient which drives the layer of cooled air down the slope; adiabatic heating results in a reverse pressure gradient, which retards the flow. As the air decelerates, friction increases, radiational cooling increases the pressure gradient, and the cycle is repeated, resulting in oscillations of the strength of the drainage flow. Because the flow is created by the cooling of the air adjacent to the ground, presumably starting in the glacier area, this cooling creates a very steep positive temperature gradient near the ground. The adiabatic heating of the descending flow will retard the acceleration until the flow has the same temperature as the ambient air. The position where this condition is reached depends on the temperature gradient of the ambient air. From then on the flow will continue its descending motion due to inertia alone, resulting in a flow of relatively warm, stable air.

Drainage flows reported from the ASCOT-experiment, that were carried out in a valley in California (Doran and Horst, 1980) clearly show oscillations in the wind speed; the direction of the flow in these experiments is always downhill.

Inspection of Fig.10 clearly indicates that oscillations in the wind speed also can be observed in the Dyrnæs valley, but the direction of the flow is partly down- and partly uphill. To the authors knowledge oscillations in the wind direction as large as 180 deg have not been reported previously. It can be seen that the temperature at 23 meters height at the valley mast increases when the flow is downhill and decreases when the flow is uphill. Also, the downhill flow is the more stable when judged from the temperature gradient alone. Thus, relatively warm, stable air flows down the valley for a period of typically 20 minutes, then the wind direction shifts, and relatively cool, less stable air flows upvalley for a similar period. Figure 11 shows a power spectrum of the downvalley component. As expected from the discussion above the spectrum has a maximum at $4 \cdot 10^{-4}$ s^{-1} which corresponds to a frequency in the oscillations of the wind speed of 1/40 min^{-1}. Figure 12 shows the temperature profiles measured by a radiosonde that was launched at the valley mast 58 minutes after the start of the meteorological measurements. When launching the radiosonde, downvalley flow had been established for approximately 8 min. The kink in the temperature profile at 25 meters height represents the height of the downvalley flow.

We believe that these characteristic oscillations in the flow direction are caused by the cold water surface at the outlet of the valley. As the land in the experimental period was always warmer than the water surface, a continuous sea-breeze will exist. At night the sea-breeze flow is upvalley (as it is during the day) close to the ground. The air that constitutes the sea-breeze has been cooled over the sea surface and therefore

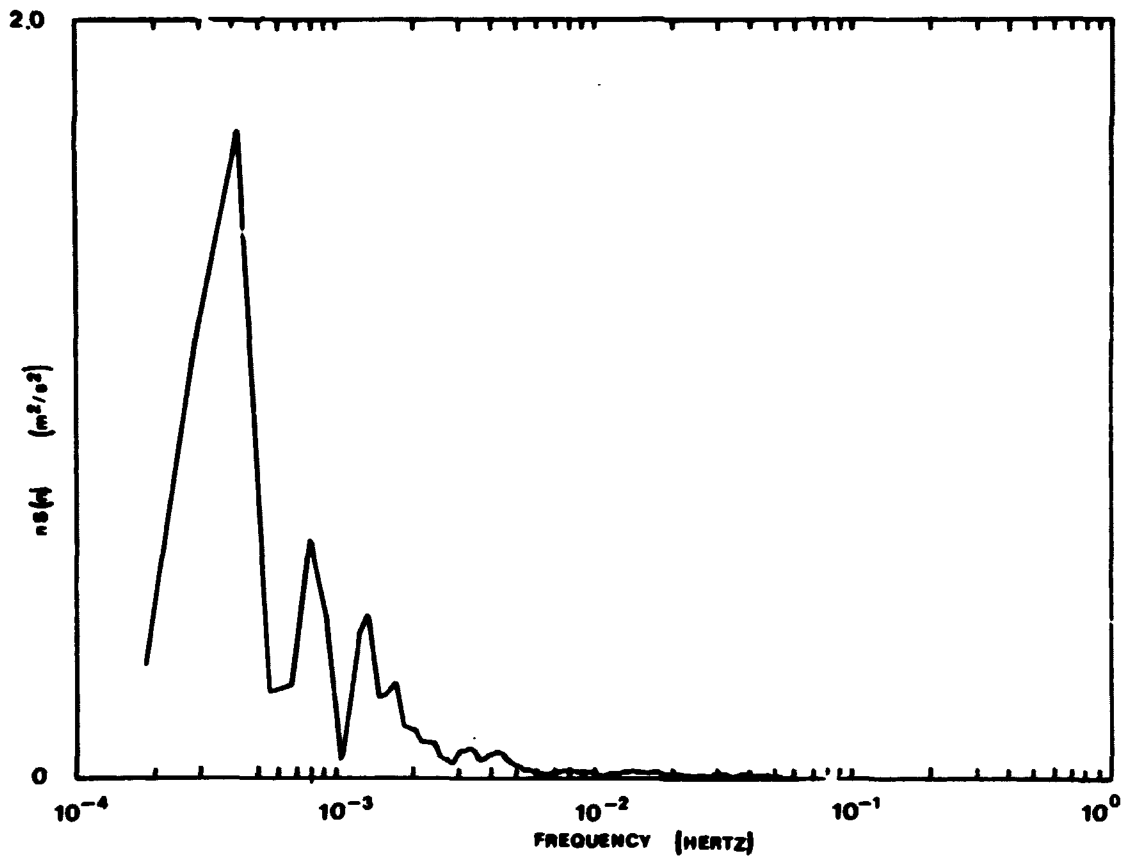

Fig.11. Power-spectrum of the downvalley wind velocity component; S denotes spectral density and n is frequency. Experiment on August 7.

will be only slightly stable or even unstable over the relatively warm land surface. This results in a constantly forced cool sea-breeze during nighttime. The interplay between the sea-breeze and the oscillating drainage flow will produce oscillations in the direction of the flow in the valley. When the drainage flow is predominant compared to the sea-breeze flow, the resulting flow will be downhill, relatively warm and stable; when the sea-breeze flow is predominant a relatively cool less stable upvalley flow results. Due to the oscillations in the strength of the drainage flow, wind direction fluctuations will be present in the valley flow. Figure 13 illustrates the suggested explanation for the observed flow-field in the valley. The flow field in the Dyrnæs valley is also discussed in Gryning and Lyck (1982) and Gryning and Lyck (1983).

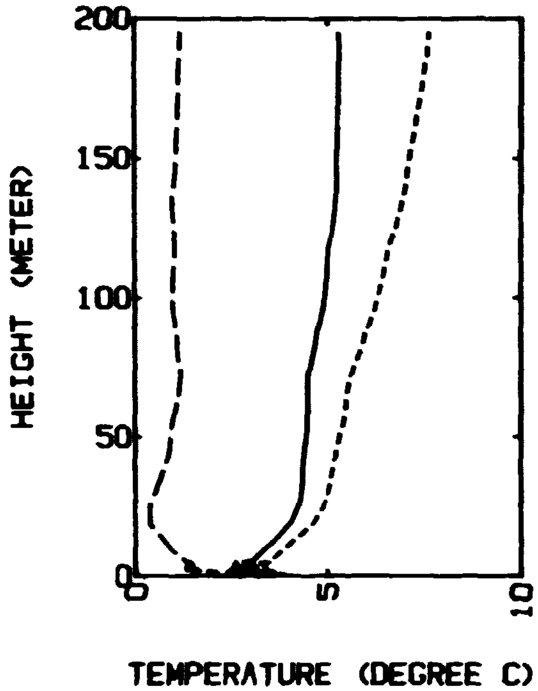

Fig.12. Temperature profiles measured by a radiosonde that was launched at the valley mast. The temperature is indicated by the solid line; the dew point temperature is shown by a coarse dashed line, and the potential temperature by a fine dashed line. Experiment on August 7.

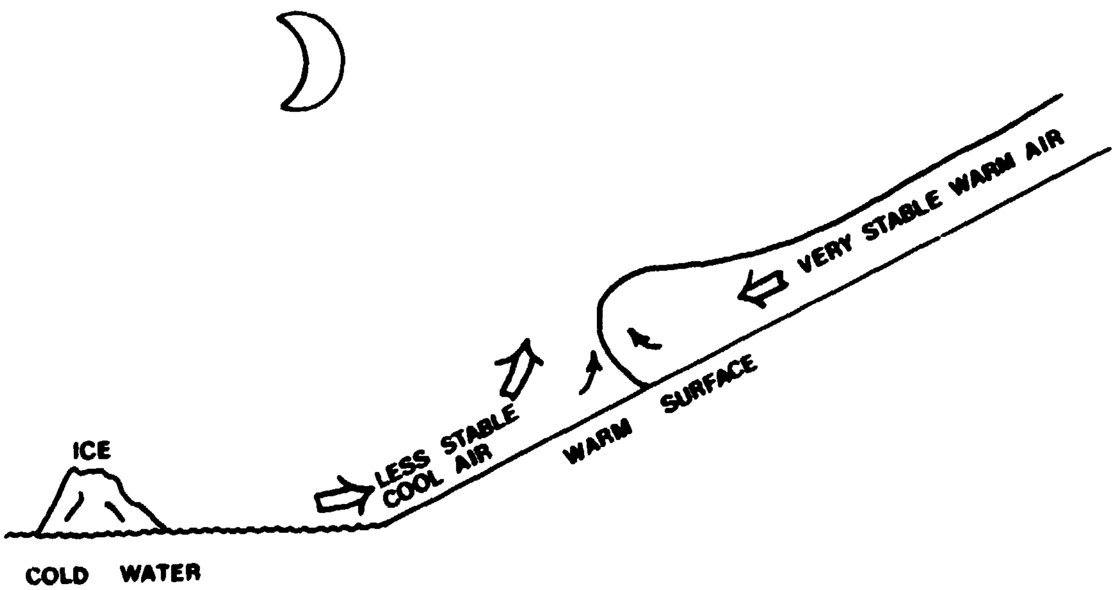

Fig.13. Illustration of the flow-field in the valley.

At what time of the year and how often does this condition occur? It is characteristic that a sea-breeze is initiated when the air temperature over land (corrected to sea-level) is higher than the water temperature in the fjord. This situation occurs during the rather short summer at Narssaq. As long as the fjord is not frozen the water temperature will be close to 0 deg C due to the icebergs in the fjord. Assuming for simplicity a temperature gradient in the valley of 0 deg C/m, it can be seen from the routine measurements at the valley mast that the monthly mean temperature at 6 GMT is positive from May to October, (Kristensen, 1982). However, from the extreme statistics it can be observed that only July and August lack nights with subzero temperatures. When the valley surface is colder than the water surface a land-breeze will be forced (opposite direction of a sea-breeze). A land-breeze will intensify the katabatic flow.

It is characteristic that the highest tracer concentrations in all experiments except for that of August 7 are found close to the position at the lower altitude, that is around the delta of the Narssaq river. This is expected from transport carried out by drainage flows.

It is intuitively clear that the oscillations in the wind velocity during the experiments must have a predominant effect on the transport velocity of the tracer through the valley. About half of the time the tracer is carried uphill and the other half downhill by the valley flow. It is characteristic that in the first four experiments the tracer was detected only at the positions close to the Narssaq river delta (if the tracer was detected at all). In experiment KVANE 1 rather high tracer concentrations were measured in the delta, but the tracer was not detected outside the delta. In these four experiments tracer release was initiated about 2 hours before the start of the tracer sampling units, which suggests that the necessary time for the tracer to travel from the release point to the delta was around or more than 2 hours, indicating an effective transport velocity of 0.5 m/s or less. In the last two experiments the tracer was released for about 6 hours before sampling was initiated, and in these experiments the tracer was detected at all sampling units in the valley. The complicated flow structure can be expected to cause great variations in the measured 20-min averaged tracer concentrations because the tracer sampling time and the characteristic time of the oscillations in the flow are about equal. It is characteristic that in experiments KVANE 1, 5 and 6 great variations are found in the measured 20-min averaged concentrations. In experiments KVANE 5 and 6 this variation is believed to be random due to the large time between the start of tracer release and tracer sampling. It is noted that these two experiments stopped just before sunrise, which immediately changes the flow. What concerns experiment KVANE 1 the tracer concentration increases systematically with time which could suggest that the tracer plume is not fully developed such that the concentrations would increase further after the sampling of the tracer was terminated. However it is interesting to compare KVANE 1 and 5. Both are carried out under near identical conditions, the meteorological measurements at the valley mast look pretty much the same and the measured tracer concentrations at the delta are nearly identical. Therefore, in experiment KVANE 1 it is possible that the tracer plume in the delta is fully developed. In the authors opinion, the measured concentrations in the delta during KVANE 1 could well have reached a stationary level, meaning that if the tracer sampling was carried out later comparable concentrations would have been measured in the delta (but certainly not outside).

To get a quantitative evaluation of the dilution at the outlet of the Dyrnæs valley of gases that have been released at the Kvanefjeld, the maximum measured concentration in each experiment divided by the tracer release rate has been calculated for the 1-h averaged measured tracer concentrations. This number is the socalled dilution factor. The results are shown in Table 2. It can be seen that the dilution of gases that have been released at Kvanefjeld is very different in the various experiments. The highest value of the dilution factor is $0.62 \cdot 10^{-6}$ s/m^3, found in the experiment on July 26. Thus, a continuous release of 1 g/s in meteorological conditions as in this experiment will result in concentrations around 0.6 μg/m^3

Table 2. Dilution factors based on measured maximum concentrations (20 min. average) and calculated maximum mean concentrations (1 h average) normalized with the tracer release rate.

Experiment 1981	Total series 1 h average Position	dilution (10^{-6} s/m^3)	20 min-average position	dilution (10^{-6} s/m^3)	Part of series along Narssaq (position 11-16) 1 h average position	dilution (10^{-6} s/m^3)	20 min-average position	dilution (10^{-6} s/m^3)
26 July	3	0.62	3	0.89	-	-	-	-
30 July	1-2-3	0.0087	1-2-3-4	0.011	-	-	-	-
1 Aug.	-	-	-	-	-	-	-	-
4 Aug.	4	0.0047	3-4	0.0075	-	-	-	-
7 Aug.	15	0.53	15	0.75	15	0.53	15	0.75
10 Aug.	3	0.22	3	0.25	11	0.015	11	0.019

at the lowest part of the valley. It is to be expected that the tracer concentration in Narssaq in this experiment was about at least 100 times lower than the maximum concentration measured in this experiment. The highest value of the dilution factor in the part of the sampling series just outside Narssaq was found in the experiment of August 7, (KVANE 5), the value of the dilution factor is $0.53 \cdot 10^{-6}$ s/m^3. Thus a continuous release of 1 g/s at the Kvanefjeld under conditions similar to this experiment will result in a concentration of about 0.53 μg/m^3 in the series. As Narssaq is situated further downwind from the position where this dilution factor was measured, the tracer will have been even more diluted when entering Narssaq.

It can be seen from Table 2 that the dilution factor based on 20-min averaged concentrations is slightly higher (up to 60%) than the dilution factor based on 1-h averaged concentrations.

To put the measured dilution factors into relief we have calculated dilution factors for flat terrain conditions in Pasquill stability class D, (neutral), using a wind velocity of 5 m/s. This meteorological condition occurs very frequently in Denmark. We have made the calculations for some typical effective stack heights, H=70, 100, and 200 m. Normalised ground-level centerline concentrations have been calculated according to Turner (1970); these concentrations are 10-min averages. As the measured dilution factors from the experiments have averaging times of 20 and 60 min, the calculated 10-min average dilution factors was converted to 20- and 60-min averages. This conversion was carried out using the standard formula

$$\left(\frac{\chi}{Q}\right)_t = \left(\frac{10}{t}\right)^{0.17}\left(\frac{\chi}{Q}\right)_{10}$$

where t indicates the desired averaging time in minutes. Table 3 shows the calculated 20- and 60-min average dilution factors for a distance of 4-5 km from the source, which corresponds to the distance between Kvanefjeld and Narssaq. Table 4 shows the highest value of the calculated dilution factor and the distance where it occurs for each of the chosen effective stack heights.

Table 3. Calculated dilution factors. Meteorological situation: Pasquill stability D, u = 5 m/s.

H_{eff} (m)	Distance from source (km)	Dilution factor χ/Q (10^{-6} s m^{-3}) 20 min	60 min
70	4-5	1.7	1.5
100	4-5	1.2	1.0
200	4-5	0.17	0.15

Table 4. Maximum value of calculated dilution factors. Meteorological situation: Pasquill stability D, u = 5 m/s.

H_{eff} (m)	Distance between source and position of maximum concentration (km)	Dilution factor χ/Q (10^{-6} s m^{-3}) 20 min.	60 min.
70	2	3.6	2.9
100	3	1.4	1.2
200	9	0.36	0.29

The measured dilution factors for the total series, Table 2, are for the experiments of July 26 and August 7 and 10 seen to correspond to the calculated dilution factors for an effective stack height of 100-200 m for 3-9 km distances. This correspondance holds for both Tables 3 and 4 and for 60- and 20-min averaged concentrations. For the part of the series along Narssaq this correspondence is valid for the August 7 experiment, while in the experiment on the 10th the measured dilution factor is one order of magnitude lower. The dilution factors in the experiments of July 30, August 1 and 4 are at least 2 orders of magnitude lower.

8. DISCUSSION

Experiments were carried out only over a rather limited period during the summer; the results from the tracer experiments are however expected to represent the concentrations that can be found during a substantial part of the summer under clear sky conditions during the night. During the day the upvalley wind prevents the tracer from being transported to Narssaq and at night under overcast conditions the transport velocity of the tracer will be very small. But we can well imagine that there might exist situations in which higher concentrations than those measured during these experiments will appear. An example of such a situation is the Pitorak-wind; the high wind speeds associated with this meteorological phenomenon will increase the dilution of the gases, but also reduce the transport time from the Kvanefjeld to Narssaq, resulting in larger exposures than found under drainage winds.

During winter, downvalley flow is well established both day and night; this is demonstrated also by the routine measurements at the meteorological mast in the valley. From an air pollution point of view this situation probably is worse than the situation which prevails during the summer because the flow tends to be more developed than in the summer and therefore more effective in transporting material to Narssaq, and because the daily cleaning in the summertime by the upvalley flow is absent. Therefore worse conditions than those measured during these experiments can well exist during the winter.

From an experimental point of view investigations in detail of the diffusion process under a Pitorak will be a rather difficult task because the Pitorak is a rather infrequent meteorological phenomena and therefore not easy to handle experimentally.

An experimental investigation of the diffusion process in the valley during the winter could well be carried out, but these experiments will be somewhat more difficult to conduct than those in summer, because transport will be hindered by snow in the valley.

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APPENDIX

KVANE 1

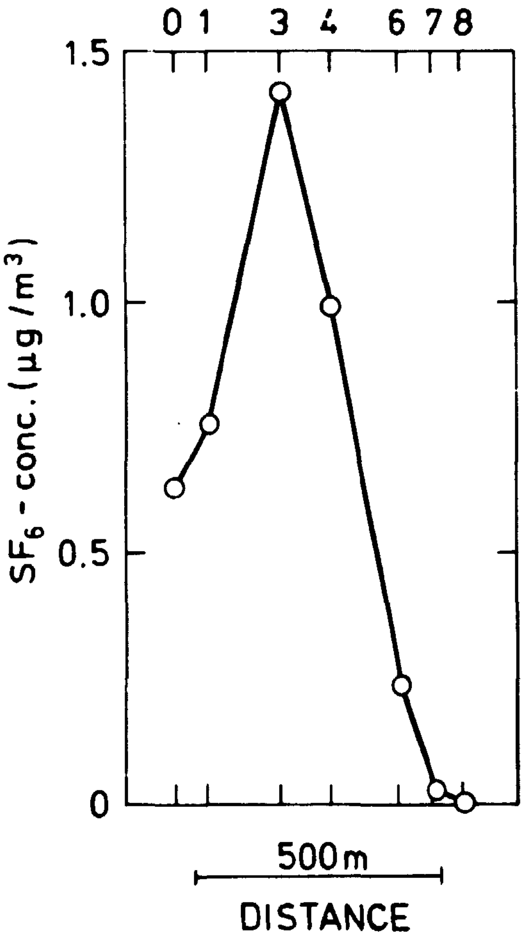

Fig.1.1. Experiment 26 July, 1981; (KVANE 1). Mean values, averaged over 1 hour, of the measured tracer concentrations. The positions have been projected on a line perpendicular to the direction R-position 3 in Fig.1.

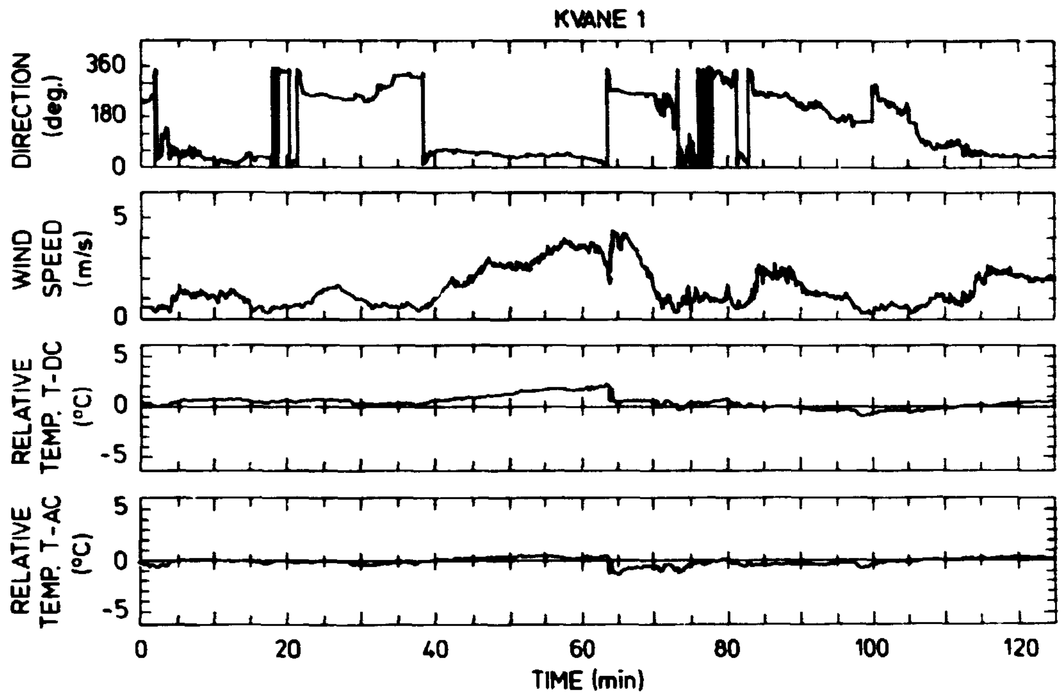

Fig.1.2. Measurements at the valley mast of the fluctuating wind speed, wind direction and temperature for the experiment on July 26, 1981. The temperature stated as T-DC are bandpass filtered with an upper frequency that can be characterized by a time constant of 1 s and a lower frequency of roughly 75 min; the temperature stated T-AC are filtered with an identical lowpass filter but the highpass filter are characterized by a time constant of 10 min. Downwind flow corresponds to a wind direction of approximately 60 deg, upwind to about 240 deg. The record starts at 0128 local time.

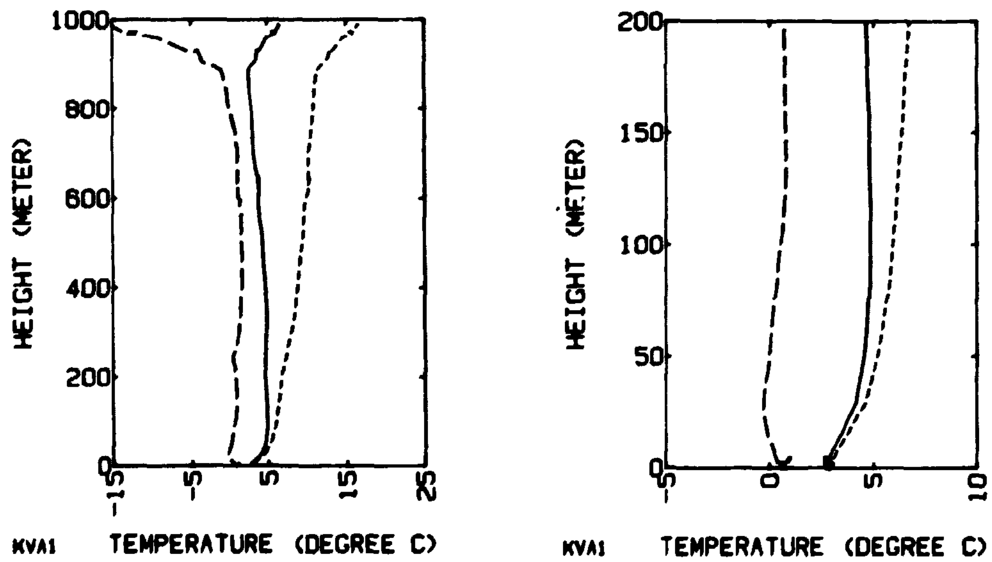

Fig.1.3. Vertical profiles of potential temperature, temperature and dew point temperature up to 1000 and 200 meter respectively for the experiment on July 26, 1981. The radiosonde was released at the Dyrnæs camp more than 1 hour after the experiment.

Table 1.1 Experiment July 26, 1981; KVANE 1.
Measured SF_6-tracer concentrations (20 min average) and mean values (1 h average) in ng/m^3. Uncertainty due to calibration ± 20%; detection limit 15 ng/m^3.

Position	Period:	0201-0221	0221-0241	0241-0301	Total (0201-0301)
0		472	507	910	630
1		577	621	1.076	758
2 1)		-	-	-	-
3		822	1.373	2.056	1.417
4		709	988	1.286	994
5 2)		-	-	-	-
6 3)		61	87	-	236
7		0	52	[illegible]7	26
8-15 4)		0	0	0	0

1) No sampling unit placed at this position. 2) Sampling unit did not function properly. 3) Sampling unit did not function properly in period 0241-0301; an interpolated value has been used to calculate the mean value. 4) The positions in the town of Narssaq is 12-15 (not shown on fig. 1.).

Table 1.2 Routine measurements of wind speed, wind direction and temperature.

Date: 26 July 1981; valley-mast; KVANE 1.

time (local summer time)	wind-speed (m/s) height 5m	height 10.3m	height 21.2m	wind-direction (deg) height 10.3m	height 21.2m	temperature (deg.C) height 2m	height 20.3m	temperature difference (deg. C) 20.3-2m
0135	0.84	0.81	0.60	57	52	4.4	4.3	0.00
0145	1.12	1.09	0.91	43	35	4.5	4.5	0.00
0155	0.70	0.56	0.70	254	251	4.2	4.3	0.33
0205	0.70	0.77	0.67	22	280	4.0	4.0	0.00
0215	1.71	1.78	1.36	48	52	4.1	4.3	0.33
0225	3.10	3.03	2.79	44	44	4.6	5.2	0.66
0235	2.89	3.21	3.49	281	261	4.2	4.0	-0.18
0245	1.75	1.68	1.50	26	15	3.8	3.6	-0.18
0255	1.12	1.22	1.19	276	260	3.6	3.6	-0.09
0305	1.22	1.36	1.40	208	176	3.4	3.2	-0.14
0315	0.46	0.32	0.32	292	191	3.3	2.8	-0.41
0325	1.92	1.64	1.22	37	47	3.4	3.2	-0.09
0335	2.65	2.48	2.09	46	51	3.5	3.6	-0.04

The wind-speed at 10.3m is from the duplicate measuring system.

Table 1.3 Routine measurements of wind speed, wind direction and temperature.

Date: 26 July 1981; mountain-mast; KVANE 1.

time (local summer time)	wind-speed (m/s) height 5m	height 10.3m	height 21.2m	wind-direction (deg) height 10.3m	height 21.2m	temperature (deg.C) height 2m	height 20.3m	temperature difference (deg. C) 20.3-2m
0135	0.91	1.15	1.05	14	6	3.4	3.8	0.04
0145	1.50	1.54	1.22	2	337	3.5	4.1	0.18
0155	1.33	1.43	1.22	23	11	3.3	3.9	0.23
0205	1.09	1.15	1.15	5	5	3.8	3.9	-0.33
0215	1.05	1.09	1.02	29	45	3.7	4.1	-0.05
0225	1.12	1.19	1.12	18	15	3.8	4.0	-0.05
0235	0.95	0.91	0.84	16	17	3.7	3.9	-0.23
0245	0.53	0.91	0.98	74	75	3.9	4.0	-0.10
0255	0.84	0.98	1.22	87	86	3.5	3.9	0.28
0305	0.67	0.84	0.84	79	85	3.5	4.0	0.23
0315	0.32	0.42	0.63	91	96	3.1	3.6	0.09
0325	0.32	0.46	0.32	112	142	2.9	3.1	0.04
0335	0.32	0.53	0.32	143	233	2.8	3.0	0.14

APPENDIX

KVANE 2

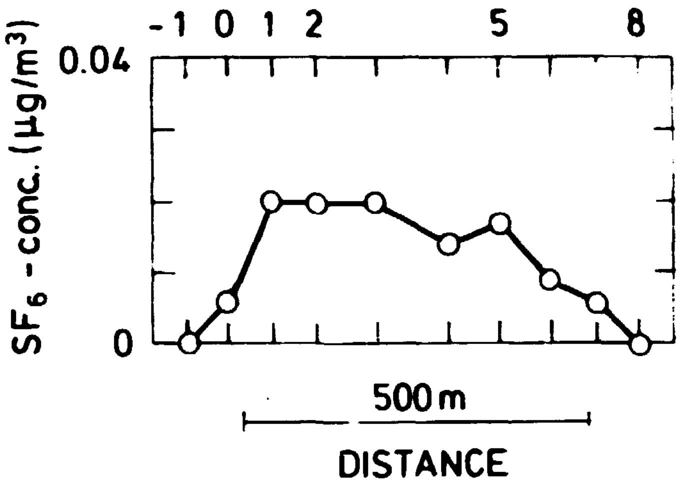

Fig.2.1. Experiment 30 July, 1981; (KVANE 2). Mean values, averaged over 1 hour, of the measured tracer concentrations. The positions have been projected on a line perpendicular to the direction R-position 3 in Fig.1.

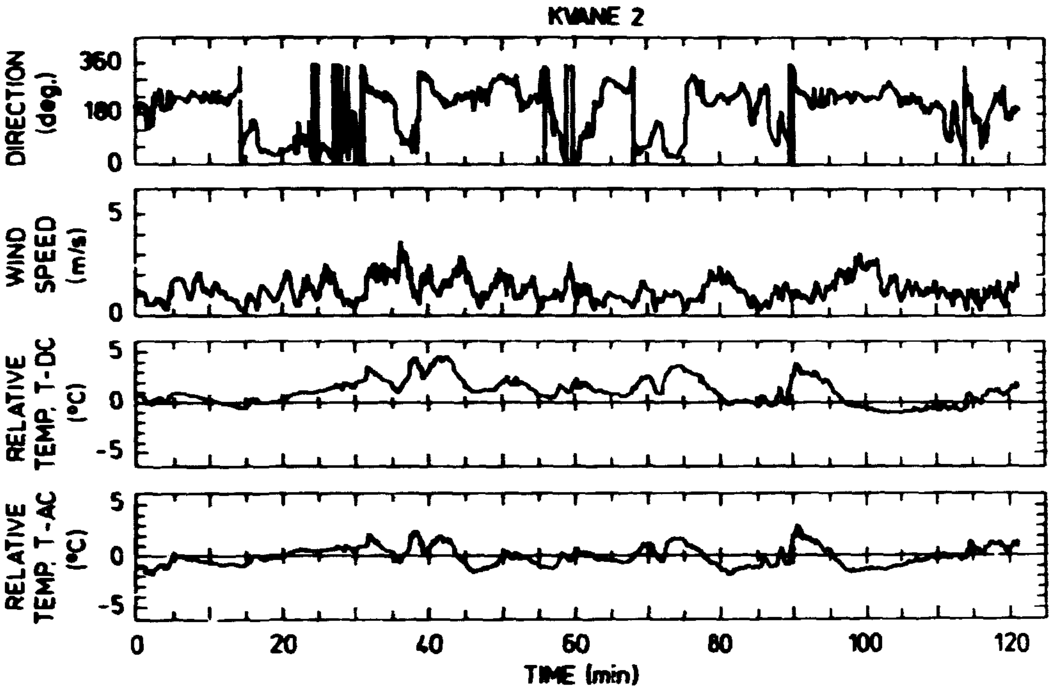

Fig.2.2. Measurements at the valley mast of the fluctuating wind speed, wind direction and temperature for the experiment on July 30, 1981. The temperature stated as T-DC are bandpass filtered with an upper frequency that can be characterized by a time constant of 1 s and a lower frequency of roughly 75 min; the temperature stated T-AC are filtered with an identical lowpass filter but the highpass filter are characterized by a time constant of 10 min. Downwind flow corresponds to a wind direction of approximately 60 deg, upwind to about 240 deg. The record starts at 0255 local time.

Table 2.1 Experiment July 30, 1981; KVANE 2.
Measured SF_6- tracer concentrations (20 min average) and mean values (1 h average) in ng/m^3. Uncertainty due to calibration ± 20%; detection limit 15 ng/m^3.

Position	Period: 0330-0350	0350-0410	0410-0430	Total (0330-0430)
-1	0	0	0	0
0	0	0	17	6
1	17	17	26	20
2	17	17	26	20
3	17	17	26	20
4	0	17	26	14
5	0	17	34	17
6	0	0	25	9
7	0	0	17	6
8-16	0	0	0	0

Table 2.2 Routine measurements of wind speed, wind direction and temperature.

Date: 30 July 1981; valley-mast; KVANE 2.

time (local summer time)	wind-speed (m/s) height 5m	height 10.3m	height 21.2m	wind-direction (deg) height 10.3m	height 21.2m	temperature (deg.C) height 2m	height 20.3m	temperature difference (deg. C) 20.3-2m
0255	2.20	2.23	2.20	209	199	10.5	11.9	1.44
0305	1.12	0.98	1.02	243	244	10.5	11.4	1.01
0315	0.77	0.70	0.84	26	36	10.3	10.8	0.57
0325	1.99	1.68	1.22	3	352	11.5	12.2	0.53
0335	1.92	1.96	1.78	328	316	12.0	13.5	1.54
0345	1.64	1.61	1.57	312	315	11.8	12.7	0.91
0355	1.40	1.33	1.26	355	354	11.4	12.2	0.91
0405	0.77	0.84	0.91	0	61	11.1	12.4	1.39
0415	1.12	0.88	0.95	251	247	11.9	12.9	0.82
0425	0.95	1.02	1.12	85	49	10.7	11.8	1.15
0435	1.75	1.57	1.47	255	245	10.7	11.4	0.77
0445	1.40	1.47	1.57	239	223	10.1	10.7	0.77
0455	1.15	0.98	0.88	77	203	10.9	11.8	1.01

The wind-speed at 10.3m is from the duplicate measuring system.

Table 2.3 Routine measurements of wind speed, wind direction and temperature.

Date: 30 July 1981; mountain-mast; KVANE 2.

time (local summer time)		wind-speed (m/s)		wind-direction (deg)		temperature (deg.C)		temperature difference (deg. C)
	height 5m	height 10.3m	height 21.2m	height 10.3m	height 21.2m	height 2m	height 20.3m	20.3-2m
0255	4.77	4.88	5.29	39	53	15.9	16.5	0.43
0305	5.33	5.33	5.75	62	56	15.9	16.6	0.58
0315	6.23	6.41	6.69	46	48	16.2	17.1	0.73
0325	6.93	7.21	7.00	37	33	16.1	17.2	0.97
0335	6.16	6.48	6.30	29	17	15.0	17.0	1.89
0345	6.90	7.28	7.08	14	5	15.5	16.9	1.26
0355	7.24	7.80	7.78	28	26	15.1	16.3	1.02
0405	4.84	5.23	5.29	40	29	15.2	16.0	0.48
0415	4.46	5.29	7.10	74	77	15.8	16.8	0.87
0425	5.47	6.30	7.90	90	83	16.3	17.3	0.97
0435	6.69	8.81	10.56	93	89	16.6	17.4	0.73
0445	5.19	7.38	9.30	71	81	16.4	17.2	0.78
0455	5.82	8.04	10.55	82	82	16.3	17.2	0.87

APPENDIX

KVANE 3

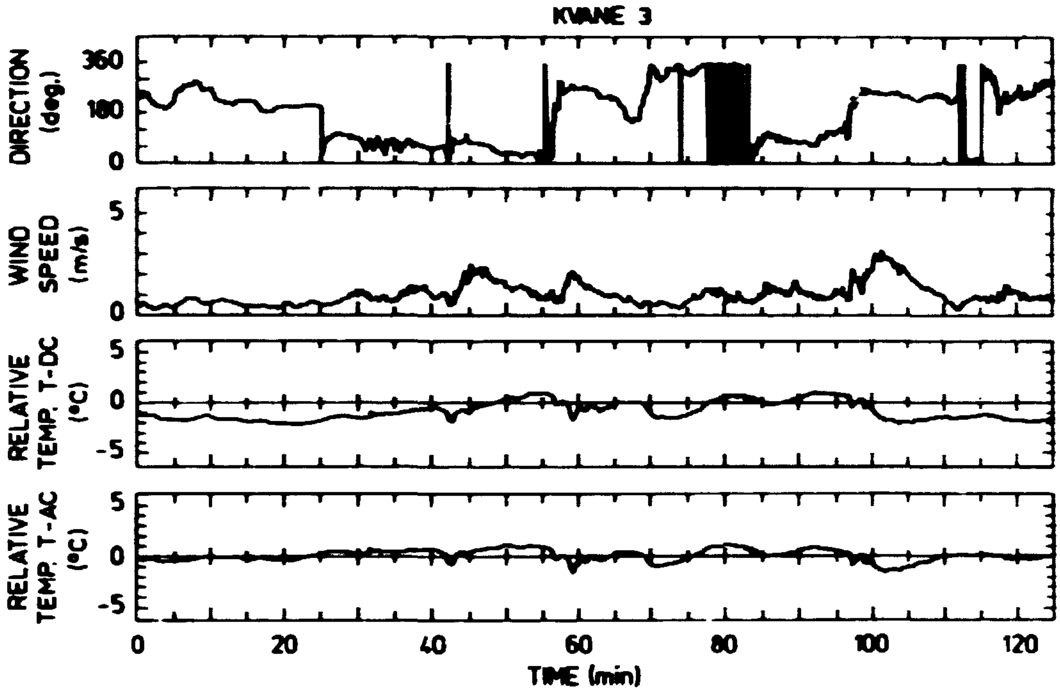

Fig.3.1. Measurements at the valley mast of the fluctuating wind speed, wind direction and temperature for the experiment on August 1, 1981. The temperature stated as T-DC are bandpass filtered with an upper frequency that can be characterized by a time constant of 1 s and a lower frequency of roughly 75 min; the temperature stated T-AC are filtered with an identical lowpass filter but the highpass filter are characterized by a time constant of 10 min. Downwind flow corresponds to a wind direction of approximately 60 deg, upwind to about 240 deg. The record starts at 0140 local time.

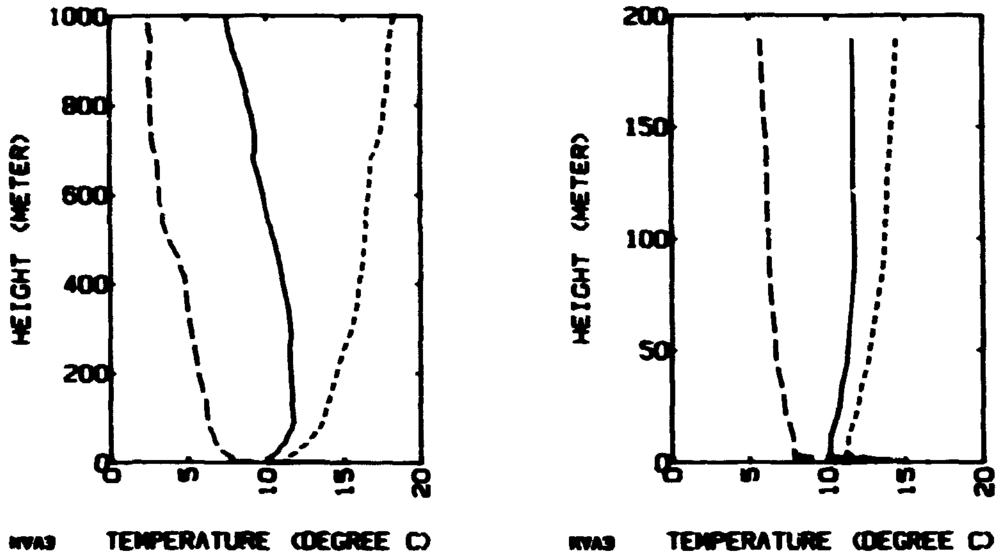

Fig.3.2. Vertical profiles of potential temperature, temperature and dew point temperature up to 1000 and 200 meter respectively for the experiment on August 1, 1981. The radiosonde was released at the valley mast.

Table 3.1 Tracer esperiment August 1, 1981; KVANE 3.
Measured SF_6-tracer concentrations (20 min average) and mean values (1 h average) in ng/m^3. Uncertainty due to calibrations ± 20%; detection limit 15 ng/m^3.

Position	Period:	0214-0234	0234-0254	0310-0330
-1				
0				
1				
.				
.		0	0	0
.				
.				
.				
.				
15				
16				

Table 3.2 Routine measurements of wind speed, wind direction and temperature.

Date: 1 August 1981; valley-mast; KVANE 3.

time (local summer time)	wind-speed (m/s) height 5m	wind-speed (m/s) height 10.3m	wind-speed (m/s) height 21.2m	wind-direction (deg) height 10.3m	wind-direction (deg) height 21.2m	temperature (deg.C) height 2m	temperature (deg.C) height 20.3m	temperature difference (deg. C) 20.3-2m
0145	0.84	0.74	0.42	288	256	11.1	11.0	-0.09
0155	0.70	0.67	0.32	247	228	10.7	10.7	0.00
0205	0.35	0.42	0.32	326	292	10.5	10.3	-0.09
0215	0.91	0.91	0.74	65	55	10.7	10.6	0.05
0225	1.15	1.22	1.26	73	71	10.7	10.9	0.34
0235	1.85	1.78	1.47	23	14	11.2	11.9	0.58
0245	0.95	1.05	1.19	168	217	10.1	10.8	0.81
0255	0.49	0.35	0.35	185	272	9.9	10.4	0.62
0305	0.91	0.84	0.91	95	100	10.0	11.2	1.15
0315	1.05	1.15	1.12	109	116	11.1	11.6	0.72
0325	1.99	2.16	2.09	244	226	9.5	9.4	0.15
0335	1.29	0.91	0.67	7	350	9.4	9.7	0.38

The wind-speed at 10.3m is from the duplicate measuring system.

Table 3.3 Routine measurements of wind speed, wind direction and temperature.

Date: 1 August 1981; mountain-mast; KVANE 3.

time (local summer time)	wind-speed (m/s) height 5m	wind-speed (m/s) height 10.3m	wind-speed (m/s) neight 21.2m	wind-direction (deg) height 10.3m	wind-direction (deg) height 21.2m	temperature (deg.C) height 2m	temperature (deg.C) height 20.3m	temperature difference (deg. C) 20.3-2m
0145	0.32	0.77	0.84	9	0	11.1	11.1	-0.10
0155	0.56	0.81	0.91	346	331	11.0	11.0	-0.10
0205	0.56	0.84	0.88	6	2	11.0	10.9	-0.15
0215	0.98	1.09	1.09	329	319	11.0	11.0	-0.10
0225	1.15	1.29	1.33	338	328	11.0	11.0	-0.19
0235	1.36	1.43	1.29	9	358	10.8	11.0	0.09
0245	1.40	1.61	1.64	348	336	10.8	11.0	0.04
0255	2.30	2.27	2.23	358	351	10.7	10.8	0.04
0305	2.69	2.76	2.72	355	357	10.8	11.1	0.19
0315	2.82	2.86	2.89	3	5	10.8	11.1	0.14
0325	3.10	3.17	3.24	343	346	10.6	10.9	0.24
0335	3.31	3.42	3.52	356	355	10.7	11.0	0.14

APPENDIX

KVANE 4

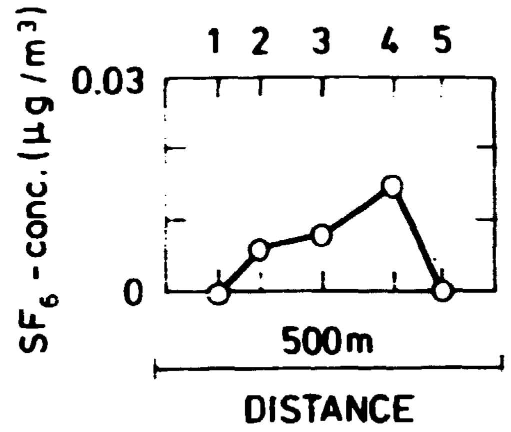

Fig.4.1. Experiment 4 August, 1981; (KVANE 4). Mean values, averaged over 1 hour, of the measured tracer concentrations. The positions have been projected on a line perpendicular to the direction R-position 3 in Fig.1.

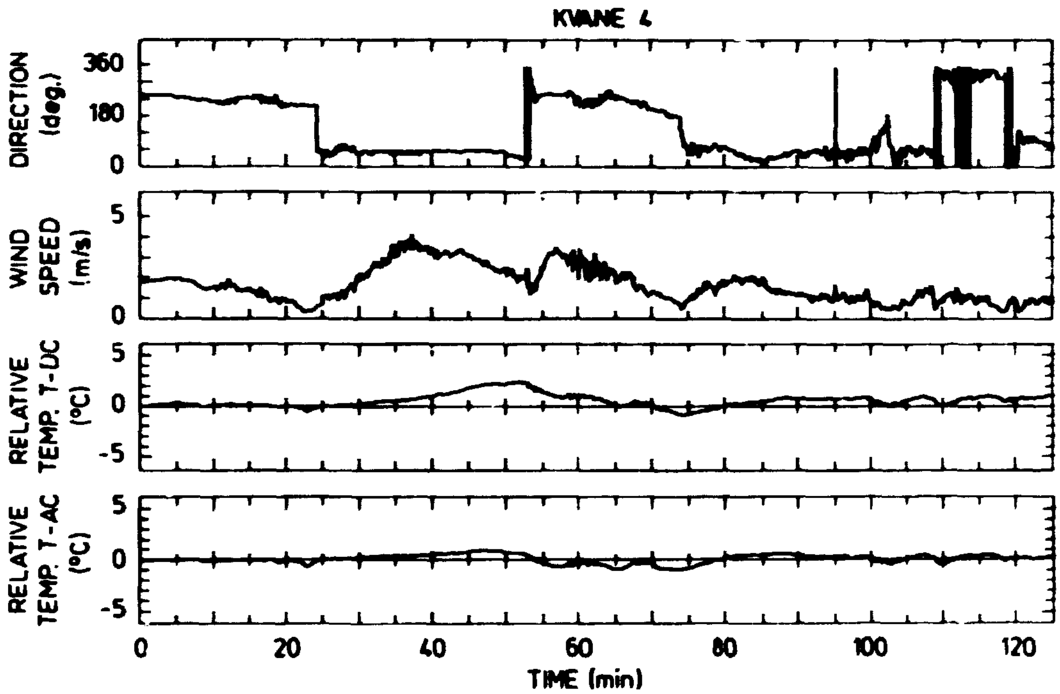

Fig.4.2. Measurements at the valley mast of the fluctuating wind speed, wind direction and temperature for the experiment on August 4, 1981. The temperature stated as T-DC are bandpass filtered with an upper frequency that can be characterized by a time constant of 1 s and a lower frequency of roughly 75 min; the temperature stated T-AC are filtered with an identical lowpass filter but the highpass filter are characterized by a time constant of 10 min. Downwind flow corresponds to a wind direction of approximately 60 deg, upwind to about 240 deg. The record starts at 0330 local time.

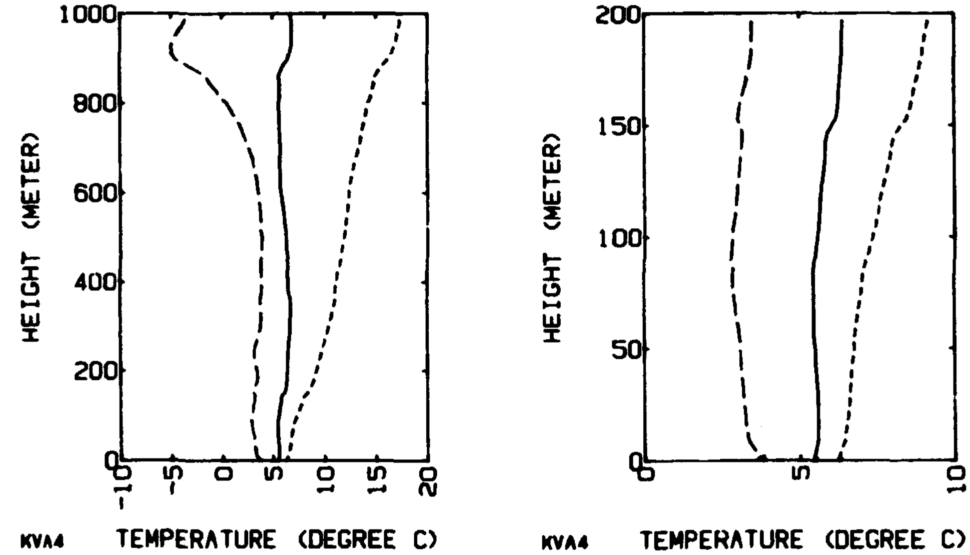

Fig.4.3. Vertical profiles of potential temperature, temperature and dew point temperature up to 1000 and 200 meter respectively for the experiment on August 4, 1981. The radiosonde was released at the valley mast.

Table 4.1 Experiment August 4, 1981; KVANE 4.
Measured SF_6-tracer concentrations (20 min average) and mean values (1 h average) in ng/m^3. Uncertainty due to calibration ± 20%; detection limit 15 ng/m^3.

Position	Period: 0425-0445	0445-0505	0505-0525	Total (0425-0525)
-1, 0,1	0	0	0	0
2	0	0	19	6
3	0	0	24	8
4	0	20	24	15
5-16	0	0	0	0

Table 4.2 Routine measurements of wind speed, wind direction and temperature.

Date: 4 August 1981; valley-mast; KVANE 4.

time (local summer time)	height 5m	wind-speed (m/s) height 10.3m	height 21.2m	wind-direction (deg) height 10.3m	height 21.2m	temperature (deg.C) height 2m	height 20.3m	temperature difference (deg. C) 20.3-2m
0325	1.50	1.47	1.15	264	266	5.8	6.4	0.57
0335	1.26	1.40	1.47	253	249	5.5	6.0	0.61
0345	1.19	1.29	1.47	254	244	5.5	5.8	0.42
0355	0.67	0.67	0.70	30	231	5.5	5.5	0.10
0405	2.20	2.06	1.68	45	47	5.7	5.9	0.33
0415	3.49	3.80	3.35	51	48	6.1	6.7	0.66
0425	2.65	2.62	2.34	250	247	6.9	7.3	0.47
0435	2.51	2.65	2.65	267	254	6.0	6.1	0.10
0445	1.12	1.29	1.29	147	178	5.3	5.3	0.10
0455	1.36	1.43	1.43	33	31	5.6	5.9	0.24
0505	1.36	1.36	1.12	53	36	6.1	6.3	0.14
0515	0.63	0.70	0.67	45	55	5.7	6.1	0.52
0525	0.81	0.88	0.88	321	333	5.8	6.2	0.24
0535	0.95	0.88	0.46	74	80	5.9	6.3	0.42
0545	1.19	1.22	0.32	50	47	6.7	6.7	1.10
0555	1.19	1.09	0.32	57	62	6.8	6.9	0.24

The wind-speed at 10.3m is from the duplicate measuring system.

Table 4.3 Routine measurements of wind speed, wind direction and temperature.

Date: 4 August 1981; mountian-mast; KVANE 4.

time (local summer time)	wind-speed (m/s) height 5m	height 10.3m	height 21.2m	wind-direction (deg) height 10.3m	height 21.2m	temperature (deg.C) height 2m	height 20.3m	temperature difference (deg. C) 20.3-2m
0325	0.32	0.95	0.32	9	354	6.7	7.0	0.09
0335	0.32	0.81	0.32	348	250	6.4	6.7	0.47
0345	0.32	0.53	0.32	281	250	6.3	6.5	0.42
0355	0.32	0.49	0.32	304	246	5.9	6.4	0.56
0405	0.81	0.91	0.60	82	84	5.9	6.4	0.51
0415	1.15	0.98	0.53	66	84	6.2	6.3	-0.05
0425	0.70	0.67	0.53	3	350	6.3	6.4	0.18
0435	0.42	0.67	0.95	261	288	6.2	6.4	0.42
0445	0.32	0.32	0.49	208	288	6.1	6.3	0.33
0455	0.46	0.63	0.32	106	288	6.3	6.4	0.09
0505	0.88	1.05	0.67	50	107	6.3	6.5	0.14
0515	0.60	0.74	0.56	353	5	6.4	6.6	-0.10
0525	0.74	0.84	0.63	352	330	6.4	6.7	0.04
0535	1.29	1.33	1.02	14	28	6.[illegible]	6.6	0.23
0545	1.26	1.19	1.02	21	14	6.5	6.7	0.14
0555	0.56	0.84	0.67	64	68	6.7	6.9	0.14

APPENDIX

KVANE 5

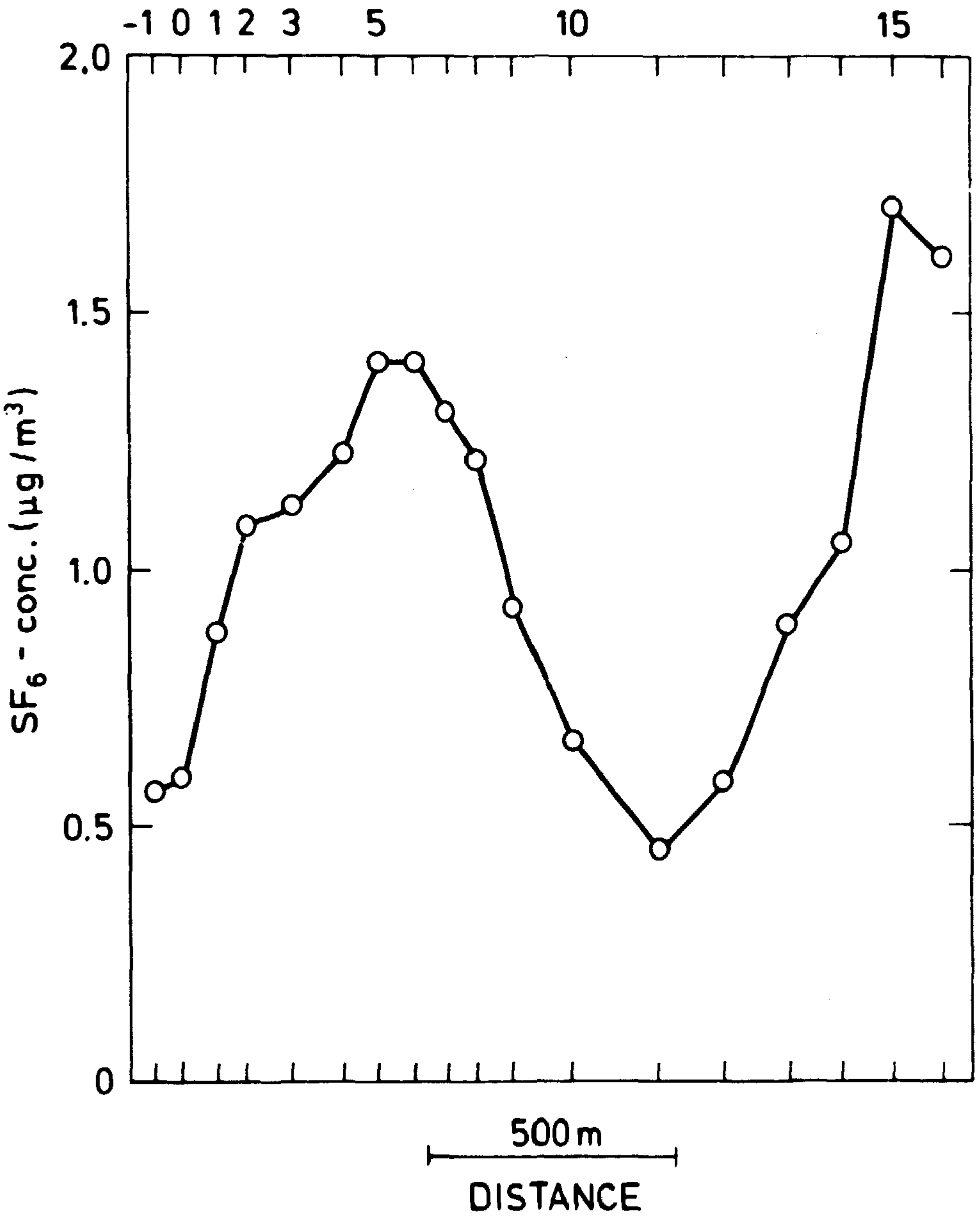

Fig.5.1. Experiment 7 August, 1981; (KVANE 5). Mean values, averaged over 1 hour, of the measured tracer concentrations. The positions have been projected on a line perpendicular to the direction R-position 3 in Fig.1.

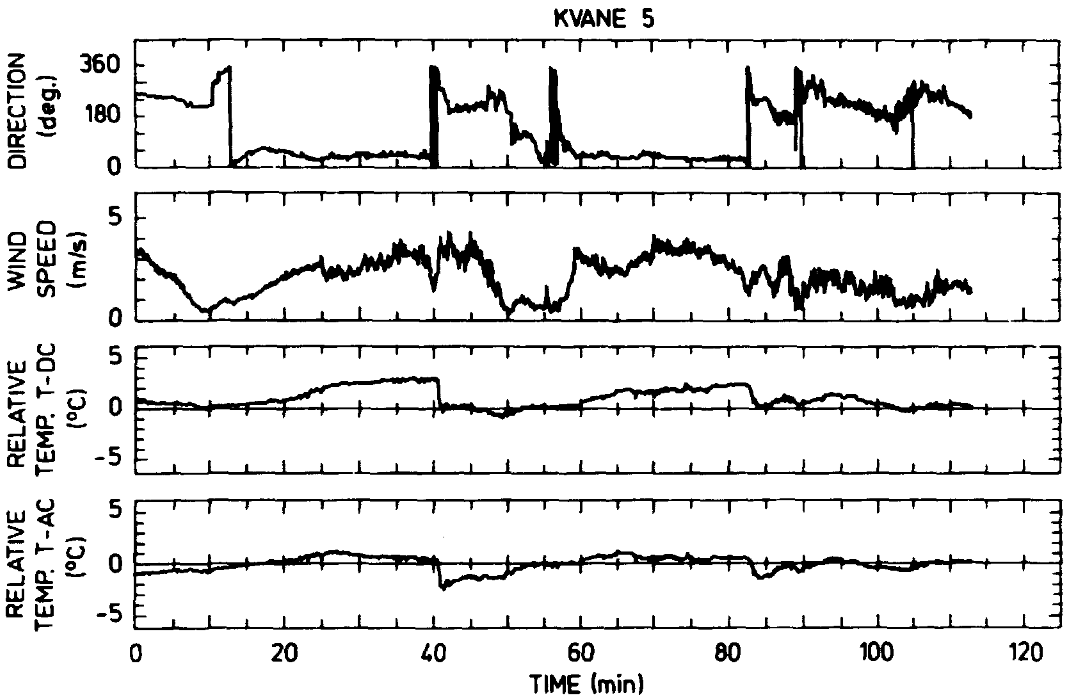

Fig.5.2. Measurements at the valley mast of the fluctuating wind speed, wind direction and temperature for the experiment on August 7, 1981. The temperature stated as T-DC are bandpass filtered with an upper frequency that can be characterized by a time constant of 1 s and a lower frequency of roughly 75 min; the temperature stated T-AC are filtered with an identical lowpass filter but the highpass filter are characterized by a time constant of 10 min. Downwind flow corresponds to a wind direction of approximately 60 deg, upwind to about 240 deg. The record starts at 0252 local time.

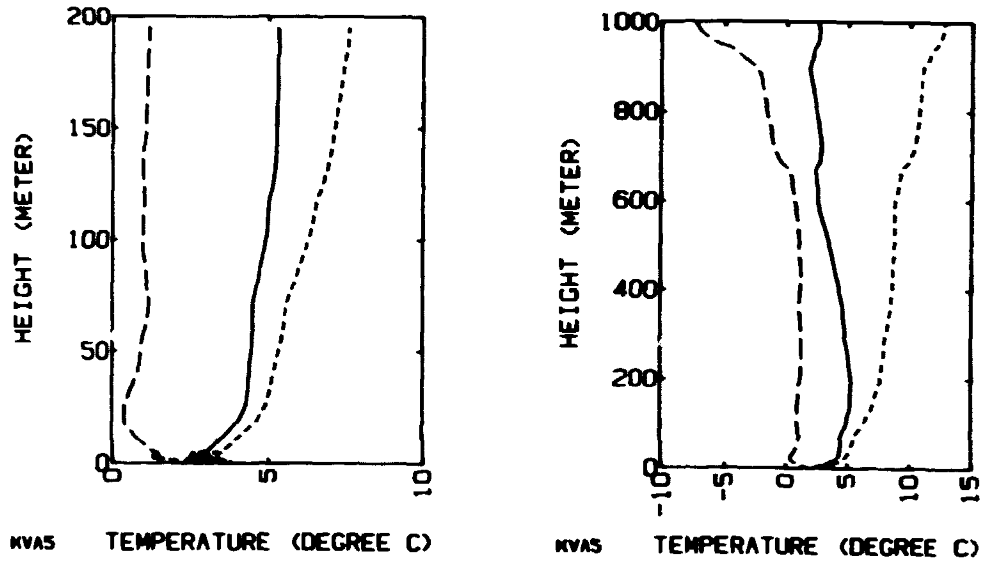

Fig.5.3. Vertical profiles of potential temperature, temperature and dew point temperature up to 1000 and 200 meter respectively for the experiment on August 7, 1981. The radiosonde was released at the valley mast.

Table 5.1 Experiment August 7, 1981; KVANE 5.
Measured SF_6-tracer concentrations (20 min average) and mean values (1 h average) in ng/m^3. Uncertainty due to calibration ± 20%.
detection limit 15 ng/m^3.

Position	Period: 0330-0350	0350-0410	0410-0430	Total (0330-0430)
-1	179	660	853	564
0	262	630	902	598
1	485	892	1.251	876
2	509	1.047	1.686	1.081
3	596	1.183	1.589	1.123
4	766	1.353	1.564	1.228
5	1.038	1.455	1.710	1.401
6	941	1.309	1.964	1.405
7	669	1.198	2.061	1.309
8	529	1.353	1.759	1.214
9	218	1.256	1.295	923
10	184	1.111	698	664
11	136	747	466	450
12	199	873	674	582
13	558	1.310	829	899
14	611	1.686	854	1.050
15	1.528	2.401	1.179	1.703
16	1.649	2.183	985	1.605

Table 5.2 Routine measurements of wind speed, wind direction and temperature.

Date: 7 August 1981; valley-mast; KVANE 5.

time (local summer time)	wind-speed (m/s) height 5m	height 10.3m	height 21.2m	wind-direction (deg) height 10.3m	height 21.2m	temperature (deg.C) height 2m	height 20.3m	temperature difference (deg. C) 20.3-2m
0255	2.13	2.20	2.09	261	259	3.7	4.1	0.47
0305	1.36	1.50	1.54	236	231	3.3	3.5	0.37
0315	1.78	1.64	1.26	50	49	3.2	3.8	0.79
0325	3.45	3.17	2.34	35	34	4.3	5.6	1.17
0335	3.03	3.17	2.82	279	270	4.4	5.2	0.80
0345	2.27	2.48	2.41	198	219	3.2	3.1	0.10
0355	2.16	1.85	1.22	38	42	3.2	4.0	0.84
0405	3.45	3.28	2.76	44	42	3.8	5.2	1.40
0415	3.14	3.42	3.21	45	32	4.8	5.8	0.89
0425	1.33	1.47	1.78	314	310	4.0	4.5	0.47
0435	1.43	1.54	1.71	199	202	4.3	4.5	0.24
0445	1.02	1.09	1.15	236	228	3.9	4.2	0.47

The wind-speed at 10.3m is from the duplicate measuring system.

Table 5.3 Routine measurements of wind speed, wind direction and temperature.

Date: 7 August 1981; mountain-mast; KVANE 5.

time (local summer time)	wind-speed (m/s)			wind-direction (deg)		temperature (deg.C)		temperature difference (deg. C)
	height 5m	height 10.3m	height 21.2m	height 10.3m	height 21.2m	height 2m	height 20.3m	20.3-2m
0255	3.21	3.38	3.59	3	353	4.2	4.3	-0.05
0305	3.14	3.28	3.42	13	9	4.2	4.3	-0.05
0315	2.76	2.96	3.10	21	9	4.1	4.2	0.00
0325	2.51	2.69	2.79	24	16	4.0	4.1	-0.05
0335	2.96	3.10	3.14	39	24	4.0	4.3	0.09
0345	2.41	2.65	2.79	23	16	4.0	4.3	0.14
0355	3.45	3.69	3.59	15	9	4.0	4.5	0.42
0405	3.97	4.15	4.08	10	8	4.1	4.7	0.46
0415	3.87	4.04	4.11	7	355	4.4	4.6	0.04
0425	3.49	3.73	3.97	0	355	4.2	4.5	0.04
0435	1.26	1.75	2.06	150	142	3.8	4.0	0.23
0445	0.35	0.49	0.74	118	29	3.4	3.7	0.28

APPENDIX

KVANE 6

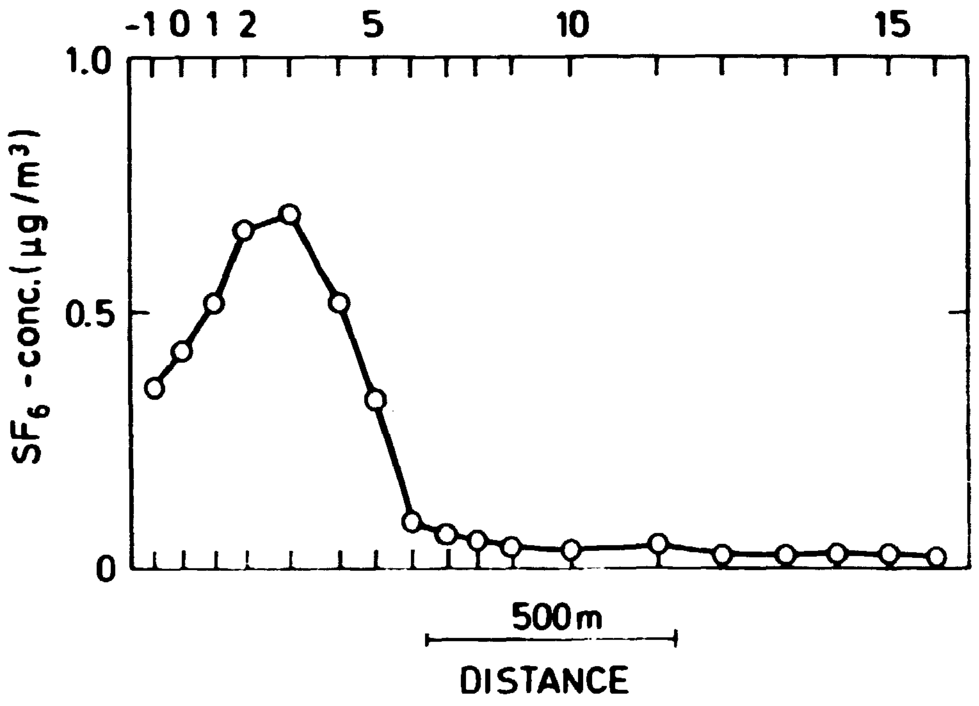

Fig.6.1. Experiment 10 August, 1981; (KVANE 6). Mean values, averaged over 1 hour, of the measured tracer concentrations. The positions have been projected on a line perpendicular to the direction R-position 3 in Fig.1.

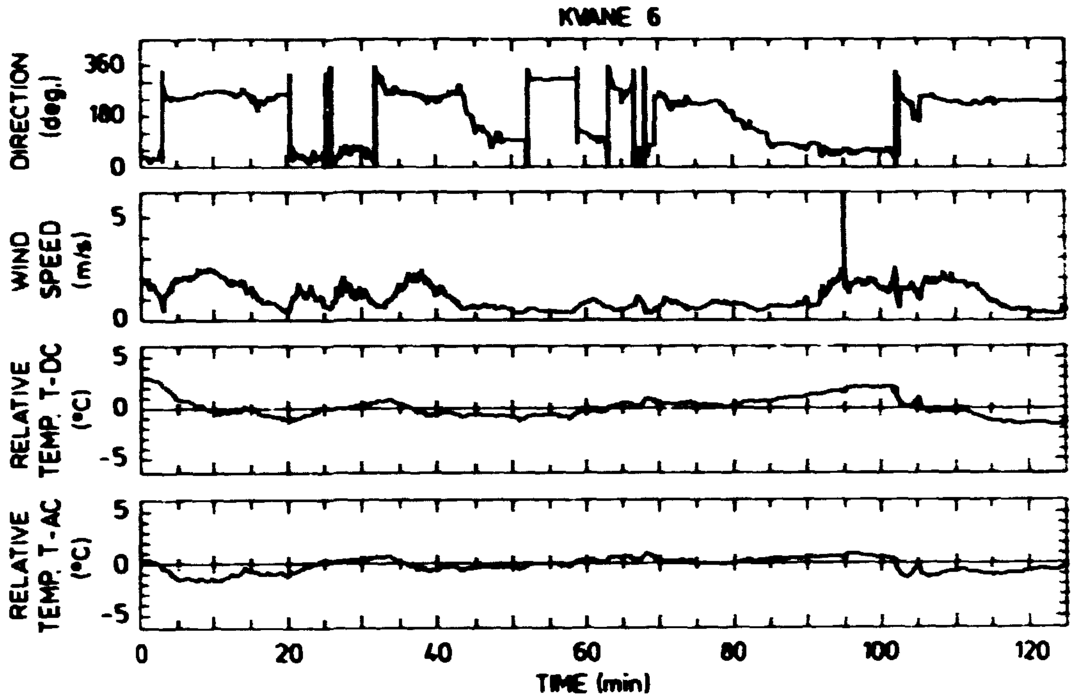

Fig.6.2. Measurements at the valley mast of the fluctuating wind speed, wind direction and temperature for the experiment on August 10, 1981. The temperature stated as T-DC are bandpass filtered with an upper frequency that can be characterized by a time constant of 1 s and a lower frequency of roughly 75 min; the temperature stated T-AC are filtered with an identical lowpass filter but the highpass filter are characterized by a time constant of 10 min. Downwind flow corresponds to a wind direction of approximately 60 deg, upwind to about 240 deg. The record starts at 0220 local time.

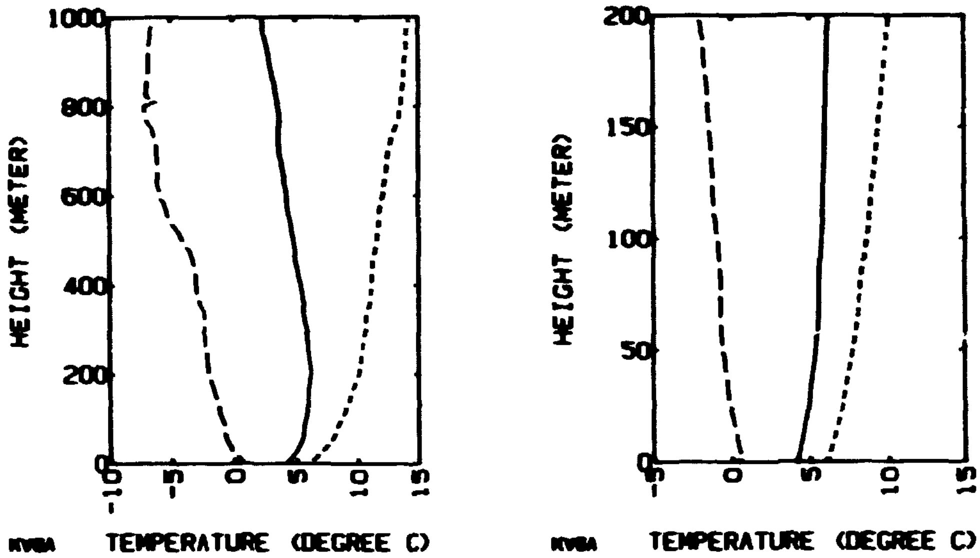

Fig.6.3. Vertical profiles of potential temperature, temperature and dew point temperature up to 1000 and 200 meter respectively for the experiment on August 10, 1981. The radiosonde was released at the valley mast at time 0345.

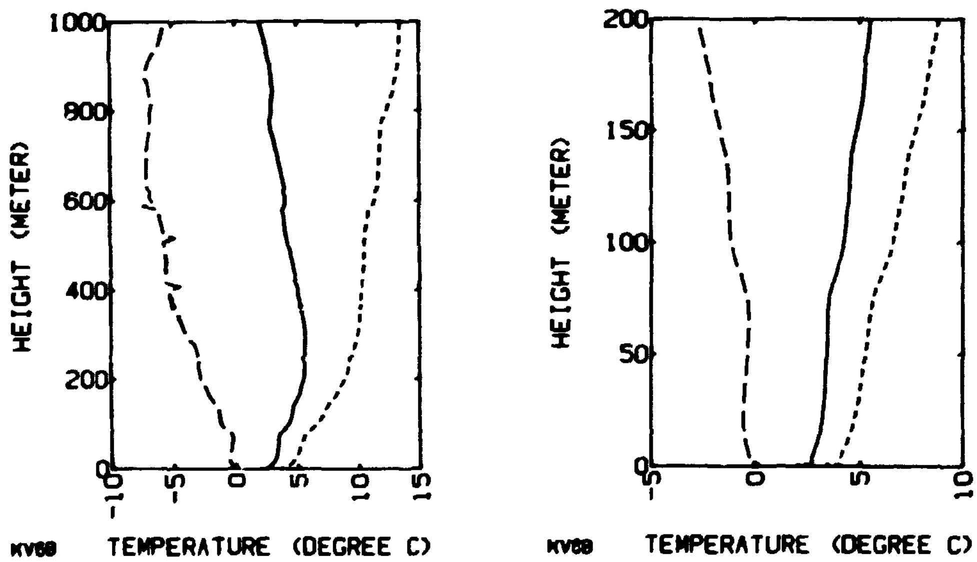

Fig.6.4. Vertical profiles of potential temperature, temperature and dew point temperature up to 1000 and 200 meter respectively for the experiment on August 10, 1981. The radiosonde was released at the valley mast at time 0445.

Table 6.1 Experiment August 10, 1981; KVAME 6.
Measured SF_6-tracer concentrations (20 min average) and mean values (1 h average) in ng/m^3. Uncertainty due to callibration ± 20; detection limit 15 ng/m^3.

Position	Period: 0330-0350	0350-0410	0410-0430	Total (0330-0430)
-1	493	287	279	353
0	517	297	455	423
1	575	364	623	521
2	690	522	771	661
3	594	675	795	688
4	374	575	613	521
5	158	374	460	331
6	72	115	86	91
7	72	77	48	66
8	72	62	38	57
9	53	48	29	43
10	38	38	29	35
11	62	48	34	48
12	38	29	19	29
13	38	19	19	25
14	38	29	19	29
15	34	48	0	27
16	38	38	0	25

Table 6.2 Routine measurements of wind speed, wind direction and temperature.

Date: 10 August 1981; valley-mast; KVANE 6.

time (local summer time)	wind-speed (m/s) height 5m	height 10.3m	height 21.2m	wind-direction (deg) height 10.3m	height 21.2m	temperature (deg.C) height 2m	height 20.3m	temperature difference (deg. C) 20.3-2m
0225	1.68	1.92	1.89	272	357	6.1	7.4	1.04
0235	1.96	2.06	1.99	255	252	4.6	4.7	0.28
0245	1.22	1.19	0.98	41	44	4.2	4.5	0.38
0255	1.61	1.47	0.95	41	14	4.9	5.4	0.38
0305	1.40	1.36	1.36	284	270	4.3	4.6	0.38
0315	0.42	0.32	0.32	9	177	4.1	4.1	0.14
0325	0.49	0.42	0.39	79	80	4.0	4.2	0.24
0335	0.67	0.49	0.49	260	252	4.5	4.7	0.28
0345	0.42	0.32	0.35	232	167	4.3	4.4	0.28
0355	1.43	1.05	0.67	52	45	5.1	5.2	0.05
0405	2.09	2.16	1.82	44	55	5.1	6.0	0.94
0415	0.91	1.33	1.57	234	230	3.5	4.0	0.61
0425	0.67	0.74	0.81	295	245	2.9	3.0	0.28
0435	0.53	0.32	0.35	11	289	2.9	2.9	0.00
0445	1.26	1.22	1.19	57	50	3.4	3.6	0.28
0455	2.06	2.02	1.78	39	28	3.9	4.5	0.56
0505	1.36	1.22	1.02	59	127	4.3	4.9	0.79
0515	1.12	1.36	1.33	249	254	3.8	4.3	0.56

The wind-speed at 10.3m is from the duplicate measuring system.

Table 6.3 Routine measurements of wind speed, wind direction and temperature.

Date: 1C August 1981; mountain-mast; KVANE 6.

time (local summer time)	wind-speed (m/s) height 5m	wind-speed (m/s) height 10.3m	wind-speed (m/s) height 21.2m	wind-direction (deg) height 10.3m	wind-direction (deg) height 21.2m	temperature (deg.C) height 2m	temperature (deg.C) height 20.3m	temperature difference (deg. C) 20.3-2m
0225	0.60	0.67	0.74	83	121	4.7	5.0	0.28
0235	0.63	0.84	0.81	86	91	4.9	5.1	0.28
0245	1.64	1.71	1.64	87	99	5.0	5.4	0.42
0255	1.40	1.82	1.99	95	94	4.6	5.4	0.70
0305	1.36	1.54	1.54	89	113	5.0	5.2	0.32
0315	1.15	1.33	1.57	116	117	5.2	5.5	0.46
0325	1.71	2.06	2.16	120	117	5.2	5.5	0.32
0335	1.75	2.06	2.13	135	133	5.2	5.4	0.28
0345	0.95	1.12	1.22	158	142	5.1	5.2	0.28
0355	0.42	0.88	1.02	98	111	4.9	5.1	0.23
0405	0.46	0.95	1.12	123	120	5.0	5.3	0.37
0415	1.22	1.40	1.61	112	131	5.0	5.2	0.37
0425	1.29	1.36	1.33	87	111	4.8	5.2	0.42
0435	0.91	1.05	1.19	125	152	4.9	5.0	0.28
0445	0.63	0.91	1.09	157	126	4 7	4.8	0.23
0455	0.32	0.63	0.91	164	168	4.3	4.9	0.56
0505	0.32	0.53	0.77	149	143	4.2	4.7	0.51
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