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AIRBORNE SEA SALT MASS CONCENTRATION AND SIZE DISTRIBUTION MEASUREMENTS ON KARMØY

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NORWEGIAN INSTITUTE FOR AIR RESEARCH
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NORWAY

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SUMMARY

Airborne sea salt concentrations and size distributions were measured at a coastal site on Karmøy in December, 1975, and January, 1976.

Results from five sampling periods of varying length with strong wind speed (ave. 5 to 13 m/sec) from the W to N sector indicated the following:

1. Total sea salt concentrations ranged from about 25 to 36 $\mu g/m^3$;

2. Average mass median diameter (equivalent aerodynamic) of the airborne sea salt particles was about 5.5 µm;

3. Still higher short-period concentrations of sea salt can occur in the area under favourable wind direction (onshore) and wind speed (up to 18 m/sec) during periods with no precipitation;

4. Precipitation scavenging and variable fetch over land modify transported sea salt concentrations, and mask clear-cut relationships between concentrations and wind speed;

5. Measured total and $\leq$ 4 µm diameter particle fraction concentration levels would require partial removal of sea salt from inlet air of gas turbines, operating in the area;

6. "Sampler effect" caused apparent differences in measurement results obtained with the various air samplers used in the study;

7. Although not without limitations and disadvantages, of all the samplers used in the study the Hi-Vol sampler and the Hi-Vol/Sierra cascade impactor were best suited for total concentration and size distribution measurements, respectively;

8. Representative samples of the entire size spectrum of airborne sea salt particles probably cannot be obtained without isokinetic sampling procedures.

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1 INTRODUCTION

The work described in this technical note is part of NILU's evaluation, for the NVE Statskraftverkene, of alternative sites for future thermal electicity generating plants in the Karmøy area (Sivertsen, 1975a). Gas turbine-powered generating stations have gained increasing acceptance in various parts of the world (Hart and Cutler, 1973) and can be considered as one of the possible means of electricity generation.

Gas turbine performance in marine environments has been detrimentally affected by the ingestion of airborne sea salt particles (Kaufman, 1969). This has been particularly dramatic in sea-going vessel installations, but has also occurred in shore-based gas turbine applications. Rapid drom in gas turbine performance has been traced to the ingestion and deposition of airborne sea salt in the first stage of the compressor of the turbine, which distorts the compressor rotor and stator blade profiles and results in the loss of compression efficiency. The phenomenon of the so-called hot zone corrosion or "sulphidation" and its precise causes are not yet fully understood, but are also thought to be partly due to airborne sea salt ingestion (Hart and Cutler, 1973; Labadie and Boutzale 1976). It results in often catastrophic breakdown in the normally protective oxide coating of the components in the hot zone of turbines, such as fuel nozzles, combustor, and first stage nozzles and blades. The severity of these effects appears to be a function of the concentration and size distribution of the ingested sea salt particles, fuel impurities, and temperatures in the hot zone. Airborne sea salt is produced over the sea surface and in surf zones along coastlines by mechanical disruption processes of sea water, and is transported inland by onshore winds. In general, the concentration and size distribution of airborne sea salt particles over the sea are a function of wind speed, relative humidity of the air, and removal "mechanisms", such as sedimentation, and rain-out and/or wash-out by precipitation. At coastal sites, however, other complicating factors, such as underwater and shore line topography, coastal vegetation cover, elevation above sea surface, and distance inland alter considerably the characteristics of the transported sea salt. Airborne sea salt concentrations and size distributions are, therefore, difficult to predict for a given coastal location with certainty, but such information is essential to designers of inlet air cleaning devices of gas turbines in shore line applications.

2 OBJECTIVES OF STUDY

The objectives of the measurement program on Karmøy were to:

a) measure airborne sea salt mass concentrations and size distributions under strong (> 5 m/sec) onshore wind (SW - NW) conditions at a coastal sampling site;

b) assess the influence of wind speed and other factors, e.g., fetch over land, precipitation, on sea salt particle concentrations and size distributions at the sampling site;

c) ascertain the suitability of various commonly used particulate matter samplers for airborne sea concentration and size distribution measurements.

3 EXPERIMENTAL

3.1 Sampling site

Sampling airborne sea salt was conducted at the existing NILU Ytraland station on the western coast of Karmøy (Fig. 1). The station is located on the east side and adjacent to the paved road between Kopervik and Kvalavåg, at the junction of the road to the village of Ytraland.

The station was already equipped with a heated shelter for instruments and a 30-meter meteorological tower.

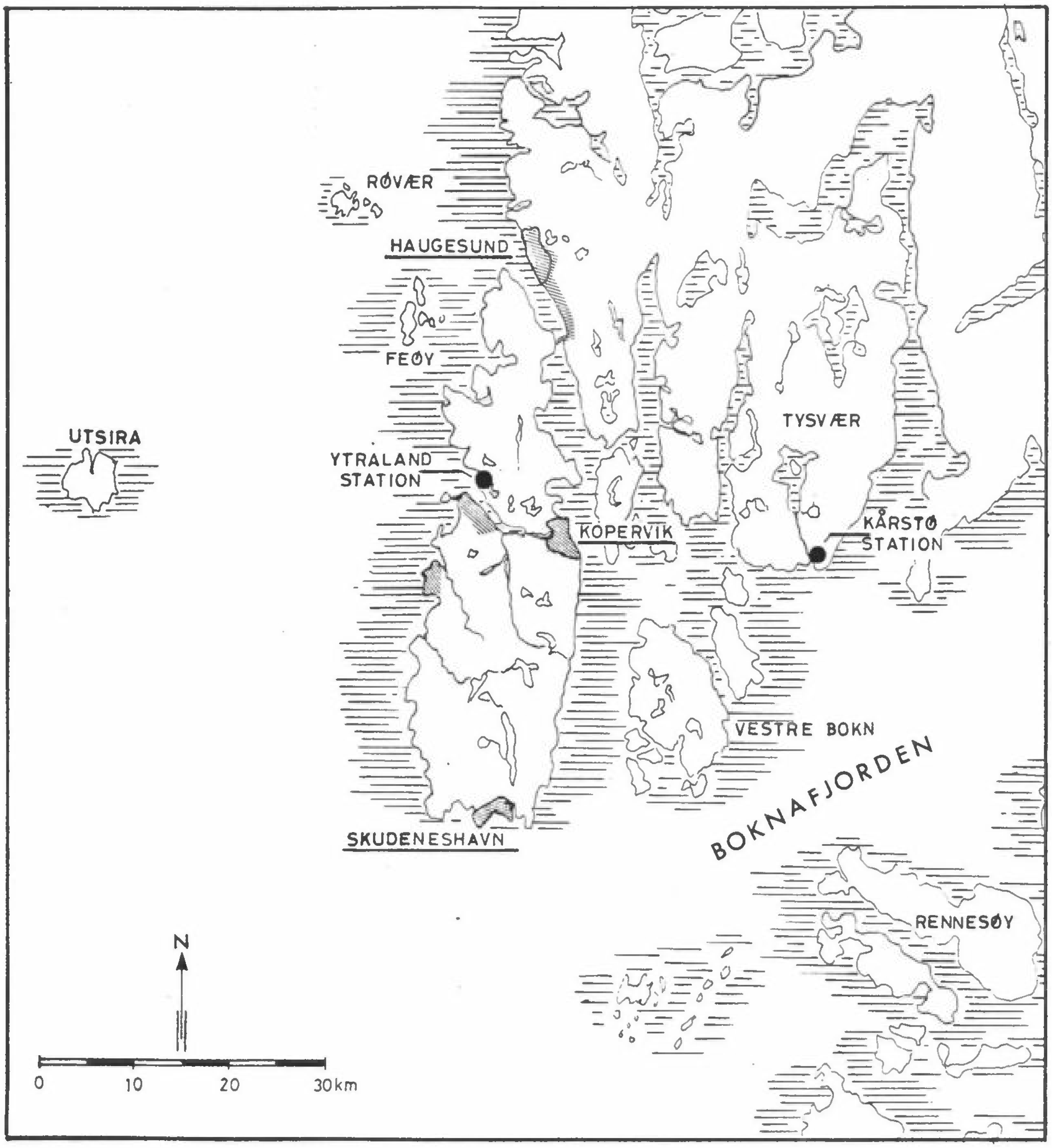

Figure 1: Simplified map of the Karmøy area. NILU's Ytraland and Kårstø station locations are shown.

The station site is on somewhat uneven pasture grounds, about 2 to 3 metres above the roadway, and about 16 metres above sea level. The site is partially sheltered on the west by a row of 3 to 4 metre high spruces, but, with the exception of a pile of tree stumps and roots some 30 metres NE of the instrument shelter, there are no prominent obstacles to airflow in any of the other directions. The nearest buildings are about 50 to 60 metres to the SW, while other houses are further down along the Ytraland road to the west. The open sea and surf around numerous skerries can be seen from the station site at a distance of about 1 to 1½ km to the west.

3.2 Sampling site instrumentation

The instrument shelter at the site housed a NILU automatic air sampler "kommunekasse" (KK) and a magnetic tape data logger for wind velocity and dew point sensors on the meteorological tower. The KK sampler had a NILU-type air inlet located outside the south wall of the instrument shelter, with its opening about 2 metres above ground level.

The following additional sampling equipment was installed at the site for this measurement program:

a) one modified Andersen sampler (PAC Fractionating Sampler, Model 2354), with "stove-pipe" type shield and inlet, orifice flowmeter, and pump and motor shelter (Fig. 2a).

The modification is the one used by the U.S.A. NASN* cascade impactor network (Lee and Goranson, 1972).

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* National Air Surveillance Network.

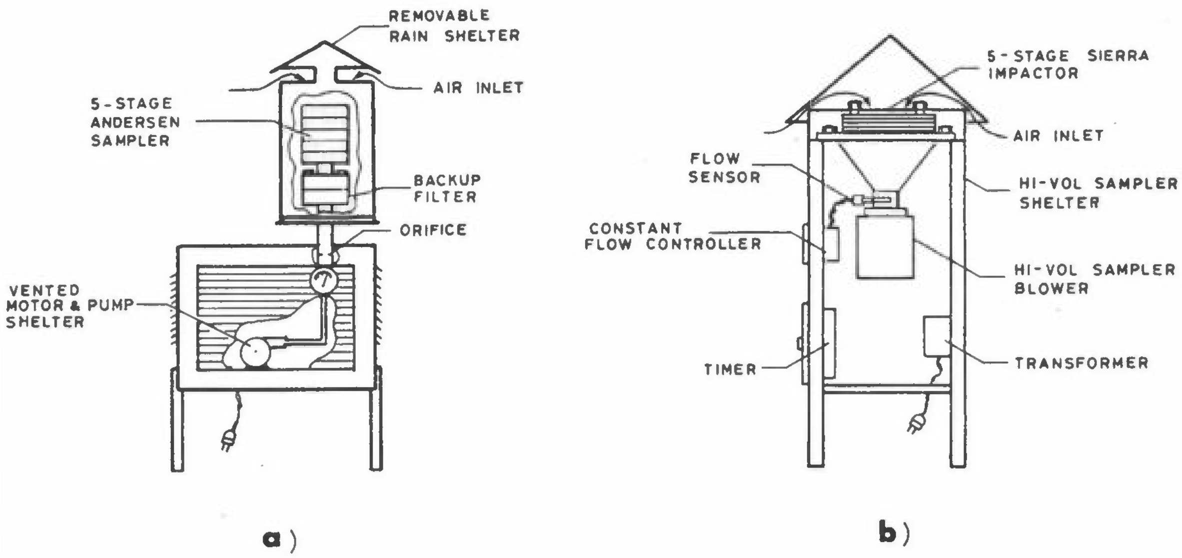

Figure 2: Diagrams of particle sizing samplers:

(a) modified Andersen Sampler with stove-pipe rain shelter;

(b) Hi-Vol/Sierra cascade impactor in standard Hi-Vol sampler shelter (square).

It consists of the first 5 stages of the 6-stage, multi-jet Andersen sampler and a membrane after-filter and holder (Dovland, 1975).

b) three high-volume suspended particulate matter samplers (Hi-Vols) of the type used by the U.S.A. NASN, housed in "standard" square shelters *, and provided with Sierra Model 310A constant flow controllers. Two of the Hi-Vols were equipped with Sierra Model 235 high-volume cascade impactors (Fig. 2b).

The Model 235 is a 5-stage, multi-slot cascade impactor with fibre glass after-filter (Willeke, 1975).

The Model 310A uses a constant-temperature anemometer to measure mass flow of the sampled air. It corrects for filter loading, and pressure drop across the filter, line voltage variations, and air temperature and pressure changes (Kurz and Olin, 1975).

c) one filter-tape sampler (RAC Model F-2), U.S.A. AISI-type*, equipped with NILU-type air inlet.
The filter-tape sampler (FTS) is a sequential sampler in which the air sample is drawn through a circular "spot" on a segment of a Whatman-type cellulose filter tape (RAC type 41). The filter tape is clamped in a sampling "head" during sampling. At the end of the sampling period (preset by a timer), the filter tape moves a few centimetres, a "clean" portion of the tape is clamped in the sampling head, and sampling resumed for the next period.

The KK sampler and the modified Andersen sampler had been used at the Ytraland site during a preliminary sea salt investigation (Sivertsen, 1975b). The May-type Casella cascade impactor, employed by Larssen (1974) for aboard-ship sea salt measurements, was not used in this study.

The three Hi-Vol samplers and the modified Andersen sampler (from here on referred to as the Andersen sampler) were positioned in a square pattern (approx. 2 metres apart from each other) and anchored to the ground about 8 to 19 metres to the east of the instrument shelter. Air intakes of these samplers were about 1.1 metre above ground. The FTS was housed inside the instrument shelter, with its NILU-type air inlet placed next to the KK air inlet, and at the same height above ground.

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* cf, for example, Lee <u>et al</u>. (1972); Lawrence Berkeley Laboratory (1975).

3.3 Air sampler calibration

3.3.1 Sampler flowrates

The orifice meter of the modified Andersen sampler had been calibrated in NILU's I-lab prior to transporting the sampler to the Ytraland site. A dry gas meter of appropriate capacity was used for the calibration.

The constant flow controllers of the three Hi-Vol samplers were adjusted to the recommended operating flowrate in the field prior to sampling by means of a Sierra Model 331 calibration orifice kit. The operating flowrates were again re-checked in the field before dismantling the samplers at the termination of the sampling program.

The flowmeter of the filter-tape sampler was calibrated in NILU's I-lab, by means of a dry gas meter, after the termination of the sampling program.

3.3.2 Cascade impactor ECD's

The latest published calibration information on the effective cut-off diameters (ECD's)[*] for the two cascade impactors was used. Cascade impactors separate airborne particles in size ranges according to their aerodynamic behavior, and their stage cut-off diameters are given in terms of equivalent aerodynamic diameters[**]. The ECD's of the 6-stage Andersen sampler have been most recently determinated at the design flowrate

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[*] ECD is the equivalent aerodynamic diameter of particles which are collected with 50% efficiency on a given impaction stage.

[**] Eqivalent aerodynamic diameter of an irregularly-shaped particle is defined as the diameter of a unit-density (1g/cm^3) sphere, which has the same terminal velocity in a gravitational or intertial force field, as the particle in question.

(0.0283 m^3/min) and with various collection substrates by Rao (1975). His ECD's for glass fibre substrates were adopted for this study, after correction for actual operating conditions. The ECD's for the Sierra high-volume cascade impactor (at the design flowrate of 1.13 m^3/min) with glass fibre collection substrates have been determined by Willeke (1975), and are the same, as given in the manufacturer's instruction manual for the impactor.

Stage ECD's for the two impactors, when operating at sampling flowrates other than calibration, were calculated from the relationship (Lee and Goranson, 1972):

$$ECD_s = ECD_c \sqrt{Q_c/Q_s},$$

where ECD_c and ECD_s are the calibration and sampling ECD's for a given stage, respectively, and Q_c and Q_s the corresponding calibration and sampling flowrates, respectively.

Table A1 in the Appendix gives calibration and sampling ECD's for the various flowrates at which the impactors were operated during this study.

3.4 Sampler preparation

Before sampling, all external and internal surfaces of the cascade impactors were rinsed with distilled water and swabbed with moist, lint-free tissue paper. The impactors were then prepared for sample collection by placing with forceps the substrate filters (approx. 8 cm dia. Whatman 40 discs for the Andersen sampler, and Whatman 40 slotted rectangles for the Sierra cascade impactor) on the collection stages and inserting the after-filters (Gelman Acropor AN800 10 cm dia. filters for the Andersen sampler, and approx. 20 cm by 25 cm Gelman Spectrograde Type A glass fibre filters for the Sierra) in their respective filter holders.

The impactors and their filter holders were usually "loaded" and assembled inside the instrument shelter at the sampling site. Stage substrates and after-filters to be used for blank determinations were exposed to the "loading room" environment during this time, but were not actually inserted in the impactors and filter holders.

After loading and assembling, the impactors were mounted in their respective samplers and the rain shields put in place.

The Hi-Vol sampler filter (Gelman Spectrograde Type A glass fibre) was inserted directly in the filter holder in the open, when possible with forceps - a difficult task under conditions of strong winds.

No special preparations were required for the KK and filter-tape samplers, in which the sample air stream is re-directed to a clean filter or filter area automatically at the end of each sampling period.

3.5 Sampling for airborne sea salt

The main objective of the measurement program was to sample airborne sea salt under strong wind speed (5 m/sec) conditions from the onshore sector (SW through NW). Thus the weather conditions at the Ytraland station mainly dictated the selection of two, approximately week-long sampling periods, one in early December, 1975, the other in early January, 1976. To conform as closely as possible to the routine operating cycle of the KK sampler at the Ytraland station, approcimately 24-hour sampling schedules for all the other particulate samplers were maintained commencing at about 0800 hours. The exact turn-on and turn-off times were somewhat staggered to allow time for exchange of the pre-loaded cascade impactors and for insertion of Hi-Vol sampler filters. The timers on the Hi-Vol sampler and the Hi-Vol/Sierra cascade impactor shelters were not used, but the samplers were started and shut-off manually. Readings of the Andersen sampler orifice meter differential pressure gauge, and of the flowmeter of the filter-tape sampler were recorded at the beginning and end of each sampling period. Rough checks of the constant flow-regulated Hi-Vol and Hi-Vol/Sierra samplers were made by means of the sampler "visifloat" flowmeters, but the exact flowrates were assumed to be those obtained from post-sampling flowrate calibrations. During one 24-hour period of high wind speeds, one of the Hi-Vol/Sierra samplers was operated on three seperate, shorter duration sampling cycles to ascertain the feasibility of short-period samples of airborne sea salt. Another sampling period was foreshortened by a power failure at the sampling site.

Periodic manual checks were also made of 5-minute average wind speed and direction read-outs of the meteorological parameter data logger, and the occurences of precipitation were noted.

3.6 Sample handling

After each sampling period, the impactor stage substrates and after-filters, as well as the Hi-Vol filter were removed with forceps from the impactors and holders and placed in clean, labelled and sealable polyetylene bags. A few unused collection substrates and filters from the same baton were also selected and sealed in bags for blank determinations.

Because it has been observed, that a considerable portion of the aerodynamically larger particles, which should be collected on the first stage of the impactors, might actually be lost from the sample due to deposition on the tops of the first stage jet plates (Lundgren, 1967; O'Donnell et al., 1970) an attempt was made to recover them. The first stage jet plates of both the Andersen and Hi-Vol/Sierra cascade impactors were washed with distilled water by means of a squeeze bottle, and scrubbed with camel's hair brush. The rinse and scrub waters were collected by means of a funnel in clean and labelled polyetylene bottles. The capped bottles and the stage substrate and filter bags were stored and returned to NILU's K-lab for chemical analyses.

3.7 Sample analysis and calculations

Impactor stage substrates, after-filters and jet plate washes, Hi-Vol and KK sampler filters and filter-tape sampler "spots" from selected sampling periods, as well as substrate and filter blanks were analyzed in NILU's K-lab for water-soluble chloride (Cl) and sodium (Na). The substrates and filters were leached in measured amounts of distilled water. The leach waters were analyzed for Na by flame emission spectroscopy, and for Cl by a spectrophotometric method.

The volumes of the first stage jet plate washes were determined and measured aliquots analyzed directly for Na and Cl. The results of the sample analyses were then adjusted to account for Na and Cl content in the substrate and filter blanks, as well as in the distilled water used for the leaching and washing.

Sample air volumes were calculated from sampling period durations and sampling flowrates. Details on sampling periods lengths and flowrates, and the calculated sample volumes for the selected sampling periods are given in Table A2 in the Appendix.

Strictly speaking, the calculated concentrations of Na and Cl, as measured by the various samplers, are not directly comparable, because their sample volumes were not corrected to the same "standard" temperature and pressure. This, however, was considered unnecessary, since a combination of the most extreme temperature and pressure encountered during the Ytraland measurements, would result in a correction of less than 5%.

4 EXPERIMENTAL RESULTS

4.1 Total airborne Cl, Na, NaCl, and sea salt concentrations

Table 1 summarizes total chloride (Cl), sodium (Na), sodium chloride (NaCl), and sea salt concentrations at the Ytraland station during those periods of measurement for which chemical analyses of samples were made. "Total" concentrations, as used here, refer to the various constituents found in particles of all sizes, sampled by the different samplers. Concentration values of Cl and Na are those directly calculated from sampling and chemical analysis data. The concentrations of NaCl represent the sum of Cl and Na concentrations (except for the KK samples, which are not routinely analyzed for Na). Sea salt concentrations were estimated, by assuming that the weight of NaCl in airborne sea salt particles is about 30% less, or that the sea salt/Cl ratio is about 1.82.

4.2 Size distributions of Cl and Na in airborne sea salt

Table 2 gives equivalent aerodynamic mass median diameters (MMD's) of chloride and sodium, as measured by the Hi-Vol/Sierra cascade impactor and the Andersen sampler during selected sampling periods at the Ytraland station. Figs. 3 through 5 show total concentrations of airborne Cl and Na, as well as the concentrations of Cl and Na collected on the different stages of the impactors (cf Tables A3 and A4 in the Appendix for detailed data). All first-stage concentrations include particles recovered from the first stage jet plates of the impactors. Combining of these collections was done on the assumption, that the majority of particles did not reach the first impaction stage because of their large aerodynamic size and, therefore, had equivalent aerodynamic diameters greater than the ECD's of the first stages of the impactors.

Table 1: Concentrations of total airborne chloride (Cl), sodium (Na), sodium chloride (NaCl), and total sea salt (T.S.S.) at Ytraland, obtained with Hi-Vol sampler (HV), Hi-Vol/Sierra cascade impactor (HV/S), modified Andersen sampler (A), "Kommunekasse" automatic sampler (KK), and filter-tape sampler (FTS).

(The Roman numerals in the sampling period column have the following meanings- (I): 0720-1350/8 Jan. 1976; (II): 1355-2155/8 Jan. 1976; (III): 2200/8 Jan. - 0730/9 Jan. 1976.)

Period of sampling	Cl, $\mu g/m^3$					Na, $\mu g/m^3$				c/NaCl, $\mu g/m^3$				d/T.S.S., $\mu g/m^3$				
	HV	HV/S	A	KK	FTS	HV	HV/S	A	FTS	HV	HV/S	A	FTS	HV	HV/S	A	KK	FTS
7-8/Dec. 1975	18.8	15.3	12.2	a/18.0	-	4.9	10.3	4.5	-	23.7	25.6	16.7	-	29.6	32.0	20.9	a/32.7	-
8-9/Dec. 1975	9.4	-	8.3	5.6	-	2.3	-	3.2	-	11.7	-	11.5	-	14.6	-	14.4	10.2	-
9-10/Dec. 1975	12.5	-	9.0	9.6	-	3.2	-	3.8	-	15.7	-	12.8	-	19.6	-	16.0	17.5	-
10-11/Dec. 1975	5.5	-	6.8	a/ 5.3	-	1.3	-	2.7	-	6.8	-	9.5	-	8.5	-	11.9	a/ 9.6	-
6-7/Jan. 1976	-	4.4	2.9	5.9	-	-	2.6	1.1	-	-	7.0	4.0	-	-	8.8	5.0	10.7	-
7-8/Jan. 1976	-	-	-	2.0	-	-	-	-	-	-	-	-	-	-	-	-	3.6	-
8/Jan. 1976 (I)	-	18.0	-	-	-	-	10.8	-	-	-	28.8	-	-	-	36.0	-	-	-
8/Jan. 1976 (II)	-	15.6	-	-	-	-	8.7	-	-	-	24.3	-	-	-	30.4	-	-	-
8-9/Jan. 1976 (III)	-	16.6	-	-	-	-	5.7	-	-	-	22.3	-	-	-	27.9	-	-	-
8-9/Jan. 1976	12.8	e/16.7	9.2	7.4	f/4.3	7.5	e/8.1	4.2	f/1.4	20.3	e/24.8	13.4	f/5.7	25.4	e/31.0	16.8	13.5	f/ 7.1
9-10/Jan. 1976	-	-	-	10.4	-	-	-	-	-	-	-	-	-	-	-	-	18.9	-
10-11/Jan. 1976	-	12.4	7.7	b/ 7.4	g/2.4	-	7.5	1.3	1.3	-	9.0	9.0	g/3.7	-	24.9	-	b/13.5	g/ 4.6

a/ KK concentration values for 24-hour sampling period.

b/ KK concentration values for approx. 21-hour sampling period.

c/ Assuming: $\mu g\ NaCl/m^3 = \mu g\ Na/m^3 + \mu g\ Cl/m^3$.

d/ Assuming that NaCl constitutes approx. 80% of total sea salt by weight, <u>or</u>, that $\mu g\ T.S.S./m^3 = 1.82 \times \mu g\ Cl/m^3$ (for KK sampler).

e/ Weighted average values of 3 separate sampling periods.

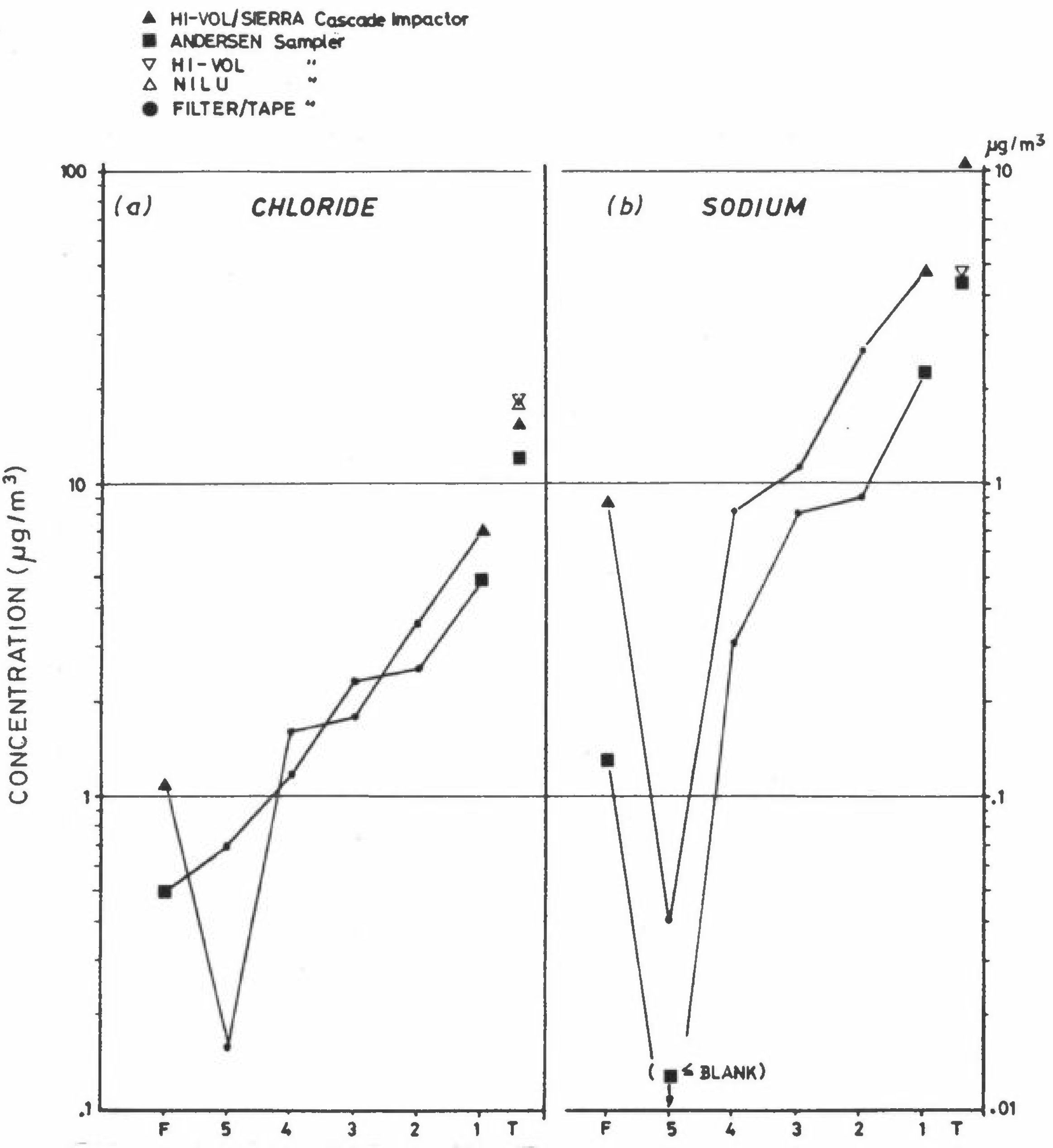
f/ Average values of eight separate 3-hour sampling periods.

g/ Average values of four separate 3-hour sampling periods.

Table 2. Mass median equivalent aerodynamic diameters (MMD's) of chloride (Cl) and sodium (Na) in airborne sea salt particles, as measured by Hi-Vol/Sierra (HV/S) and Andersen (A) cascade impactors.

(For the meaning of the Roman numerals (I), (II), and (III) see Table 1.

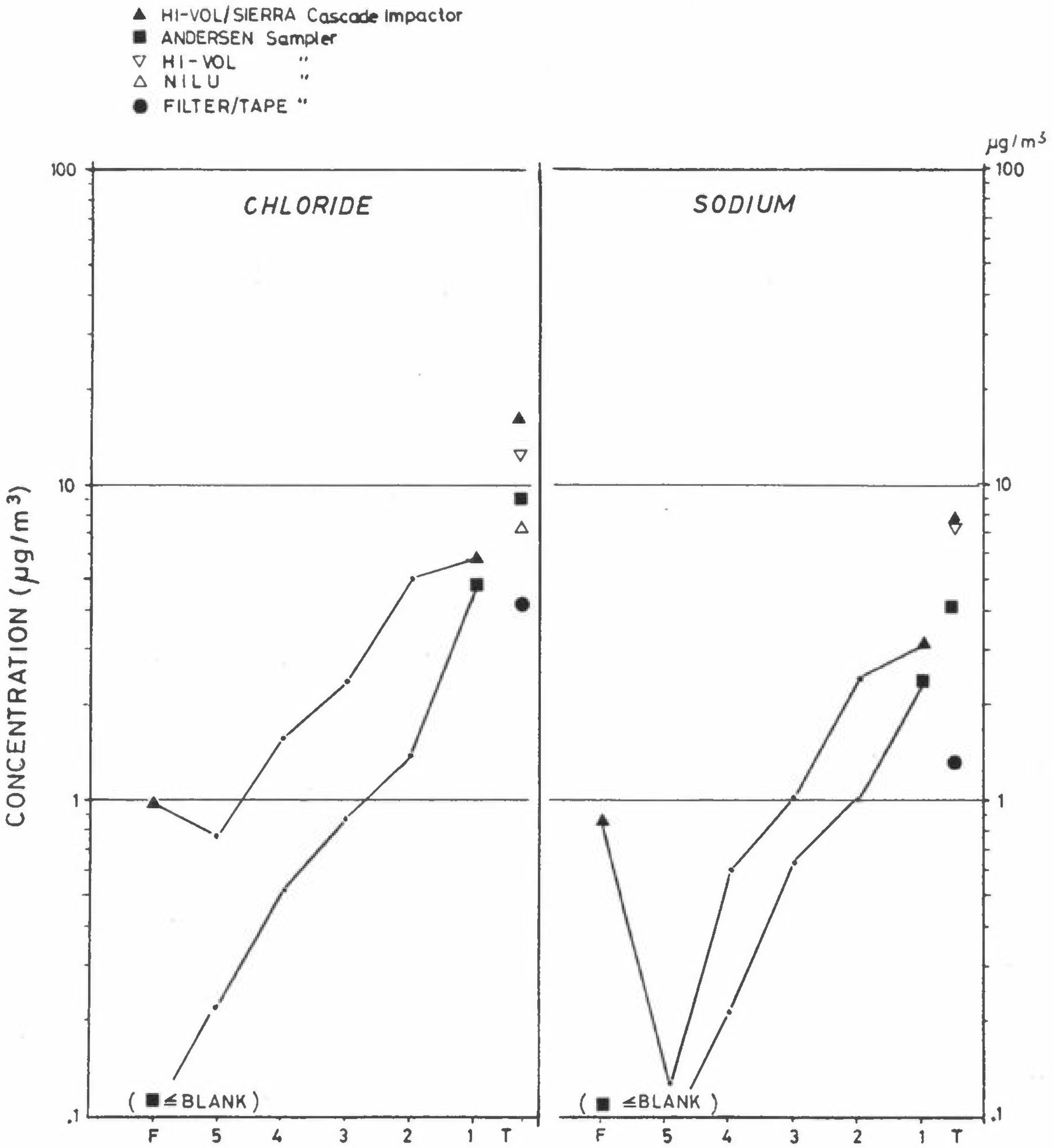
Period of sampling	MMD, µm			
	(HV/S)		(A)	
	Cl	Na	Cl	Na
7-8/Dec. 1975	6.4	6.5	3.8	4.9
6-7/Jan. 1976	5.1	4.7	6.7	6.1
8/Jan. 1976 (I)	4.6	4.7	--	--
8/Jan. 1976 (II)	5.8	5.1	--	--
8-9/Jan. 1976 (III)	4.2	6.0	--	--
8-9/Jan 1976	--	--	4.6	6.3
10-11/Jan. 1976	5.8	5.8	6.3	6.2
Averages:	5.3	5.5	5.4	5.9



F = Impactor After-Filter
1-5 = Impaction Stages
T = Total concentration

Figure 3: *Total mass concentrations and size-mass concentration distributions, as measured by various samplers (7-8/Dec., 1975 period).*

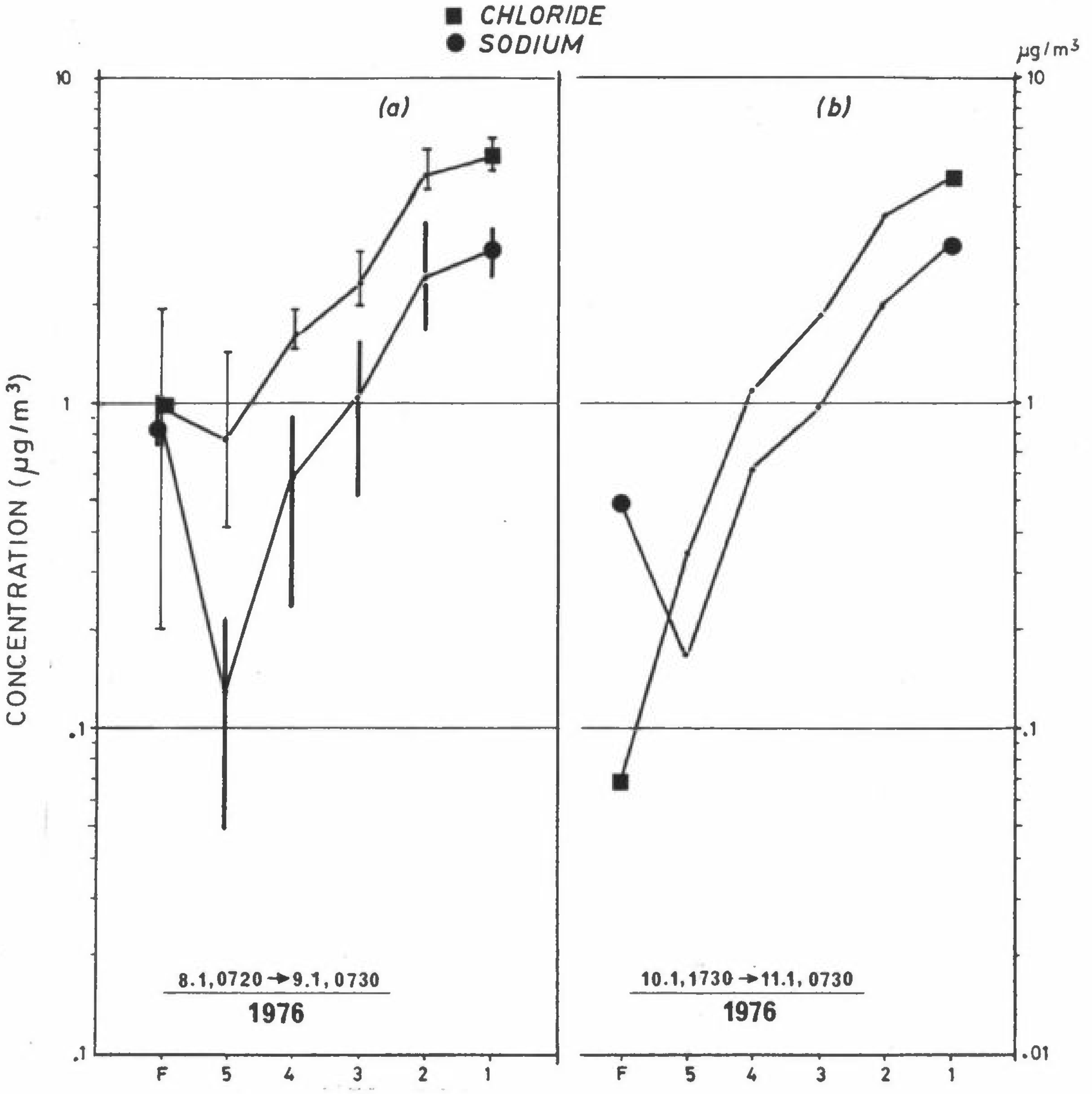
(a) chloride (Cl);
(b) sodium (Na).



F = Impactor After-Filter
1-5 = Impaction Stages
T = Total concentration

Figure 4: *Total mass concentration and size-mass concentration distributions, as measured by various samplers (8-9/Jan., 1976 period).*

(Concentration values for the Hi-Vol/Sierra cascade impactor represent a weighted average from 3 separate short-period sampling.)



F = Impactor After-Filter
1-5 = Impaction Stages

Figure 5: Mass concentration distributions of chloride (Cl) and sodium (Na) in airborne sea salt, as measured by Hi-Vol/Sierra cascade impactor:

(a) range of concentrations of Cl and Na, and weighted averages of 3 separate sampling periods during 8-9/Jan. 1976;

(b) concentration distributions of Cl and Na for 10-11/Jan. 1976 sampling period.

Figs. 6 through 9 show cumulative size-mass concentration distributions of Cl and Na in the particles measured by the two impactors (cf. Tables A5 through A8 in the Appendix for detailed data). The size distribution graphs were obtained by plotting the ECD of each impactor stage as a function of the cumulative mass percent less than or equal to that collected on each stage (Dovland, 1975). The MMD's in Table 2 were obtained from the 50% mass cumulative points of the cumulative distribution graphs (Figs. 6 through 9). The distributions, however, do not appear to approximate log-normal distributions well, and the MMD's should, therefore, be re regarded as estimates only. Because of this apparent lack of log-normality, no attemt was made to evaluate the geometric standard deviations of Cl and Na particles from their respective graphs.

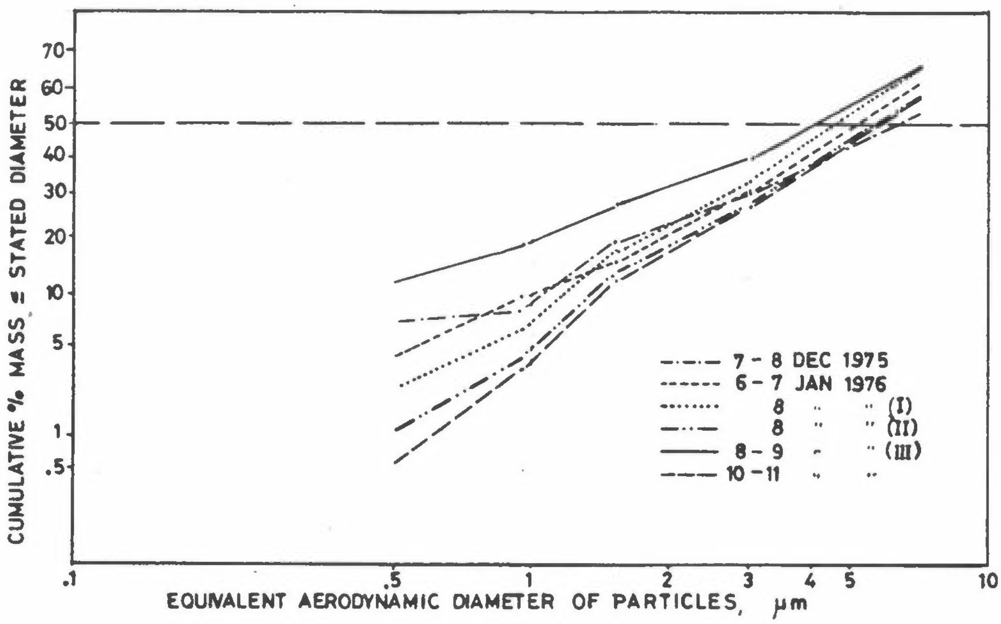


Figure 6: Cumulative chloride (Cl) particle size mass distribution from cascade impactor measurements for 6 sampling periods of varying length. (cf. Table 1 for meaning of (I), (II), and (III) for the 8-9/Jan., 1976 period.)

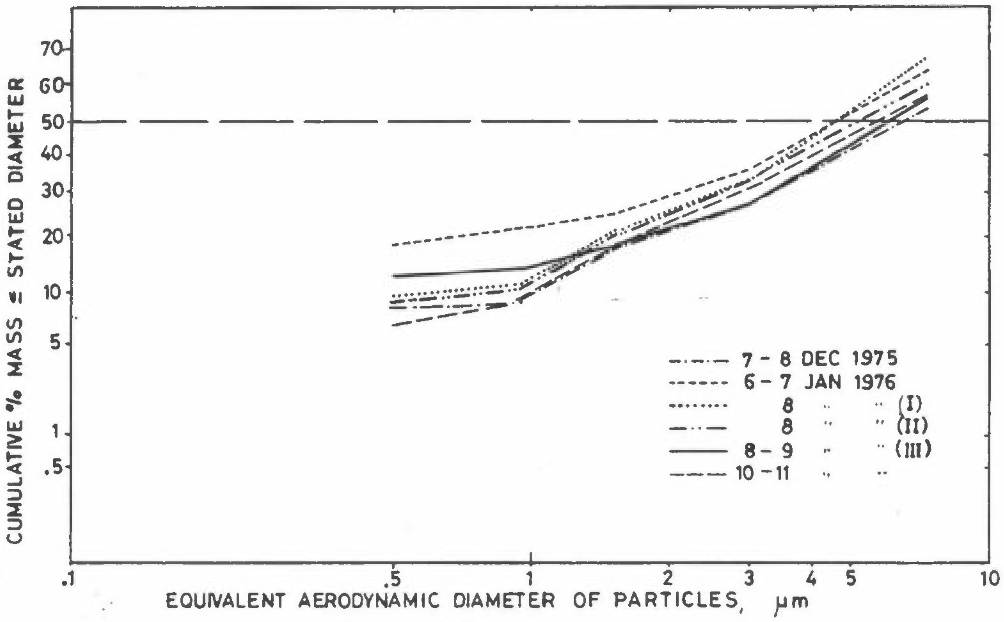


Figure 7: Cumulative sodium (Na) particle size-mass distribution from Hi-Vol/Sierra cascade impactor measurements for 6 sampling periods of varying length. (cf. Table 1 for meaning of (I), (II), and (III) for the 8-9/Jan., 1976 period.)

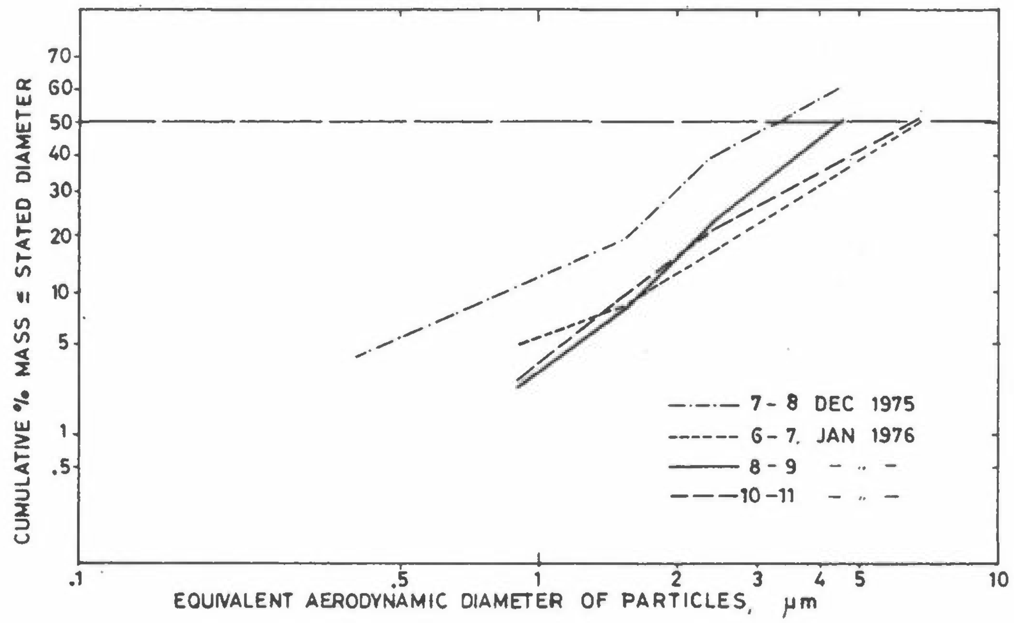
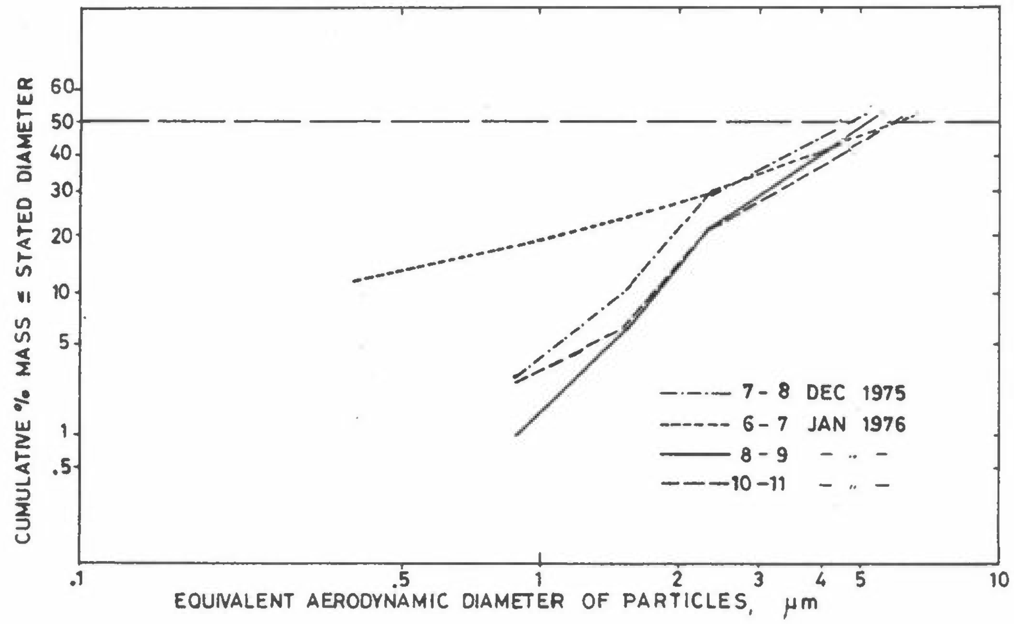


Figure 8: Cumulative chloride (Cl) particle size-mass distribution from Andersen sampler measurements for 4 sampling periods.



← [illegible]

Figure 9: Cumulative sodium (Na) particle size-mass distribution from Andersen sampler measurements for 4 sampling periods.

4.3 Wind speed and airborne sea salt concentrations

Table 3 summarizes observed wind and precipitation conditions during five strong wind (24-hour averages from about 5 to 13 m/sec) periods, and gives the corresponding total concentrations of airborne chloride, sodium, sodium chloride, and sea salt. In addition to total concentrations, concentration values for particles of equivalent aerodynamic diameters equal of less than 4 µm are also listed. The latter were computed by first determining the percent of particle mass equal or below the 4 µm diameter from the cumulative size-mass distribution graphs, and then multiplying the corresponding total concentration by the percent of that fraction. Due to the breakdown of the meteorological tower at Ytraland, wind speed for the 7-8/Dec., 1975 period was estimated from NILU's Kårstø station (Fig. 1) 30-meter level wind data.

Fig. 10 relates results of Ytraland Hi-Vol/Sierra cascade impactor (Table 3) and Andersen sampler measurements (*) (Sivertsen, 1975b) to published data on airborne sea salt concentrations, obtained mainly over the open sea. The vertically-hatched area in Fig. 10 denotes the range of sea salt concentrations reported by Woodcock (1953), Chesselet _et al._ (1972), and the data of several other investigators, summarized by Junge (1963).

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*Concentrations do not include particles deposited on first-stage jet plate.

Table 3: Wind speed and direction, precipitation conditions, and concentrations ($\mu g/m^3$) of chloride (Cl), sodium (Na), and total sea salt (T.S.S.) in all airborne sea salt particles and the $\leq$ 4 μm diameter$^+$ fraction, during five sampling periods at Ytraland, from Hi-Vol/Sierra cascade impactors measurements.

(For the meaning of the Roman numerals (I), (II), and (III), see Table 1.)

Period of sampling	7-8/Dec. 1975	8/Jan. 1976 (I)	8/Jan 1976 (II)	8-9/Jan. 1976 (III)	10-11/Jan. 1976
Average wind speed, m/sec.	13^{++}	9.2	8.7	5.6	10.1
Average wind speed, knots	25	17.9	16.9	10.9	19.6
Hourly average min. and max. wind speed, m/sec.	7-18	8.0-10.1	7.2-10.7	1.0 -7.3	8.3-12.3
Wind direction	NW-N	W	W-WNW	NW-N	WNW-NW
Total Cl, $\mu g/m^3$	15.3	18.0	15.6	16.6	12.4
Total Na, $\mu g/m^3$	10.3	10.0	8.7	5.7	7.5
*$\leq$ 4 μm dia$^+$ Cl, $\mu g/m^3$	5.8 (38)	7.7 (43)	5.6 (36)	8.0 (48)	4.6 (37)
*< 4 μm dia$^+$ Na, $\mu g/m^3$	3.6 (35)	5.0 (46)	3.6 (41)	2.1 (36)	2.8 (38)
T.S.S., $\mu g/m^3$	32.0	36.0	30.3	27.9	24.9
$\leq$ 4 μm dia$^+$ T.S.S., $\mu g/m^3$	11.8	15.9	11.5	12.5	9.3
T.S.S. ppm (by weight)	0.024	0.028	0.024	0.022	0.019
$\leq$ 4 μm dia$^+$ T.S.S., ppm (by weight)	0.009	0.012	0.009	0.010	0.007
Remarks:	Driving rain during most of sampling period.	Brief, but intence rain and hail showers near end of sampling period.	Several intermittent rain showers throughout sampling period	No precipitation throughout sampling period.	Intermittent rain and hail showers changing to snow towards end of sampling period

+ equivalent aerodynamic diameter

++ estimated from NILU's Kårstø station 30-meter level data.

* figures in parentheses (after concentration values) indicate cumulative % mass in particles $\leq$ 4 μm in equivalent aerodynamic diameters.

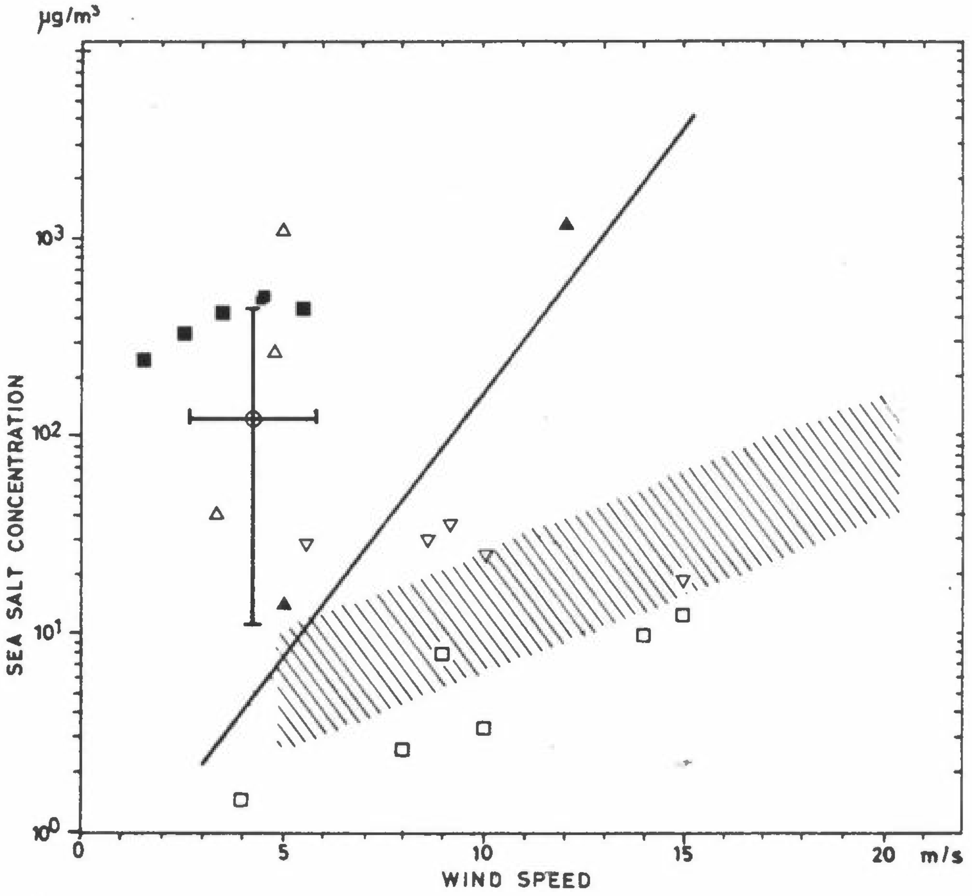


Figure 10: Dependence of airborne sea salt concentrations on wind speed over the ocean and in the surf zones of coastal areas.
Vertically-hatched area represents the "Woodcock-Junge-Chesselet et al. range".

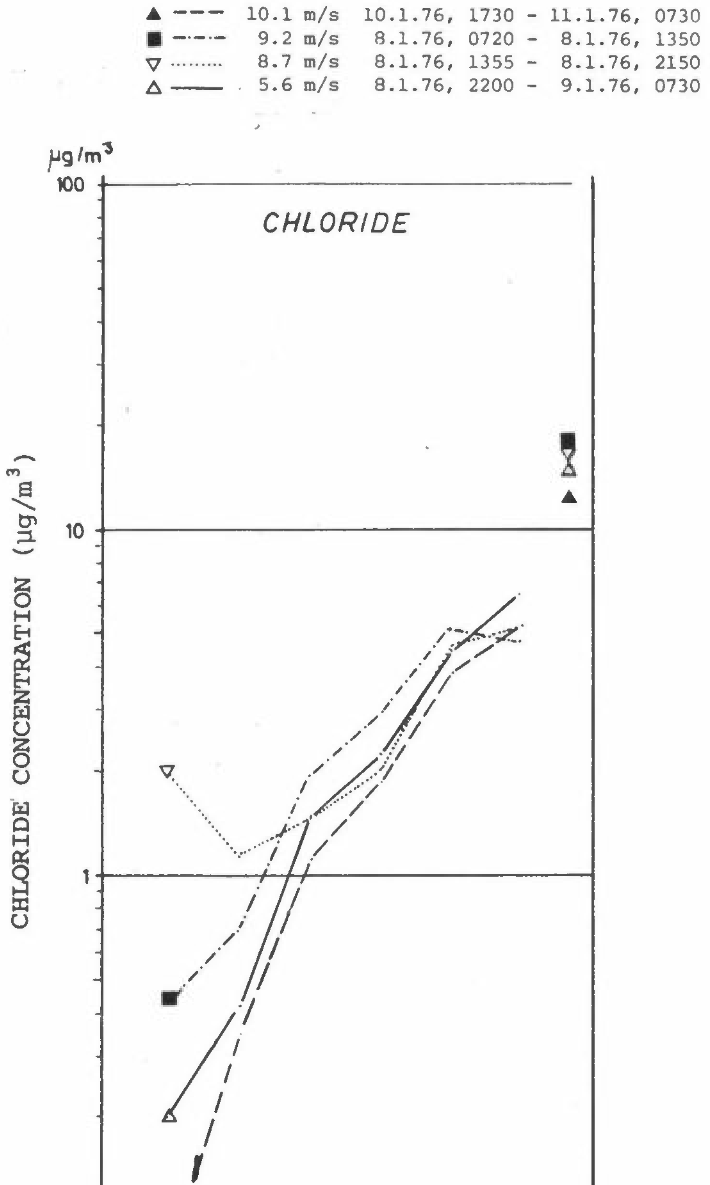
Solid line : Tsunogai et al. (1972)
■ : Jacobs (1937)
▲ : Riedel (1938)
⊕ : average of Holzworth's (1959) surf zone and coastal area data; the vertical and horizontal bars indicate the range of concentrations and wind speed measured, respectively.
△ : Whelan (1975)
▽ : Ytraland, 1975-76 (Table 3)
□ : Ytraland, 1974-75 (Sivertsen, 1975)

Fig. 11 shows chloride (Cl) particle mass concentration distributions from the five strong onshore wind sampling runs at Ytraland station, and Fig. 12 gives cummulative size-mass concentration distribution for the same sampling periods. Fig. 13 compares the Ytraland sampling results with airborne sea salt measurements aboard ships by the U.S.A. Navy (Rogus and Weinert, 1972) and the British Royal Navy (Shaw and Jefferis, 1976) sources. These latter measurements have been made to gather information relating to the design of gas turbine inlet protection devices, an represent the current state of knowledge on airborne sea salt concentrations encountered aboard ships under a variety of wind speed conditions. Measurements of airborne sea salt aboard high-speed marine vessels, which also include high concentrations of ship-generated sea salt particles, have been reported by Yoshimoto _et al_. (1976).

5 DISCUSSION OF MEASUREMENT RESULTS

5.1 Airborne sea salt concentrations and size distributions

Even with increasing reliability of the 5-day weather forecasts, it is difficult to program sea salt sampling schedules in such a way, that only a minimum of complicating factors will be encountered during the sampling periods. The desirable conditions would, for example, consist of 24-hour, or longer, periods of strong onshore winds, with a range of slowly but steadily changing speeds, and free of precipitation. As the Remarks in Table 3 indicate, such ideal conditions were never present during the prime sampling periods at the Ytraland station.



F = Impactor After-Filter
1-5 = Impaction Stages
T = Total concentration

Figure 11: Size-mass concentration distributions of chloride (Cl) particles on Hi-Vol/Sierra cascade impactor stages under various onshore wind speed conditions.

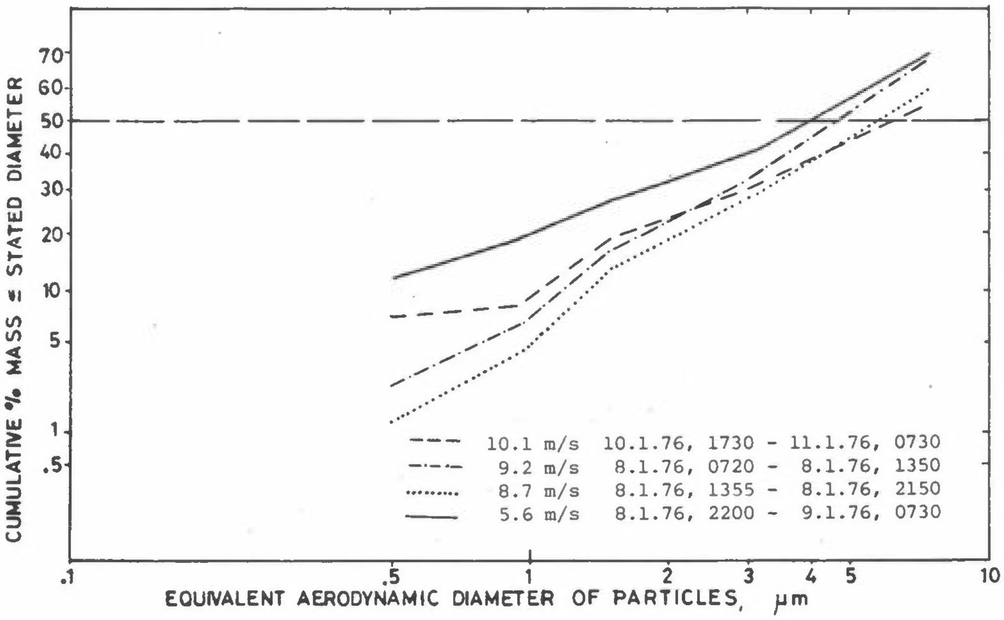


Figure 12: Cumulative size-mass concentration distributions of chloride (Cl) particles as measured by the Hi-Vol/Sierra cascade impactor under various onshore wind speed conditions.

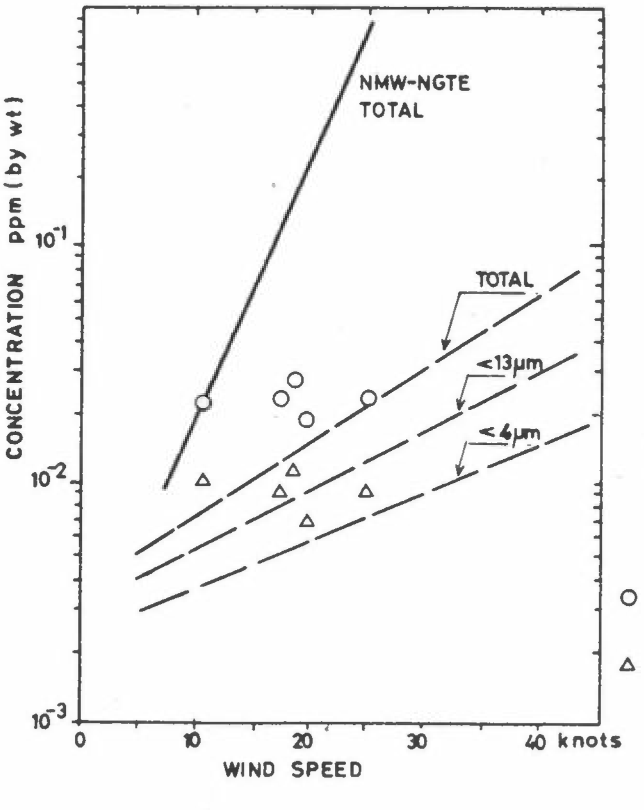


Figure 13: Dependence of airborne sea salt concentrations on particle size and wind speed, as measured aboard ships and at Ytraland coastal station (Table 3).

——— : *British NMW-NGTE standard data, ppm NaCl (Shaw and Jefferis, 1976)*

— — : *U.S. NAVSECPHILA DIV data, ppm sea salt (Rogus and Weinert, 1975)*

○ : *Total sea salt, ppm, Ytraland (Table 3)*

△ : *Sea salt ≤ 4 μm equivalent aerodynamic diameter, ppm, Ytraland (Table 3)*

The coastal area near Ytraland, with its contorted shoreline and large number of small islands and skerries offshore, is conducive to airborne sea salt production in the surf zones. As can be seen in Fig. 10, surf zone sea salt concentrations often reach and exceed several hundred $\mu g/m^3$, even under relatively moderate wind speeds. Similar conditions could be expected to arise along the Ytraland shoreline.

On the other hand, the Ytraland shore and coastal area presents many obstacles to the smooth transport of sea salt inland, due to its steeply-rising, rocky shores, uneven terrain, and at places dense, bushy vegetation cover.

Thus, it could also be expected, that airborne sea salt particles arriving at the Ytraland station, even with onshore wind, would undergo considerable concentration and size distribution modifications by scavenging mechanisms, such as, sedimentation, impaction on a variety of surface obstacles, and wash-out during periods of precipitations.

Sea salt concentrations in Table 1 show about one order of magnitude variation. The lower concentrations are associated with wind directions other than onshore (i.e., not from the SW to NW sector) for example, the 8-11/Dec., 1975, and the 6-8/Jan., 1976 periods, although on Karmøy winds from almost any direction will pass over some stretch of salt water.

Fig. 10 shows, that with onshore westerly winds sea salt concentrations at the Ytraland station, measured with Hi-Vol/ Sierra cascade impactor lie between those observed in surf zones and those in the over-the-ocean "Woodcock-Junge-Chesselet range". The Andersen sampler results, reportet by Sivertsen (1975b) are considerably lower (cf. also section 5.4) but do not include particles deposited on first-stage jet plate.

The mass median diameters of chloride and sodium particles (Table 2) range from about 4 to 7 μm in aerodynamic diameters, indicating that the source of these relatively large particles are the mechanical disruption processes of sea water at the sea surface and in surf zones. Furthermore, if the sea were the source of chloride and sodium in these particles, chloride and sodium should have the same size distributions. Figs. 3 through 9 generally bear this out. Similarly, the ratio of chloride to sodium (Cl/Na) in airborne sea salt could be expected to be similar to that of sea water, i.e., about 1.8. Most sea salt measurements have confirmed this (Junge, 1972), but anomalously high and low Cl/Na ratios have also been detected (Hidy _et al_., 1974; Martens _et al_., 1973). Ratios calculated from total chloride and sodium concentrations from the various Ytraland sampling periods have an overall range from 1.5 to 5.9 (cf Table A9 in the Appendix for details). Although chemical composition variations in airborne sea salt can be particularly pronounced in surf zones (Duce and Wookcock, 1971), and there are also land sources of chlorides (e.g., burning of fuels and PVC compounds), it is by no means certain, that the apparent deviations in Cl/Na ratios at Ytraland from the sea water value are real. As a matter of fact, it is unlikely that the indicated range of values is reliable, since data from the different samplers for the same sampling period give different ratios. The Cl/Na ratios calculated from Hi-Vol/Sierra cascade impactor results have the narrowest range (1.5 to 2.9), with an average of about 1.9. The particle size distribution graphs (Figs. 3 through 5) hint at a bimodality in the distributions, that is, one concentration maximum in the sub-micrometer diameter range and another somewhere above 7 μm diameter. It is doubtful, however, that the relatively narrow particle size fractionation ranges of both the Hi-Vol/Sierra and the Andersen cascade impactors permit sufficient resolution to clearly define multimodal features in particle size distributions (Lee and Goranson, 1976). It is more likely, that some of the relatively high concentrations found on the cascade impactor after-filters are artifacts, caused by uncertainties in chloride and sodium blank determinations. Repeated analyses of the Spectrograde Type A and the Acropor AN 800 membrane after-filters, selected from the same batches, yielded a wide range of blank values (cf Table A10 in the Appendix), and average values for Cl and Na in the blanks were used to adjust sample colletions. Thus, the shapes of the size distribution graphs could be altered and the high after-filter concentrations lowered, or even eliminated entirely, by the use of higher blank values.

5.2 Effect of wind speed

The results of measurements at the Ytraland station (Dec. 1975 & Jan. 1976) of total airborne sea salt concentrations (Table 3, and Figs. 10 and 13), and concentrations of particles equal or less than 4 µm equivalent aerodynamic diameter (Table 3, and Fig. 13) show no clear-cut dependence on wind speed.

As previously noted, ideal conditions of strong, direct onshore wind and no precipitation did not prevail during the various sampling periods. The lack of the expected concentration-wind speed relationship is, therefore, probably caused by the variable masking effects of precipitation scavenging, fetch over land, and land surface characteristics on airborne sea salt concentrations. The highest total sea salt concentration of 36 $\mu g/m^3$ was measured during the only period (0720-1350/ 8 Jan. 1976) with direct onshore (W) wind of relatively high speed (ave. 9.2 m/sec). Although short-duration showers occured, the fetch over land (and thus the distance from the surf zone source of sea salt to the sampling site) and the time available for scavenging were the shortest.

The two periods (7-8/Dec. 1975, and 10-11/Jan. 1976) with highest wind speeds (ave. 13 m/sec and 10 m/sec, respectively) had somewhat similar conditions of winds and precipitation. Initially from NW, the winds shifted towards N as the sampling progressed, gradually diminishing in speed. As can be seen from Fig. 1, such a wind shift results in drastically increased fetch over land. Since moderate to heavy precipitation also persisted during these periods, concentrations of only 32 $\mu g/m^3$ and 25 $\mu g/m^3$, respectively, were measured, despite the initially high wind speeds.

The only sampling period without precipitation (2200/8 Jan. - 0730/9 Jan., 1976) also had the lowest wind speed (ave. 5.6 m/sec), but a comparatively high sea salt concentration of 28 $\mu g/m^3$. It would appear then, that while the length of fetch over land had a definite effect, all other things being equal, wash-out by precipitation exerts a dominant influence on airborne sea salt concentrations.

Rossknecht _et al_. (1973) have pointed out, that there could be a lag time in the buildup and decay of airborne sea salt concentrations in regard to onset of wind. Low concentrations have been measured with high wind speeds if the wind has just begun, and high concentrations can be found after moderate, but persistent winds have just died down.

As far as the sea salt particle size-mass concentrations are concerned, there are indications in Figs. 11 and 12, that during periods of higher wind speed the mass distribution tends to shift towards the aerodynamically larger particle sizes. This can be expected, since higher winds result in more violent action at the sea surface and in the surf zone, which enhances the production and transport of the more massive particles.

A comparison, in Fig. 13, of Ytraland measurements with aboard-ship concentrations of total and the $\leq$ µm diameter particle mass fraction indicates that, for the most part, the respective concentrations at Ytraland exceeds those considered typical aboard ships by the U.S.A. Navy (Rogus and Weinert, 1972), but were well within the "standard range" of the British Royal Navy (Shaw and Jefferies, 1976).

5.3 Effect on gas turbines

Airborne sea salt concentrations, measured at Ytraland during five relatively strong wind (ave. from about 5 to 13 m/sec) periods, shown in Table 3 and Fig. 13, ranged from 0.019 to 0.028 ppm (by weight) for total sea salt and from about 0.007 to 0.012 ppm (by weight) for particles $\leq$ 4 µm equivalent aerodynamic diameter.

Although the frequency of winds on Karmøy from the SW through NW sector does not exceed about 10-15% for all seasons (Sivertsen, 1975a), and the annual average wind speed from those directions is only about 5 m/sec, short-period wind speeds are considerably higher. Hourly averages of 18 m/sec and 24-hour averages of 15 m/sec have been observed at the Ytraland station (Sivertsen, 1975b). It is reasonable, therefore, to assume that during periods of westerly winds of comparable force and with no precipitation, concentrations of airborne sea salt higher than those measured during this study, could be expected to occur.

Gas turbine manufacturers recommend "safe" turbine inlet concentrations in the range from 0.003 to 0.010 ppm (Labadie and Boutzale, 1976). This implies, that even the mass fraction of $\leq$ 4 µm diameter particles at Ytraland is borderline. Thus, any gas turbine installations built at or near the Ytraland site would require at least partial removal of airborne sea salt particles from the inlet air, to avoid performance deterioration and corrosion problems. For this, simple bends, baffles or louvers in the air inlet ducts are probably not sufficient, and collection devices with appropriately high efficiencies for the $\leq$ 4 µm diameter range would be required.

5.4 Sampler effect

In addition to the variability in Cl/Na ratios (noted in Section 5.1), differences in measured concentrations of total chloride and sodium can be seen in Table 1, and Figs. 3 and 4. Since all the samplers sampled the atmosphere during the same sampling periods, the differences in concentrations must be apparent, not real. Such a "sampler effect" has been previously reported by Hidy _et al_. (1974), and Miller and DeKoning (1974), among others.

In general, the total suspended particulate matter samplers, such as the Hi-Vol and KK samplers, are expected to give somewhat higher concentration values, than the cascade impactors, when sampling from the same atmosphere. This is due to the so-called wall losses of cascade impactors, i.e., the deposition of particles on the interior surfaces other than the collection stages, which normally cannot be recovered (Lundgren, 1967; Rao, 1975; Willeke, 1975).

From the Ytraland measurement results (Table 1, and Figs. 3 and 4), no systematic differences between the concentrations measured by the Hi-Vol sampler and the Hi-Vol/Sierra cascade impactor can be discerned. This could be attributed, perhaps, to the uncertainties in Hi-Vol sampler air volume measurements, due to its constant flow controller malfunction. Furthermore, it was virtually impossible to exchange and remove the Hi-Vol sampler filters in the open with strong winds, without some damage to the filters and perhaps some sample losses.

With two exceptions, both the Hi-Vol sampler and the Hi-Vol/Sierra cascade impactor gave higher total chloride concentrations that the KK sampler. One of the exceptions (the 7-8/Dec., 1975 period) could be explained by the fact, that the KK sampling period was considerably longer, than those of the other samplers, under presumably heavy sea salt concentrations, before the storm subsided.

For the most part, the KK and the Andersen samplers gave roughly comparable total concentrations, but the Andersen sampler results were systematically lower, than those of the Hi-Vol/Sierra cascade impactor (see Table A 11 in the Appendix). The apparent undersampling by the Andersen sampler was variable, but particularly significant for sodium in the airborne sea salt. The validity of this result, however, was already questioned (Section 5.1), in connection with the abnormal Cl/Na concentration ratios. A comparison on the basis of sodium chloride (NaCl) might, therefore, be more meaningful. This shows, that NaCl concentrations measured by the Andersen sampler were from 45 to 65% of those measured by the Hi-Vol/Sierra cascade impactor, with an average of about 55% for four sampling periods (Table A 11 in the Appendix).

Finally, on the basis of only a limited number of results available, measurements with the filter-tape sampler amounted to only about one-half of the concentrations measured by the Andersen and KK samplers.

The fact, that the concentration values for the Andersen, KK, and filter-tape samplers were not corrected to 25°C and 760 mm Hg (as maintained by the Hi-Vol sampler and Hi-Vol/Sierra cascade impactor constant flow controllers) does not alter the above situation. Such corrections would have the effect of reducing further the calculated concentrations of the Andersen, KK, and filter-tape samplers.

5.5 Intake efficiencies

Intake efficiency of a particulate sampler or sampling system is defined as the ratio of the particle concentration measured by the sampler to the true particle concentration in the original air sample, prior to entrance into the instrument. "Sampler effect" is thought to be largely due to differences in intake efficiencies of different samplers. Intake efficiency, in general, is a function of the air velocity into the inlet of the sampler, the aerodynamic sizes of the airborne particles, and the horizontal wind speed at the sampler inlet. Criteria for predicting intake efficiencies of air sampler inlets withdrawing suspended particles from still air have been proposed on theoretical and experimental grounds (Davies, 1968; Agarwal, 1975), but very little is known about intake efficiencies of different types of samplers under changing wind and turbulence conditions (Steen and Andreasson, 1974; Ogden and Wood, 1975; Steen and Johansson, 1975).

Despite its extensive use in North America, there is considerable uncertainty about the intake efficiency of the standard Hi-Vol sampler shelter. Under varying wind conditions, the aerodynamic cut-off diameter of particles can reportedly be as low as 30 μm, or as high as 200 μm or more (Lawrence Berkeley Laboratory, 1975). In the most thorough investigation to date, Lundgren and Paulus (1975) found, that with wind speeds up to about 5 m/sec the shelter allows the intake of up to 97% of the total mass of suspended particles, and has its 50% cut-off at about 60 μm diameter. At higher wind speeds, however, they found the ability of the Hi-Vol intake to sample airborne particles representatively difficult to assess. Because of the square shape, the orientations of the shelter with respect to wind direction could further affect the intake efficiency of the inlet.

There is no published information on the intake efficiency of the stove-pipe type air inlet of the modified Andersen sampler, other than that its design is said to simulate the intake characteristics of the Hi-Vol sampler. The intake efficiency of the NILU-type, downward-facing vertical elutriator inlet (used with the KK and filter-tape samplers) has also not been determined. When used with the KK sampler, it is said to collect particles smaller than about 10 μm diameter. Crude estimates, however, of its intake efficiency can be attempted by interpolating the experimentally determined efficiencies of the LIB and OECD-type samplers at various wind speeds and particle sizes, as reported by Steen and Johansson (1975). The inlets of these samplers are also of the vertical elutriator type, but they are operated at flowrates that differ by more than two orders of magnitude. Consequently their intake velocities and thus their intake efficiencies are widely different, particularly for the aerodynamically larger particles and higher wind speeds. For example, the OECD-type and the LIB inlets have essentially zero and about 50% intake efficiency, respectively, for 9 μm diameter particles at a wind speed of 13 m/sec. Since the NILU-type inlets, used with both the KK and filter-tape sampler, had intake velocities approximating those of the OECD inlet, their intake efficiencies were probably considerably less than 50% for comparable particle sizes and wind speeds.

Because of the relatively large aerodynamic sizes of airborne sea salt particles, particularly near surf zones in coastal areas, differences in simultaneously measured concentrations and bias in size distributions of sea salt can be largely due to the arbitrariness of the upper cut-off sizes of inlets of different samplers. Assuming then all other things equal, Table 1, and Figs. 3 and 4 would indicate, that the intake efficiency of the Hi-Vol shelter was higher than those of the modified Andersen sampler stove-pipe and NILU-type air inlets.

5.6 Suitability of samplers

None of the total sea salt concentration samplers, used in the Ytraland study, could be expected to give completely representative measurements because of their unknown or variable intake efficiencies under different wind speed conditions.

Despite its desirable semi-automatic operation feature, the filter-tape sampler has the further handicap of relatively low sampling rates (approx. 6 litres/min) and short sampling periods (maximum 3 hours), which usually do not allow the collection of large enough samples for reliable chemical analyses. At the Ytraland station, 3-hour sampling periods gave chloride and sodium amounts, that were only barely above the blank values of the filter-tape itself. The filter-tape is, therefore, judged unsuitable for measuring airborne sea salt concentrations encountered in coastal areas.

The KK sampler also has the advantage of semi-automatic operation, and it collects sufficient sample over its normal 24-hour sampling period. Because it also has a low flowrate (approx. 25 litres/min), a modified sampling cycle using shorter time periods is likely not feasible. The present uncertainty about the intake efficiency of the NILU-type inlet, the KK sampler uses, is further compounded by possible particle losses in the rather long (about 2 metres) and small-diameter intake line between the inlet and the filter holders of the KK sampler.

There is virtually no possibility of loss of particles in the Hi-Vol sampler before they reach the filter. The Hi-Vol sampler uses an "open-face" filter holder, which is in front of all other components in the sampling train. The only element preceeding it is the shelter inlet (of uncertain intake efficiency), which is required to protect the upward-facing filter from the weather and direct dustfall. The normal operating flowrates (from 1.1 to 1.7 m^3/min) of Hi-Vol samplers result in the collection of substantial amounts of suspended particles even during relatively short sampling periods. Accuracy of chemical analyses is, therefore, enhanced and the effects of inadvertent sample contamination minimized. For sea salt concentrations encountered at Ytraland, adequate samples for chloride and sodium analyses would be collected over sampling periods, as short as 2 to 2 hours. To facilitate trouble-free exchange of filters and prevent sample loss or contamination, the pre-loadable "cartridges" should be used with Hi-Vol samplers. The constant flow controllers of the samplers also give the most accurate sample volume metering of all the samplers used in this study. Thus, although the Hi-Vol is strictly a "manual" sampler, it is best suited for short-period measurements of total airborne sea salt concentrations.

The reproducibility (i.e., precision) of Hi-Vol sampler measurements would require parallel operation of several samplers, and was not assessed in this study. It has been reported to be within 10% (Clements _et al_., 1972; McKee _et al_., 1972), provided the sample flow is regulated and its calibration periodically checked.

The accuracy og Hi-Vol measured total sea salt concentrations under all-weather conditions could not be ascertained, because "true" sea salt concentrations were not known, due to the afore-mentioned (Section 5.5) uncertainties in the intake efficiencies of the standard square shelter. A replacement of the standard shelter inlet by wind vane-oriented, directional preseparators * would be expected to increase the representativity of samples. True concentrations, however, could only be obtained by isokinetic sampling procedures (Steen and Andreasson, 1974), for which the Hi-Vol sampler would be difficult to adapt.

Total sea salt concentrations, no matter how accurately measured, connot supply all the information needed by designers of gas turbine inlet protection equipment. The aerodynamic size classification data from cascade impactor measurements are particularly suitable for studies of sea salt ingestion in gas turbines, because the collection characteristics of most sea salt separation devices are also dependent on the aerodynamic behavior of airborne sea salt particles.
Of the two cascade impactors used in the Ytraland study, the Hi-Vol/Sierra instrument had the advantage of not only high sampling rates (1.12 m^3/min) and thus greater flexibility in choosing short-interval sampling periods, but also in terms

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* for example, Sierra Model 230CP cyclone preseparator.

of stage ECD calibration reliability, flowrate constancy, and user convenience. The impactor has been calibrated (Willeke, 1975) as a unit with glass fibre filter substrates at the design flowrate (1.13 m^3/min). Whatman 40 filter substrates were used in Ytraland sampling. This type of substrate has poorer retention characteristics for dry particles, than the glass fibre type, due to particle bounce and blow-off (Rao, 1975).

The high relative humidites at coastal sites with onshore winds, however, virtually insure, that airborne sea salt is in the form of liquid droplets, which do not bounce or get blow-off the substrates (Winkler, 1974; Rao, 1975; Willeke and McFeters, 1975; Dzubay et al., 1976) making the Whatman 40 filter and adequate substrate material for this application. Whatman 40 substrates, when moist, do tend to swell and, being rigidly clamped between the stage plates in the Hi-Vol/Sierra impactor, bulge up toward the undersides of the jet plates. This creates uneven jet-to- substrate distances and some alteration of the collection characteristics of the stages could be expected to result.

At the present time, stage ECD calibration information for the modified Andersen sampler is in a state of confusion (Lee and Goranson, 1976). Several calibrations have been performed at the design flowrate (0.028 m^3/min) of the 6-stage sampler, but only inconclusive (and unpublished) data have been cited by Lee and Goranson (1976) for the normal operating conditions of about 0.142 m^3/min. These show, that the lower impaction stages (3 through 5) of the modified Andersen sampler have poor and undefined size classification characteristics.

Uneven impaction patterns on the upper collection stages of 8-stage Andersen samplers, as a result of air flow disturbances caused by the design of the sampler inlet, have been reported by Laskus and Bake (1976). During the Ytraland study, it was noted, that the lower stage jets tended to get blocked by particle deposits within the jet holes. This resulted in uneven collection patterns, and undoubtedly also affected the cut sizes. From the user's point of view, the fact that in the Andersen sampler there is no positive means of securing the collection places and substrates in place presents and additional uncertainty. Even with the greatest of care, it is difficult to be sure, that the plates remain in place during handling of the impactor, because the slightest jarring will dislodge them from their positioning pins. Judging from the Ytraland sampling experience, the Hi-Vol/Sierra cascade impactor should be the instrument of choice for airborne sea salt size-mass distribution measurements. It is estimated, that sufficient samples of sea salt for chloride and sodium analyses would be collected on all stages of the impactor during sampling periods as short as 3 hours. It would be desirable to use after-filters with lower and less variable blanks in chloride and sodium, than the Gelman Spectrograde Type A glass fibre filters, to reduce the uncertainties in sample concentration values.

It is obvious (cf. Tables A3 and A4 in the Appendix), that there was indeed a sizable proportion of particles deposited on the first-stage jet plates, which should have been properly collected on the first stage substrates. For the Hi-Vol/Sierra cascade impactor this proportion ranged from 0 to 15%, and for the Andersen sampler from 6 to 27%. Due to the unwieldy size of the Hi-Vol/Sierra plates, however, the recovery for this sampler cannot be claimed to have been fully quantitative, and field procedures for reclaiming the deposited material should be improved.

The arbitrariness of the upper cut-off size of sampler inlets is especially worrisome for cascade impactors, and the accuracy of size-mass distribution cannot be reliably estimated for the entire aerodynamic size spectrum of airborne sea salt particles at the Ytraland station.

A directional sampling system (Sehmel, 1973), or the use of a directional preseparator (cf. Footnote, p. 43) for the Hi-Vol/ Sierra cascade impactor would improve chances of sampling a more representative population of sea salt particles. As was the case with total sea salt concentrations, "true" sea salt size distributions could only be obtained through isokinetic sampling procedures. This is particularly difficult task when using cascade impactors, which require constant operating flowrates to maintain predictable size fractionation characteristics. The answere may lie in the further development of a wind pressure-operated, variable intake area device, proposed by Steen*. Used as the inlet for a windvane-oriented Hi-Vol/ Sierra sampler, it would automatically maintain isokinetic intake conditions, while the cascade impactor is operating at a constant flowrate.

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* B. Steen, IVL, Gothenburg; personal communication, March 1976.

6 CONCLUSIONS

Measurements at NILU's Ytraland station on Karmøy in December, 1975 and January, 1976 showed that:

(1) During periods of west to north winds of 5 to 13 m/sec average speeds, chloride and sodium concentrations in airborne sea salt ranged from 12.4 to 18.0 μg/m^3, and 5.7 to 10.3 μg/m^3, respectively;

(2) Corresponding mass median diameters (equivalent aerodynamic) of chloride and sodium in sea salt particles ranged from 4.2 to 6.4 μm, and 4.7 to 6.5 μm, respectively;

(3) Corresponding total airborne sea salt concentrations during the same periods were calculated to be from 25 to 36 μg/m^3;

(4) For the most part, the measured sea salt concentrations were intermediate to surf zone and open sea values, as reported in the literature;

(5) No clear-cut relationships existed between sea salt concentrations and wind speed at the sampling site, presumably as a result of various modifying influences on sea salt perticles during transport from sources;

(6) Precipitation scavenging and fetch over land appeared to be the major sea salt concentration modifying factors;

(7) Relatively high concentrations of airborne sea salt (28 μg/m^3) occurred during a period with no precipitation, even with moderate winds (ca. 5 m/sec);

(8) Onshore winds of speeds typical for the Karmøy area can be expected to result in short-period (several hours) concentrations of airborne sea salt in excess of those measured in this study;

(9) Measured concentrations of total and $\leq$ 4 µm diameter sea salt particles exceeded concentrations recommended for gas turbine inlet air;

(10) Gas turbine installations at or near the measurement site (Ytraland) should have provisions for at least partial removal of sea salt from turbine inlet air;

(11) Considerable "sampler effect" caused apparent differences in sea salt concentrations measured by different samplers;

(12) Unknown or variable intake efficiencies of air sampler inlets, and uncertainties in the amounts of chemical constituents in sampler filter and substrate blanks, can bias and/or distort measured size distributions of sea salt particles;

(13) Total mass concentration and size fractionation samplers used in this study did not always sample airborne sea salt particles representatively over their entire size spectrum;

(14) Despite their limitations, the Hi-Vol sampler and the Hi-Vol/Sierra cascade impactor were judged best suited for relatively short-period sampling of airborne sea salt total mass concentration and size distribution measurements, respectively;

(15) Isokinetic sampling procedures, or at least directional sampling methods, are indicated, if representative samples of the entire size spectrum of airborne sea salt particles are to be obtained.

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APPENDIX

A1 - A11

Table A1: Effective stage cut-off diameters (ECD's) of the Hi-Vol/Sierra cascade impactor (HV/S) and the modified Andersen sampler (A) at calibration flowrate (ECD), and at the different operating flowrates (ECD_S) during various sampling periods at Ytraland.*

**equivalent aerodynamic diameter*

STAGE NO	HV/S		A				
	ECD_c^{+}, µm at 1.13 m^3/min	ECD_s, µm at 1.12 m^3/min	ECD_c^{++}, µm at 0.082 m^3/min	ECD_s, µm at 0.150 m^3/min	ECD_s, µm at 0.148 m^3/min	ECD_s, µm at 0.147 m^3/min	ECD_s, µm at 0.146 m^3/min
1	7.20	7.27	10.5	4.56	4.58	4.60	4.62
2	3.00	3.03	5.36	2.33	2.34	2.35	2.36
3	1.50	1.52	3.55	1.54	1.55	1.56	1.56
4	0.95	0.96	2.06	0.89	0.90	0.90	0.91
5	0.50	0.50	0.91	0.40	0.40	0.40	0.40

$^{+}$ according to Willeke (1975)

$^{++}$ according to Rao (1975)

Table A2: Sampling periods, sampling rates, and sample volumes of Hi-Vol sampler (HV), Hi-Vol/Sierra cascade impactor (HV/S), modified Andersen sampler (A), and filter-tape sampler (FTS) for selected airborne sea salt sampling periods at Ytraland.

Sampler	HV					HV/S						FTS		A						
Time and date of sampling period	1610/7 Dec. 0805/8 Dec. 1975	0815/8 Dec. 0815/9 Dec. 1975	0845/9 Dec. 0735/10 Dec. 1975	0740/10 Dec. 1510/11 Dec. 1975	0807/9 Jan. 0807/10 Jan. 1976	1615/7 Dec. 0830/8 Dec. 1975	2000/6 Jan. 1000/7 Jan. 1976	0720/8 Jan. 1350/8 Jan. 1976	1355/8 Jan. 2155/8 Jan. 1976	2200/8 Jan. 0730/9 Jan. 1976	1730/10 Jan. 0730/11 Jan. 1976	0800/8 Jan 0800/9 Jan. 1976	2000/10 Jan. 0800/11 Jan. 1976	1617/7 Dec. 0825/8 Dec. 1975	0825/8 Dec. 0835/9 Dec. 1975	0837/9 Dec. 0747/10 Dec. 1975	0748/10 Dec. 1548/11 Dec. 1975	2000/6 Jan. 1000/7 Jan. 1976	0720/8 Jan. 0800/9 Jan. 1976	1730/10 Jan. 0800/11 Jan. 1976
Sampling duration, min.	995^{+}_{o}	1440^{+}_{o}	1370^{+}_{o}	1890^{+}_{o}	1440^{+}_{o}	975	840	390	480	570	840	$\sim 1440^{*}$	$\sim 720^{**}$	968	1450	1390	1920	840	1480	870
Sampling flowrate, m^3/min.	1.092^{+}_{o}	1.092^{+}_{o}	1.148^{+}_{o}	1.148^{+}_{o}	1.148^{+}_{o}	1.120+	1.120^{+}	1.120^{+}	1.120^{+}	1.120^{+}	1.120^{+}	0.0012^{+++}	0.0012^{+++}	0.1500^{++}	0.1485^{++}	0.1485^{++}	0.1485^{++}	0.1460^{++}	0.1470^{++}	0.1485^{++}
Calculated sample volume, m^3	1043^{+}_{o}	1572^{+}_{o}	1573^{+}_{o}	2170^{+}_{o}	1654^{+}_{o}	1092^{+}	941^{+}	437^{+}	538^{+}	+	941^{+}	9.6^{+++}	4.8^{+++}	145.2^{++}	215.3^{++}	206.4^{++}	285.1^{++}	122.6^{++}	217.6^{++}	129.2^{++}

$^{+}$ at 25°C and 760 mm Hg

$^{++}$ at filed conditions: temp. ∿ -1°C to +8°C; pressure ∿ 740 to 762 mm Hg.

$^{+++}$ at shelter conditions: temp. ∿ +15°C to +20°C; pressure ∿ 740 to 762 mm Hg.

^{o} uncertain, because of flow controller malfunction.

* sum of eight 3-hour sampling periods.

** sum of four 3-hour sampling periods.

Table A3: Airborne chloride (Cl) and sodium (Na) concentrations, µg/m³, in various equivalent aerodynamic diameter intervals from Hi-Vol/Sierra cascade impactor sampling at Ytraland.

(The Roman numerals have the following meanings -
(I) : 0720-1350/8 Jan. 1976,
(II) : 1355-2155/8 Jan. 1976,
(III): 2200/8 Jan. - 0730/9 Jan. 1976.)

	Stage number and diameter interval \ Sampling period	7-8/DEC. 1975	6-7/JAN. 1976	8/JAN. 1976 (I)	8/JAN. 1976 (II)	8-9/JAN. 1976 (III)	8-9/JAN. 1976 (time-weighted average)	10-11/JAN. 1976
Chloride (Cl), µg/m³	Plate wash	2.39	0.37	1.74	1.85	0.39	-	1.68
	1: >7.27 µm	4.66	1.25	4.14	4.70	4.84	5.85*	3.45
	2: 3.03 - 7.27 µm	3.56	1.39	6.15	4.70	4.71	5.10	3.90
	3: 1.52 - 3.03 µm	1.80	0.70	2.92	2.24	2.02	2.34	1.84
	4: 0.960 - 1.52 µm	1.62	0.23	1.95	1.50	1.48	1.61	1.11
	5: 0.495 - 0.960 µm	0.16	0.25	0.68	0.42	1.14	0.78	0.35
	6: Filter 0.495 µm	1.09	0.18	0.43	0.20	1.99	0.97	0.07
	TOTAL	15.28	4.37	18.01	15.61	16.57	16.65	12.40
Sodium (Na), µg/m³	Plate wash	1.47	0.25	0.98	1.06	0.23	-	1.06
	1: >7.27 µm	3.29	0.66	2.46	2.29	2.25	3.03*	2.12
	2: 3.03 - 7.27 µm	2.70	0.74	3.65	2.44	1.69	2.47	2.01
	3: 1.52 - 3.03 µm	1.13	0.32	1.54	1.18	0.52	1.02	0.98
	4: 0.960 - 1.52 µm	0.82	0.07	0.91	0.75	0.24	0.60	0.64
	5: 0.495 - 0.960 µm	0.04	0.10	0.22	0.15	0.05	0.13	0.17
	6: Filter 0.495 µm	0.88	0.46	1.05	0.79	0.75	0.84	0.50
	TOTAL	10.33	2.60	10.81	8.66	5.73	8.09	7.48

[*] Plate wash + stage 1.

Table A4: Airborne chloride (Cl) and sodium (Na) concentrations, µg/m³, in various equivalent aerodynamic diameter intervals from Andersen sampler measurements at Ytraland.

{(-) means a concentration equal to or less than blank concentrations.}

	Stage number and diameter interval \ Sampling period	7-8/DEC. 1975	8-9/DEC. 1975	9-10/DEC. 1975	10-11/DEC. 1975	6-7/JAN. 1976	8-9/JAN. 1976	10-11/JAN. 1976
Chloride (Cl), µg/m³	Plate wash	1.29	0.68	0.56	0.74	0.52	0.82	1.78
	1: >4.58 µm	3.60	3.24	3.74	3.25	1.32	3.62	2.92
	2: 2.34 - 4.58 µm	2.56	1.73	1.90	1.01	0.55	2.65	1.37
	3: 1.55 - 2.34 µm	2.36	0.94	1.49	0.76	0.22	1.36	0.87
	4: 0.90 - 1.55 µm	1.18	0.64	0.74	0.49	0.10	0.54	0.52
	5: 0.40 - 0.90 µm	0.70	0.61	0.52	0.52	0.14	0.22	0.21
	6: Filter < 0.40 µm	0.49	0.43	(-)	(-)	(-)	(-)	(-)
	Total	12.18	8.27	8.95	6.77	2.85	9.21	7.67
Sodium (Na), µg/m³	Plate wash	0.72	0.36	0.37	0.47	0.30	0.39	1.04
	1: 4.58 µm	1.58	1.60	1.74	1.53	0.57	1.93	1.55
	2: 2.34 - 4.58 µm	0.91	0.58	0.75	0.33	0.15	0.99	0.87
	3: 1.55 - 2.34 µm	0.81	0.33	0.51	0.18	(-)	0.63	0.65
	4: 0.90 - 1.55 µm	0.32	0.07	0.14	0.05	(-)	0.21	0.15
	5: 0.40 - 0.90 µm	(-)	0.05	0.05	0.02	(-)	(-)	(-)
	6: Filter < 0.40 µm	0.13	0.19	0.27	0.14	0.07	0.04	0.12
	Total	4.47	3.18	3.83	2.72	1.09	4.19	4.38

Table A5: Cumulative mass distribution of chloride (Cl) from Hi-Vol/Sierra cascade impactor sampling.

(For the meaning of the Roman numerals (I), (II) and (III), see Table A3.)

7-8/DEC. 1975				6-7/JAN 1976			
Cumm. µg/m^3	Cumm. %	Cumm. % ≤ stated ECD	ECD µm	Cumm. µg/m^3	Cumm. %	Cumm. % ≤ stated ECD	ECD µm
7.05*	46.1	53.9	7.27	1.62*	37.1	62.9	7.27
10.61	69.4	30.6	3.03	3.01	68.9	31.1	3.03
12.41	81.2	18.8	1.52	3.71	84.9	15.1	1.52
14.03	91.8	8.2	0.960	3.94	90.2	9.8	0.960
14.19	92.9	7.1	0.495	4.19	95.9	4.1	0.495
15.28	100.0		Filter	4.37	100.0		Filter
8/JAN. 1976 (I)				8/JAN. 1976 (II)			
5.88*	32.6	67.4	7.27	6.55*	42.0	58.0	7.27
12.03	66.8	33.2	3.03	11.25	72.1	27.9	3.03
14.95	83.0	17.0	1.52	13.49	86.4	13.6	1.52
16.90	93.8	6.2	0.960	14.99	96.0	4.0	0.960
17.58	97.6	2.4	0.495	15.41	98.8	1.2	0.495
18.01	100.0		Filter	15.61	100.0		Filter
8/JAN. - 9/JAN. 1976 (III)				8-9/JAN. 1976 (time-weighted average)			
5.23*	31.6	68.4	7.27	5.89*	35.3	64.7	7.27
9.94	60.0	40.0	3.03	11.08	66.3	33.7	3.03
11.96	72.2	27.8	1.52	13.47	80.47	19.3	1.52
13.44	81.1	18.9	0.960	15.08	90.3	9.7	0.960
14.58	88.0	12.0	0.495	15.83	94.8	5.2	0.495
16.57	100.0		Filter	16.70	100.0		Filter
10-11/JAN. 1976							
5.13*	41.4	58.6	7.27				
9.03	72.8	27.2	3.03				
10.87	87.7	12.3	1.52				
11.98	96.6	3.4	0.960				
12.33	99.4	0.6	0.495				
12.40	100.0		Filter				

* Plate wash + stage 1 collection.

Table A6: Cumulative mass distribution of sodium (Na) from Hi-Vol/Sierra cascade impactor sampling.

(For the meaning of the Roman numerals (I), (II) and (III), see Table A3.)

7-8/DEC. 1975				6-7/JAN. 1976			
Cumm. µg/m³	Cumm. %	Cumm. % < stated ECD	ECD µm	Cumm. µg/m³	Cumm. %	Cumm. % $\leq$ stated ECD	ECD µm
4.76*	46.1	53.9	7.27	0.91*	35.0	65.0	7.27
7.46	72.2	27.8	3.03	1.65	63.5	36.5	3.03
8.59	83.2	16.8	1.52	1.97	75.8	24.2	1.52
9.41	91.1	8.9	0.960	2.04	78.5	21.5	0.960
9.45	91.5	8.5	0.495	2.14	82.3	17.7	0.495
10.33	100.0		Filter	2.60	100.0		Filter
8/JAN. 1976 (I)				8/JAN. 1976 (II)			
3.44*	31.8	68.2	7.27	3.35*	38.7	61.3	7.27
7.09	65.6	34.4	3.03	5.79	66.9	33.1	3.03
8.63	79.8	20.2	1.52	6.97	80.5	19.5	1.52
9.54	88.3	11.7	0.960	7.72	89.1	10.9	0.960
9.76	90.3	9.7	0.495	7.87	90.9	9.1	0.495
10.81	100.0		Filter	8.66	100.0		Filter
8/JAN.-9/JAN. 1976 (III)				8-9/JAN. 1976 (time-weighted average)			
2.48*	4.33	56.7	7.27	5.85*	35.1	64.9	7.27
4.17	72.8	27.2	3.03	10.95	65.8	34.2	3.03
4.69	81.8	18.2	1.52	13.29	79.8	20.2	1.52
4.93	86.0	14.0	0.960	14.90	89.5	10.5	0.960
4.98	86.9	13.1	0.495	15.68	94.2	5.8	0.495
5.73	100.0		Filter	16.65	100.0		Filter
				10-11/JAN. 1976			
				3.18*	42.5	57.5	7.27
				5.19	69.4	30.6	3.03
				6.17	82.5	17.5	1.52
				6.81	91.0	9.0	0.960
				6.98	93.3	6.7	0.495
				7.48	100.0		Filter

* Plate wash + stage 1 collection.

Table A7: Cumulative mass distribution of chloride (Cl) from Andersen sampler measurements.

7-8/DEC. 1975				8-9/DEC. 1975			
Cumm. µg/m³	Cumm. %	Cumm. % ≤stated ECD	ECD µm	Cumm. µg/m³	Cumm. %	Cumm % ≤stated ECD	ECD µm
4.89*	40.1	59.9	4.56	3.92*	47.5	52.5	4.58
7.45	61.2	38.8	2.33	5.65	68.4	36.6	2.34
9.81	80.5	19.5	1.54	6.59	79.8	20.2	1.55
10.99	90.2	9.8	0.89	7.23	87.5	12.5	0.90
11.69	96.0	4.0	0.40	7.84	94.9	5.1	0.40
12.18	100.0		Filter	8.26	100.0		Filter

9-10/DEC. 1975				10-11/DEC. 1975			
4.30*	48.0	5.20	4.58	3.99*	58.9	41.1	4.58
6.20	69.3	30.7	2.34	5.00	73.9	26.1	2.34
7.69	85.9	14.1	1.55	5.76	85.1	14.9	1.55
8.43	94.2	5.8	0.90	6.25	92.3	7.7	0.90
8.95	100.0		0.40	6.77	100.0		0.40
8.95			Filter	6.77			Filter

6-7/JAN. 1976				8-9/JAN. 1976			
1.84*	64.6	35.4	4.62	4.44*	48.2	51.8	4.60
2.39	83.9	16.1	2.36	7.09	77.0	23.0	2.35
2.61	91.6	8.4	1.56	8.45	91.7	8.3	1.56
2.71	95.1	4.9	0.91	8.99	97.6	2.4	0.90
2.85	100.0		0.40	9.21	100.0		0.40
2.85			Filter	9.21			Filter

10-11/JAN. 1976			
4.70*	61.3	38.7	4.60
6.07	79.1	20.9	2.34
6.94	90.5	9.5	1.55
7.46	97.3	2.7	0.90
7.67	100.0		0.40
7.67			Filter

* Plate wash + stage 1 collection.

Table A8: Cumulative mass distribution of sodium (Na) for Andersen sampler measurements.

7-8/DEC. 1975				8-9/DEC. 1975			
Cumm. µg/m³	Cumm. %	Cumm. % ≤stated ECD	ECD µm	Cumm. µg/m³	Cumm. %	Cumm. % ≤stated ECD	ECD µm
2.30*	51.5	48.5	4.56	1.96*	61.6	38.4	4.58
3.21	71.8	28.2	2.33	2.54	79.9	20.1	2.34
4.02	89.9	10.1	1.54	2.87	90.3	9.7	1.55
4.34	97.1	2.9	0.89	2.94	92.5	7.5	0.90
-	-	-	0.40	2.99	94.0	6.0	0.40
4.47	100.0		Filter	3.18	100.0		Filter
9-10/DEC. 1975				10-11/DEC. 1975			
2.11*	55.1	44.9	4.58	2.00*	73.5	26.5	4.58
2.86	74.7	25.3	2.34	2.33	85.7	14.3	2.34
3.37	88.0	12.0	1.55	2.51	92.3	7.7	1.55
3.51	91.6	8.4	0.90	2.56	94.1	5.9	0.90
3.56	93.0	7.0	0.40	2.58	94.9	5.1	0.40
3.83	100.0		Filter	2.72	100.0		
8-9/JAN. 1976				10-11/JAN. 1976			
2.32*	55.4	44.6	4.60	2.59*	59.1	40.9	4.60
3.31	79.0	21.0	2.35	3.46	79.0	21.0	2.34
3.94	94.0	6.0	1.56	4.11	93.6	6.4	1.55
4.15	99.0	1.0	0.90	4.26	97.3	2.7	0.90
-	-	-	0.40	-	-	-	0.40
4.19	100.0		Filter	4.38	100.0		Filter

* Plate wash + stage 1 collection.

Table A9: Ratios of chloride (Cl) to sodium (Na) concentrations in airborne sea salt particles, as measured by Hi-Vol sampler (HV), Hi-Vol/Sierra cascade impactor (HV/S), Andersen sampler (A), and filter-tape sampler (FTS) at Ytraland.

(For the meaning of the Roman numerals (I), (II) and (III), see Table A3.)

Period of sampling	CONCENTRATION, µg/m³								Ratio = $\frac{Cl}{Na}$			
	HV		HV/S		A		FTS					
	Cl	Na	Cl	Na	Cl	Na	Cl	Na	HV	HV/S	A	FTS
7-8/Des. 1975	18.8	4.9	15.3	10.3	12.2	4.5	-	-	3.8	1.5	2.7	-
8-9/Dec. 1975	9.4	2.3	-	-	8.3	3.2	-	-	4.1	-	2.6	-
9-10/Dec. 1975	12.5	3.2	-	-	0.9	3.8	-	-	3.9	-	2.4	-
10-11/Dec. 1975	5.5	1.3	-	-	6.8	2.7	-	-	4.2	-	2.5	-
6-7/Jan. 1976	-	-	4.4	2.6	2.9	1.1	-	-	-	1.7	2.6	-
8/Jan. 1976 (I)	-	-	18.0	10.8	-	-	-	-	-	1.7	-	-
8/Jan. 1976 (II)	-	-	15.6	8.7	-	-	-	-	-	1.8	-	-
8-9/Jan. 1976 (III)	-	-	16.6	5.7	-	-	-	-	-	2.9	-	-
8-9/Jan. 1976	12.8	7.5	-	-	9.2	4.2	4.3	1.4	1.7	-	2.2	3.1
10-11/Jan. 1976	-	-	12.4	7.5	7.7	1.3	2.4	1.3	-	1.7	5.9	1.8

Table A10: Chloride (Cl) and sodium (Na) blank analyses of the various filters and substrates used at Ytraland. (All filters and substrates selected from the same batches.)

Date of analysis	Type of filter or substrate	Amount of constituent, μg per filter or substrate	
		Cl	Na
Jan., 1976	Whatman 40 substrate for Andersen sampler	50	< 5
Jan., 1976		70	< 5
Jan., 1976	Gelman Acropor <u>AN 800</u> after-filter for Andersen sampler	340	70
Jan., 1976		310	66
Feb., 1976		50	92
Feb., 1976		50	88
Feb., 1976		50	84
Feb., 1976	Whatman 40 substrate for Hi-Vol/Sierra cascade impactor	50	< 10
Feb., 1976		50	< 10
Feb., 1976		210	40
Jan., 1976	Gelman Spectrograde Type A filter for Hi-Vol sampler and after-filter for Hi-Vol/Sierra cascade impactor	1400	760
Jan., 1976		1060	912
Jan., 1976		1040	600
Jan., 1976		900	480
Feb., 1976	Whatman 41 filter tape for filter-tape sampler	3.0	1.4
Feb., 1976		5.5	1.4

Table A11: Ratios of Andersen sampler (A) to Hi-Vol/Sierra cascade impactor (HV/S) concentration measurements of chloride (Cl), sodium (Na), and sodium chloride (NaCl) at Ytraland.

Period of sampling	CONCENTRATIONS, $\mu g/m^3$						Ratio = $\frac{A}{HV/S}$		
	HV/S			A					
	Cl	Na	NaCl	Cl	Na	NaCl	Cl	Na	NaCl
7-8/Dec. 1975	15.3	10.3	25.6	12.2	4.5	16.7	0.797	0.437	0.652
6-7/Jan. 1976	4.4	2.6	7.0	2.9	1.1	4.0	0.659	0.421	0.571
8-9/Jan. 1976	16.7*	8.1*	24.8*	9.2	4.2	13.4	0.551	0.519	0.540
10-11/Jan. 1976	1.24	7.5	19.9	7.7	1.3	9.0	0.621	0.173	0.452

* time-weighted average from three separate sampling periods.