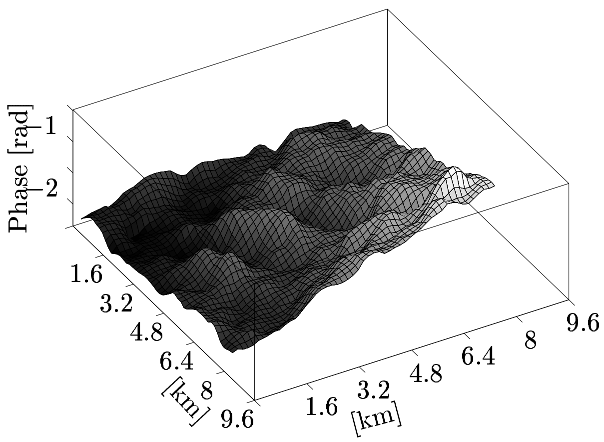

Figure 5.40 *Extraction A from interferogram gdex2*

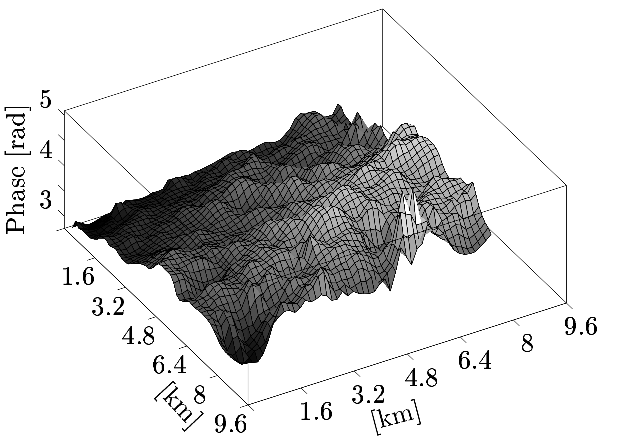

Figure 5.41 *Extraction B from interferogram gdex2*

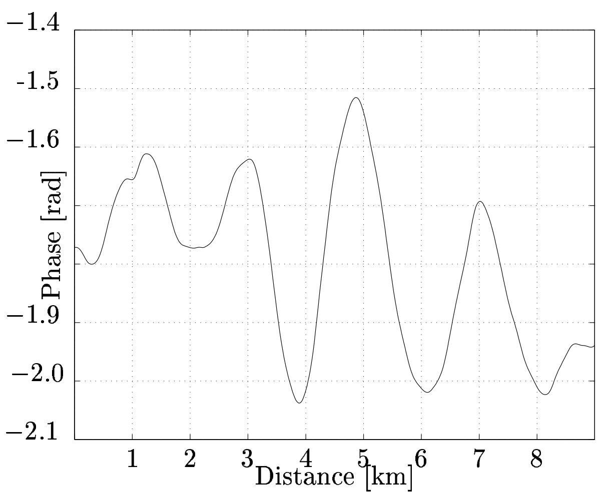

Figure 5.42 *Profile over extraction A, perpendicular to waves in gdex2*

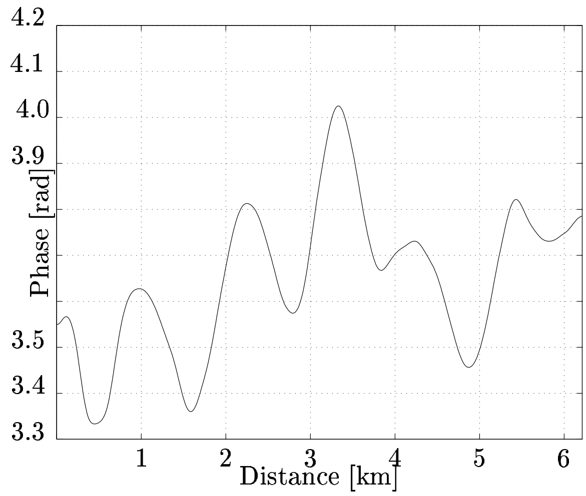

Figure 5.43 *Profile over extraction B, perpendicular to waves in gdex2*

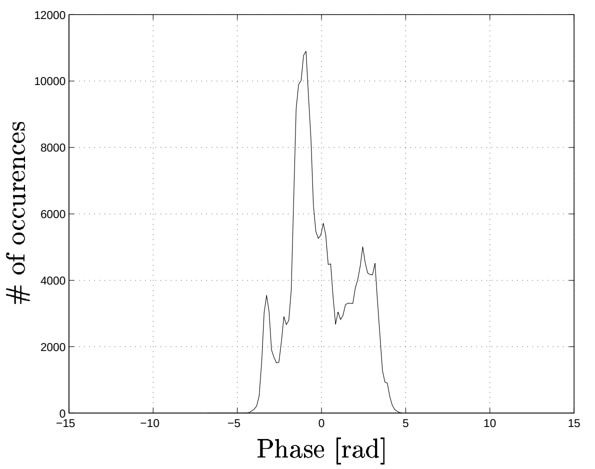

Figure 5.44 *Histogram of major part of interferogram gdex2*

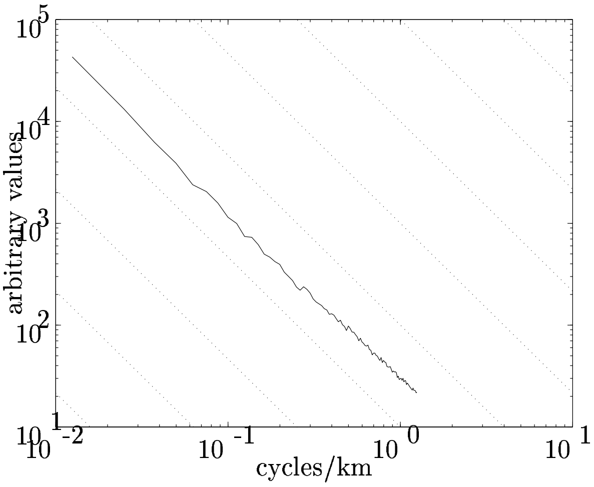

Figure 5.45 *Rotational averaged spectrum of interferogram gdex2*

quasi-stationary frontal system during both days.

From the Meteosat data we derive that the meteorological situation is complicated: a cold front smoothly turns into a warm front when following the front from north to south. The area can, however, be classified as a frontal zone. The second day, the front has shifted little to the east.

The weather radar does not reach far enough into the area of interest. However, from the available data we expect that the rain area is oriented in north-east–south-western direction, and it covers most of the south-eastern part of the study area, shifting even slightly more to the south-east on day 2.

From the synoptic data we derive that there was slight drizzle and rain at the first day, and local fog or freezing fog at the second day with a visibility at Eelde of 700–1400 m. The Eelde station reported three cloud layers at day 1: 1/8 stratus at 300 m, 4/8 stratocumulus at 800 m , and 8/8 altostratus at 4 km. At both days there was a high relative humidity of 100%. The second day, it reported 2/8 stratus at 30 m, and 6/8 altocumulus at 4 km. There was not much wind, 3–5 m/s, from south-western direction. It was approximately 4°C.

Unfortunately, only the radiosonde profile from Emden for the first day was available, and wind speed and direction measures were not available as well. The radiosonde profile at day 1, however, indicated a fully saturated layer at 1.2 km. It is possible that the small waves are gravity waves, which find their origin around this layer.

Station	#	UTC	Day	Level 1	Level 2	Level 3
Eelde	280	1000	1	1/8, St, 300 m	4/8, Sc, 800 m	8/8, As, 3300 m
Eelde	280	1100	1	3/8, Sc, 1200 m	8/8, As, 3300 m	
Eelde	280	1000	2	1/8, St, 0 m	6/8, Ac, 3300 m	
Eelde	280	1100	2	2/8, St, 0 m	6/8, Ac, 3300 m	

Table 5.8 *Cloud observations gdex2: 26-02/27-02-1996. The observations give the amount of cloud cover (okta), the type of cloud, and the cloud base at 3 levels.*

The interferogram seems to indicate the frontal zone. In the Meteosat WV image, the structure (wave) of the front is clearly visible, and the direction closely corresponds with the direction of the long wavelength effect in the interferogram. Unfortunately, no AVHRR imagery was available. Based on the sign of the disturbance, which is positive, the main disturbance is expected at the first day.

5.2.8.3 Conclusions

The large scale disturbance in the interferogram is believed to be caused by a quasi-stationary front at the first day. Synoptic weather charts give a first indication for this explanation, and Meteosat confirms this as well. The orientation of the waves, where the wave crests are perpendicular to the wind direction, indicates their origin as gravity waves, possibly in a small, fully saturated layer at day 1.

5.3 Analysis Delft descending

A single SAR pair was processed interferometrically and interpreted over the south-western parts of the Netherlands, over the provinces *Zeeland*, *Noord-Brabant*, and *Zuid-Holland*. The south-eastern part of the interferogram is situated over *Belgium*. Especially the province Zeeland is characterized as a delta region of the rivers Maas and Rhine, and consists of a number of islands. Figure 5.46 shows the location of the islands. Over most of the area the topographic variation is less than 2 meters. A small area in the south-west of the interferogram reaches heights of 20 meters.

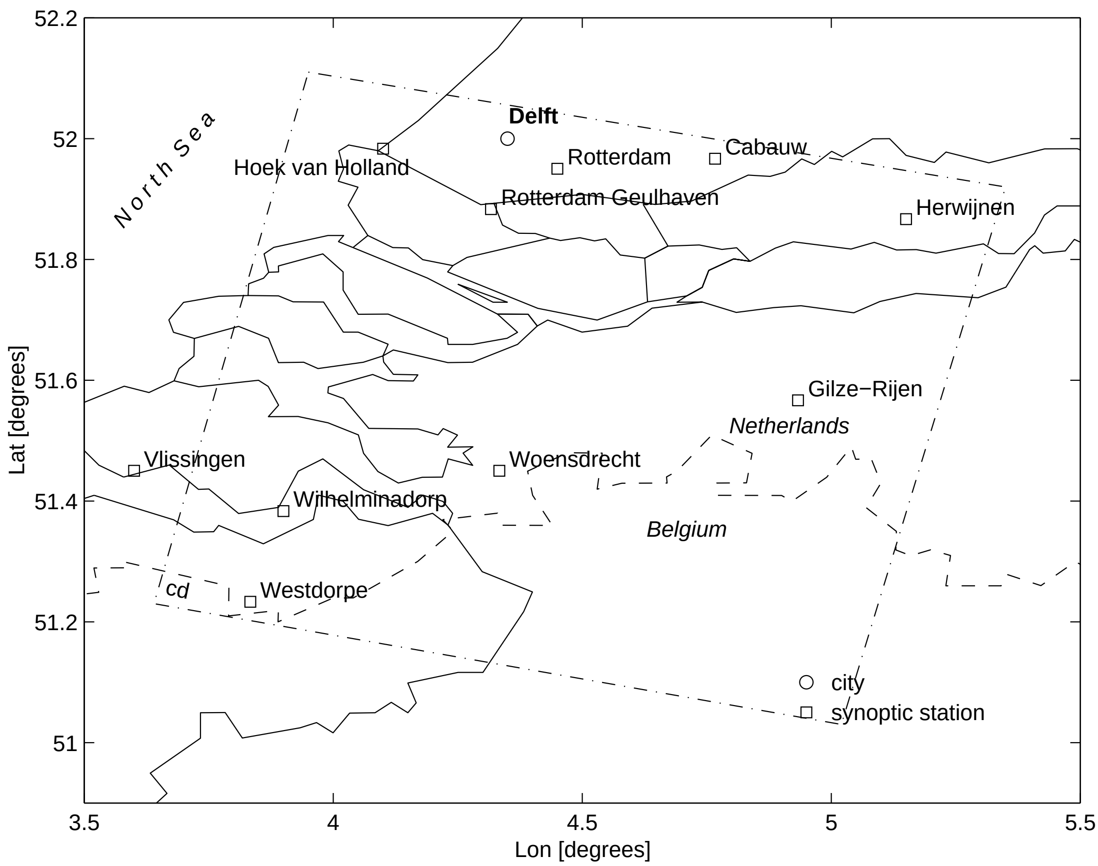

Figure 5.46 *Map of the area for the interferogram Delft descending, showing the position of the synoptic stations with some relevant topographical information, referred to in the text.*

This area is also labeled *CLARA descending*, since the data were acquired simultaneously with a part of the meteorological *CLouds And RAdiation* experiment (van Lammeren et al., 1997), which enables comparison with many additional and more unconventional atmospheric observations.[2] Aircraft measurements of droplet size, temperature, pressure, and relative humidity were carried out in the region over the city of *Delft*, shown

[2] see `http://www.knmi.nl/CLARA/`

in figure 5.46, as well as water vapor radiometer, lidar, GPS, ground based radar, and radiosonde observations. The analysis of the interferograms using these additional observations is, however, beyond the scope of this report, and a subject for further research.

5.3.1 Analysis of interferogram cd1

Interferogram cd1 was acquired at April 23 and 24, 1996, at 10:38:07 UTC (12:38:07 LT). The SAR frame number is 2565, for ERS-1 orbit 24960, and ERS-2 orbit 5287. The parallel baseline is 38 m, the perpendicular baseline 78 m. Phase unwrapping was performed using the method of Ghiglia and Romero (1994).

5.3.1.1 Observations

The interferogram labeled cd1, figure 5.47, shows lineated series of small anomalies, with some stronger disturbances just under the center of the image. Phase changes are limited to about one cycle. The unwrapped interferogram is shown in figure 5.48. Water areas are masked out for this analysis.

The rms value of the interferogram is 1 rad. The full histogram is shown in figure 5.49, revealing a Gaussian shape. The rotationally averaged spectrum, figure 5.50, completes the analysis. The spectrum follows the $-5/3$ lines for wavelengths between 0.5 and 2 km.

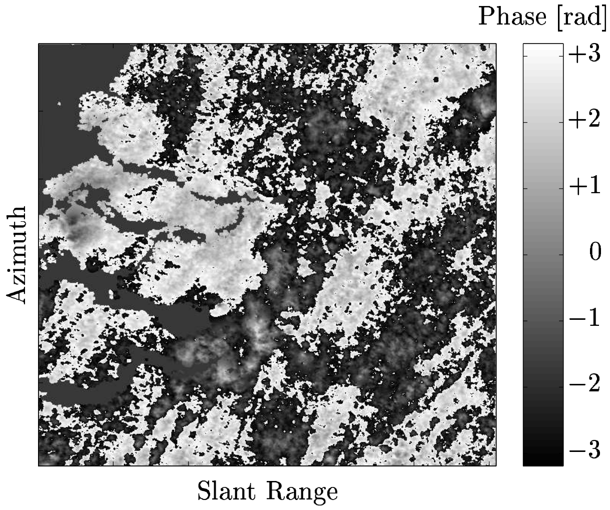

Figure 5.47 *Interferogram cd1*

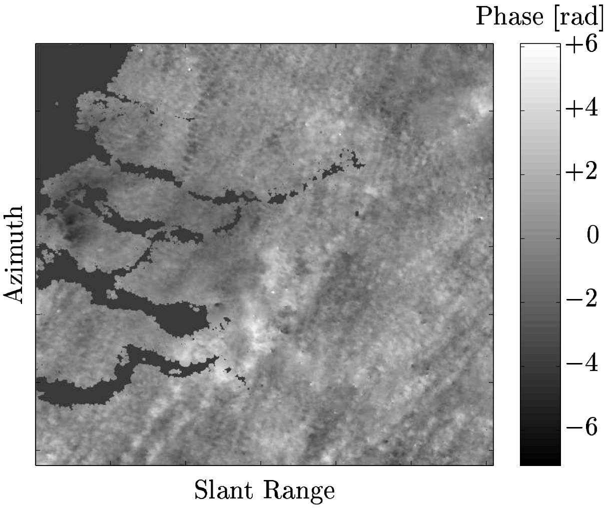

Figure 5.48 *Unwrapped interferogram cd1*

5.3.1.2 Interpretation

In the interferogram, the phase striations have a clear orientation. This corresponds very accurately to the wind directions observed, see figure 5.54. In the upper left corner, also wave features perpendicular to the wind direction are apparent.

At day 1, a cold front has just passed the test area. This gives rise to isolated showers. Cloud tops reach up to 6 km. The wind direction was south-southwest. At 10:00 UTC, both Gilze-Rijen and Woensdrecht reported rain. Rotterdam reported no rain. At 11:00 UTC,all stations reported “no rain”. The synoptic situation confirms the showery weather. In the radiosondes we see instabilities and cold advection.[3] The relative humidity is 60–80%. There is a lot of wind: wind force 6 or 7 (see table 4.3, p. 38), and

[3] Advection is the horizontal transport of air or atmospheric properties. The term is commonly used

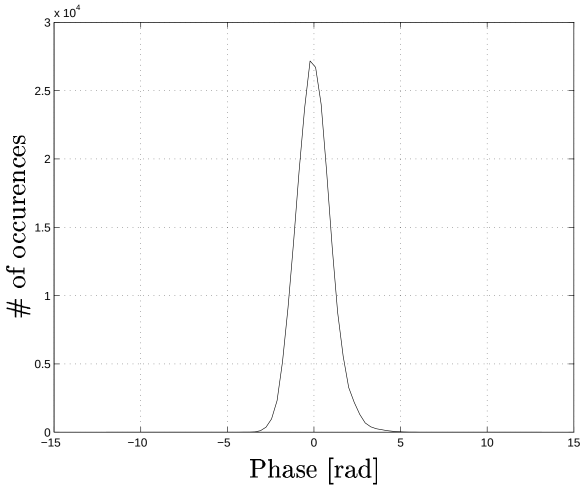

Figure 5.49 Histogram of major part of interferogram cd1

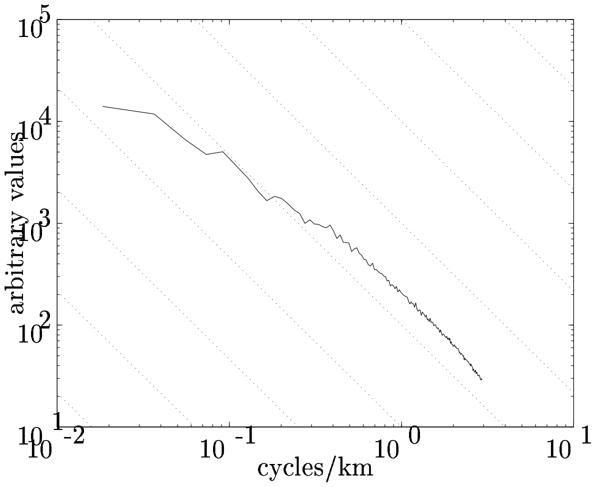

Figure 5.50 Rotational averaged spectrum of interferogram cd1

not much precipitation. The cloud cover observations report cumulus, cumulonimbus, stratocumulus, and altocumulus, see table 5.9.

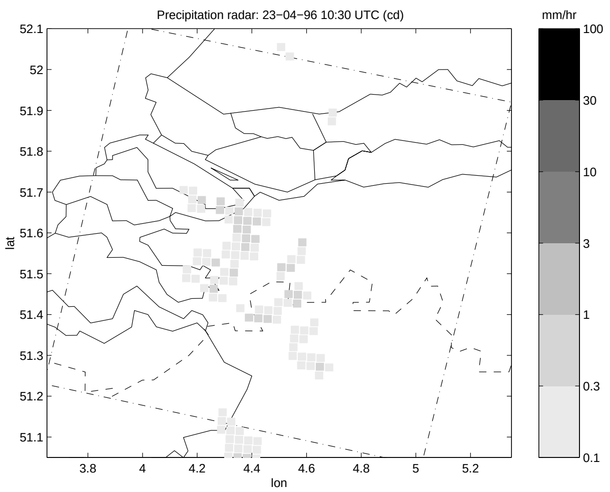

Figure 5.51 Weather radar cd1, day 1, 10:30 UTC

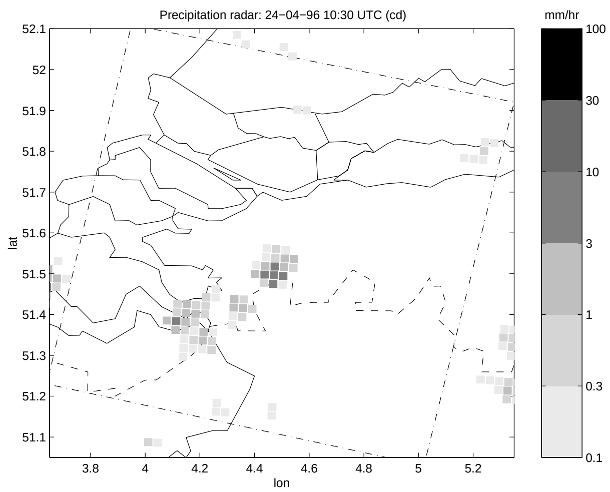

Figure 5.52 Weather radar cd1, day 2, 10:30 UTC

Stratocumulus fields are visible in the AVHRR imagery and the interferometric images.

At day 2 the front is already far away, over Central Europe. There is advection of polar air. The weather radar indicates a shower over Woensdrecht, with cloud tops at 8 km. Vlissingen indicates a moderate shower and Woensdrecht a light shower. In terms of cloud cover, cumulonimbus, stratocumulus, cumulus, and altocumulus is reported. The wind direction is mainly southwest.

with temperatures, i.e., "warm air advection". A cold advection is defined as the transport of cold air into a region by horizontal winds.

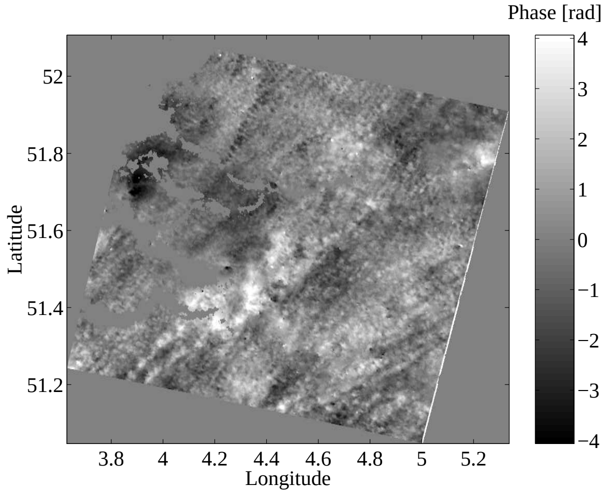

Figure 5.53 *Geocoded absolute interferogram cd1*

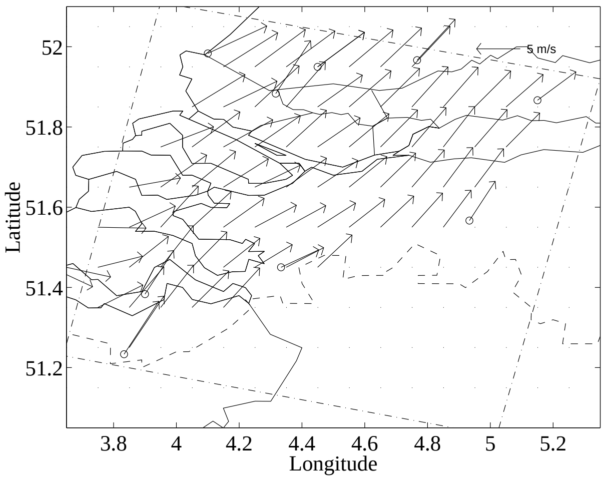

Figure 5.54 *Pressure and surface wind field cd1, day 2*

Station	#	UTC	Day	Level 1 (m)	Level 2 (km)	Level 3 (km)
Vlissingen	310	1000	1	1/8, Cu, 1000	3/8, Cu, 1.1	7/8, Ac, 3.3
Hoek v. Holland	330	1000	1			
Woensdrecht	340	1000	1	2/8, Cu, 800	3/8, Sc, 3.0	6/8, Ac, 3.3
Rotterdam	344	1000	1	2/8, Cu, 800	3/8, Sc, 3.0	7/8, Ac, 3.3
Gilze-Rijen	350	1000	1	1/8, Cb, 650	3/8, Sc, 1.6	6/8, Ac, 3.0
Vlissingen	310	1100	1	3/8, Cu, 1200	6/8, Ac, 3.3	
Hoek v. Holland	330	1100	1			
Woensdrecht	340	1100	1	2/8, Cu, 1000	6/8, Ac, 3.3	
Rotterdam	344	1100	1	3/8, Cu, 1000	6/8, Ac, 3.0	
Gilze-Rijen	350	1100	1	1/8, Cu, 800	6/8, Sc, 3.0	
Vlissingen	310	1000	2	2/8, Cu, 900		
Hoek v. Holland	330	1000	2			
Woensdrecht	340	1000	2	1/8, Cu, 1000	6/8, Ac, 3.0	
Rotterdam	344	1000	2	1/8, Cu, 1000	7/8, Ac, 3.3	
Gilze-Rijen	350	1000	2	1/8, Cu, 900	5/8, Ac, 3.0	
Vlissingen	310	1100	2	2/8, Cb, 1000	4/8, Sc, 1.5	
Hoek v. Holland	330	1100	2			
Woensdrecht	340	1100	2	1/8, Cb, 1000	3/8, Sc, 1.6	
Rotterdam	344	1100	2	3/8, Cu, 1100		
Gilze-Rijen	350	1100	2	4/8, Cu, 1200		

Table 5.9 *Cloud observations cd1: 23-04/24-04-1996. The observations give the amount of cloud cover (okta), the type of cloud, and the cloud base at 3 levels.*

5.3.1.3 Conclusions

The observed structures are probably not cloud streets: with the instabilities seen and the strong winds reported no cloud streets will form. Furthermore, no inversion exists that could give rise to cloud street formation. However, the orientation of the rectilinear structures corresponds closely with the wind direction, and could therefore be caused by transport of moisture. The stronger phase signatures are attributed to the showers. Weather radar signals coincide with the main phase disturbances.

5.4 Analysis Flevoland descending

Interferogram *Flevoland descending* covers the central part of the Netherlands, and shows the central lake, *IJsselmeer*, surrounded by the provinces *Noord-Holland* in the west, *Utrecht* in the south, *Overijssel* in the south-east, and *Friesland* in the north. Within the IJsselmeer, two polders are situated. *Flevoland* covers the southern part of the IJsselmeer, and is sometimes subdivided in a northern and a southern part, *Noord-Flevoland* and *Zuid-Flevoland* respectively. *Noord-oostpolder* is situated in the most eastern part of the IJsselmeer lake area. Both polders are very flat areas with heights varying between -2 and $+3$ meters.

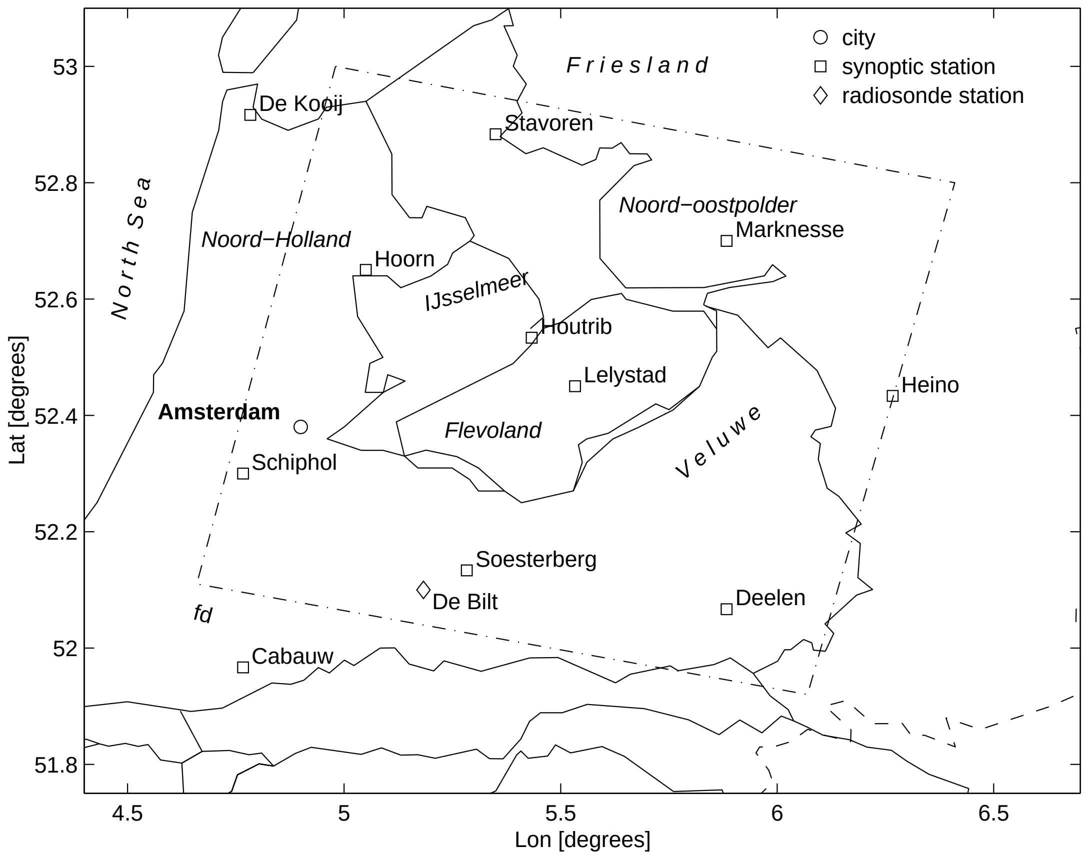

Figure 5.55 *Map of the area for the interferograms Flevoland descending, showing the position of the synoptic and radiosonde stations with some relevant topographical information, referred to in the text.*

In the south-eastern part of the interferogram area, the *Veluwe* is a hilly elevated area of glacial origin. The maximum height is approximately 100 m. Additionally to the Veluwe area, some small, less elevated areas are situated in the southern part of the interferograms. Apart from these area, the variation of topographic height in the interferogram area is small, within 5 meters.

The map in figure 5.55 shows the position of the synoptic stations, as well as the city of *Amsterdam*. Manual cloud observations are available from the stations *De Kooij*, *Schiphol*, *Soesterberg*, *Deelen* and *De Bilt*. Radiosondes are being launched four times daily from the latter station.

5.4.1 Analysis of interferogram fd1

Interferogram fd1 was acquired at August 3 and 4, 1995, at 10:35:06 UTC (12:35:06 LT). SAR frame number 2547, for ERS-1 orbit 21181, and ERS-2 orbit 1508. The parallel baseline is 32 m, the perpendicular baseline 58 m. The minimal cost flow algorithm (Costantini, 1996) is used for phase unwrapping.

5.4.1.1 Observations

Interferogram *fd1*, (figure 5.56), shows phase variations with a magnitude of one cycle. Lineated structures, referred to as striation, crossing the interferogram diagonally, can be observed over the whole image. Especially in the unwrapped interferogram, figure 5.57, it can be observed how the striation organized. The main direction is from upper right to lower left, but some deviations can be seen at the left side of the image, where the directions tends more towards a horizontal direction, and at the lower right corner, where the striation seem to "curve". First the direction is more vertically inclined, but after some distance, it re-finds its original direction. The position where this curve appears, is just before the *Veluwe*, an elongated hill with a maximum height of about 100 meters.[4]

The histogram, shown in figure 5.58 shows a smooth Gaussian distribution, with an rms of 1.7 rad. The rotationally averaged spectrum in figure 5.59 shows how wavelengths between 400 and 2000 m, and 12.5 and 25 km follow roughly the −5/3 exponential reference line.

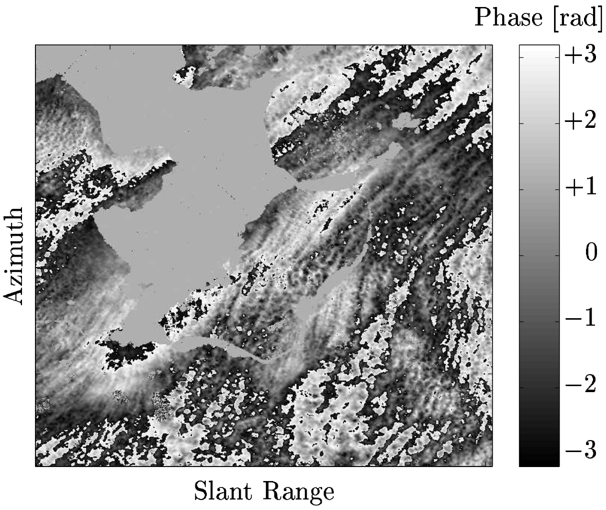

Figure 5.56 *Interferogram fd1*

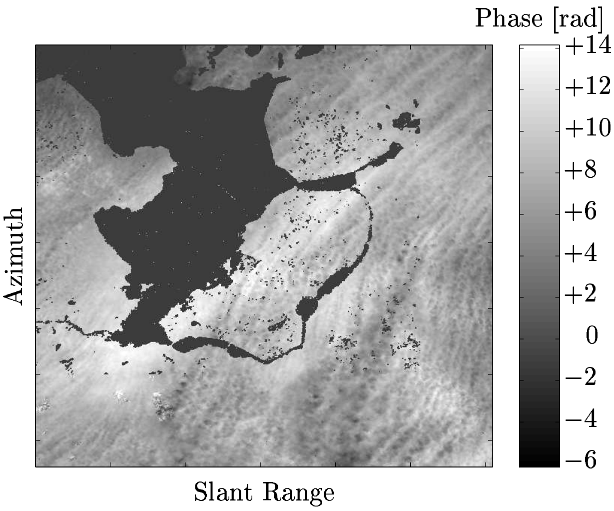

Figure 5.57 *Unwrapped interferogram fd1*

5.4.1.2 Interpretation

The interferogram shows lineated structures or striation which at some points become more diffused, and form more or less isolated cells in the lower part of the image.

[4]See figure 5.73 at page 81 for an impression of the topography

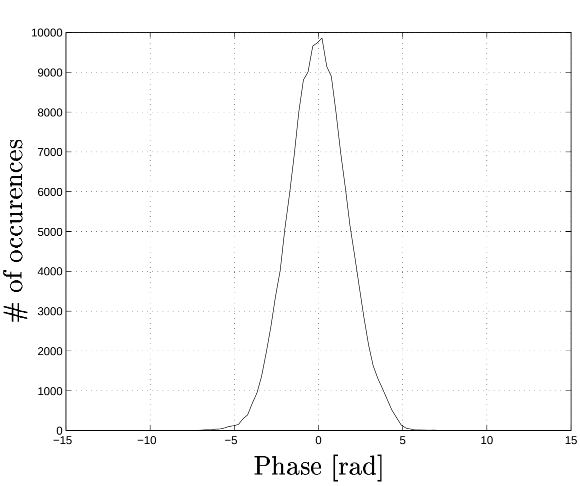

Figure 5.58 *Histogram of major part of interferogram fd1*

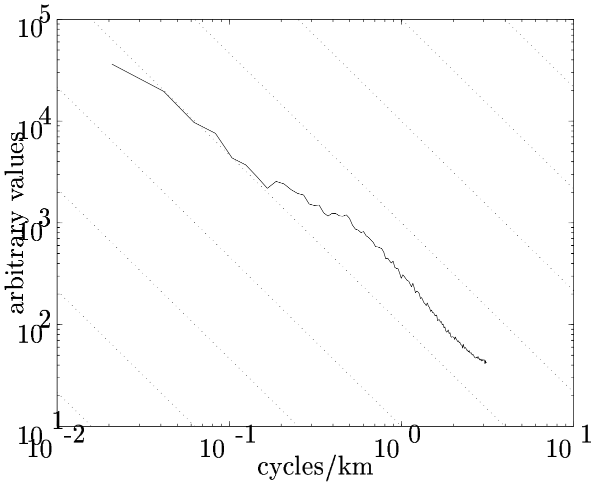

Figure 5.59 *Rotationally averaged spectrum of interferogram fd1*

The Meteosat image of day 1 reveals a large area of fog/stratus over the North Sea. The weather radar gives some signal over Noord-Flevoland. This however, is an artifact associated with the scatter of the precipitation radar at an inversion layer. Therefore, there is no rain in the test area. The synoptic data at Houtrib indicate that there is some haze, with a reduced visibility to about 5 km. It is not that humid in the area, the relative humidity is around 60-70%. From the radiosonde data we conclude that there is quite some humidity throughout the whole tropospheric column. It concentrates around the inversion.

The radiosonde data clearly show that there is a subsidence inversion, lowering from 2000 m at day 1 to approximately 1200 m at day 2. At the second day, the inversion is stronger than at the first day.

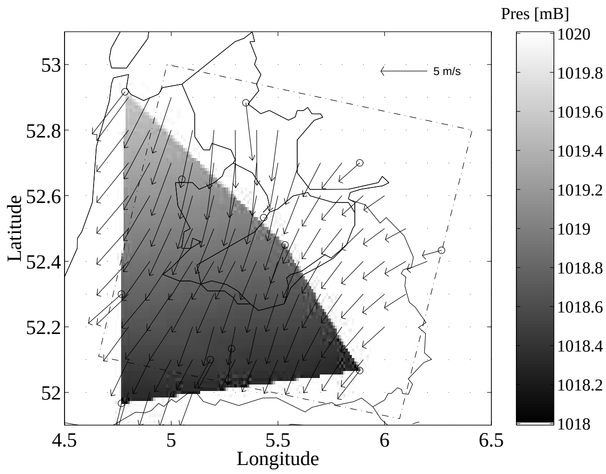

Figure 5.60 *Pressure and surface wind field fd1, day 1, 10:00 UTC*

At day 1 there is around 1/8 cumulus at 1.6 km, and 5/8 cirrus with a temperature around 23°C. At day 2 the temperature is slightly lower, around 21°C, and there is more cloud cover. In most parts of the area low level cumulus clouds are reported, see table 5.10.

Wind directions are northeast at day 1 and north at day 2.

A comparison of the unwrapped interferogram with a plot of wind directions at the synoptic stations at day 1, see figure 5.60, shows striking similarities, especially since it has such a characteristic behavior at this day. The striation aligns with the wind vectors of most stations. In the lower right part of the interferogram the elongated hills of the *Veluwe*, seem to spread the flow apart. Since the wind direction was more north at day 2, the observed effects cannot be caused at that time. The relatively low relative humidities at the surface indicate that the moisture must be at higher altitudes, possibly at the inversion altitude.

Station	#	UTC	Day	Level 1	Level 2
De Kooij	235	1000	1	1/8, Ac, 3300 m	3/8, Ci, 8300 m
Schiphol	240	1000	1	5/8, Ci, 8300 m	
De Bilt	260	1000	1	1/8, Cu, 1600 m	
Soesterberg	265	1000	1	1/8, Cu, 1300 m	6/8, Ci, 8300 m
Deelen	275	1000	1	1/8, Cu, 1500 m	4/8, Ci, 8300 m
De Kooij	235	1100	1	1/8, Ac, 3300 m	4/8, Ci, 8300 m
Schiphol	240	1100	1	1/8, Cu, 1600 m	4/8, Ci, 8300 m
De Bilt	260	1100	1	2/8, Cu, 1500 m	
Soesterberg	265	1100	1	1/8, Cu, 1400 m	5/8, Ci, 8300 m
Deelen	275	1100	1	1/8, Cu, 1600 m	5/8, Ci, 10000 m
De Kooij	235	1000	2	1/8, Cu, 800 m	6/8, Sc, 1400 m
Schiphol	240	1000	2	2/8, Sc, 1200 m	7/8, Ci, 10000 m
De Bilt	260	1000	2	3/8, Cu, 1000 m	6/8, Ci, 8300 m
Soesterberg	265	1000	2	2/8, Cu, 1000 m	6/8, Ci, 10000 m
Deelen	275	1000	2	1/8, Sc, 800 m	5/8, Ci, 8300 m
De Kooij	235	1100	2	1/8, Cu, 800 m	6/8, Sc, 1400 m
Schiphol	240	1100	2	1/8, Cu, 1000 m	6/8, Sc, 1200 m
De Bilt	260	1100	2	1/8, Cu, 1200 m	5/8, Ci, 8300 m
Soesterberg	265	1100	2	2/8, Cu, 1200 m	5/8, Ci, 10000 m
Deelen	275	1100	2	2/8, Sc, 900 m	4/8, Ci, 8300 m

Table 5.10 *Cloud observations fd1: 03-08/04-08-1995. The observations give the amount of cloud cover (okta), the type of cloud, and the cloud base at 2 levels.*

5.4.1.3 Conclusions

The observed effects are most likely due to moisture fluctuations, transported by the wind at day 1. The moisture does, however, not necessary indicate visible cloud streets. It may be appropriate to speak of "moisture streets" in this context.

5.4.2 Analysis of interferogram fd2

Interferogram fd2 was acquired at September 7 and 8 , 1995, at 10:35:04 UTC, or 12:35:04 LT. SAR frame number 2547, for ERS-1 orbit 21682, and ERS-2 orbit 2009. The parallel baseline is 30 m, the perpendicular baseline 37 m. Phase unwrapping was performed using the minimal cost flow algorithm (Costantini, 1996).

5.4.2.1 Observations

The variation in the interferometric phase of interferogram fd2, figure 5.61, is relatively smooth for large parts, although small variations can be found as well. Wave effects can be observed in the Noord-oostpolder (at the right side of the IJsselmeer), and just under the Veluwe, in the lower right corner. The absolute phase is shown in figure 5.62. Note that there is loss of coherence over some forested areas. These areas have been masked for the analysis.

The histogram is shown in figure 5.63. The rms is 1.3 rad. The rotationally averaged spectrum of a significant area of the interferogram is drawn in figure 5.64. Over the whole range of wavenumbers, the slope angle differs from $-5/3$, although some similarity can be found for wavelengths within 3 and 8 km.

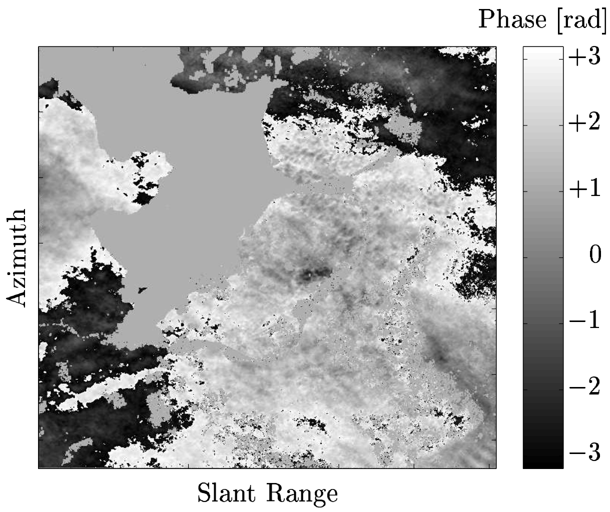

Figure 5.61 *Interferogram fd2*

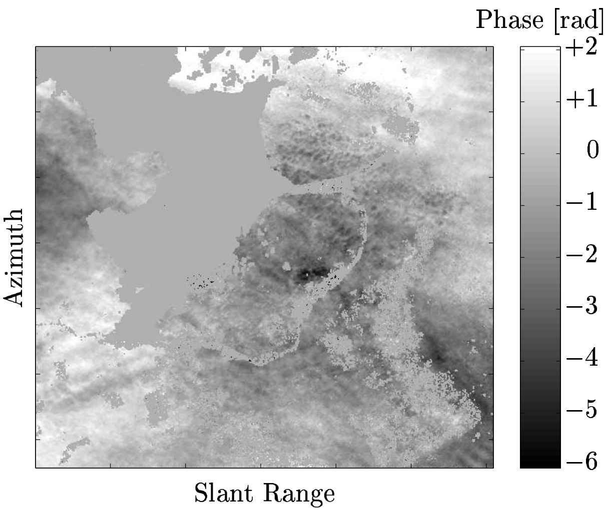

Figure 5.62 *Unwrapped interferogram fd2*

5.4.2.2 Interpretation

The light variations in the phase can be due to humidity changes associated with a frontal passage, or precipitation. A frontal zone has just passed the area, which makes it very humid. There are showers on day 1, after a front passage, and rain on day 2, associated with a secondary cold front just over the area. There is much cloud cover, on day 1 it is layered, on day 2 the cloud formation is solid up to 4 km. Above that level it is more layered.

The weather radar shows precipitation at both days. The radar image of day 1, figure 5.66, closely correlates with the anomalies in the interferogram. The rain cells have tops at around 4 km, which is not extremely high. The weather charts indicate an occlusion over the north-eastern part of the Netherlands. This results in an “upper level warm front”. This means that the cold front overtakes the warm front, and forces the warm air to move upwards, see figure 5.65.

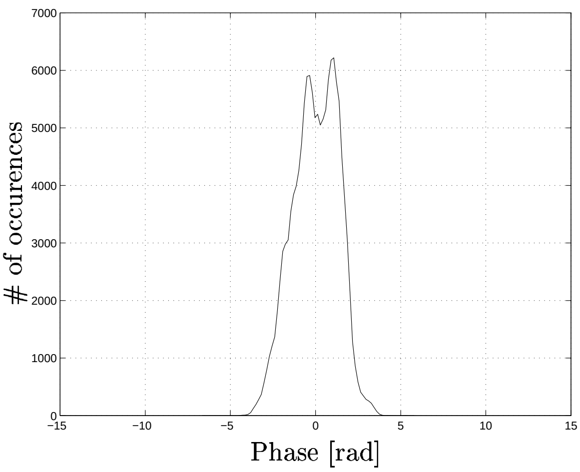

Figure 5.63 *Histogram of a significant part of interferogram fd2*

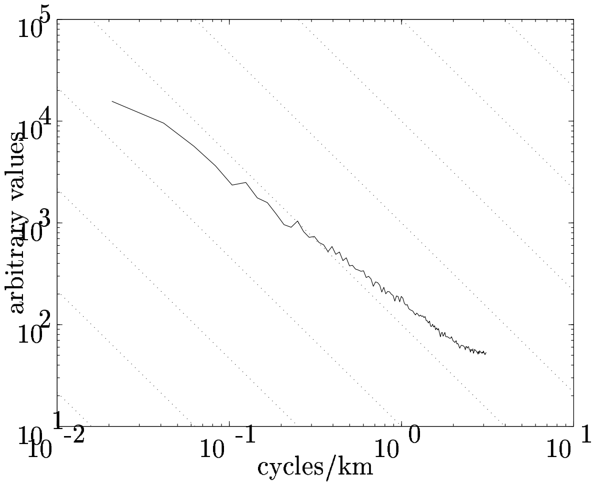

Figure 5.64 *Rotationally averaged spectrum of interferogram fd2*

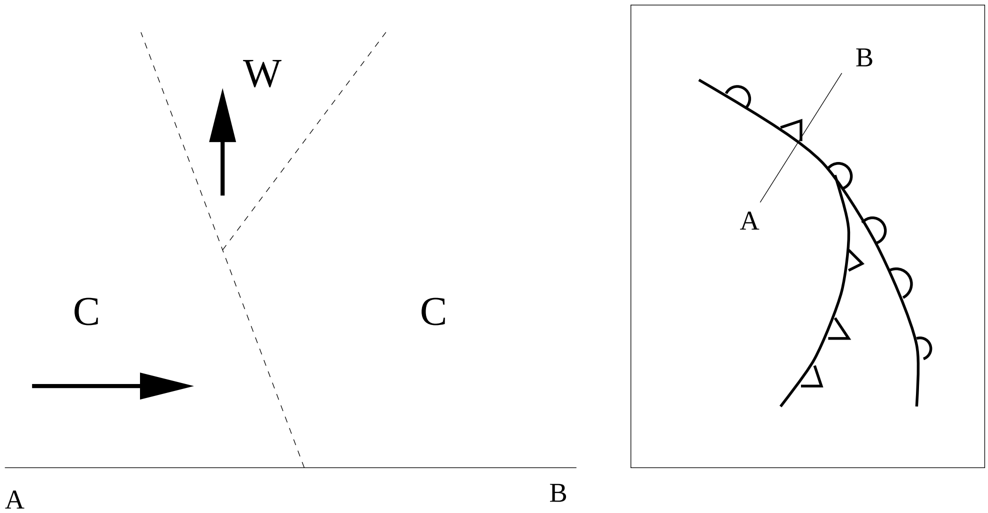

Figure 5.65 *An occlusion front. The right figure shows a top view of the configuration. The left figure shows the cross section labeled AB. Warm air is forced upward, creating an upper level warm front.*

At the second day, the low pressure area is centered right over the Netherlands. Weather radar time-loops clearly confirm the counterclockwise rotation. The anomalies in the north-eastern area of the interferogram correlate with the rain fields from the weather radar of day 2, see figure 5.67.

The synoptic data from Schiphol indicate that at day 1 there are rain showers over the area: it rains around 2 mm. At day 2 almost all stations report drizzle and/or rain.

The cloud reports are listed in table 5.11. Observations at day 1 include mainly stratocumulus and altocumulus. At day 2, it is mainly stratus and stratocumulus.

At day 1 the wind direction was southeast over nearly the whole image, at day 2 it turned from southeast at the right side of the image, to east at the left side. Due to this wind direction, the waves over the Noord-oostpolder are probably gravity waves at day 1.

The weather radar indicates tops of rain cells at 8 km for the second day. Synoptic data

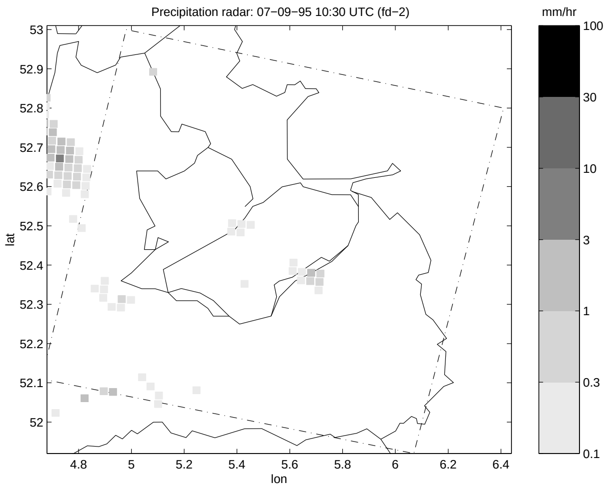

Figure 5.66 *Weather radar interferogram fd2, day 1, 10:30 UTC*

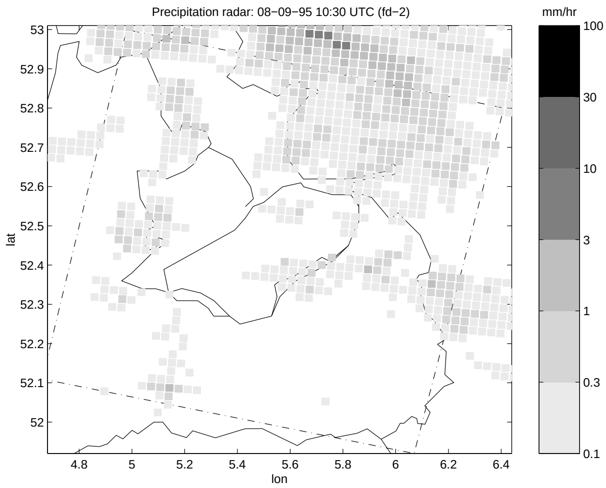

Figure 5.67 *Weather radar interferogram fd2, day 2, 10:30 UTC*

report showery precipitation. The radiosonde data confirm this cloud and rain analysis. At day 2, the whole boundary layer has a relative humidity of nearly 100%.

Station	#	UTC	Day	Level 1	Level 2	Level 3
De Kooij	235	1000	1	1/8, Cu, 1300	4/8, Sc, 1600	7/8, Ac, 3000
Schiphol	240	1000	1	1/8, Sc, 800	6/8, Ac, 3000	8/8, Cs, 6600
De Bilt	260	1000	1	1/8, Sc, 3000	4/8, Ac, 3000	7/8, As, 3300
Soesterberg	265	1000	1	2/8, Sc, 3000	8/8, Cs, 8300	
Deelen	275	1000	1	4/8, Sc, 1600	3/8, Ac, 3300	6/8, Ci, 8300
De Kooij	235	1100	1	1/8, Cu, 1300	3/8, Sc, 1600	5/8, Ac, 3000
Schiphol	240	1100	1	2/8, Ac, 3000	6/8, Ac, 3000	8/8, Cs, 6600
De Bilt	260	1100	1	3/8, Cu, 1000	7/8, As, 3300	8/8, Cs, 6600
Soesterberg	265	1100	1	2/8, Sc, 1100	3/8, Ac, 3300	7/8, Cs, 8300
Deelen	275	1100	1	1/8, Cu, 900	3/8, Sc, 3000	6/8, Ci, 8300
De Kooij	235	1000	2	2/8, Sc, 1000	5/8, Sc, 1500	6/8, Ac, 3300
Schiphol	240	1000	2	1/8, St, 250	5/8, Sc, 400	6/8, Sc, 500
De Bilt	260	1000	2	3/8, St, 200	5/8, St, 250	8/8, St, 300
Soesterberg	265	1000	2	3/8, St, 200	8/8, St, 300	
Deelen	275	1000	2	1/8, St, 200	3/8, Sc, 400	8/8, Sc, 650
De Kooij	235	1100	2	1/8, St, 250	3/8, Sc, 500	6/8, Sc, 700
Schiphol	240	1100	2	2/8, St, 150	5/8, St, 250	6/8, Sc, 400
De Bilt	260	1100	2	4/8, St, 200	6/8, St, 250	8/8, St, 300
Soesterberg	265	1100	2	4/8, St, 200	8/8, St, 300	
Deelen	275	1100	2	2/8, St, 200	4/8, Sc, 400	8/8, Sc, 600

Table 5.11 *Cloud observations fd2: 07-09/08-09-1995. The observations give the amount of cloud cover (okta), the type of cloud, and the cloud base at 3 levels. Height is given in meters.*

5.4.2.3 Conclusions

The phase variations are caused by precipitation at both days, which causes humidity variations. Other effects, such as the waves, are probably gravity waves at the first day. There is strong correlation between precipitation in the weather radar images and phase disturbance in the interferogram.

5.4.3 Analysis of interferogram fd3

Interferogram fd3 was acquired at October 12 and 13, 1995, at 10:34:58 UTC, or 11:34:58 LT. SAR frame number 2547, for ERS-1 orbit 22183, and ERS-2 orbit 2510. The parallel baseline is −127 m, the perpendicular baseline is −324 m. The phase unwrapping is performed using the minimal cost flow algorithm (Costantini, 1996).

5.4.3.1 Observations

Interferogram fd3, shown in figure 5.68, has an absolute perpendicular baseline of approximately 324 m. Therefore, the sensitivity of the interferometric configuration for height is high. The Veluwe is clearly visible in the interferogram, and causes up to 4 fringes. A reference DEM was transformed into the slant range geometry of the interferogram, and subtracted from the unwrapped interferogram. This differential unwrapped interferogram is shown in figure 5.69. A diagonal feature is visible in this differential interferogram, from the lower left corner to the upper right. Near Amsterdam, the phase gradient perpendicular to this feature is largest, while the gradient diminishes over the Noord-oostpolder.

The histogram is shown in figure 5.70, rms 1.3 rad, and the rotationally averaged spectrum in figure 5.71. The −5/3 gradient is only found in the 20–50 km wavelength range.

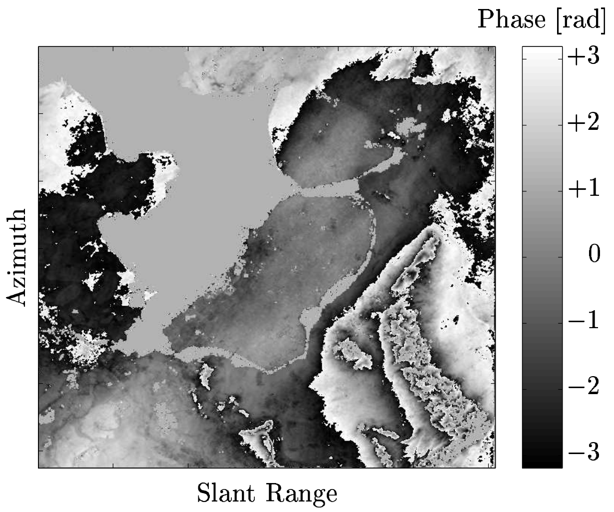

Figure 5.68 *Interferogram fd3, showing topographical as well as atmospheric fringes*

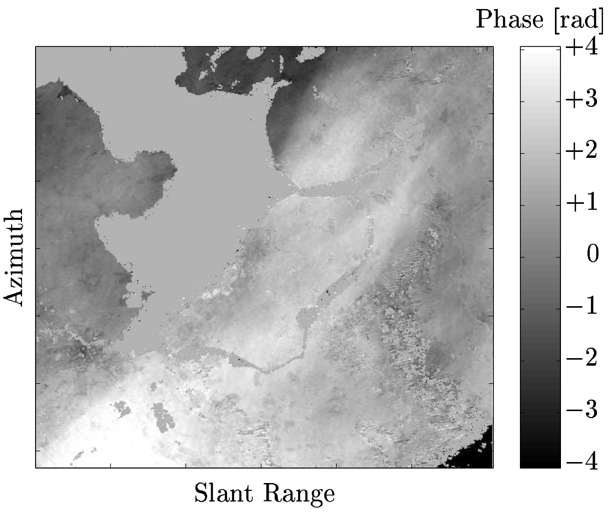

Figure 5.69 *Unwrapped differential interferogram fd3. Only atmospheric phase delay remains visible.*

5.4.3.2 Interpretation

At day 1, around 10:00 (12:00 local time) there was fog at Houtrib (in the middle of Flevoland). The strong intrusion over Flevoland could have some relation with the foggy area. Marknesse reports a reduced visibility of 1100 m: haze. Deelen reports a relative humidity of 92%, and reduced visibility to 1800 m. Also Lelystad reports reduced visibility: 1700 m. Therefore, the whole area can be considered as foggy, with visibilities between 900–2300 m. At 11:00 (13:00 local time) there is still fog, but now in more localized areas. The weather radar at day 1 indicates no rain, but has some signal due to an inversion layer. The radiosonde profile gives an inversion at approximately 400 m. The lower 40 m must be 100% humid. Meteosat lacks in resolution for this area. AVHRR shows the field of fog, which is not totally homogeneous.

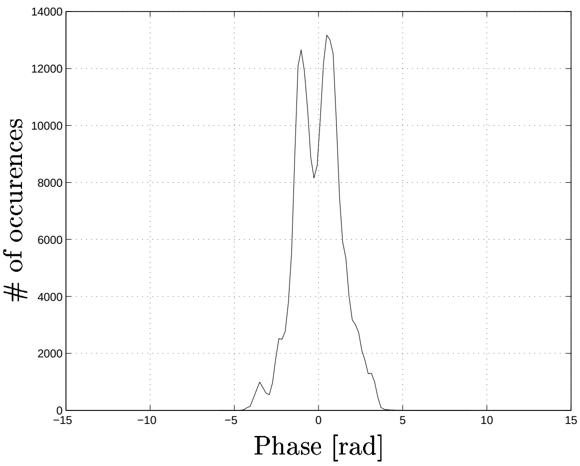

Figure 5.70 *Histogram of major part of interferogram fd3*

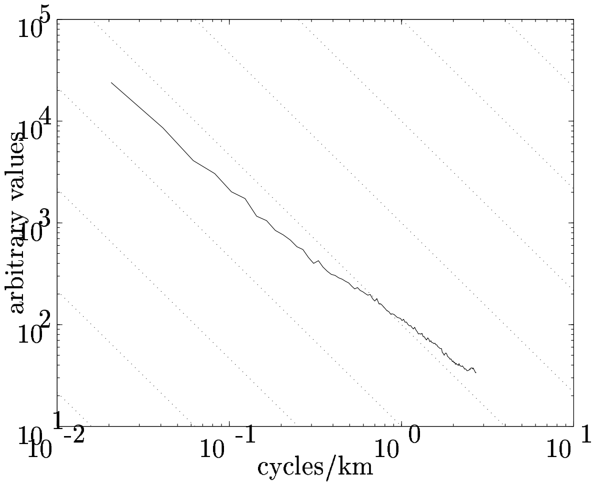

Figure 5.71 *Rotationally averaged spectrum of interferogram fd3*

At day 2 the fog covers a wider area: all stations report 100% relative humidity, with reduced visibility between 100–1400 m, both at 10:00 and 11:00 UTC. The humidity below the inversion is now completely mixed according to the radiosonde. The weather radar detects no rain signal.

Cloud cover and type observations are listed in table 5.12. The cloud cover at day 1 is mainly stratus. At day 2, De Bilt report 9/8 total cloud cover (not listed in the table), which means that the vertical visibility is less than 30 m. Other stations report stratus at low levels (70–100 m).

5.4.3.3 Conclusions

Water vapor distribution caused by fog gives rise to phase shifts. The diagonal feature over Flevoland is probably due to fog heterogeneities at day 1.

Station	#	UTC	Day	Level 1	Level 2	Level 3
De Kooij	235	1000	1	1/8, St, 150 m	6/8, St, 200 m	7/8, St, 300 m
Schiphol	240	1000	1	4/8, St, 150 m	8/8, St, 200 m	
De Bilt	260	1000	1	5/8, St, 150 m	8/8, St, 200 m	
Soesterberg	265	1000	1	2/8, St, 200 m	6/8, St, 200 m	8/8, St, 300 m
Deelen	275	1000	1	3/8, St, 200 m	8/8, St, 300 m	
De Kooij	235	1100	1	2/8, St, 150 m	6/8, St, 200 m	8/8, St, 250 m
Schiphol	240	1100	1	3/8, St, 200 m	6/8, St, 200 m	8/8, St, 300 m
De Bilt	260	1100	1	4/8, St, 200 m	7/8, St, 250 m	
Soesterberg	265	1100	1	6/8, St, 300 m	7/8, Ci, 8300 m	
Deelen	275	1100	1	2/8, St, 200 m	8/8, Sc, 350 m	
De Kooij	235	1000	2	1/8, St, 50 m	5/8, St, 100 m	8/8, St, 150 m
Schiphol	240	1000	2	6/8, St, 0 m	8/8, St, 0 m	
De Bilt	260	1000	2			
Soesterberg	265	1000	2	6/8, St, 0 m	8/8, St, 100 m	
Deelen	275	1000	2	8/8, St, 0 m		
De Kooij	235	1100	2	1/8, St, 50 m	5/8, St, 100 m	8/8, St, 150 m
Schiphol	240	1100	2	7/8, St, 0 m	8/8, St, 50 m	
De Bilt	260	1100	2	8/8, St, 150 m		
Soesterberg	265	1100	2	4/8, St, 0 m	8/8, St, 100 m	
Deelen	275	1100	2	4/8, St, 100 m	8/8, St, 100 m	

Table 5.12 *Cloud observations fd3: 12-10/13-10-1995. The observations give the amount of cloud cover (okta), the type of cloud, and the cloud base at 3 levels.*

5.4.4 Analysis of interferogram fd4

Interferogram fd4 was acquired at November 16 and 17, 1995, at 10:35:01 UTC, or 11:35:01 LT. SAR frame number 2547, for ERS-1 orbit 21181, and ERS-2 orbit 3011. The parallel baseline is 259 m, the perpendicular baseline 531 m. Phase unwrapping is performed using the minimal cost flow algorithm (Costantini, 1996).

5.4.4.1 Observations

Figure 5.72 is showing interferogram fd4. The absolute perpendicular baseline is 531 m, which explains the amount of fringes over the Veluwe and other small elevated areas in the terrain. The absolute phase of this interferogram, figure 5.73, is dominated by the effects of topography. Using the reference DEM of the area, a differential interferogram was created, see figure 5.74. Especially the upper left corner of this differential interferogram exhibits phase artifacts, starting from the lower-left/upper-right diagonal. The amount of phase bias in these areas reaches a maximum of more than a phase cycle. Figure 5.75 shows the unwrapped differential interferogram.

The histogram is shown in figure 5.78, (rms 1.8 rad), and the rotationally averaged spectrum in figure 5.79. The −5/3 range of wavelengths is 7–20 km.

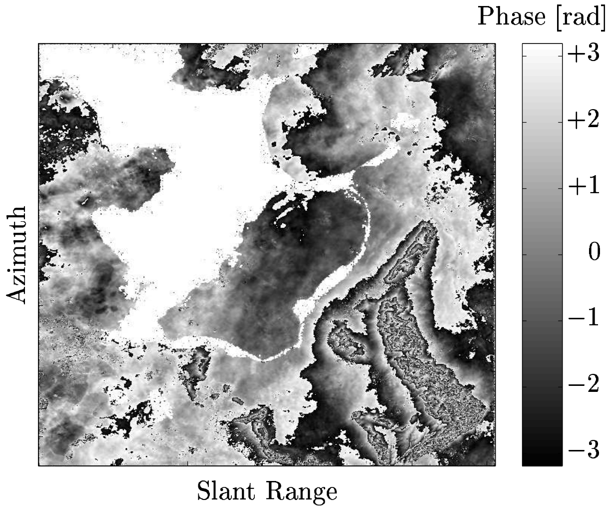

Figure 5.72 *Interferogram fd4*

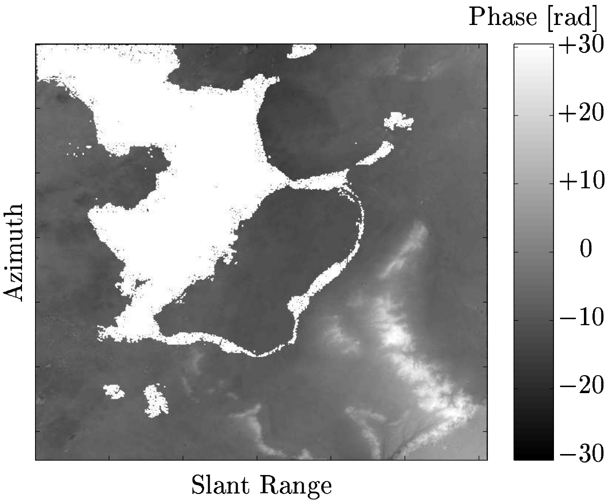

Figure 5.73 *Unwrapped interferogram fd4*

5.4.4.2 Interpretation

There is a cold front passage at day 1. Especially at day 2, there is showery precipitation. This may give rise to the small flake-like features in the interferogram.

The weather charts show that a cold front is passing over the Netherlands from the northwest. The weather radar indicates showers at day 1 over the northern part of the SAR image, consisting of embedded cumulonimbus clouds. Tops of the rain cells are located at about 6 km over Friesland, and 4 km over Noord-Holland. The rain rates over Friesland and Noord-Holland reach 10–30 mm/hr at some spots, which is heavy rain fall. This rain image corresponds very well with the disturbances in the interferogram, including the cloud heights and the amount of phase shift.

Meteosat High Resolution VIS shows the cells of heavy rain of the weather radar very clearly as “embedded Cb’s” (cumulonimbus) over the Netherlands.

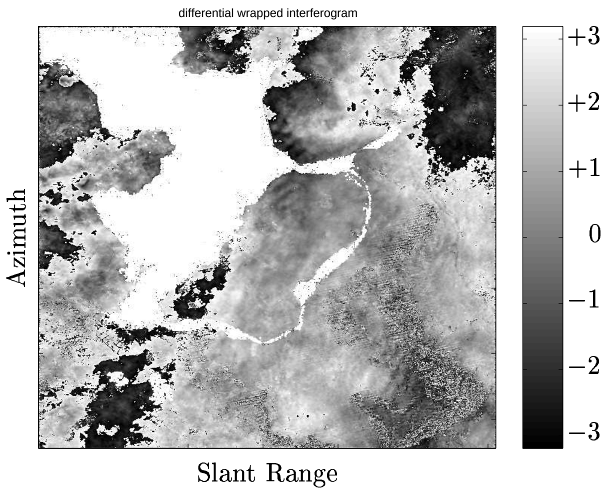

Figure 5.74 *Wrapped differential interferogram fd4*

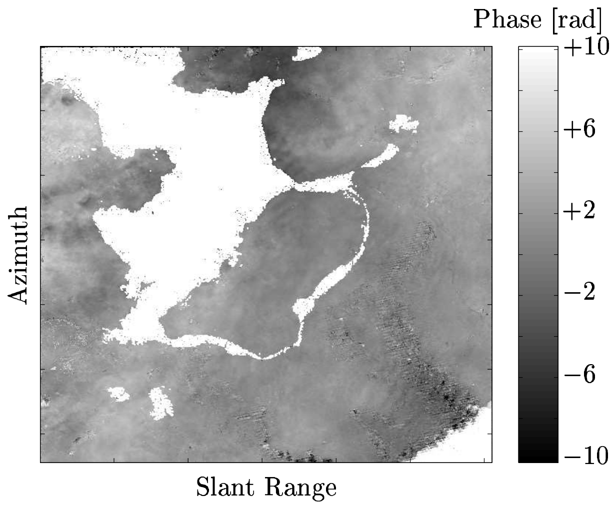

Figure 5.75 *Unwrapped differential interferogram fd4*

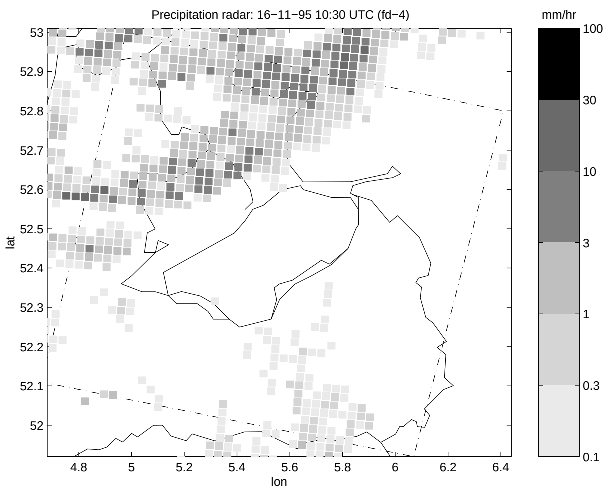

Figure 5.76 *Weather radar fd4, day 1*

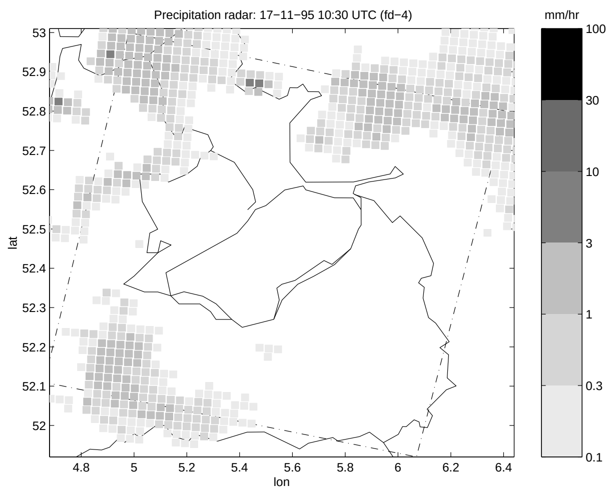

Figure 5.77 *Weather radar fd4, day 2*

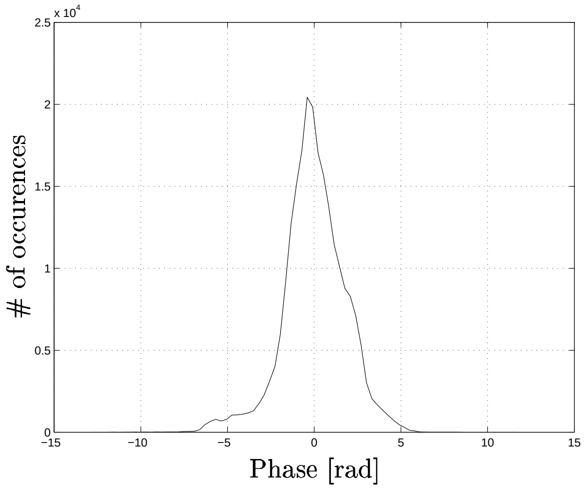

Figure 5.78 *Histogram of major part of interferogram fd4*

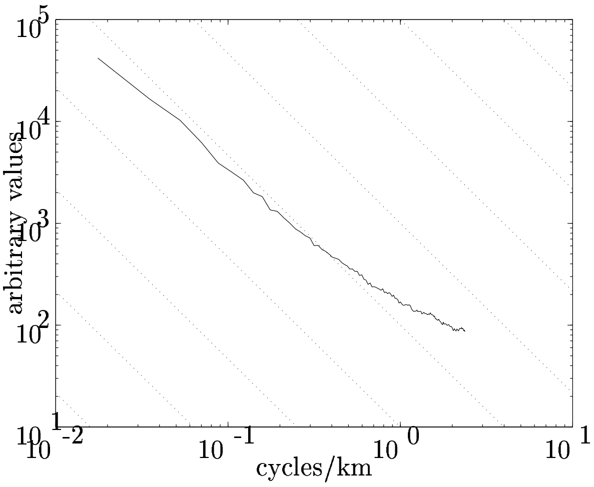

Figure 5.79 *Rotationally averaged spectrum of interferogram fd4*