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THE BLOWOUT AT EKOFISK BRAVO, APRIL 1977
AIRCRAFT MEASUREMENTS OF
HYDROCARBON CONCENTRATIONS IN THE AIR

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SUMMARY

Several flights were made through the gas cloud created by the blowout at the oil platform Bravo in the North Sea in April 1977. Concentrations of hydrocarbons were measured at different distances and heights and their cross sectional horizontal and vertical distributions established. Estimates of gas mass transports varied from 6.3 to 11.5 kg/s.

On the basis of formulas of turbulent diffusion in the atmosphere and from data of diffusion experiments over water under similar weather conditions danger area were estimated in terms of a lower flammability concentration. These distances most probably were less than 200 meters.

Bag samples of air were taken for subsequent analysis in the laboratory. Relative fractions of individual hydrocarbon concentrations varied, but the variations were not systematic with respect to height above sea or distance from the source.

Measurements from a vessel taken over the oilslick some hours after the blowout was capped showed concentrations of about 1/50 of maximum concentrations in the gas cloud, and just above background values.

THE BLOWOUT AT EKOFISK BRAVO, APRIL 1977

AIRCRAFT MEASUREMENTS OF HYDROCARBON CONCENTRATIONS IN THE AIR

1 INTRODUCTION

The blowout at the oil platform Bravo in the North Sea started 22 April and was stopped 30 April 1977. After contacting the Oil Directorate, it was decided that NILU should try to measure the concentrations of hydrocarbons in the gas cloud. Agreement was reached on the proposed flight plans, provided minimum distances (3-5 km) were kept from the platform.

Objectives were:

- a) to estimate the extent of the plume (gas cloud)
- b) to estimate the total mass transport through cross-sections in order to estimate the gas release
- c) to ascertain agreement between observed turbulent diffusion and theoretical formulas and information from experiments over sea under similar weather conditions
- d) to establish danger area in terms of distance from the platform to the lower flammability point.

The Continental Shelf Institute wanted measurements just above the oilslick from a vessel using the same sampling equipment as in the aircraft. However, when the vessel reached Ekofisk, the blowout had been capped several hours earlier and only a few air samples were taken.

2 THE MEASUREMENTS

2.1 Instrumentation

A flame-ionization total hydrocarbon analyzer¹⁾ was used to measure the concentration of total hydrocarbons in the air.

For the qualitative determination of the hydrocarbon species in the gas cloud, air was sampled in aluminium-plastic laminate bags. The air samples were later analyzed in the laboratory by gas chromatography.

An integrating nephelometer was used to measure the scattered light coefficient in a specific wave length, indicative of the amount of small particles (aerosols) in the air. Vertical temperature gradient, an important diffusion parameter, was measured with a temperature sensor²⁾.

2.2 The flights

The two-engined Piper Aztec light aircraft used for the flights, is owned by NILU, and is specifically equipped for air research work.

Flights were made on 27 April and 29 April 1977. Minimum approach distance downwind from the platform Bravo were set well above estimated safety limits, somewhere between 2.5 and 5 km, depending on the wind speed. The aircraft was at all times in close radio contact with the local air control center at Ekofisk and through its relay facilities with the corvette "Stavanger", one of the navy vessels which kept all shipping at safe distances.

The weather conditions at Ekofisk on 27 April were favourable for the measurements with good visibility, scattered clouds

¹⁾ Model 8401, Bendix Corp. Ronceverte, W. Virginia, USA.

²⁾ Model 102, Rosemount Eng. Comp. Minneapolis, Minn. USA.

and a steady westerly wind of 8 m/s. The thin film of oil on the water clearly damped the surface waves, and the air turbulence was very weak. The oilslicks could be clearly seen, particularly the scattered streaks along the wind direction formed by brown lumps of oil. The blowout plume was clearly visible from up to about 1 km from the platform and had a grey-brownish colour typical of oil droplet clouds.

A total of 16 traverses were made through the plume at distances of 18 km, 15 km, 7.5 km, 5.5 km and 4 km from the platform and at heights above the sea ranging from 460 m to 6 m. One set of measurements was made upwind of the platform. Positions of the aircraft relative to Bravo were estimated from flown distances, bearings and distances to other platforms in the area, as well as to the "Stavanger", which gave its radar distance to Bravo.

The weather conditions on 29 April were about the same, although the wind direction was more southerly and the visibility not as good as on 27 April. Again flight conditions were good, with practically no turbulence. The flight programme of 27 April was followed, only that the approach distances to Bravo were shortened.

A total of 13 traverses were made through the plume at downwind distances ranging from 11 km to 2.5 km and at heights from 300 m to 6 m above the sea.

2.3 Measurements from a vessel

After landing at Sola late in the evening of 29 April, the sampling equipment was transferred to a trawler in Stavanger harbour. The trawler arrived at Ekofisk the following day some hours after the blowout had been capped. At that time the air concentrations of hydrocarbons were too low to be distinguished from the background by the flame ionization detector. Three air samples in bags were taken.

3 RESULTS

The results of the measurements and analyses are presented in Tables 1 through 8 and Figures 1 through 9.

3.1 27 April

Ekofisk wind direction was 290 degrees and wind speed 8 m/s. The wind direction agreed well with the plume drift observed from the aircraft. The thermal stability was close to neutral (see Figure 1). However, a thin layer, just above the sea surface had very stable air, the temperature of the sea being lower than the air temperature at 6 m. (The reported sea temperature from the Ekofisk centre is then considered representative of the oil film temperature).

Hydrocarbon concentrations from the flame ionization detector and scattering coefficients from the nephelometer measurements are shown in Figures 2a, 2b and 2c. Values of the evaluated parameters for each crossing are given in Table 1. The cloud boundary is defined as the point where the concentration is one tenth of the maximum value. The crosswind integrated concentrations, expressed by the area under the concentration curve, may be more representative for a single crossing than the observed maximum concentrations and are, therefore, included in Table 1. Vertical distributions of maximum concentrations and of crosswind integrated concentrations are shown in Figures 3 and 4.

Table 2 gives the results of the air sample analyses. Unfortunately, there was no time to install an air pump to secure a proper sampling speed matching the speed of the aircraft. Hence, the samples do not represent mean concentrations, even though the filling of the bags was synchronized with the detector chart recordings. The observed concentrations are probably somewhat low and relative values are, therefore, also included in Table 2.

Table 1: Concentrations of hydrocarbons, scattering coefficients, and plume parameter values, 27 April 1977.

Time GMT	Distance from Bravo km	Height m	Aircraft speed m/s	Cloud 1) width m	max 2) conc. ppm	Crosswind integrated conc. g/m ²	3) Light scattering coeff. 3) (max) x10 ⁻⁵ m ⁻¹	Air Sample no
1135	18	150	64	1150	3.6	1.8	-	
1141	18	60	64	1470	6.2	3.2	7	1
1146	18	30	64	1310	7.8	4.2	-	2
1208	15	30	64	1150	12.0	6.5	7	3
1212	15	180	64	640	8.1	1.6	6	4
1215	15	460	64	190	1.2	0.1	4.5	
1219	15	300	64	608	5.5	1.2	4.5	5
1226	7.5	300	57	860	3.0	0.9	4	6
1229	7.5	90	57	540	11.0	2.2	6	7
1233	7.5	25	70	830	24.0	8.8	9	8
1235	7.5	6	70	980	27.0	11.0	10	9
1238	5.5	150	70	1400	9.7	3.9	6	10
1240	5.5	90	70	1470	9.3	3.4	6.5	11
1242	5.5	30	70	1470	15.0	8.2	8	12
1249 ⁴⁾	-	150 ⁴⁾	-	-	-	-	3.5 ⁴⁾	13 ⁴⁾
1253	4.0	30	70	700	34.0	-	11	14
1255	4.0	25	70	770	31.0	-	10	-

1) Defined as the distance between points where concentration is one tenth of the maximum value.

2) Above the background concentration.

3) Background value: ca. $4 \cdot 10^{-5} \text{m}^{-1}$.

4) Upwind of Ekofisk.

Table 2: Hydrocarbon concentrations, ppm, 27 April.
 Measured concentrations may not be representative
 of mean mass wind concentrations (see text).

Air sample no.	Measured concentrations					Relative concentrations, CH ₄ =100%			
	CH ₄	C ₂ H ₆	C ₃ H ₈	C ₄ H ₁₀	C ₅ H ₁₂	C ₂ H ₆	C ₃ H ₈	C ₄ H ₁₀	C ₅ H ₁₂
1	4.3	0.5	0.1	0.1	<0.1	12	2	2	<2
2	3.3	0.6	0.1	<0.1	<0.1	18	3	<3	<3
3	4.9	1.1	0.2	0.1	<0.1	22	4	2	<2
4	1.7	0.3	<0.1	<0.1	0.0	18	<6	<6	-
5	1.3	0.2	<0.1	<0.1	0.0	20	<7	<7	-
6	1.2	0.1	<0.1	0.0	0.0	8	<8	-	-
7	2.1	0.3	0.1	0.1	<0.1	14	5	5	<5
8	3.8	0.5	0.2	0.2	0.1	13	5	5	3
9	4.4	0.7	0.3	0.2	0.1	16	7	5	<2
10	1.8	0.2	0.1	0.1	<0.1	11	6	<0	<6
11	2.3	0.3	0.1	<0.1	0.1	13	4	4	4
12	3.1	0.5	0.2	0.1	<0.1	16	7	3	<3
13 ¹⁾	0.8	0.1	0.0	0.0	0.0	<13	-	-	-
14	4.8	0.7	0.3	0.2	<0.1	15	6	4	4
Release 2)						11.1	3.9	1.1	0.2

1) upwind of Ekofisk (at a height of 150 m).

2) according to "official" estimates.

3.2 29 April

Ekofisk wind direction 190 degrees and speed 8 m/s. Thermal stability again was near neutral (see Figure 1). Measured concentrations and scattering coefficients are shown in Figures 5a and 5b, and plume parameters are presented in Table 3. The vertical distributions of maximum concentration are shown in Figure 6, and integrated cross wind concentrations in Figure 7. The results of the air analysis are given in Table 4.

Table 3: Concentrations of hydrocarbons, scattering coefficients, and plume parameter values, 29 April 1977.

Time GMT	Distance from Bravo km	Height m	Aircraft speed m/s	1) Cloud width m	2) Max conc. ppm	Crosswind integrated conc. g/m ²	3) Light scat. coeff. (max) x10 ⁻⁵ m ⁻¹	Air Sample no.
1625	ca 10	300	62	-	0	0	-	-
1629	ca 10	180	62	430	0.9	0.3	-	-
1643	11	90	62	870	7.2	1.7	-	1
1648	11	45	62	680	47	13.0	17	
1650	11	6	62	500	57	11.0	18	2
1658	5.5	90	62	680	28	6.2	13	3
1700	5.5	30	62	620	36	10.0	14	
1704	5.5	6	62	740	41	11.0	15	4
1715	3.	90	62	500	20	3.8	15	5
1717	3.	30	62	500	51	11.0	38	
1718	3.	6	62	560	65	14.0	16	
1720	2.5	90	62	370	74	12.0	20	
1723	2.5	15	62	680	59	15.0	18	

1) Defined as distance between points where the concentration is one tenth of the maximum value.

2) Above background concentration.

3) Background value: ca. $9.5 \cdot 10^{-5} \text{m}^{-1}$

Table 4: Hydrocarbon concentrations, ppm, 29 April.
Measured concentrations may not be representative of mean mass wind concentrations (see text).

Air sample no.	Measured concentrations					Relative concentrations CH ₄ =100%			
	CH ₄	C ₂ H ₆	C ₃ H ₈	C ₄ H ₁₀	C ₅ H ₁₂	C ₂ H ₆	C ₃ H ₈	C ₄ H ₁₀	C ₅ H ₁₂
1	1.5	0.1	0.05	0.03	0.0	7	3	2	-
2	6.9	1.2	0.6	0.3	0.2	17	9	4	3
3	4.9	0.8	0.4	0.2	0.1	16	8	4	2
4	8.2	1.5	0.7	0.4	0.2	18	9	5	2
5	4.8	0.8	0.4	0.2	0.07	17	8	4	2

3.3 30 April - air samples from the vessel

The results of the air analysis are shown in Table 5. Every sample bag was filled with about 5 litres of air in 4 to 5 minutes.

Table 5: Hydrocarbon concentrations, ppm, over the oil slick, 30 April.

Air sample no.	Measured concentrations					Relative concentrations CH ₄ =100%			
	CH ₄	C ₂ H ₆	C ₃ H ₈	C ₄ H ₁₀	C ₅ H ₁₂	C ₂ H ₆	C ₃ H ₈	C ₄ H ₁₀	C ₅ H ₁₂
1	1.7	0.04	0.0	0.0	-	2	-	-	-
2	1.7	0.02	0.02	0.0	-	1	1	-	-
3	1.6	0.02	0.0	0.0	-	1	-	-	-

Sample 1: Time: 1656-1659, 1.5 m above the surface
Position: 56° 35'N, 03° 07'E.
Ekofisk Bravo: 56° 33'54N 03° 12'13'E.

Sample 2: Time: 2051-2055, 0.5 m above the surface
Position: 56° 33.5'N, 03° 13'E.

Sample 3: Time: 2217-2222, 6 m above the surface
Position: 56° 33.5'N, 03° 13'E.

4 DISCUSSION

4.1 Extent of plume

Most measurements from the plume traverse flights show symmetrical concentration profiles. The vertical extent of the plume is defined as the height to the level where the concentration is one tenth of the maximum concentration. Estimated plume widths and heights indicate a somewhat more narrow plume on 29 April.

Plume dimension estimated from only one traverse at each height is uncertain, due to turbulent fluctuations in concentrations and short periodic variations in wind direction. The instantaneous shape of a plume is irregular. Repeated traverses could have given a more regular shape, but would have left less time for measurements at different distances. Besides, short time peak values rather than mean values determine critical concentrations and safety distances.

4.2 Mass transport through individual cross sections

The mass transport rate of hydrocarbons, M , through a cross section has been determined from the vertical distribution of the integrated concentrations and from the corresponding mean wind speed according to:

$$M = \bar{u} \int_{-\infty}^{\infty} \int_0^{\infty} c \, dy \, dz \quad (1)$$

where c is the concentration, \bar{u} the mean wind speed, and y and z are the horizontal and vertical coordinates in a cartesian coordinate system, with the x -axis oriented along the wind direction.

Transport rates, expressed in kg/s (calculated as methane) were:

<u>27 April</u>		<u>29 April</u>	
15 km -	9.9 kg/s	11 km -	11.1 kg/s
7.5 km -	7.4 kg/s	5.5 km -	7.8 kg/s
5.5 km -	9.9 kg/s	3 km -	6.3 kg/s
4 km -	11.5 kg/s	2.5 km -	10.0 kg/s

Emission estimates received indicated a gas release of 18.5 Nm³/s equivalent to a total release of 16 kg/s (as methane). Considering the uncertainties involved in the calculations, the agreement between various estimated values is quite good. The mean value is 9.3 kg/s. This value is lower than the release, but not more than what should be expected, considering for instance the sampling procedure whereby peak values may have escaped detection.

4.3 Particle concentrations

The nephelometer measures only light scattering from aerosols in the visible range (0.2 - 0.8 μm) and not directly mass concentration. However, a series of measurements in a variety of locations have shown nearly linear relationship between mass concentration and the scattering coefficient, b_{scat} , measured with the integrating nephelometer. The relation is(1):

$$\text{Mass}/b_{\text{scat}} \approx 0.4 \text{ g/m}^2 \quad (2)$$

The size distribution of the oil droplets is not known, but can be expected to be larger than of the aerosols outside the plume, for which the above relationship has been determined. Thus, the calculated mass concentrations will be too low, but give at least the lower limits.

Using (2) the highest nephelometer readings correspond to 40 μg/m³ on 27 April compared to 16 μg/m³ in the outside air. On 29 April the values are 120 μg/m³ and 40 μg/m³, respectively. The corresponding mass transports of oil droplets are 1 kg/s or less.

4.4 Composition of the gas cloud

The composition of the gas release given by Phillips Oil Company is shown in Table 6. The results of the analysis of the air samples in Table 2 and Table 4 vary around the given values in the relative amounts of the different compounds, but no systematic variation with height above the sea or with distance from the release is apparent. The bag sample taken upwind of Bravo at 150 m on 27 April, show a background value of 0.8 ppm for methane.

The samples taken from the vessel on 30 April gave a different composition, but the concentrations were low and partly below detection limits of analysis. The methane concentration was 1.7 ppm, i.e. less than 1/80 of the maximum plume concentration when the background concentration is taken as 1 ppm.

Table 6: *Composition of gas releases.*

		Volume percent	Explosive range (volume concentration)
Methane	(CH ₄)	83.84	5 - 15 %
Ethane	(C ₂ H ₆)	9.34	3 - 12.5 "
Propane	(C ₃ H ₈)	3.27	2.1 - 9.5 "
Iso-Butane	(C ₄ H ₁₀)	0.32	1.8 - 8.4 "
Normal Butane	(C ₄ H ₁₀)	0.59	1.8 - 8.4 "
Iso-Pentane	(C ₅ H ₁₂)	0.09	
Pentane	(C ₅ H ₁₂)	0.08	
Hexane	(C ₆ H ₁₄)	0.03	
Nitrogen dioxide	(NO ₂)	0.46	
Karbon dioxide	(CO ₂)	1.99	

5 COMPARISON WITH DIFFUSION FORMULAE AND DIFFUSION EXPERIMENTS

Most diffusion formulas assume normal (Gaussian) crosswind concentration distributions. This gives the normalized axial (maximum) concentration from a point source as:

$$\frac{c \cdot \bar{u}}{Q} = \frac{1}{\pi \sigma_y \sigma_z} \quad (3)$$

where c is the maximum concentration in a cross-section at distance x , \bar{u} is the wind speed, Q the release per time unit, and σ_y and σ_z are the horizontal and vertical standard deviations. It is assumed that no material is deposited at the surface (100% reflection).

Gaussian distributions in the horizontal crosswind direction agree reasonably with most observations. A Gaussian vertical distribution, however, is a more questionable assumption.

In Table 7, σ_y is calculated using the most representative values of cloud width (assuming a Gaussian distribution), while σ_z is calculated directly from the observed vertical distribution of the crosswind integrated concentrations. Maximum concentration, normalized for windspeed and the rate of release is then calculated using equation (3).

Table 7: Standard deviations and normalized maximum concentrations.

27 April				29 April			
Distance km	σ_y m	σ_z m	$c \bar{u}/Q$ m^{-2}	Distance km	σ_y m	σ_z m	$c \bar{u}/Q$ m^{-2}
18	300	-	-	11	200	58	$3.6 \cdot 10^{-5}$
15	270	140	$1.1 \cdot 10^{-5}$	5.5	160	48	$5.5 \cdot 10^{-5}$
7.5	190	70	$3.2 \cdot 10^{-5}$	3	120	39	$9.2 \cdot 10^{-5}$
4	160	-	-	2.5	85	-	-

Standard deviations are often expressed as power functions of x , i.e., $\sigma_y = ax^p$ and $\sigma_z = bx^q$. Here a , b , p and q are constants, their values depending of the static stability of the air (2). This gives for the normalized concentration:

$$c \cdot u / Q = A \cdot x^B \quad (4)$$

where $A = \frac{1}{\sqrt{a} b}$, and $B = -p-q$.

For near neutral conditions the value of B is about -1.7 over a smooth land surface. The slopes on a log-log plot of σ_y and σ_z , Figure 8, indicate values of p and q close to 0.5 and therefore a value of B that is closer to -1.0 than to -1.7 . This indicates that the turbulent spread of the plume over sea surface covered by an oil spill is reduced compared to spread over flat homogeneous land during the same wind and stability conditions.

The discussion above is based on dispersion from a point source. The source configuration at Bravo was somewhat more complicated. A mixture of gas and oil with a temperature of 100°C , escaped through a pipe (with 11.5 cm diameter) at a height 35 m above sea level. The platform structures above and the continuous spraying with water affected the initial dispersion. A considerable part (about 40%) of the released oil evaporated before it reached the sea surface.

The gas release may therefore partly be treated as released from a point (the initial gas release), partly from a volume source (the evaporating oil). Additional evaporation of gas from the oil on the sea surface should be treated as a ground level area source. An area or a volume source may be described by assuming fictitious sources located upwind, at distances corresponding to the crosswind dimensions of the original source.

The observations of vertical concentration distributions suggest a modest plume rise due to vertical exit velocity or buoyancy. This is confirmed by photographs of the plume of oil droplets which show a rise to about 80 m above sea level.

Normalized concentrations, calculated directly from the estimated maximum concentrations, are shown in Table 8.

Table 8: Normalized concentrations based on estimated maximum concentrations.

27 April			29 April		
Distance km	C _{max} ppm	c u/Q m ⁻²	Distance km	C _{max} ppm	c u/Q m ⁻²
18	9.5	4.9 · 10 ⁻⁶	11	49	1.9 · 10 ⁻⁵
15	14	1.4 · 10 ⁻⁶	5.5	51	2.0 · 10 ⁻⁵
7.5	22	1.1 · 10 ⁻⁵	3	76	2.8 · 10 ⁻⁵
4.5	34	1.8 · 10 ⁻⁵	2.5	93	3.5 · 10 ⁻⁵

Neither of the two different ways of calculating normalized concentrations are very accurate. The first assumes Gaussian crosswind distributions, horizontally as well as vertically, and involves relatively uncertain estimates of the standard deviations. The other method assumes that observed maximum concentrations are representative, while they most probably are too low. This method also gives the lowest normalized concentrations.

In Figure 9 the measurement results are compared with normalized concentration curves for different stability conditions taken from Workbook of Atmospheric Dispersion Estimates (3). They are also compared with results of some diffusion experiments performed over the sea by the Norwegian Defence Research Establishment (NDRI)*

* Unpublished report

shown as points A and B. These points refer to a point source and mean hourly concentrations observed under weather conditions very similar to those at Ekofisk, where the sea temperature was also some degrees lower than the air temperature, and the static stability of the air was near neutral (slightly stable). In the NDRI experiments, repeated crossings by a small boat close to the source were made, using a sample time of one second. The corresponding points A^+ and B^+ are maximum values, and are seen to be 10 times higher than the corresponding hourly values. Although mean concentrations usually decrease with increasing sampling time, the difference is here higher than expected. The curves D, E and F and the points A and B, A^+ and B^+ , all refer to ground level point sources.

The assumption of a crosswind area source (height 80 m, width 25 m) is shown (Figure 9) to have a marked effect on the concentrations at shorter distances. The difference from the calculated concentrations using a point source is hardly detectable at the longer distances, where the measurement were taken.

Maximum concentrations are of greater interest in estimating danger areas, i.e. distances to flammability points. For a very conservative estimate, curve F in Figure 9 may be used. The lower flammability points at 5% corresponds to a normalized concentration of $1.7 \cdot 10^{-2} \text{m}^{-2}$ on 27 April, and to $1.5 \cdot 10^{-2} \text{m}^{-2}$ on 29 April. This gives distances less than 200 m to the lower flammability point.

6 EXPERIENCE USING AN INSTRUMENTED AIRCRAFT

The air sampling flights described demonstrate the versatility of an instrumented aircraft and its ability to obtain a three-dimensional assessment of a gas cloud. The installation of the equipment was done on short notice and improvisations had to be made. Fortunately, all instruments functioned well.

The limited time available for each aircraft flight made it necessary to decide whether to make as many single traverses as possible at different distances and heights above the sea, or to make repeated crossings at a given height and distance and thus obtain reliable mean values, with a greater likelihood of detecting maximum concentrations. The first alternative was selected. Maximum concentrations are perhaps less reliable, but the use of integrated crosswind concentrations should give reliable vertical distributions. Besides, far more traverses could be studied.

Technically, one of the greatest difficulties was to establish the correct positions and distances. The need of an airborne radar and an accurate electronic position indicator was greatly felt. But from the known positions of other oil platforms in the area, and from relative directions and bearings of the corvette "Stavanger", the estimated distances of the aircraft from the platform Bravo should be accurate enough for the type of calculations made here.

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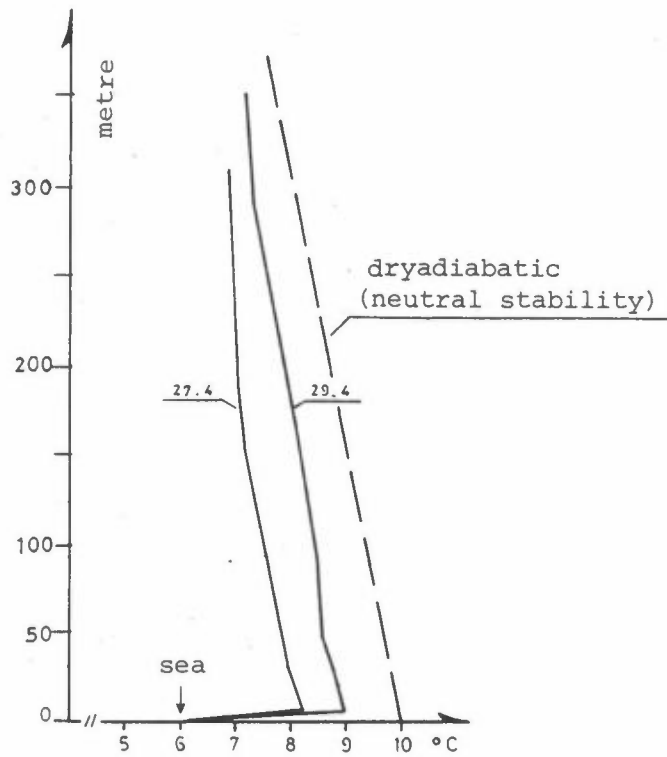


Figure 1: Temperature profiles, Ekofisk, 27 and 29 April 1977

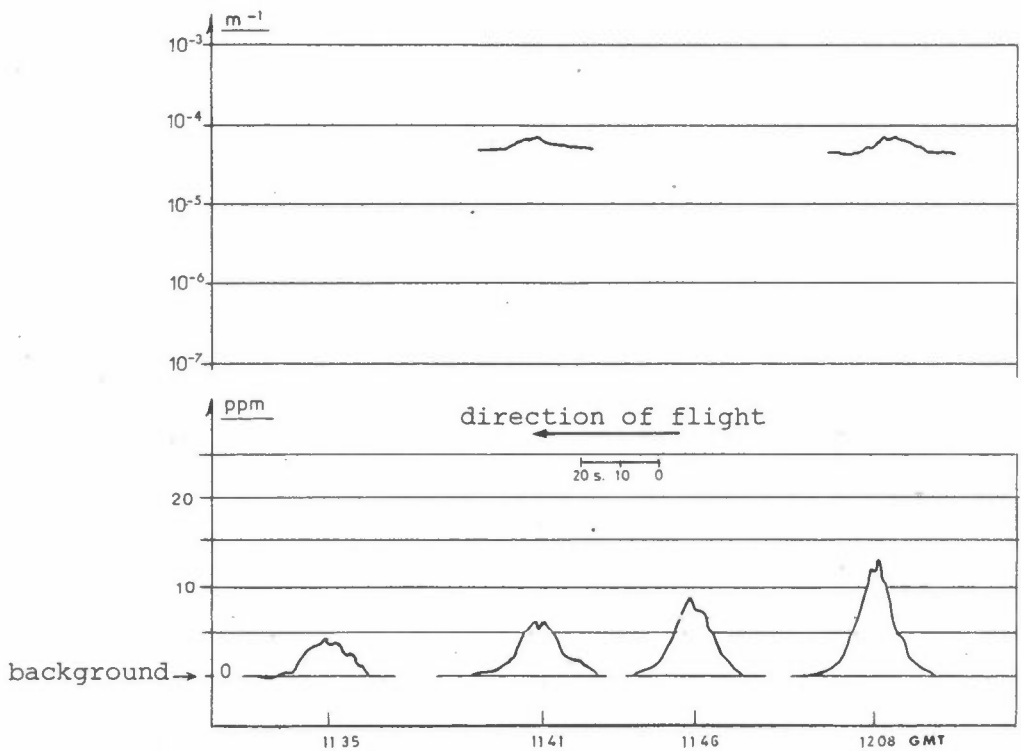


Figure 2a: Hydrocarbon concentration, ppm, and scattering coefficient, $b_{scat} m^{-1}$, 27 April.

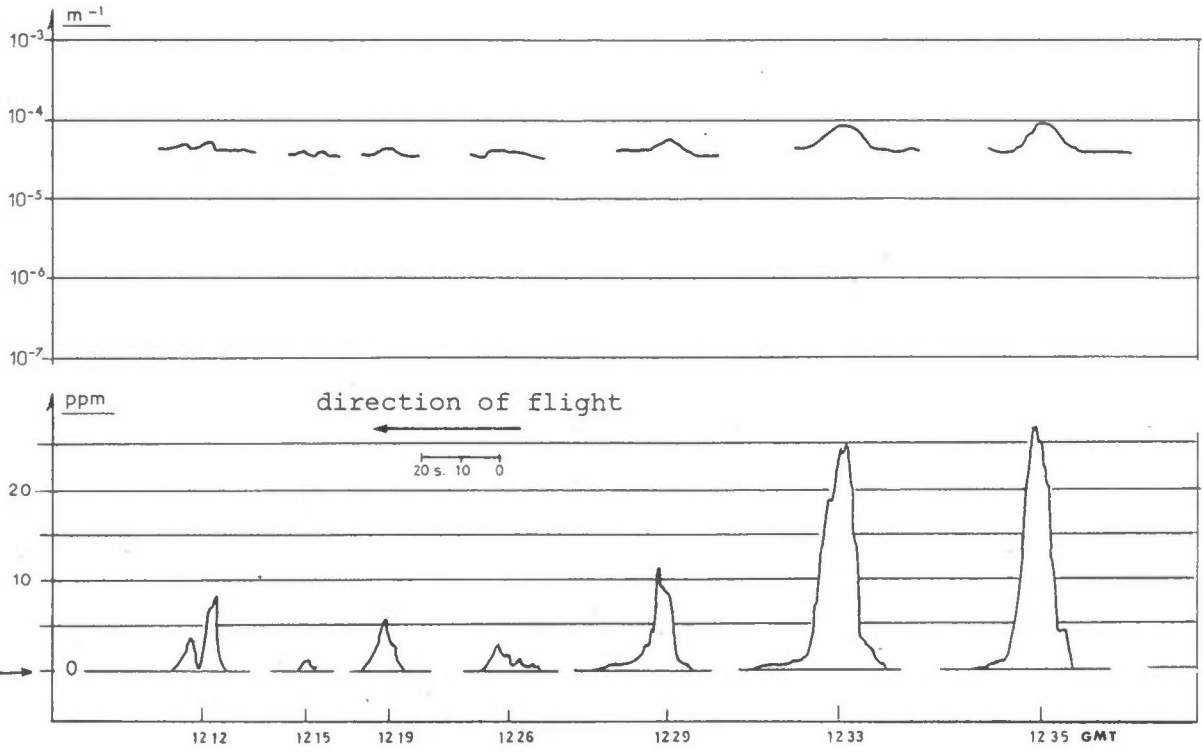


Figure 2b: Hydrocarbon concentration, ppm, and scattering coefficient, $b_{scat} m^{-1}$, 27 April.

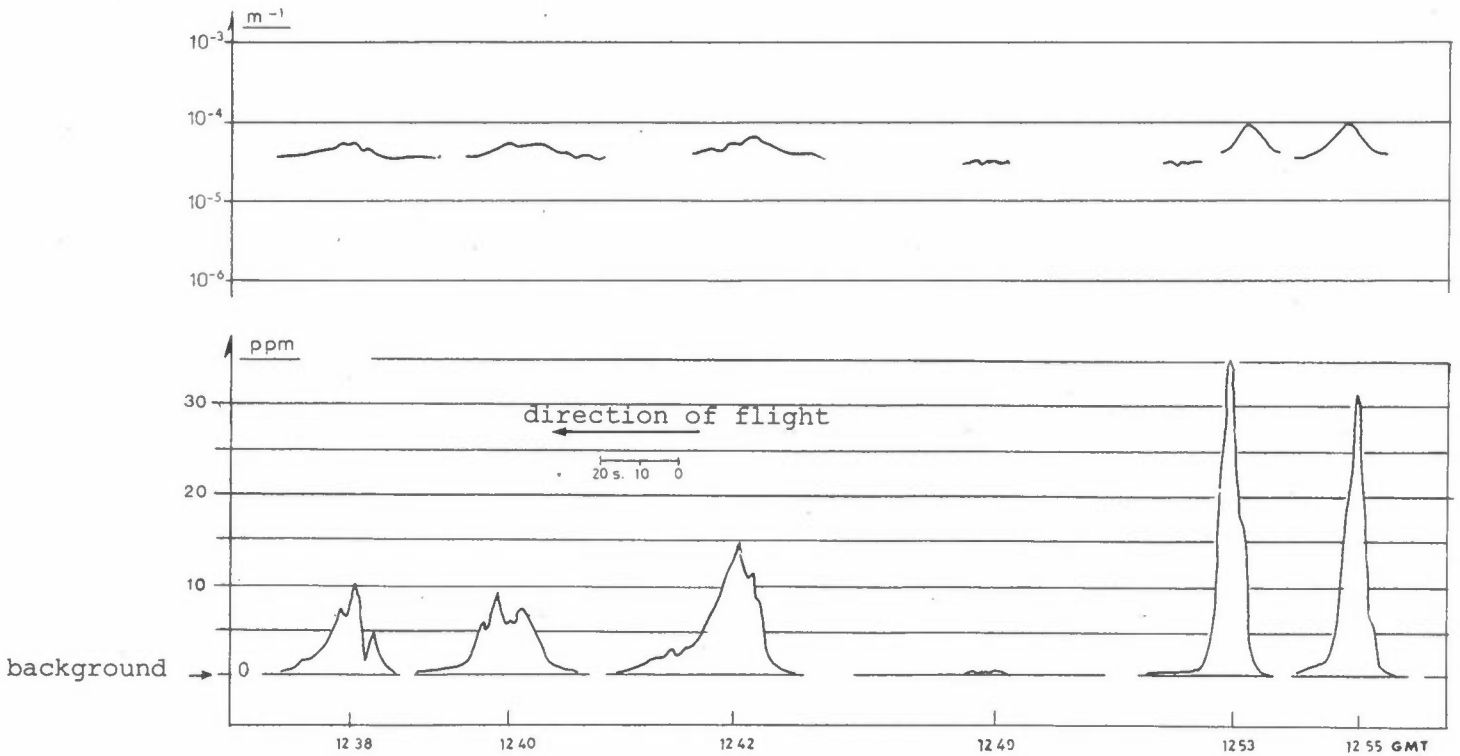


Figure 2c: Hydrocarbon concentration, ppm, and scattering coefficient, $b_{scat} m^{-1}$, 27 April.

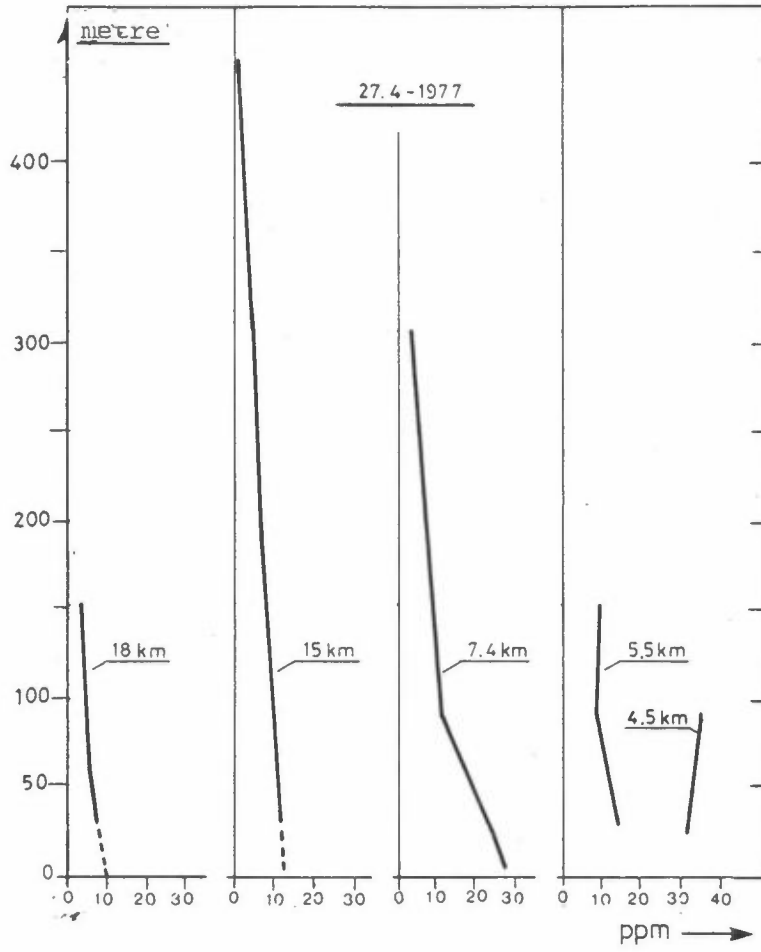


Figure 3: Maximum concentration, 27 April 1977.

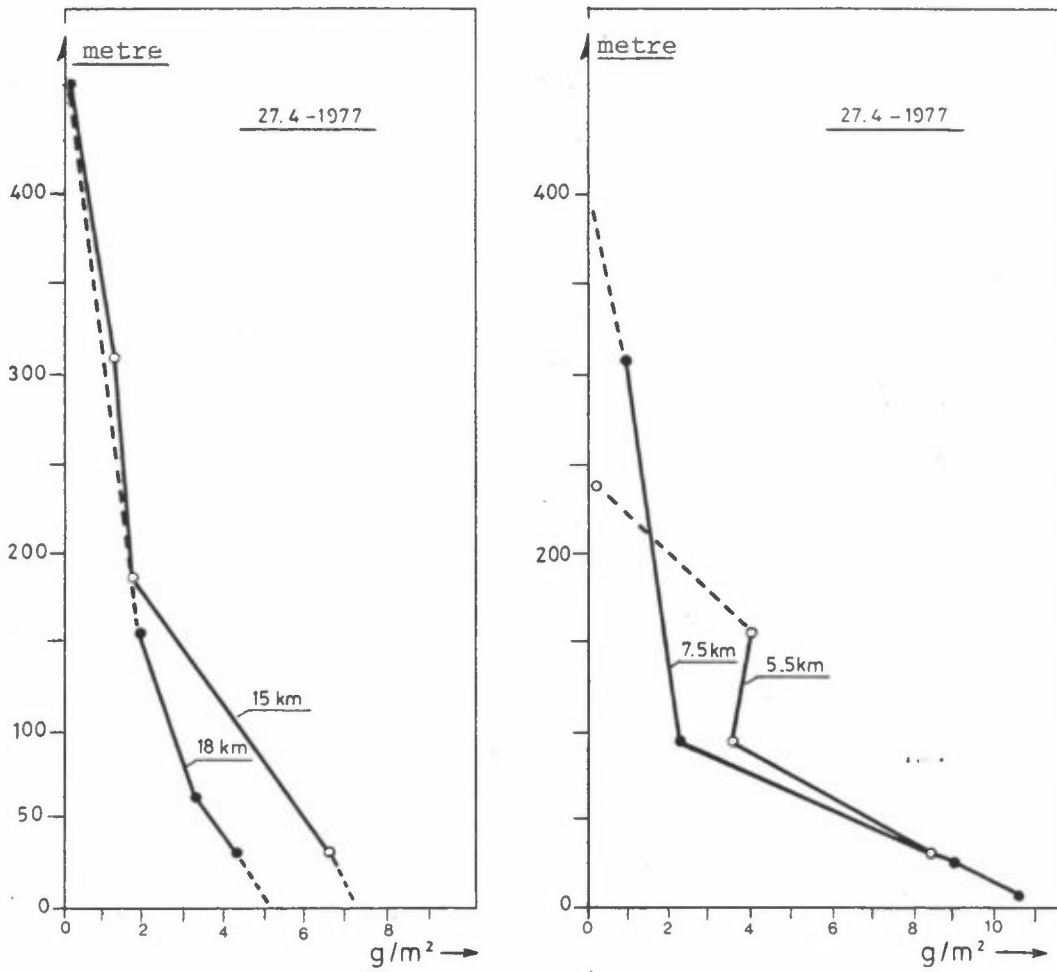


Figure 4: Crosswind integrated concentrations, 27 April 1977.

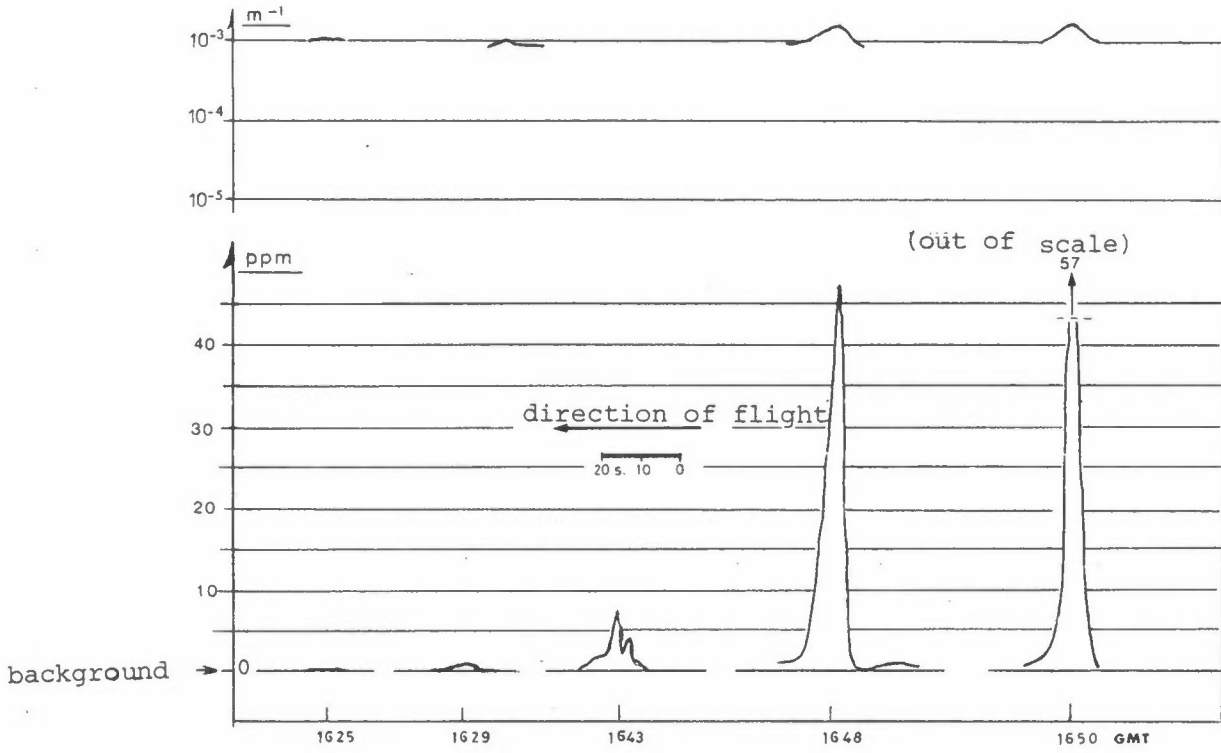


Figure 5a: Hydrocarbon concentration, ppm, and scattering coefficient, $b_{scat} m^{-1}$, 29 April 1977.

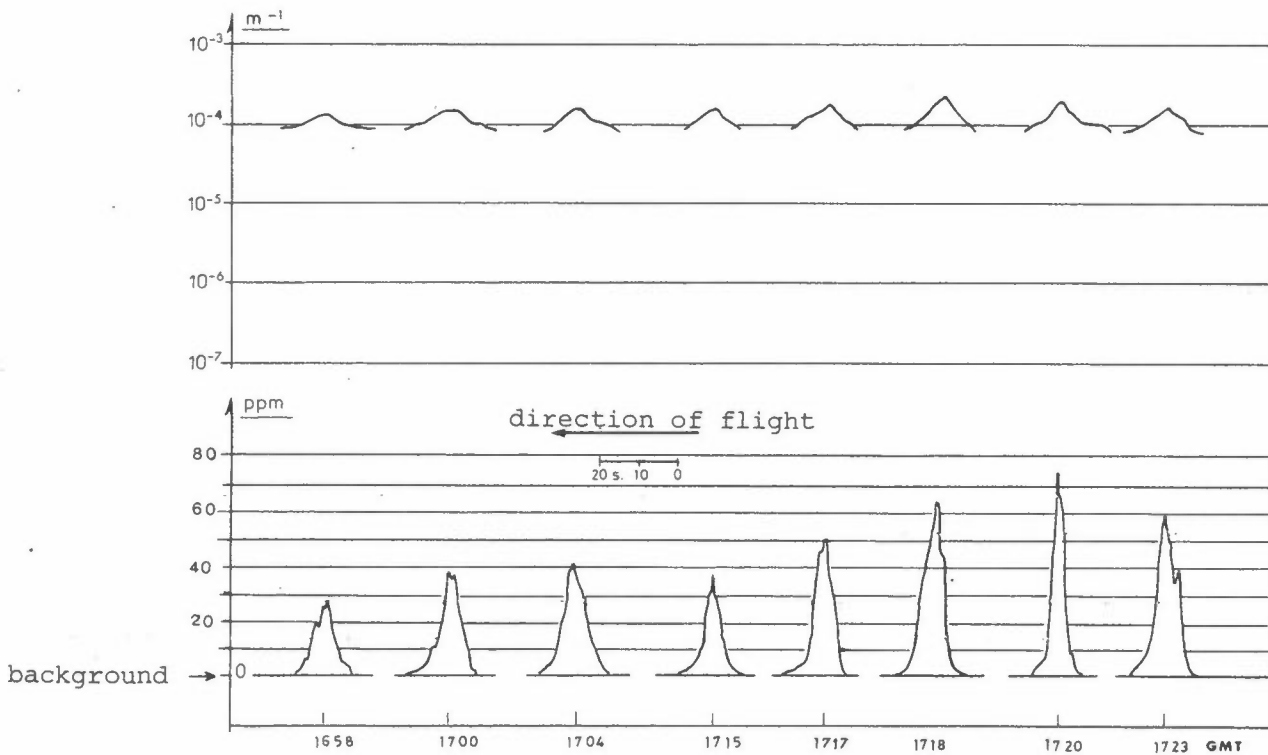


Figure 5b: Hydrocarbon concentration, ppm, and scattering coefficient, $b_{scat} m^{-1}$, 29 April 1977.

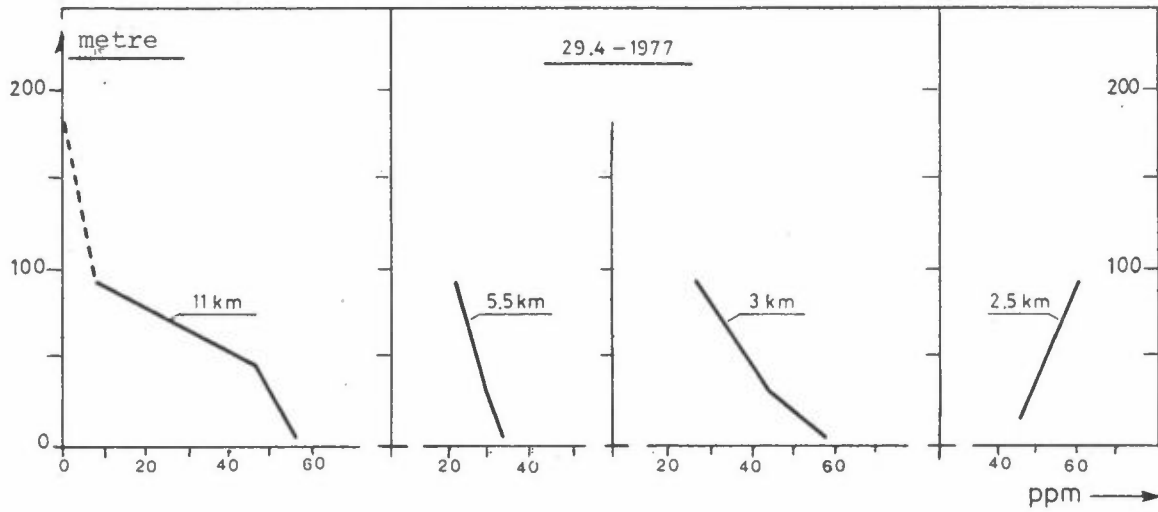


Figure 6: Maximum concentrations, 29 April 1977.

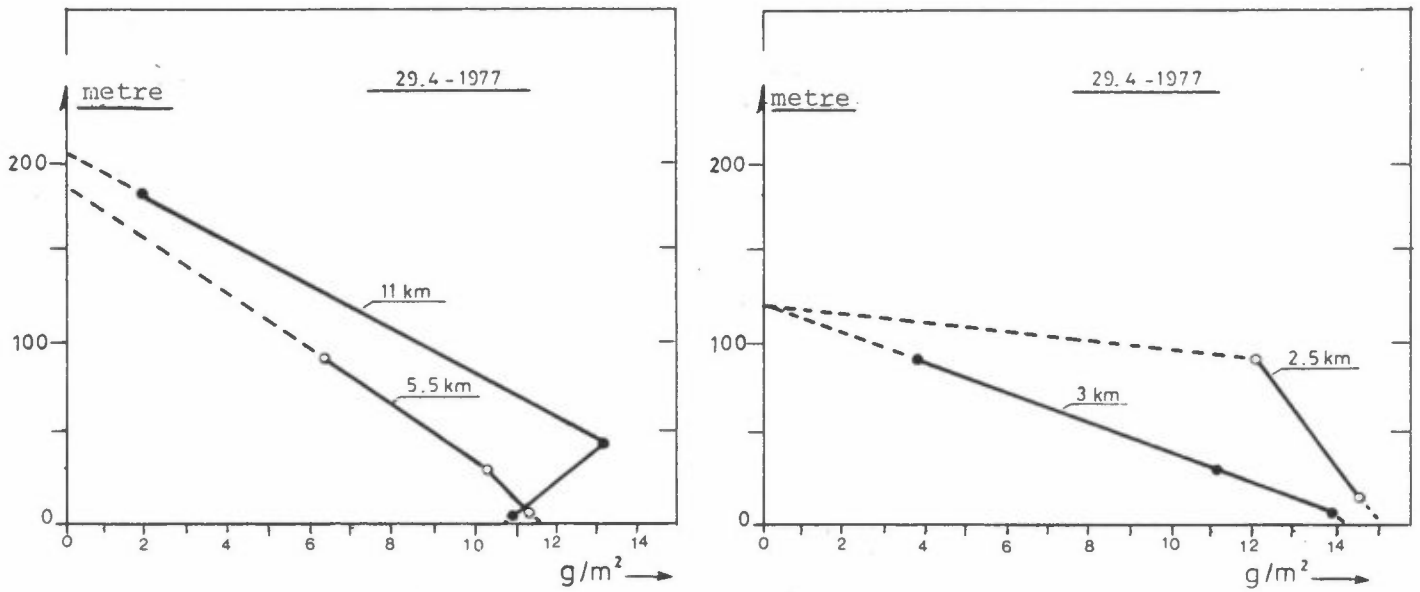


Figure 7: Crosswind integrated concentrations, 29 April 1977.

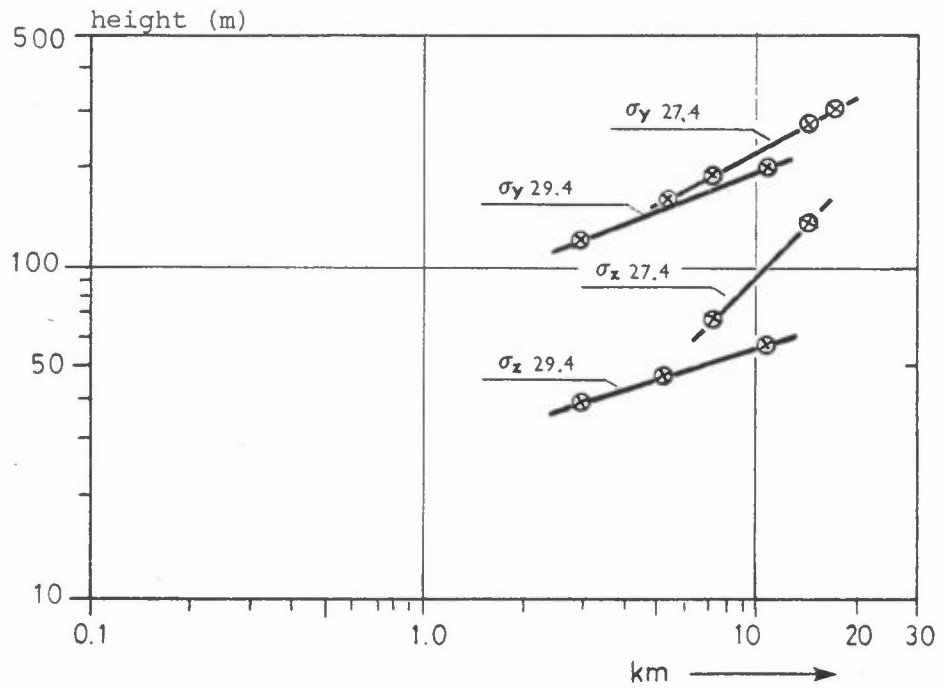


Figure 8: Standard deviations, 27 and 29 April.

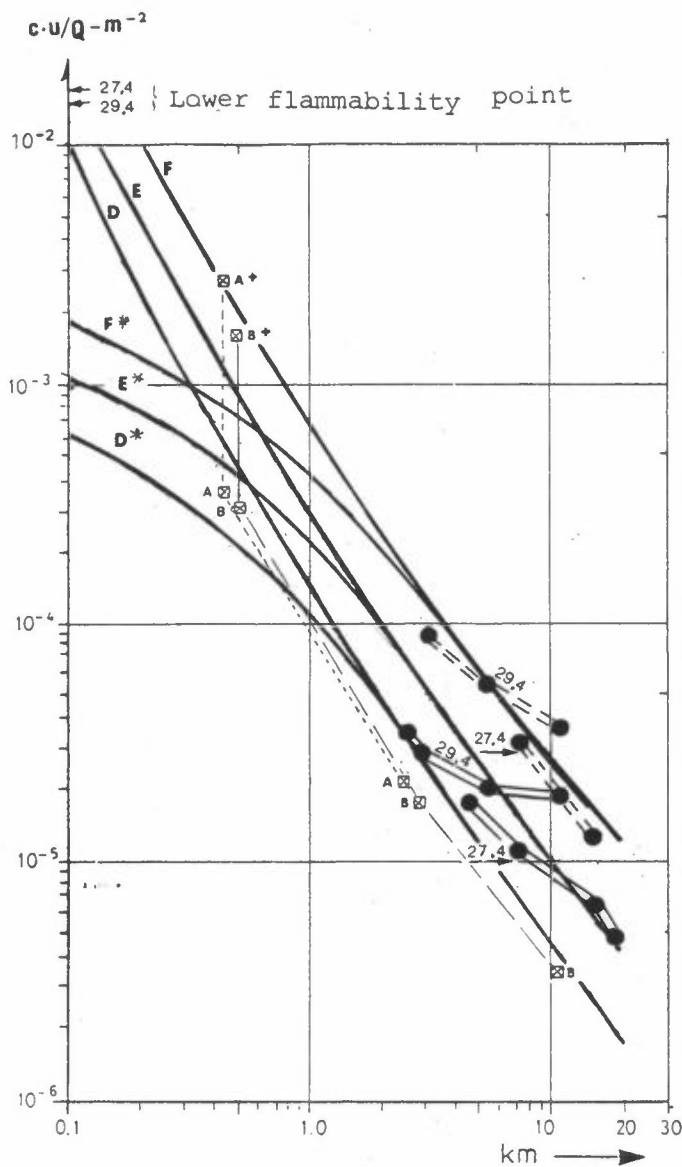


Figure 9: Normalized concentrations, $c \cdot u / Q - m^{-2}$

c = maksimum crosswind concentration
 u = windspeed
 Q = release

=== Ekofisk 27 and 29 April, based on the standard deviations in Table 7, $Q = 16.7$ kg/s

==== Ekofisk 27 and 29 April, based on estimated concentrations, Table 8, $Q = 16.7$ kg/s

A, B : Observations over sea, NDRE, hourly means

A^+, B^+ : Instantaneous values

D, E, F : Curves from Workbook of Atmospheric Dispersion Estimates (1), D=light stable, E=stable, F=very stable air

D^*, E^*, F^* : Crosswind area source 80 m (height) x 25 m.