# Lidar metingen in de omgeving van De Panne

Periode 27 november - 15 december 2000

VMM
Vlaamse Milieumaatschappij

VLAAMSE MILIEUMAATSCHAPPIJ
AFDELING MEETNETTEN EN ONDERZOEK
CDVP IMMISSIEMEETNETTEN LUCHT

# LIDAR METINGEN IN DE OMGEVING VAN DE PANNE

## 27 NOVEMBER – 15 DECEMBER 2000

Erembodegem, mei 2001

**Documentbeschrijving**

## 1. Titel rapport

Lidar metingen in de omgeving van De Panne.
27 november – 15 december 2000.

## 2. Uitvoerende Dienst

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Vlaamse Milieumaatschappij in het kader van het Interreg project: Polluerende atmosferische deeltjes langsheen de Frans-Vlaamse Noordzeekust: grenstransporten en impact op het leefmilieu. Grensoverschrijdende samenwerking en sensibilisering (AEROSOL).

De studie werd verricht met steun van:

- De Provincie West-Vlaanderen
- De Vlaamse Gemeenschap
- De Europese Unie (Interreg)

## 4. Inhoud

Dit rapport beschrijft de resultaten van de Lidar metingen uitgevoerd in De Panne, Houtem in de periode van 27 november tot 15 december 2000.
De metingen werden uitgevoerd en het rapport werd samengesteld door de firma Lidar s.r.o.

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Samenvatting

In de periode van 27 november tot en met 15 december 2000 werden Lidar metingen uitgevoerd in De Panne en Houtem. Er werden metingen uitgevoerd van zwaveldioxide ($SO_2$), stikstofdioxide ($NO_2$), ozon ($O_3$) en de distributie van aerosolen.

Op 27 november 2000 werden metingen uitgevoerd in Adinkerke. Op 28 november, 2 en 3 december, 10 en 14 december 2000 werden metingen uitgevoerd in De Panne. Op 15 december werd een meting uitgevoerd in Houtem.

De Lidar meetmethodologie heeft als basiselement een laser. Deze laser emitteert korte lichtpulsen met twee verschillende golflengten, $\lambda$ on resp. $\lambda$ off. De intensiteit van het licht met golflengte $\lambda$ on is gekozen binnen een absorptieband van het gas dat men wenst te meten. Het licht met golflengte $\lambda$ off wordt niet geabsorbeerd door de polluent en fungeert als referentie. Een gedeelte van het uitgezonden licht wordt teruggestrooid naar het Lidar systeem, na interactie met luchtmoleculen en aerosolen. Analyse van de teruggestrooide lichtstraling, laat toe om een concentratieprofiel over het gemeten traject op stellen.

Profielen kunnen opgesteld worden in horizontale en verticale richting. Tevens werd de windsnelheid en -richting gemeten tot een hoogte van 1500 meter met een SODAR systeem. De doelstelling van de meetcampagne was na te gaan of enige impact van de industriële zone rond Duinkerken kon vastgesteld worden.

In de periode van 27 november tot 9 december 2000 waren de meteo-omstandigheden niet zo geschikt om de luchtverontreiniging komende van Duinkerken te meten. De wind kwam vooral vanuit het zuiden. Dit betekent dat de luchtverontreiniging vanuit Duinkerken vooral over de zee waait en de impact in De Panne niet of slechts beperkt kon gemeten worden. Dit deed zich zeker voor in de eerste vier dagen. In deze meetperiode was de gemeten verontreiniging van $SO_2$ en $NO_2$ meestal laag. Verhoogde concentraties tot 100µg/m³ van $NO_2$ werden gemeten op 27 november. Deze verhoogde concentraties konden toegeschreven worden aan de verkeersemissies boven een autostrade. Ook andere verhoogde metingen konden toegeschreven worden aan lokale bronnen. In deze periode werden ook aerosol lagen gedetecteerd, deze konden toegeschreven worden aan een natuurlijke oorsprong, zoals wolken, mist.

In de periode van 10 tot 15 december werd verhoogde luchtverontreiniging van $SO_2$, concentraties tot 250µg/m³, gemeten. $SO_2$ pluimen werden zowel aan de grond als in hogere lagen gemeten. Gelet op de windrichting (west tot zuidwest) kon deze luchtverontreiniging toegeschreven worden aan industriële emissies vanuit Duinkerken. De verhoogde $SO_2$ concentraties gingen soms samen met verhoogde aerosol concentraties.

# Report on the Lidar Measurement of Air Pollution in the Area of De Panne 27. 11. - 15. 12. 2000

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# Table of measurement days

| Chapter | Date | Location | Pollutants Measured | | | |
|---|---|---|---|---|---|---|
| 3 | 27.11.2000 | Adinkerke | Aerosols | | $NO_2$ | |
| 4 | 28.11.2000 | De Panne | Aerosols | $SO_2$ | | Ozon |
| 5 | 2.12.2000 | De Panne | Aerosols | | $NO_2$ | |
| 6 | 3.12.2000 | De Panne | Aerosols | $SO_2$ | | Ozon |
| 7 | 10.12.2000 | De Panne | Aerosols | $SO_2$ | | Ozon |
| 8 | 11.12.2000 | De Panne | | | | Ozon |
| 9 | 13.12.2000 | De Panne | Aerosols | $SO_2$ | | Ozon |
| 10 | 14.12.2000 | De Panne | Aerosols | $SO_2$ | | Ozon |
| 11 | 15.12.2000 | Houtem | Aerosols | $SO_2$ | | Ozon |

# 1 Introduction

In the period from the 27th November to the 15th December, the company Lidar s.r.o. performed air pollution measurements in the area of De Panne in Belgium. The measurement campaign was ordered by The Flemish Environmental Agency (Vlaamse Milieumaatschappij-VMM). Measurements of aerosol distribution and $SO_2$, $NO_2$, and Ozone concentrations were carried out at various spots of De Panne region. Together with the lidar measurement also sodar data about wind speed and direction in various heights were collected. The measurements were carried out using a mobile laboratory that consists of the LIDAR 510M and SODAR PA2 systems.

This report consists of 12 sections. In the first section, which is called **Measurement Principles,** theoretical principles of the lidar and sodar method are described. In the following 9 sections named by the **Place and Date** of each measurement, conditions on each day, and the measurement itself, and it's results are described. In the **Conclusion** achieved results are briefly summarized.

# 2 Measurement Principles

## 2.1 Lidar Measurement Principles

### Measurement of Gas Concentration

**LIDAR** (**L**ight **D**etection **A**nd **R**anging) is a laser remote sensing technique that provides high spatial resolution. For air pollution measurements a special lidar method called **DIAL** (**Di**fferential **A**bsorption **L**idar) is used. The DIAL method profits from unique absorption properties of each gas. It means that each gas has a characteristic absorption spectrum that can be used for its detection. The heart of our lidar system is a tunable Ti-Sapphire laser periodically emitting short light pulses on two different wavelengths $\lambda_{on}$ and $\lambda_{off}$. The intensity of the light of $\lambda_{on}$ wavelength, which is chosen within an absorption band of the gas measured, is being decreased by absorption as passing through areas of pollution. The light of $\lambda_{off}$ wavelength is not being absorbed by the pollutant and serves as reference.

A portion of the light emitted (of both wavelengths) is scattered on air molecules and aerosols back towards the lidar system. Intensity of such back-scattered light is detected with fine time resolution (40 ns). Analysis of the back-scattered light intensity of both wavelengths $\lambda_{on}$ and $\lambda_{off}$ permits determination of a concentration profile of pollutant measured on the trajectory of the laser pulses.

Mathematically the analysis represents solution of differential lidar equation, which is an analogy to radar equation. The final expression for the pollutant concentration $N_{gas}(r)$ in a distance r from the lidar system on the laser pulse trajectory is:

$$N_{gas}(r) = -\frac{1}{2\Delta\sigma_{gas}}\frac{d}{dr}\ln\frac{P(r,\lambda_{on})}{P(r,\lambda_{off})}.$$

$\Delta\sigma_{gas}$ is the absorption cross-section difference of pollutant measured, which is for given $\lambda_{on}$ and $\lambda_{off}$ a known value; $P(r,\lambda_{on})$ and $P(r,\lambda_{off})$ are the powers of detected back-scattered light for a given wavelength.

In addition the LIDAR 510M system enables motion of the periscope in both vertical and horizontal directions. As the periscope is simultaneously emitting laser pulses, and detecting the back-scattered light, concentration profile can be measured in any direction, and two-dimensional vertical and horizontal concentration maps can be created.

In the case of $SO_2$, Ozone, and $NO_2$ concentration measurements, the system LIDAR 510M has the following parameters:

| | $SO_2$ | Ozone | $NO_2$ |
|---|---|---|---|
| $\lambda_{on}$ [nm] | 286.9 | 282.4 | 398.3 |
| $\lambda_{off}$ [nm] | 286.3 | 286.9 | 397.0 |
| Laser pulse duration [ns] | 35 | 35 | 35 |
| Maximal reach* [m] | 2200 | 2100 | 2500 |
| Detection limit * [μg/m³] | 8 | 2 | 20 |

**Maximal reach and detection limits were determined, in accordance with the guideline VDI 4210, for a 15-minute measurement in one direction with a space resolution of 1000 m under the concentration of Ozone lower then 30 μg/m³ and visibility higher than 20 km.*

## Measurement of Aerosols

In order to capture quantitative distribution of aerosols in the air, a different method of the analysis of back-scattered signal is used. In literature it is often denoted as the **slope method**.

In this case just the back-scattered signal of one wavelength is studied, and as the name of the method suggest, the slope of this signal is analyzed. As a result the extinction coefficient $\alpha$ is computed. The final expression for this coefficient in a distance $r$, when on wavelength $\lambda$ is measured is:

$$\alpha(r,\lambda) = -\frac{1}{2}\frac{d}{dr}\ln\left(P(r,\lambda)r^2\right)$$

$P(r,\lambda)$ is the intensity of the detected back-scattered signal on the wavelength $\lambda$ and in a distance $r$ from the lidar.

As described above, the slope method provides only information about a spatial distribution of the extinction coefficient, whose value is proportional to the presence of aerosols. Nevertheless, we can't judge what kinds of aerosols are present in the air.

The slope method is also based on the assumption that the back-scattering coefficient remains constant, which is mainly the case by so called "dark aerosols", which aren't reflecting the light back to the lidar system. If "reflecting aerosols" are present in the air, then results of the slope analyses are usually distorted in the following way: The extinction coefficient first seemingly decreases in the area, where a reflecting aerosol cloud begins, and then it increases, as the aerosol cloud is deeper entered by the laser light. If we are aware of this behavior, we can profit from it and use it for a distinction between so called "dark" and "reflecting" aerosols. An example of a detected lidar signal from measurements in areas where "dark" and "reflecting" aerosols were present is shown in Fig. 2.1.

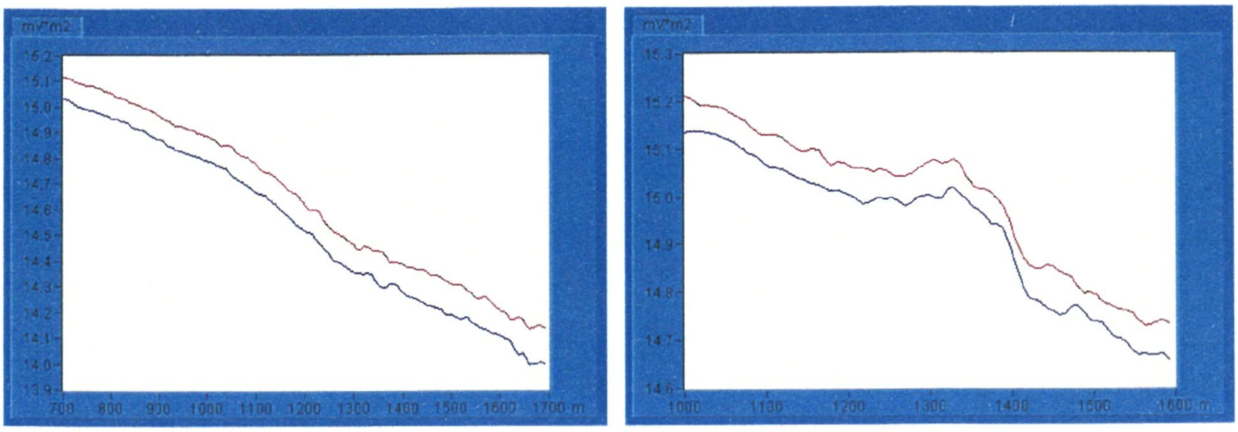



*Fig. 2.1 Lidar signal from the measurements in areas where, on the left picture, "dark aerosols" are present in the distance between 1000 and 1300 m and, on the right picture, "reflecting aerosols" are present in the distance between 1200 and 1400 m*

In the case of aerosol measurements the system LIDAR 510M has the following parameters:

| | Aerosols |
|---|---|
| λ [nm] | any |
| Laser pulse duration [ns] | 35 |
| Maximal reach* [m] | 3000 |
| Detection limit * [km$^{-1}$] | 0.05 |

* *Maximal reach and detection limits were determined, in accordance with the guideline VDI 4210, for a 15-minute measurement in one direction with a space resolution of 1000 m under the concentration of Ozone lower then 30 μg/m$^3$ and visibility higher than 20 km.*

## 2.2 Sodar Measurement principles

A **SODAR** (**So**und **D**etection **A**nd **R**anging) is an acoustic system designed for remote measurements of wind speed and direction in lower layers of the atmosphere. It can reach a height of 1500 m.

The sodar principle is again analogous to the one of radar or lidar. The sodar antenna emits short sound pulses (with frequency about 2 kHz) which are back-scattered at temperature inhomogeneities in the air. The antenna receives the echoed sound pulses, and so the amplitude and frequency of the back-scattered wave can be evaluated.

The height resolution is achieved by range gating, i.e. by considering the time the pulse needs to propagate from the antenna to the measured layer and back. From the amplitude of the back-scattered wave, detailed information about a turbulence structure in the atmospheric boundary layer is obtained. By evaluation of the spectrum, the wind speed is determined. This is possible because of Doppler frequency shift resulting from movement of the scattering temperature inhomogeneities with the wind. When multiple beams are emitted at different angles, a vertical profile of a three-dimensional wind vector is derived. Phase-delayed driving and sensing of the rows and columns of acoustic transducers generates different beam angles.

The hearth of the SODAR PA2 system forms an array of acoustic transducers that work as detectors of the echoed signals as well. Maximal reach of this system is 1500 m with a space resolution of 50 m. The used sound waves have a length between 10 and 30 cm.

# 3 Adinkerke 27. 11. 2000

## 3.1 Measurement Location and Time

On November the 27th, we measured concentration of $NO_2$; also extinction coefficients, hence the distribution of aerosols, were determined from the signal on $NO_2$ reference wavelength. The measurement was carried out from a location in Adinkerke, which is a village situated 3 km to the south from De Panne. The exact location of the mobile system is marked in Fig. 3.1. The measurement was conducted in a form of vertical scans. The exact direction of the two types of vertical scans V1 and V2 is also shown in Fig. 3.1. Direction to Dunkerque industrial area is marked by an arrow D. A picture of the lidar system during the measurement is shown in Fig. 3.2. The lidar measurement was carried out between 11:30 and 18:30.

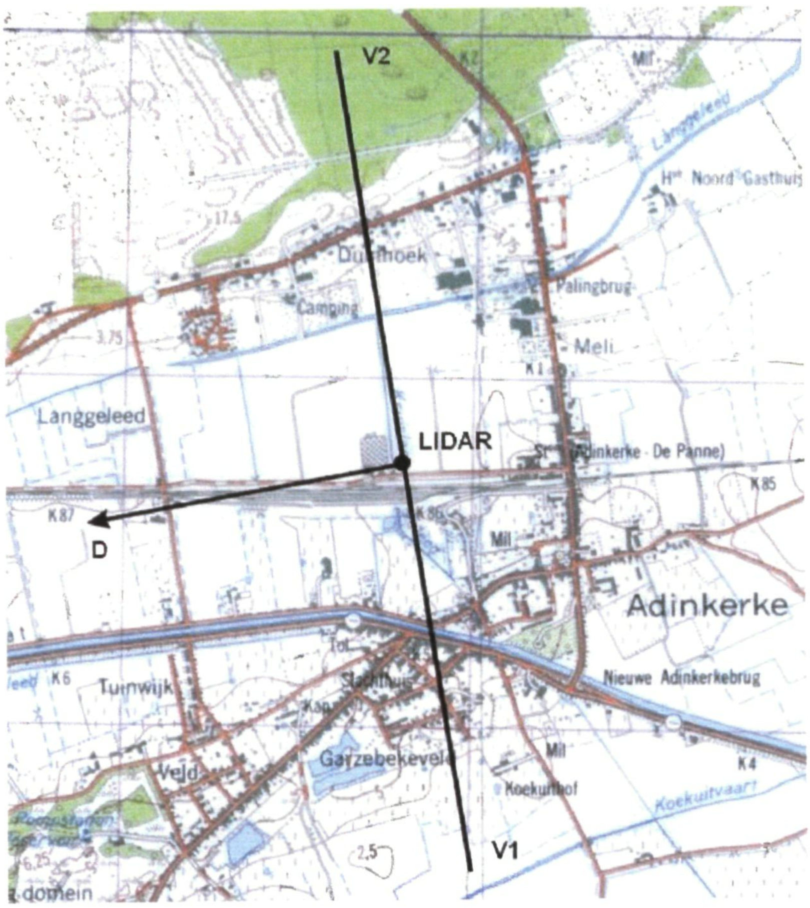



*Fig. 3.1 Location of the lidar system and the direction of vertical scans*

*Fig. 3.2 Lidar system during the measurement*

# 3.2 Meteorological situation

Figures 3.3 and 3.4 demonstrate the synoptical situation over Europe before and after the measurement.

In the beginning of the measurement, round noon, it was partly cloudy. In the afternoon it was cloudy and later overcast. The measurement ended before 19:00, when steady rain started. The temperature was round 11 °C.

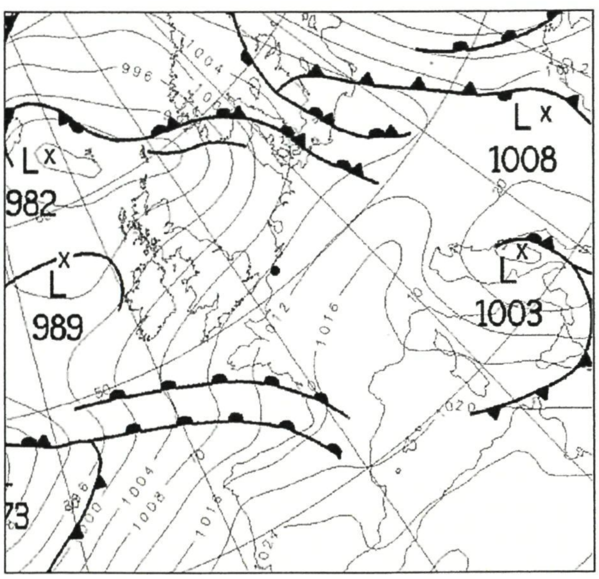



*Fig. 3.3 Synoptical situation*
*27. 11. 2000 at 0:00 UTC*

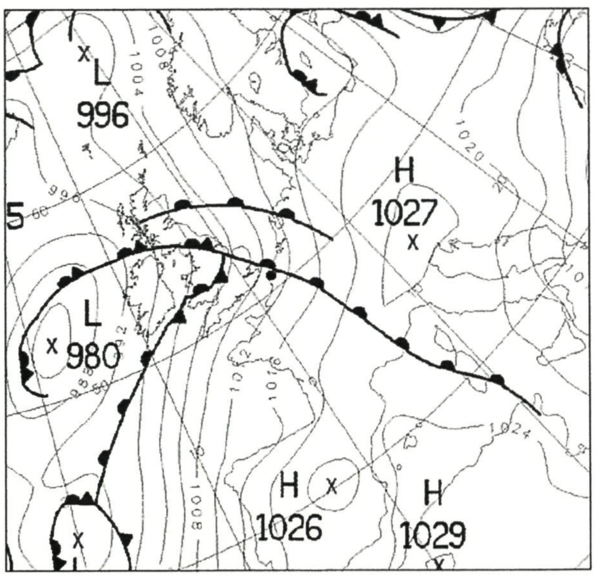



*Fig. 3.4 Synoptical situation*
*28. 11. 2000 at 0:00 UTC*

Wind speed and direction measured by sodar in various heights are graphed in Fig. 3.5 and Fig. 3.6. In the beginning of the measurement, round noon, the wind speed was reaching values over 6 m/s and it was increasing over the time until it reached more than 9 m/s by the ground at 19:00.

In the beginning of the lidar measurement, at 11:30, the wind direction was round 210°, which is the southwest, and it was turning towards the south until it reached 160° at 19:00.

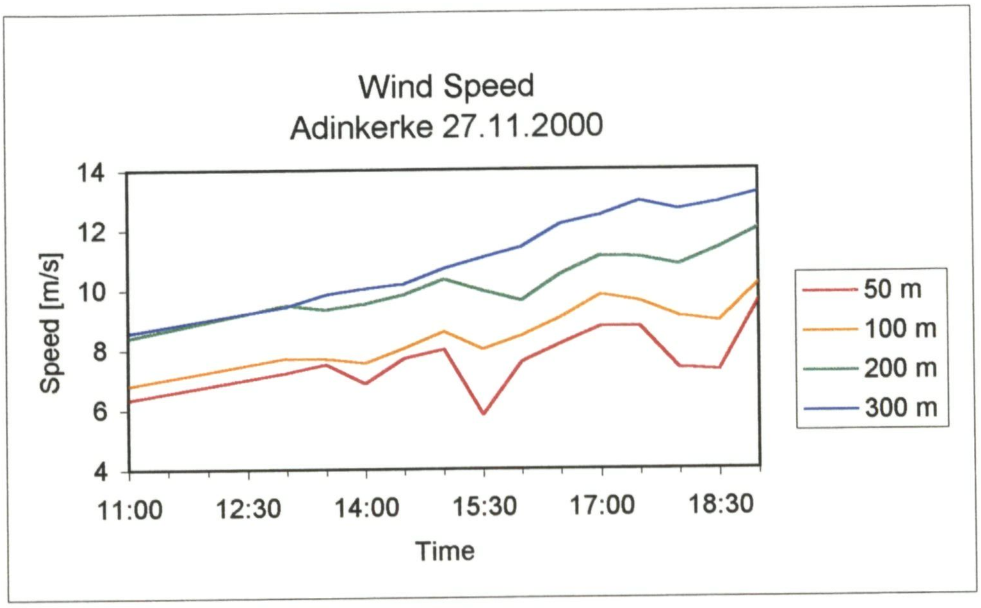



*Fig. 3.5 Wind speed in various heights during the measurement time*

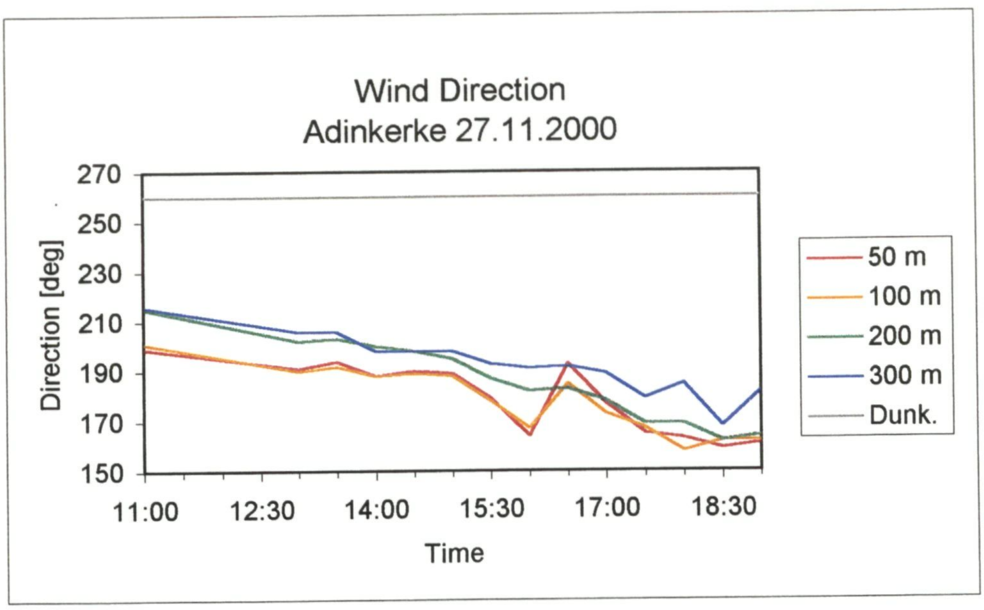



*Fig. 3.6 Wind direction in various heights during the measurement time*

# 3.3 Measurement Results

## Measurement of $NO_2$ Concentration

In Figures 3.7 – 3.10, vertical scans of $NO_2$ concentration are shown. In the period between 11:30 and 14:00 we measured vertical scans V1. The average $NO_2$ concentrations in these scans were less than 40 $\mu g.m^{-3}$. However, significantly increased $NO_2$ concentrations by the ground were detected in a distance of approximately 1200 m from the lidar (Fig. 3.7 and 3.8). Maximal concentrations were almost 100 $\mu g.m^{-3}$ in this area. As there was a highway in a distance of some 1200 m from the lidar, we suppose that the increased concentrations were caused by vehicle traffic. The highway can't be seen on the map (Fig. 3.1), because it was constructed after the map was printed.

In the period between 14:00 and 17:00 we measured vertical scans V2. The average $NO_2$ concentrations in these scans were less than 10 $\mu g.m^{-3}$, and no distinct areas with significantly increased concentrations were detected (Fig. 3.9 and 3.10).

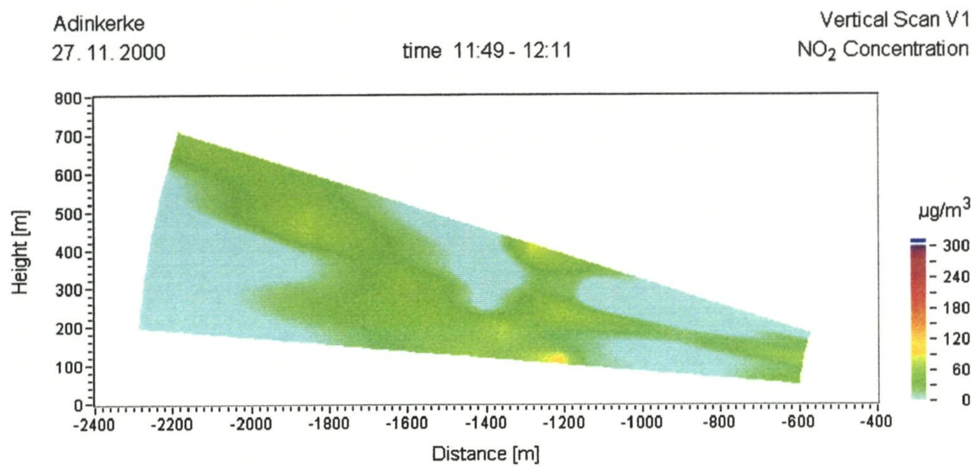



*Fig. 3.7*

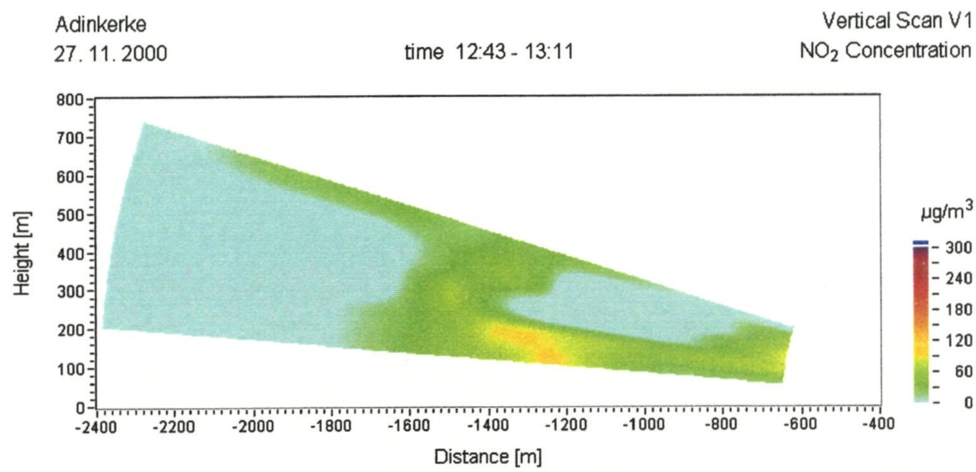



*Fig. 3.8*

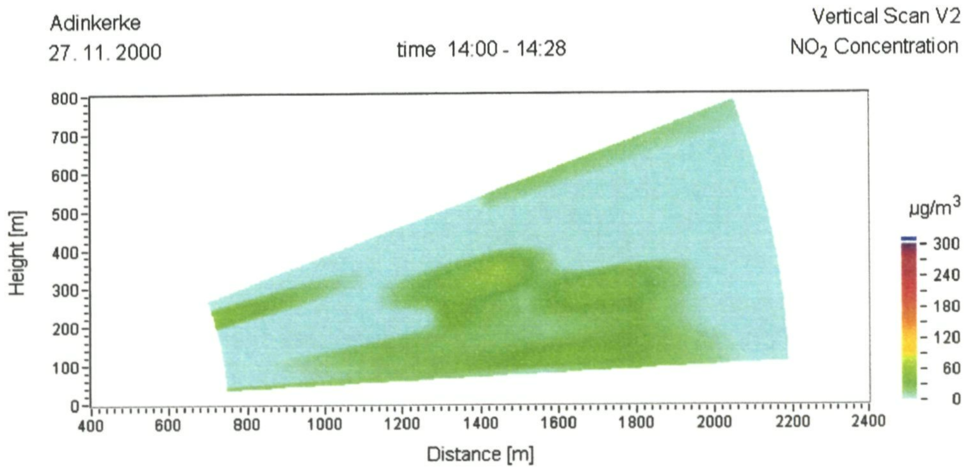



*Fig. 3.9*

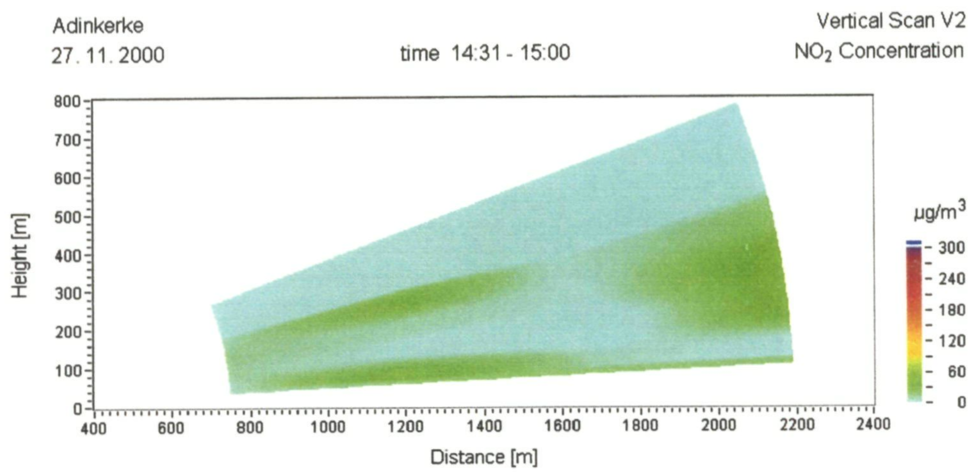



*Fig 3.10*

## Measurement of Aerosols

In Figures 3.11 – 3.16, vertical scans of extinction coefficient are shown. The extinction coefficients were measured on the wavelength 397.0 nm.

In the period between 11:30 and 14:00 we measured vertical scans V1. A weak aerosol layer was detected in a height of 250 m in these scans (Fig. 3.11 and 3.12).

In the period between 14:00 and 17:00 we measured vertical scans V2. A significant aerosol layer appeared in a height between 300 m and 400 m on these scans (Fig. 3.13 and 3.14). We suppose that it could be a thin layer of lower clouds. After 15:00, two aerosol layers were detected (Fig. 3.15). The first, less significant, was in a height of approximately 300 m and the second was between 450 m and 550 m. It seems that the second layer is of the same origin as the layers in Figures 3.13 and 3.14.

From 17:00 to 18:30 large vertical scan V1+V2 were measured. No distinguished isolated aerosol layers were detected on these scans (Fig. 3.16). The fall in extinction coefficient in the height of 1300 m is caused by clouds, which behaved as "reflecting aerosols" in this case.

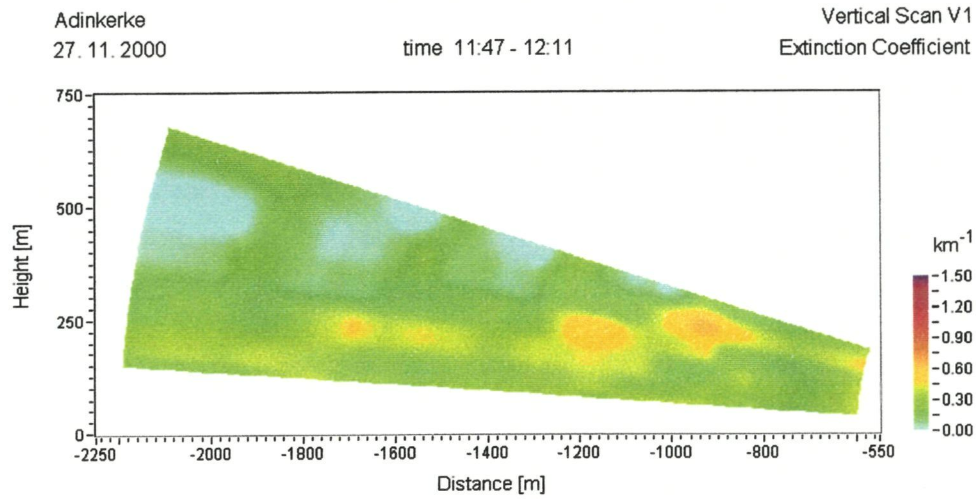



*Fig. 3.11*

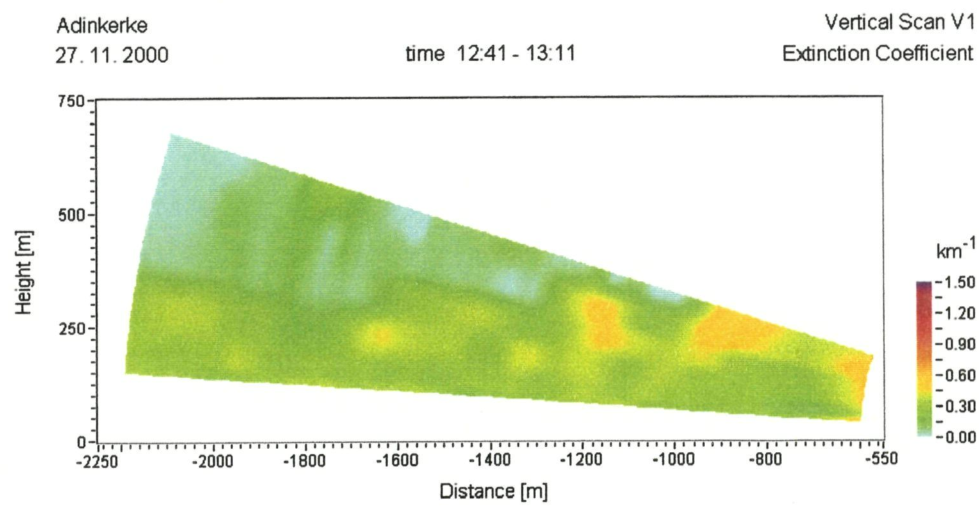



*Fig. 3.12*

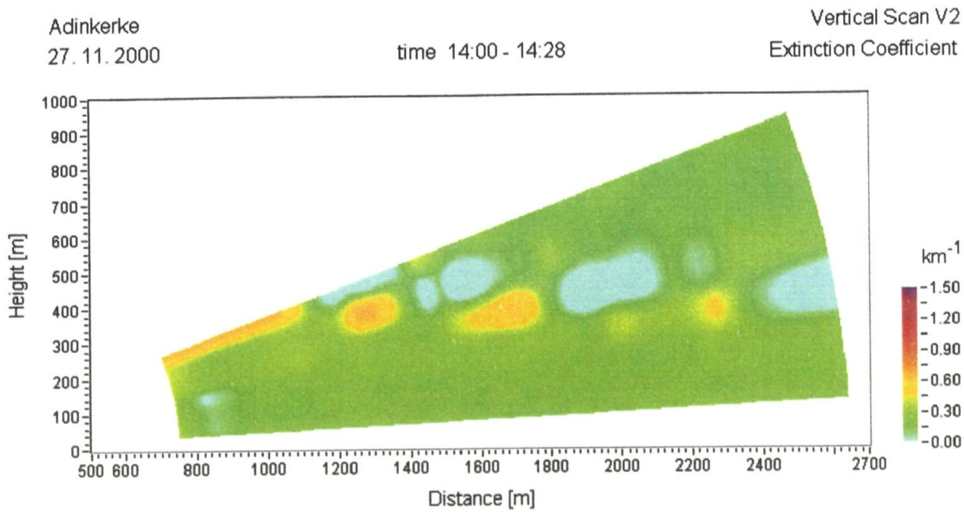



*Fig. 3.13*

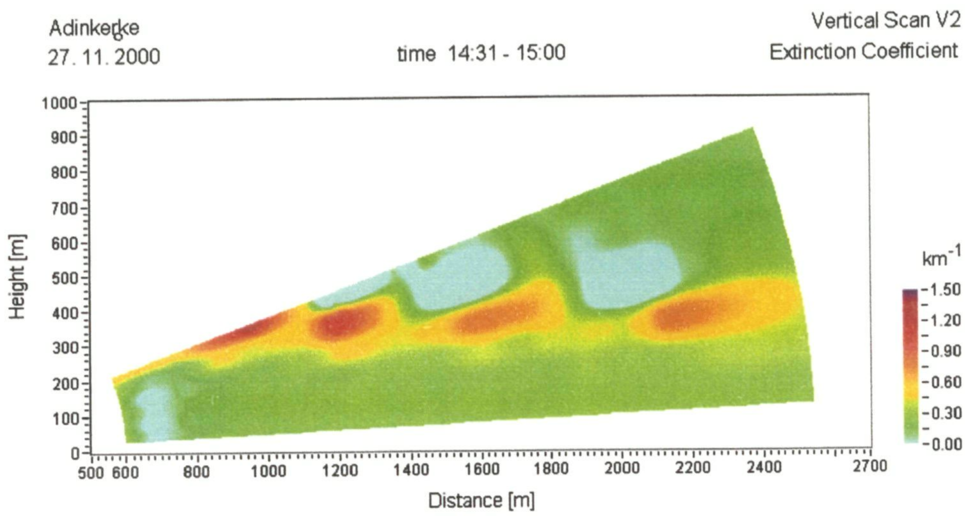



*Fig. 3.14*

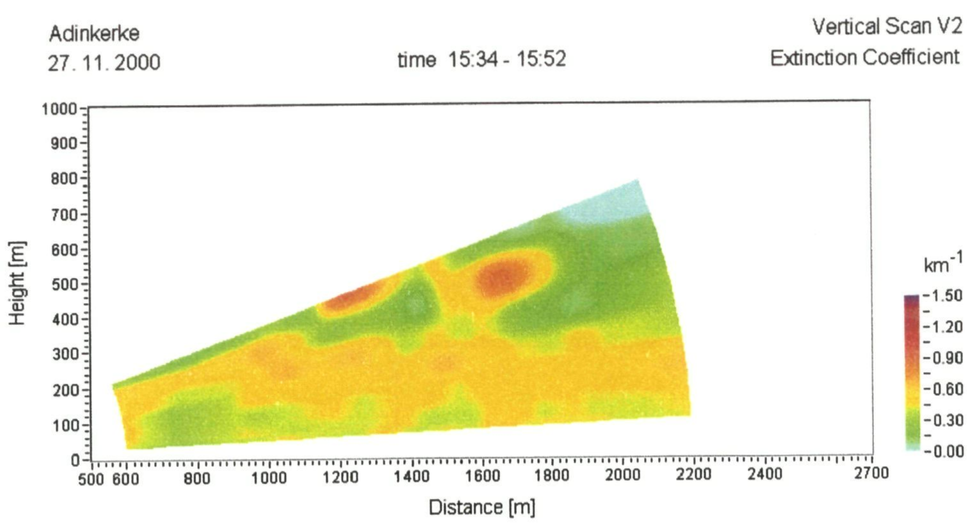
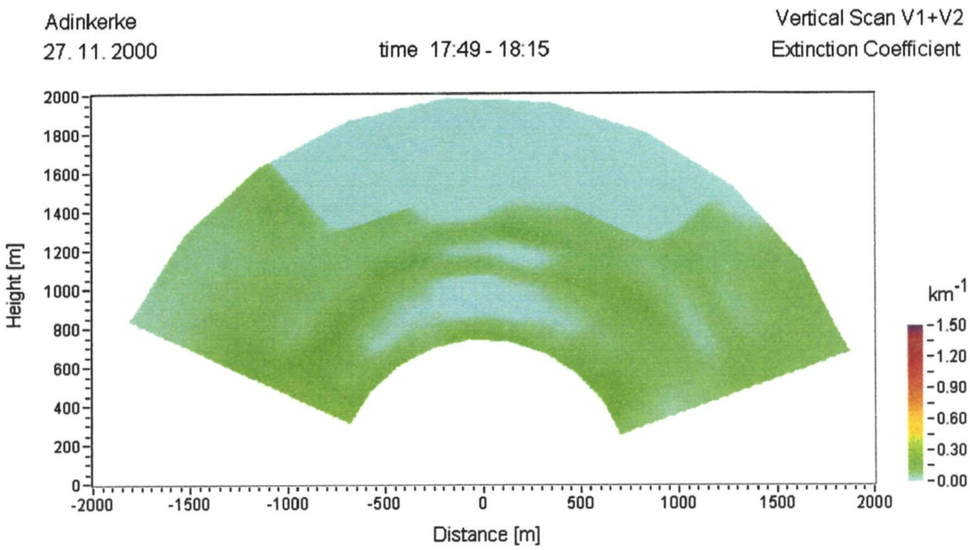



*Fig. 3.15*



Adinkerke
27. 11. 2000
time 17:49 - 18:15
Vertical Scan V1+V2
Extinction Coefficient
Height [m]
Distance [m]
km-1
-1.50
-1.20
-0.90
-0.60
-0.30
-0.00


*Fig. 3.16*

# 4 De Panne 28. 11. 2000

## 4.1 Measurement Location and Time

On November the 28th, we measured concentration of $SO_2$ and Ozone. Also extinction coefficients, hence the distribution of aerosols, were determined from the signal on $SO_2$ reference wavelength. The measurement was carried out from the sea bank in De Panne. The exact location of the mobile system is marked in Fig. 4.1. The measurement was conducted in a form of vertical scans. We measured in the direction over the sea (V1) and also large vertical scans were carried out including both directions over the sea and over the land (V1+V2). The exact direction of vertical scans is shown in Fig. 4.1. Direction to Dunkerque industrial area is marked by an arrow D. A picture of the lidar system during the measurement is shown in Fig. 4.2. The lidar measurement started at 10:00 and continued until 19:00.

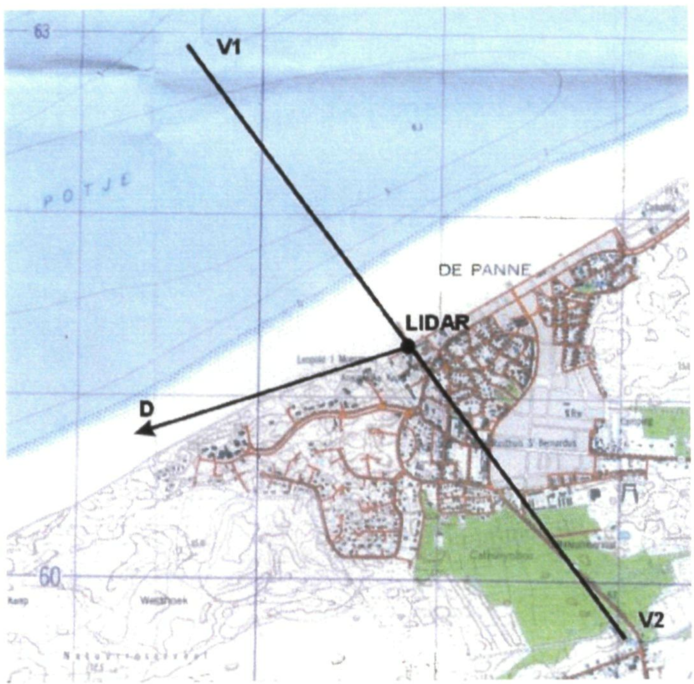



*Fig. 4.1 Location of the lidar system and the direction of vertical scans*

*Fig. 4.2 Lidar system during the measurement*

## 4.2 Meteorological situation

Figures 4.3 and 4.4 demonstrate the synoptical situation over Europe before and after the measurement. During the whole measurement it was mostly overcast, but not raining. The temperature was round 15 °C.

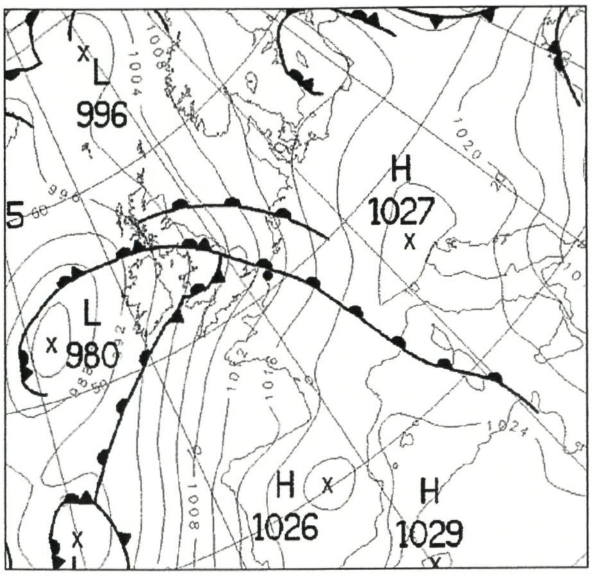



*Fig. 4.3 Synoptical situation*
*28. 11. 2000 at 0:00 UTC*

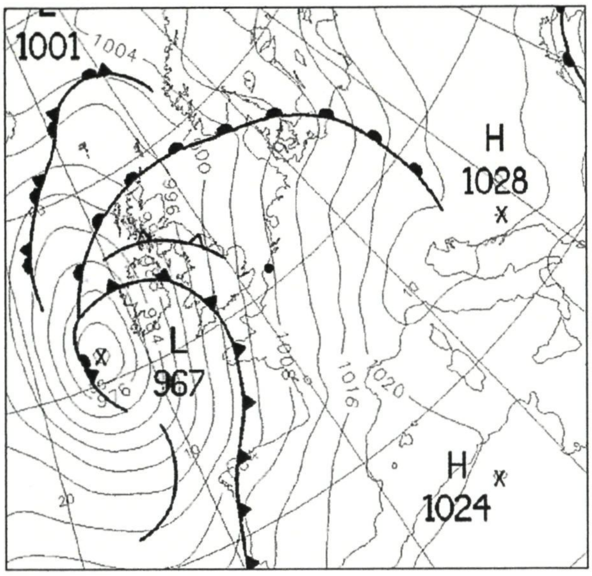



*Fig. 4.4 Synoptical situation*
*29. 11. 2000 at 0:00 UTC*

Wind speed and direction measured by sodar in various heights are graphed in Fig. 4.5 and Fig. 4.6. The wind speed was reaching values round 10 m/s by the ground, and it was increasing with the height, which is a normal behavior.

In the beginning of the lidar measurement at 10:00 the wind direction was round 220°, which is the southwest, and it was turning towards the south until it reached 170° at 19:00.

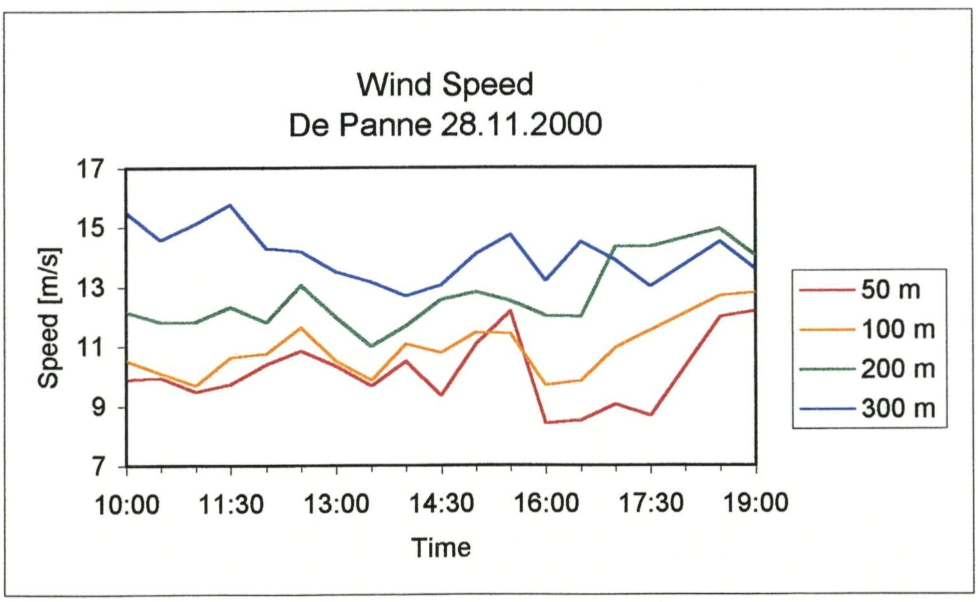



*Fig. 4.5 Wind speed in various heights during the measurement time*

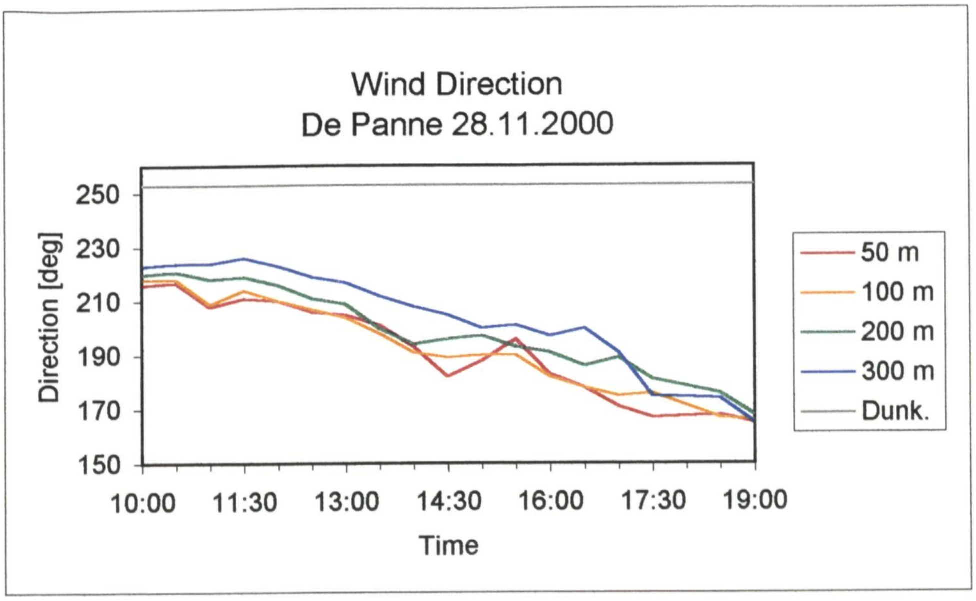



*Fig. 4.6 Wind direction in various heights during the measurement time*

# 4.3 Measurement Results

## Measurement of $SO_2$ Concentration

In Figures 4.7 – 4.10, vertical scans of $SO_2$ concentration are shown; Fig. 4.11 demonstrates time development of the vertical profile of $SO_2$ concentration.

The concentrations in the vertical profile represent a vertical projection of all vertical scans measured in a corresponding time period, hence the values are averaged in horizontal distance and over time. As a result the average concentrations in the vertical profile are significantly lower than concentrations measured locally in single vertical scans. For this reason there is a different color concentration scale used by the vertical scans and by the vertical profile. Concentrations of $SO_2$ from the vertical profile in chosen heights and at chosen times are contained in table 4.1.

During the whole measurement, from 10:00 to 19:00, concentrations of $SO_2$ were very low with average values under 7 $\mu g.m^{-3}$. Also the maximal concentrations on single vertical scans were very low (Fig. 4.7 - 4.10).

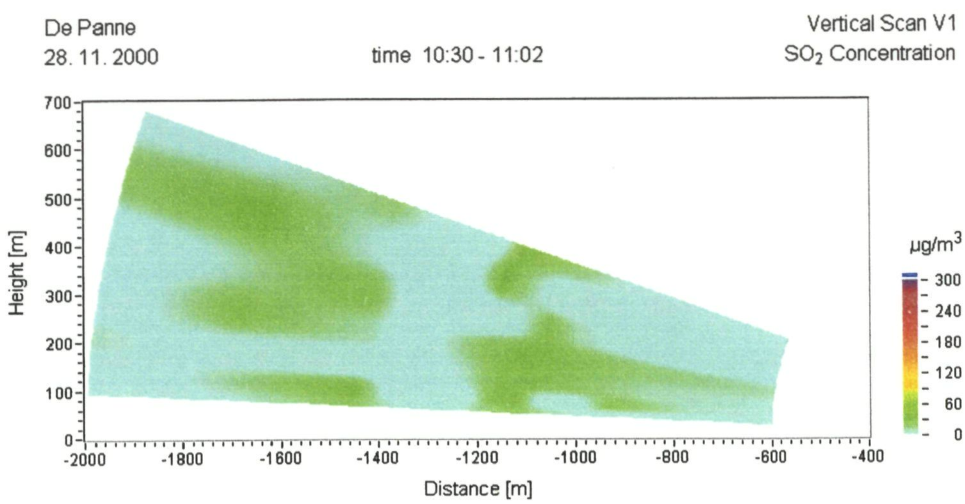



*Fig. 4.7*

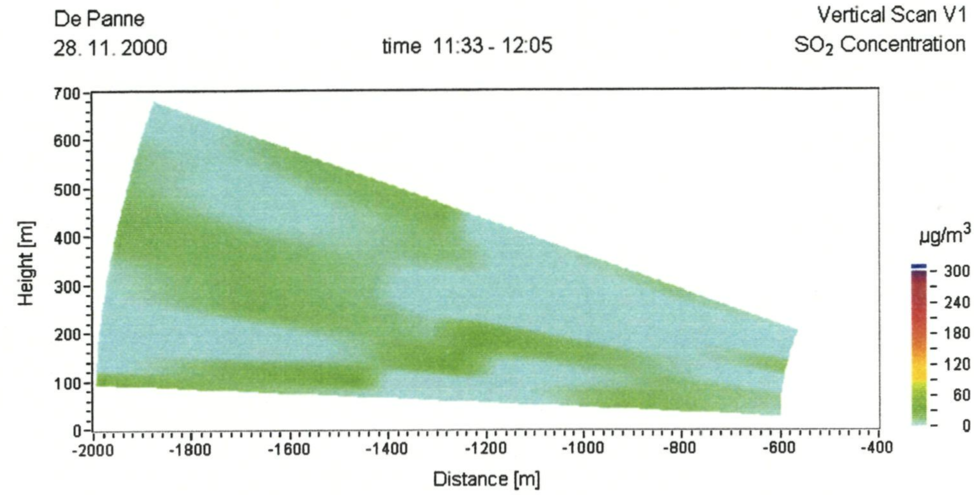



*Fig. 4.8*

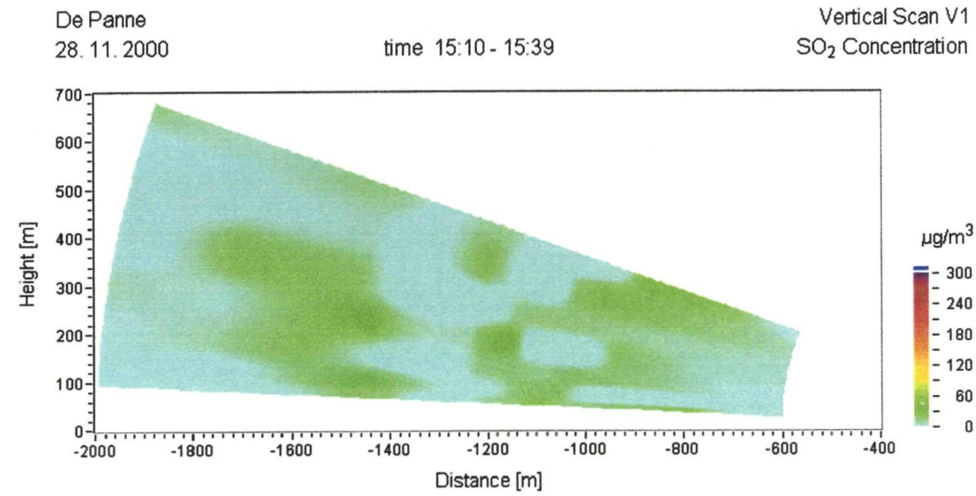



*Fig. 4.9*

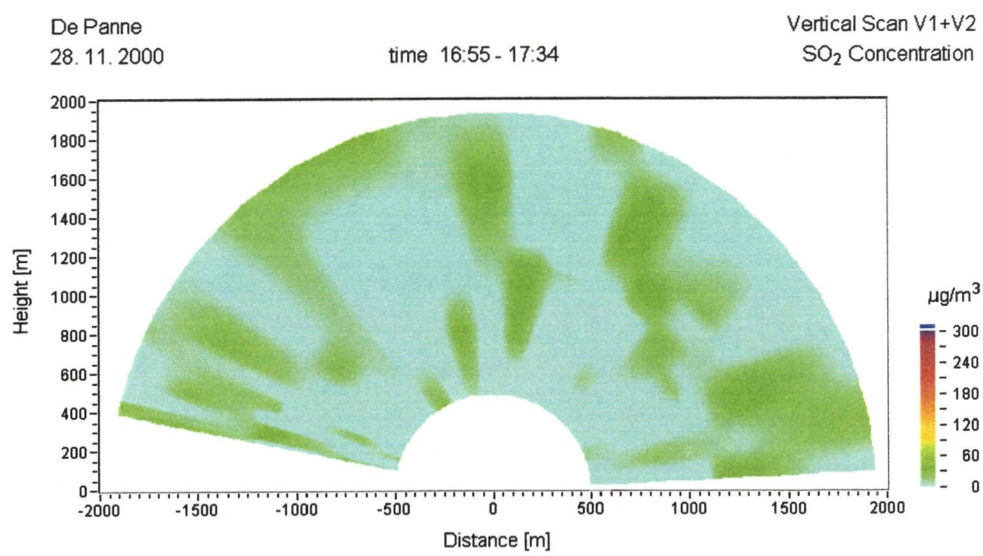



*Fig 4.10*

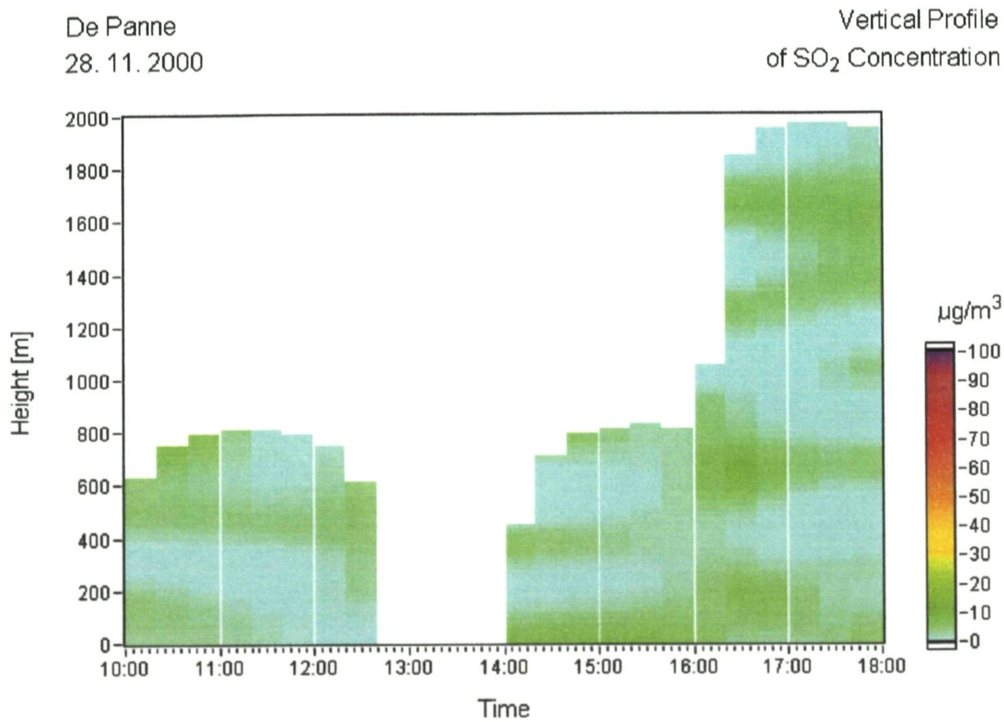



*Fig. 4.11 Time development of the vertical profile of $SO_2$ concentration*

| | Height | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Time | 0 m | 200 m | 400 m | 600 m | 800 m | 1000 m | 1200 m | 1400m | 1600 m | 1800 m |
| 10:40:00 | 3 | 1 | 2 | 2 | - | - | - | - | - | - |
| 11:40:00 | 1 | -1 | 3 | 1 | - | - | - | - | - | - |
| 15:20:00 | 7 | 1 | 2 | 0 | 2 | - | - | - | - | - |
| 17:20:00 | 3 | 2 | -3 | 2 | -1 | 1 | 0 | 5 | 7 | 2 |

*Tab. 4.1 Concentration of $SO_2$ in $\mu g.m^{-3}$ at chosen times and in chosen heights*

## Measurement of Ozone Concentration

By application of our lidar method Ozone concentration appears also as fake $SO_2$ concentration. Therefore it was necessary to determine the average Ozone concentration, which was then used for correction of $SO_2$ data. Vertical scans in Fig. 4.12 and 4.13 show the distribution of Ozone concentration. The average Ozone concentration was 37 $\mu g/m^3$ round 13:00, and its distribution was for our purposes sufficiently homogeneous in both vertical and horizontal directions (Fig.4.12). In the evening the ozone concentration was round 20 $\mu g/m^3$ in the ground layer up to 300 m and round 55 $\mu g/m^3$ in higher layers. These values were used for $SO_2$ concentration correction.

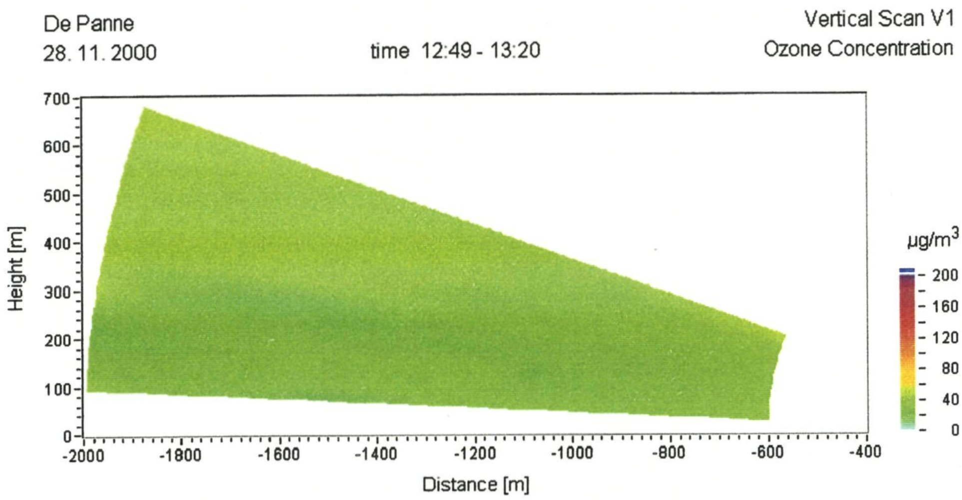



*Fig 4.12*

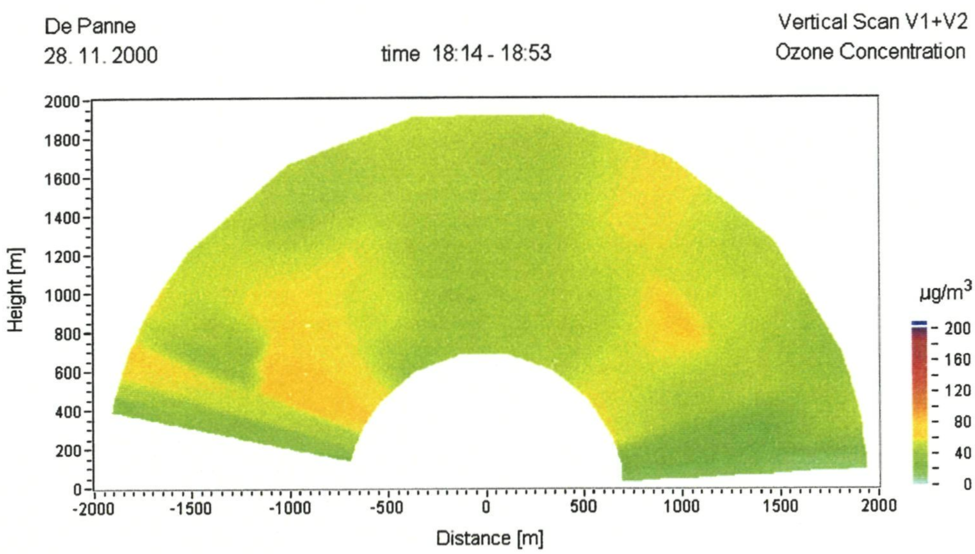



*Fig 4.13*

## Measurement of Aerosols

In Figures 4.14 – 4.17, vertical scans of extinction coefficient are shown; Figure 4.18 demonstrates time development of the vertical profile of extinction coefficient.

The values of extinction coefficients in the vertical profile are significantly lower than those in single vertical scans, because they represent a vertical projection of all vertical scans measured in a corresponding time period, hence the values are averaged in horizontal distance and over time. Extinction coefficients from the vertical profile in chosen heights and at chosen times are contained in table 4.2. Common values of these coefficients were 0,4 $km^{-1}$. The extinction coefficients were measured on the wavelength 286.3 nm.

No distinguished isolated aerosol clouds were detected. Some small changes in extinction coefficient due to aerosols were observed from time to time near the earth (Fig. 4.17).

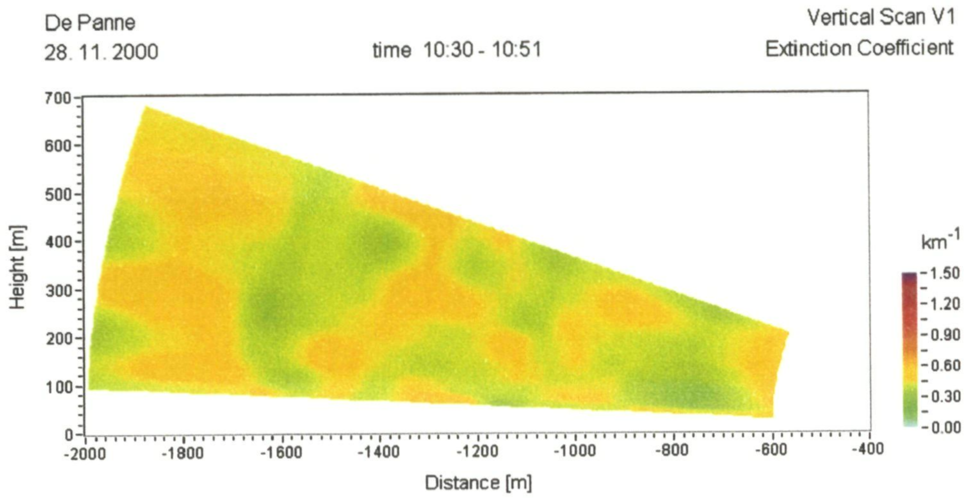



*Fig. 4.14*

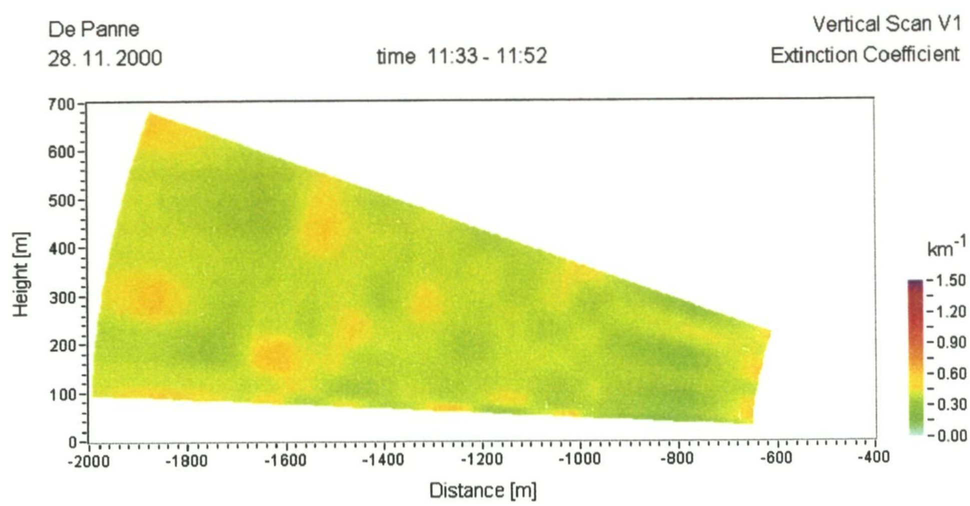



*Fig. 4.15*

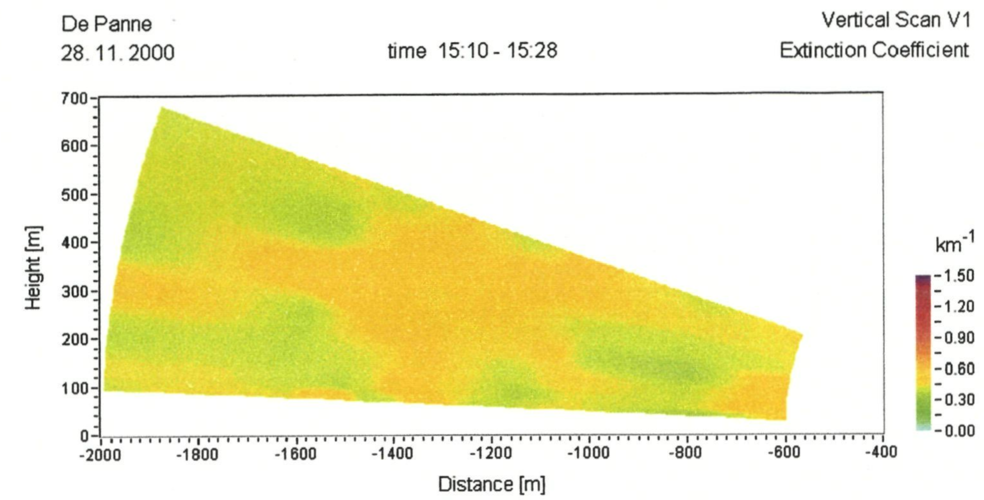



Fig. 4.16

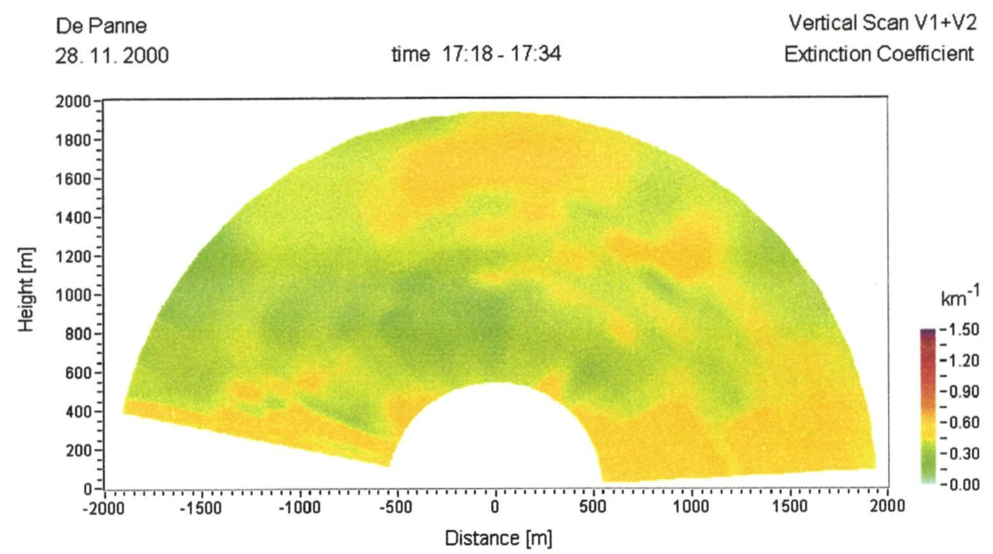



Fig. 4.17

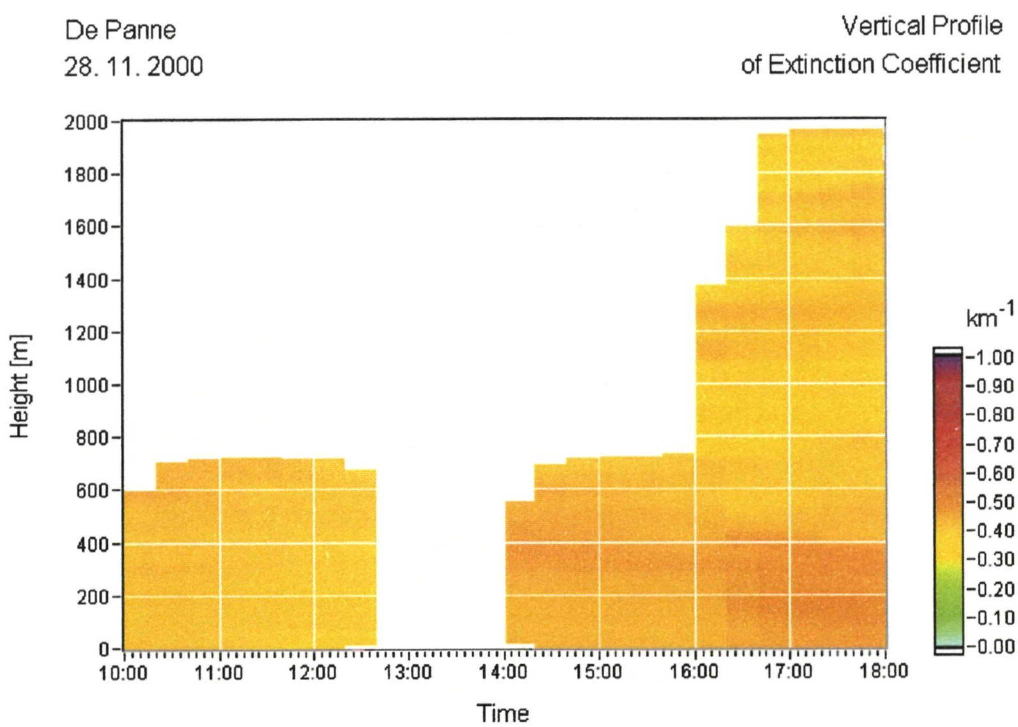



*Fig. 4.18 Time development of the vertical profile of extinction coefficient*

| | Height | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Time | 0 m | 200 m | 400 m | 600 m | 800 m | 1000 m | 1200 m | 1400 m | 1600 m | 1800 m |
| 10:40:00 | 0,4 | 0,4 | 0,4 | 0,4 | - | - | - | - | - | - |
| 11:40:00 | 0,4 | 0,4 | 0,4 | 0,4 | - | - | - | - | - | - |
| 15:20:00 | 0,4 | 0,4 | 0,4 | 0,4 | - | - | - | - | - | - |
| 17:20:00 | 0,5 | 0,5 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 |

*Tab. 4.2 Extinction coefficients in km$^{-1}$ at chosen times and in chosen heights*

# 5 De Panne 2. 12. 2000

## 5.1 Measurement Location and Time

On December the 2nd, we measured concentration of $NO_2$; also extinction coefficients, hence the distribution of aerosols, were determined from the signal on $NO_2$ reference wavelength. The measurement was carried out from the sea bank in De Panne. The exact location of the mobile system is marked in Fig. 5.1. The measurement was conducted in a form of vertical scans. The direction of vertical scans alternated so that it was measured both above the sea (vertical scans V1) and above the land (vertical cans V2). The exact direction of the two types of vertical scans is also shown in Fig. 5.1. Direction to Dunkerque industrial area is marked by an arrow D. The lidar measurement started at 11:00 and continued until 19:30.

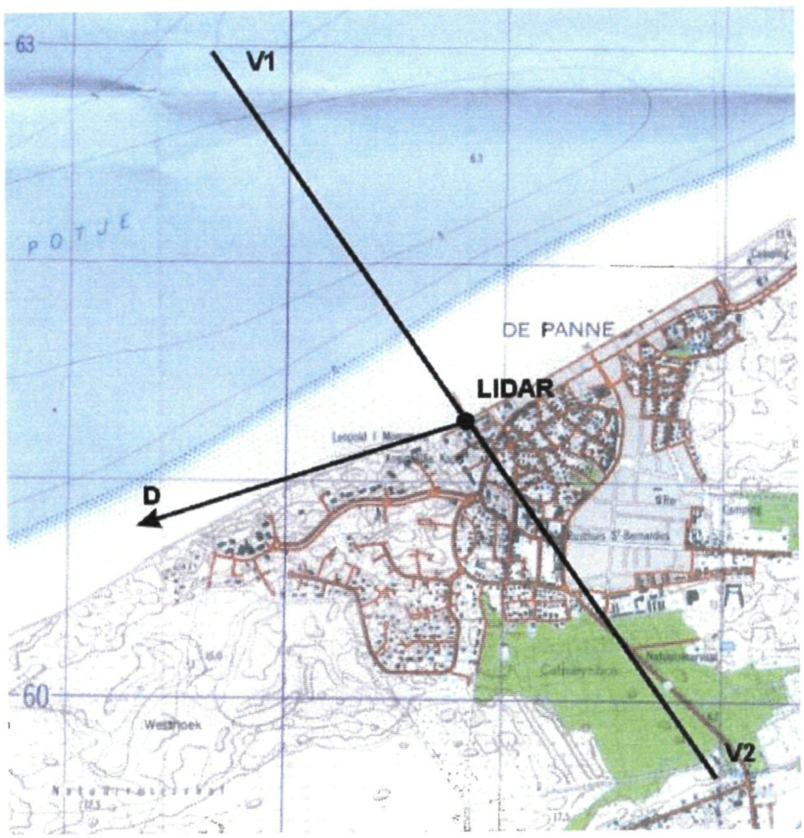



*Fig. 5.1 Location of the lidar system and the direction of vertical scans*

## 5.2 Meteorological situation

Figures 5.2 and 5.3 demonstrate the synoptical situation over Europe before and after the measurement.

In the beginning of the measurement it was partly cloudy, but there was a haze layer apparent over the sea. In the afternoon it was cloudy, and in the evening almost overcast. The temperature was round 11 °C.

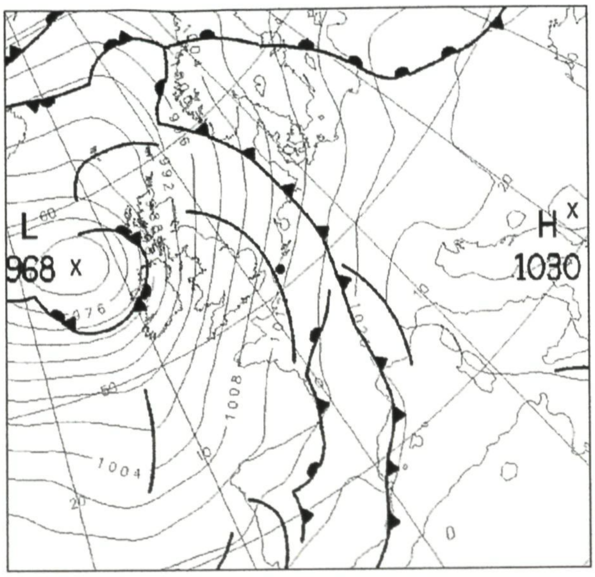



*Fig. 5.2 Synoptical situation 2. 12. 2000 at 0:00 UTC*

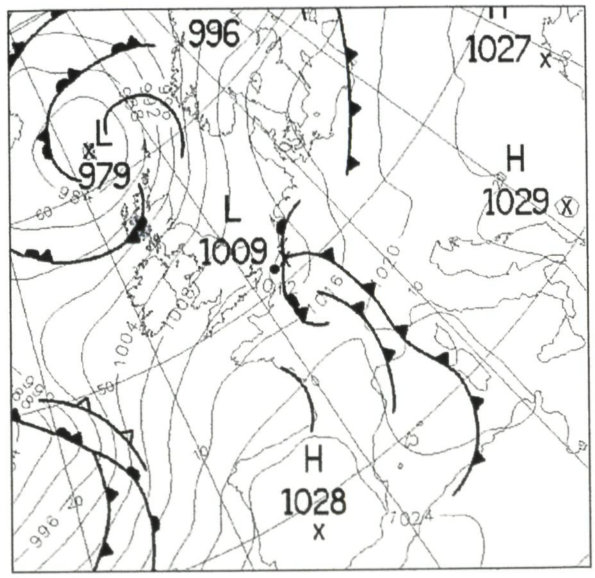



*Fig. 5.3 Synoptical situation 3. 12. 2000 at 0:00 UTC*

Wind speed and direction measured by sodar in various heights are graphed in Fig. 5.4 and Fig. 5.5. In the beginning of the measurement the wind speed was over 6 m/s, and in higher levels it was reaching more than 10 m/s. During the measurement the wind speed was slowly decreasing, and in the evening it was round 5 m/s. The wind direction was round 170°, which is the south, during the whole measurement.

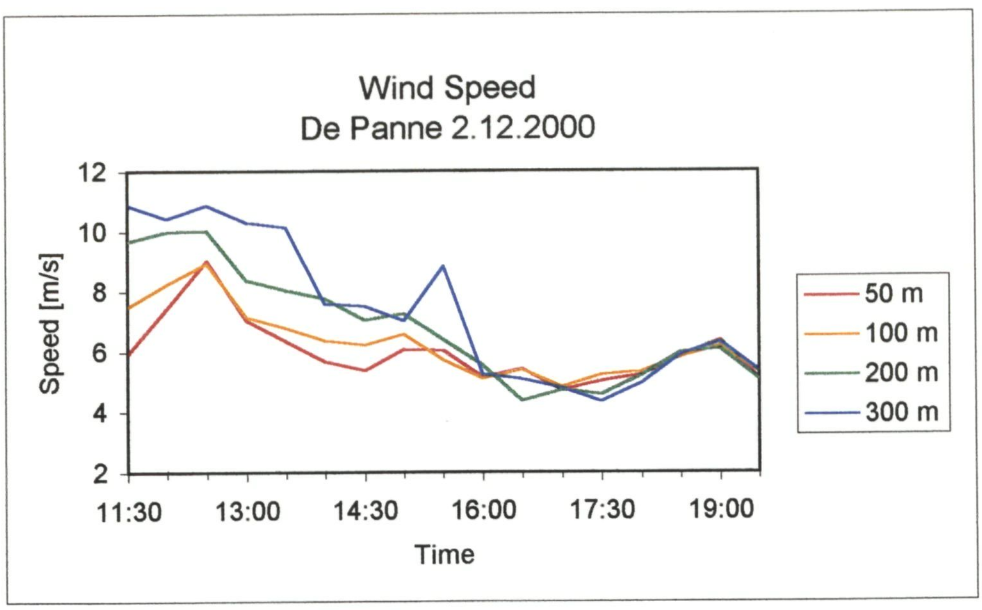



*Fig. 5.4 Wind speed in various heights during the measurement time*

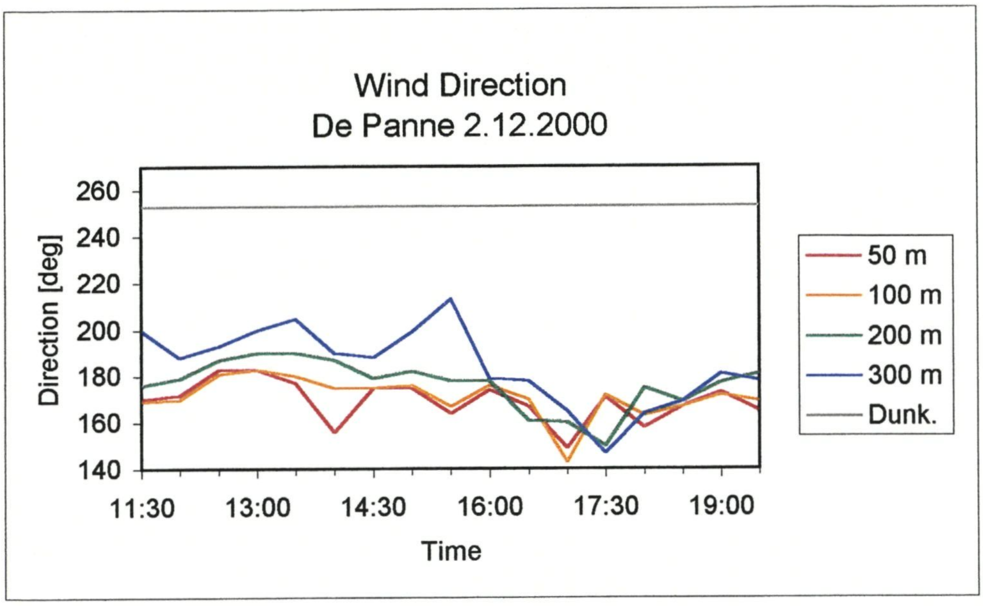



*Fig. 5.5 Wind direction in various heights during the measurement time*

# 5.3 Measurement Results

## Measurement of $NO_2$ Concentration

In Figures 5.6 – 5.11, vertical scans of $NO_2$ concentration are shown; Fig. 5.12 demonstrates time development of the vertical profile of $NO_2$ concentration from the period between 12:00 and 15:00.

The concentrations in the vertical profile represent a vertical projection of all vertical scans measured in a corresponding time period, hence the values are averaged in horizontal distance and over time. As a result the average concentrations in the vertical profile are significantly lower than concentrations measured locally in single vertical scans. For this reason there is a different color concentration scale used by the vertical scans and by the vertical profile. Concentrations of $NO_2$ from the vertical profile in chosen heights and at chosen times are contained in table 5.1.

During the whole measurement the concentrations of $NO_2$ both, over the sea and over the land, were low. Average values were under 20 $\mu g.m^{-3}$ round 12:00 and under 40 $\mu g.m^{-3}$ in the afternoon. Also the maximal concentrations on single vertical scans were low, under 60 $\mu g.m^{-3}$.

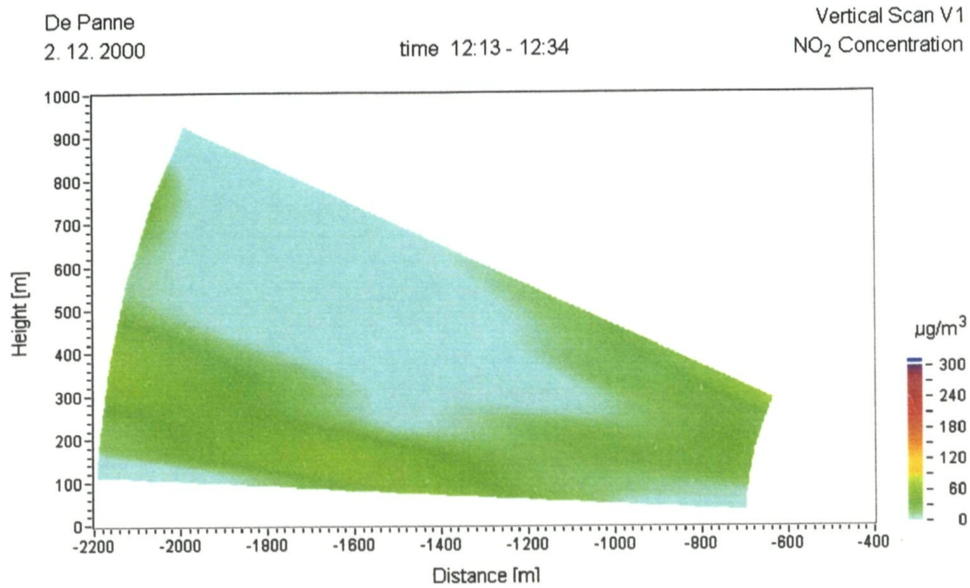



*Fig. 5.6*

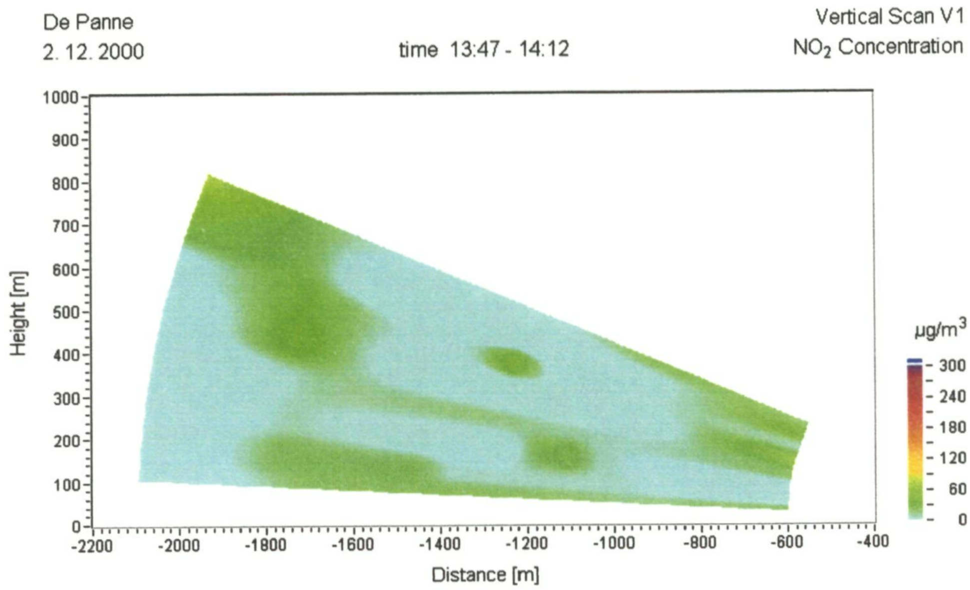



*Fig. 5.7*

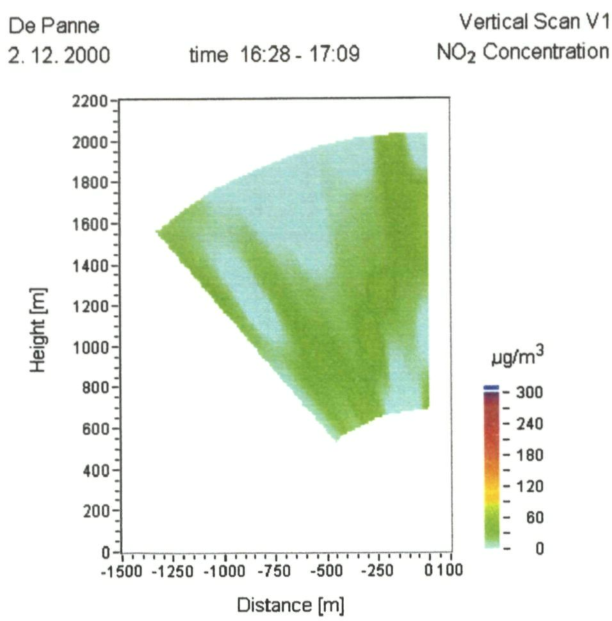



*Fig. 5.8*

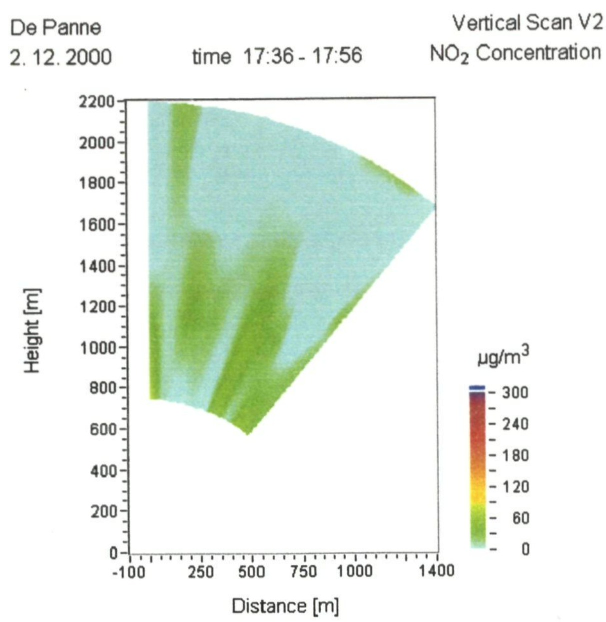



*Fig. 5.9*

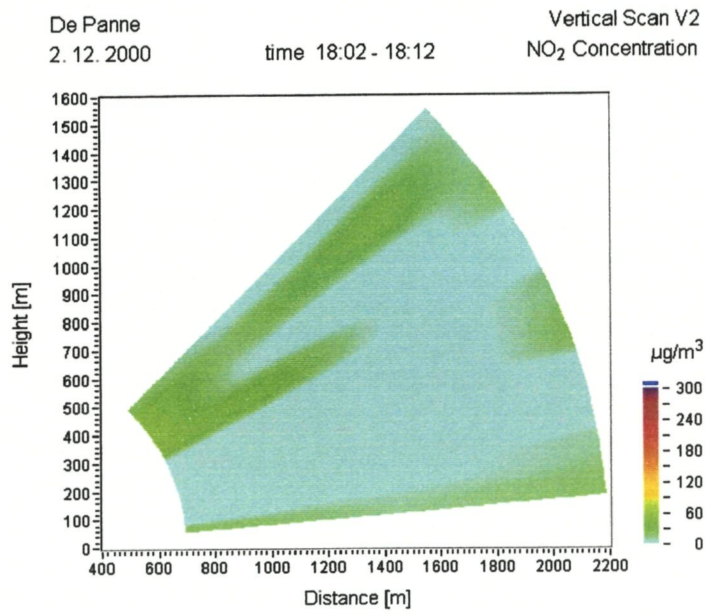



*Fig. 5.10*

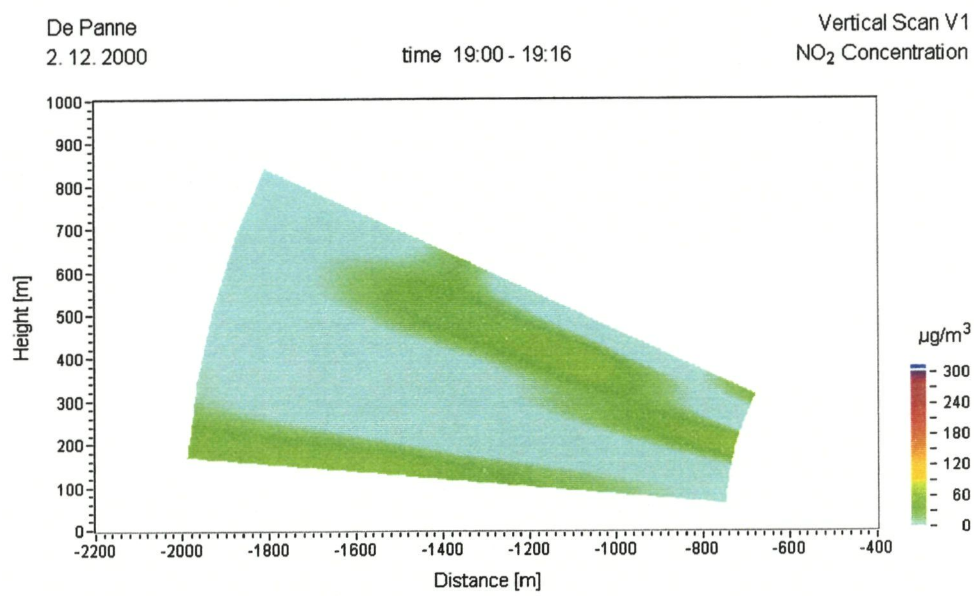



*Fig 5.11*

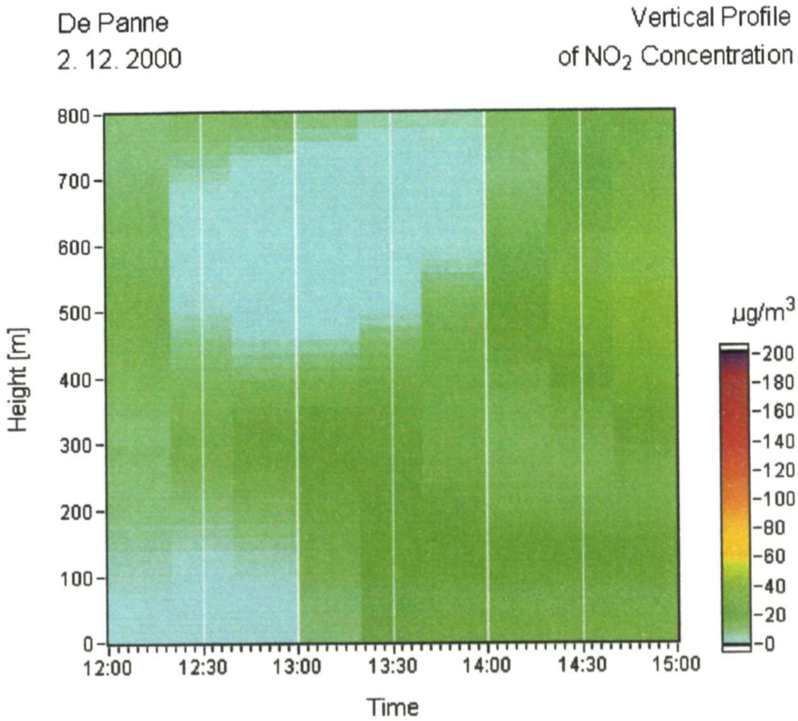



*Fig. 5.12 Time development of the vertical profile of $NO_2$ concentration*

| | Height | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Time | 0 m | 100 m | 200 m | 300 m | 400 m | 500 m | 600 m | 700 m | 800 m |
| 12:20:00 | -8 | -1 | 8 | 14 | 9 | 1 | -4 | 4 | 12 |
| 13:40:00 | 26 | 24 | 19 | 14 | 15 | 11 | -3 | -7 | 6 |
| 14:00:00 | 27 | 23 | 15 | 10 | 15 | 21 | 16 | 8 | 12 |
| 14:40:00 | 30 | 24 | 15 | 19 | 31 | 39 | 36 | 29 | 21 |

*Tab. 5.1 Concentration of $NO_2$ in $\mu g.m^{-3}$ at chosen times and in chosen heights*

## Measurement of Aerosols

In Figures 5.13 – 5.19, vertical scans of extinction coefficient are shown; Figure 5.20 demonstrates time development of the vertical profile of extinction coefficient.

The values of extinction coefficients in the vertical profile are significantly lower than those in single vertical scans, because they represent a vertical projection of all vertical scans measured in corresponding time period, hence the values are averaged in horizontal distance and over time. Extinction coefficients from the vertical profile in chosen heights and at chosen times are contained in table 5.2. Common values of these coefficients were between 0,3 and 0.4 $km^{-1}$. The extinction coefficients were measured on the wavelength 397.0 nm.

Between 11:00 and 12:00 distinguished isolated aerosol clouds were detected over the sea (scans V1), by the surface and in higher layers over 300 m (Fig. 6.13). We assume that these aerosols can be identified with a haze that was present at that time.

Between 12:30 and 18:00, after the haze disappeared, vertical scans became much more smooth and no such significant aerosol clouds were detected neither over the sea nor in higher layers (Fig. 5.14 – 5.17). However, thin layers of clouds can be still seen on these scans.

In the evening, after 18:30 a distinguished aerosol layer was detected in the height above 500 m (Fig. 5.19). It was already overcast by this time, so it's obvious that it was a layer of clouds.

Between 18:00 and 18:30 vertical scans over the land were measured (V2). Some aerosols appeared by the ground and in a height between 300 and 400 m on these scans (Fig. 5.18).

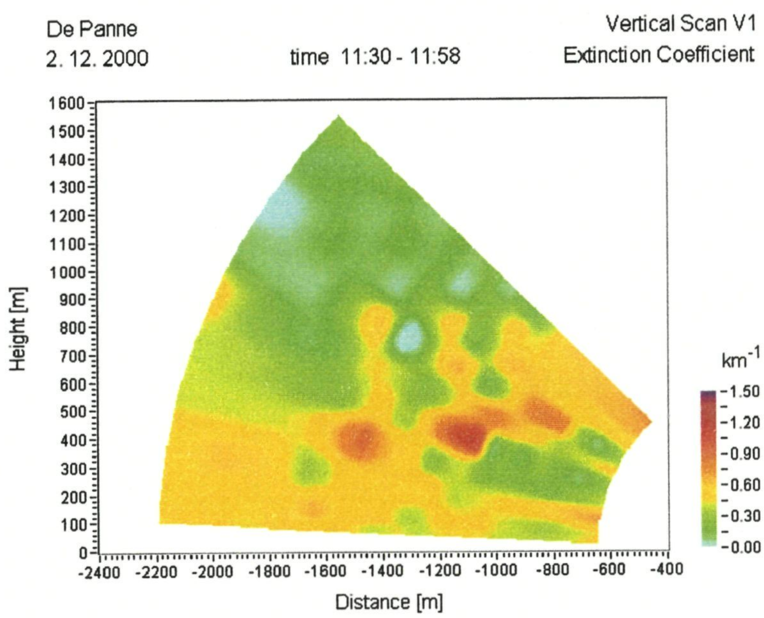



*Fig. 5.13*

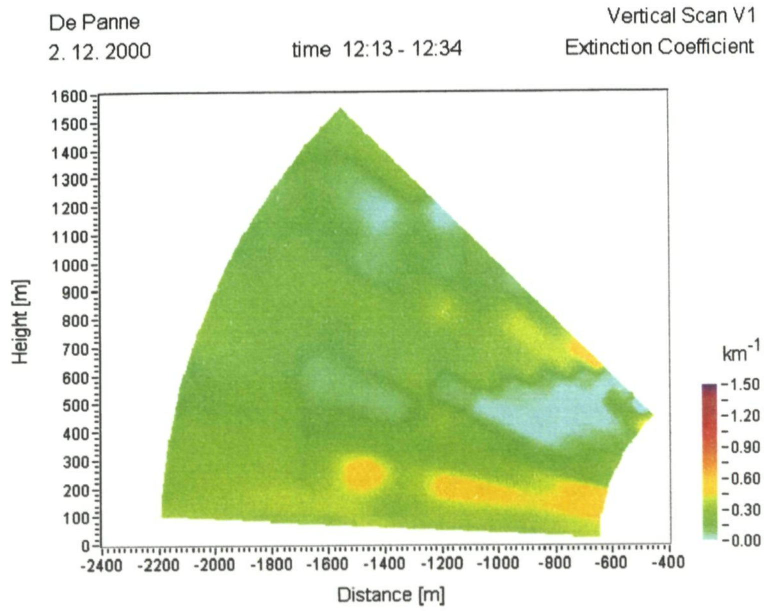



*Fig. 5.14*

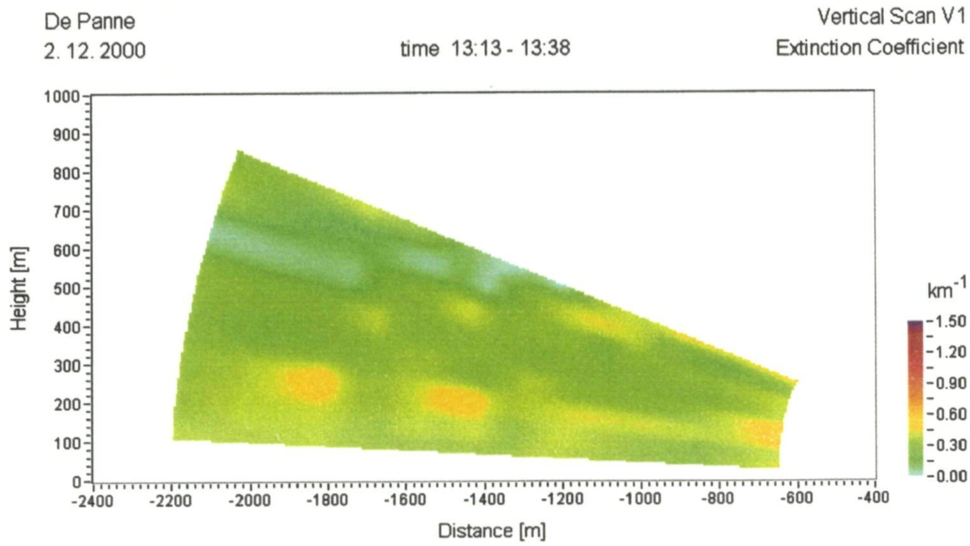



*Fig. 5.15*

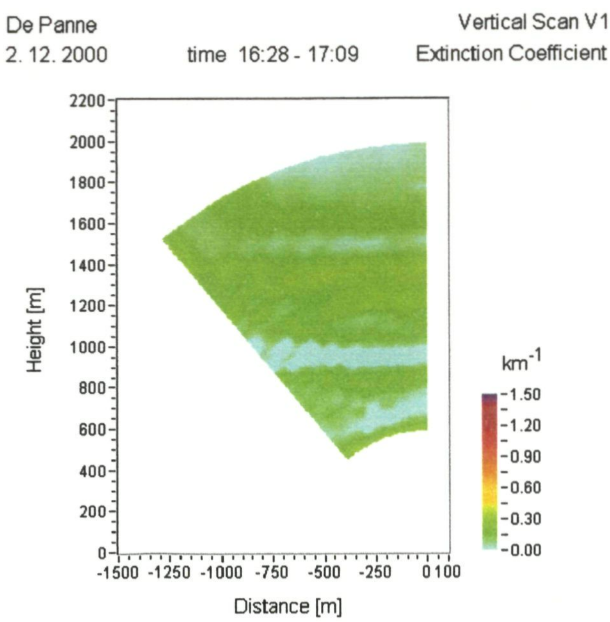



*Fig. 5.16*

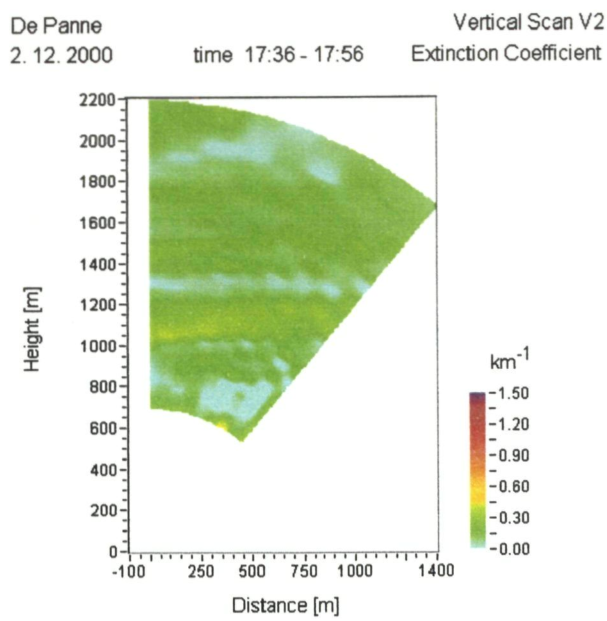



*Fig. 5.17*

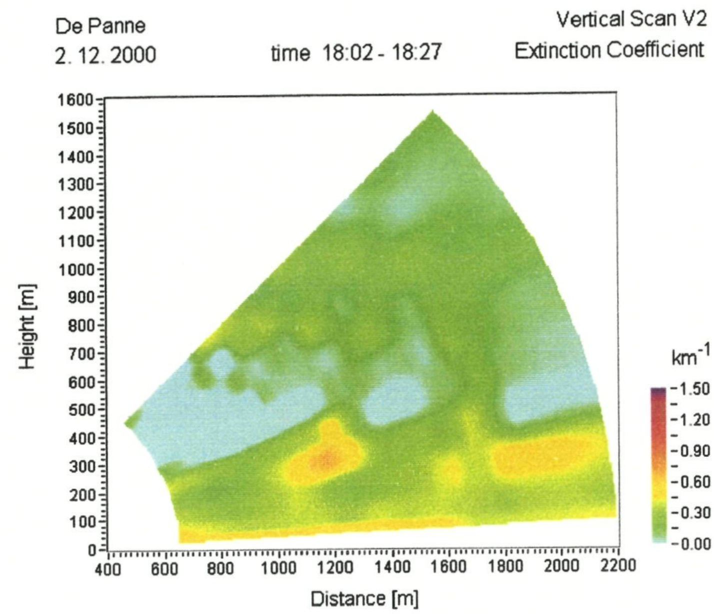



*Fig. 5.18*

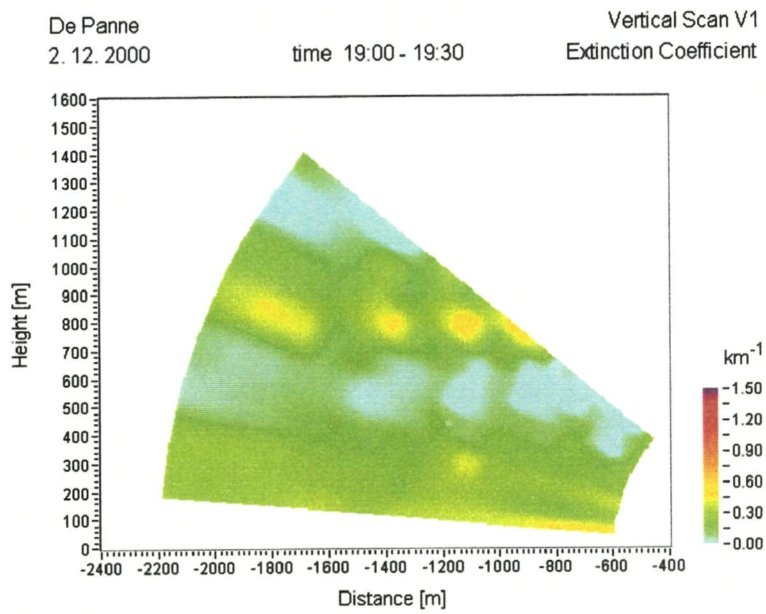



*Fig. 5.19*

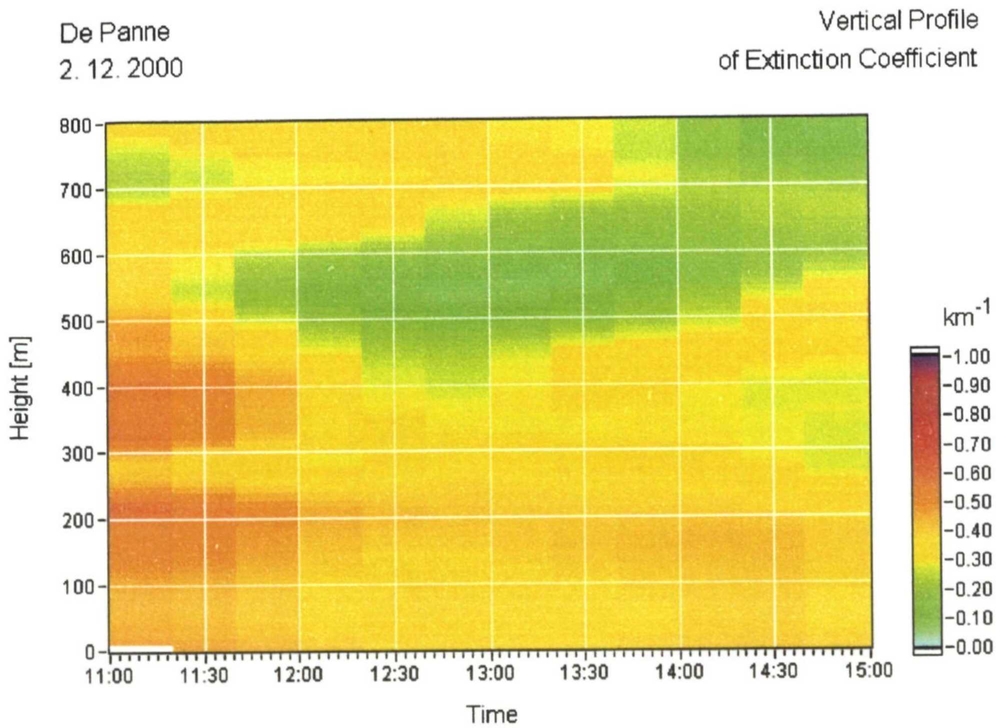



*Fig. 5.20 Time development of the vertical profile of extinction coefficient*

| | Height | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Time | 0 m | 100 m | 200 m | 300 m | 400 m | 500 m | 600 m | 700 m | 800 m |
| 11:20:00 | 0,5 | 0,4 | 0,5 | 0,4 | 0,5 | 0,3 | 0,3 | 0,3 | 0,4 |
| 12:40:00 | 0,3 | 0,3 | 0,4 | 0,3 | 0,3 | 0,1 | 0,2 | 0,3 | 0,3 |
| 13:40:00 | 0,4 | 0,4 | 0,4 | 0,3 | 0,3 | 0,2 | 0,1 | 0,3 | 0,3 |
| 14:40:00 | 0,4 | 0,4 | 0,4 | 0,3 | 0,3 | 0,4 | 0,2 | 0,2 | 0,1 |

*Tab. 5.2 Extinction coefficients in $km^{-1}$ at chosen times and in chosen heights*

# 6 De Panne 3. 12. 2000

## 6.1 Measurement Location and Time

On December the 3rd, we measured concentration of $SO_2$ and Ozone. Also extinction coefficients, hence the distribution of aerosols, were determined from the signal on $SO_2$ reference wavelength. The measurement was carried out from a location on the coast in De Panne. The exact location of the mobile system is marked in Fig. 6.1. The measurement was conducted in a form of vertical scans, whose exact direction is also shown in Fig. 6.1. Direction to Dunkerque industrial area is marked by an arrow D. A picture of the lidar system during the measurement is shown in Fig. 6.2. The lidar measurement was carried out between 11:30 and 16:30.

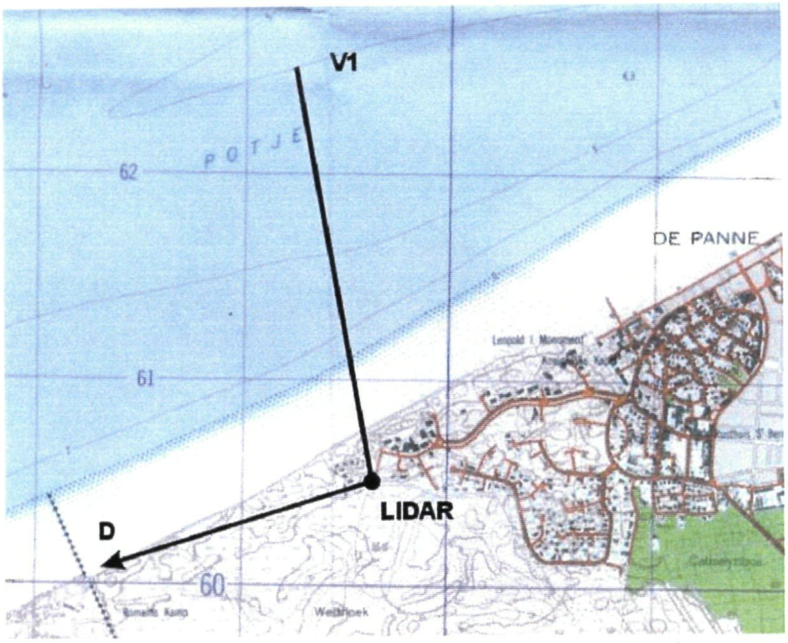



*Fig. 6.1 Location of the lidar system and the direction of vertical scans*

*Fig. 6.2 Lidar system during the measurement*

# 6.2 Meteorological situation

Figures 6.3 and 6.4 demonstrate the synoptical situation over Europe before and after the measurement.

In the beginning of the measurement, round noon, the sky was almost clear. In the afternoon it was partly cloudy or cloudy. The temperature was round 10 °C.

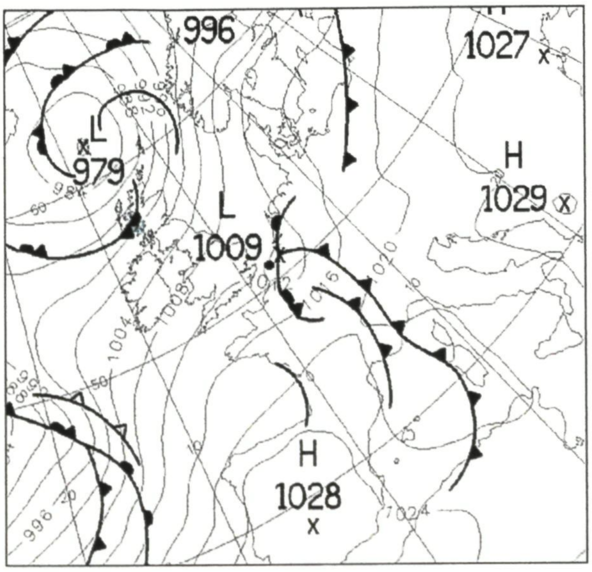



*Fig. 6.3 Synoptical situation 3. 12. 2000 at 0:00 UTC*

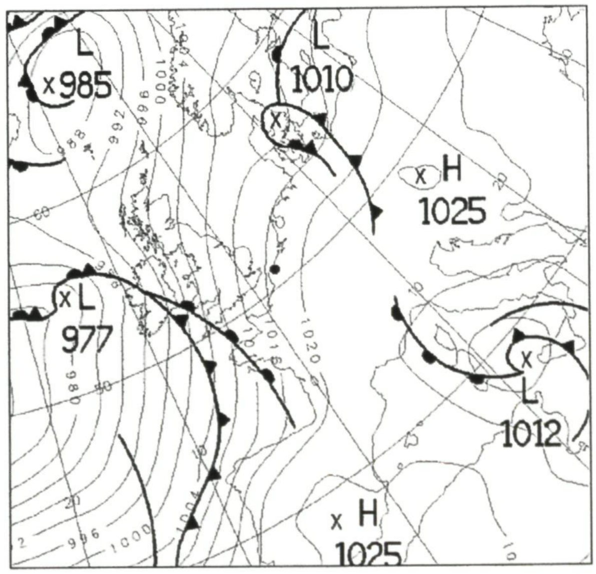



*Fig. 6.4 Synoptical situation 4. 12. 2000 at 0:00 UTC*

Wind speed and direction measured by sodar in various heights are graphed in Fig. 6.5 and Fig. 6.6. The wind speed was reaching values round 6 m/s in the beginning of the measurement, and it was increasing until it reached 8 m/s by the ground at 14:00. After 14:00 the wind speed was falling again, and at 16:00 it was round 7 m/s.

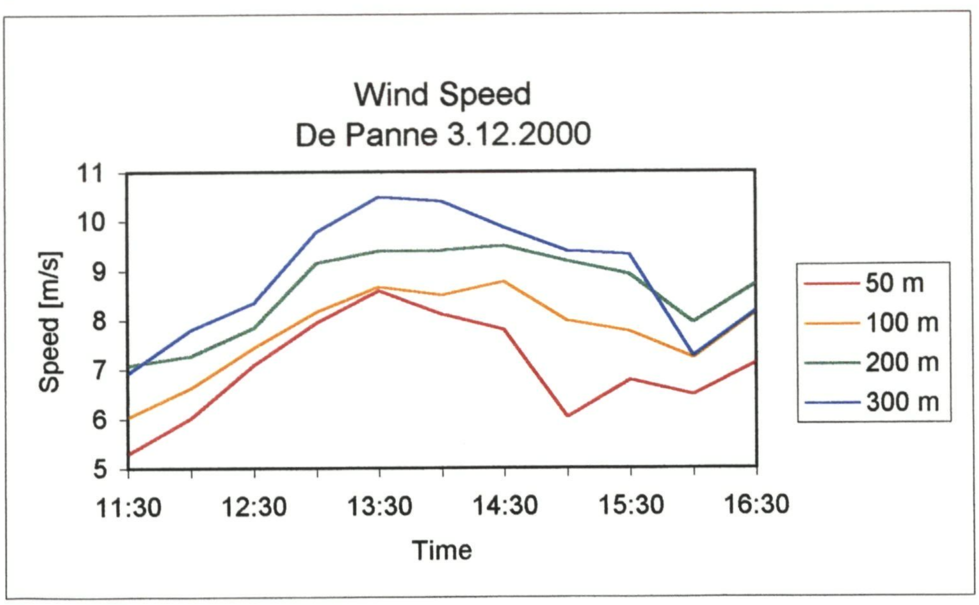



*Fig. 6.5 Wind speed in various heights during the measurement time*

In the beginning of the measurement at 11:30 the wind direction was round 230°, which is the southwest. It was turning towards the south until it reached almost 180° at 16:30, which is the south. However, between 13:00 and 15:00, the wind direction remained stable at approximately 220°.

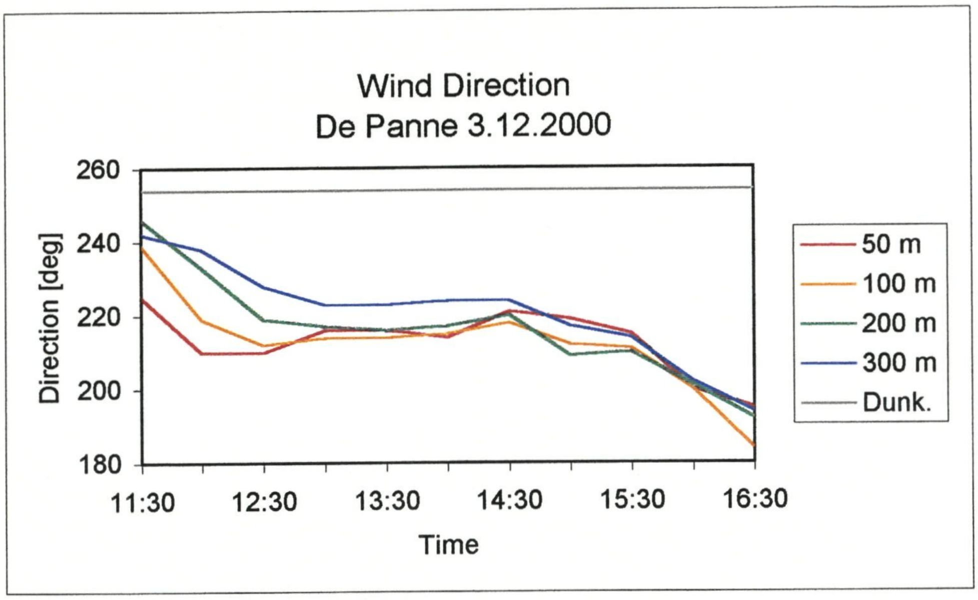



*Fig. 6.6 Wind direction in various heights during the measurement time*

# 6.3 Measurement Results

## Measurement of $SO_2$ Concentration

In Figures 6.7 – 6.9, vertical scans of $SO_2$ concentration are shown. During the whole measurement concentrations of $SO_2$ were low with average values round 15 $\mu g.m^{-3}$. Also the maximal concentrations on single vertical scans were low, under 40 $\mu g.m^{-3}$.

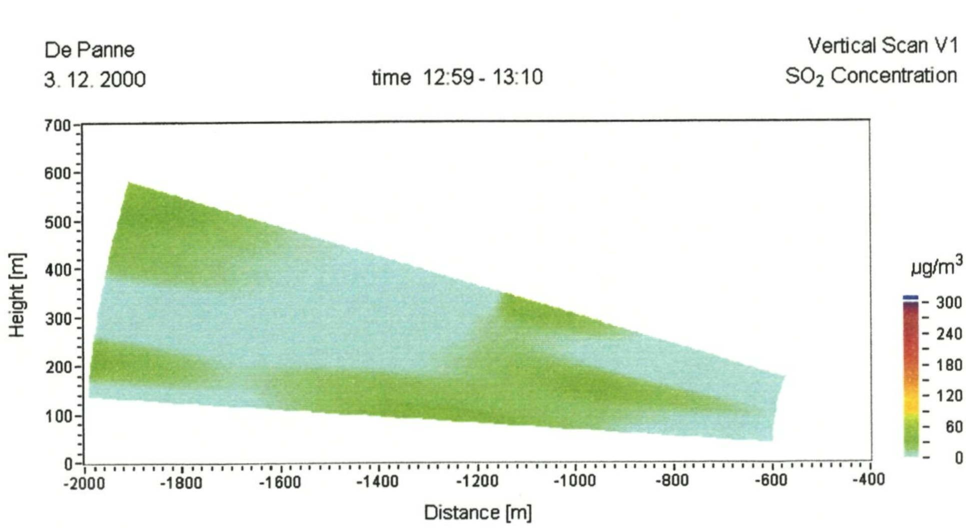



*Fig. 6.7*

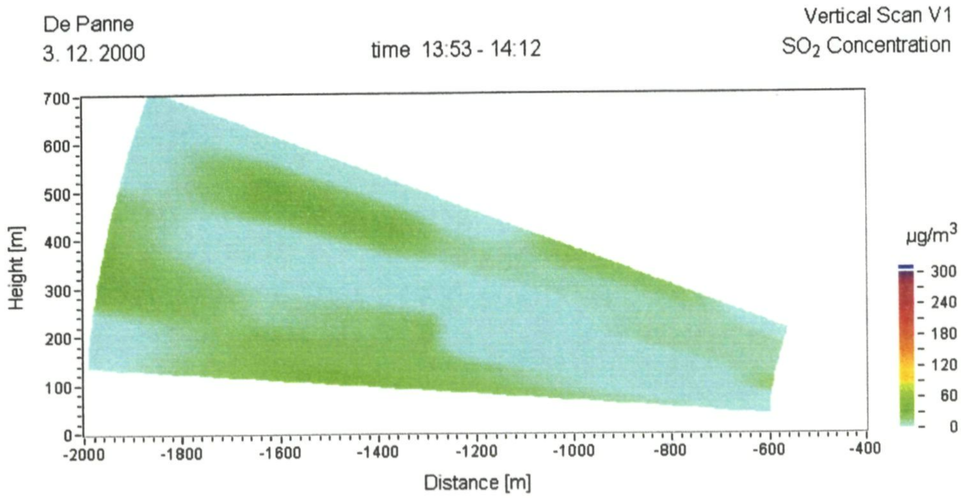

De Panne
3. 12. 2000
time 13:53 - 14:12
Vertical Scan V1
$SO_2$ Concentration
Height [m]
Distance [m]
µg/m³
300
240
180
120
60
0

*Fig. 6.8*

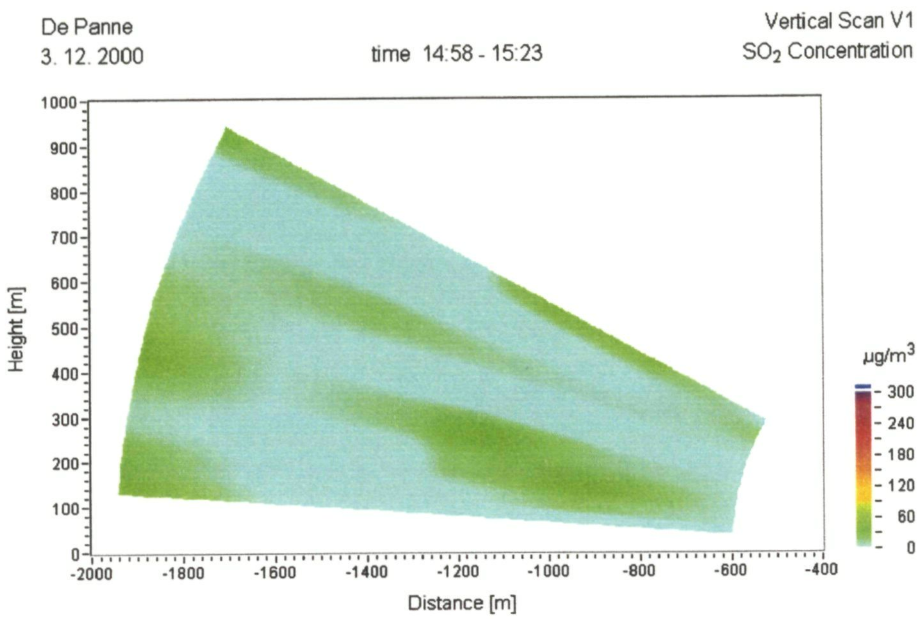

De Panne
3. 12. 2000
time 14:58 - 15:23
Vertical Scan V1
$SO_2$ Concentration
Height [m]
Distance [m]
µg/m³
300
240
180
120
60
0

*Fig. 6.9*

## Measurement of Ozone Concentration

By application of our lidar method, Ozone concentration appears also as fake $SO_2$ concentration. Therefore it was necessary to determine the average Ozone concentration, which was then used for correction of $SO_2$ data. Vertical scan in Fig. 6.10 shows the distribution of Ozone concentration, which was for our purposes sufficiently homogeneous in both vertical and horizontal directions. The average Ozone concentration was 65 $\mu g/m^3$. This value was used for $SO_2$ concentration correction.

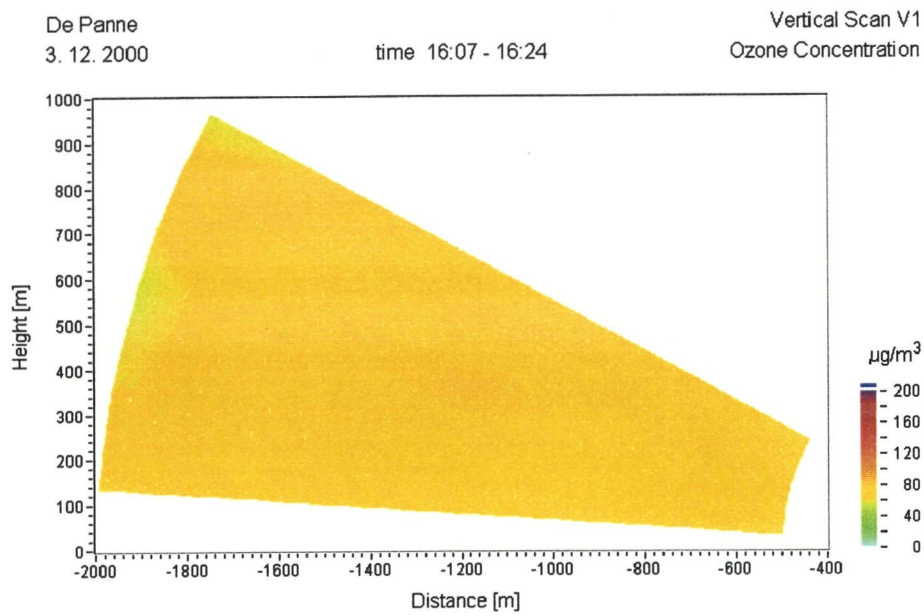



*Fig 6.10*

## Measurement of Aerosols

In Figures 6.11 – 6.13, vertical scans of extinction coefficient are shown. The extinction coefficients were measured on the wavelength 286.3 nm.

No distinguished isolated aerosol clouds were detected. Some changes in extinction coefficient due to aerosols were observed only in higher layers over 400 m.

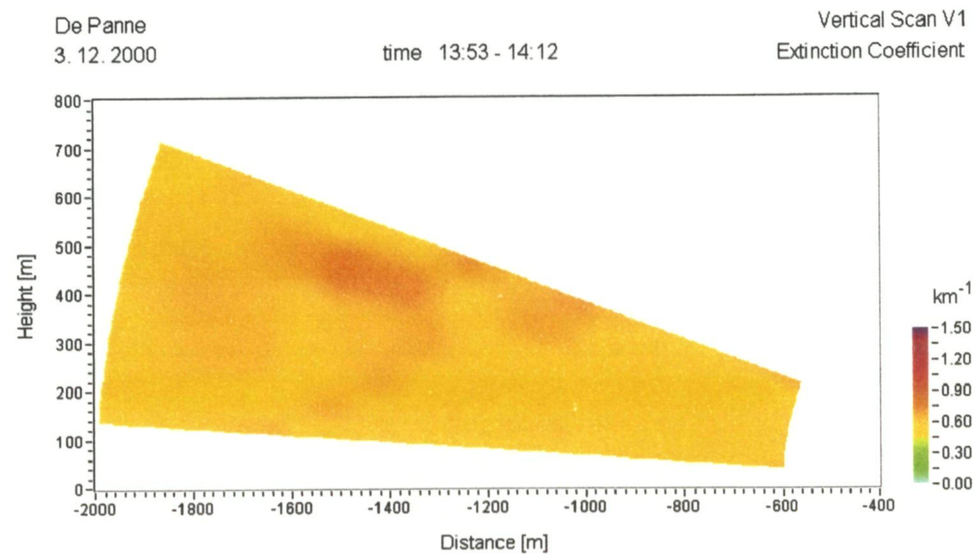



*Fig. 6.11*

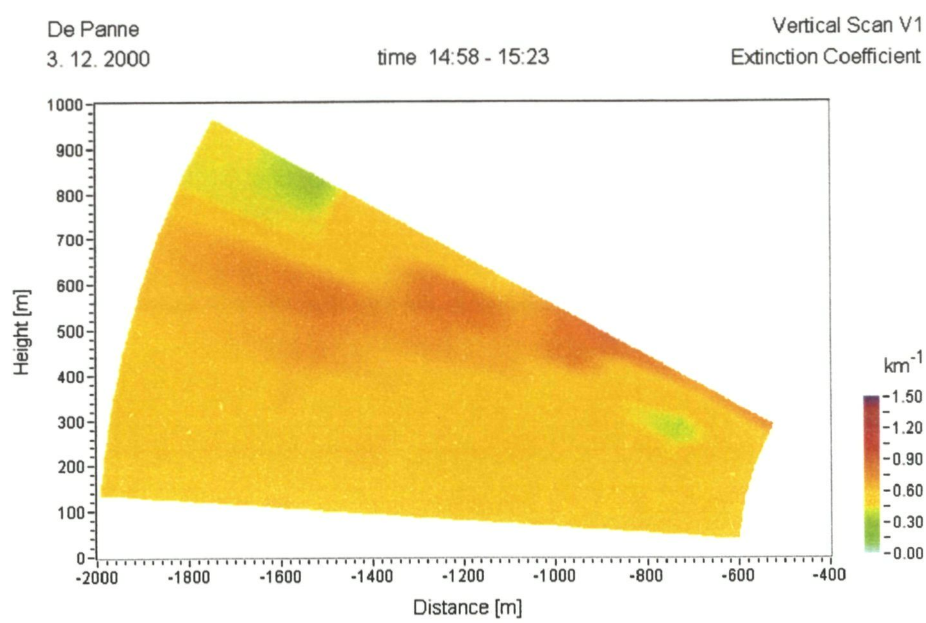



*Fig. 6.12*

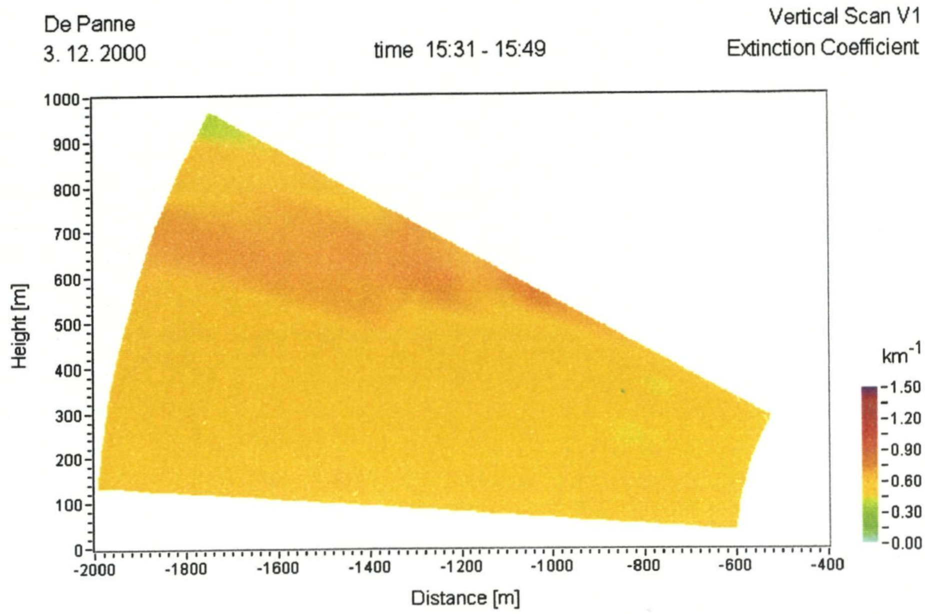

De Panne
3. 12. 2000
time 15:31 - 15:49
Vertical Scan V1
Extinction Coefficient
Height [m]
Distance [m]
km-1
1.50
1.20
0.90
0.60
0.30
0.00
1000
900
800
700
600
500
400
300
200
100
0
-2000
-1800
-1600
-1400
-1200
-1000
-800
-600
-400

*Fig. 6.13*

# 7 De Panne 10. 12. 2000

## 7.1 Measurement Location and Time

On December the 10th, we measured concentration of $SO_2$ and Ozone. Also extinction coefficients, hence the distribution of aerosols, were determined from the signal on $SO_2$ reference wavelength. The measurement was carried out from the sea bank in De Panne. The exact location of the mobile system is marked in Fig. 7.1. The measurement was conducted in a form of vertical scans. The direction of vertical scans alternated so that it was measured both above the sea (vertical scans V1) and above the land (vertical cans V2). The exact direction of the two types of vertical scans is also shown in Fig. 7.1. Direction to Dunkerque industrial area is marked by an arrow D.

The measurement started at 12:00, but shortly after the beginning, at 12:15, it was interrupted by a strong steady rain. We started the measurement again after the rain at 14:30 and continued until 21:30.

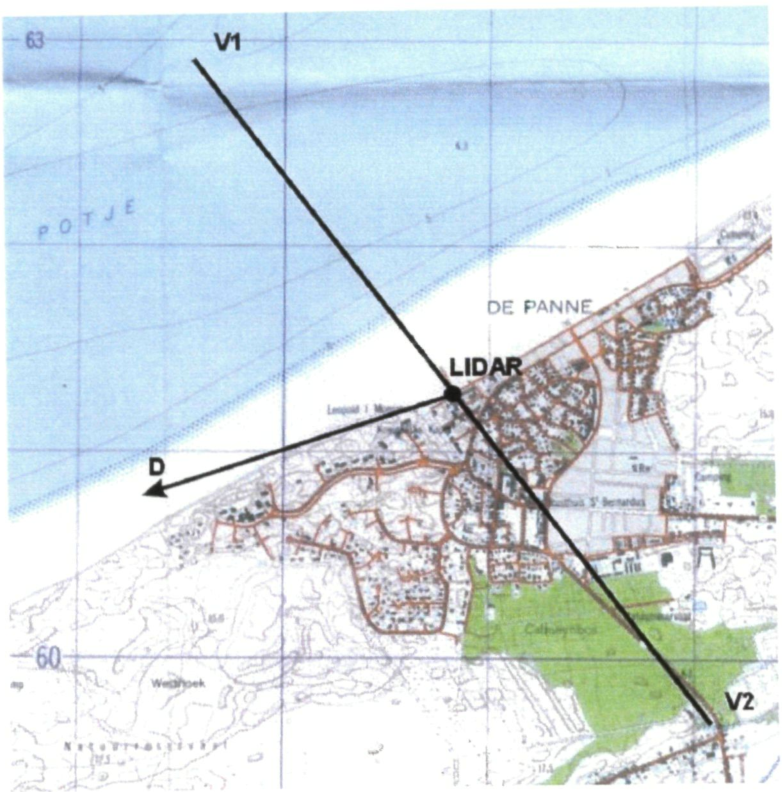



*Fig. 7.1 Location of the lidar system and the direction of vertical scans*

## 7.2 Meteorological situation

Figures 7.2 and 7.3 demonstrate synoptical situation over Europe before and after the measurement.

Round noon it was overcast, and between 12:15 and 14:30 it was raining steadily. After the rain it was overcast or cloudy, and in the late afternoon the clouds waned until it was almost clear. After 18:00 clouds reappeared, and round 22:00 it started to rain again. The temperature was about 10 °C during the whole measurement.

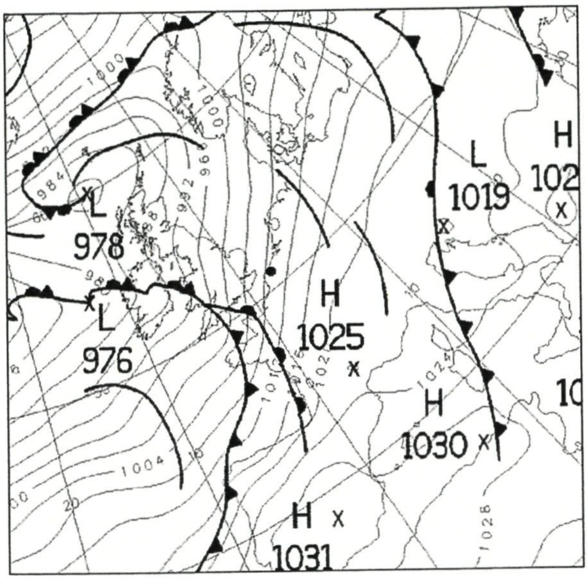



*Fig. 7.2 Synoptical situation*
*10. 12. 2000 at 0:00 UTC*

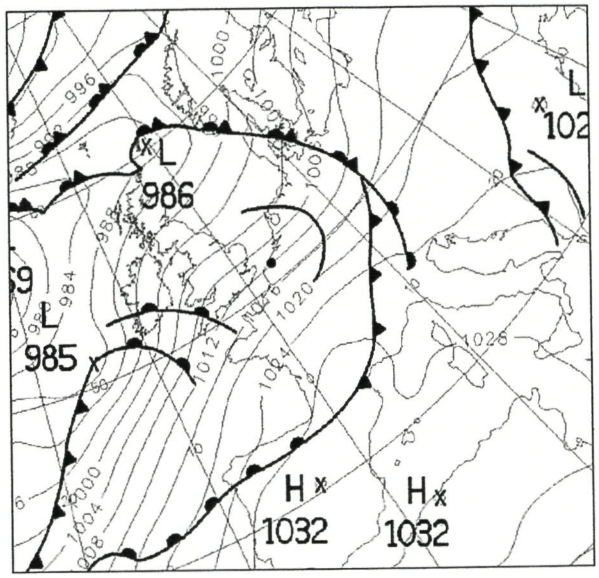



*Fig. 7.3 Synoptical situation*
*11. 12. 2000 at 0:00 UTC*

Wind speed and direction measured by sodar in various heights are graphed in Fig. 7.4 and 7.5. The wind speed was reaching high values round 12 m/s as the measurement started ,and it was increasing during the afternoon. In the end of the measurement the wind speed was round 18 m/s. As it approached the speed of a wind gale several times during the day, we had problems with our sodar measurements; therefore there are no sodar data available in the period between 14:30 and 17:30.

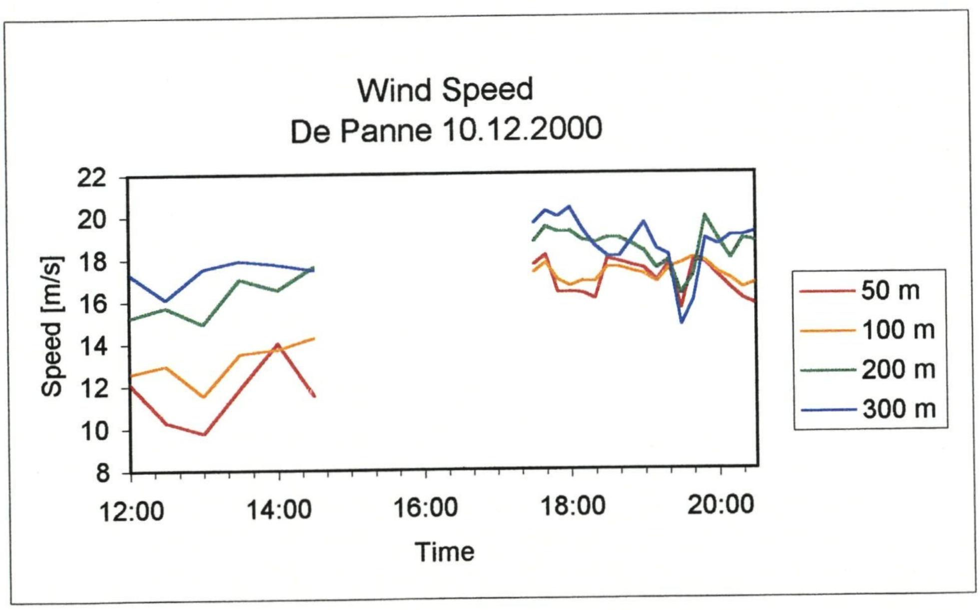



*Fig. 7.4 Wind speed in various heights during the measurement time*

In the beginning of the measurement the wind direction was round 200°, which is almost the south, and it started to turn towards the west at 13:30. After 17:30 it was almost 250° and it remained so until the end of the measurement. For the period between 14:30 and 17:30 we use the data measured by a meteorological station on the beach near the lidar system. After 14:30 the wind continued to turn towards the west, and between 16:00 and 17:00 its direction by the ground was round 260°. After 17:00 it turned back to 250° and so it remained.

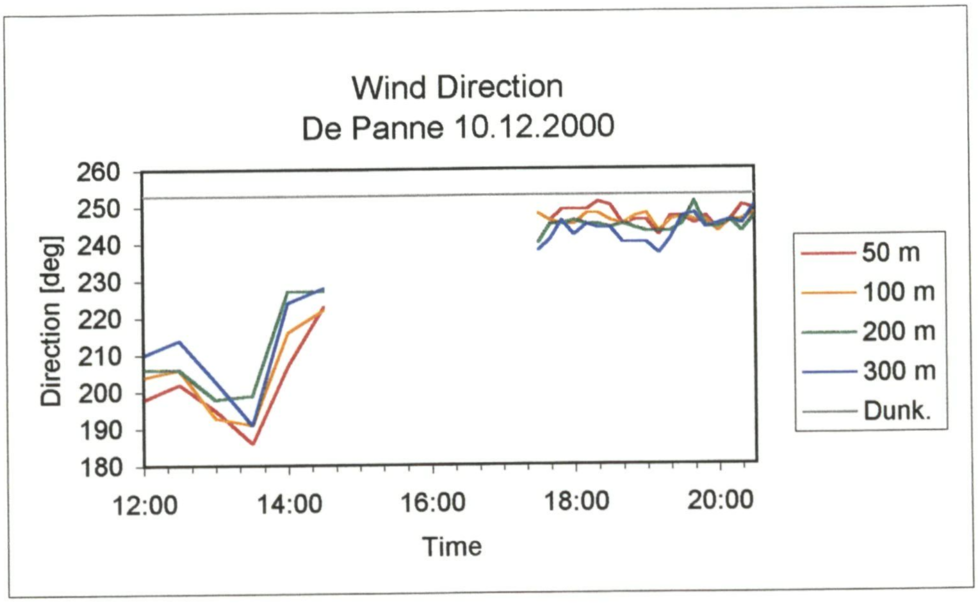



*Fig. 7.5 Wind direction in various heights during the measurement time*

# 7.3 Measurement Results

## Measurement of $SO_2$ Concentration

In Figures 7.6 – 7.11, vertical scans of $SO_2$ concentration are shown; Fig. 7.12 demonstrates time development of the vertical profile of $SO_2$ concentration.

The concentrations in the vertical profile represent a vertical projection of all vertical scans measured in a corresponding time period, hence the values are averaged in horizontal distance and over time. As a result the average concentrations in the vertical profile are significantly lower than concentrations measured locally in single vertical scans. For this reason there is a different color concentration scale used by the vertical scans and by the vertical profile. Concentrations of $SO_2$ from the vertical profile in chosen heights and at chosen times are contained in table 7.1.

Round 12:00, in the beginning of the measurement, before the rain started, no increased $SO_2$ concentrations were detected (Fig. 7.6).

Between 15:00 and 16:00 higher concentrations of $SO_2$ were detected above the sea in the ground layer up to the height of 300 m. Average values in the vertical profile were from 30 to 40 $\mu g.m^{-3}$. Extreme concentrations on the vertical scan were round 100 $\mu g.m^{-3}$ (Fig. 7.7).

Between 16:00 and 17:00 slightly increased $SO_2$ concentrations over the sea were measured only near the coast (Fig. 7.8). Also in the height between 700 and 800 m some higher concentrations appeared.

From 17:00 to 20:30 we again detected high $SO_2$ concentrations when measured over the sea. Round 17:30 average concentrations were more than 50 $\mu g.m^{-3}$ by the ground and round 40 $\mu g.m^{-3}$ in higher layers. Extreme concentrations on the corresponding vertical scan reached 100 $\mu g.m^{-3}$ (Fig. 7.9). About 20:00 the concentrations were little lower with averages up to 40 $\mu g.m^{-3}$ both by the ground and in higher layers (Fig. 7.11).

In between, from 18:30 to 19:30, we conducted also vertical scans over the land but no higher $SO_2$ concentrations were measured there unless the area near the coast. After 20:30 the concentrations decreased significantly also above the sea.

If we compare the concentrations measured by lidar with the data on wind direction measured by sodar and with the meteorological station, we can notice that increased concentrations appeared, whenever the wind could transport air masses from Dunkerque industrial area through measured vertical scans. The wind blew from the area of Dunkerque from 15:00, but depending on its exact direction, increased concentrations appeared sometimes only over the sea and sometimes only over the land. For this reason no high concentrations were detected from 16:00 to 17:00 over the sea and from 18:30 to 19:30 over the land.

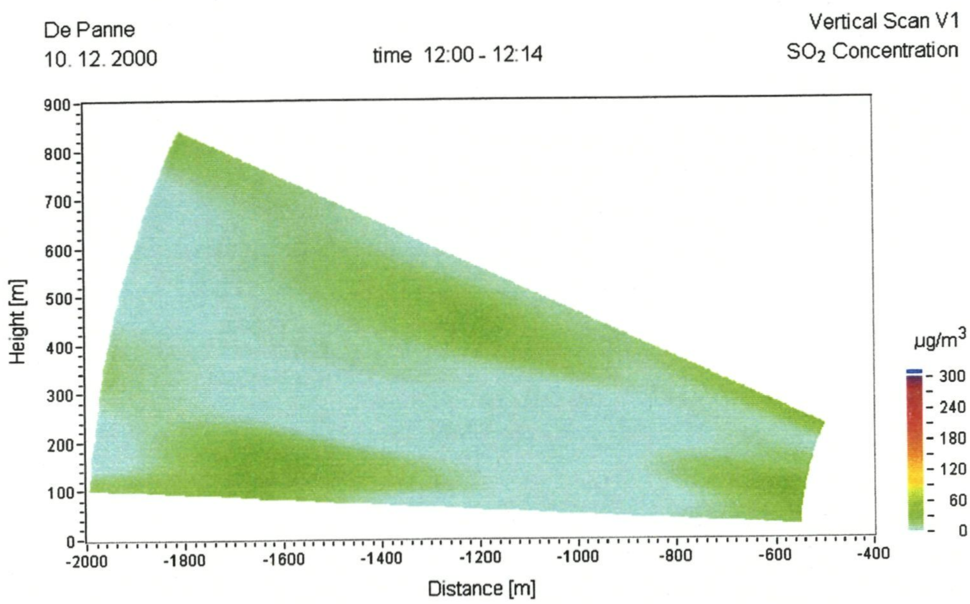



*Fig. 7.6*

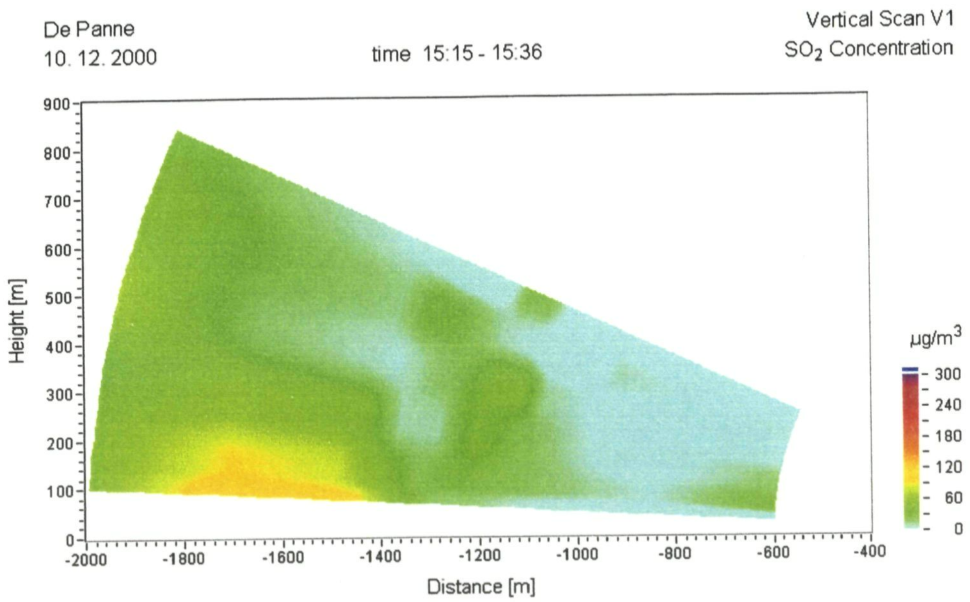



*Fig. 7.7*

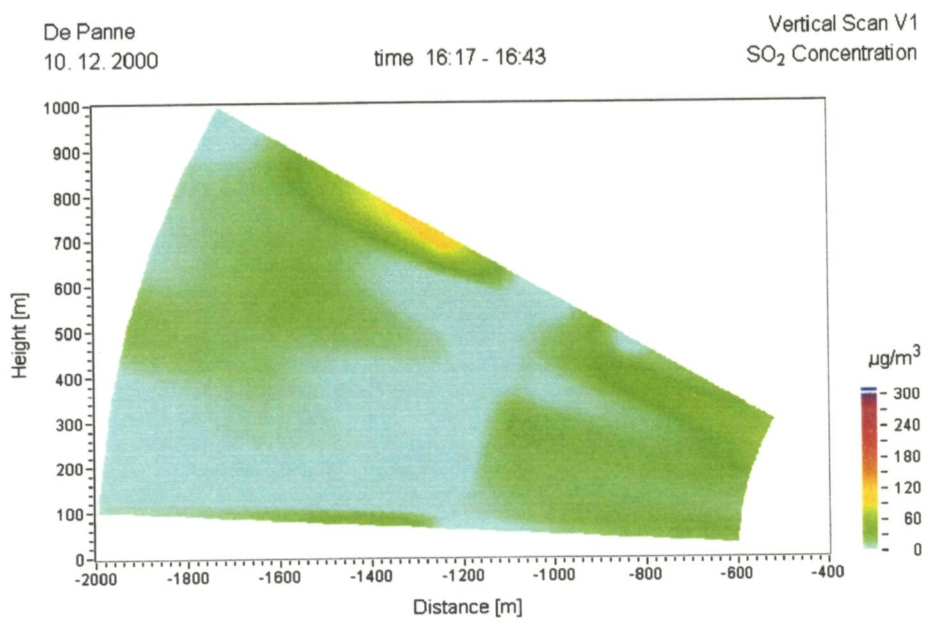



*Fig. 7.8*

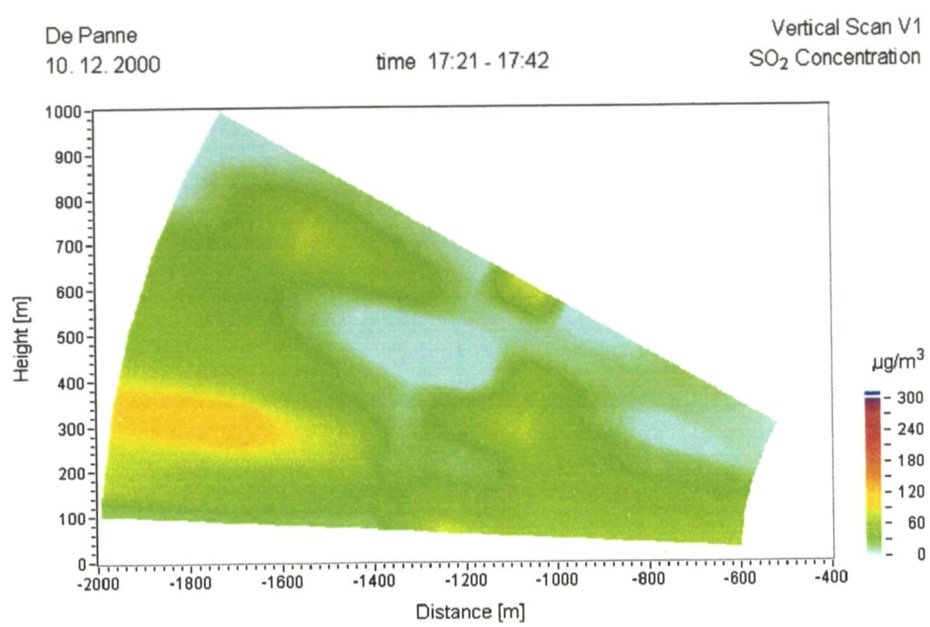



*Fig 7.9*

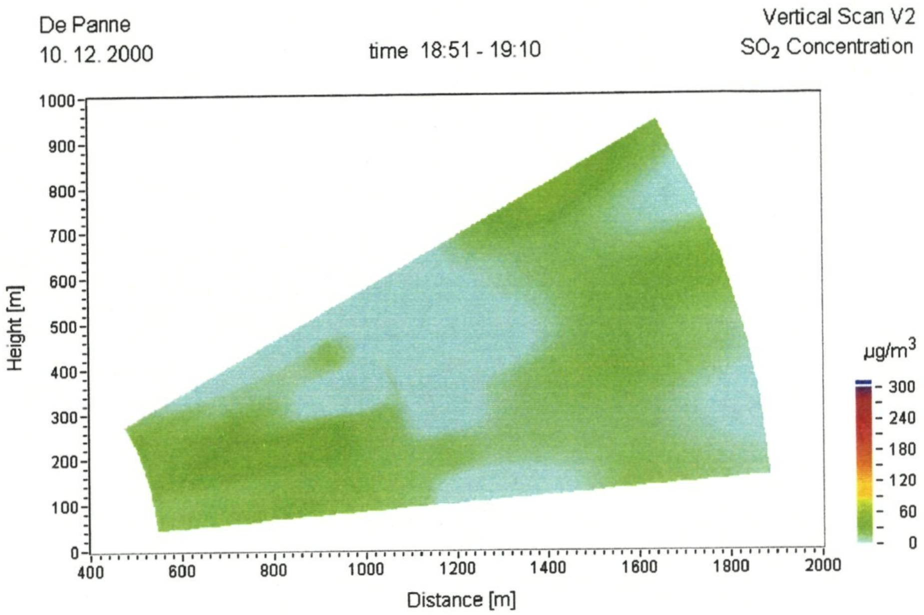



*Fig 7.10*

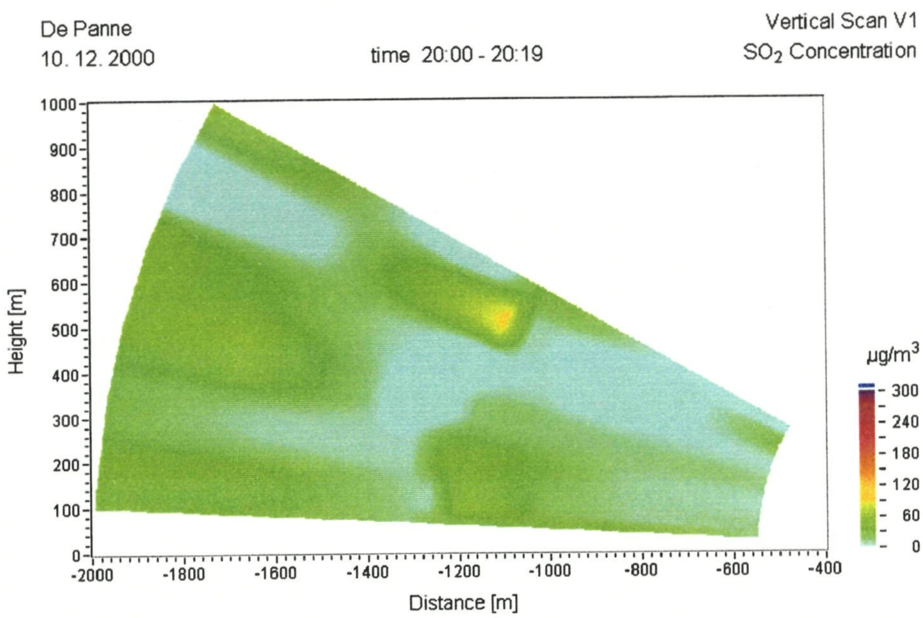



*Fig. 7.11*

| | Height | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Time | 0 m | 100 m | 200 m | 300 m | 400 m | 500 m | 600 m | 700 m | 800 m |
| 15:30:00 | 30 | 39 | 38 | 40 | 13 | 12 | 3 | 23 | 13 |
| 16:30:00 | 8 | 18 | 7 | 10 | -1 | 19 | 0 | 33 | 4 |
| 17:30:00 | 56 | 45 | 40 | 51 | 30 | 26 | 37 | 43 | 24 |
| 19:00:00 | 18 | 15 | 21 | 2 | 7 | 9 | 15 | 23 | 23 |
| 20:00:00 | 38 | 37 | 36 | 22 | 19 | 39 | 34 | 0 | 14 |
| 20:45:00 | 19 | 15 | 18 | 11 | 12 | 15 | 4 | 10 | 26 |

*Tab. 7.1 Concentration of $SO_2$ in $\mu g.m^{-3}$ at chosen times and in chosen heights*

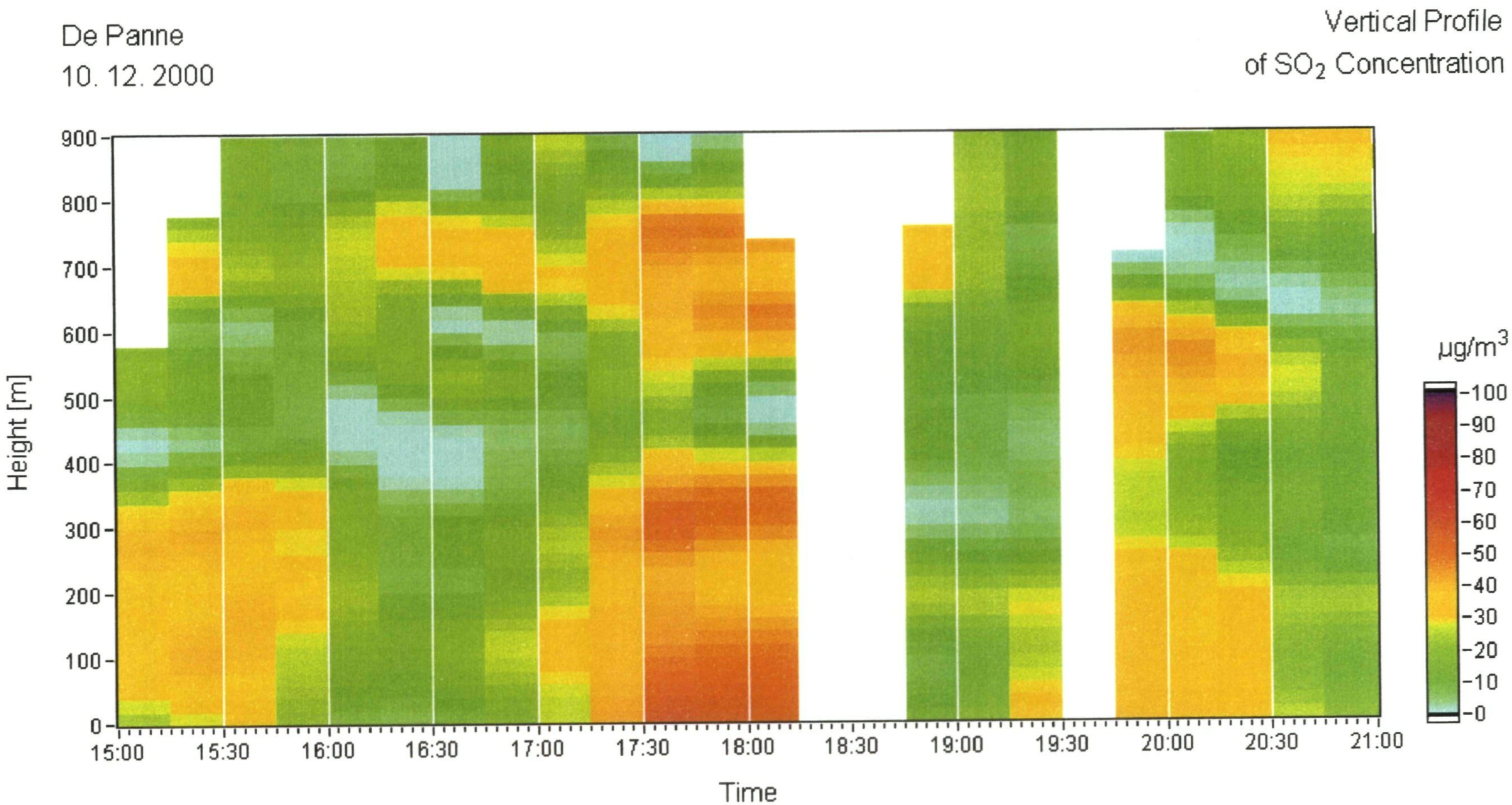



*Fig. 7.12 Time development of the vertical profile of $SO_2$ concentration*

## Measurement of Ozone Concentration

By application of our lidar method, Ozone concentration appears also as fake $SO_2$ concentration. Therefore it was necessary to determine the average Ozone concentration, which was then used for correction of $SO_2$ data. Vertical scans in Fig.7.13 and 7.14 show the distribution of Ozone concentration, which was for our purposes sufficiently homogeneous in both vertical and horizontal directions. Round 15:00 the average Ozone concentration was 80 μg/m$^3$ and in the evening it fell to 74 μg/m$^3$. These values were used for $SO_2$ concentration correction.

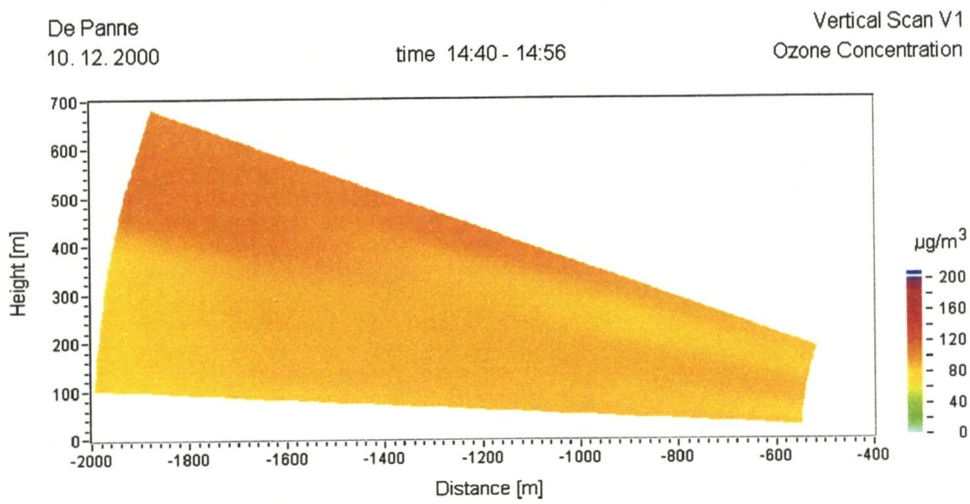



*Fig 7.13*

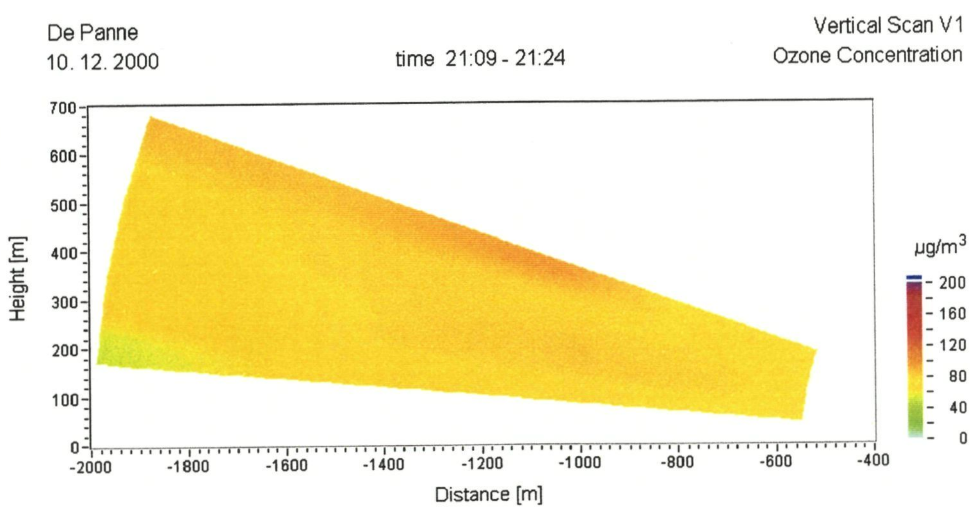



*Fig. 7.14*

## Measurement of Aerosols

In Figures 7.15 – 7.20, vertical scans of extinction coefficient are shown; Figure 7.21 demonstrates time development of the vertical profile of extinction coefficient.

The values of extinction coefficients in the vertical profile are significantly lower than those in single vertical scans, because they represent a vertical projection of all vertical scans measured in a corresponding time period, hence the values are averaged in horizontal distance and over time. Extinction coefficients from the vertical profile in chosen heights and at chosen times are contained in table 7.2. Common values of these coefficients were 0,6 and 0,7 $km^{-1}$, which is significantly more than on the following measurement days, when the wind speed was not so high. The extinction coefficients were measured on the wavelength 286.3 nm.

The values of extinction coefficient are relatively high also on all the vertical scans. This was caused by strong wind that was raising dust from the coast and water droplets from the sea. Through this effect no distinguished isolated aerosol clouds could have been detected. The only exceptions were aerosols measured in higher layers in the period from 16:00 to 17:00 and from 19:45 to 21:00 (Figures 7.17 and 7.20). However, we can't identify the character of these aerosols. They might be part of a plume, but considering their high position they could be some thin layer of clouds as well.

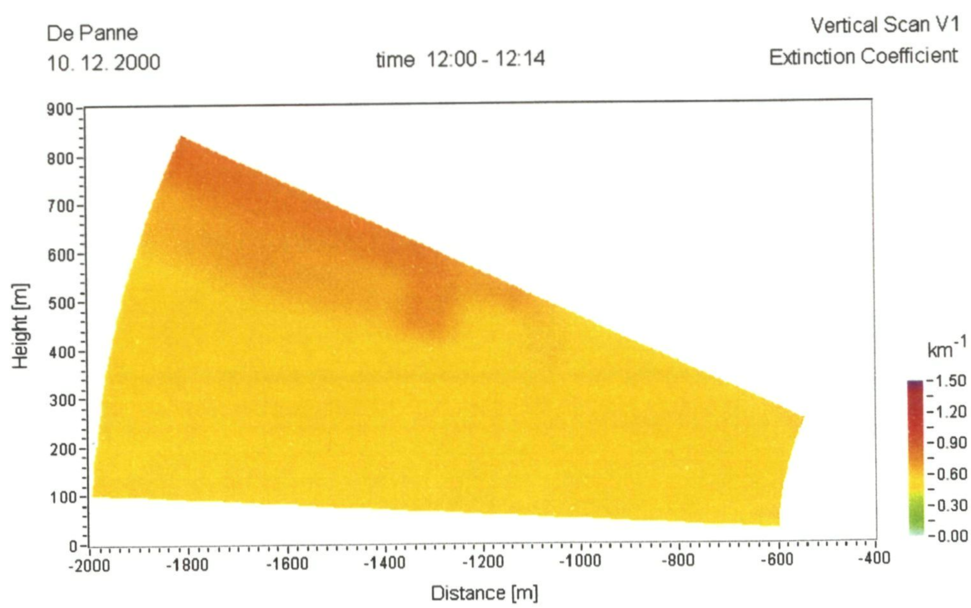



*Fig. 7.15*

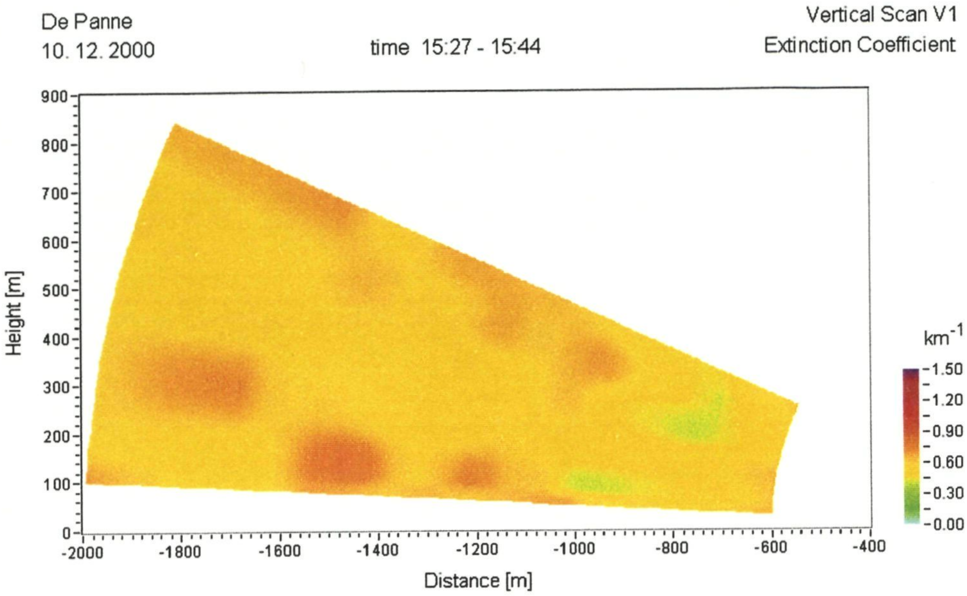



*Fig. 7.16*

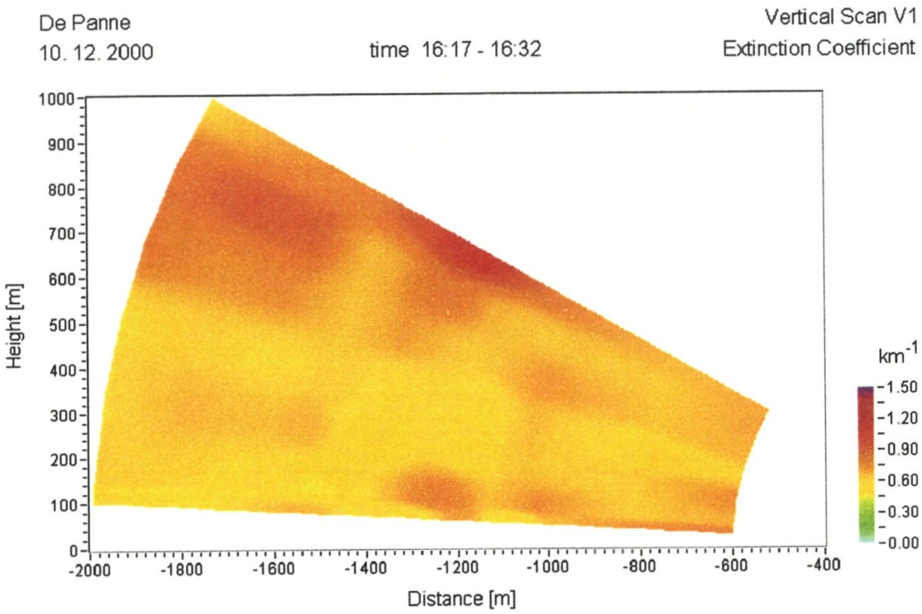



*Fig. 7.17*

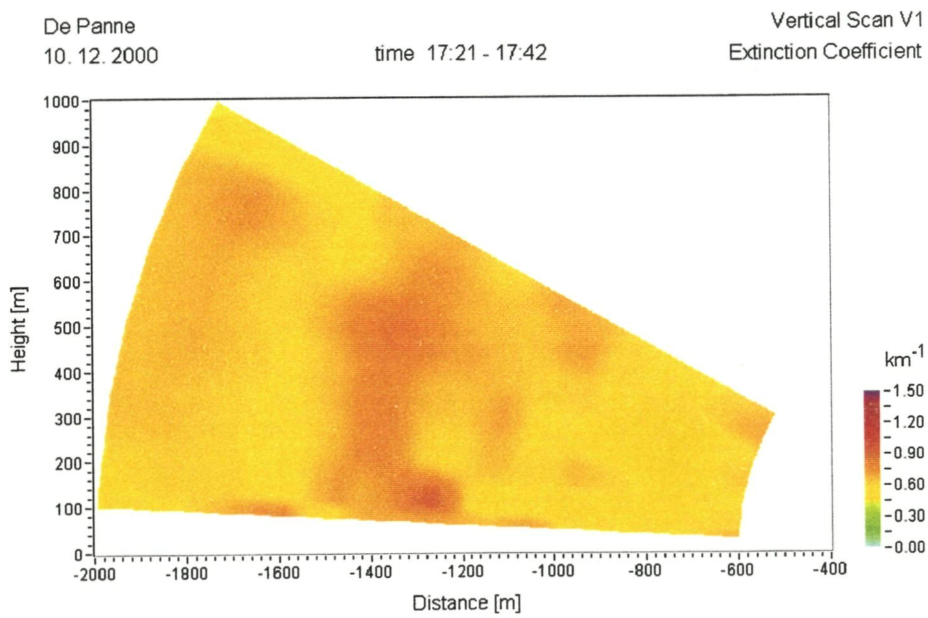



*Fig. 7.18*

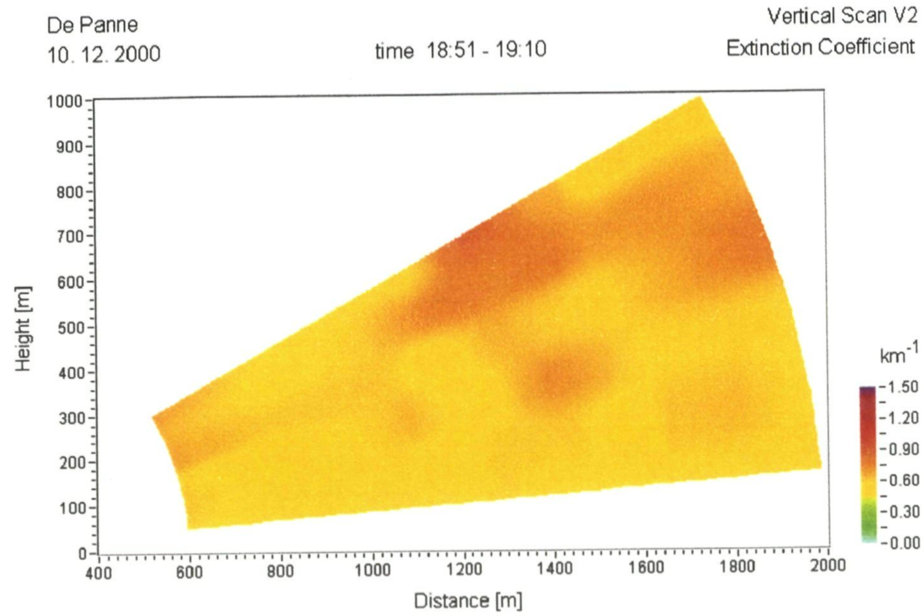



*Fig. 7.19*

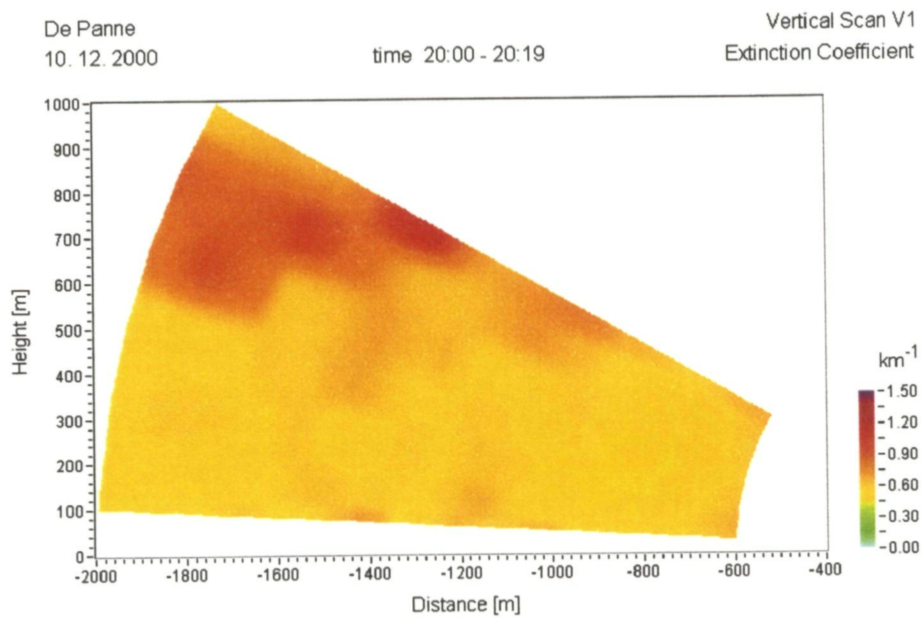



*Fig. 7.20*

| | Height | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Time | 0 m | 100 m | 200 m | 300 m | 400 m | 500 m | 600 m | 700 m | 800 m |
| 15:30:00 | 0,6 | 0,6 | 0,5 | 0,5 | 0,6 | 0,6 | 0,6 | 0,6 | 0,6 |
| 16:30:00 | 0,6 | 0,6 | 0,6 | 0,6 | 0,7 | 0,7 | 0,8 | 0,8 | 0,7 |
| 17:30:00 | 0,6 | 0,6 | 0,6 | 0,6 | 0,6 | 0,6 | 0,6 | 0,6 | 0,6 |
| 19:00:00 | - | 0,5 | 0,6 | 0,6 | 0,6 | 0,6 | 0,7 | 0,8 | 0,6 |
| 20:00:00 | 0,6 | 0,6 | 0,6 | 0,6 | 0,6 | 0,6 | 0,6 | 0,8 | 1,0 |
| 20:45:00 | 0,6 | 0,6 | 0,5 | 0,6 | 0,6 | 0,6 | 0,7 | 0,9 | 0,9 |

*Tab. 7.2 Extinction coefficients in $km^{-1}$ at chosen times and in chosen heights*

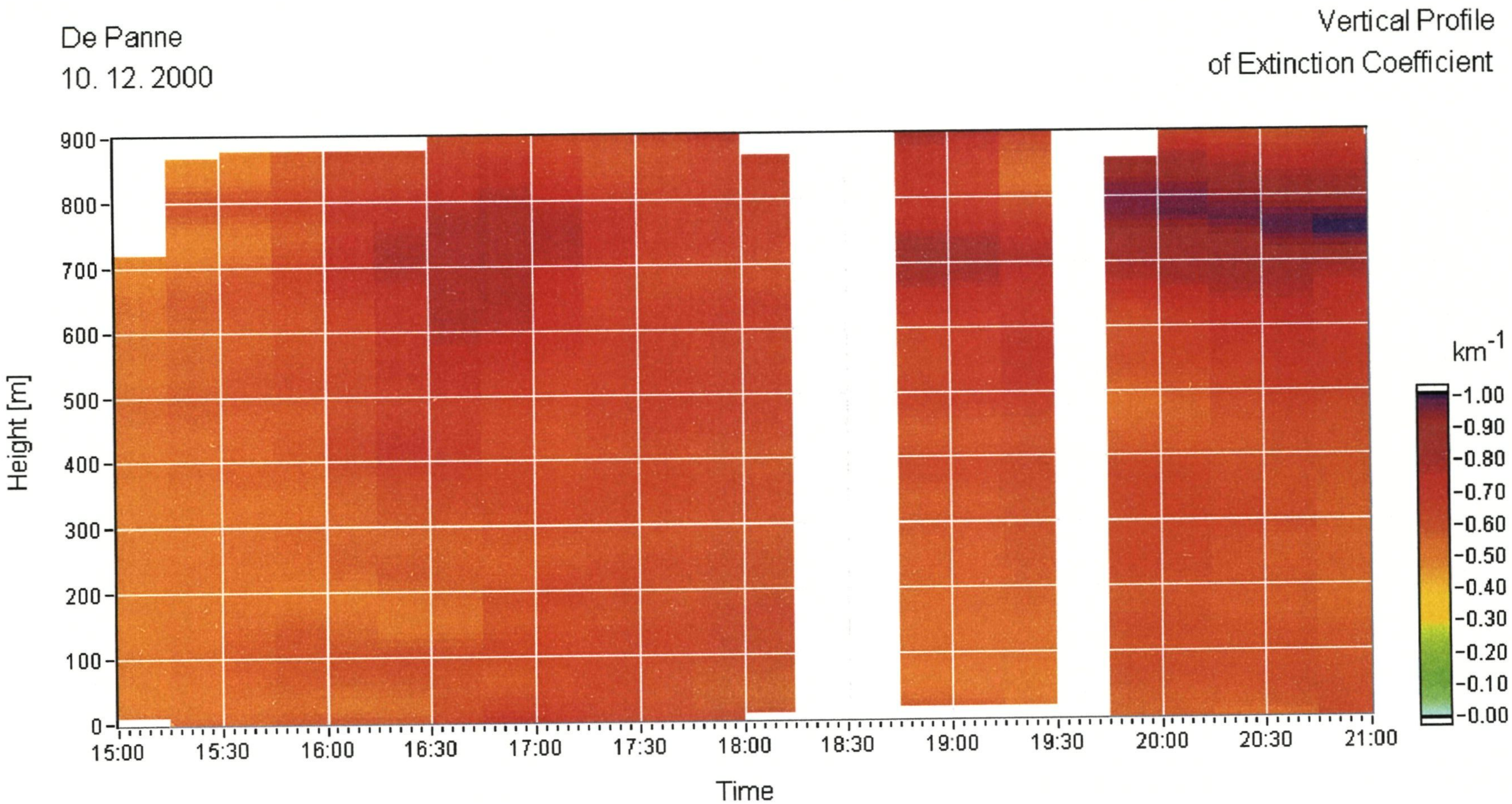



*Fig. 7.21 Time development of the vertical profile of extinction coefficient*

# 8 De Panne 11. 12. 2000

## 8.1 Measurement Location and Time

On December the 11th, we measured concentration of Ozone from the sea bank in De Panne. The exact location of the mobile system is symbolized in Fig. 8.1. The measurement was carried out in a form of vertical scans. The direction of vertical scans alternated so that it was measured both above the sea (vertical scans V1) and above the land (vertical cans V2). The exact direction of both types of vertical scans is also shown in Fig. 8.1.

The measurement started at 12:00 and continued until 19:20. It was interrupted for one hour by a rain in the period between 15:20 and 16:20.


*Fig. 8.1 Location of the lidar system and the direction of vertical scans*

## 8.2 Meteorological situation

Figures 8.2 and 8.3 demonstrate synoptical situation over Europe before and after the measurement.

Around noon it was cloudy; in the afternoon it was overcast; and between 15:20 and 16:20 it was raining. In the evening it was still overcast, and round 19:00 a steady rain started. The temperature was approximately 12 °C during the whole measurement time.

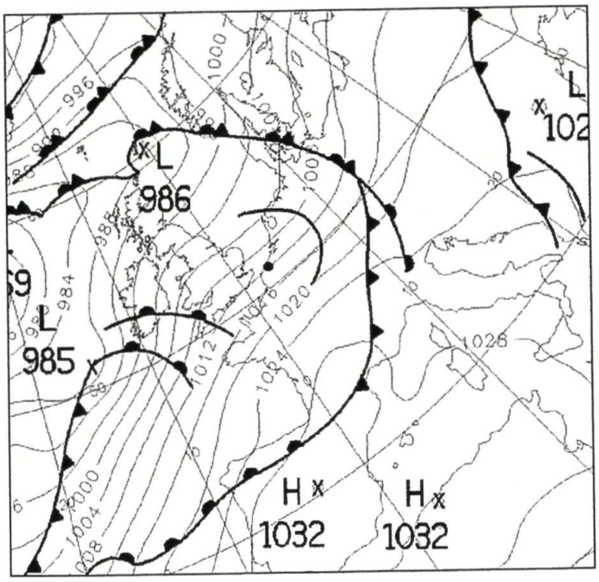


Fig. 8.2 Synoptical situation
*11. 12. 2000 at 0:00 UTC*

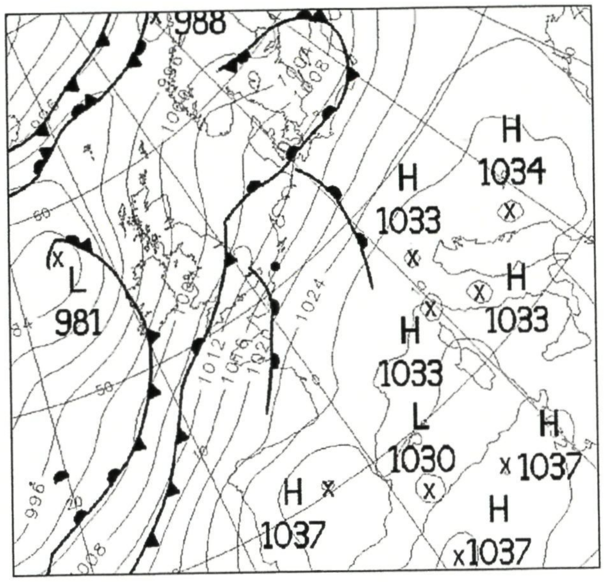


Fig. 8.3 Synoptical situation
*12. 12. 2000 at 0:00 UTC*

Wind speed and direction measured by sodar in various heights are graphed in Fig. 8.4 and Fig. 8.5. The wind speed was reaching relatively high values above 8 m/s during the whole measurement period. It increased with the height, which is natural, and it decreased slightly about the time of the rain. In the beginning of the measurement, the wind blew from southwestern direction and during the day its direction was moving towards the south.

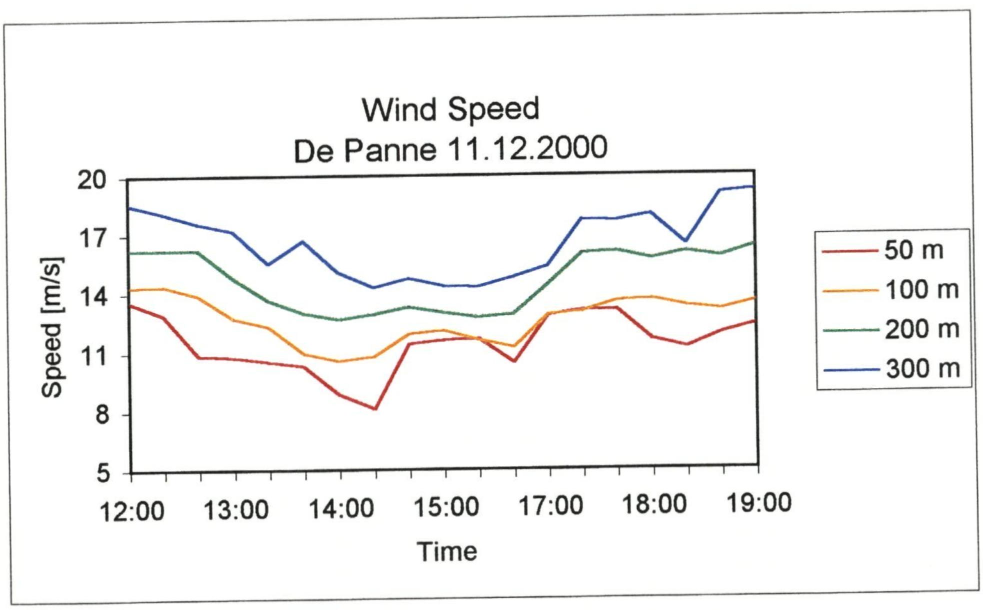



*Fig. 8.4 Wind speed in various heights during the measurement time*

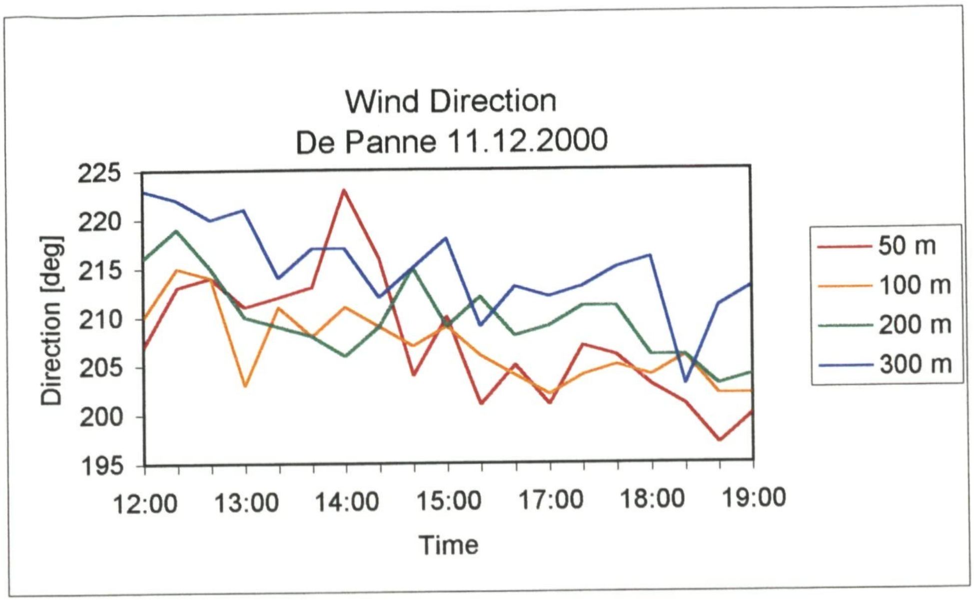



*Fig. 8.5 Wind direction in various heights during the measurement time*

## 8.3 Measurement Results

Figures 8.6 – 8.12 display vertical scans of Ozone concentration. From these results it's obvious that the Ozone concentration was the same both above the sea as above the land. Because of the wind the concentration was fairly homogeneously distributed, however it rose slightly with the height, which is a typical behavior. Before the rain the Ozone concentration was between 50 and 60 $\mu g.m^{-3}$ by the ground and round 70 $\mu g.m^{-3}$ in the height of 800 m (Fig. 8.6 and 8.7). Exceptionally the concentration reached almost 100 $\mu g.m^{-3}$ in higher layers. After the rain the concentration fell significantly to values under 40 $\mu g.m^{-3}$ by the ground and round 50 $\mu g.m^{-3}$ in higher layers (Fig. 8.7 – 8.12). It was only possible to reach the heights of 500 m after the rain, because of clouds.

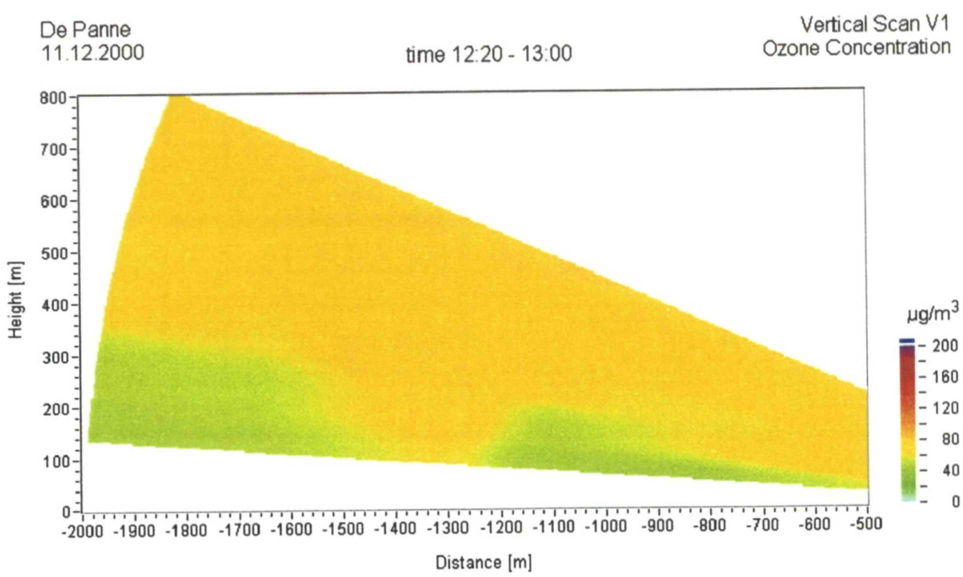



*Fig. 8.6*

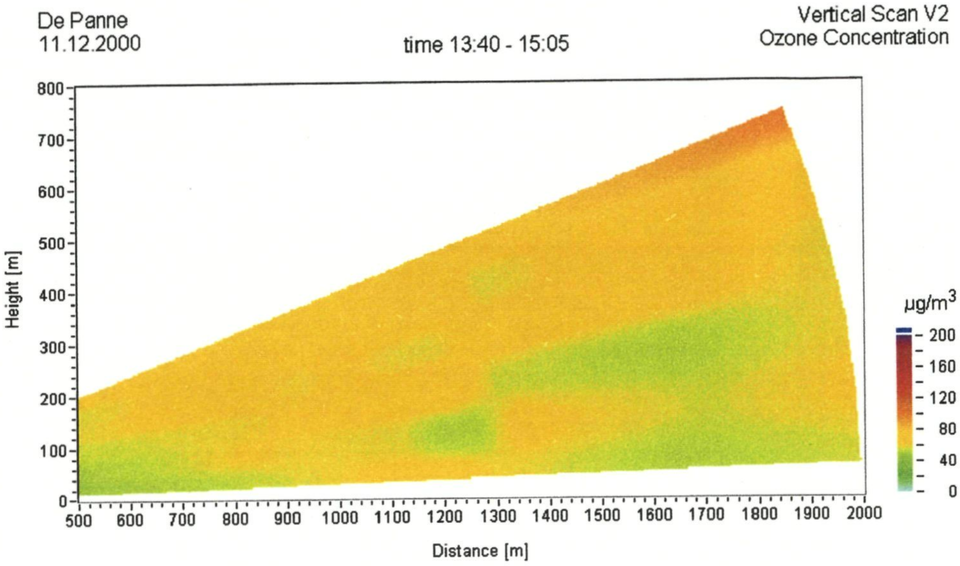



*Fig. 8.7*

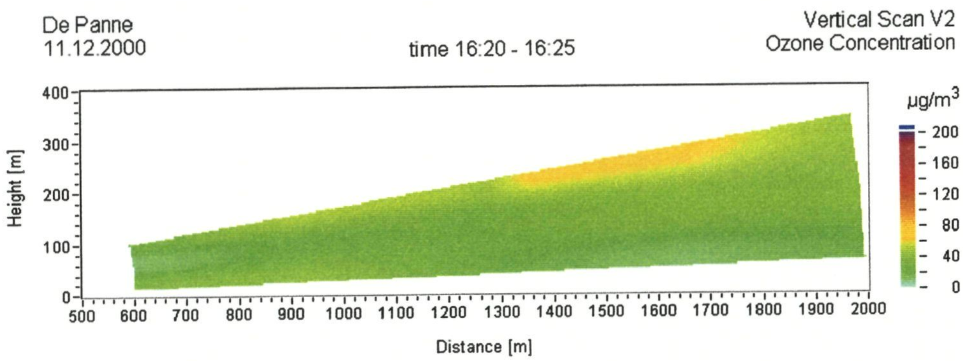



*Fig. 8.8*

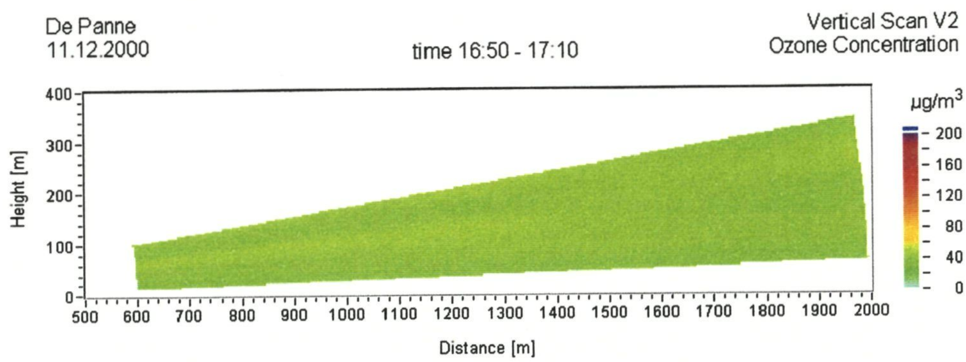



*Fig 8.9*

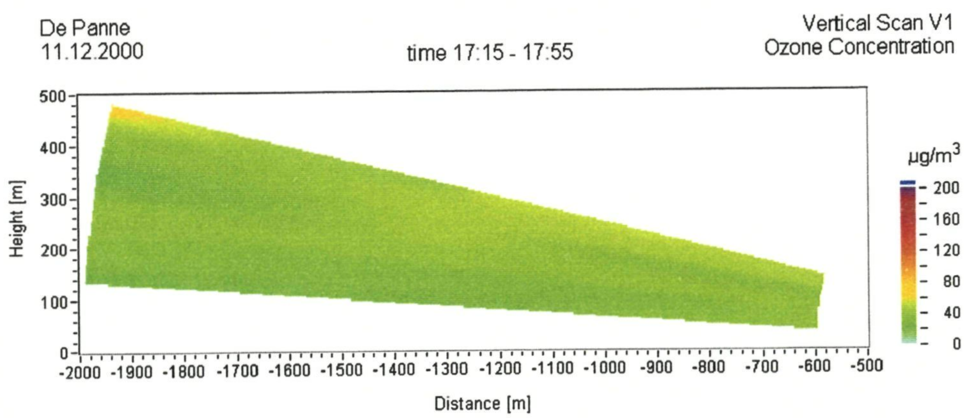



*Fig 8.10*

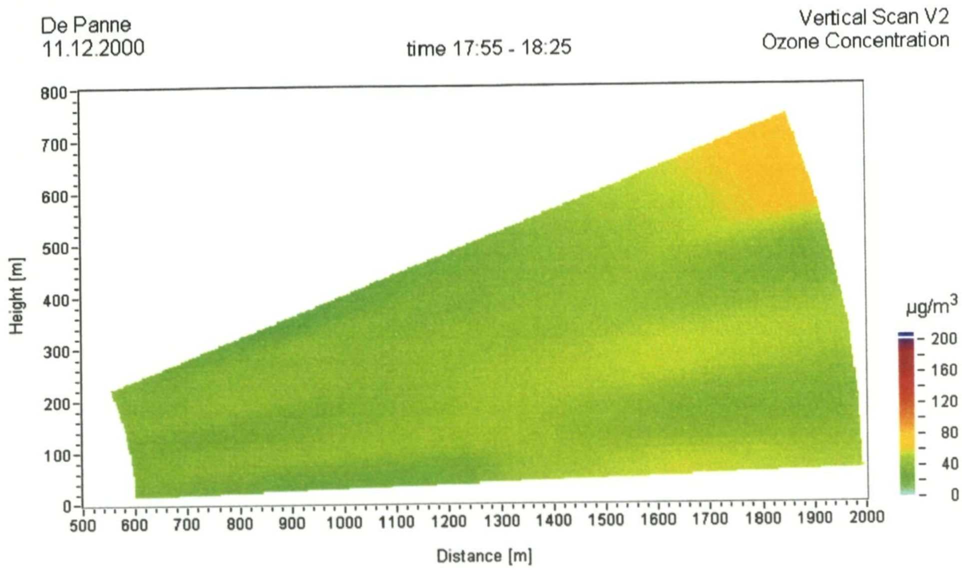



*Fig. 8.11*

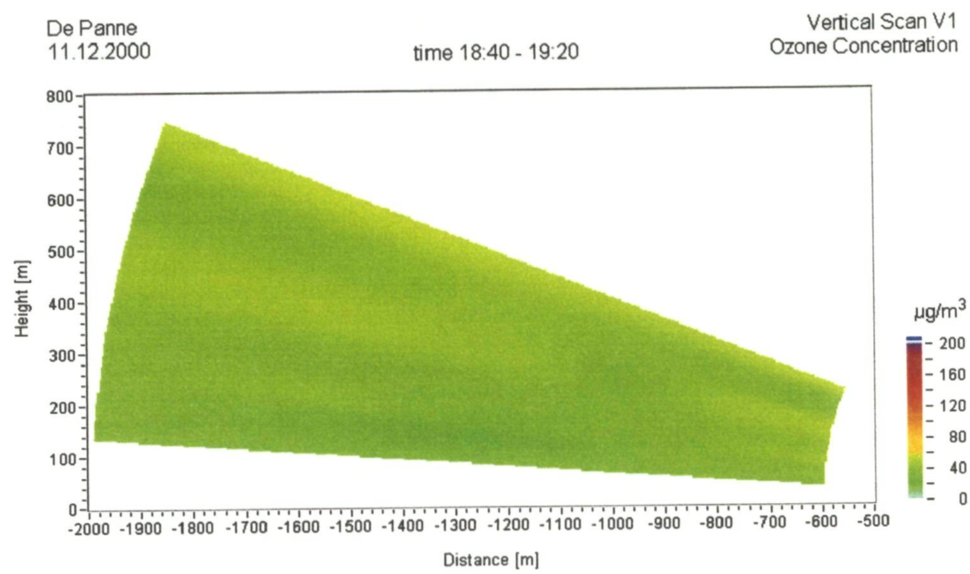



*Fig 8.12*

Time development of the vertical profile of Ozone concentration is demonstrated in Fig. 8.13. Here the Ozone concentration is averaged from both vertical scans above the sea (V1) and vertical scans above the land (V1). Both types of scans were used, because they don't perform any significant differences in Ozone distribution. Fig 8.13 demonstrates the evolution of Ozone concentration, as described above, more clearly. Before the rain the Ozone concentration was between 50 and 60 $\mu g.m^{-3}$ by the ground and about 70 $\mu g.m^{-3}$ in the height of 800 m. After the rain the concentration decreased to values less than 40 $\mu g.m^{-3}$ by the ground and about 50 $\mu g.m^{-3}$ in higher layers. During the rain the measurement wasn't possible, and therefore there are no data available for this period.

Table 8.1 contains Ozone concentrations in $\mu g.m^{-3}$ at chosen times and in chosen heights.

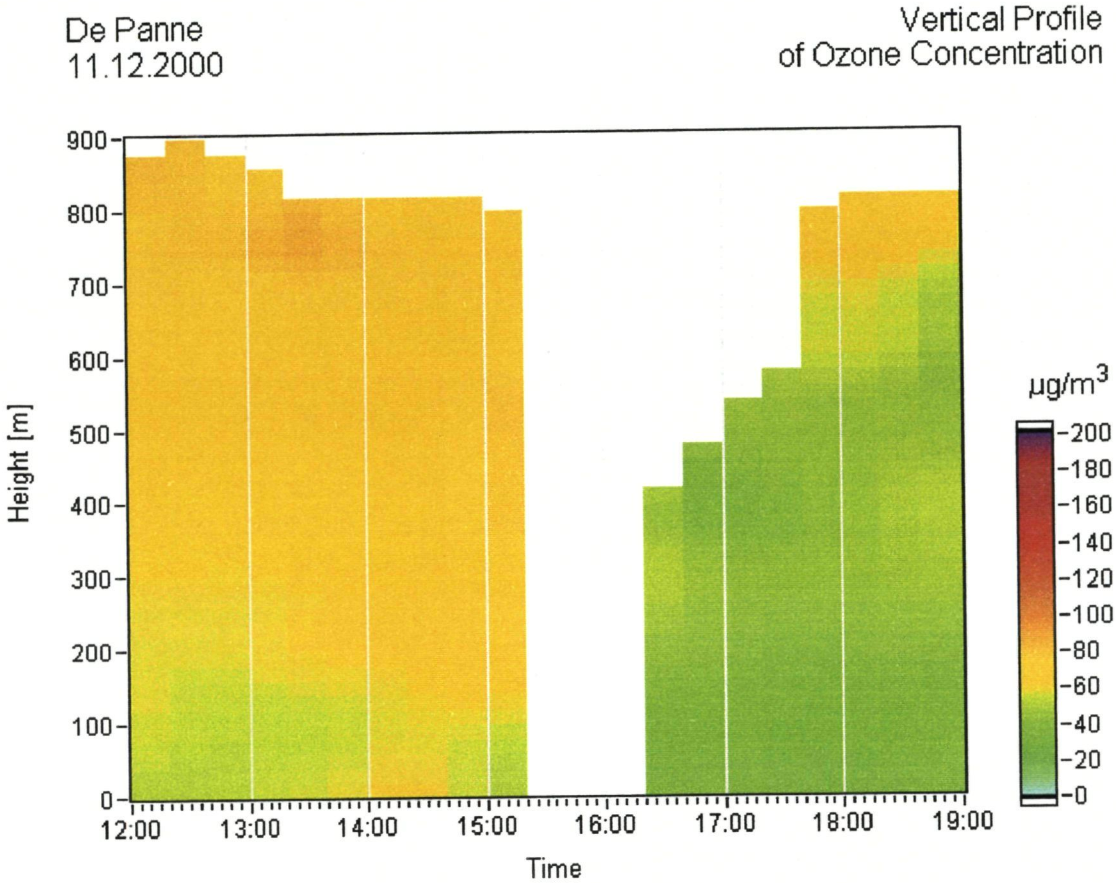



*Fig. 8.13 Time development of the vertical profile of Ozone concentration*

| | Height | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Time | 0 m | 100 m | 200 m | 300 m | 400 m | 500 m | 600 m | 700 m | 800 m |
| 12:20:00 | 51 | 54 | 56 | 59 | 60 | 64 | 71 | 74 | 76 |
| 14:00:00 | 59 | 56 | 60 | 64 | 65 | 66 | 65 | 72 | 71 |
| 15:00:00 | 51 | 57 | 66 | 69 | 77 | 76 | 71 | 68 | - |
| 16:20:00 | 37 | 38 | 46 | 52 | 48 | - | - | - | - |
| 17:00:00 | 37 | 38 | 42 | 44 | 39 | 46 | - | - | - |
| 18:00:00 | 35 | 37 | 42 | 47 | 47 | 45 | 55 | 60 | 65 |
| 19:00:00 | 37 | 36 | 41 | 49 | 50 | 41 | 40 | 48 | 59 |

*Tab. 8.1 Concentration of Ozone in $\mu g.m^{-3}$ at chosen times and in chosen heights*

# 9 De Panne 13. 12. 2000

## 9.1 Measurement Location and Time

On December the 13th, we measured concentration of $SO_2$ and Ozone. Also extinction coefficients, hence the distribution of aerosols, were determined from the signal on $SO_2$ reference wavelength. The measurement was carried out from the sea bank in De Panne. The exact location of the mobile system is marked in Fig. 9.1. The measurement was conducted in a form of vertical scans. The direction of vertical scans alternated so that it was measured both above the sea (vertical scans V1) and above the land (vertical cans V2). The exact direction of the two types of vertical scans is also shown in Fig. 9.1. Direction to Dunkerque industrial area is marked by an arrow D.

The lidar measurement started at 16:00 and continued until 21:00. Before 16:00 it was raining most of the time. However, the sodar measurement started already at 12:00. It was interrupted repeatedly because of technical problems, sometimes caused by the heavy rain.

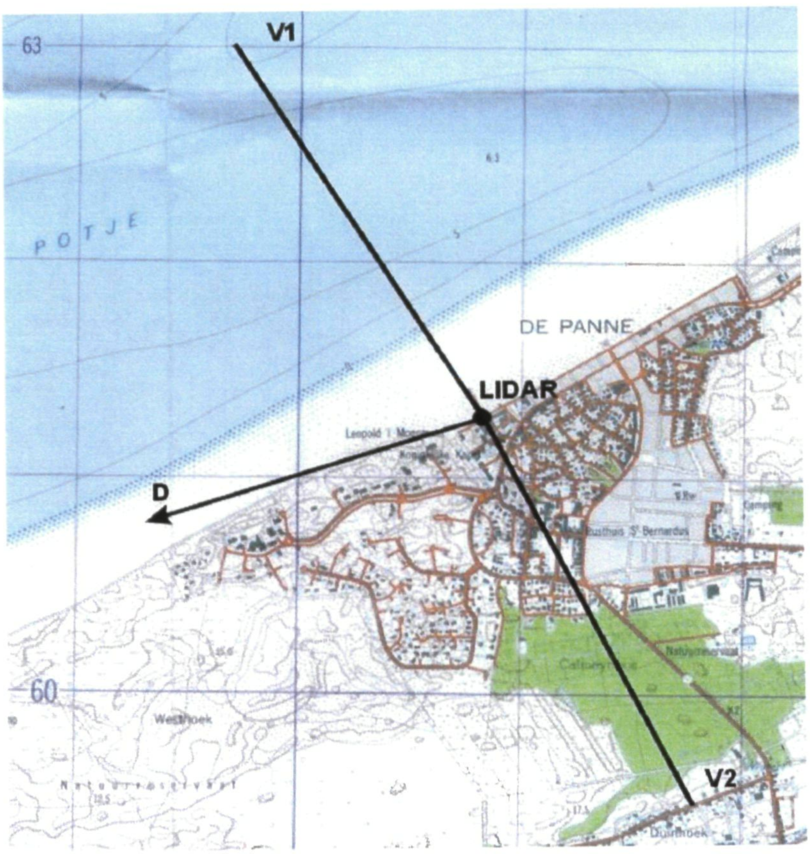



*Fig. 9.1 Location of the lidar system and the direction of vertical scans*

## 9.2 Meteorological situation

Figures 9.2 and 9.3 demonstrate the synoptical situation over Europe before and after the measurement.

Until the beginning of the measurement it was cloudy or overcast with frequent showers or rain. During the lidar measurement, between 16:00 and 21:00, it was mostly cloudy, but not raining. The temperature was round 10 °C.

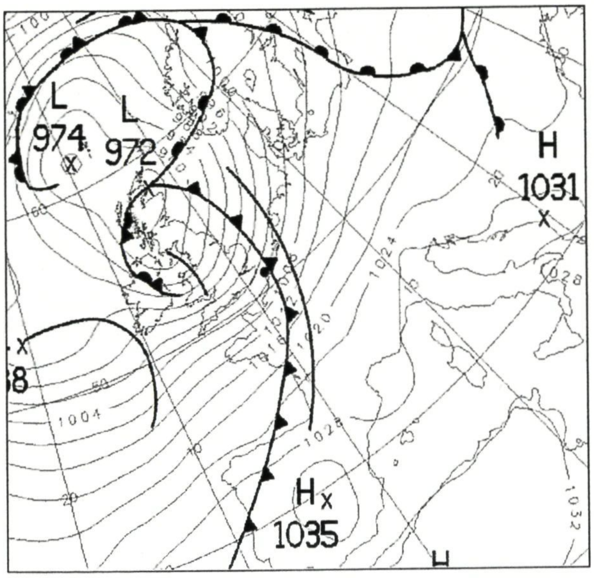



*Fig. 9.2 Synoptical situation 13. 12. 2000 at 0:00 UTC*

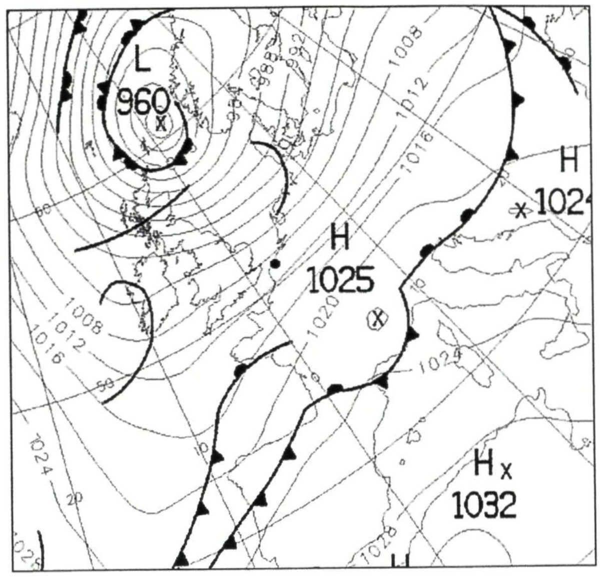



*Fig. 9.3 Synoptical situation 14. 12. 2000 at 0:00 UTC*

Wind speed and direction measured by sodar in various heights are graphed in Fig. 9.4 and Fig. 9.5. The wind speed was reaching high values round 16 m/s during the whole measurement.

In the beginning of the lidar measurement at 16:00 the wind direction was round 230°, which is the southwest, and it was turning towards the west until it reached almost 250° at 21:00.

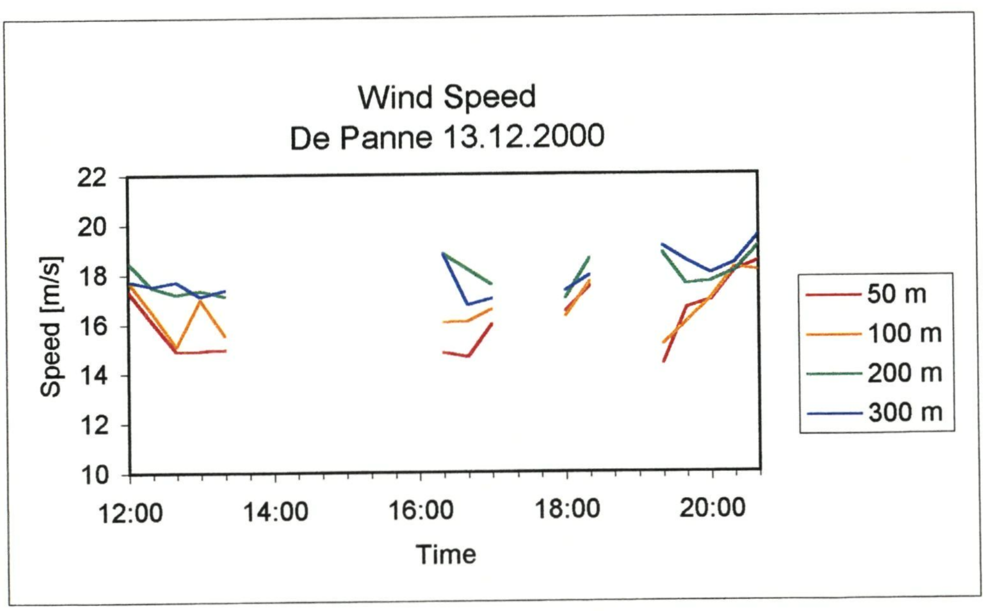



*Fig. 9.4 Wind speed in various heights during the measurement time*

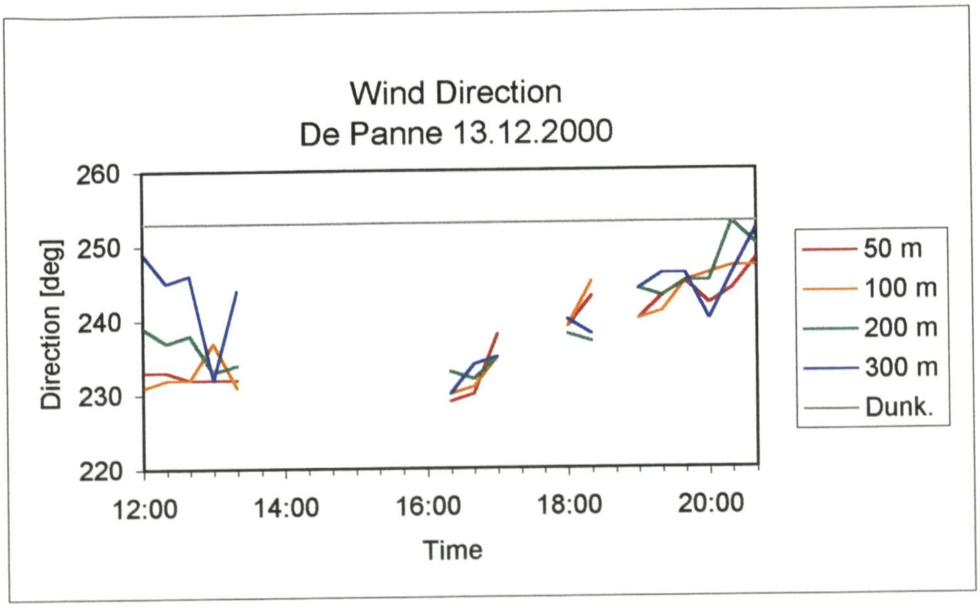



*Fig. 9.5 Wind direction in various heights during the measurement time*

# 9.3 Measurement Results

## Measurement of $SO_2$ Concentration

In Figures 9.6 – 9.9, vertical scans of $SO_2$ concentration are shown; Fig. 9.10 demonstrates time development of the vertical profile of $SO_2$ concentration.

The concentrations in the vertical profile represent a vertical projection of all vertical scans measured in a corresponding time period, hence the values are averaged in horizontal distance and over time. As a result the average concentrations in the vertical profile are significantly lower than concentrations measured locally in single vertical scans. For this reason there is a different color concentration scale used by the vertical scans and by the vertical profile. Concentrations of $SO_2$ from the vertical profile in chosen heights and at chosen times are contained in table 9.1.

From 16:00 to 20:00 concentrations of $SO_2$ were very low with average values under 12 $\mu g.m^{-3}$. Also the maximal concentrations on single vertical scans were very low (Fig. 9.6 - 9.9).

After 20:00 the average concentrations increased slightly to values round 15 $\mu g.m^{-3}$, however, it is still a low value. Regarding the wind direction after 20:00, one could expect higher concentrations, because the wind could bring air masses from Dunkerque industrial area. Nevertheless, these air masses were probably transported over the sea only. Unfortunately, exactly at 20:00, we changed the measurement direction from the sea to the land (from scans V1 to V2).

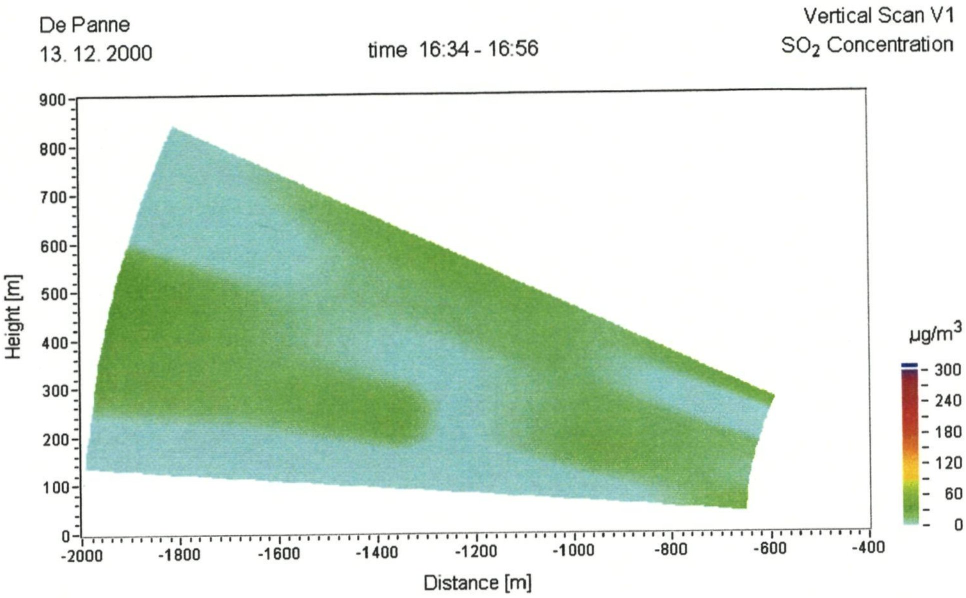



*Fig. 9.6*

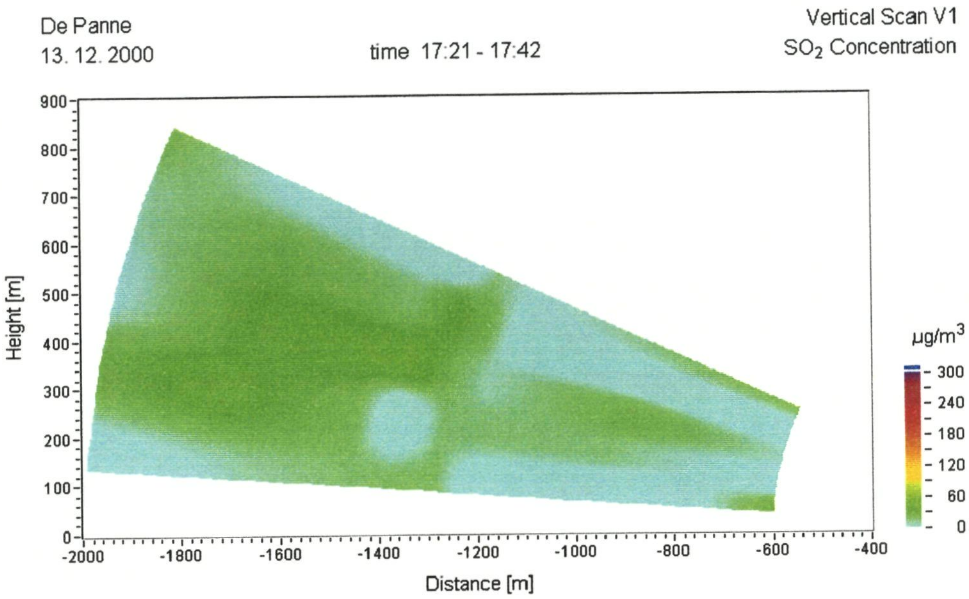



*Fig. 9.7*

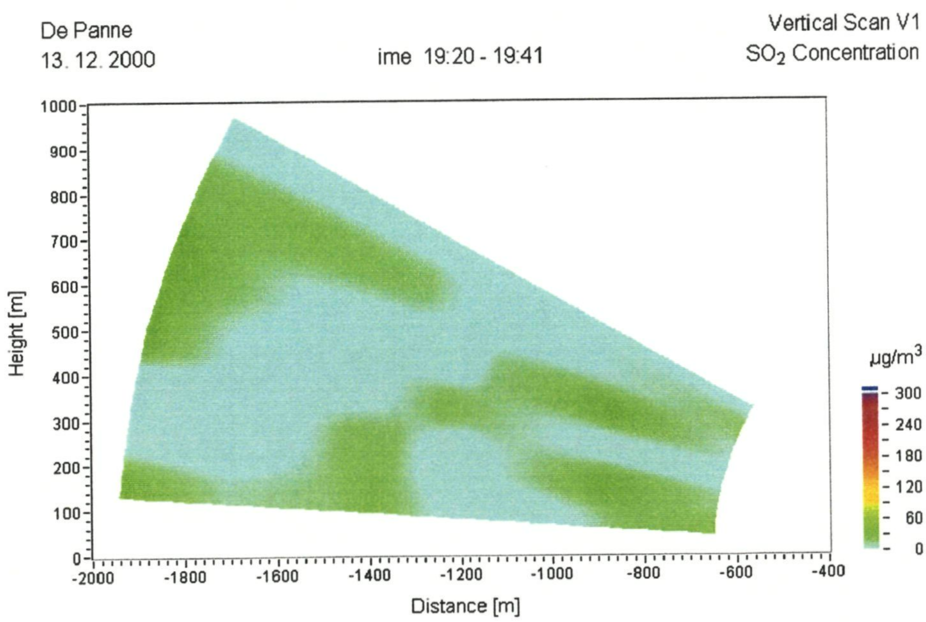



*Fig. 9.8*

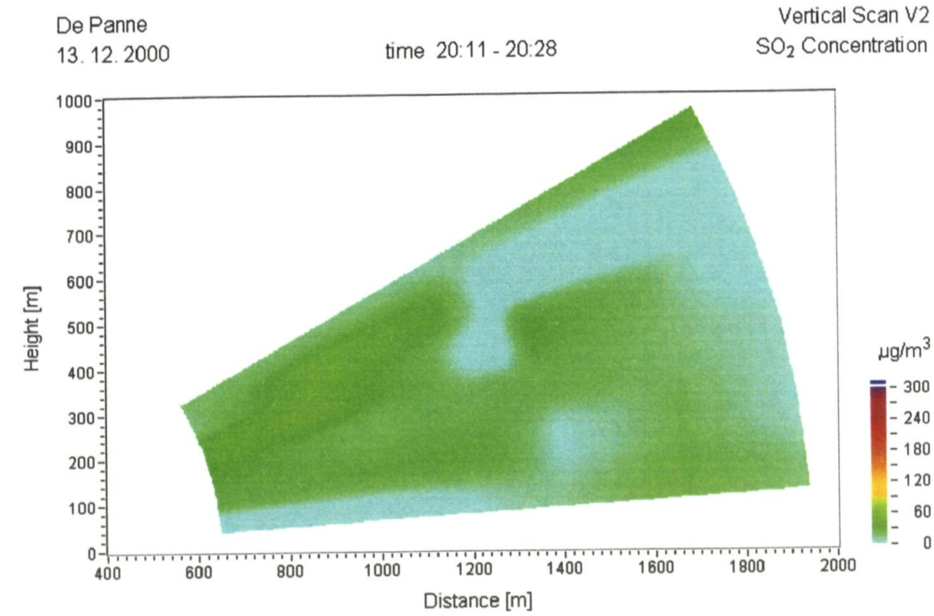



*Fig 9.9*

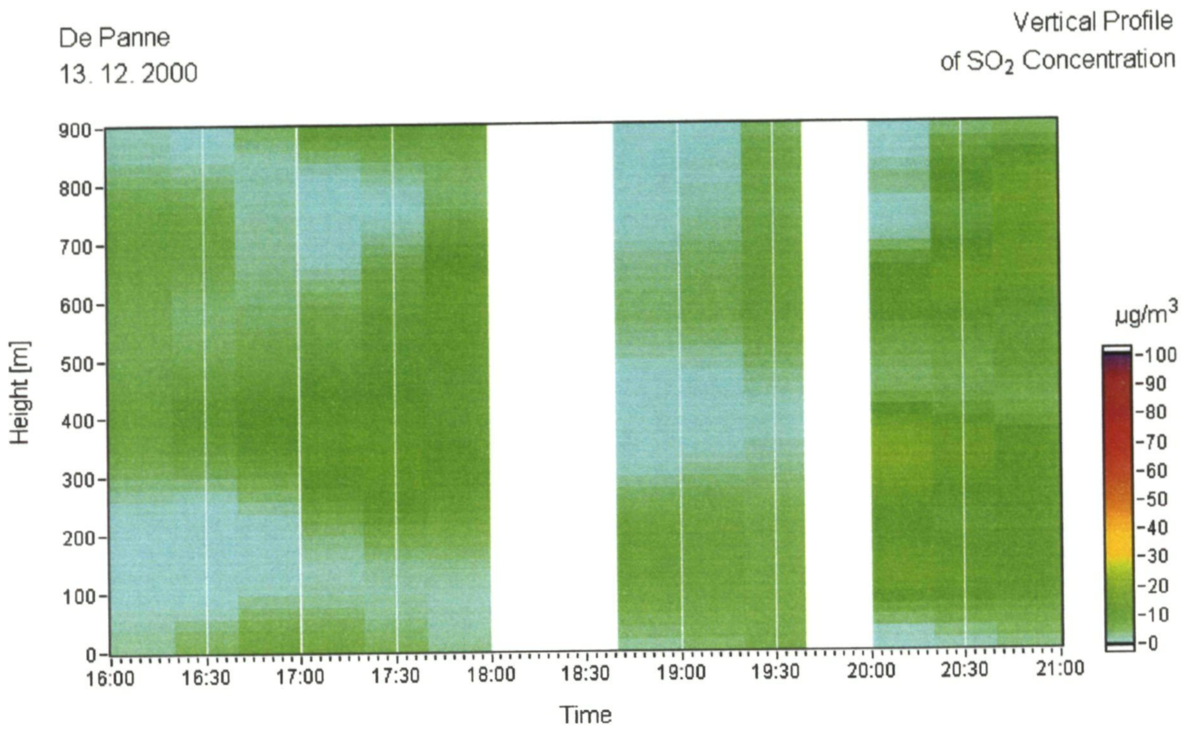



*Fig. 9.10 Time development of the vertical profile of $SO_2$ concentration*

| | Height | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Time | 0 m | 100 m | 200 m | 300 m | 400 m | 500 m | 600 m | 700 m | 800 m |
| 16:40:00 | 8 | 0 | -1 | 7 | 10 | 6 | 3 | 2 | 1 |
| 17:40:00 | 2 | 1 | 6 | 10 | 9 | 11 | 12 | 7 | 3 |
| 19:20:00 | 6 | 6 | 6 | 3 | 0 | 4 | 7 | 5 | 5 |
| 20:20:00 | 1 | 12 | 8 | 16 | 8 | 6 | 15 | 8 | 10 |

*Tab. 9.1 Concentration of $SO_2$ in $\mu g.m^{-3}$ at chosen times and in chosen heights*

## Measurement of Ozone Concentration

By application of our lidar method, Ozone concentration appears also as fake $SO_2$ concentration. Therefore it was necessary to determine the average Ozone concentration, which was then used for correction of $SO_2$ data. Vertical scan in Fig. 9.11 shows the distribution of Ozone concentration, which was for our purposes sufficiently homogeneous in both vertical and horizontal directions. The average Ozone concentration was 75 μg/m$^3$. This value was used for $SO_2$ concentration correction.

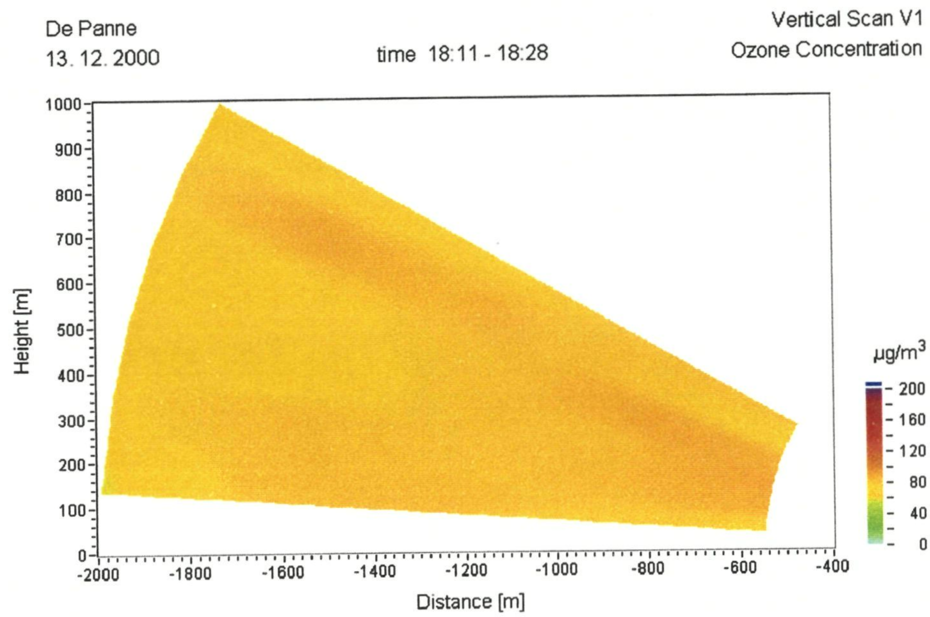



*Fig 9.11*

## Measurement of Aerosols

In Figures 9.12 – 9.15, vertical scans of extinction coefficient are shown; Figure 9.16 demonstrates time development of the vertical profile of extinction coefficient.

The values of extinction coefficients in the vertical profile are significantly lower than those in single vertical scans, because they represent a vertical projection of all vertical scans measured in a corresponding time period, hence the values are averaged in horizontal distance and over time. Extinction coefficients from the vertical profile in chosen heights and at chosen times are contained in table 9.2. Common values of these coefficients were 0,5 $km^{-1}$, which is little more than on the following measurement days, when the wind speed was not so high. The extinction coefficients were measured on the wavelength 286.3 nm.

No distinguished isolated aerosol clouds were detected. Some small changes in extinction coefficient due to aerosols were observed only near the earth and in higher layers over 600 m (Fig. 9.12 – 9.15).

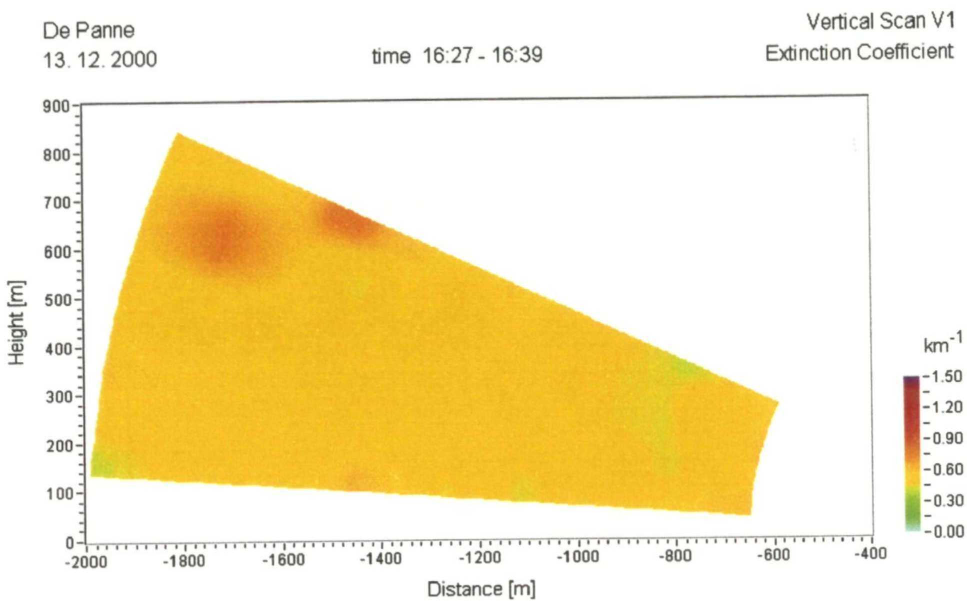



*Fig. 9.12*

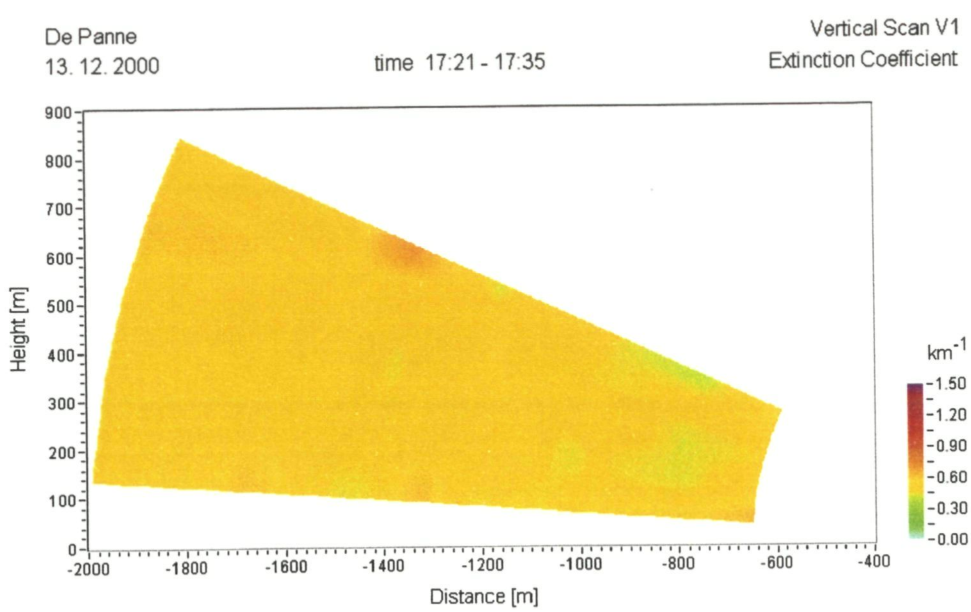



*Fig. 9.13*

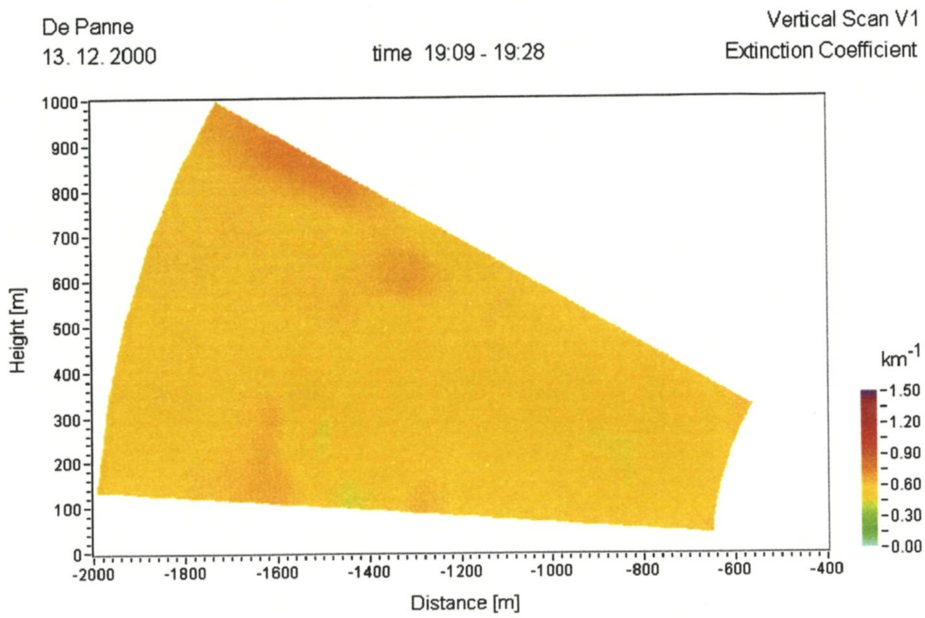



*Fig. 9.14*

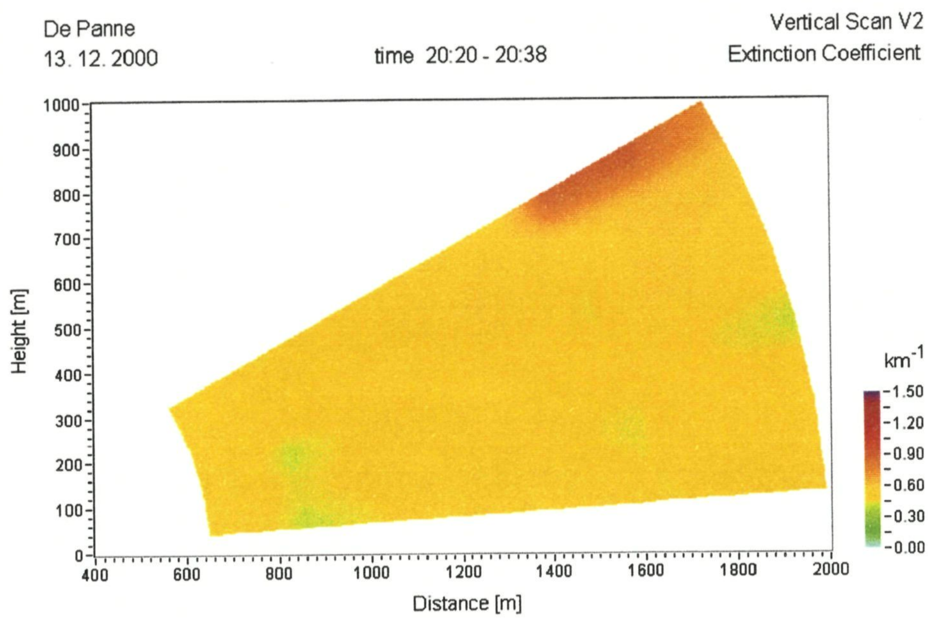



*Fig. 9.15*

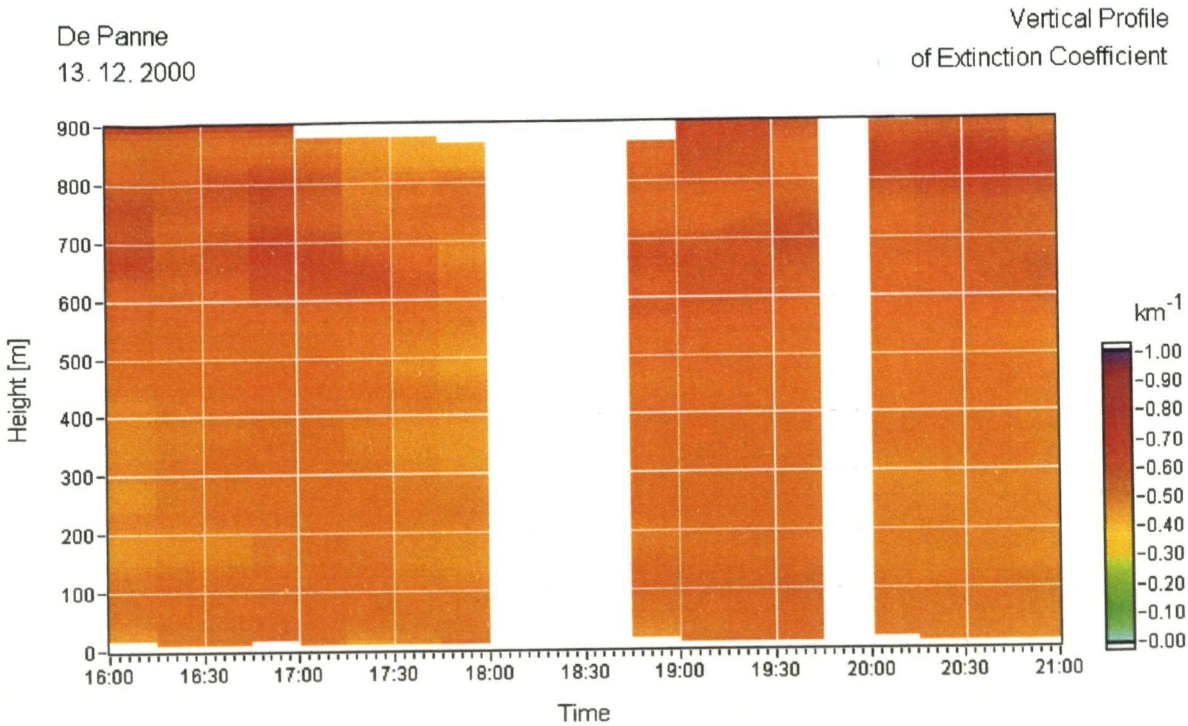



*Fig. 9.16 Time development of the vertical profile of extinction coefficient*

| | Height | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Time | 20 m | 100 m | 200 m | 300 m | 400 m | 500 m | 600 m | 700 m | 800 m |
| 16:30:00 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,6 | 0,6 |
| 17:30:00 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 |
| 19:15:00 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,6 | 0,6 | 0,5 |
| 20:30:00 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,7 |

*Tab. 9.2 Extinction coefficients in $km^{-1}$ at chosen times and in chosen heights*

# 10 De Panne 14. 12. 2000

## 10.1 Measurement Location and Time

On December the 14th, we measured concentration of $SO_2$ and Ozone. Also extinction coefficients, hence the distribution of aerosols, were determined from the signal on $SO_2$ reference wavelength. The measurement was carried out from the sea bank in De Panne. The exact location of the mobile system is marked in Fig. 10.1. The measurement was conducted in a form of vertical and horizontal scans. The exact direction of different types of vertical and horizontal scans is also shown in Fig. 10.1. The vertical scans are denoted as V1, V2, and V3, and for the horizontal scan sign H1 is used. Direction to Dunkerque industrial area is marked by an arrow D.

The measurement started at 10:00 and continued until 22:30. It was interrupted for one and half hour by a rain in the period between 13:00 and 14:30.

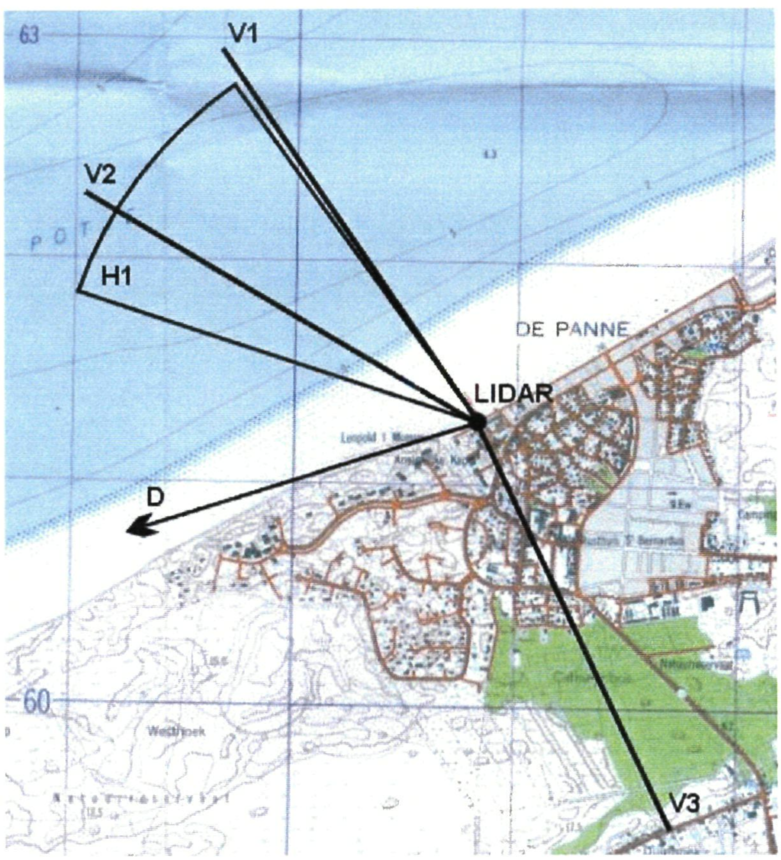



*Fig. 10.1 Location of the lidar system and the direction of vertical scans*

## 10.2 Meteorological situation

Figures 10.2 and 10.3 demonstrate synoptical situation over Europe before and after the measurement.

In the morning and round noon it was cloudy with temperature about 7°C; between 13:00 and 14:30 it was raining. After the rain, in the afternoon, it was cloudy or partly cloudy with temperature round 5 °C. These conditions didn't change until the night.

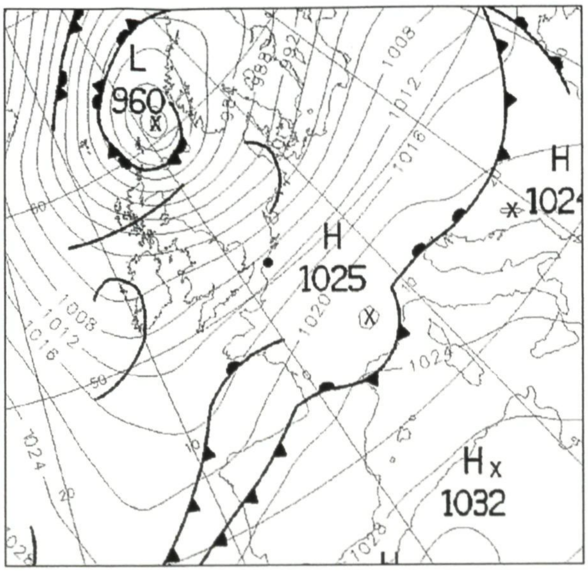



*Fig. 10.2 Synoptical situation*
*14. 12. 2000 at 0:00 UTC*

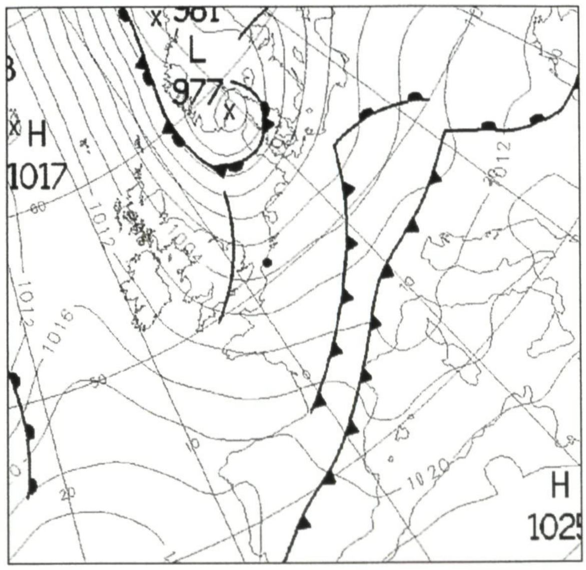



*Fig. 10.3 Synoptical situation*
*15. 12. 2000 at 0:00 UTC*

Wind speed and direction measured by sodar in various heights are graphed in Fig. 10.4 and Fig. 10.5. The wind speed was reaching relatively high values above 9 m/s in the morning and round noon. After the rain the wind calmed down slightly, but it increased again in the evening.

The wind blew almost from the south in the beginning of the measurement, and before noon its direction moved to southwest. In the afternoon and in the evening, the wind direction turned two times slightly towards the west, in the period between 16:00 and 17:30 and between 18:00 and 20:00. Finally, after 20:00 the wind changed its direction to the west significantly.

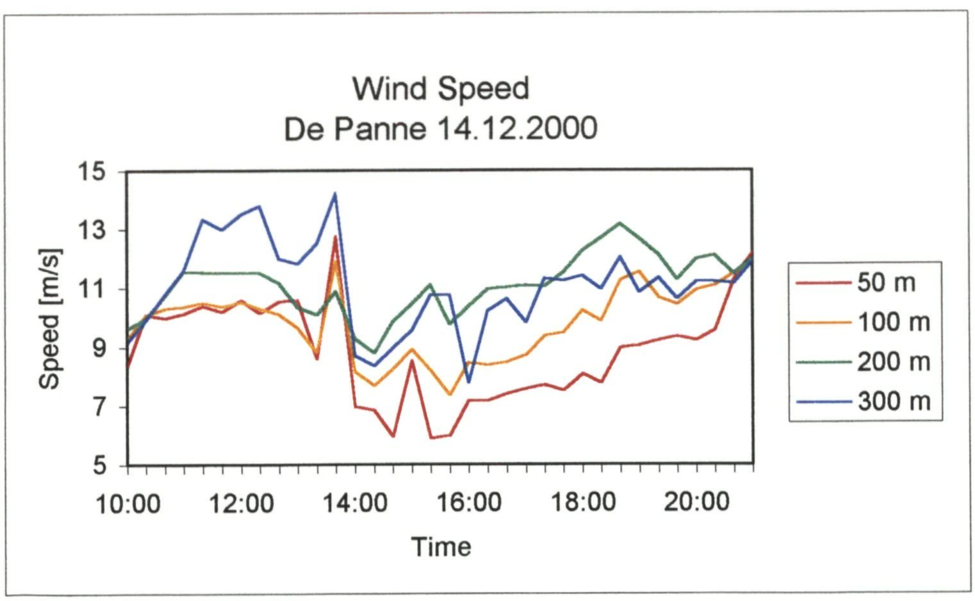



*Fig. 10.4 Wind speed in various heights during the measurement time*

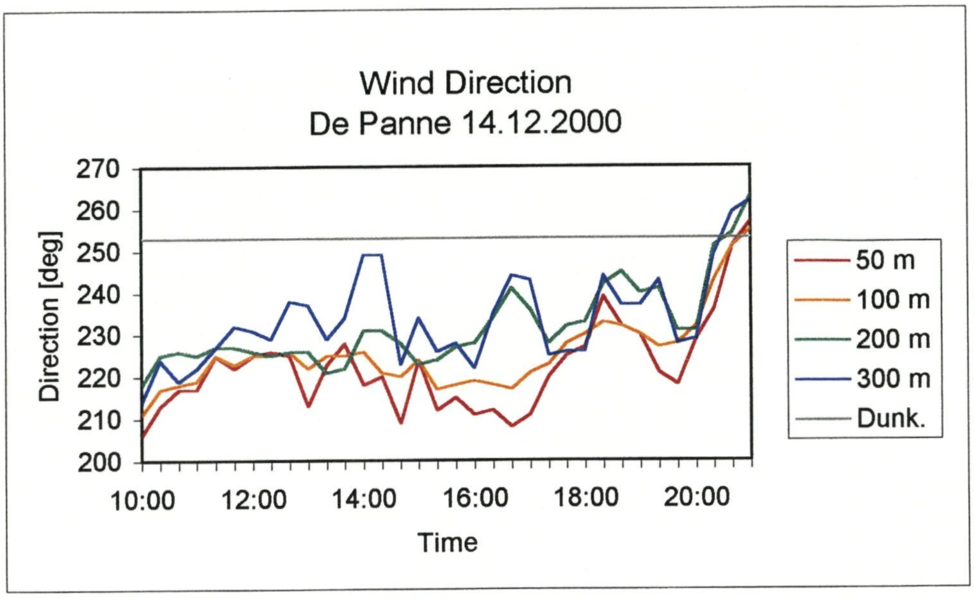



*Fig. 10.5 Wind direction in various heights during the measurement time*

## 10.3 Measurement Results

### Measurement of $SO_2$ Concentration

In Figures 10.6 – 10.13, vertical scans of $SO_2$ concentration are shown; Fig. 10.14 displays horizontal scan of SO2 concentration; Figures 10.15 and 10.16 demonstrate time development of the vertical profile of $SO_2$ concentration.

The concentrations in the vertical profiles represent a vertical projection of all vertical scans measured in a corresponding time period, hence the values are averaged in horizontal distance and over time. As a result the average concentrations in the vertical profiles are significantly lower than concentrations measured locally in single vertical scans. For this reason there is a different color concentration scale used by the vertical and horizontal scans, and by the vertical profiles. Concentrations of $SO_2$ from the vertical profiles in chosen heights and at chosen times are contained in table 10.1.

From 10:00 to 12:30, concentrations of $SO_2$ were low with average values in the vertical profile under 20 $\mu g.m^{-3}$. The situation remained similar for a certain time after the rain, between 14:30 to 16:00. Examples of vertical scans reflecting these conditions are in Fig. 10.6 and 10.7.

In the period between 16:00 and 17:30 the concentrations increased. There was a layer of higher $SO_2$ concentrations in a height of 300 m. Average concentrations reached 50 $\mu g.m^{-3}$ in this layer. However, maximal concentrations in single vertical scans (Fig. 10.8 and 10.9) exceeded 130 $\mu g.m^{-3}$. We suppose that the increased concentrations were caused by a temporary change in wind direction towards the west. After this change the wind could have brought pollution from Dunkerque industrial area. This change of the wind direction was measured by sodar.

The high concentration layer is not continuous on suggested vertical scans, which is a result of the lidar measurement method – vertical scans are created through interpolation between values measured on single beams. This interpolation may not be always perfect.

In the period between 17:30 and 18:00 the concentrations of $SO_2$ fell back to average values under 20 $\mu g.m^{-3}$ (Fig. 10.10.). However, after 18:00 the wind direction turned towards west again and also the $SO_2$ concentrations rose, this time even more dramatically. In the height of 300 m there was a layer with average concentrations exceeding 60 $\mu g.m^{-3}$, and extreme concentrations on the corresponding vertical scan reaching over 250 $\mu g.m^{-3}$ (Fig.10.11). We carried out also a horizontal scan (Fig. 10.14) in order to capture this situation in a greater detail. The angle between the plane of this horizontal scan and the terrain was 13°. The high $SO_2$ concentrations were completely confirmed on this horizontal scan.

The wind continued to turn towards the west after 20:00, therefore the $SO_2$ layer was moving directly across the position of the lidar system. As a result the increased concentrations were detected in a distance lower than 1000 m from the lidar (Fig. 10.12).

After 21:00 we changed the direction of vertical scans from the sea towards the land (from V2 to V3). In this way we tried to catch the $SO_2$ layer after the change of wind direction. In Fig. 10.13 is the corresponding vertical scan from this measurement. There are no higher $SO_2$ concentrations detected any more. We suppose that the wind direction changed to such an extend that the $SO_2$ layer was carried away over the land, to an area where our measurement didn't reach.

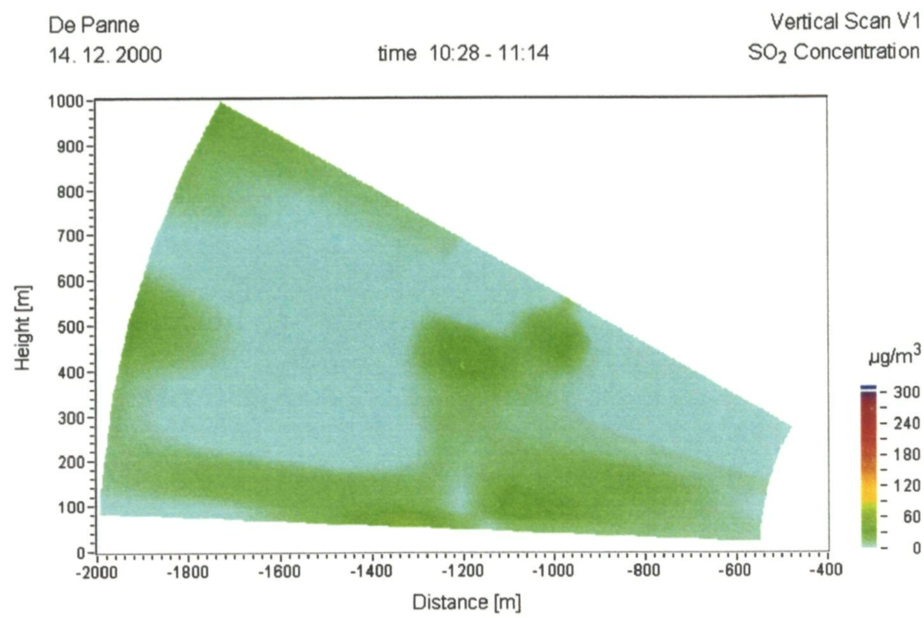



*Fig. 10.6*

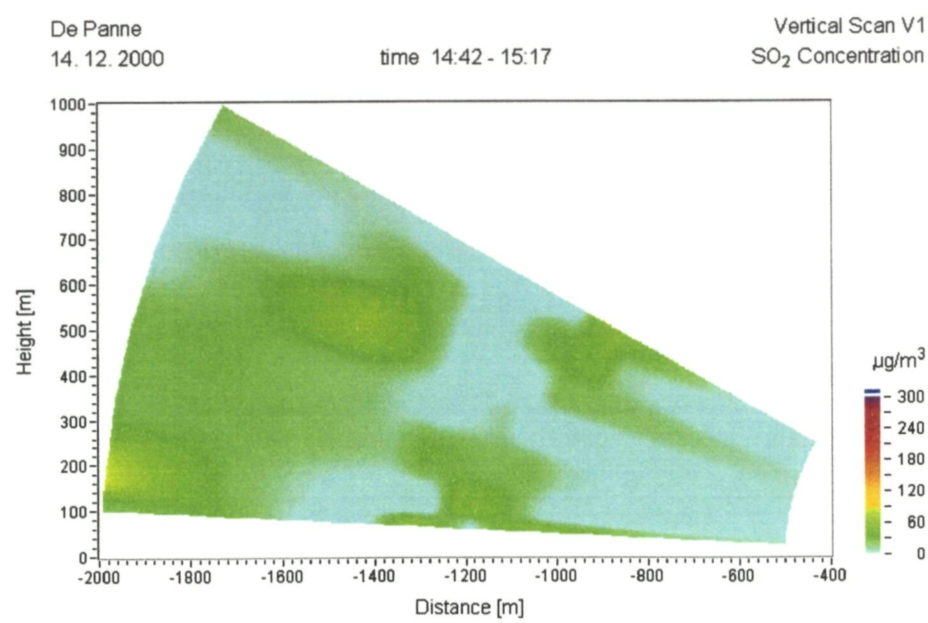



*Fig. 10.7*

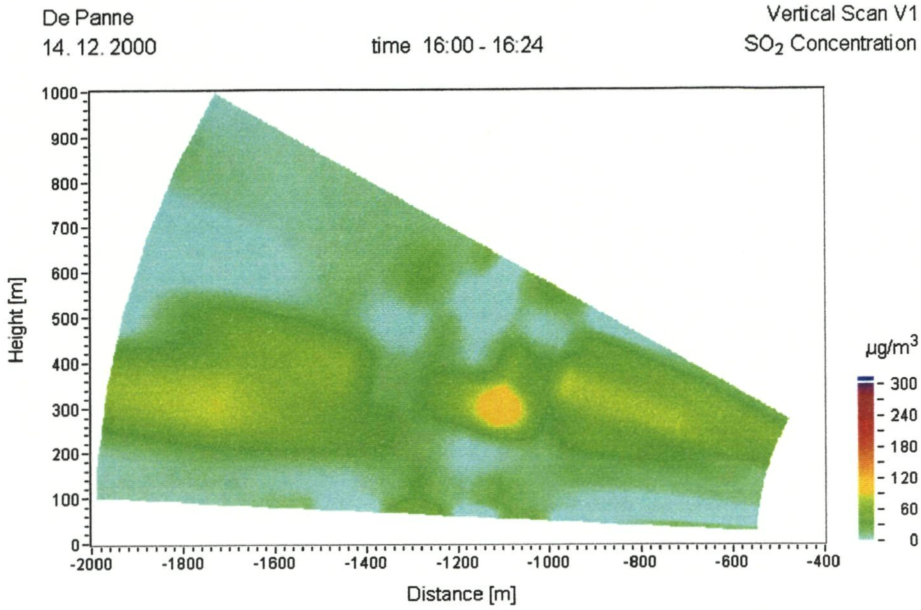



*Fig. 10.8*

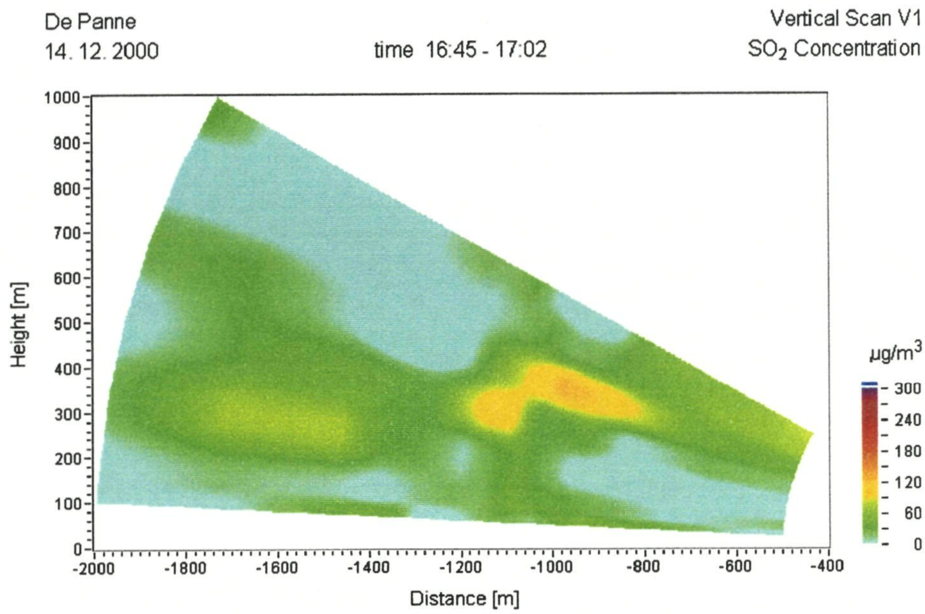



*Fig 10.9*

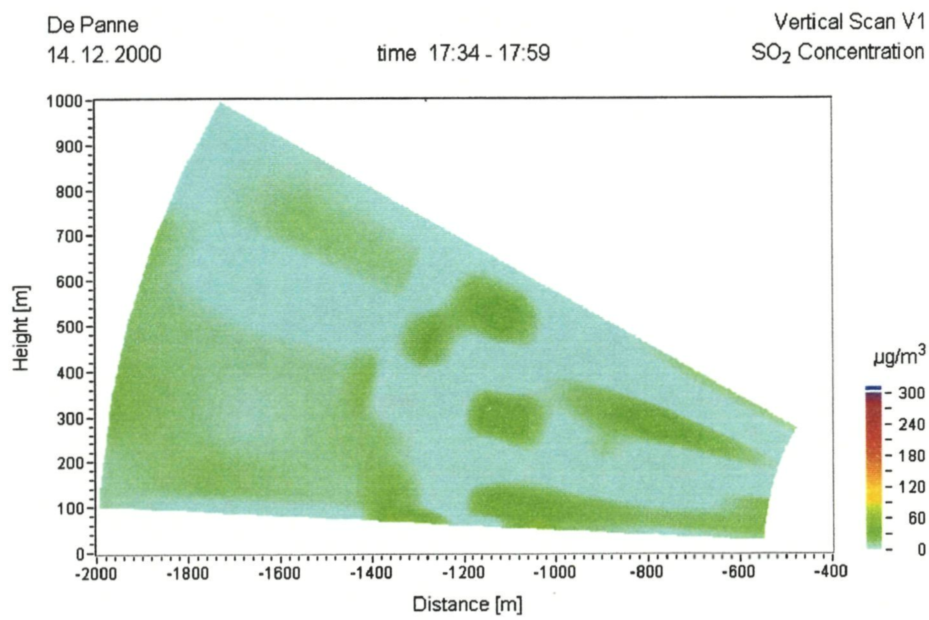



*Fig 10.10*

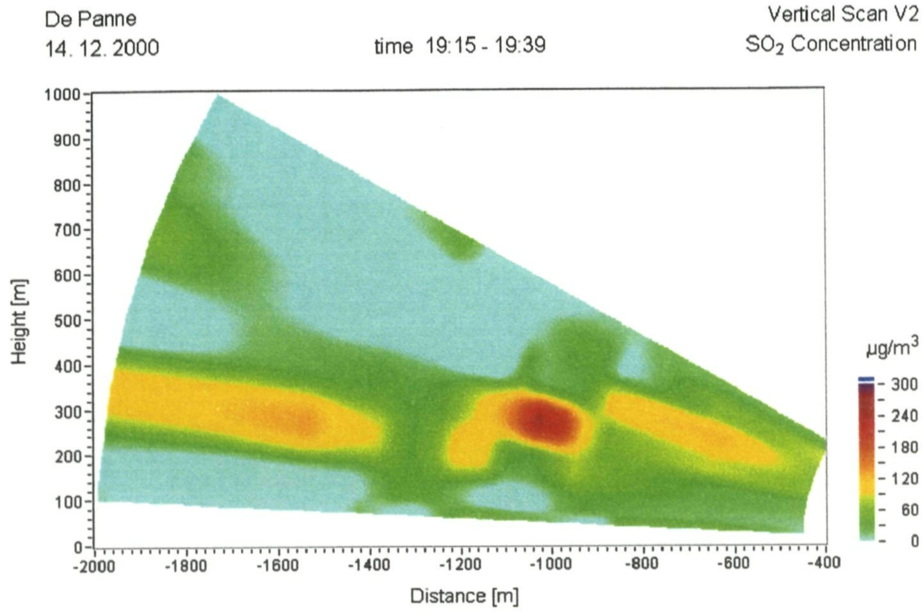



*Fig. 10.11*

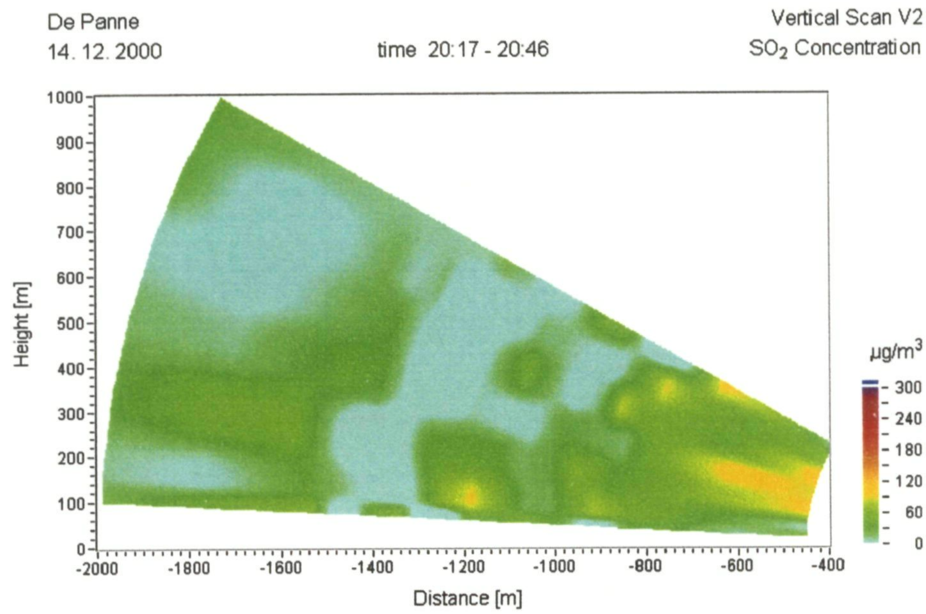



*Fig 10.12*

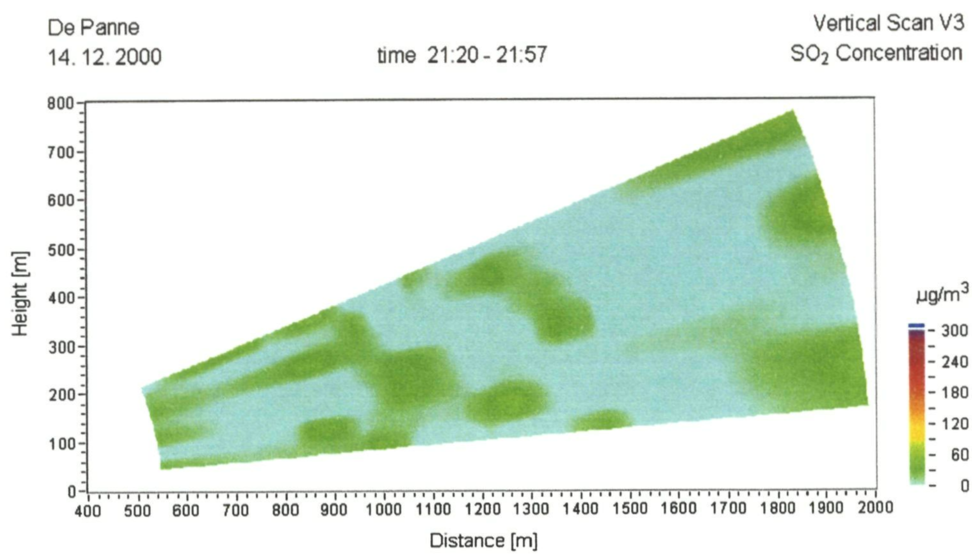



*Fig 10.13*

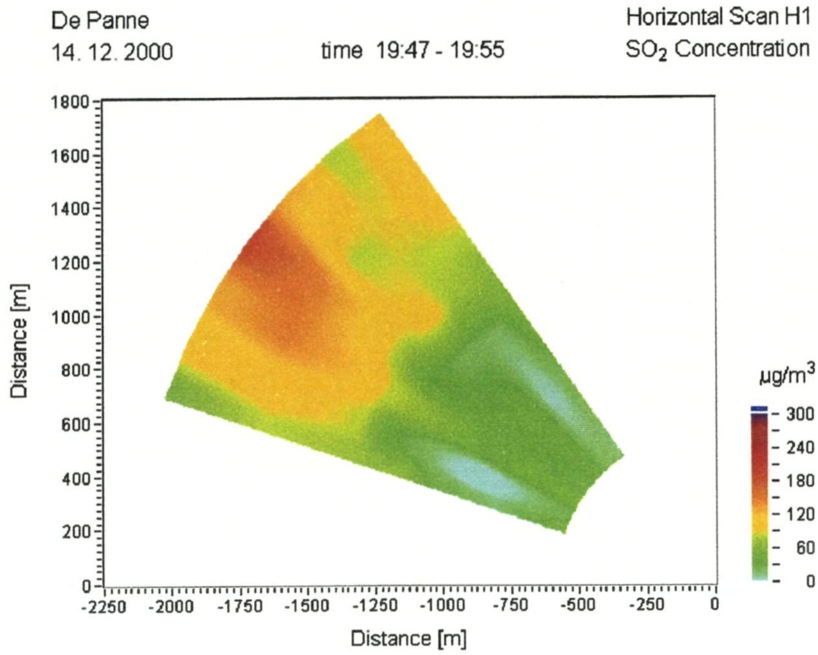



*Fig. 10.14*

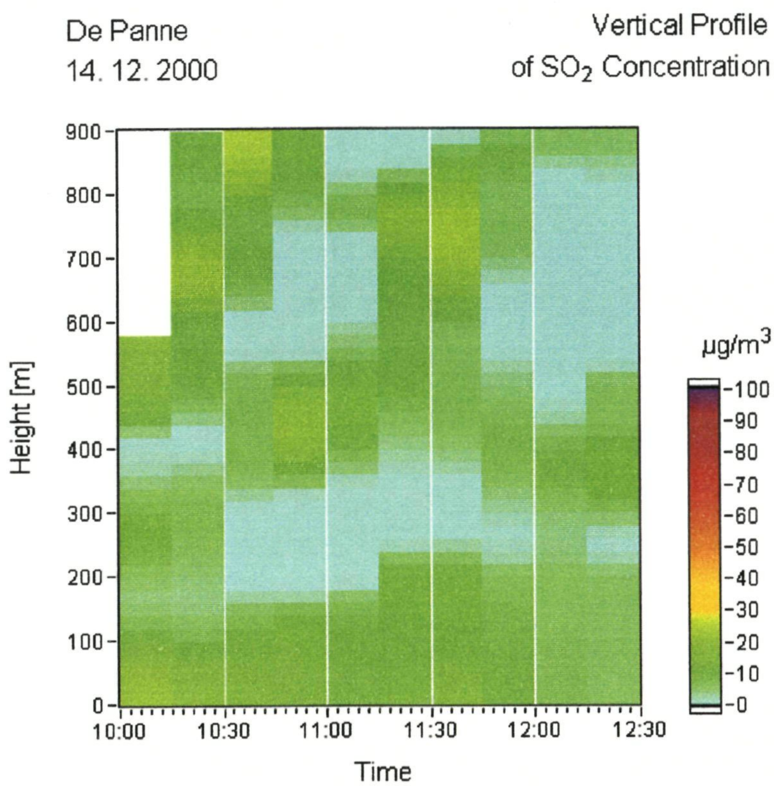



*Fig. 10.15 Time development of the vertical profile of $SO_2$ concentration*

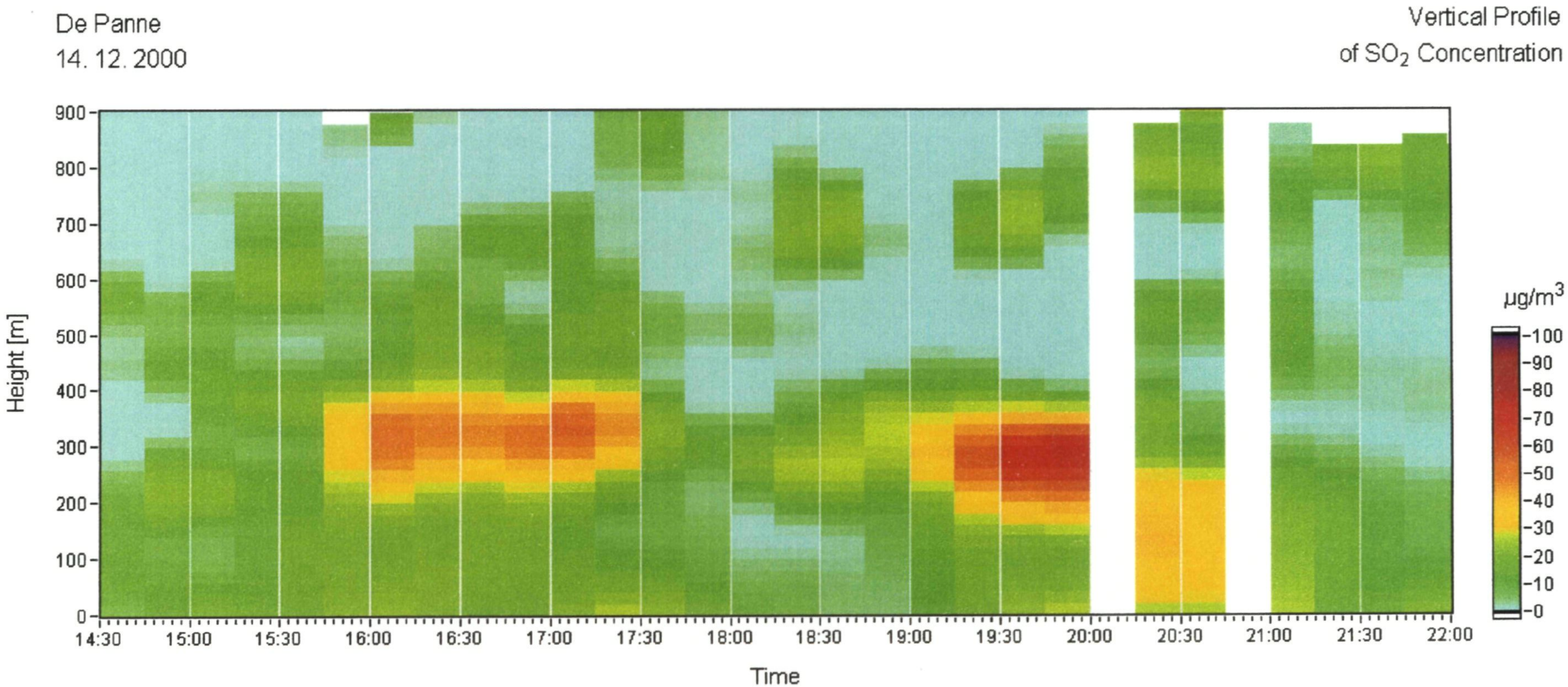



*Fig. 10.16 Time development of the vertical profile of $SO_2$ concentration*

| | Height | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Time | 0 m | 100 m | 200 m | 300 m | 400 m | 500 m | 600 m | 700 m | 800 m |
| 10:45:00 | 13 | 12 | -5 | -3 | 18 | 11 | -3 | -4 | 9 |
| 14:45:00 | 11 | 8 | 20 | 4 | 7 | 6 | -5 | -5 | -3 |
| 16:15:00 | 18 | 17 | 23 | 47 | 27 | 16 | 8 | 0 | -8 |
| 17:00:00 | 19 | 14 | 20 | 52 | 27 | 16 | 11 | 9 | -7 |
| 17:45:00 | 15 | 7 | 3 | 12 | -4 | 4 | -4 | -2 | 2 |
| 19:30:00 | 22 | 17 | 47 | 65 | 7 | -6 | -1 | 23 | -3 |
| 20:30:00 | 26 | 36 | 35 | 10 | 0 | 7 | 1 | 6 | 18 |
| 21:30:00 | 14 | 9 | 8 | 0 | 1 | -2 | 2 | 4 | 21 |

*Tab. 10.1 Concentration of $SO_2$ in $\mu g.m^{-3}$ at chosen times and in chosen heights*

## Measurement of Ozone Concentration

By application of our lidar method, Ozone concentration appears also as fake $SO_2$ concentration. Therefore it was necessary to determine the average Ozone concentration, which was then used for correction of $SO_2$ data. Vertical scans in Fig.10.17 – 10.19 show the distribution of Ozone concentration, which was homogeneous in both vertical and horizontal directions. Round noon the average Ozone concentration was 77 $\mu g/m^3$ and in the evening it fell to 58 $\mu g/m^3$. These values were used for $SO_2$ concentration correction. The $SO_2$ concentration correction in between Ozone measurements was interpolated.

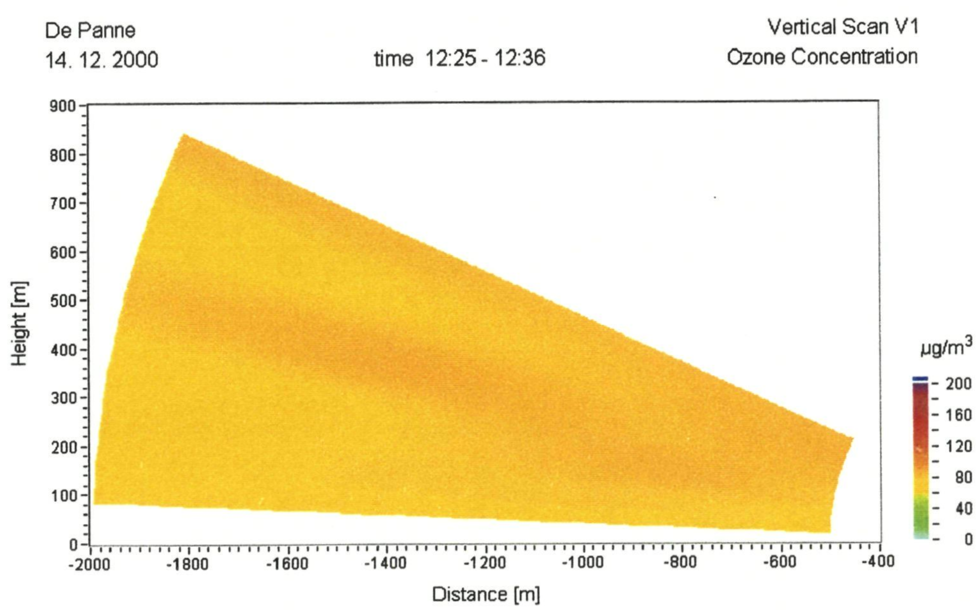



*Fig 10.17*

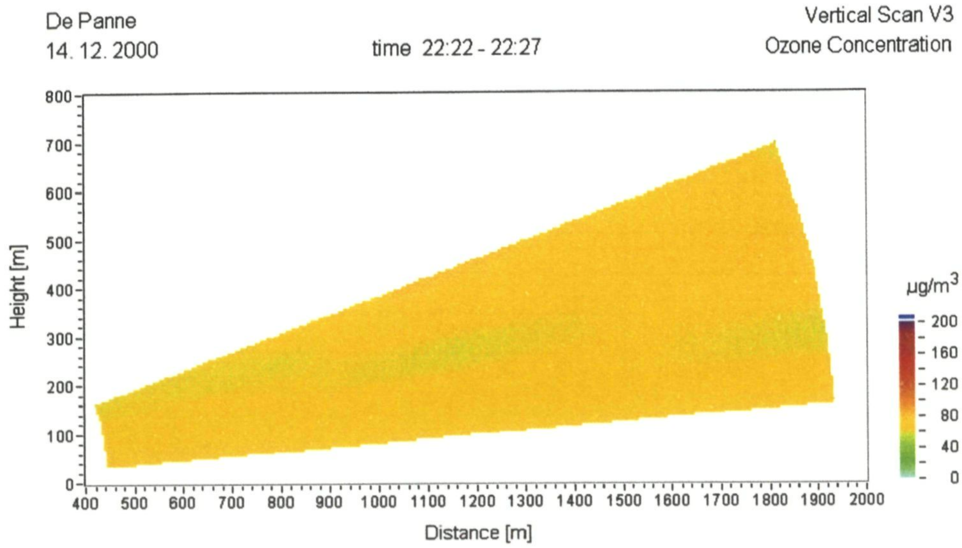



*Fig. 10.18*

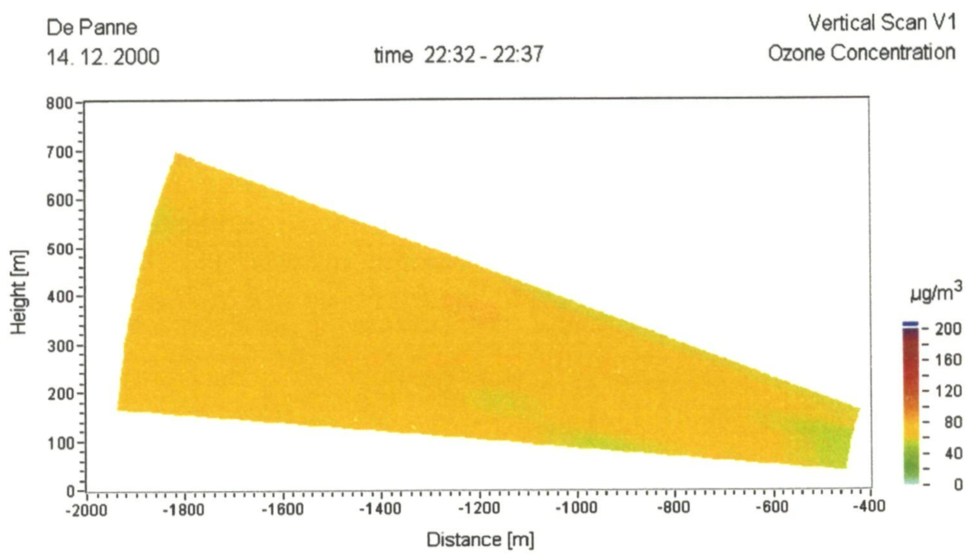



*Fig. 10.19*

## Measurement of Aerosols

In Figures 10.20 – 10.27, vertical scans of extinction coefficient are shown; Fig. 10.28 displays horizontal scan of extinction coefficient; Figures 10.29 and 10.30 demonstrate time development of the vertical profile of extinction coefficient.

The values of extinction coefficients in the vertical profiles are significantly lower than those in single vertical scans, because they represent a vertical projection of all vertical scans measured in a corresponding time period, hence the values are averaged in horizontal distance and over time. Extinction coefficients from the vertical profiles in chosen heights and at chosen times are contained in table 10.2. Common values of these coefficients were between 0,4 and 0,5 $km^{-1}$ in the areas where no aerosol clouds were present. The extinction coefficients were measured on the wavelength 286.3 nm.

In the following Figures, an aerosol layer is typically represented by an area of very low extinction coefficients immediately followed by an area of very high extinction coefficients. As it was described in the section 2 (Measurement Principles), this behavior is typical for so-called "reflecting aerosols". The wavy shape of aerosol layers doesn't reflect reality; it is caused by the applied lidar method and the evaluation software. Lidar measures on single beams and extinction coefficients between these beams are interpolated by the software.

Between 10:00 and 12:30 such layer was detected. At 11:00 it was in a height of 500 m (Fig. 10.20). The height of this layer was increasing over the time up to almost 800 m at 12:30; this process is observable in Fig. 10.29. In the period from 14:30 to 15:00 the aerosol layer was measured in a height of approximately 600 m (Fig. 10.21).

Between 15:30 and 17:30 significant aerosol layer was detected in an altitude round 300 m (Fig. 10.22 and 10.23). Similar aerosol layer was captured also between 18:30 and 20:00 (Fig. 10.25), which was confirmed in a horizontal scan (Fig. 10.28). These results correspond very well to $SO_2$ measurements, which show in these periods and in the same heights increased $SO_2$ concentrations. Also in the period from 17:30 to 18:30, when $SO_2$ concentrations were low, no significant aerosol layers were detected (Fig. 10.24).

After 20:00 no considerable layer of aerosols was detected as well (Fig. 10.26 and 10.27)

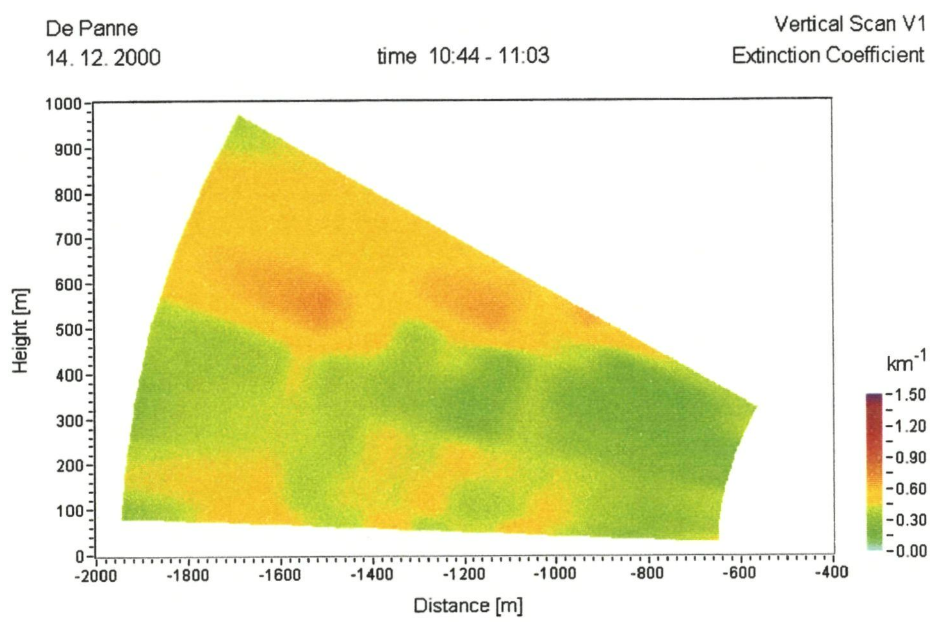



*Fig. 10.20*

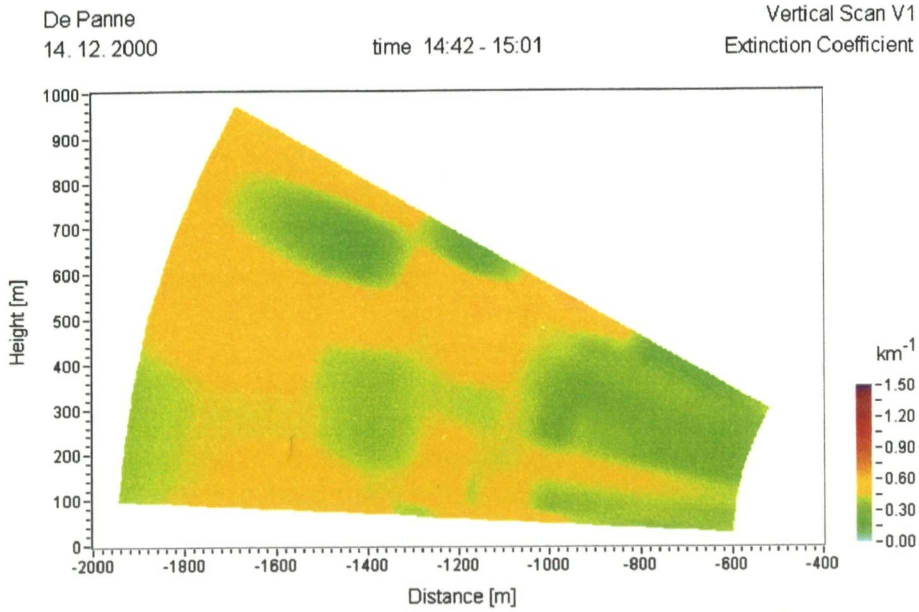



*Fig. 10.21*

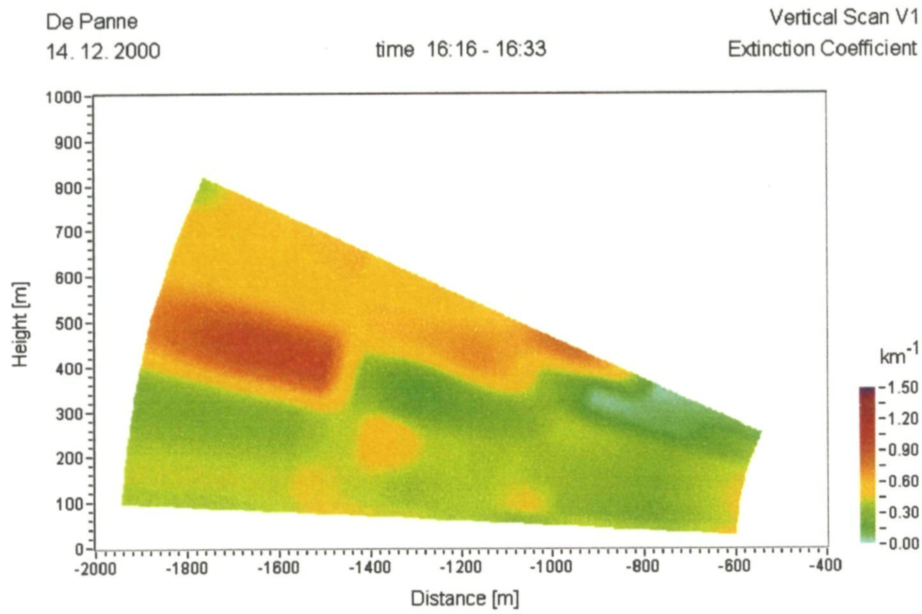



*Fig. 10.22*

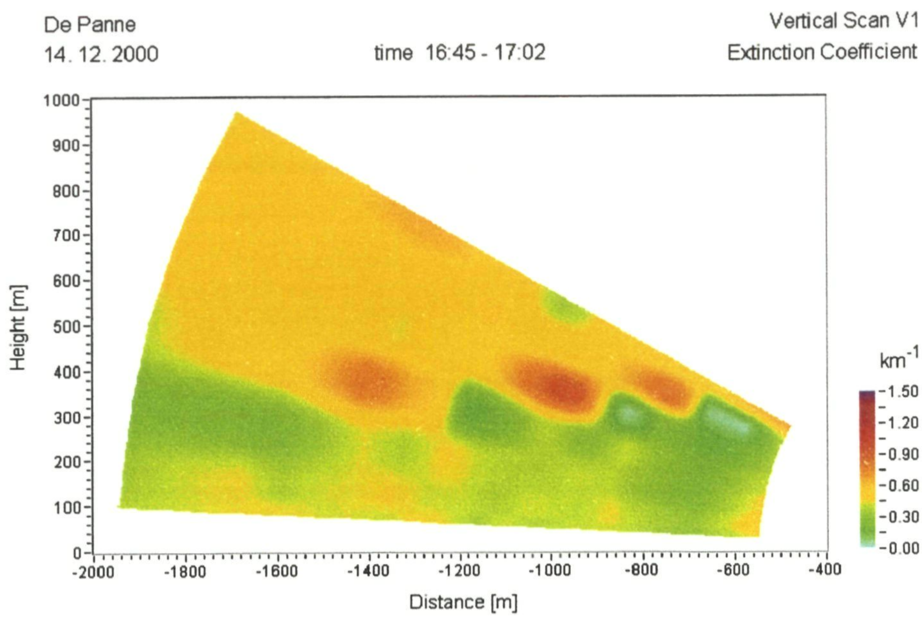



*Fig. 10.23*

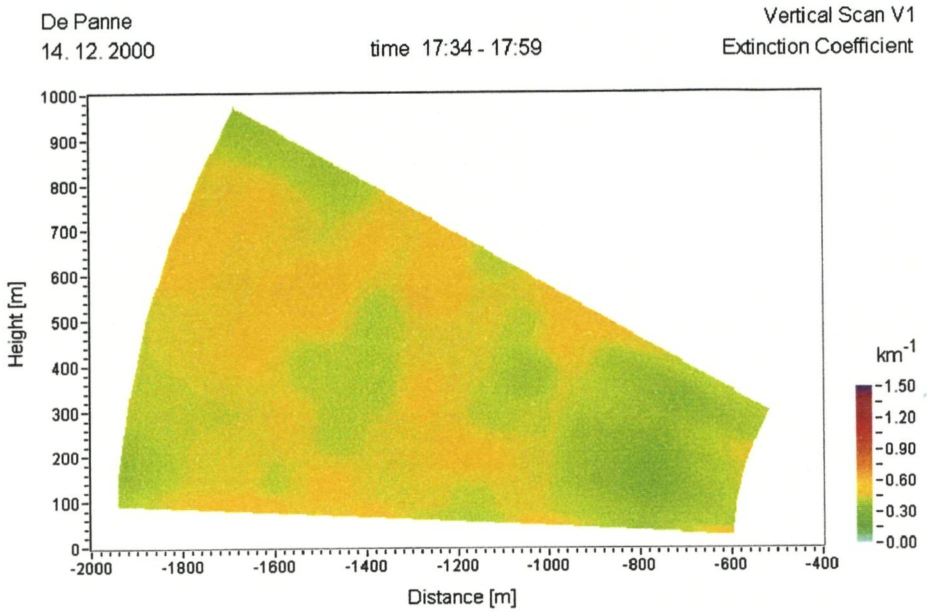



*Fig. 10.24*

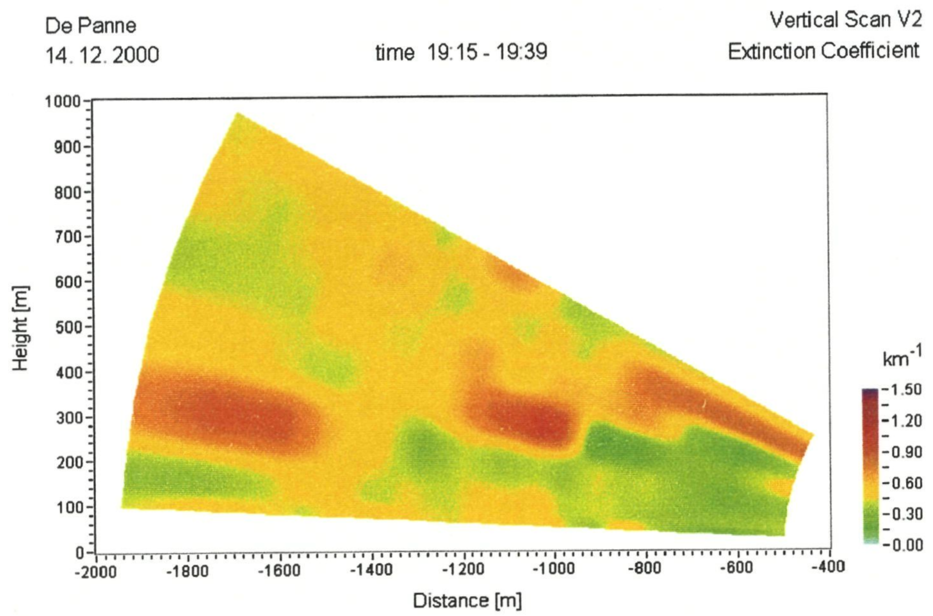



*Fig. 10.25*

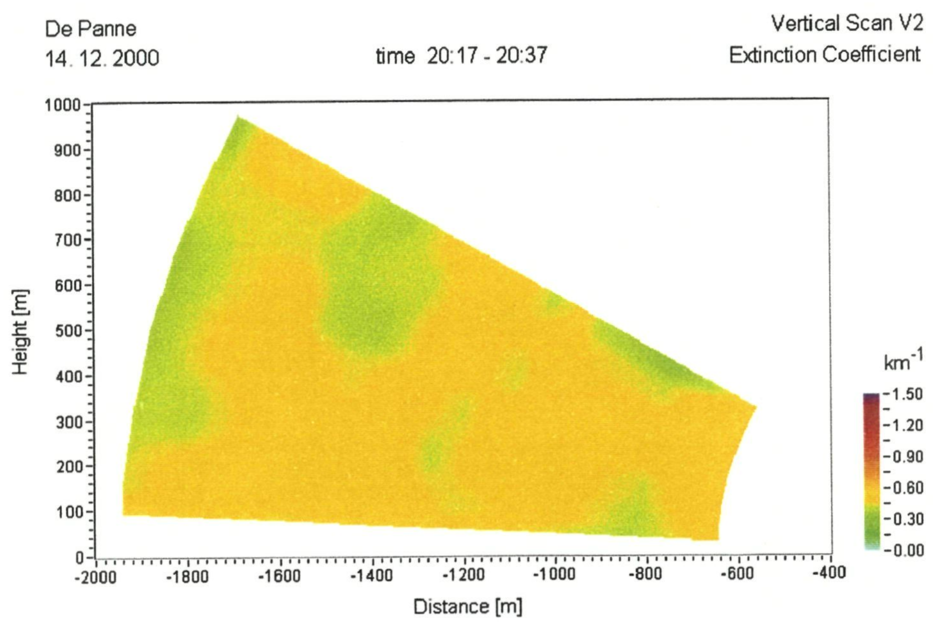



*Fig. 10.26*

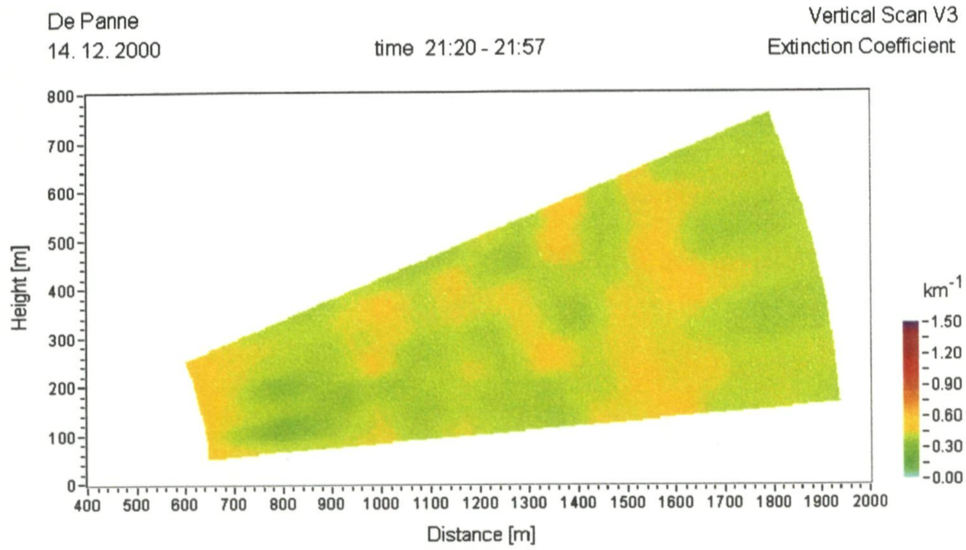



*Fig. 10.27*

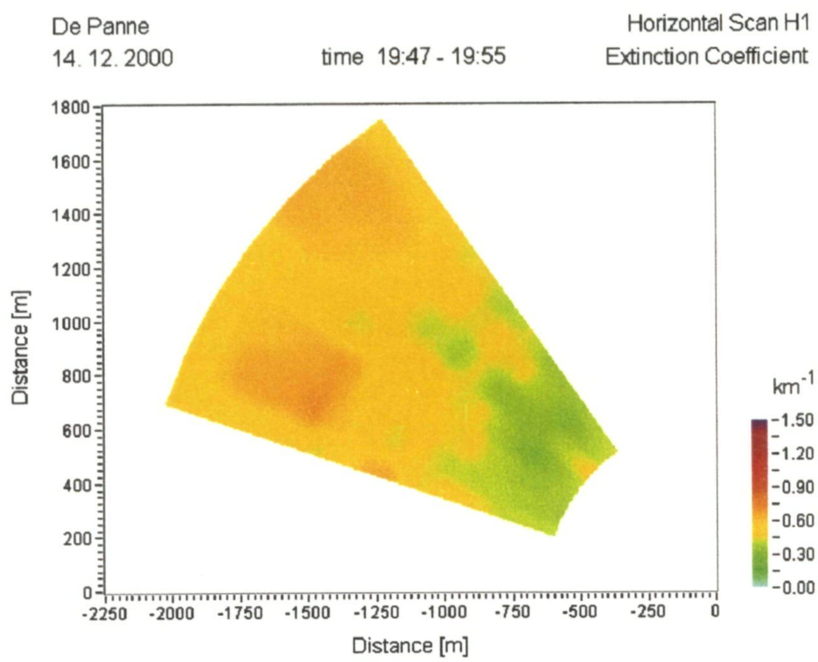



*Fig. 10.28*

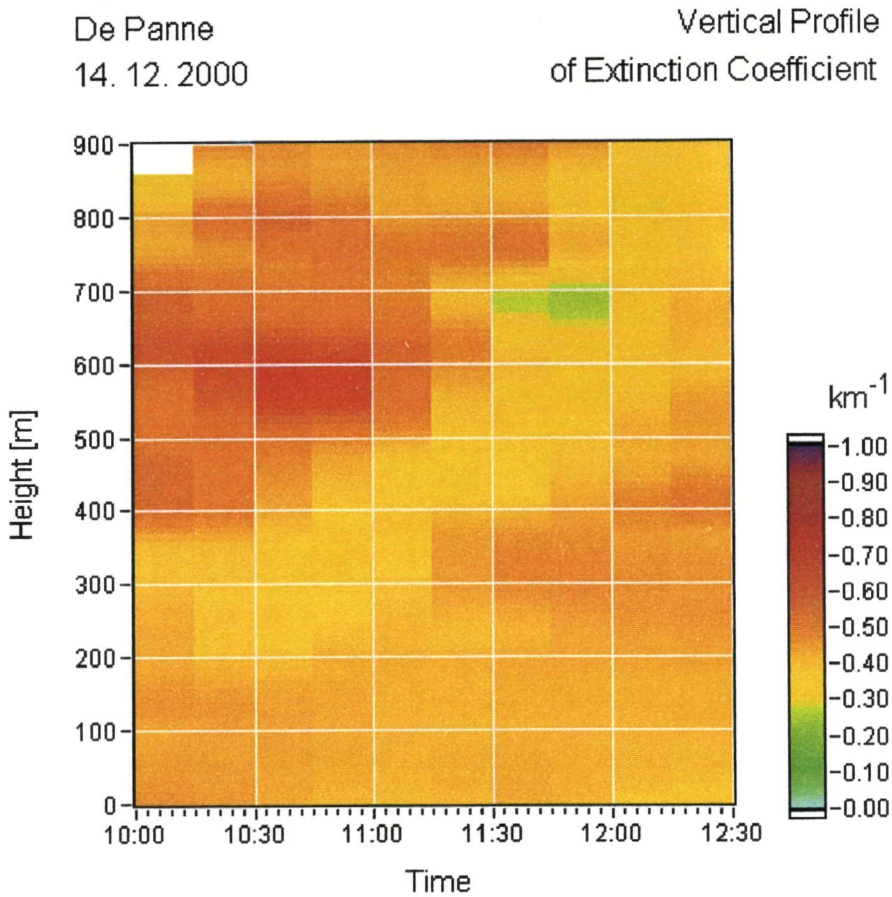



*Fig. 10.29 Time development of the vertical profile of extinction coefficient*

| | Height | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Time | 0 m | 100 m | 200 m | 300 m | 400 m | 500 m | 600 m | 700 m | 800 m |
| 10:45:00 | 0,4 | 0,4 | 0,4 | 0,3 | 0,4 | 0,5 | 0,6 | 0,5 | 0,5 |
| 14:45:00 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,5 | 0,5 | 0,3 | 0,5 |
| 16:15:00 | 0,4 | 0,4 | 0,4 | 0,3 | 0,5 | 0,5 | 0,5 | 0,5 | 0,4 |
| 17:00:00 | 0,4 | 0,4 | 0,4 | 0,3 | 0,6 | 0,5 | 0,5 | 0,5 | 0,6 |
| 17:45:00 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 |
| 19:30:00 | 0,4 | 0,4 | 0,4 | 0,6 | 0,5 | 0,4 | 0,5 | 0,4 | 0,5 |
| 20:30:00 | 0,4 | 0,5 | 0,5 | 0,5 | 0,5 | 0,4 | 0,4 | 0,4 | 0,4 |
| 21:30:00 | - | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 |

*Tab. 10.2 Extinction coefficients in $km^{-1}$ at chosen times and in chosen heights*

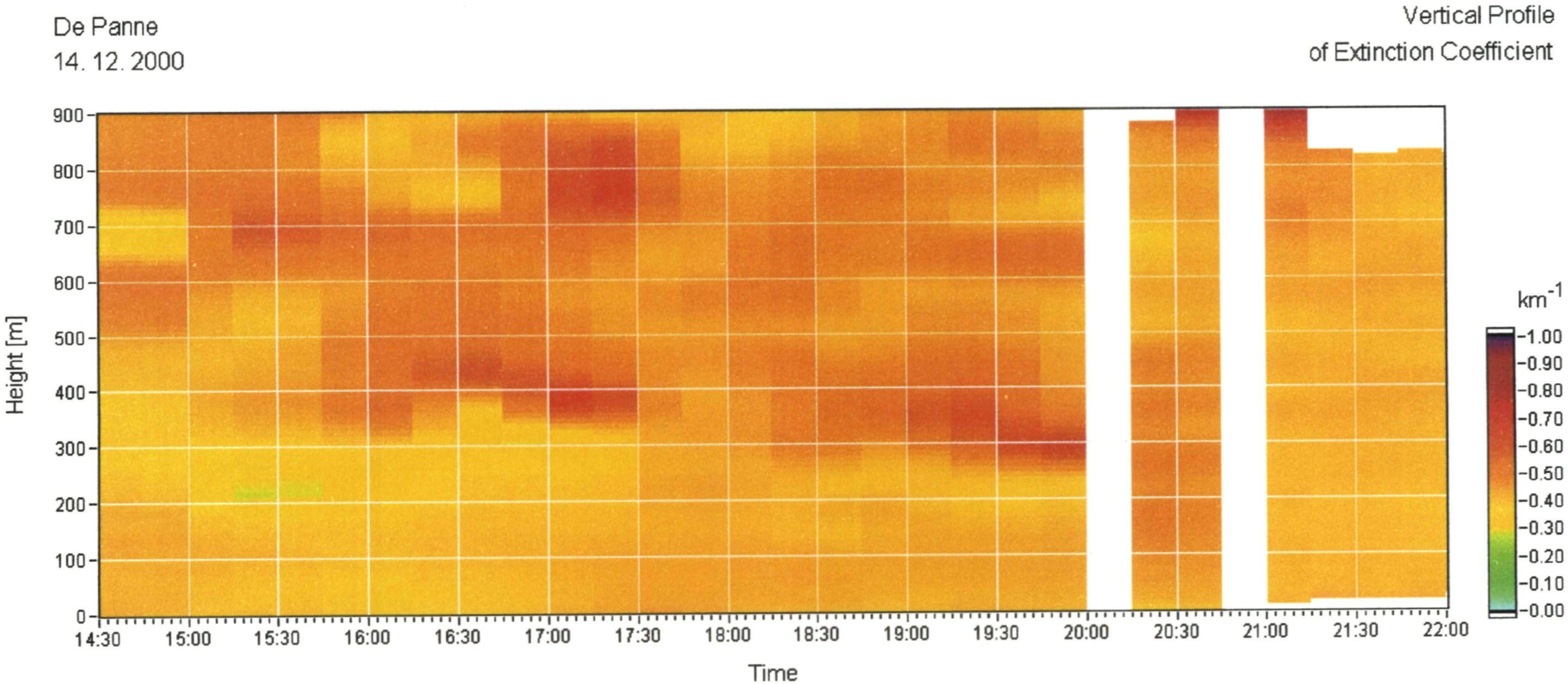



*Fig. 10.30 Time development of the vertical profile of extinction coefficient*

# 11 Houtem 15. 12. 2000

## 11.1 Measurement Location and Time

On December the 15th, we measured concentration of $SO_2$ and Ozone. Also extinction coefficients, hence the distribution of aerosols, were determined from the signal on $SO_2$ reference wavelength. The measurement was carried out from a field road on the French frontier near Houtem, which is a village situated 10 km to the south from De Panne. The exact location of the mobile system is marked in Fig. 11.1. A picture of the lidar system during the measurement is shown in Fig. 11.2.

The measurement was conducted in a form of vertical and horizontal scans. The exact direction of different types of vertical and horizontal scans is also shown in Fig. 11.1. The vertical scans are denoted as V1 and V2, and for the horizontal scan sign H1 is used. Direction to Dunkerque industrial area is marked by an arrow D. The measurement started at 12:00 and continued until 21:00.

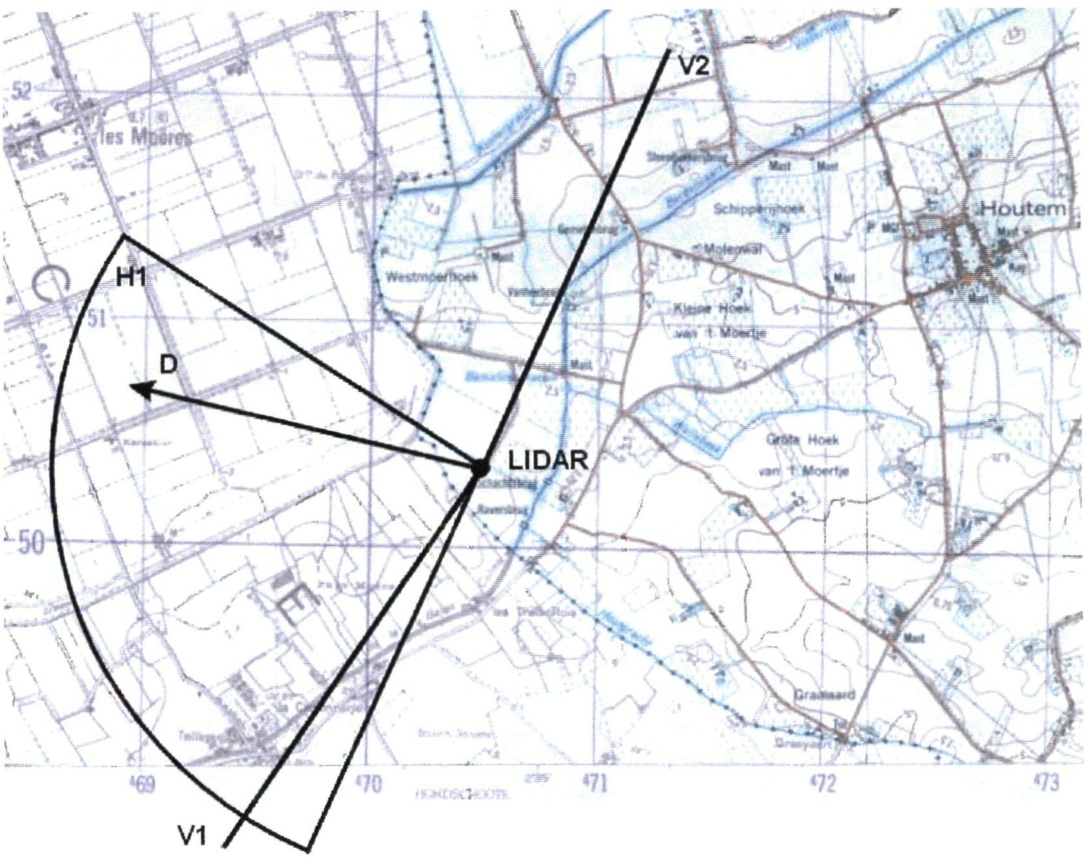



*Fig. 11.1 Location of the lidar system and the direction of vertical scans*

*Fig. 11.2 Lidar system during the measurement*

## 11.2 Meteorological situation

Figures 11.3 and 11.4 demonstrate synoptical situation over Europe before and after the measurement.

Round noon and in the afternoon it was cloudy. In the late afternoon the clouds waned until sky was clear in the evening. Temperature was round 6 °C during the whole measurement time.

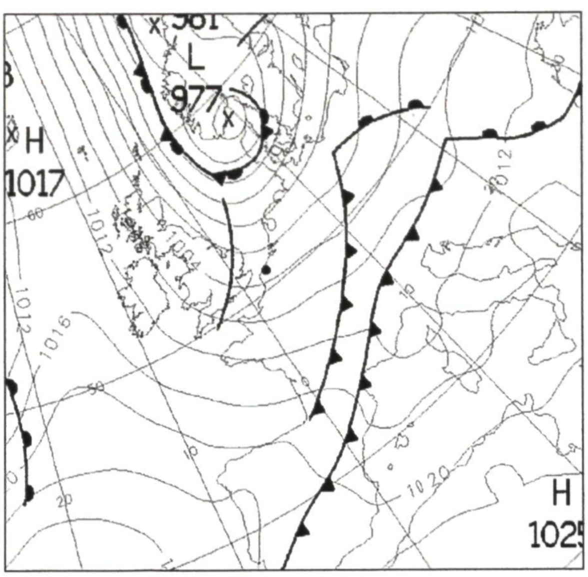



*Fig. 11.3 Synoptical situation*
*15. 12. 2000 at 0:00 UTC*

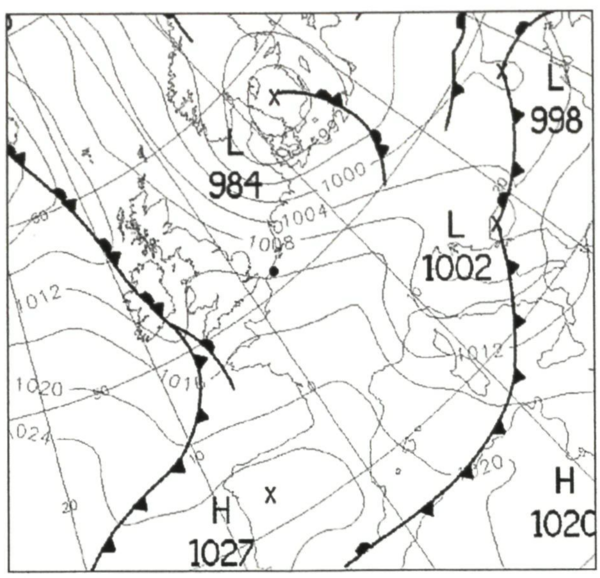



*Fig. 11.4 Synoptical situation*
*16. 12. 2000 at 0:00 UTC*

Wind speed and direction measured by sodar in various heights are graphed in Fig. 11.5 and Fig. 11.6. The wind speed was about 9 m/s during the day, and it increased up to almost 11 m/s in the evening.

The wind blew mostly from the northwest in the beginning of the measurement, from 13:00 to 14:30. Before 15:00 the wind turned towards the west, and it blew from the direction round 290° until 19:00. In the evening, after 19:00, the wind direction changed again to the northwest.

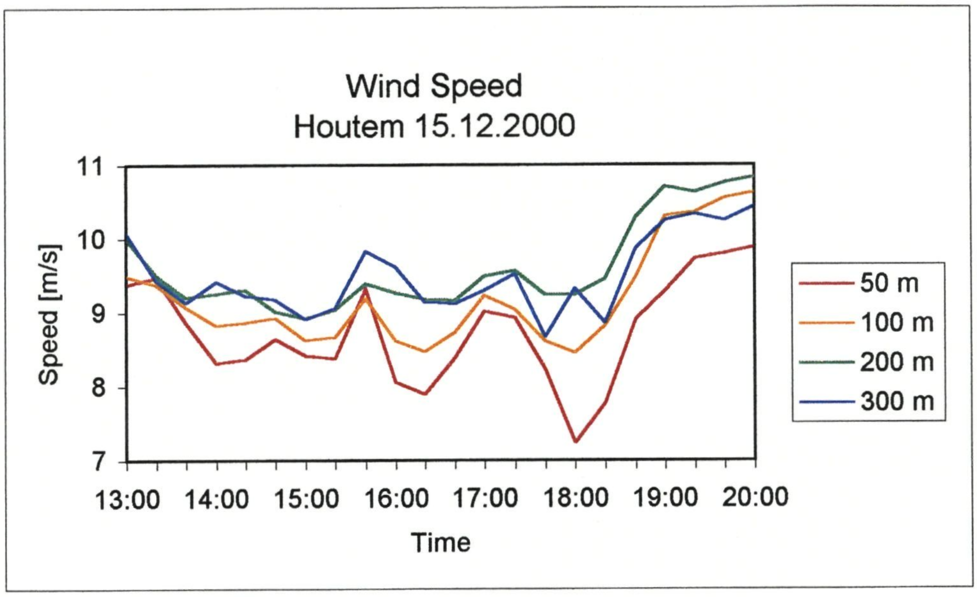



*Fig. 11.5 Wind speed in various heights during the measurement time*

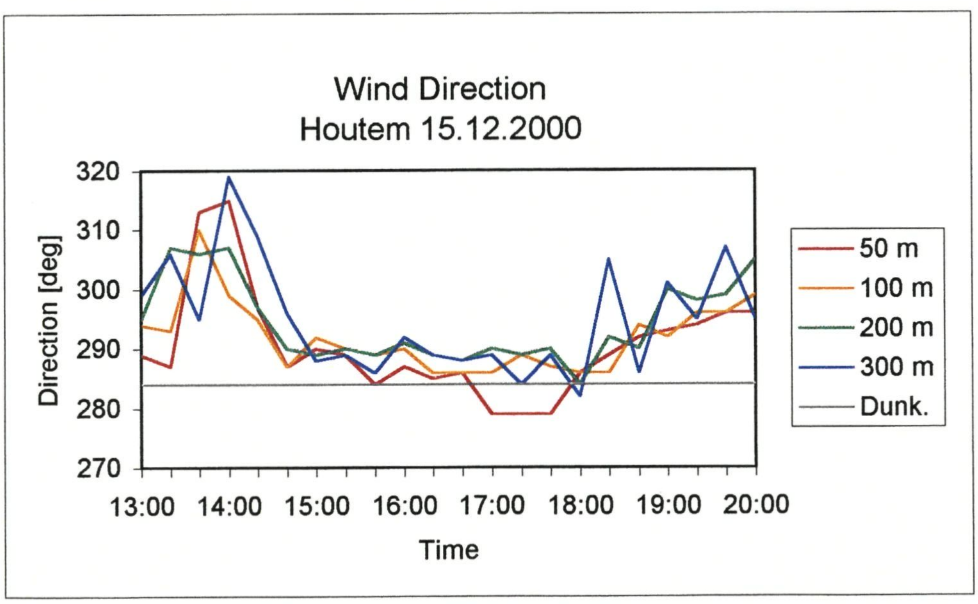



*Fig. 11.6 Wind direction in various heights during the measurement time*

## 11.3 Measurement Results

### Measurement of $SO_2$ Concentration

In Figures 11.7 – 11.12, vertical scans of $SO_2$ concentration are shown; Fig. 11.13 displays horizontal scan of SO2 concentration; Figure 11.14 demonstrates time development of the vertical profile of $SO_2$ concentration.

The concentrations in the vertical profiles represent a vertical projection of all vertical scans measured in a corresponding time period, hence the values are averaged in horizontal distance and over time. As a result the average concentrations in the vertical profile are significantly lower than the concentrations measured locally in single vertical scans. For this reason there is a different color concentration scale used by the vertical and horizontal scans, and by the vertical profile. Concentrations of $SO_2$ from the vertical profile in chosen heights and at chosen times are contained in table 11.1.

From 13:00 to 14:30, concentrations of $SO_2$ were low with average values in the vertical profile under 20 $\mu g.m^{-3.}$

In the period between 14:30 and 15:00 increased concentrations of $SO_2$ appeared in higher layers. Average concentrations were about 50 $\mu g.m^{-3}$ in the height between 600 and 700 m. However, maximal concentrations in the vertical scan (Fig. 11.7) reached almost 100 $\mu g.m^{-3}$. For the time between 15:00 and 15:30 the increased concentrations disappeared again.

In the period between 15:30 and 19:00 high concentrations of $SO_2$ were measured on vertical scans V1, which were conducted over the territory of France (Fig. 11.8 and 11.10). Increased concentrations were detected in the ground layer, to the height of 300 m, and also in higher layer between 600 and 700 m. Average concentrations reached almost 60 $\mu g.m^{-3}$ in the ground layer and near 50 $\mu g.m^{-3}$ in the higher layer. Highest concentrations on the corresponding vertical scans were 110 $\mu g.m^{-3}$ (Fig.11.8).

The high concentration layer is not continuous on suggested vertical scans, which is a result of the lidar measurement method – vertical scans are created through interpolation between values measured on single beams. This interpolation isn't always perfect.

Round 17:00 and round 19:00 also vertical scans V2 over the territory of Belgium were conducted (Fig. 11.9 and 11.11). Concentrations measured here were much lower compared to those measured over France especially further from the French frontier.

In order to capture this situation in a greater detail, we carried out also a horizontal scan (Fig. 11.13). The angle between the plane of this horizontal scan and the terrain was 5°. This measurement confirmed increased $SO_2$ concentrations over France and their fall in the direction towards the territory of Belgium. We suppose that the increased concentrations detected over the French territory were caused by the wind blowing from direction near west. From this direction the wind could have brought pollution from Dunkerque industrial area. Almost western wind direction was measured by sodar in the time period between 15:30 and 19:00. Moreover, if we suppose the pollution to be brought from Dunkerque, the wind direction measured by sodar would suggest increased concentrations over the French territory only – just as we measured.

After 19:00 $SO_2$ concentrations decreased even over the French territory (Fig. 11.12). Average concentrations were under 20 $\mu g.m^{-3}$ again. In this period the wind blew from the northwest like in the beginning of the measurement.

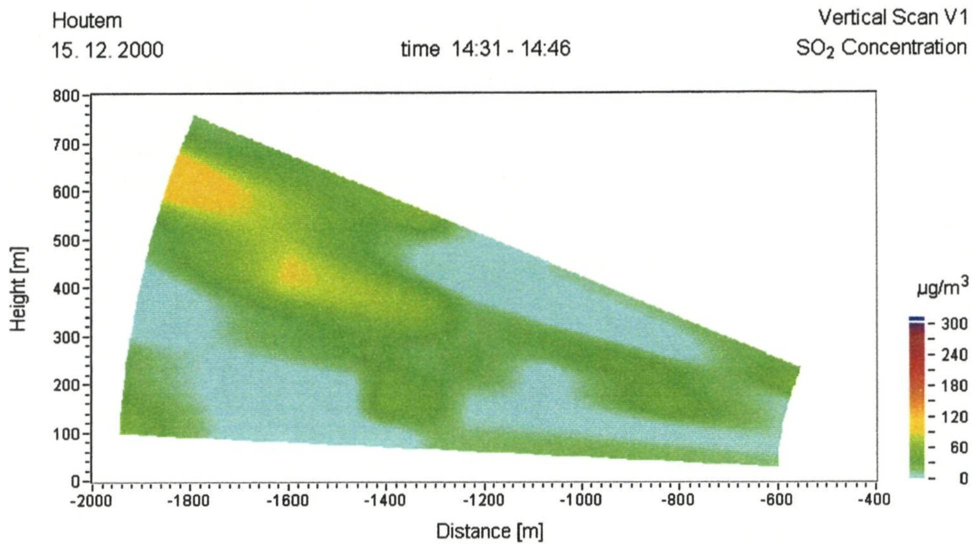



*Fig. 11.7*

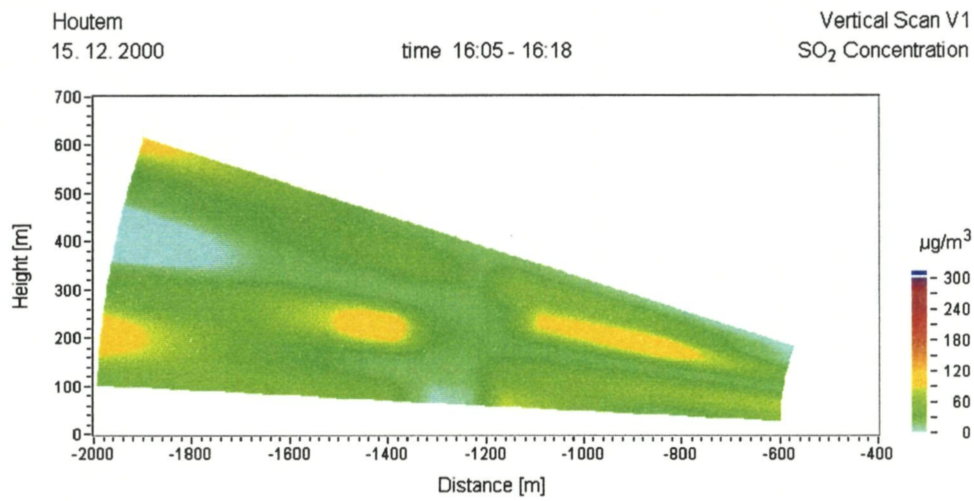



*Fig. 11.8*

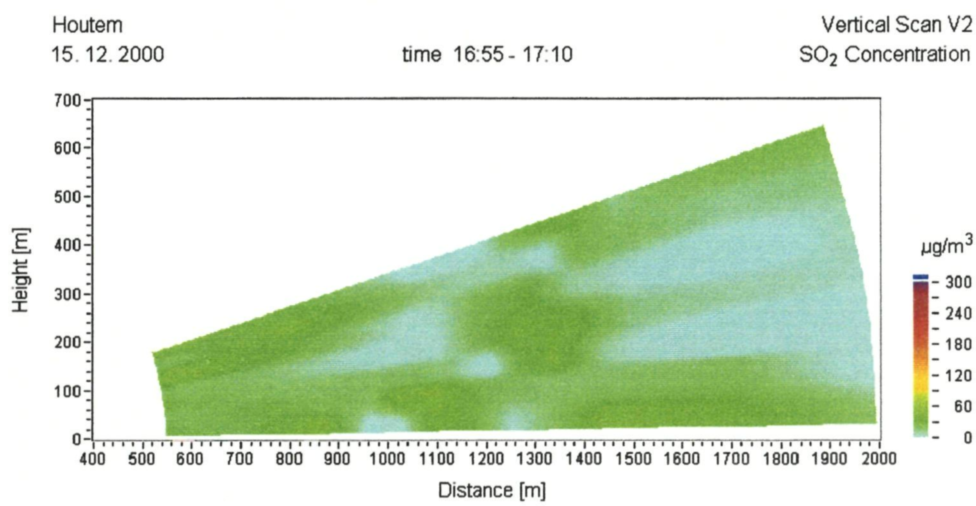



*Fig. 11.9*

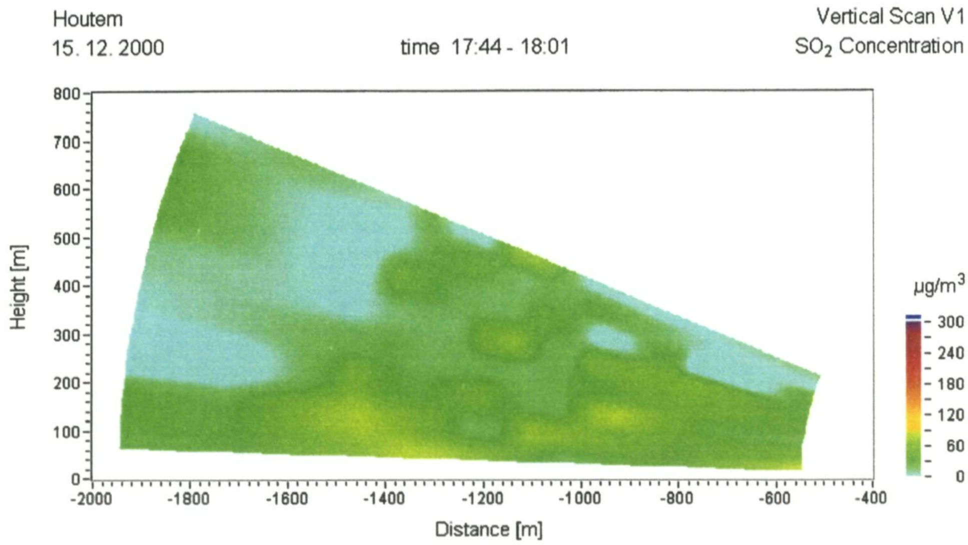



*Fig 11.10*

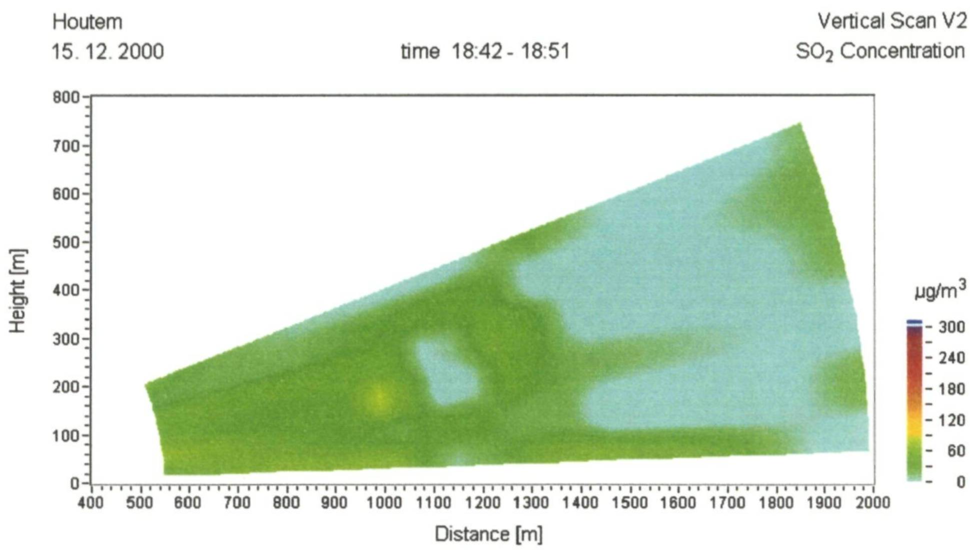



*Fig 11.11*

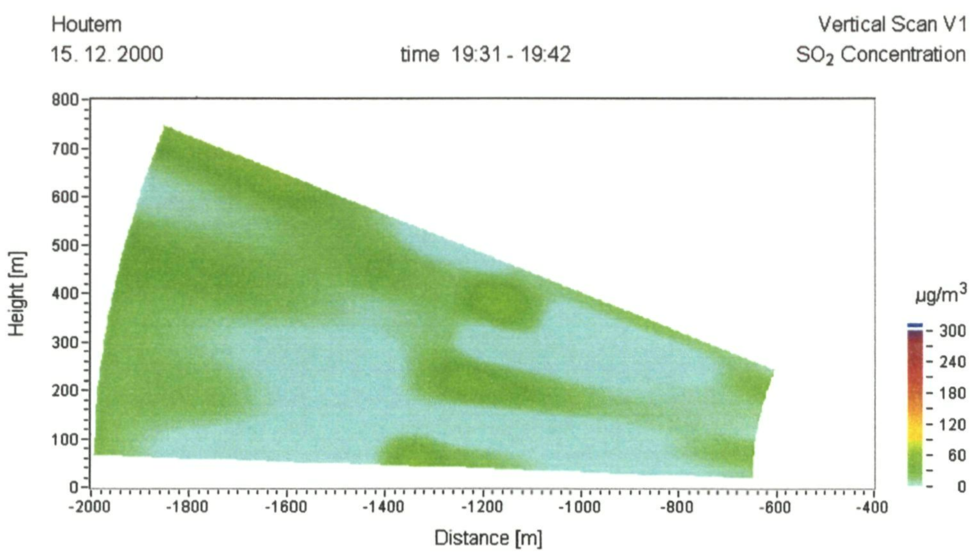



*Fig. 11.12*

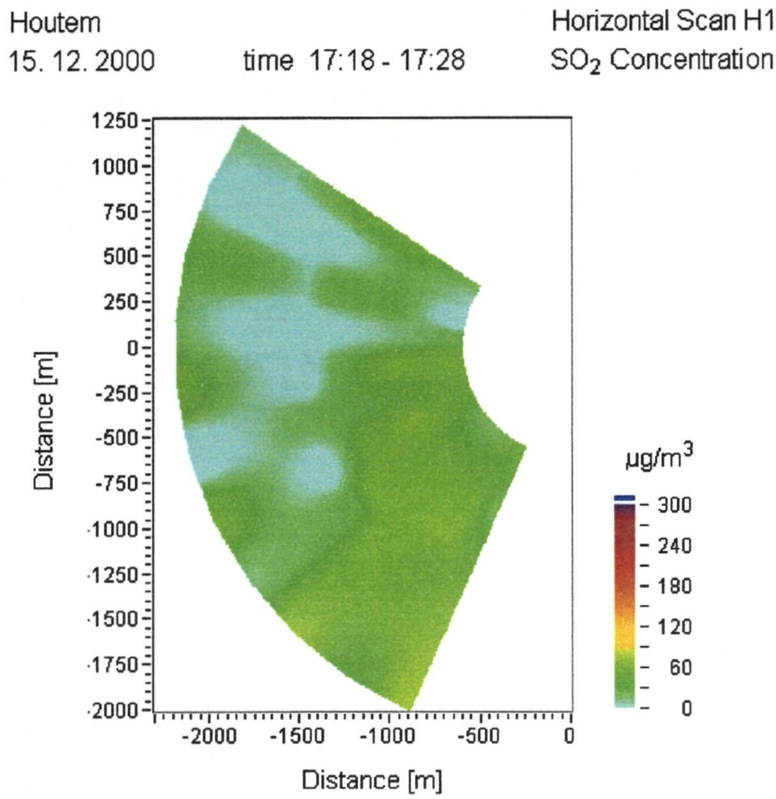



*Fig 11.13*

| | Height | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Time | 0 m | 100 m | 200 m | 300 m | 400 m | 500 m | 600 m | 700 m |
| 13:15:00 | 7 | 7 | 4 | 19 | 17 | 4 | 10 | - |
| 14:30:00 | 15 | 15 | 10 | 18 | 20 | 19 | 50 | 31 |
| 16:15:00 | 57 | 47 | 44 | 38 | 21 | 30 | 47 | - |
| 17:00:00 | 25 | 12 | 15 | 20 | 10 | 22 | 29 | - |
| 17:45:00 | 49 | 38 | 23 | 23 | 16 | 33 | 32 | 8 |
| 18:45:00 | 37 | 30 | 25 | 25 | 5 | 24 | 5 | 9 |
| 19:30:00 | 13 | 10 | 18 | 5 | 15 | 1 | 6 | 25 |

*Tab. 11.1 Concentration of $SO_2$ in $\mu g.m^{-3}$ at chosen times and in chosen heights*

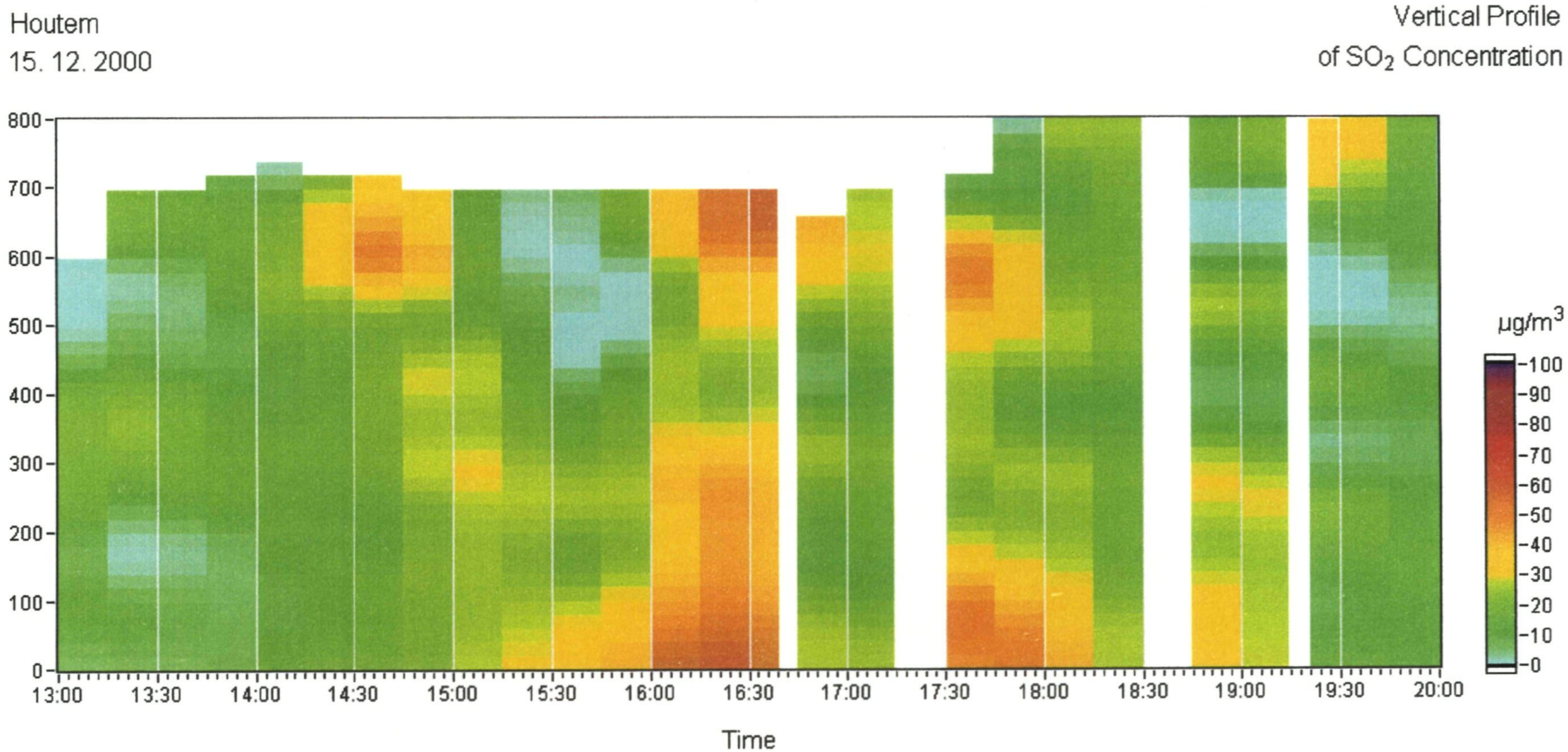



*Fig. 11.14 Time development of the vertical profile of $SO_2$ concentration*

## Measurement of Ozone Concentration

By application of our lidar method, Ozone concentration appears also as fake $SO_2$ concentration. Therefore it was necessary to determine the average Ozone concentration, which was then used for correction of $SO_2$ data. Vertical scans in Fig.11.15 – 11.16 show the distribution of Ozone concentration, which was homogeneous in both vertical and horizontal directions. Round noon the average Ozone concentration was 55 μg/m$^3$ and in the evening round 65 μg/m$^3$. These values were used for $SO_2$ concentration correction. The $SO_2$ concentration correction in between Ozone measurements was interpolated.

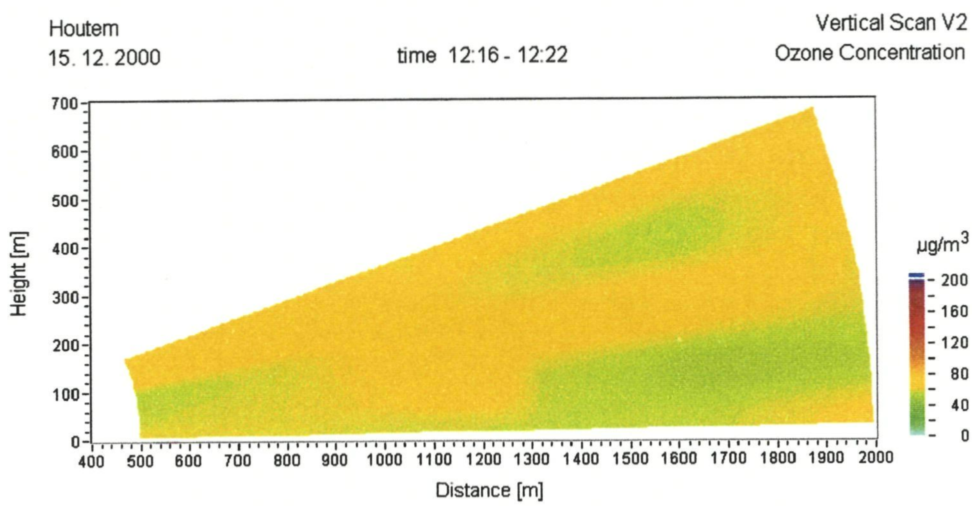



*Fig 11.15*

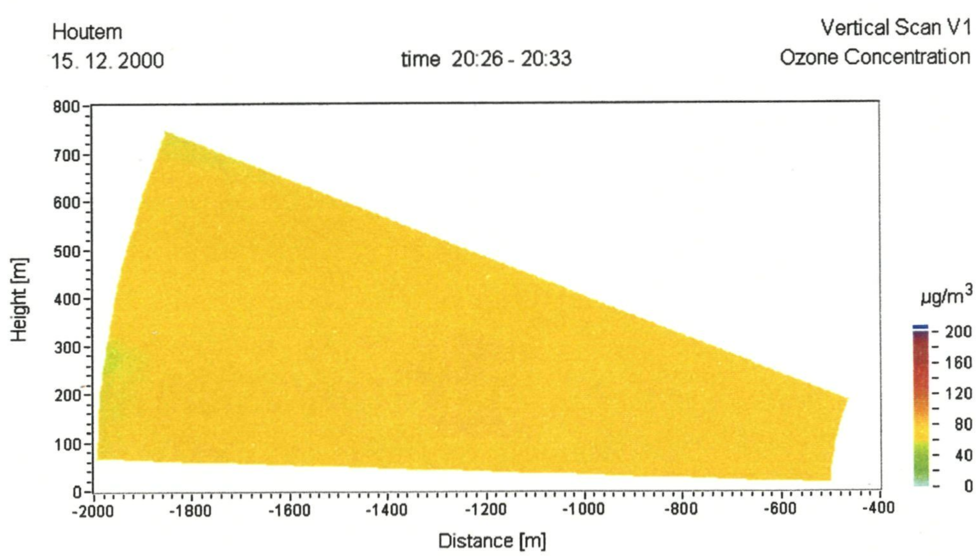



*Fig. 11.16*

## Measurement of Aerosols

In Figures 11.17 – 11.22, vertical scans of extinction coefficient are shown; Fig. 11.23 displays horizontal scan of extinction coefficient; Figure 11.24 demonstrates time development of the vertical profile of extinction coefficient.

The values of extinction coefficients in the vertical profile are significantly lower than those in single vertical scans, because they represent a vertical projection of all vertical scans measured in a corresponding time period, hence the values are averaged in horizontal distance and over time. Extinction coefficients from the vertical profile in chosen heights and at chosen times are contained in table 11.2. Average values of these coefficients were between 0,4 and 0,5 $km^{-1}$. The extinction coefficients were measured on the wavelength 286.3 nm.

In the following Figures, aerosol clouds are typically represented by an area of higher extinction coefficients. As it was described in the section 2 (Measurement Principles), this behavior is typical for so called "dark aerosols". The inhomogenity of aerosol clouds doesn't have to necessarily reflect reality; it might be caused by the applied lidar method and the evaluation software. Lidar measures on single beams and extinction coefficients between these beams are interpolated by the software.

Round 14:30 such aerosol cloud was detected in a height of 500 m (Fig. 11.17). However, more significant presence of aerosols was detected in the period between 16:00 and 16:40, when higher extinction coefficients were measured in the ground layer, to the height of 300 m, and also in the height above 500 m (Fig. 11.18). These results correspond to the highest $SO_2$ concentrations measured during this day.

We conducted a horizontal scan round 17:20 as well (Fig. 11.23). There was a presence of aerosols detected over the French territory. Also on a vertical scan measured short after this horizontal scan slightly increased values of extinction coefficients were detected in the same area. These results correspond with $SO_2$ concentration in the horizontal scan very well.

In the rest of the time, no increased values of extinction coefficients suggesting presence of aerosols were detected (Fig. 11.19, 11.21, and 11.22).

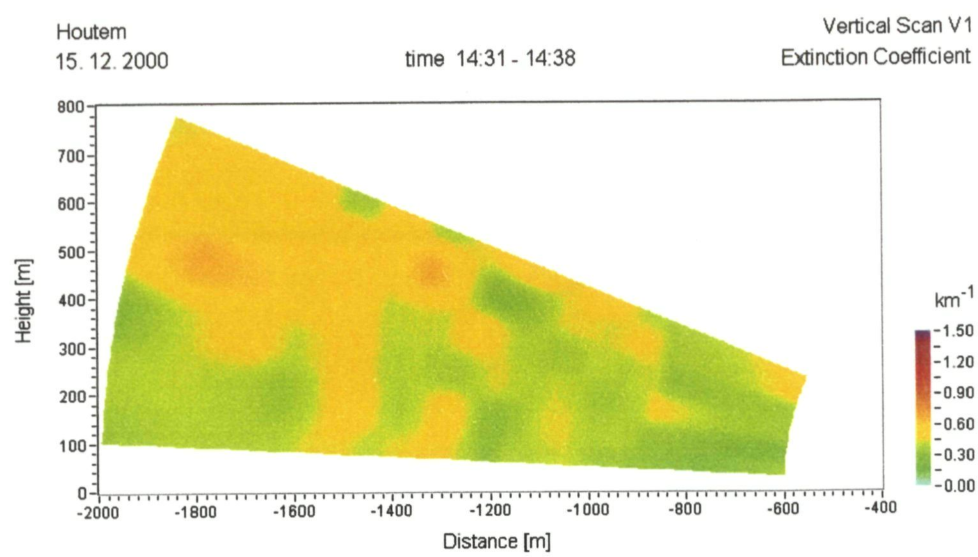



*Fig. 11.17*

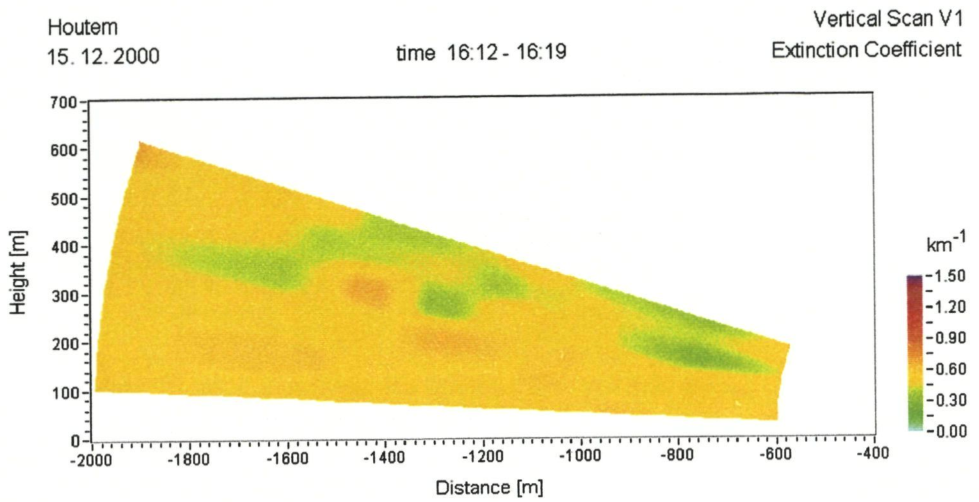



*Fig. 11.18*

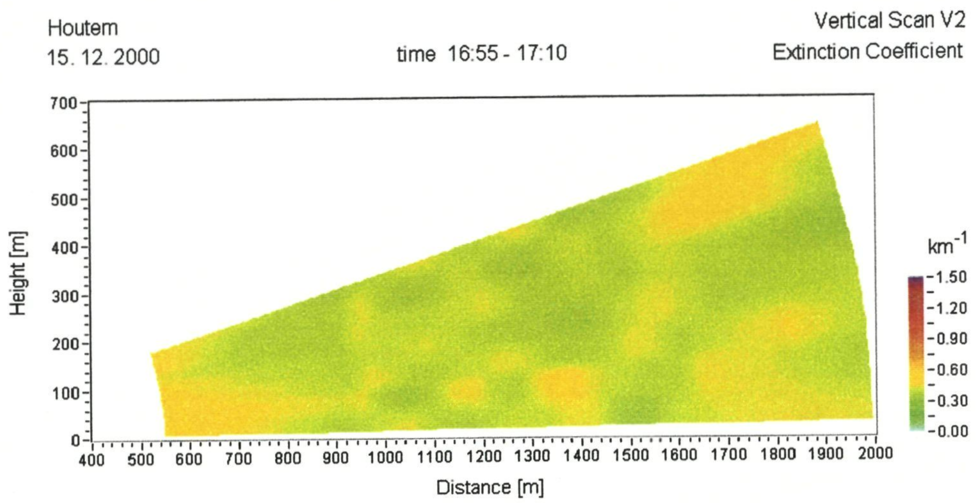



*Fig. 11.19*

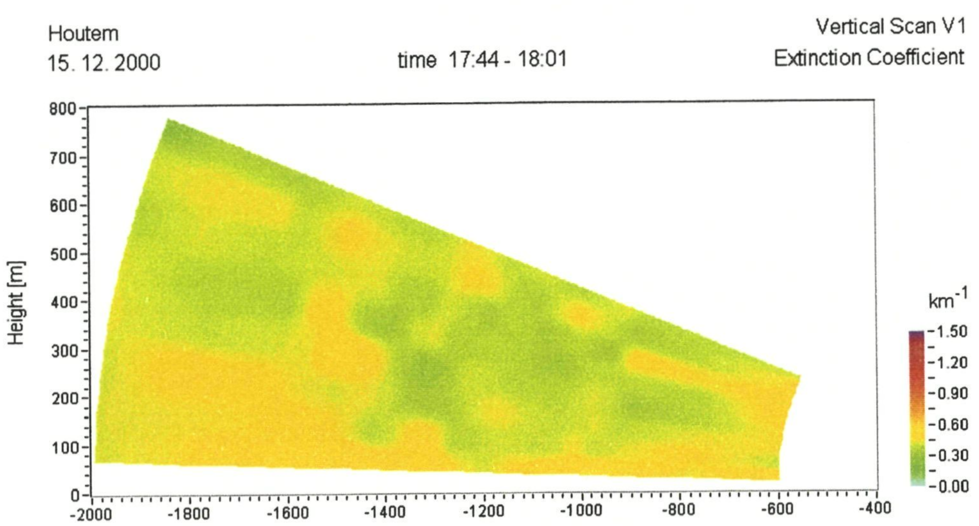



*Fig. 11.20*

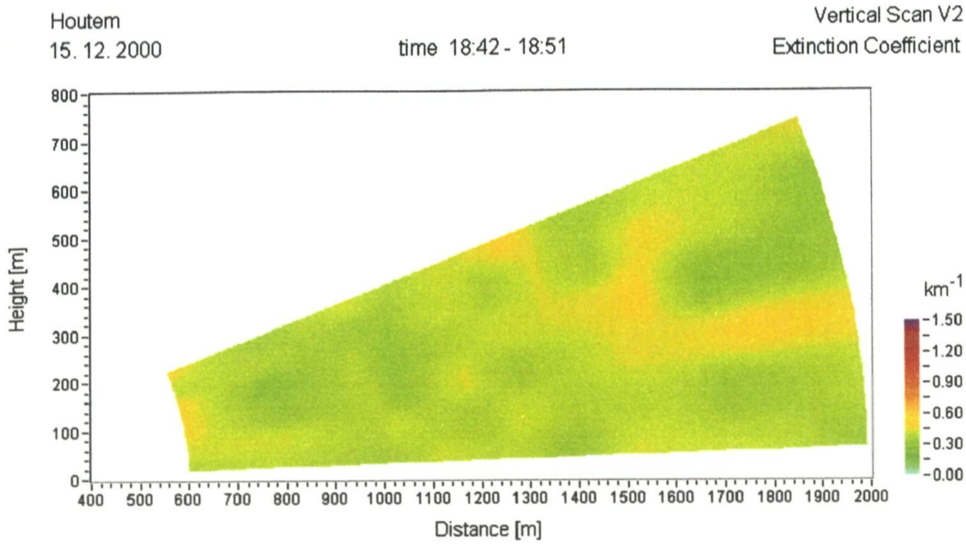



*Fig. 11.21*

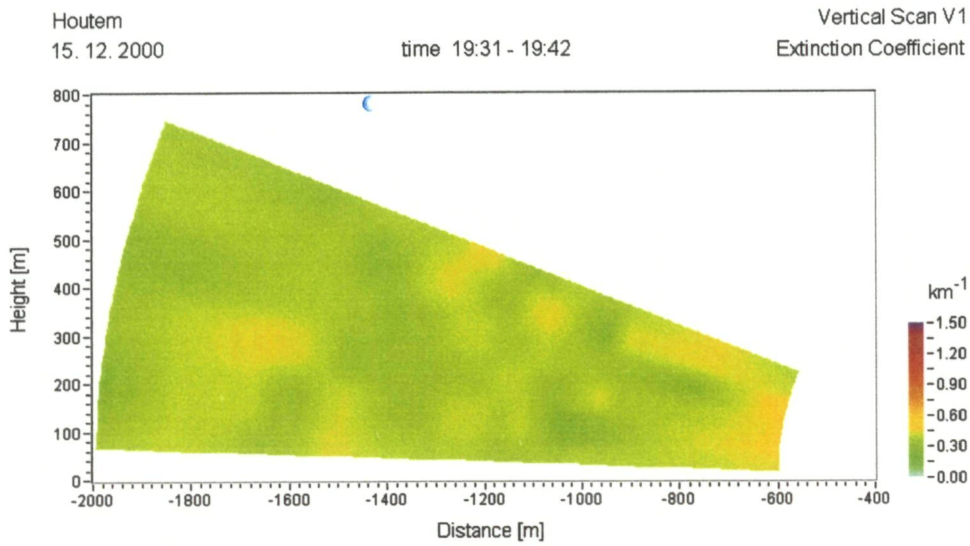



*Fig. 11.22*

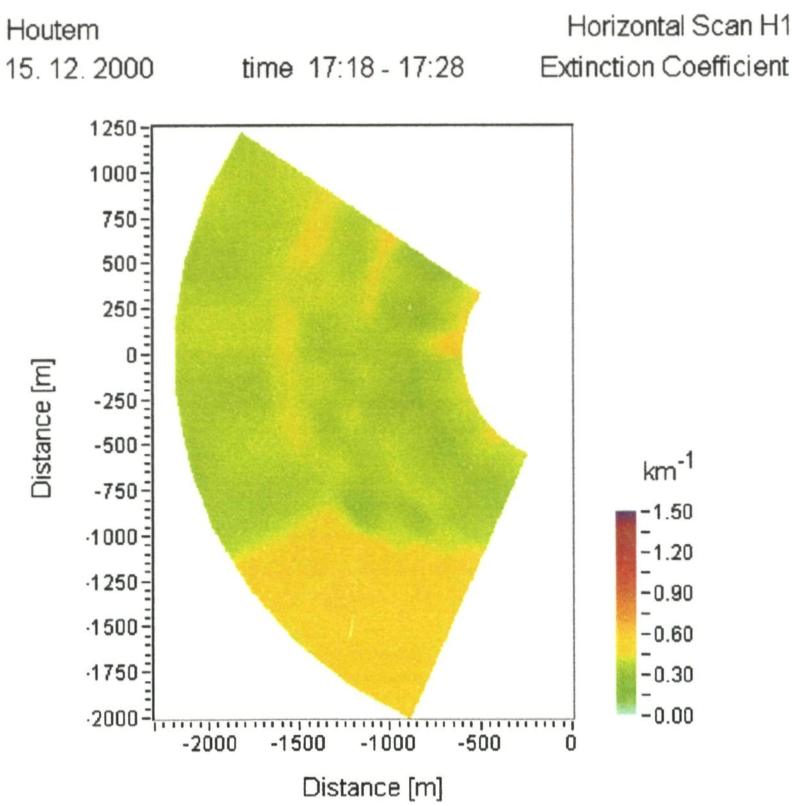



*Fig. 11.23*

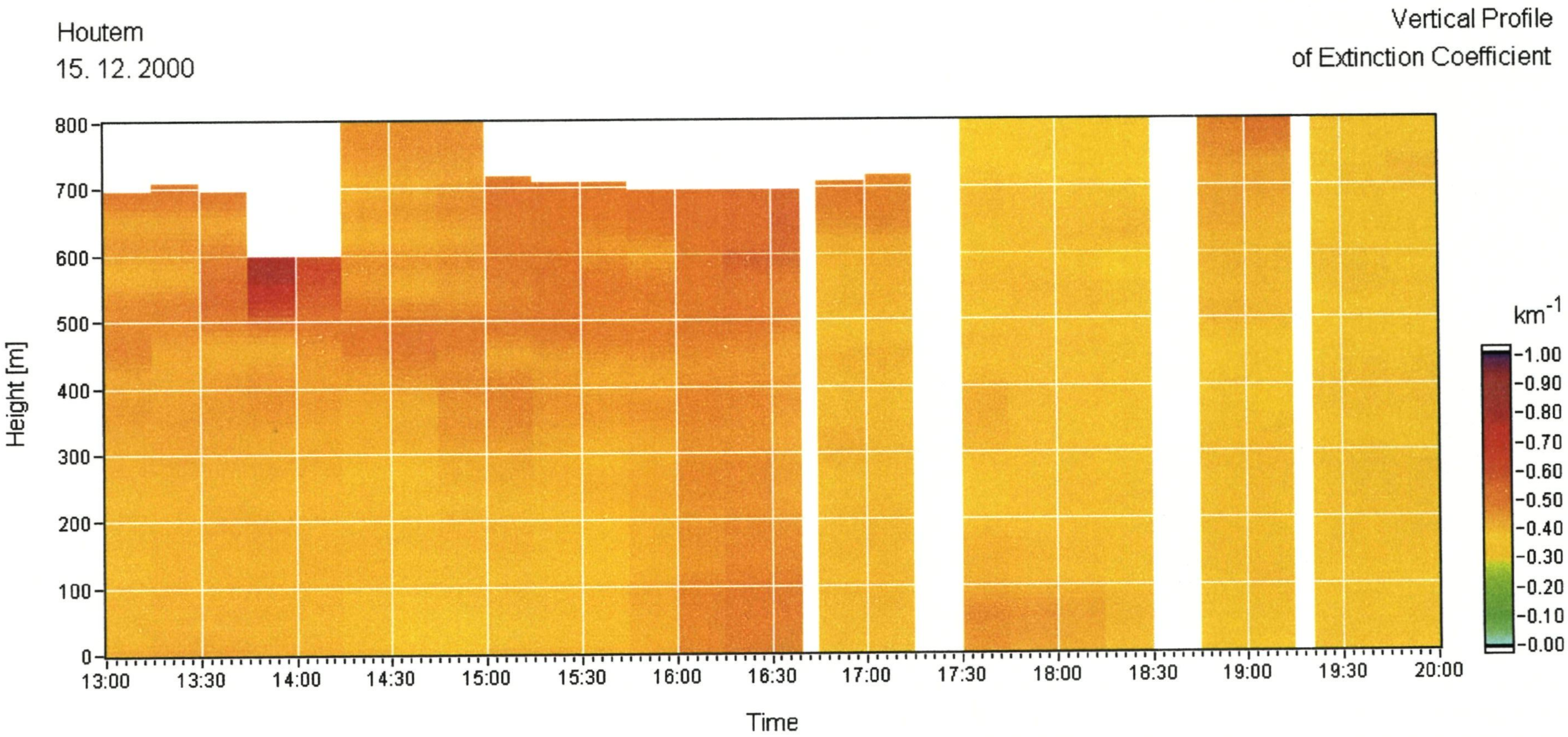



*Fig. 11.24 Time development of the vertical profile of extinction coefficient*

| | Height | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Time | 0 m | 100 m | 200 m | 300 m | 400 m | 500 m | 600 m | 700 m |
| 13:15:00 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,5 | 0,5 | 0,5 |
| 14:30:00 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,5 | 0,4 | 0,4 |
| 16:15:00 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | - |
| 17:00:00 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,5 |
| 17:45:00 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 |
| 18:45:00 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 |
| 19:30:00 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 |

*Tab. 11.2 Extinction coefficients in $km^{-1}$ at chosen times and in chosen heights*

# 12 Conclusion

In the period from the 27th November to the 15th December, our company Lidar s.r.o. performed air pollution measurements in the area of De Panne in Belgium. Extinction coefficients, hence the distribution of aerosols, and concentrations of $SO_2$, $NO_2$, and Ozone were determined during our measurements. The main goal of the measurement campaign was to describe the impact of pollution coming from Dunkerque industrial area on the region of De Panne. The air pollution measurements were conducted using lidar technology. Together with air pollution we measured also speed and direction of the wind in various heights using sodar technology. The measurements were carried out with modern mobile laboratory that consists of the Lidar 510 M and Sodar PA2 systems. Altogether we measured during nine days within the whole period of the measurement campaign.

In the period from the 27th November to the 9th December, conditions for measuring the pollution impact of Dunkerque industrial area weren't convenient. The wind blew predominantly from the south, so that the air masses from Dunkerque were carried over the sea and didn't reach the region of De Panne. This situation was captured during the first four measurement days (Chapters 3 – 6). In these days usually very low concentrations of pollutants were detected. If increased concentrations measured then their origin was in local sources. For example, increased concentrations of $NO_2$ were detected over a highway near De Panne on the 27th November (Chapter 3). We detected also some aerosol layers during the first four measurement days. We can't exactly distinguish what were the sources of these aerosols, but in most cases they were of natural origin (clouds, fogs, etc.).

Air pollution from Dunkerque industrial area was detected during several measurement days in the period from the 10th to the 15th December. We measured significantly increased $SO_2$ concentrations when air masses were transported by the wind from the direction of Dunkerque (Chapters 7, 10, and 11). Plumes of $SO_2$ were detected both, by the ground and in higher layers in such cases. The maximal $SO_2$ concentration reached 250 $\mu g/m^3$ in these plumes. Sometimes the $SO_2$ plumes corresponded to areas with high presence of aerosols. It might be a prove that these aerosol clouds were coming from the same source as $SO_2$, which was Dunkerque industrial area (Chapter 10, 11).

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