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Abstract

During several days in November 1985 an international field experiment took place in the Swiss plateau region near the cities of Aarau, Olten. As indicated by the name of the project SIESTA ($\underline{S}\underline{F}_6$ $\underline{I}$nternational $\underline{E}$xperiments in $\underline{St}$agnant $\underline{A}$ir) its aim is to obtain knowledge of the general nature of turbulence advection and atmospheric dispersion processes in a cold pool with very low wind speed and undefined wind direction. An outline of the general concept of the project is followed by a more detailed description of a special research activity with Radar tracked tetroons. In the second part of the report it is shown how to determine the horizontal dispersion parameter from the trajectories of the tetroon flights. Two different methods are described and the result of the flights performed during SIESTA are presented.

Auswertungen von Tetroonflügen, die bei Schwachwindlagen während des Feldexperimentes SIESTA durchgeführt wurden

Zusammenfassung

Ein internationales Feldexperiment wurde an mehreren Tagen im November 1985 im Schweizer Mittelland in der Nähe der Städte Aarau, Olten durchgeführt. Wie durch den Namen des Projektes SIESTA angezeigt ($\underline{S}\underline{F}_6$ $\underline{I}$nternational $\underline{E}$xperiments in $\underline{St}$agnant $\underline{A}$ir), ist es das Ziel, ein besseres Verständnis der Turbulenz, der Advektion und der Ausbreitungsprozesse in der Atmosphäre im Falle eines Kaltluftsees mit geringen Windgeschwindigkeiten und unbestimmten Windrichtungen zu erhalten.
Nach einer Einführung in die Konzeption des Experiments erfolgt eine ausführlichere Beschreibung der radarverfolgten Tetroonflüge. Im zweiten Teil des Berichtes wird gezeigt, wie der horizontale Ausbreitungsparameter aus den Trajektorien der Tetroonflüge bestimmt werden kann. Es werden zwei verschiedene Methoden beschrieben und Ergebnisse bezüglich der durchgeführten Flüge bei SIESTA gezeigt.

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1. Introduction

During several days in November 1985 an international field experiment, SIESTA (SF_6 International Experiments in Stagnant Air) took place in the Swiss plateau region of Aarau-Olten.

From an air pollution point of view this region is of specific interest, partly because the population density is high there, partly because it is completely surrounded by mountains (Alps in the south and east, Jura in the north and west) so that stagnant situations, so-called cold pools, occur frequently, especially during the winter season. A cold pool is formed by air flowing down to the Swiss plateau after having been cooled by radiative cooling in the prealpine and alpine regions.

The chosen test region between Olten and Aarau is a near-ideal site for cold pool investigations. The Jura in the north-west forms a well defined boundary of the flow field including only a few and rather narrow overflow regions, and the cold pool is deepest in the test region. Furthermore, a large nuclear power plant is situated between the two cities of Aarau and Olten, at distances of 5 and 7 km, respectively, from the power station.

2. Aim of the Project

As indicated by the name of the project, SIESTA, its aim is to obtain knowledge of the general nature of turbulence, advection and atmospheric dispersion processes in a cold pool with very low wind speed and undefined wind direction.

3. General Layout of the Project

The measuring campaign took place between November 14 and November 30, 1985. Five SF_6-tracer experiments were carried out during that period. The release rate was about 1 g/s and the release height was 10 m above ground near the Gösgen meteorological tower which is situated about 1 km east of the nuclear power station (Fig. 1). Up to 50 sampling units were used to collect the air at 3 to 8 km distance around the point of emission.

To investigate the flow field in the test region, the following measurements were performed:

- Tethered balloons: 3 tethered balloon sounding systems measured the temperature, humidity, wind speed and direction at places near the meteorological tower, near Trimbach and near Niedererlinsbach.
- Meteorological tower: The 110 m high tower of the Gösgen power plant measures 10 minute averages of wind direction and velocity at 10 and 110 m altitude. A sonic anemometer at the 2 m level measures the vertical heat flux, friction velocity, and wind speed.
- Small masts: 4 small masts of 2 to 10 m height have been installed to measure the wind speed and direction continuously.
- Radar tracked tetroon: Radar-tracked tetroons are a very effective tool to investigate the wind flow system in a Lagrangian manner. Two teams performed tetroon flights independently.

The following organizations participated in SIESTA:

- EIR (Eidgenössisches Institut für Reaktorforschung): Scientific responsibility and tethered ballon.
- APL/Risø (Air pollution Laboratory of the Danish National Agency of Environmental Protection): SF_6-tracer technique, emission system, automatic samplers, and mobile sampling van, small masts and sonic anemometer.

- JRC (Joint Research Center Ispra, Italy): automatic samplers, sonic anemometer, tethered balloon.
- LAPETH (Laboratory for Atmospheric Physics at ETH Zürich): radar tracked tetroons.
- IMK/KFK (Institut für Meteorologie und Klimaforschung, Kernforschungszentrum Karlsruhe): radar tracked tetroons.

Only these tetroon flights of IMK/KfK will be presented in the following chapters.

4. Tetroon Measurements

A detailed description of the experimental technique and of the evaluation of data measured previously has been published /VO83/, /BO84/.

4.1 Description of the Radar Site and of the Points of Launching

During all tetroon flights the radar was located on a hill (460 m height) about 1.8 km south-east of the point of tracer release. The coordinates of this site are 641900/244400 in a Swiss Ordinance Survey map. The tetroons were launched either 150 m north of the point of tracer release or 350 m east of that point near the Niedergösgen Mehrzweckhalle. The difference in height between the radar and the launching site is 85 m. The width of the Aare river valley varies between 1 and 4 km in the near distance of the radar and tetroon launching points.

4.2 Flights

During three days 10 tetroons were tracked in total. All tetroons carried transponders. The relevant flight data are shown in Tab. 1. All transponders were found and sent back to KfK. So it was possible to indicate in Tab. 1 also the points of touch-down of each tetroon.

Information about the stability category was collected at a nearby (4 km east of launching point) micrometeorological station operated by JRC-Ispra.

Based on 30 min mean values of the horizontal wind, visible radiation or radiation balance a stability category was estimated according to the Pasquill classification scheme. The stability category prevailing during the tetroon flights is indicated in Tab. 1.

4.3 Data Acquisition and Evaluation

During automatic tracking of the tetroons by radar the following data were printed with a teletype and punched on paper tape every 10 s:

- time after release of the tetroon in min and s;
- distance d between the radar and tetroon, in m;
- elevation angle ϕ, in degrees;
- azimuthal angle α, in degrees.

Averages of d, ϕ and α were calculated off-line using a window of 70 s shifted by steps of 10 s in such a manner that an average of e.g. $\bar{d}$ is composed of seven instantaneous values d(t) [d(t-30s), d(t-20s),...., d(t),..., d(t+30s)].

From these averages the position of the tetroons was calculated for each 10-s-step in x-, y- and z-coordinates. This rectangular system is oriented with the x- and y-axes in the east and north directions, respectively. The origin of the system is identical with the operating base of the radar.

$$x = d \cdot \cos\phi \, \sin\alpha \qquad (1)$$

$$y = d \cdot \cos\phi \, \cos\alpha \qquad (2)$$

$$z = d \cdot \sin\phi \qquad (3)$$

Taking into account the earth curvature, the true height h of the tetroon is:

$$h \cong Z + \frac{d^2}{2R} \qquad (4)$$

R = 6378 km is the radius of the earth.

The refraction of the radar beam is also taken into account but only roughly: In Eq. (4) it is assumed that the earth radius can be replaced by an "equivalent radius" of $\frac{4}{3}$ R.

Besides the average values $\bar{d},\bar{\phi},\bar{\alpha},\bar{x},\bar{y}$ and $\bar{h}$, the velocities u,v and w, the wind direction in an x-, y-plane and the flight path are calculated for each 10-s-step based on these average values.

4.4 Graphs of Trajectories

The trajectories of all flights are plotted in three different types of graphs in Figs. 2 to 11.

Figures 2 to 4 show the projection of the flight path into the x-, y-plane in an ordinance survey map.

The trajectories of SI8508 and SI8510 show several changes in the flight direction. Therefore, these flights have been plotted again on a larger scale in Fig. 5, which is the relevant section of Fig. 4.

Figures 6 to 8 show the height profile of the tetroon as a function of the travel distance. The length scale is 10 times larger than the height scale.

In Figs. 9 to 11 the projection of the trajectories into the plane perpendicular to the mean transport direction (looking downstream) is shown. Tetroon positions are marked at 5 min intervals by circles.

5. Determination of the Horizontal Dispersion Parameter

5.1 Lateral Diffusion Estimates from Successive Tetroon Releases

As shown in /SL68/, it is possible to estimate lateral diffusion from successive tetroon flights. Panofsky and Brier /PA58/ showed that the best estimate of the variance of the tetroon trajectories (σ_y^2) is given by:

$$\sigma_y^2 = (N-1)^{-1} \sum_{i=1}^{N} (y_i - \bar{y})^2 \qquad (5)$$

where N is the number of trajectories, y_i is the position of tetroon No. i on the y-axis, and $\bar{y}$ is the mean position of the N tetroons on the y-axis.

The square root of this lateral variance is the horizontal dispersion parameter σ_y in the Gaussian dispersion formula.

According to this procedure, circles with different radii are drawn and the distances between points of intersection of the trajectories with these circles are measured yielding σ_y-values at individual downwind distances x.

This was done for the series of tetroon flights on November 15 and 17. Series No. 1 consists of the tetroons Si8501, SI8502 and SI8503 whereas series No. 2 comprises four tetroons, SI8504 to SI8507. It is not possible to evaluate with this method the flights made on November 27, because it is impossible to define a reasonable mean wind direction for this series.

For the values σ_y obtained in this way the dependency of the downstream distance is supposed to take the form

$$\sigma_y = \sigma_o x^p \qquad (6)$$

The reason for choosing such a function is to make the comparison with former tracer experiments more easier /TH85,VO78,MC69/. In all these tracer experiments such a functional dependence on the downstream distance has been used. By a least squares fit σ_o and p are evaluated for each series of flights. The results are listed in Tab. 2 and indicated by a solid line in Fig. 12.

5.2 Lateral Diffusion Estimates from a Single Trajectory

As shown in /SL68/ and /HA82/, it is also possible to estimate lateral diffusion from a single tetroon trajectory based on the lateral wind fluctuation. The relevant formula is:

$$\sigma_y = \sigma_v \ t \ f_y \qquad (7)$$

where σ_y is the lateral standard deviation after travel time t, σ_v , is the square root of the variance of the lateral wind speed averaged over the diffusion or travel time t. The rectangular coordinates x′, y′, z′ are oriented in such a way that the x′-axis points to the mean flight direction of the individual tetroon trajectory. f_y is a universal function and its approximation has been derived by Irwin /IR79/:

$$f_y = (1 + 0.031x^{0.46})^{-1} \qquad (x \leqslant 10^4 m)$$
$$= 33x^{-\frac{1}{2}} \qquad (x > 10^4 m) \qquad (8)$$

where x is expressed in meters.

Then, according to Eq. (7), the horizontal dispersion parameter σ_y is calculated for each individual tetroon. The same functional dependency as in Chapter 5.1 was assumed for each value of σ_y. The individual values of σ_o and p for each tetroon trajectory were determined again by least squares fit and the results are shown in Tab. 2. For the comparison in Chapter 5.3 the values of σ_y of several single tetroon trajectories are combined by forming the geometric mean value according to the following formulas:

$$\bar{\sigma}_{y_{ind.}} = \bar{\sigma}_o \; x^{\bar{p}} \tag{9}$$

$$\bar{\sigma}_o = \left(\prod_{i=1}^{N} \sigma_{o_i} \right)^{1/N} \tag{10}$$

$$\bar{p} = \frac{1}{N} \sum_{i=1}^{N} p_i \tag{11}$$

where N is the number of tetroons within a series. The mean regression lines are indicated as a dotted-dashed line in Fig. 12.

5.3 Comparison of the Different Methods of Estimating Horizontal Diffusion Parameters

It can be seen from Tab. 3 and Fig. 12 that the σ_y calculated from successive release (first method) is always higher than that based on single tetroon trajectories (second method).

Of course, this is not surprising as the second method, unlike the first method, does not include the effect of wind meandering over several hours.

In order to make an honest comparison one must calculate the total diffusion also in case of the second method. This can be done with the following formula suggested by Gifford /GI59/:

$$\bar{\sigma}_{y_{tot}} = \left(\bar{\sigma}_{y_{ind}}^{2} + \bar{\sigma}_{y_m}^{2} \right)^{1/2} \tag{12}$$

Gifford assumes two separate scales of diffusion:

$\bar{\sigma}_{y_{ind}}$ stands for the mean small scale of turbulence within one series and $\bar{\sigma}_{y_m}$ is caused by the meandering of the large scale wind field. The effect of meandering according to /HA82/ can be estimated as follows:

$$\bar{\sigma}_{y_m} = \bar{\sigma}_{\Theta_m} \times f_y \qquad (13)$$

with

$$\bar{\sigma}_{\Theta_m} = (N-1)^{-1} \sum_{i=1}^{N} [\Theta_i(x) - \bar{\Theta}(x)]^2 \qquad (14)$$

and

$$\bar{\Theta}(x) = \frac{1}{N} \sum_{i=1}^{N} \Theta_i(x) \qquad (15)$$

$\bar{\sigma}_{\Theta_m}$ is the mean standard deviation in radians, N is the number of tetroons within one flight series. $\bar{\Theta}_i(x)$ is the wind direction derived from the i-th tetroon flight path between the point of launching and the relevant downwind distance x.

Values of the total diffusion $\bar{\sigma}_{y_{tot}}$ for two flight series have been calculated according to formula (12) and are shown in Tab. 3.

In the case of series No. 1 the diffusion values estimated from successive releases (first method) differ only by 7 % on the average from the values calculated according to Eqs. (12) and (13). Therefore,the assumption of Gifford to split up the diffusion into two separate scales is justified for this series.

But in the case of series No. 2 the differences amount to nearly 45 % on the average between the σ_y-values estimated from such successive releases (first method) and those calculated according to Eqs. (12) and (13). This is due mainly to the low σ_y-values based on single trajectories (second method).

The conclusion of this chapter is that both methods (successive releases and single trajectories) can be adopted to estimate lateral diffusion. But only the first method takes into account the large scale of turbulence (several hours) whereas the second method is appropriate if only the small scale of turbulence (minutes) is of interest.

6. Dispersion Under Weak Wind and Calm Conditions

Normally one distinguishes between low wind conditions– the mean vector wind speed V is between 0.5 and 1 m/s – and situations with nearly no mean wind speed ($V < 0.5$ m/s) /US77/.

6.1 Lateral Diffusion Estimates Under Weak Wind and Calm Conditions

The wind shear of the wind direction with height is often so effective, that abrupt changes of the flight direction of tetroon trajectories will take place. The flights made on Nov. 27 (see Figs. 4,5 and 8) are an excellent example for such conditions. As already stated in Chapter 5.1, it is impossible to estimate lateral diffusion from successive tetroon releases in such situations.

Nevertheless, diffusion estimates from a single trajectory are possible. The concept is to divide one single tetroon trajectory into several (k) parts, then to estimate an individual $\sigma_{y,i}$ for each part and, finally, to calculate an effective horizontal dispersion parameter $\sigma_{y,eff}$ according to /VO80/:

$$\sigma_{y,eff} = \left(\sum_{i=1}^{k} \sigma_{y,i}^2 \right)^{1/2} \qquad (16)$$

For example, the whole trajectory of tetroon SI8508 (see also Fig. 5) can be divided into three parts. Each part has its own mean transport direction.

For the flights made on Nov. 27 effective horizontal dispersion parameters have been calculated according to Eqs. (7) and (16). As Tab. 4 shows, σ_y is much higher in the vicinity of the source than the corresponding values of the Pasquill-Gifford curve of category B. With increasing downwind distance the difference decreases.

6.2 Wind Direction and Turbulence Intensity Under Calm Conditions

The magnitude and periods of the fluctuations in wind direction are functions of the intensity of atmospheric turbulence. So the standard deviation of fluctuations in wind direction in the lateral direction σ_Θ and the turbulence intensities i_x, i_y and i_z have been calculated for time periods with $\mathbb{V} < 0.5$ m/s. $\mathbb{V}$ is the mean vector wind speed within the time period and it is assumed that $\mathbb{V}$ is equal to the mean transport speed of the tetroon. The turbulence intensity along each axis is defined by

$$i_x = \left(\frac{\overline{u'^2}}{\mathbb{V}^2} \right)^{1/2} \tag{17}$$

$$i_y = \left(\frac{\overline{v'^2}}{\mathbb{V}^2} \right)^{1/2} \tag{18}$$

$$i_z = \left(\frac{\overline{w'^2}}{\mathbb{V}^2} \right)^{1/2} \tag{19}$$

The orthogonal coordinate system is orientated in such a way that u is the component of the wind along the x-axis and coincides with the mean vector wind direction, v is the component in the y-direction, and w is the component along the z-axis. The averaging time is between 1 min and 10 min, so only a portion of the turbulence spectra is taken into account in equation (17) to (19).

Besides the values of turbulence intensity and σ_Θ, Tab. 5 also shows the corresponding stability categories according to the criterion given by US NRC /US72/, information about the minimum and maximum of the wind speed, and the differences between the maximum and minimum of the lateral wind direction ($\Delta\Theta = \Theta_{max} - \Theta_{min}$) and the ratio of $\Delta\Theta/\sigma_\Theta$.

The following conclusions can be drawn from Tab. 5:

- the atmosphere is not isotropic under calm conditions. The lateral turbulence intensity is a factor of 1.2 higher than the vertical components.
- The turbulence intensities in the three directions show a large variation in such calm situations. But the mean turbulence intensities, especially the vertical component, are similar to those found in other tetroon flights under unstable conditions /TH86/.
- The variation of σ_Θ is also large; it ranges from 13.3° to 71.6°.
- The ratio of $\Delta\Theta/\sigma_\Theta$ is about 3. This is about half of the value reported by IAEA /IA80/. But in /IA80/ the sampling time is 3600 s, whereas in our case the mean sampling time is only 213 s.

6.3 Wind Direction and Turbulence Intensity Under Weak Wind Condition

Table 6 shows the same information as Tab. 5, and the conclusions drawn from Tab. 6 are similar to those in the previous chapter. However, there are some differences:

- The turbulence intensities are in general smaller, especially the components i_x and i_y.
- The lateral turbulence intensity is by a factor of 0.77 smaller than the vertical intensity.
- The average value of σ_Θ is smaller than that in the calm situation.
- The variation of σ_Θ is larger; it ranges from 5.5° to 64.5°.

7. Conclusion

Radar tracked tetroons are an effective tool:

- to investigate the dispersion processes in a Lagrangian manner,
- to evaluate the horizontal dispersion parameter with different methods according to different scale of turbulence,
- to derive selected turbulence parameters even under special conditions, i. e. low wind speed and wintry situations (temperature below 0 °C).

Nevertheless it is not possible to draw general conclusions from the evaluations presented for similar meteorological situations because of the specific site and the relative small number of tetroon flights.

8. Literature:

/BO84/ Bortoli, M.D., Gaglione, P., Thomas, P., Vogt, S.; Experimental Determination of Atmospheric Dispersion in the Mesoscale by Tracer and Tetroons. EUR 9598 EN (1984)

/GI59/ Gifford, F.A.; Statistical Properties of a Fluctuating Plume Dispersion Model, in Advances in Geophysics, Vol. 6 pp. 117-138 F.N. Frankiel and P.A. Sheppard (Eds) Academic Press, New York (1959)

/HA82/ Hanna, S.R., Briggs, G.A., Hosker, R.P.; Handbook on Atmospheric Dispersion, DOE/TIC-11223 (1982)

/IA80/ IAEA, Atmospheric Dispersion in Nuclear Power Plant Siting, Safety Series No. 50-SG-S3 (1980)

/IR79/ Irwin, J.S.; Estimating Plume Dispersion - A Recommended Generalized Scheme. Proceedings of 4th Symp. on Turbulence, Diffusion and Air Pollution, Reno, Jan 15-18 (1979)

/UC69/ McElroy, J.; A Comperative Study of Urban and Rural Dispersion, J. of Appl. Meteorol. 8 No. 1, pp 15-31 (1969)

/PA58/ Panofsky, H.A., Brier, G.W.; Some Applications of Statistics to Meteorology, Pennsylvania State University (1958)

/SL68/ Slade, D.H.; Meteorology and Atomic Energy, USAEC Report TID-24190, Env. Science Series Administration (1968)

/TH85/ Thomas, P., Nester, K.; Experimental Determination of the Atmospheric Dispersion Parameters at the Karlsruhe Nuclear Research Center for Emission Heights of 60 and 100 m, Nuclear Technology 68/3, p. 293 (1985)

/TH86/ Thomas, P., Vogt, S., Gaglione, P.; Mesoscale Atmospheric Dispersion Experiments by Tracer and Tetroons at the Karlsruhe Nuclear Research Center. KfK-report, to be published in 1986.

/US72/ USNRC, On Site Meteorological Programs, Safety Guide 23 (1972)

/US77/ USNRC, Regulation Guide 1.111 (1977)

/VO78/ Vogt, K.J., Geis, H., Polster, G.; New Sets of Diffusion Parameters Resulting from Tracer Experiments in 50 m and 100 m Source Height, 9th Int. Meeting on Air Pollutions Modelling and its Application, Toronto (1978).

/VO80/ Vogt, K.J., Geiss, H., Straka, I.; A Model for Calculating the Dispersion of Accidental Discharges in Varying Weather Conditions. EG-Seminar on Radioactive Release and their Dispersion in the Atmosphere Following a Hypothetical Reactor Accident, Risø, Denmark, April 22-25 (1980).

/VO83/ Vogt, S., Thomas, P.; Analysis of Tetroon Flights Performed during the PUKK Meso-scale Experiment. 14th Int. Techn. Meeting on Air Pollution Modelling and its Application. Copenhagen,Denmark,Sep. 27-30 (1983)

Tetroon	Launch time CET	Stability category	Mean flight level above launching site	Mean transport speed	Mean wind direction**)	Range		Site of touchdown
						flight distance tracked	duration of flight	
SI8501	15.11 10:10	D	400 m	3.3 m/s	69°	9.8 km	0:49 h:min	Rumisberg
SI8502	15.11 11:37	D	250 m	3.4 m/s	88°	6.4 km	0:31 h:min	Olten
SI8503	15.11 12:25	D	300 m	4.3 m/s	75°	10.8 km	0:42 h:min	Hägendorf
SI8504	17.11 9:21	D	300 m	5.5 m/s	80°	10.6 km	0:32 h:min	Rickenbach
SI8505	17.11 10:46	D	550 m	5.4 m/s	71°	14.1 km	0:44 h:min	Highway intersection Härkingen
SI8506	17.11 11:48	D	<700 m*)	4.7 m/s	71°	4.5 km	0:16 h:min	Kappel
SI8507	17.11 13:14	D	150 m	3.8 m/s	69°	4.2 km	0:19 h:min	Dulliken
SI8508	27.11 10:15	B	300 m	1.2 m/s	256°	2.9 km	0:42 h:min	Thalheim
SI8509	27.11 11:47	A	150 m	1.0 m/s	83°	5.1 km	1:24 h:min	Wintnau bei Olten
SI8510	27.11 14.40	D	300 m	1.5 m/s	229°	6.4 km	1:11 h:min	Auenstein

*) mean flight level not reached within tracked distance
**) derived from tetroon flight data

Tab. 1 Tetroon flight data

Method of calcualtion σ_y	No of series	Tetroon used	Range of flight	σ_o	p	Correlation coefficient
From successive tetroon releases	1	SI8501 SI8502 SI8503	6.0 km	0.430	0.853	0.868
	2	SI8504 SI8505 SI8506 SI8507	4.0 km	7.850	0.499	0.847
From a single trajectory		SI8501	6.0 km	0.053	1.103	0.967
		SI8502	6.0 km	0.017	1.219	0.951
		SI8503	6.0 km	1.095	0.692	0.971
		SI8504	4.0 km	0.203	0.804	0.989
		SI8505	4.0 km	0.022	1.185	0.978
		SI8506	4.0 km	0.077	0.901	0.982
		SI8507	4.0 km	0.056	1.030	0.994
Combination of several single tetroon trajectories	1	SI8501 SI8502 SI8503	6.0 km	0.099	1.005	
	2	SI8504 SI8505 SI8506 SI8507	4.0 km	0.066	0.980	

Tab. 2 σ_y-evaluation based on different method ($\sigma_y = \sigma_o x^p$).

Series No.	Method to calculate σ_y	Downwind distance x in m 1000	2000	3000	4000	5000	6000
1	$\sigma_{y1}=0.430x^{0.853}$ (first method, successive trajectories)	155	281	389	508	614	718
	$\sigma_{y2}=0.099x^{1.005}$ (second method, combination of single trajectories)	102	205	309	412	515	619
	$\overline{\sigma_{ym}}$	120	155	120	203	278	298
	$\sigma_{ytot} = \left(\sigma_{y2}^2 + \overline{\sigma}_{ym}^2\right)^{1/2}$	158	257	331	450	586	687
	$\Delta\sigma_y = \frac{(\sigma_{ytot} - \sigma_{y1})}{\sigma_{y1}} \cdot 100$	+1.9%	-8.5%	-16.8%	-9.6%	-4.6%	-4.3%
2	$\sigma_{y1} = 7.850x^{0.499}$	250	350	430	492	-	-
	$\sigma_{y2} = 0.066x^{0.980}$	58	114	169	224	-	-
	$\overline{\sigma}_{ym}$	91	189	190	161	-	-
	σ_{ytot}	108	221	254	276	-	-
	$\Delta\sigma_y$	-56.8%	-36.9%	-40.9%	-43.9%	-	-

Tab. 3 σ_y - values in m estimated by different methods

Part of trajectory	Duration of flight (s)	Flight path (m)	Downwind distance (m)	$\sigma_{yK}=\sigma_v \cdot tf_y$	$\sigma_{y,eff}=(\sum_{i=1}^{K}\sigma_{y,i}^2)^{1/2}$	$\sigma_{y,PG}(B)$ *)
K_1	339	256	-164	70	70	
K_2	370	407	101	83	109	18
K_3	439		503	35	115	76
	830		1000	100	152	141
	1180		1500	154	216	203
	1600		2001	171	275	263

*) σ_y-value of the Pasquill-Gifford curves for category B

Tab. 4: σ_y-evaluation based on tetroon SI8508

Tetroon	Flight time CET	Duration (s)	Vector wind $\mathbb{V}$ (m/s)			Turbulence intensity			Fluctuation of wind direction (degree)		$\Delta\theta/\sigma_\theta$
			mean	min	max	i_x	i_y	i_z	σ_θ	$\Delta\theta$	
SI8509	12.17.10-12.28.40	90	0.43	0.36	0.50	0.068	0.346	0.224	18.43	57.26	3.11
	12.37.10-12.46.50	580	0.39	0.24	0.57	0.219	0.190	0.156	14.19	63.10	4.45
	12.48.10-12.50.50	160	0.36	0.19	0.48	0.256	0.469	0.267	24.65	57.10	2.32
	12.56.20-12.58.40	140	0.47	0.38	0.59	0.170	0.435	0.148	26.46	79.80	3.02
SI8510	13.42.50-13.44.10	80	0.35	0.24	0.45	0.271	0.073	0.073	13.34	42.58	3.19
	13.51.10-13.55.00	230	0.32	0.16	0.50	0.545	0.557	0.929	71.56	255.20	3.57
Average		213	0.39	0.26	0.52	0.255	0.348	0.299	28.11	92.51	3.28

Tab. 5: Wind conditions and turbulence intensity under calm conditions

Tetroon	Flight time CET	Duration (s)	Vector wind $\mathbb{V}$ (m/s)			Turbulence intensity			Fluctuation of wind direction (degree)		
			mean	min	max	i_x	i_y	i_z	σ_Θ	$\Delta\Theta$	$\Delta\Theta/\sigma_\Theta$
SI8508	10.18.50–10.20.40	110	0.83	0.74	0.95	0.162	0.366	0.318	61.45	126.53	2.06
	10.25.50–10.29.10	200	0.87	0.74	0.99	0.080	0.212	0.018	11.10	40.93	3.69
SI8509	12.22.40–12.27.20	280	0.66	0.50	0.97	0.268	0.469	0.622	26.65	100.27	3.76
	12.28.40 12.37.10	510	0.58	0.50	0.71	0.109	0.231	0.189	13.35	58.19	4.36
	12.50.50–12.53.00	130	0.78	0.59	0.95	0.149	0.069	0.145	5.49	17.75	3.23
	12.54.20–12.56.20	120	0.71	0.50	0.95	0.216	0.129	0.185	9.10	27.46	3.02
	13.01.30–13.04.50	200	0.90	0.81	0.99	0.056	0.210	0.241	14.09	43.97	3.12
	13.05.00–13.07.10	130	0.79	0.64	0.99	0.115	0.251	0.366	12.27	35.40	2.89
SI8510	13.45.50–13.47.40	110	0.66	0.51	0.95	0.242	0.159	0.437	10.51	32.95	3.14
	13.49.50–13.51.20	90	0.70	0.50	0.95	0.239	0.026	0.084	42.71	180.01	4.21
Average		188	0.75	0.60	0.94	0.164	0.215	0.280	20.68	66.35	3.35

Tab. 6: Wind conditions and turbulence intensity under weak wind conditions

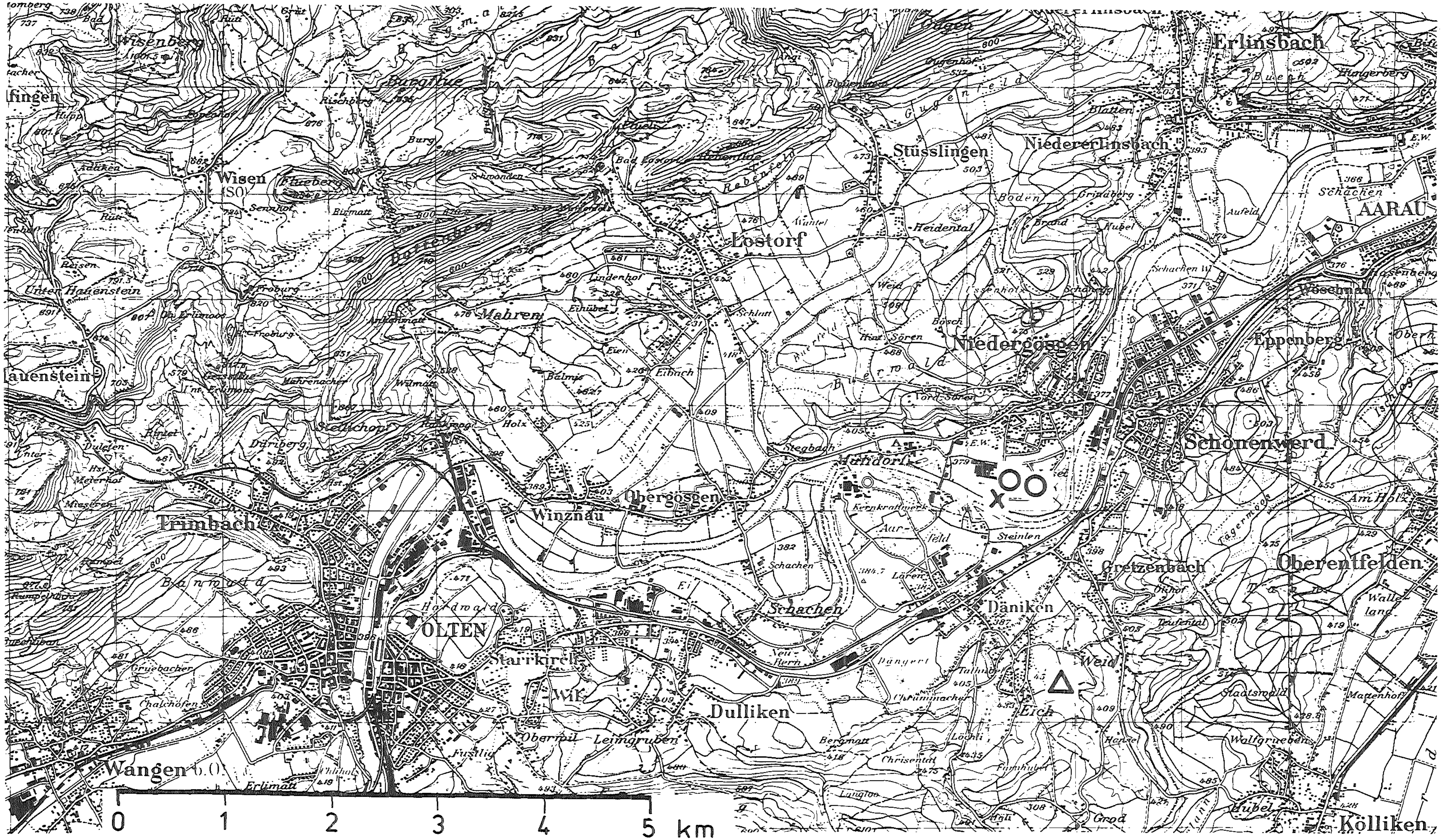

Fig. 1 Experimental area

△ Operation base of radar

○ Tetroon launching points

x Meteorological tower and tracer release point

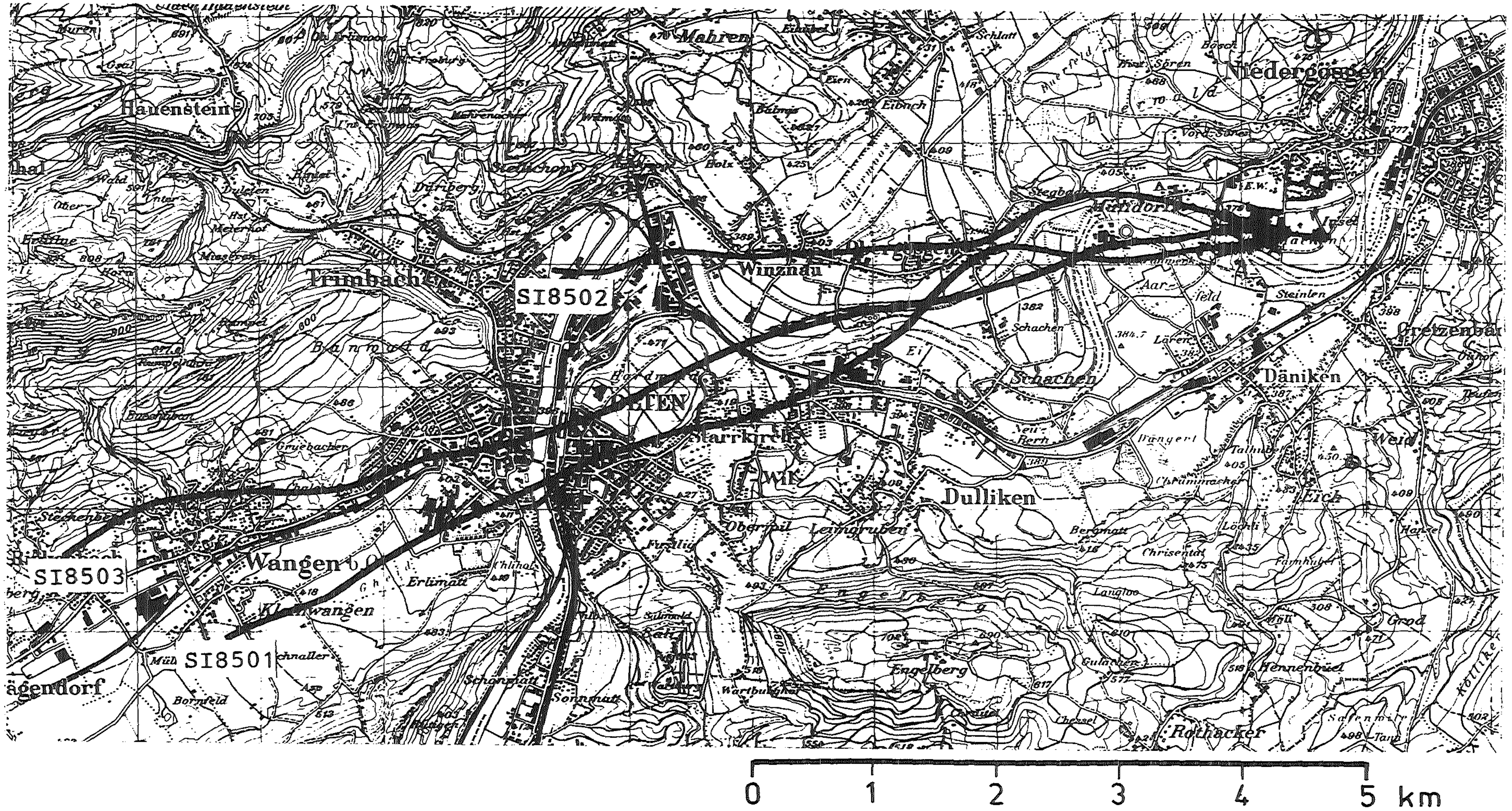

Fig. 2 Trajectories of flights on November 15, 1985

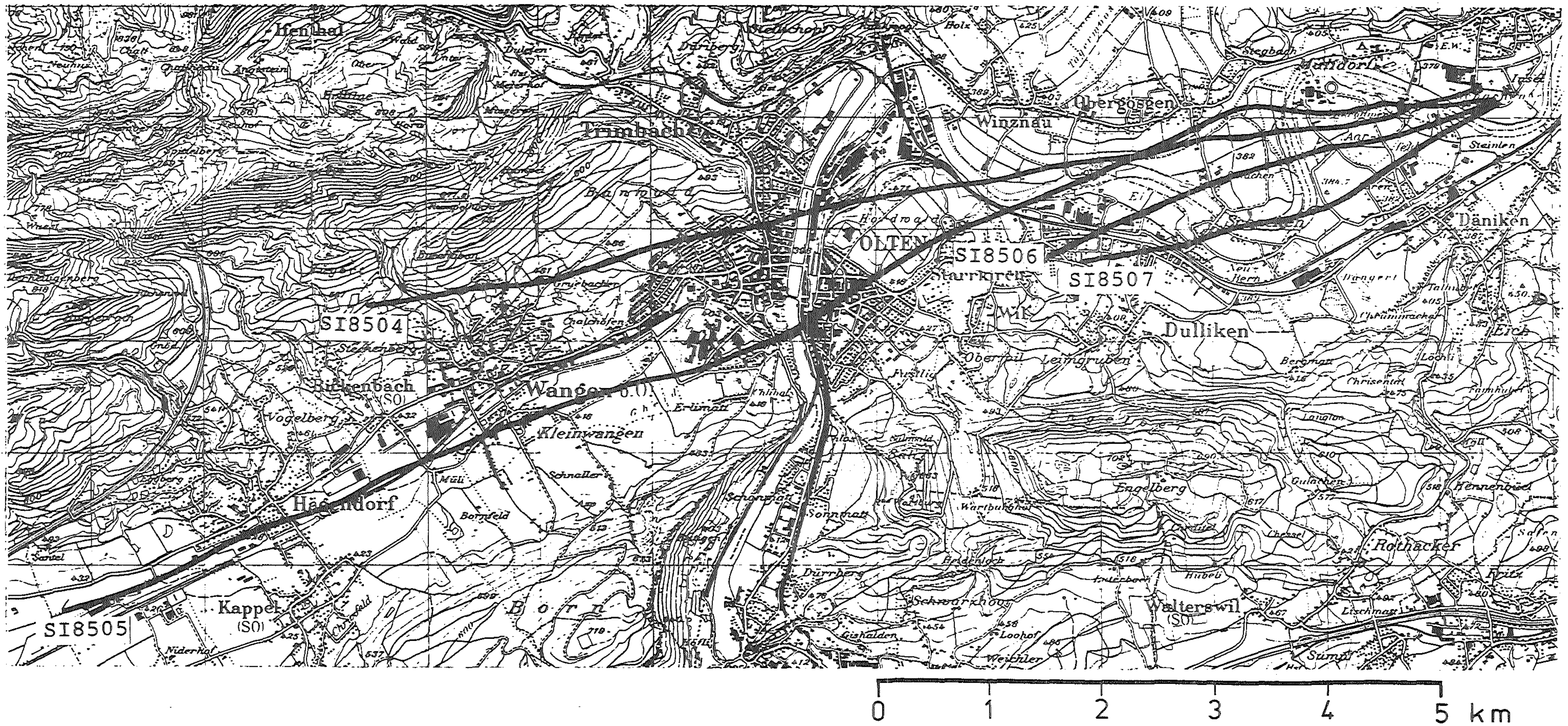

Fig. 3 Trajectories of flights on November 17, 1985

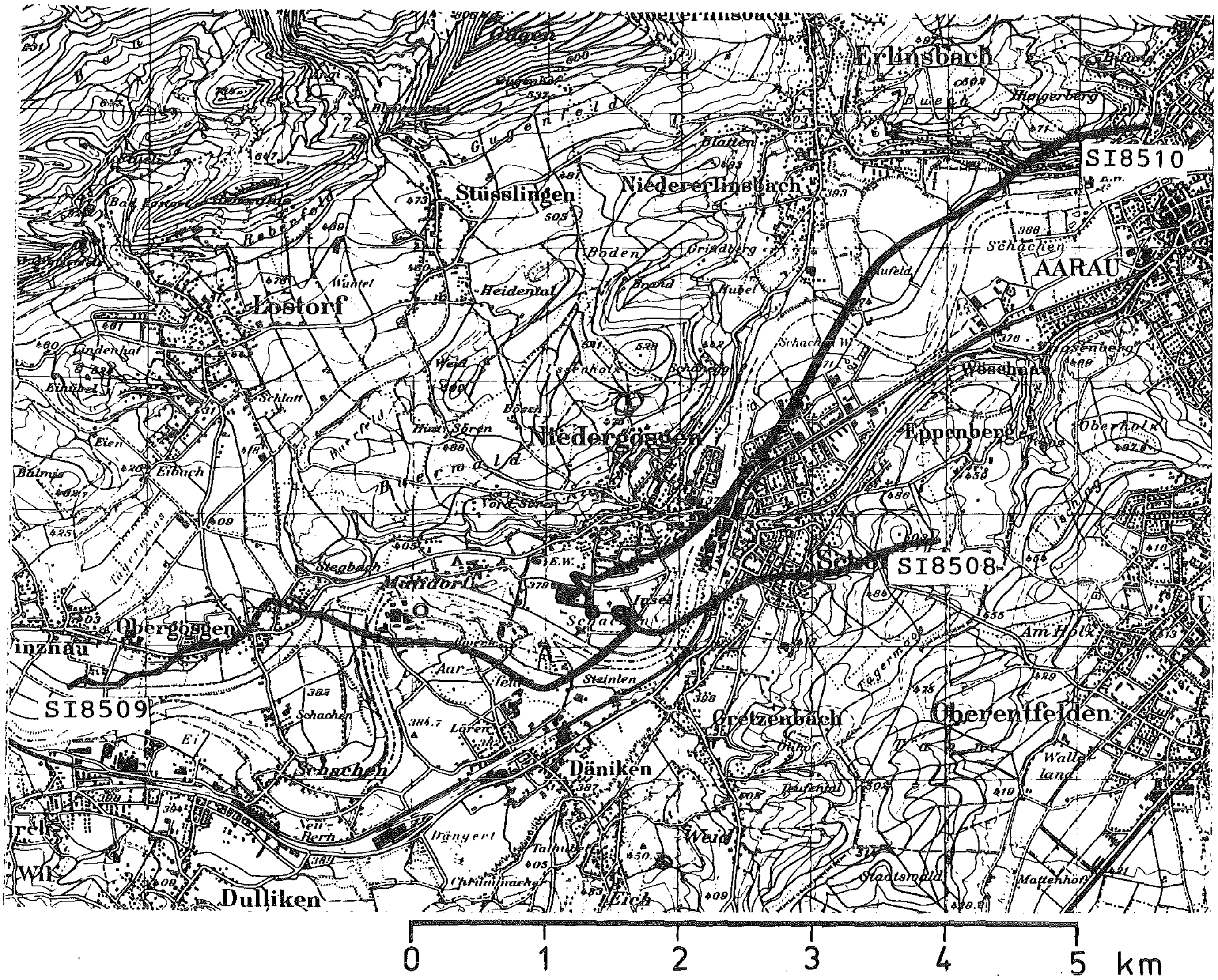

Fig. 4 Trajectories of flights on November 27, 1985

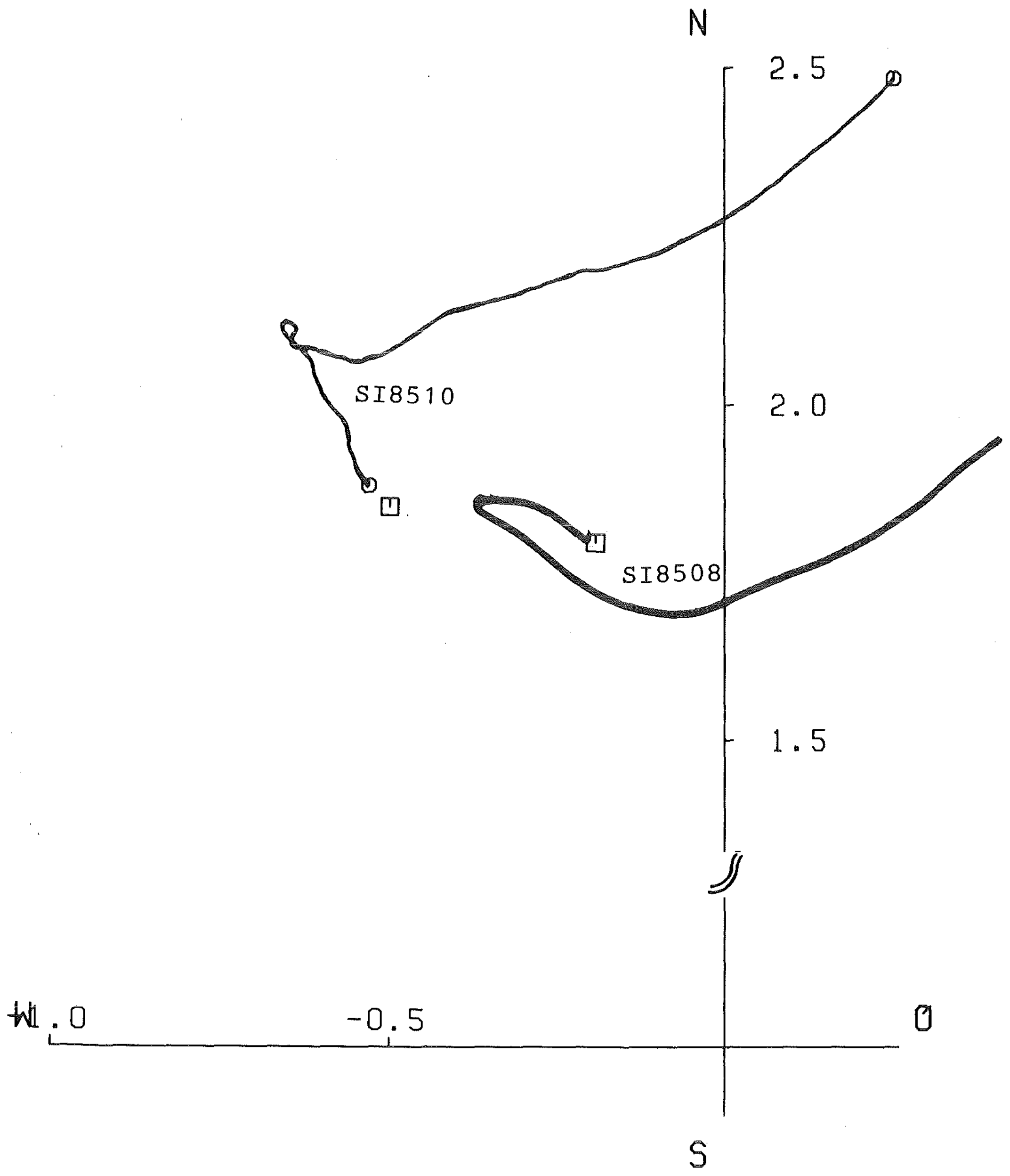

Fig. 5 Enlargement of Fig. 4 for flights SI8508 and SI8510

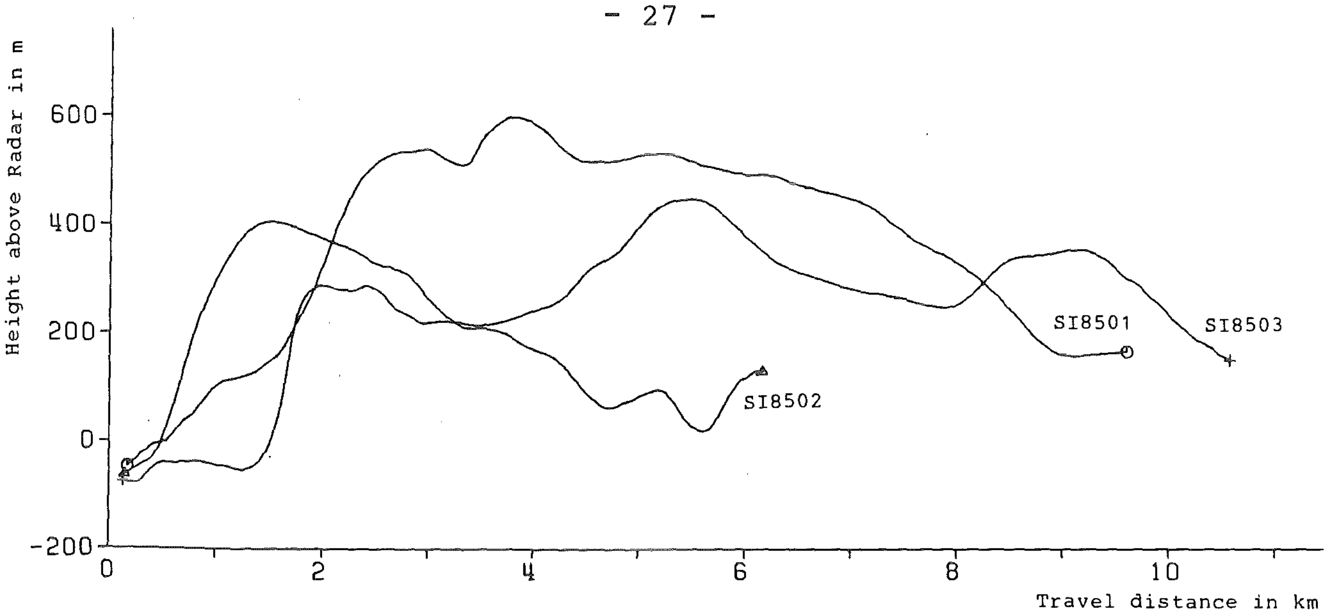

Fig. 6 Profile of tetroon flights on November 15, 1985

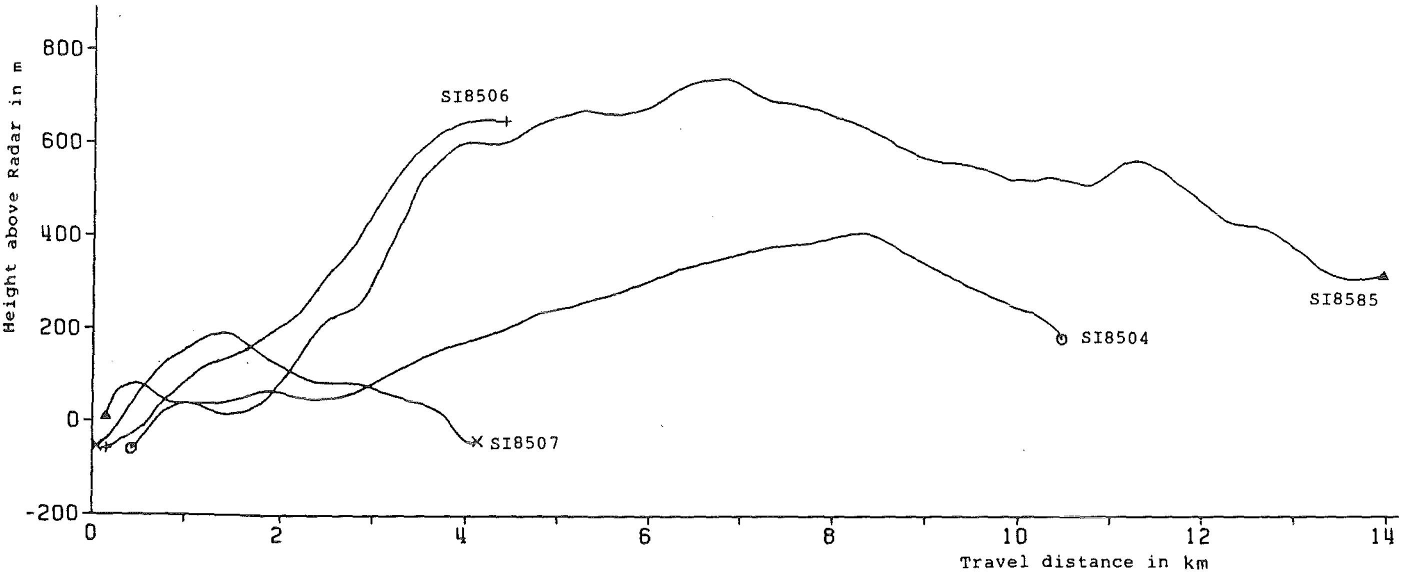

Fig. 7 Profile of tetroon flights on November 17, 1985

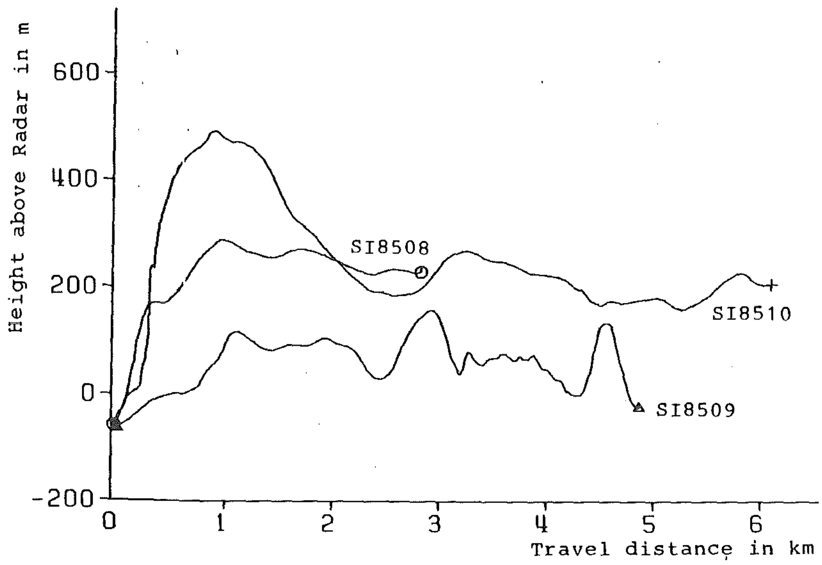

Fig. 8 Profile of tetroon flights on November 27, 1985

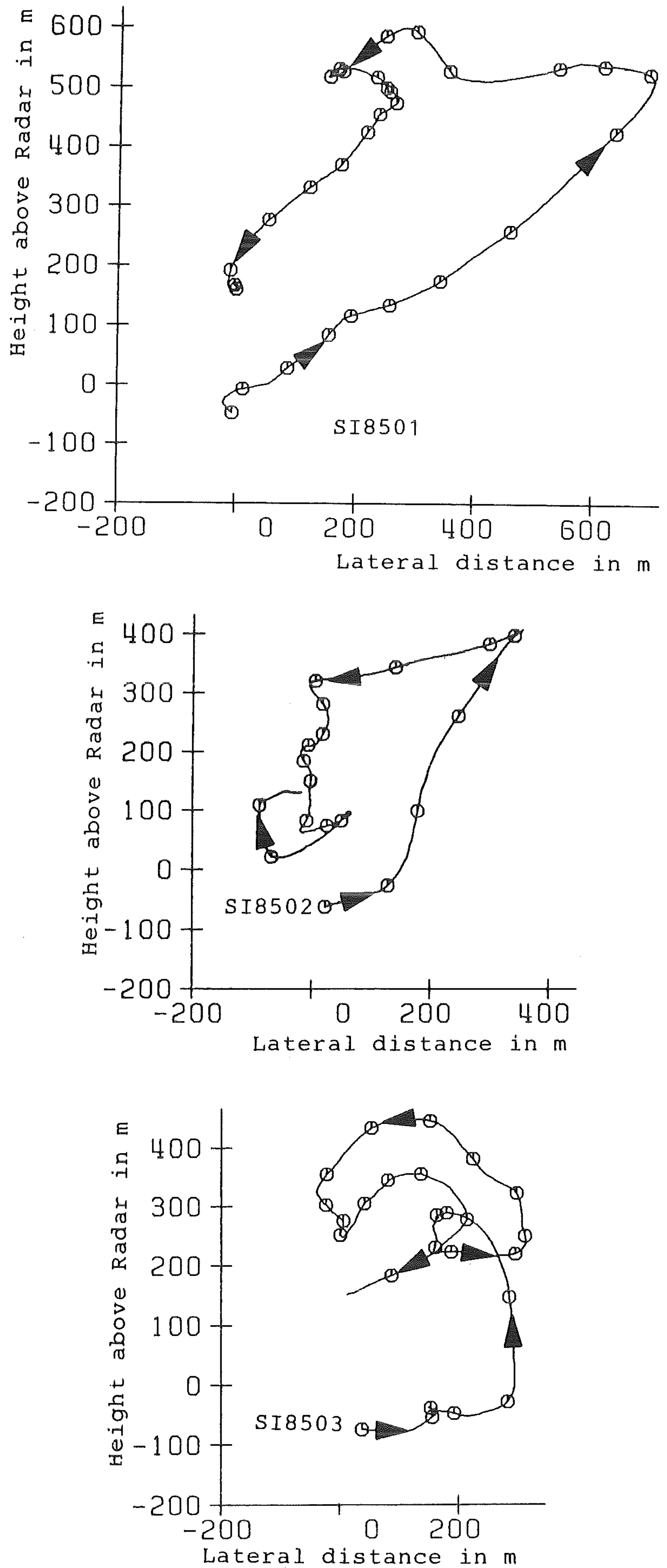

Fig. 9 Trajectories in the vertical-lateral plane looking downstream for the flights on November 15, 1985

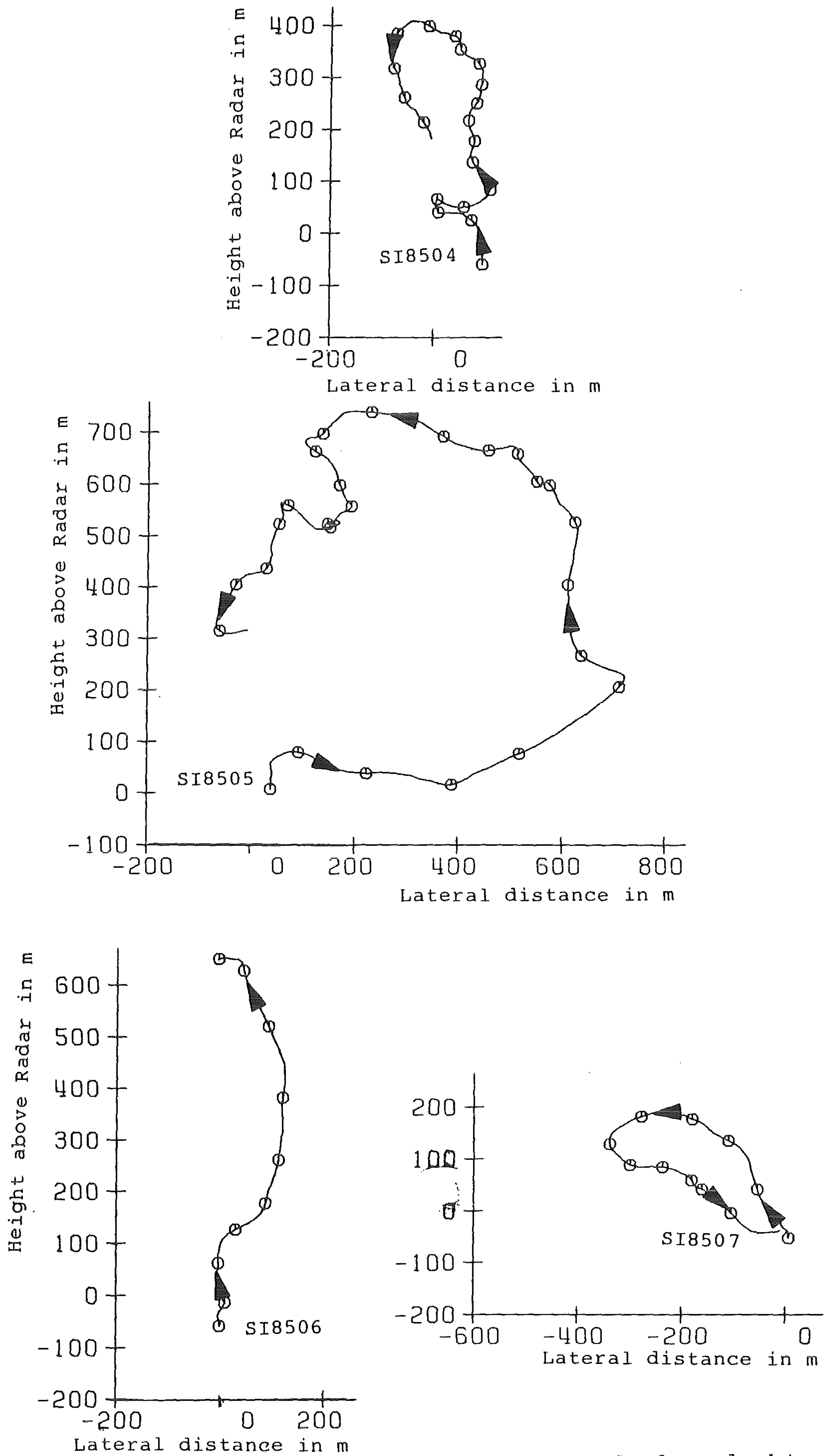

Fig. 10 Trajectories in the vertical-lateral plane looking downstream for the flights on November 17, 1985

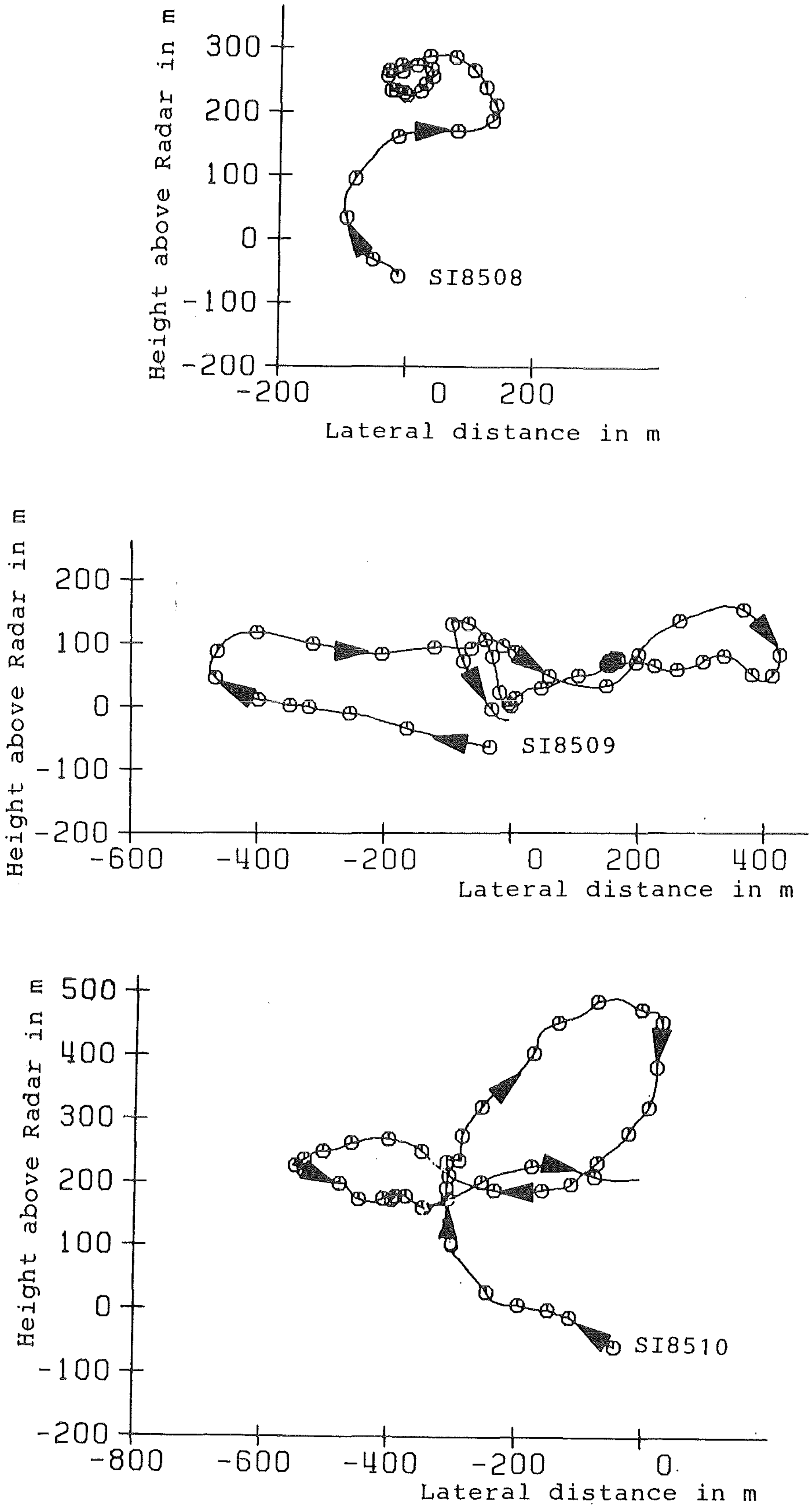

Fig. 11 Trajectories in the vertical-lateral plane looking downstream for the flights on November 27, 1985

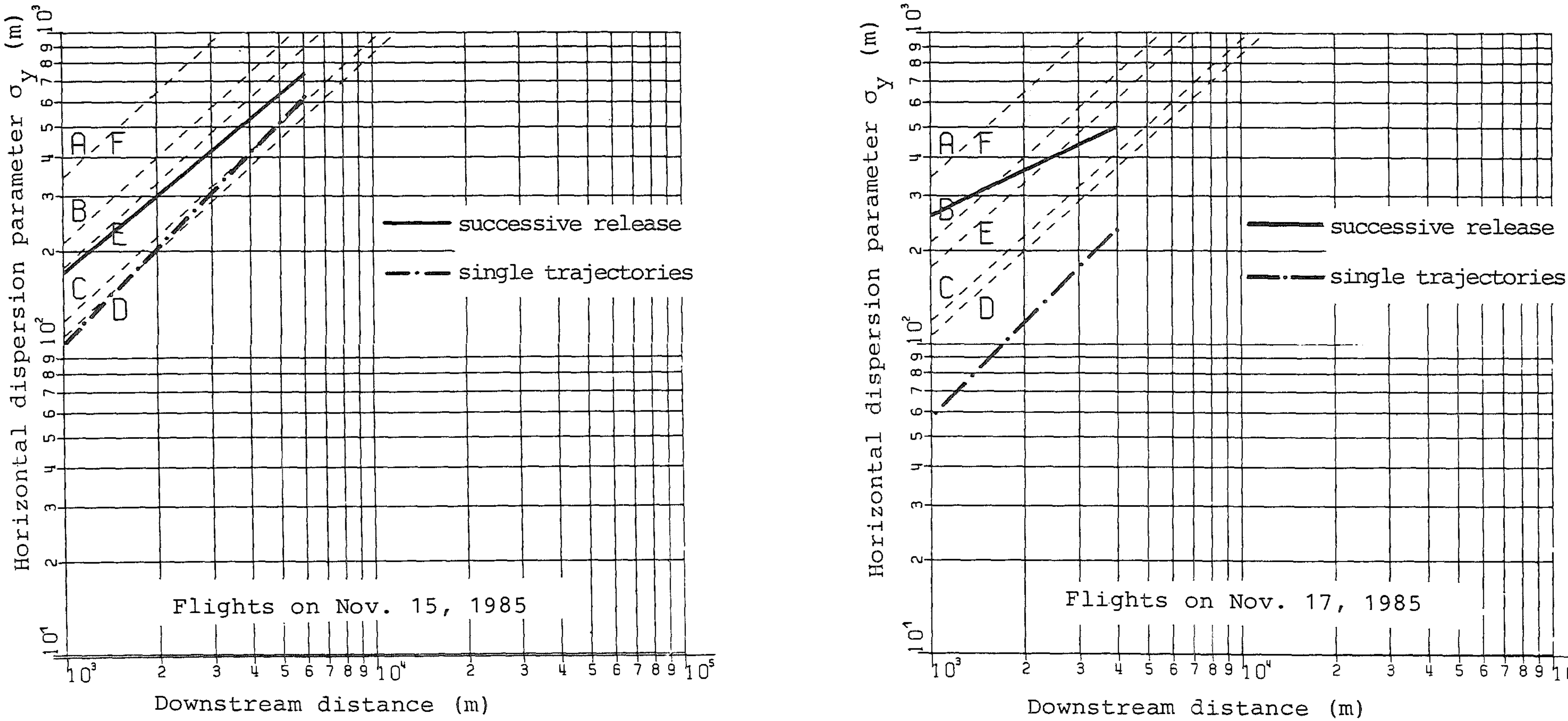

Fig. 12 Horizontal dispersion parameter σ_y as a function of downstream distance