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Distribution Patterns of Temperatur and Water Colour in the Baltic Sea as recorded in Satellite Images: Indicators for Phytoplankton Growth

by

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SUMMARY

This compilation of satellite images of the Baltic is composed of recordings in the infra-red spectrum obtained by the satellites NOAA 6 and 7 and TIROS N, and in the visible spectral range recorded by the Coastal Zone Colour Scanner of NIMBUS G. A brief description of corresponding meteorological situations and data on water temperatures from a few sporadic stations are included.

With the aid of satellite data concerning temperature anomalies in the surface and changes of the ocean colour in the near-surface layer, processes typical for the Baltic can be recognized, as there are: The strong appearance of suspended matter along the coastal areas of the southeastern Baltic, the repeatedly observed warmer surface water in the bays of Pomerania and Danzig, or the characteristic row of vortices, which sometimes can be traced all the way from the Gulf of Finland along the Island of Öland up to Bornholm Island.

Sequences of satellite images extending over two or several days suggest transport processes in the surface water which are of considerable importance for the primary productivity of the phytoplankton in the Baltic, as there is: Upwelling along the Baltic coast or the significant appearance of cold water northwest of the Island of Rügen during outflow situations.

Remarkable patterns of eddies and vortexlike structures observed on satellite images of the Baltic are described and their genesis, size and migration velocity are discussed.

ZUSAMMENFASSUNG

Es wurden Satellitenbilder der Ostsee zusammengestellt, die Aufnahmen im Infrarotspektrum der Satelliten NOAA 6, 7 und TIROS N sowie Bilder im sichtbaren Wellenbereich des "Coastal Zone Colour Scanners" von NIMBUS G zeigen. Eine kurze Beschreibung der meteorologischen Situation und Wassertemperaturangaben von vereinzelten Stationen sind den aufgezeichneten Bildern beigefügt.

An Hand von Temperaturdifferenzen der Wasseroberfläche und Unterschieden der Wasserfarbe in der oberflächennahen Schicht, die auf den Satellitenaufnahmen erkennbar sind, lassen sich in der Ostsee typische Phänomene erkennen, wie das verstärkte Auftreten suspendierten Materials im Küstenbereich der südöstlichen Ostsee, das häufig zu beobachtende wärmere Oberflächenwasser in der Pommerschen und Danziger Bucht oder charakteristische Verwirbelungen, deren Verlauf vom Finnischen Meerbusen entlang der Insel Öland bis nach Bornholm zu verfolgen ist.

Serien von Satellitenaufnahmen mehrerer aufeinander folgender Tage lassen weiträumig Transportvorgänge im Oberflächenwasser erkennen, die für die Primärproduktion des Phytoplankton in der Ostsee von besonderer Bedeutung sind, wie die Entstehung von Auftriebsgebieten entlang den Küsten der Ostsee oder das bei Ausstrom häufig sichtbare Auftriebsphänomen nordwestlich der Insel Rügen.

Für die Ostsee charakteristisch und auf Satellitenaufnahmen gut erkennbar sind Wirbel und wirbelähnliche Strukturen. Ihre Entstehung, Größe und Wanderung wird beschrieben und diskutiert.

INTRODUCTION

From the Baltic Sea fascinating satellite images have been recorded during the last few years. Most of the data, however, lie dormant on high density tapes in the magazines of recording stations. At the present state of remote sensing technology it is essential for the community engaged in the oceanography of the Baltic to utilize these data.

In the visible range of the electromagnetic spectrum of reflected sunlight satellite images exhibit informative patterns of suspended matter including plankton. In the infra-red range of emitted heat radiation surface structures are traceable through temperature anomalies. Especially when comparing recordings of temperature with those of water colour of a multispectral scanner, surface patterns can supply information on various phenomena in the water column. Furthermore, through the analysis of satellite images, whereby suspended matter and temperature anomalies are used as tracers, the horizontal distribution of surface watermasses and their contents can be presented on a major scale. If picture sequences are available, long-distance transport characteristics may be considered, which is hardly conceivable with data gathered from a research ship.

The intent of this first volume presenting a compilation of satellite images is to provide some insight into distribution patterns and their temporal variations in the central and western Baltic, and, thereby, to also point out the possibilities of the appplication of satellite data analysis, for biological processes in the Baltic.

For every presented scene a short description of the most apparent patterns at the water surface and in the surface water is given to guide the readers' attention to the points of interest in the image and in some cases to compensate for loss of contrast that may have occurred during the process of reproduction. With the task of describing the images one is tempted to suggest processes in the sea that seem to be obvious but which would need additional evidence. Such speculation, albeit seemingly well founded, was avoided whenever possible. In this volume as many scenes of considerable quality as were available from the Baltic during the last three years are presented. In a second volume (in preparation) the correlation of specific phenomena identified on the satelite images of the Baltic with available sea truth data is attempted.

MATERIAL AND METHODS

This compilation of satellite images presents details of the southwestern and central Baltic. The data were gathered with the satellites NOAA 6, NOAA 7, TIROS N and NIMBUS G by the Department of Electrical Engineering at the University of Dundee in Scotland and generously made available to me by P. Baylis. Additional scenes are also included from LANDSAT 2. The photographic products presented here are reproduced without special processing of the received data, although a maplike representation of the NOAA 6, 7 and TIROS N scenes are created through a one-dimensional linearization of the images (correction of earth curvature in scanning direction). This process has not yet been applied to the data of the Coastal Zone Colour Scanner (CZCS) of NIMBUS G. In addition, the attainment of the clearest possible reproduction of structures on the water surface was attempted through contrast enhancement. A further rectification in the processing of the images in regard to the application of algorithms towards reducing the effects of atmospheric disturbance (Grassl and Koepke 1981) would in some cases have been desirable. Unfortunately, due to time and cost factors this processing could not be undertaken at the time. It was also not attempted to evaluate absolute temperatures from the infra-red scenes as is possible through data processing (McClain 1981).

The majority of the images originate from the years 1980 and 1982, during which a comparatively large number of cloud-free scenes of the Baltic could be recorded. Only a few scenes were available from 1981. For the elucidation of the different spectral bands of the Coastal Zone Colour Scanner of NIMBUS G a scene from the year 1979 is consulted. Various processes individual scenes and also image sequences from the years 1979 and 1981 are consulted. The present selection of scenes was chosen for its picture quality and cloud-free conditions from quicklooks recorded in Scotland. The images were compiled in a chronological order, and the date and time (GMT) of recording are marked on the pictures. If possible the CZCS data were correlated with the more numerous scenes of the IR-Band of NOAA 6, 7 and TIROS N. The NOAA and TIROS scenes were reproduced exclusively using the infra-red channel number 4 for day as well as for night orbits. From the Coastal Zone Color Scanner of the NIMBUS G the channel 3 was in most cases

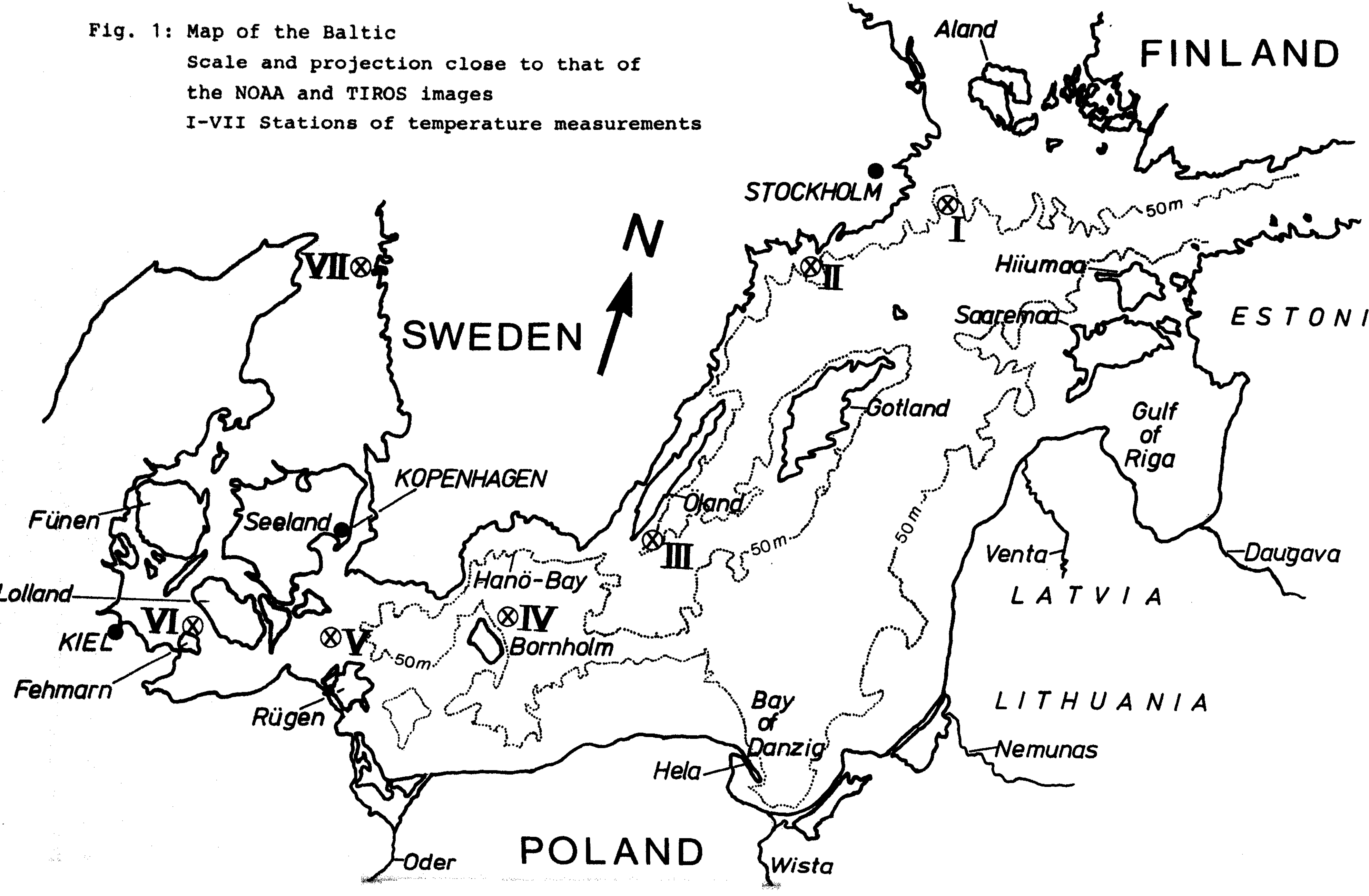
reproduced (see Tab. 1). As a comparison the channels 1 to 6 are also presented in one example (page 6 and 7).
A short compilation of the general weather situation of the Baltic area previous to the day of the recorded scenes is given. Details of the Baltic Sea area of the European weather report, as compiled by the German Weather Service, corresponding to each day of recording and the day previous are provided. For the weather chart the topography of the 950 mbar level was applied, since the charts at surface level appear to be unsuitable due to the restricted influence of wind. Furthermore, the recording of water temperatures was attempted for each presented image at the following stations (Fig. 1).

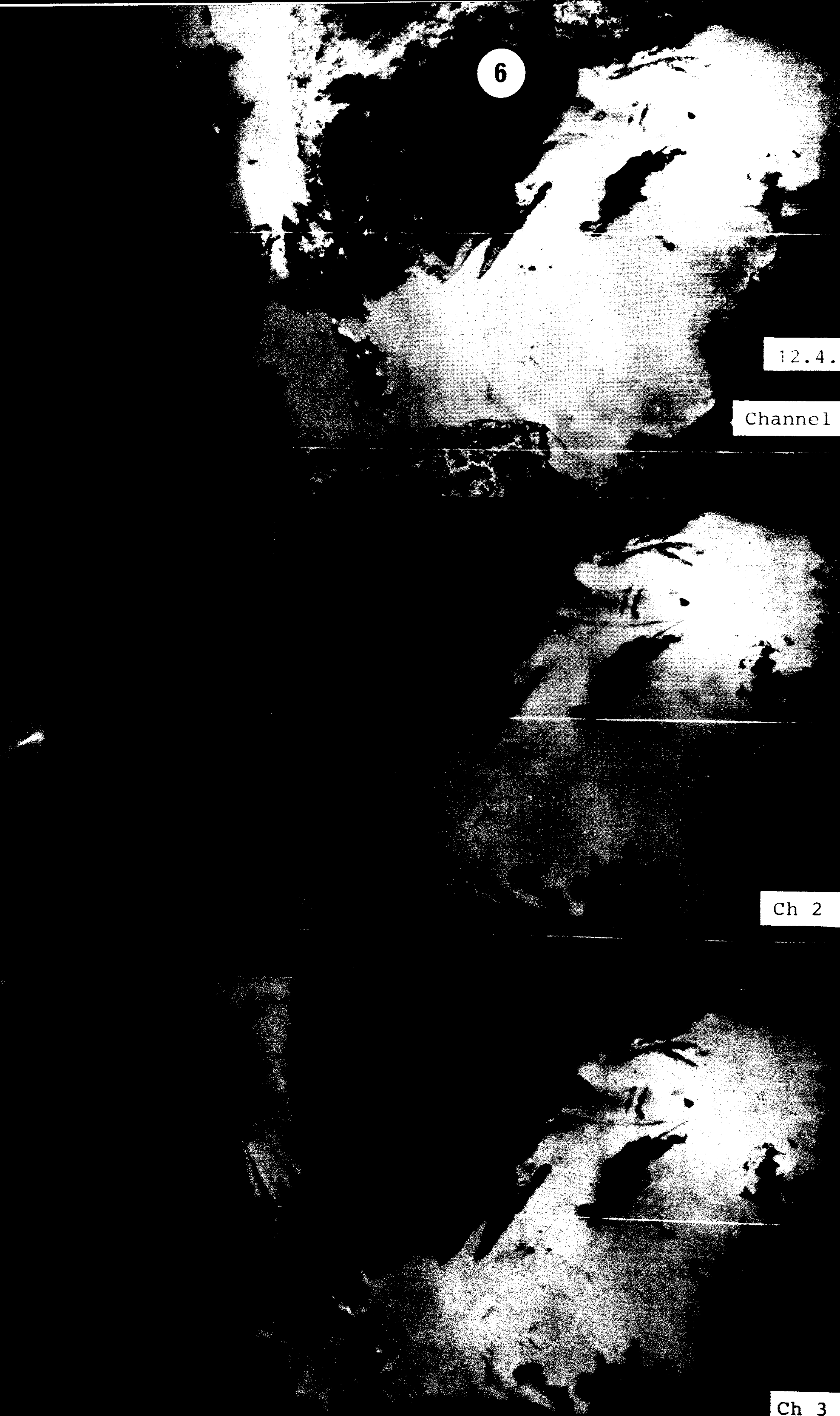
I. Almagrundet: SE of Stockholm
II. Gustaf Dalen: SE of Nyköping
III. Oelands Soedre Grund: S of Öland
IV. Christiansö: NE of Bornholm
V. Mön SE Light Vessel: between the islands of Rügen and Mön
VI. Fehmarn Belt Light Vessel: N of Fehmarn
VII. Trobaduren: in the NE Kattegat

From Mön light vessel data of estimated surface current speed (Cs) and direction (Cd) are given. The data from Mön and Christiansö were kindly provided by G. Stongard Nielsen of the Meteorologisk Institute in Copenhagen, all the other temperature data by

Dr. K. Huber of the German Hydrographic Institute in Hamburg.
During the interpretation of the satellite images it is often uncertain to what extent the patterns are of an atmospheric nature or relate to surface features. Scenes of the day before and the following day are of considerable analytical aid. However, images from the previous or following night are especially helpful, since atmospheric disturbances near the ground or water surface are, as a rule, different during the day from those at night. Furthermore, particularly in regard to uncertainties arising from infrared scenes from NOAA 6 and 7 and TIROS N, scenes from the visible spectral range were consulted and proved to be a helpful analytical facility. They are, however, not presented in this work, but are considered in the description of patterns and contours attributed to the images. Besides the literature cited, a short bibliography is added for further readings on the satellites used and on remote sensing in oceanography and its applications.

Fig. 1: Map of the Baltic
Scale and projection close to that of
the NOAA and TIROS images
I-VII Stations of temperature measurements



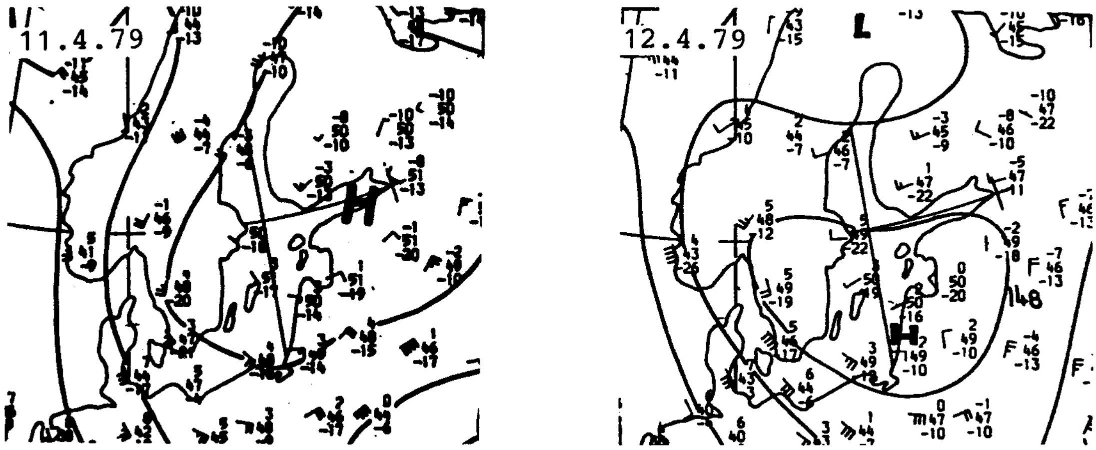

6
12.4.
Channel
Ch 2
Ch 3


7
79 10.
1 (443
Ch 4
(520 n
Ch 5 (
(550
Ch 6 (1

RESULTS:

12 April 1979

From 7 to 9 April 1979 the southern Baltic lay under a zone of high pressure. After 10 April an eastern European high influenced the weather over northern Europe.



12.4.79, 10.10 h, CZCS. Ch. 1, 2, 3 and Ch. 4, 5, 6 (IR) *

Pages 6 and 7 present scenes from the Baltic excluding the Bothnian Bay. Depicted are the 6 channels of the Coastal Zone Colour Scanner of NIMBUS G (including the infra-red channel 6, which was still functioning at this time). In contrast to all of the subsequent recordings the scenes on page 6 and 7 are reproductions of photographic negatives. Therefore the dark areas here correspond to a greater reflection of light which, in turn indicates the existence of more suspended matter in the water. Pale areas show less reflection. In the infra-red band warmer areas appear pale.

The images in the channels 2, 3 and 4 particularly reveal structures in the water of the Bay of Danzig with extensions towards the north as well as along the westcoast of Lithuania. Patterns of reflected solar radiation are also observed off the northwest coast of Latvia and in the southern part of the Gulf of Riga. The suspended matter which apparently originates from the northern outlet of the Courland Lagoon and further north from the mouth of the River Venta (compare channels 1-5) has a particular character.

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* The CZCS image of 12.4.79 was made available by H. van der Piepen, DFVLR

These patterns apparently have the same reflection characteristics as those of the northeastern part of the Courland Lagoon (compare channels 1, 2, and 5). Considering that the water from the River Nemunas flows into this area it seems likely that these patterns indicate 'river material' from the USSR (see also 7.4.81, p.61).

On a purely optical basis, band 1, adjusted to measure the absorption of chlorophyll at 434 nm, displays considerably fewer structures than does band 2, which is used to determine the chlorophyll correlation. Set for the recording of chlorophyll absorption at 670 nm, band 4 also distinctly exhibits structures. Band 3 meant to measure the Gelbstoff content of the water (see table 1), reveals structures quite clearly, although the Gelbstoff apparently is not recorded in this channel. For the detection of Gelbstoff in the Baltic a spectral band of much lower wavelength would be needed (Grassl, pers. communication). Atmospheric disturbances such as vapour trails produced by aircraft north of Gotland and bands of haze in the western Baltic, which are especially strongly formed along the Polish northcoast, appear in bands 1 to 4 and are, therefore, practically impossible to eliminate even through the application of algorithms during a numerical comparison of these bands. These disturbances are, however, relatively easy to recognize from their structural character. Despite its poor quality the infra-red recording reveals that the features of temperature anomalies in the southeastern Baltic partly match those of water colour.

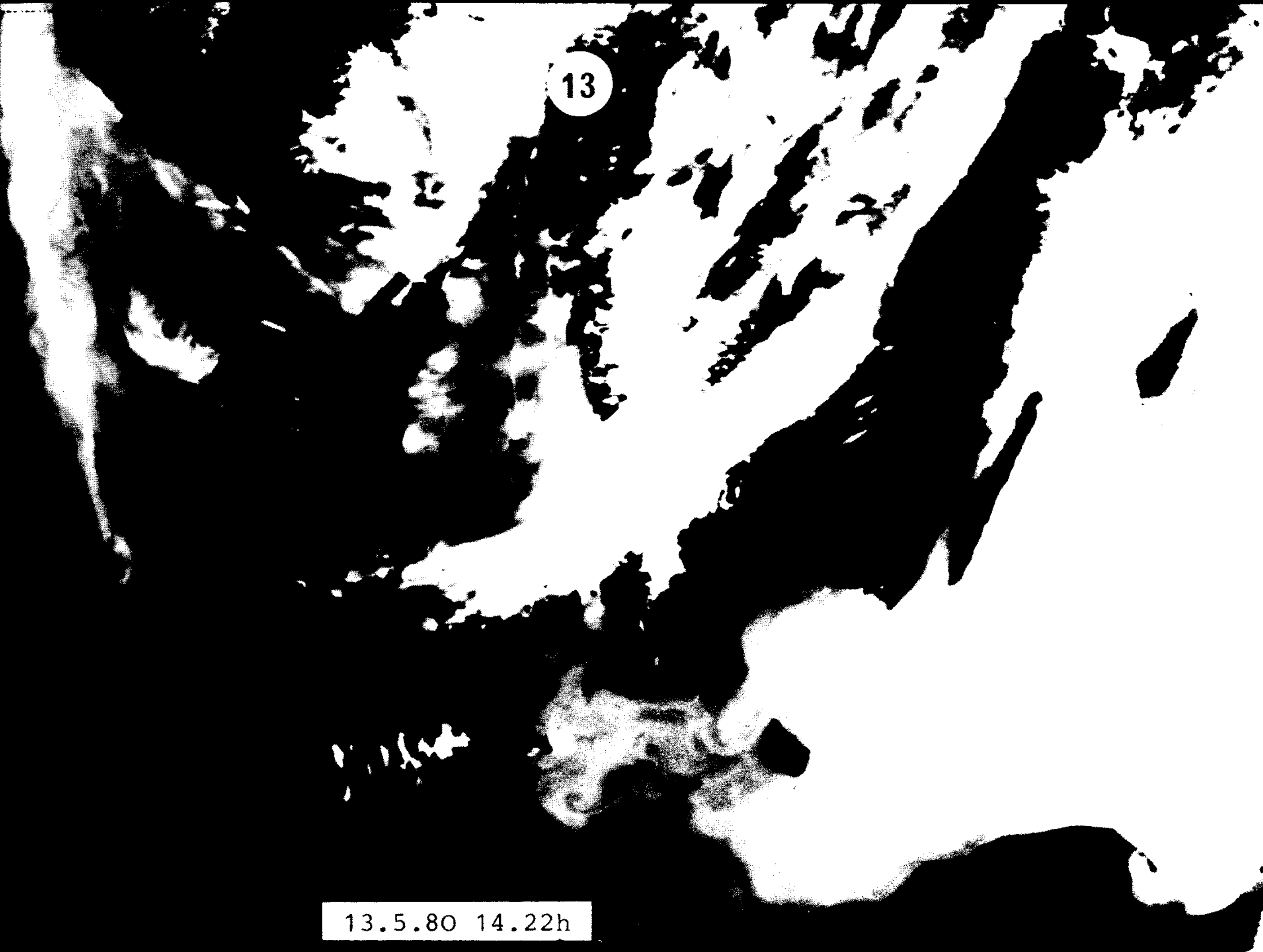
There is no doubt that to a certain extent qualitative and even quantitative determinations of suspended matter would be possible, if image processing using the appropriate algorithms would be applied (Sturm 1981).

Performance Parameters	Channels					
	1	2	3	4	5	6
Scientific Observation	Chlorophyll Absorption	Chlorophyll Correlation	Yellow Stuff	Chlorophyll Absorption	Surface Vegetation	Surface Temperature
Center Wavelength λ Micrometers	0.443 (blue)	0.520 (green)	0.550 (yellow)	0.670 (red)	0.750 (far red)	11.5 (infrared)
Spectral Bandwidth $\Delta\lambda$ Micrometers	0.433 – 0.453	0.510 – 0.530	0.540 – 0.560	0.660 – 0.680	0.700 – 0.800	10.5 – 12.5

Table 1: CZCS Performance Parameters (after Hovis 1978)

12.5.80 14.32h

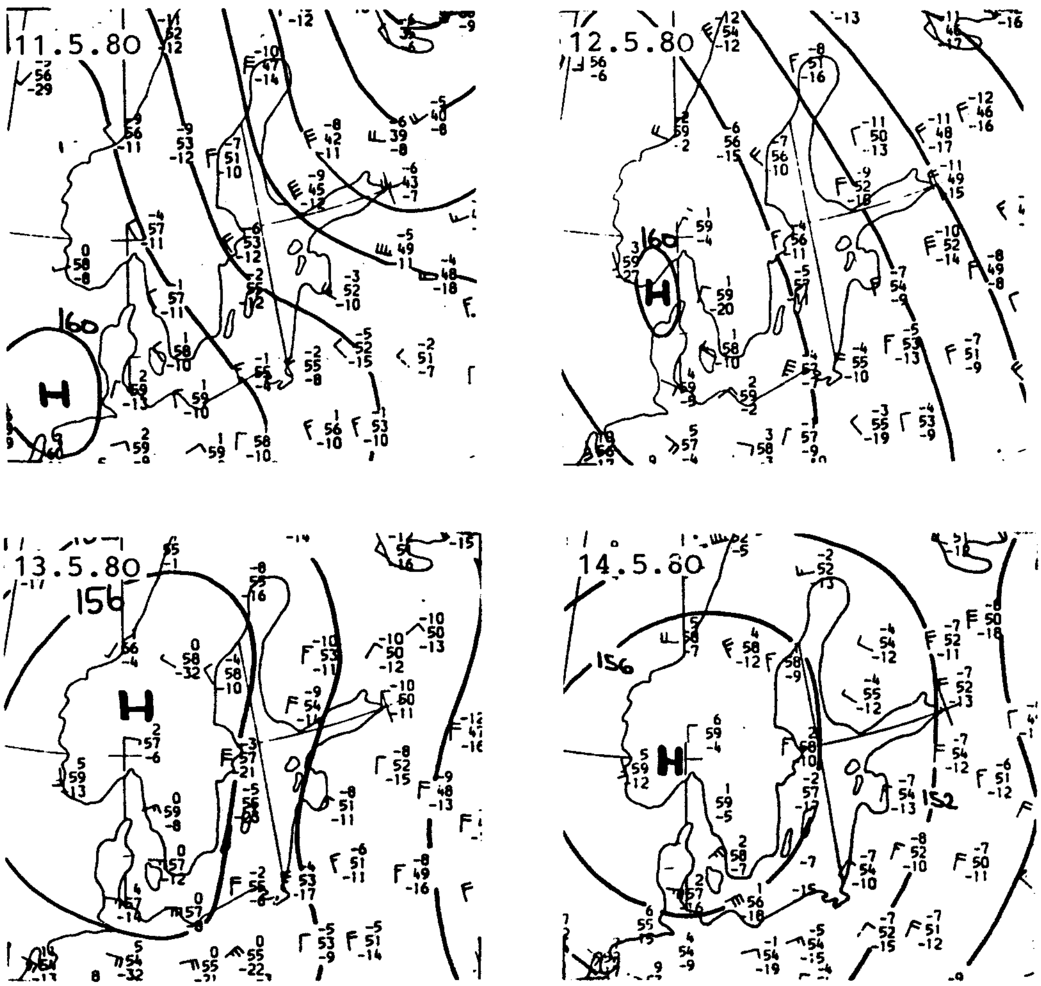
13.5.80 9.50h


13
13.5.80 14.22h


14.5.80 14.11h

12 May to 14 May 1980

From 1 to 6 May a high pressure region over the northeastern Atlantic governed the weather over the Baltic. Low pressure troughs moved out across the Baltic on 7 and 8 May, and a high lay over northern Scandinavia from 10 May onwards.



Temperature at different depths in degrees centigrade

Current direction (Cd) in degrees

Current speed (Cs) in knots

	IV (Christiansö)	V (Mön)					VI (Fehmarnbelt)		
	0m	0m	5m	15m	Cd	Cs	0m	5m	15m
12.5.80	-	-	-	-	-	-	7.8	7.5	5.8
13.5.80	5.2	6.4	6.3	5.2	360	0.2	7.9	7.2	6.0
14.5.80	4.8	5.6	5.6	6.2	50	0.2	7.5	7.5	6.2

12.5.80, 14.32 h, TIROS N IR

Despite the poor quality of the infra-red scene of TIROS N recorded along the scanning periphery on 12 May 80, one can make out warmer water, which disperses from the Bay of Danzig northwards along the Latvian and Lithuanian coast. In the area west of Rügen and in the Arkona Sea, eddies are recognizable.
In this and all the following infra-red images light tones indicate colder water surface temperatures.

13.5.80, 9.50 h, CZCS Ch 3

A scene recorded by NIMBUS G the following day, depicts patterns of suspended material in the southeastern Baltic corresponding to those of the infra-red scene. Clearly observable are the Oder Bank east of Rügen and, somewhat more weakly, the Rönne Bank with Adler Ground southwest of Bornholm, indicating, that spectral band 3 of the CZCS penetrates deeply into the water, which, in turn, is a sign of the presence of only little suspended material in this area at this time.

13.5.80, 14.22 h, TIROS N IR and 14.5.80, 14.11 h, TIROS N IR

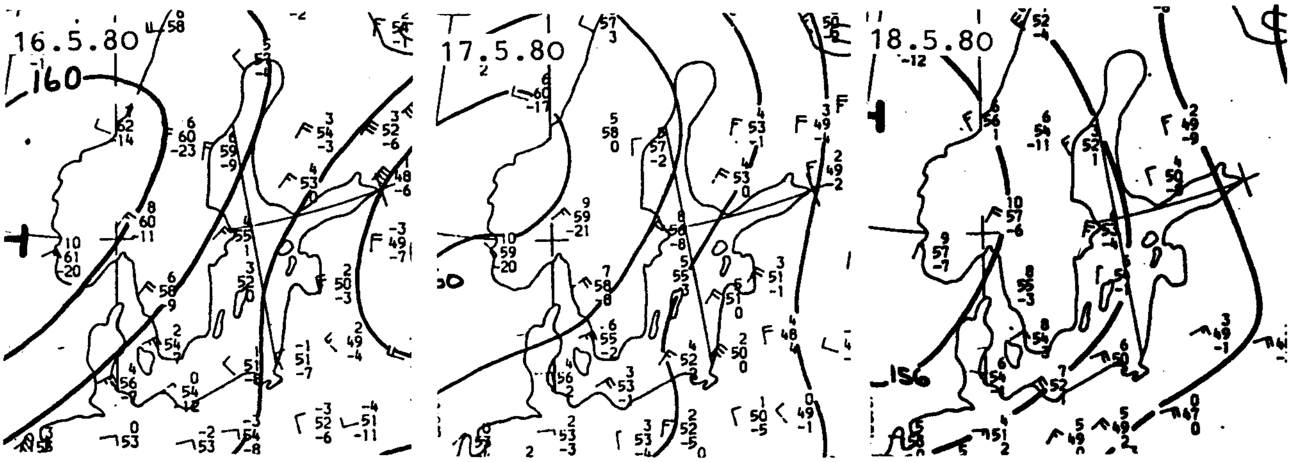
Along the Polish coast the scenes from 13 to 14 May disclose a narrow band of warmer water, which extends into the Bay of Danzig towards northeast. Warmer water is also visible southwest of Bornholm and in the major portion of the Pomeranian Bay from which a front extends north-northwestwards. Two eddies appear to be dissociating from the ends of this front. On 14 May somewhat colder water is discernable west of Rügen.


18
17.5.80 13.37h


19
5.6.80 8.32h
5.6.80 18.22h

17 and 18 May 80

From 16 May onwards, a high pressure area reaching from the Azores up to northern Europe was the chief feature determining weather for the Baltic.



<u>Temperature</u>

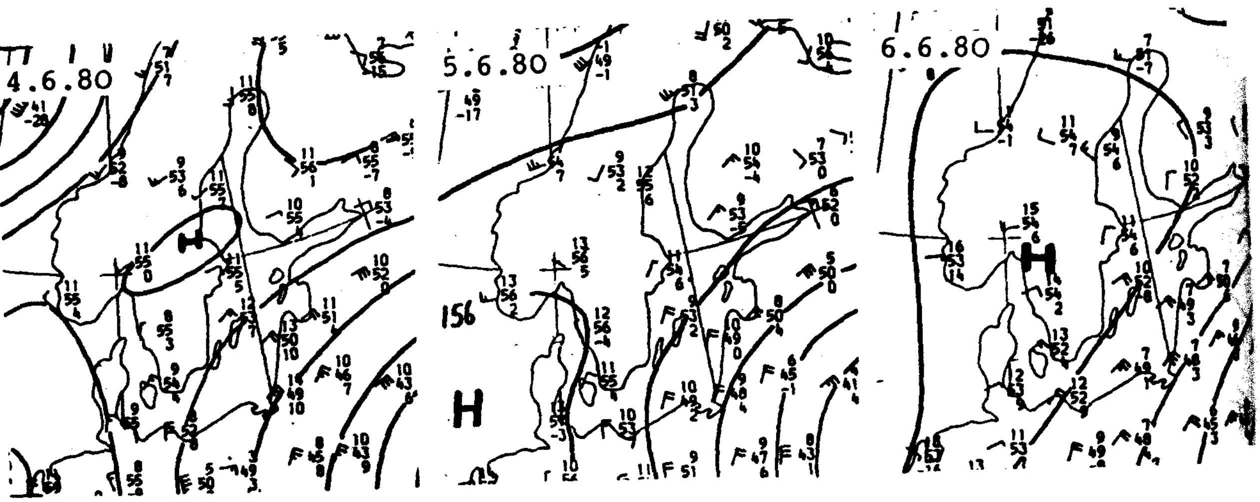
	IV	V				
	0m	0m	5m	15m	Cd	Cs
17.5.80	5.8	7.5	7.2	6.7	50	0.1
18.5.80	6.6	10.2	10.2	5.8	90	0.5

17.5.80, 13.37 h, NOAA 6 IR and 18.5.80, 13.26 h TIROS N IR

The scenes from 17 May and from 18 May disclose no large-scale temperature differences in the Baltic. Nevertheless, they provide a picture of near-surface fronts and eddies and their movement within the next 24 hours in the southern region of the Baltic. Since the land contours of the 2 scenes are congruent with one another, positional changes can be assessed employing dividers. The darker areas west of Bornholm as well as the light structures in the Kiel Bight and Mecklenburg Bay on 18 May 80 are obviously atmospheric disturbances.

5 to 8 June 80

From 2 to 5 June a high pressure area moved from the southwest towards northern Europe and from 6 to 8 June a high lay over Scandinavia.

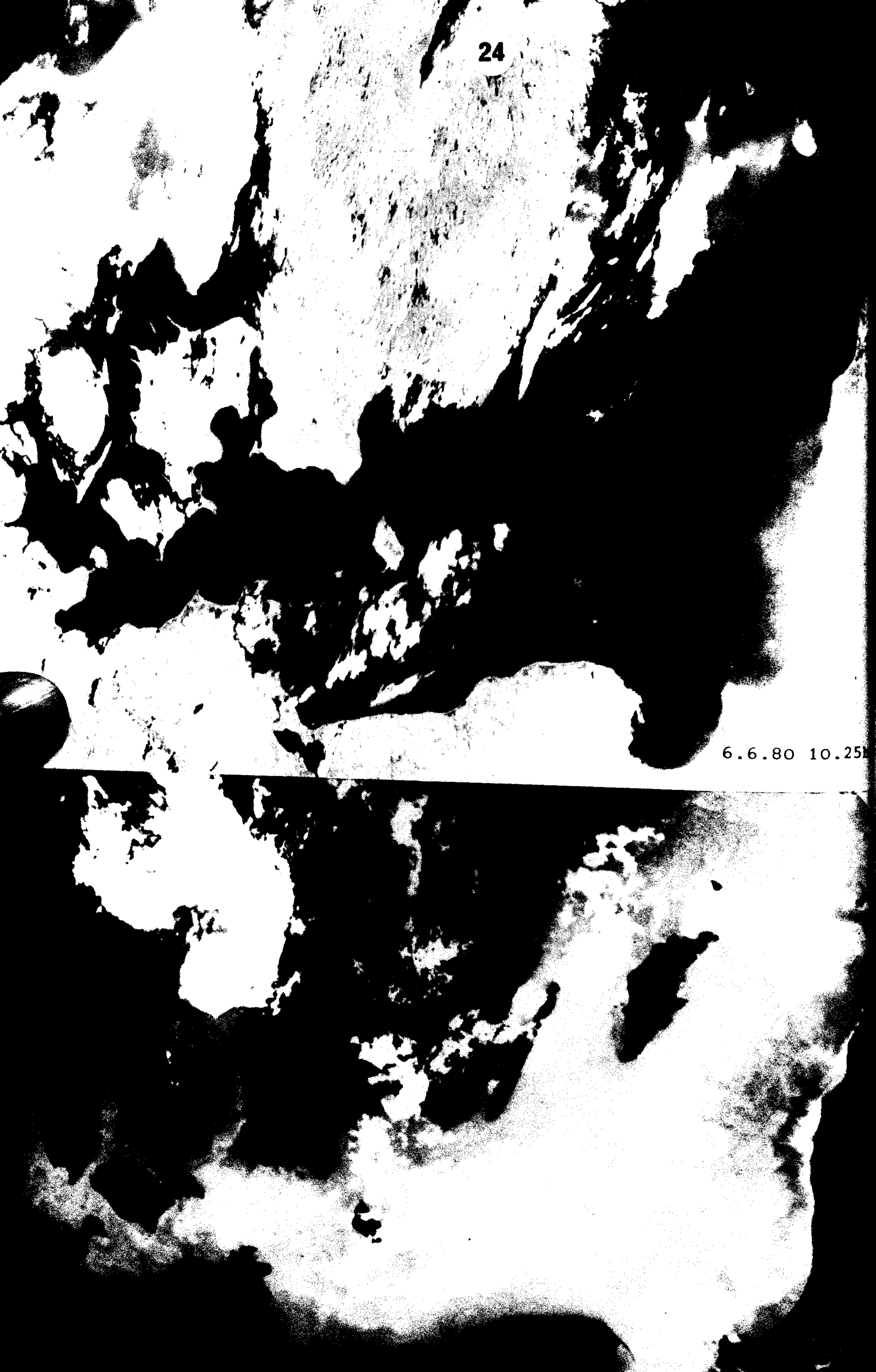


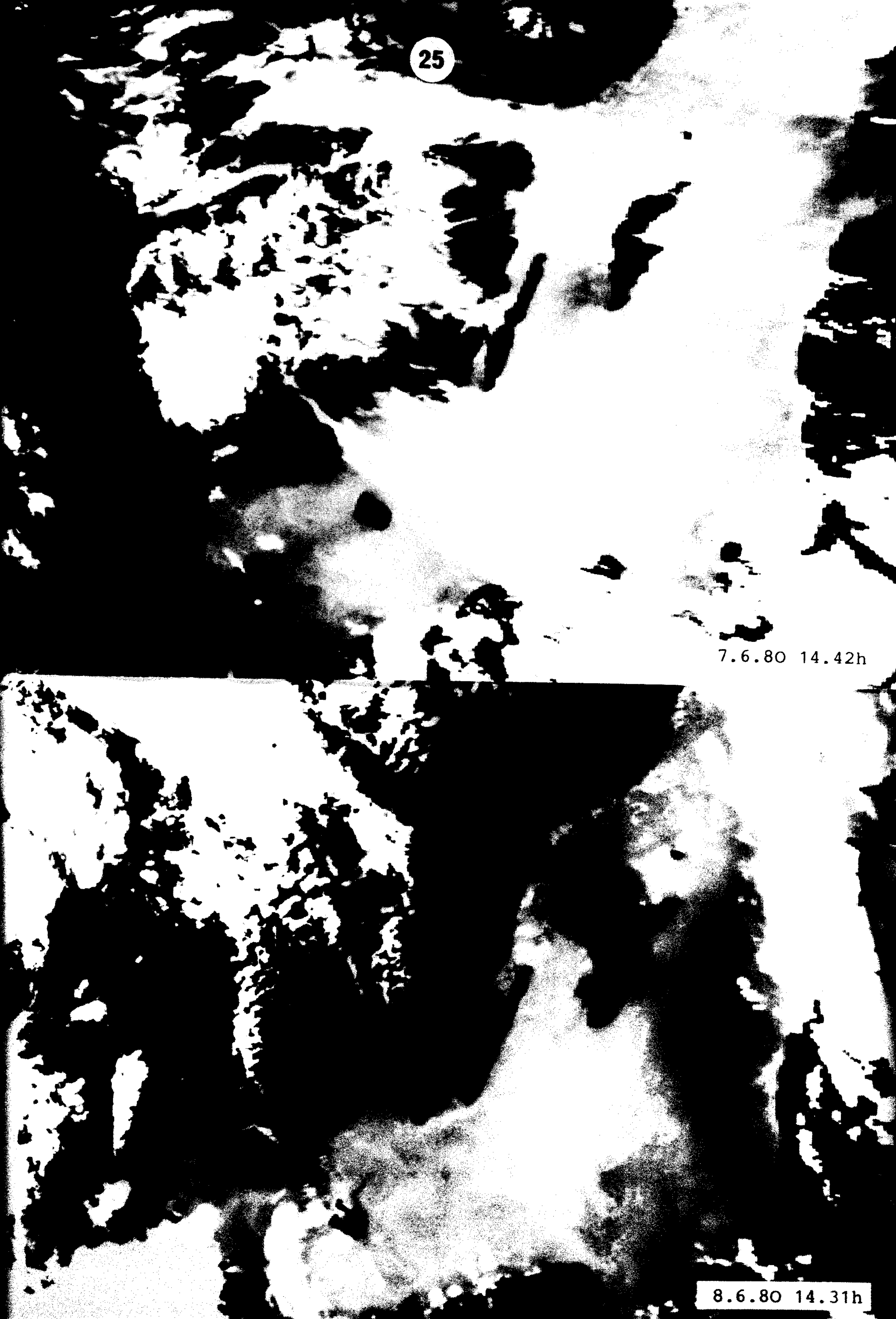
Temperature

	IV	V				
	0m	0m	5m	15m	Cd	Cs
5.6.80	9.3	10.4	9.4	10.0	270	0.2
6.6.80	9.6	11.4	10.0	9.1	290	0.3

5.6.80, 8.32 h, NOAA G IR and 5.6.80, 18.22 h, NOAA G IR

Both scenes from 5 June 80 display the temperature distribution of the surface of the Baltic at an interval of 10 hours. In the southeastern Baltic warm water is, again, visible at the surface while colder water appears at the surface off the northcoast of Hiimuaa. In the Belt Sea inflowing water to the Baltic prevails. A narrow band of warm water extends along the Polish caost.


24
6.6.80 10.25

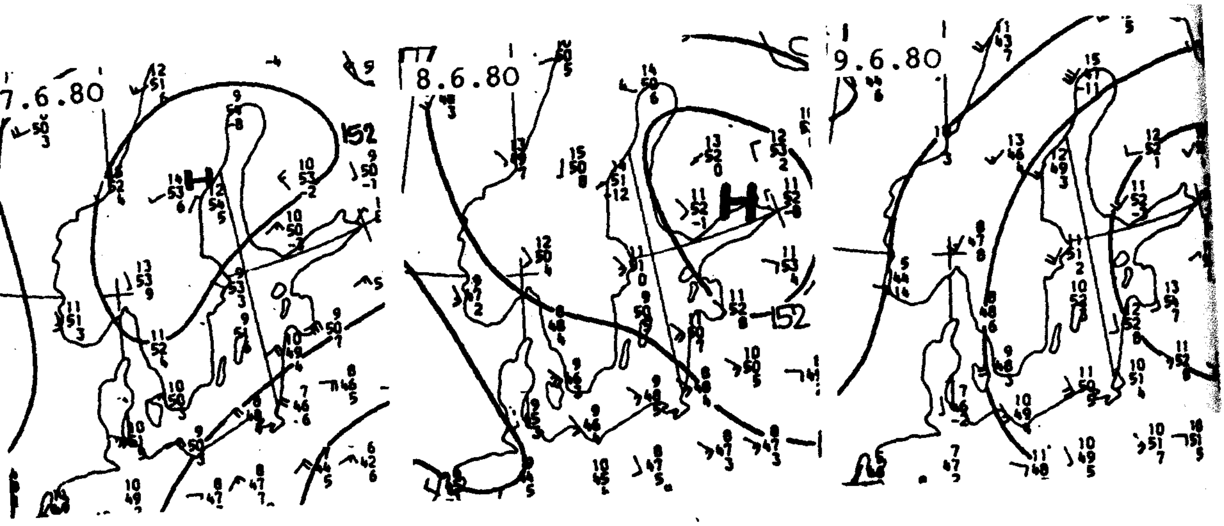

25
7.6.80 14.42h
8.6.80 14.31h

Weather and water temperature information see p. 22.

6.6.80, 10.25 h, CZSC, Channel 3 and 6.6.80, 8.10 h, NOAA G IR

The scene from channel 3 of the water colour scanner reveals traces of suspended material in the Kiel Bight, in the Lübeck and Mecklenburg Bays as well as along the coast of Poland. Due to atmospheric disturbances, without the aid of supplementary evaluation of data from the different spectral bands, the paler features along the coast of Lithuania are not positively identifiable as structures in the water.

The infra-red scene of this region, nevertheless, reveals colder surface water in the vicinity of the coast. The front of warmer water, which extends from west of Fehmarn to the Danish Island, Mön, is apparently identical with water rich in suspended material documented 2 hours later by NIMBUS G. Similar patterns in the southern Belt Sea have been observed in early spring. At that time suspended material could be attributed to the phytoplankton spring bloom (Horstmann and Hardtke 1981).

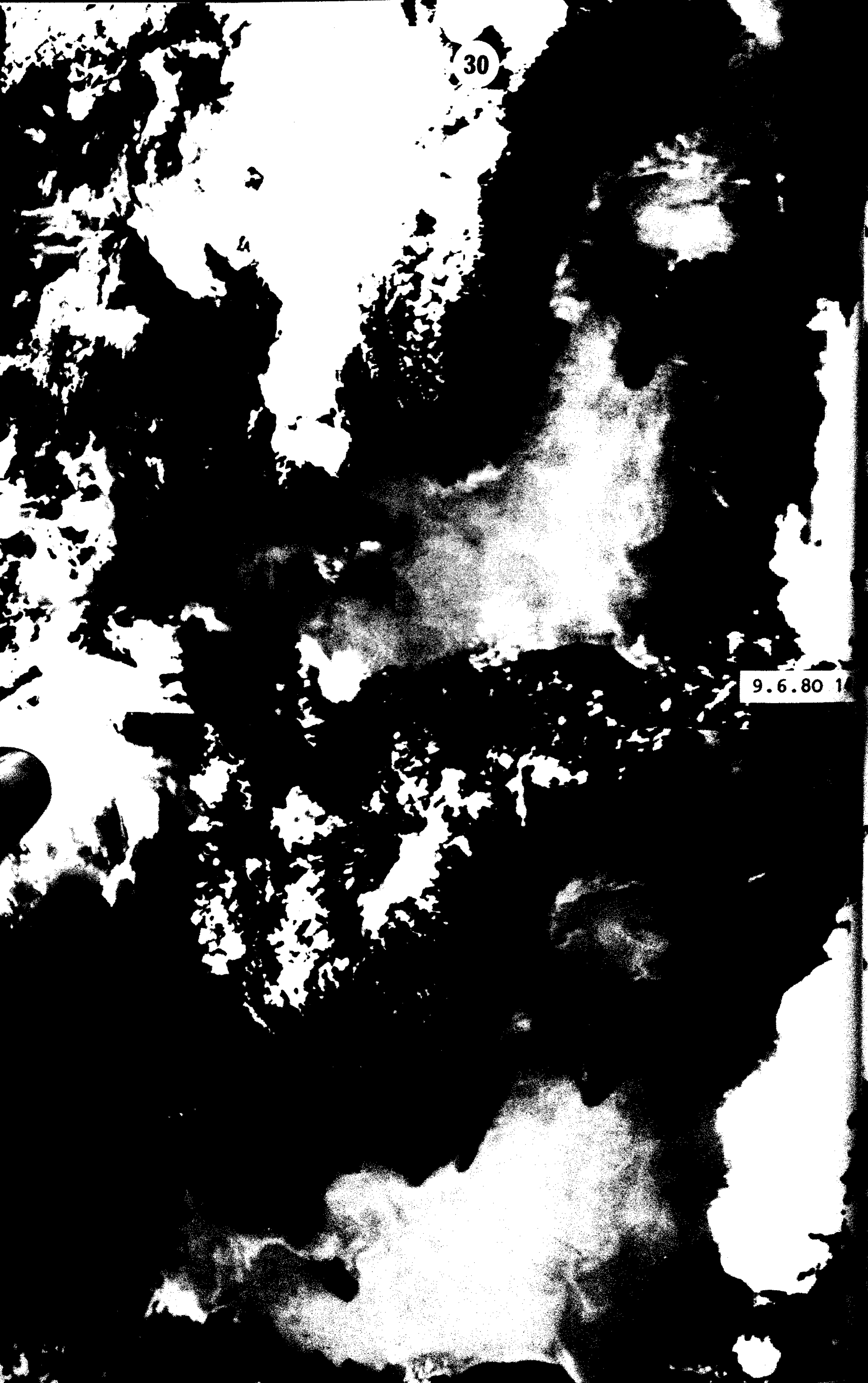


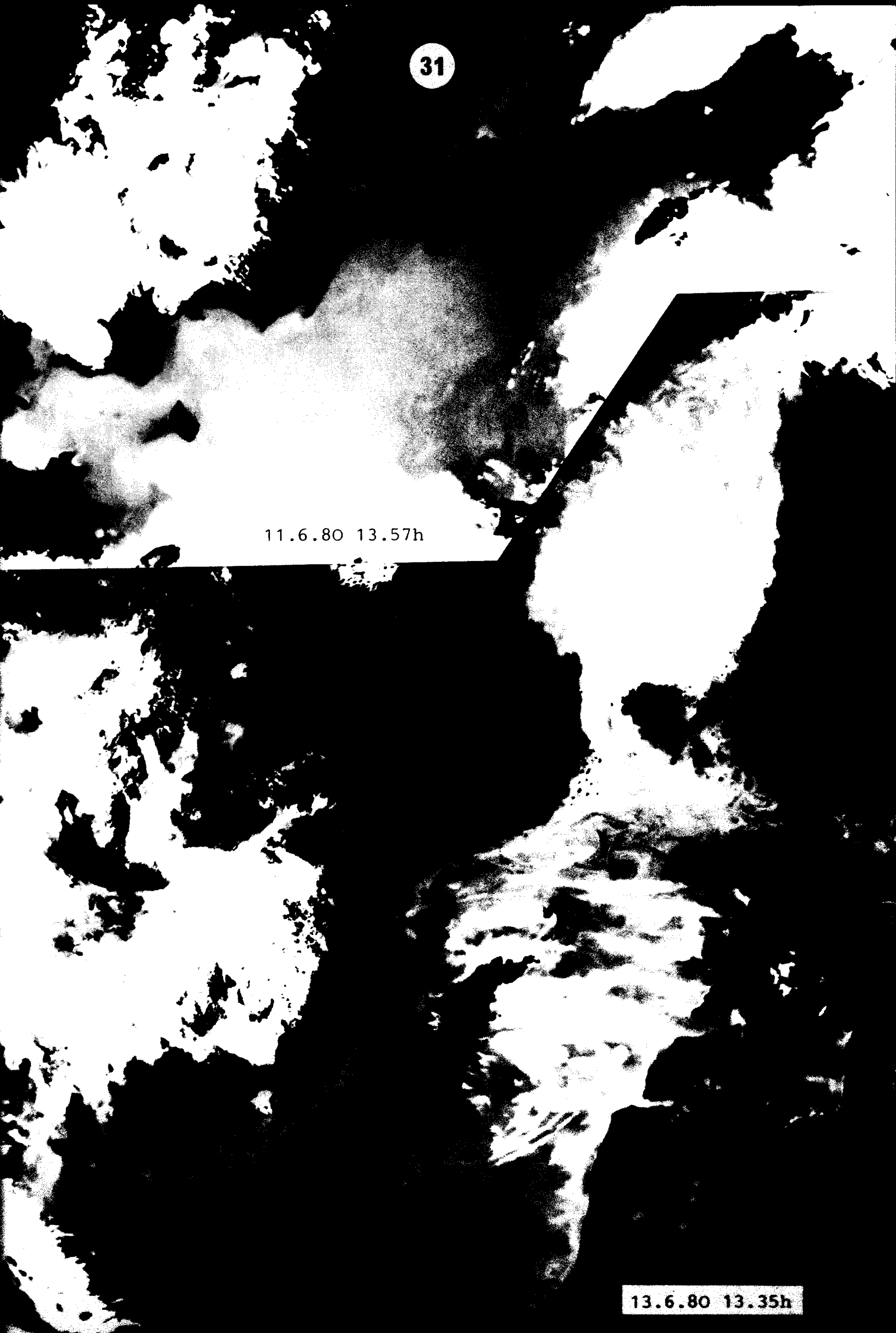
Temperature

	IV			V				
	0m	5m	15m	0m	5m	15m	Cd	Cs
7.6.80	13.8	12.3.	10.6	12.0	9.9	8.1	320	0.3
8.6.80	13.2	12.5	10.1	12.0	9.8	8.0	320	0.3

7.6.80, 14.42 h, NOAA 7 IR and 8.6.80, 14.31 h TIROS N JR

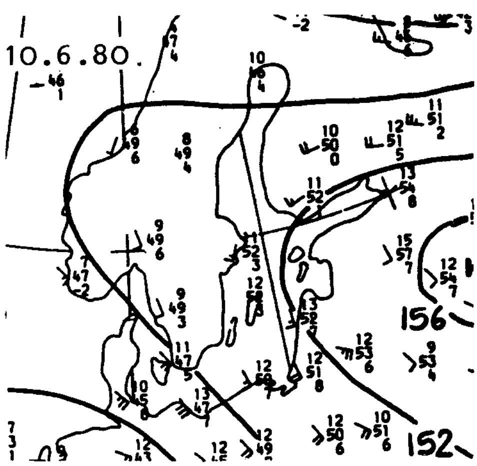
The scenes from 7 June 80 and 8 June 80 lie along the scanning periphery and are, therefore, of relatively poor quality. They are presented here in connection with the images of consecutive days pages 30 and 31. On 7 June colder water is seen to be present at the Sill of Darss west of Rügen. On 8 June one observes an expanding band of warm water along the Polish coast and cold water off the northern and southern points of Öland as well as north of Gotland and in the Baltic proper.

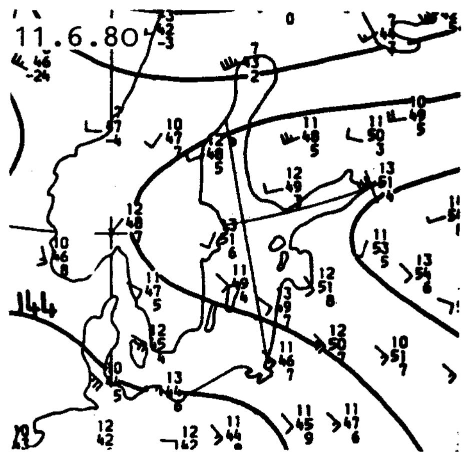

30
9.6.80 1


31
11.6.80 13.57h
13.6.80 13.35h

9 to 13 June 80

From 9 to 11 June a high pressure area over the USRR governed the weather situation over central Europe.





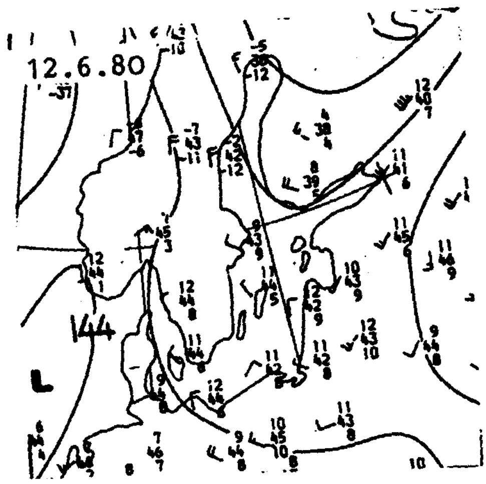
Temperature

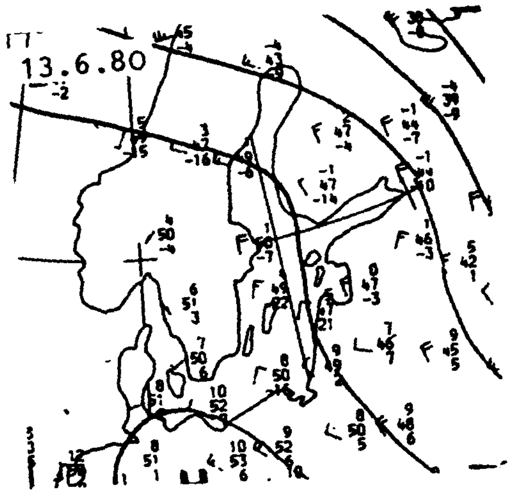
	IV	V					VI		
	0m	0m	5m	15m	Cd	Cs	0m	5m	15m
9.6.80	10.9	11.3	11.4	9.2	320	0.2	14.2	12.2	10.0
10.6.80	11.0	11.8	11.8	8.9	50	0.2	14.9	14.6	9.5
11.6.80	11.2	11.8	11.7	8.9	50	0.2	11.8	11.7	8.9

9.6.80, 14.19 h, 10.6.80, 14.08 h and 11.6.80, 13.35 h, all TIROS N IR

On 9 June the cold water area west of Rügen had enlarged. From a colder water front flowing into the Kattegat one can assume on an outflow situation, as watermasses leave the Baltic. At lightship Mön SE, however, current towards northeast is registered. Of particular interest are two eddies west of Bornholm with warm centres. They can be followed in this region from 7 to 13 June, and they continually change their position to one another. The dark patches west of the islands, Bornholm, Öland and Gotland, are indicators of warm air, which drifted from the islands westwards as a result of easterly winds. In the eastern part of the Bay of Pomerania as well as in the Bay of Danzig warmer water can be identified.

The infra-red scenes of 10 June and 11 June depict the further course of changes in surface temperature in the Baltic.





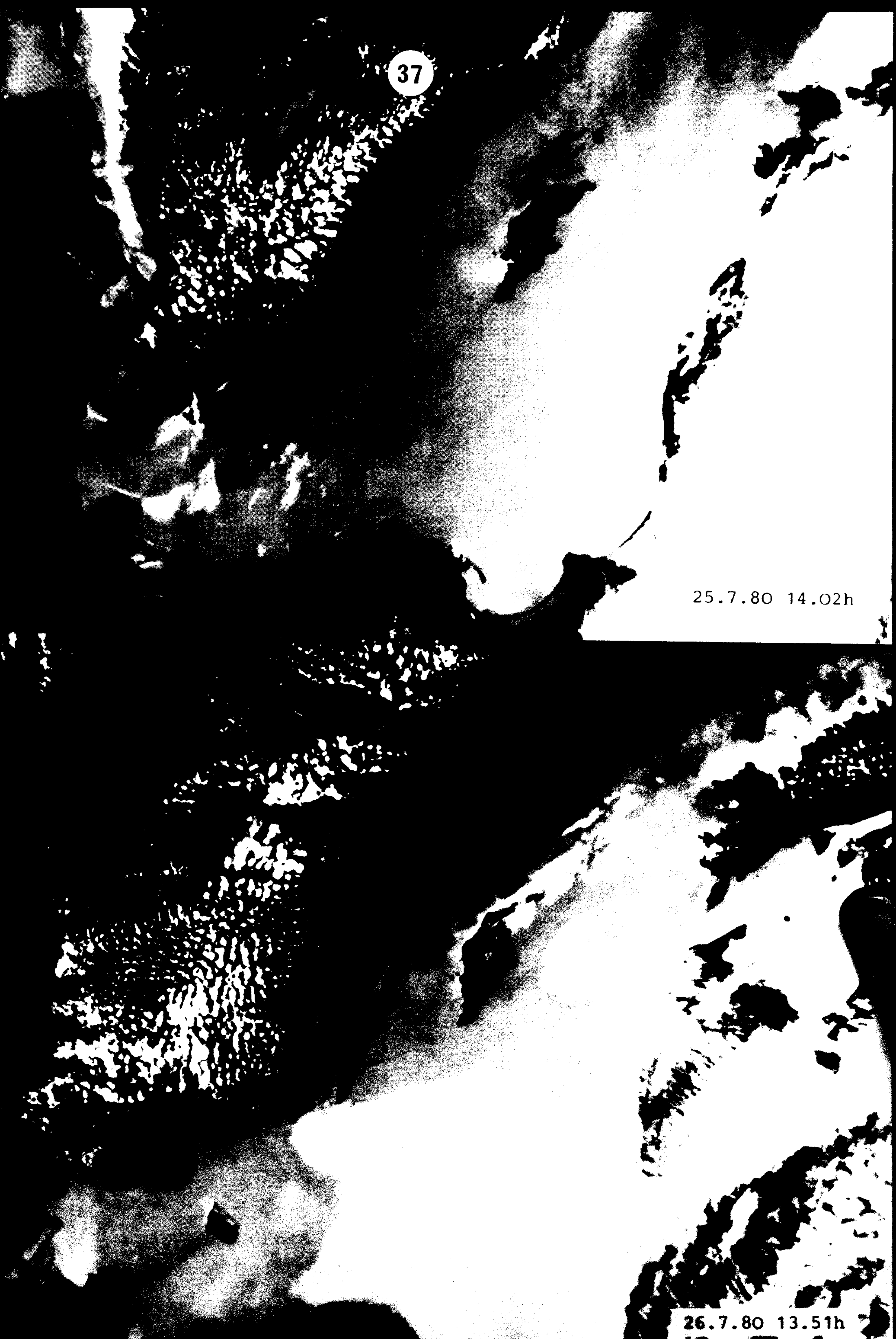
Temperature

	IV	V				
	0m	0m	5m	15m	Cd	Cs
13.6.80	11.4	12.6	12.5	8.9	140	0.2

13.6.80, 13.57 h, TIROS N IR

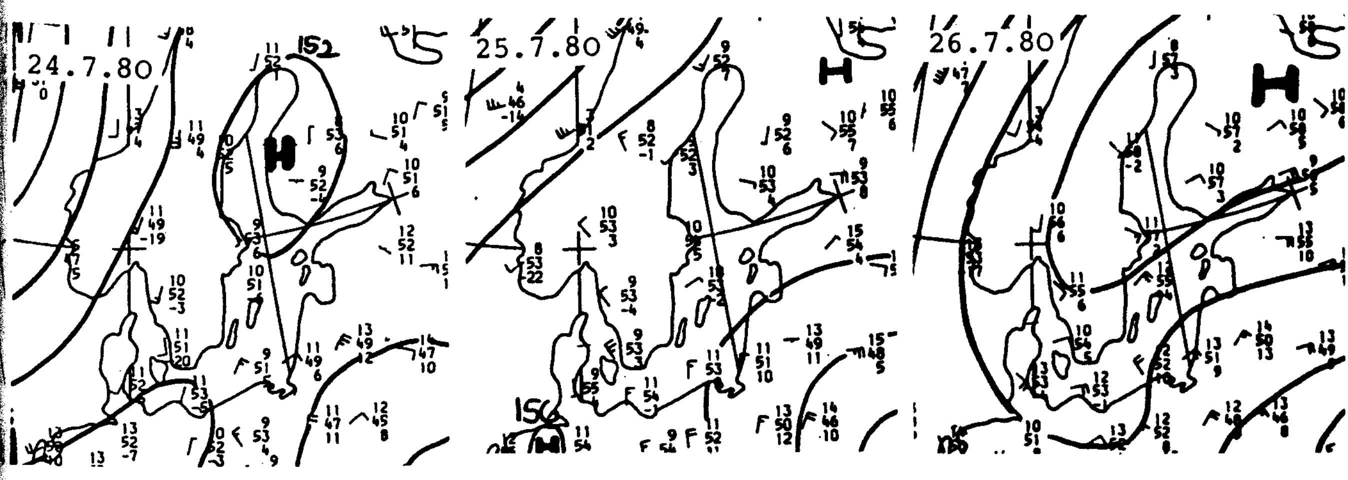
On 13 June a well developed series of vortices is seen extending from the Gulf of Finland to the northern tip and along the south east coast of Öland almost up to the Island of Bornholm. Special attention should be given to the vortex structures in the Bothnian Bay showing colder water in its centre. In the Bay of Danz warm water is again perceptible at the surface. Without additional data it is impossible to substantiate the existence of cold water indicated through lighter coloration along the eastcoast Latvia and Lithuania due to disturbances in the atmosphere.


36
25.7.80 10.


37
25.7.80 14.02h
26.7.80 13.51h

25 July 80 to 2 August 80

From 11. to 21 July Atlantic low pressure areas with accompanying troughs and high pressure ridges crossed over central Europe in an easterly direction. From 22 to 25 July a high pressure area was the major weather determinant over the Baltic. From 26 to 31 July a region of high pressure lay over northern Europe and drifted towards southeastern Europe on 1 August.



<u>Temperature</u>

	IV	V				
	0m	0m	5m	15m	Cd	Cs
25.7.80	15.7	15.4	15.0	14.6	270	0.2
26.7.80	15.8	16.0	15.9	11.5	320	0.4

25 July 80, 10.10 h and 26 July 80, 10.29 h CZCS Channel 3

The scenes from these 2 successive days reveal well developed structures in the region of the Baltic not obscured by clouds or haze. Without doubt these can be attributed to accumulations of blue-green algae near the surface; sea truth data support this assumption. Such aggregations of blue-green algae are characteristic for the Baltic at this time of year (Horstmann et al. 1981). Especially distinct are the structures in the Hanö Bay, northeast and south of Bornholm as well as those northwest and northeast of

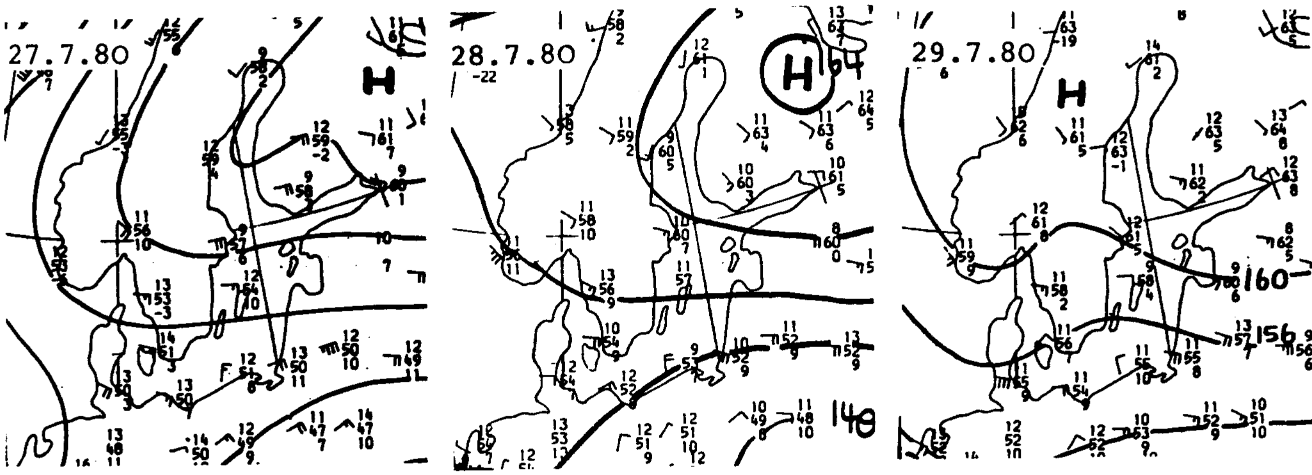
Gotland. Along the southeast coast of Öland the masses of blue-green algae demonstrate elongated patterns, which are also characteristic for this area (see 31.7.80, p.43). On 25 July one can discern the contours of the Oder Bank southeast of Rügen, which suggests that only little suspended material is present in the water column in this region. In general one can distinguish the vague structures of suspended material situated in the North Sea (mouth of the Elbe), and in northwestern Skagerrak from the structures caused by the aggregation of blue-green algae in the surface area of the Baltic.

25 July 80, 14.02 h and 26 July 80, 13.51 h TIROS N IR

On 25 July cold water is noticeable along the coasts of Lithuania and Latvia. On 26 July areas of cold water appear at the north-coast of Estonia and northwest coast of Gotland. Characteristic vortex patterns extend from the Gulf of Finland to the northern tip of Öland. Cold water is also obvious west of Rügen.


42
28.7.80 13.29h


31.7.80 10.18h CH3
2.8.80 14.54h



Temperature

	IV	V				
	0m	0m	5m	15m	Cd	Cs
28.7.80	16.6	15.6	15.5	11.8	50	0.2

28.7.80, 13.29 h, TIROS N IR

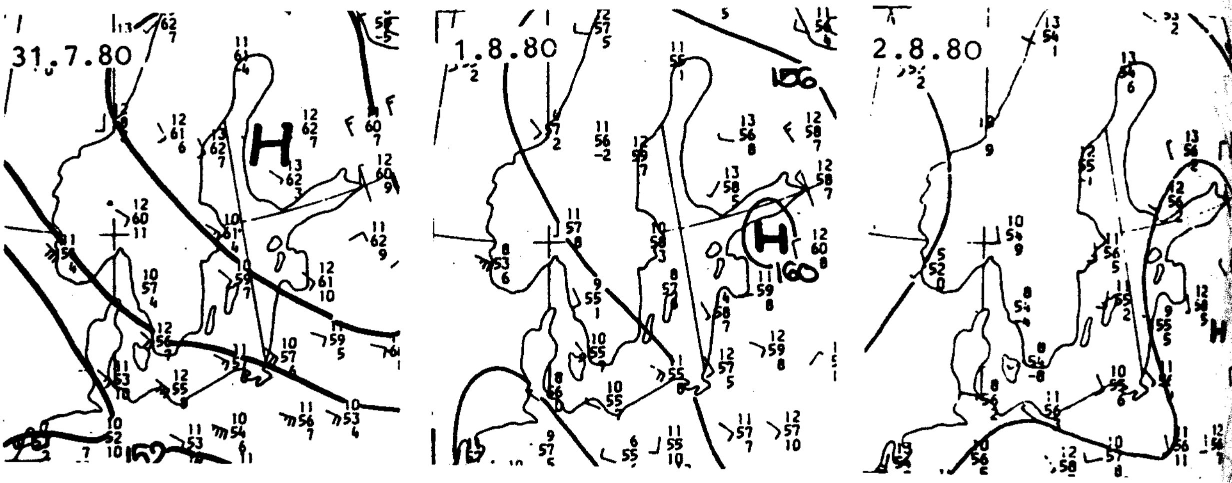
The upwelling off the northcoast of Estonia and the northwestern coast of Gotland was intensified. Also, off the northwestern coast of Latvia, in the southern section of the Gulf of Riga as well as off the westcoast of Finland colder water can be noticed.

Temperature

	IV	V					VI		
	0m	0m	5m	15m	Cd	Cs	0m	5m	15m
29.7.80	16.7	16.0	16.0	12.0	50	0.2	17.2	17.4	12.6

29.7.80, 14.57 h, TIROS N IR

This detail from a scene recorded on 29 July elucidates the extent of the upwelled watermass northwest of Rügen.



Temperature

	IV	V				
	0m	0m	5m	15m	Cd	Cs
31.7.80	16.8	16.2	16.1	12.7	0	0.0

31.7.80, 10.18 h, CZCS, Channel 3

Again, the scene depicts structures of blue-green algae congregations in the western Baltic. Although this picture is considerably obscured by clouds and vapour trails caused by aircraft south of Gotland, one can still recognize eddylike structures in the Hanö Bay. One also sees typical longish structures along Öland (compare p. 36), and structures of eddies within a considdderable radius surrounding Bornholm.

Temperature

	IV	V				
	0m	0m	5m	15m	Cd	Cs
2.8.80	17.9	17.0	16.8	13.2	90	0.1

2.8.80, 14.54 h, TIROS N IR

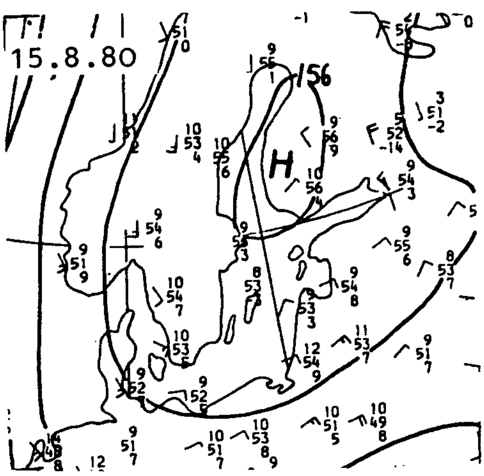
This recording elucidates the drifting of cold water from the Sill of Darss into the Mecklenburg and Lübeck Bays and, also, into the Kiel Bight. One recognizes to what extent this cold water can influence the Belt Sea.

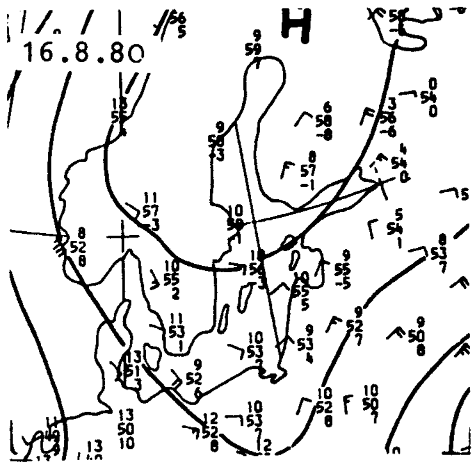

16.8.80 10.0

49

16 August 80

Following the dissolution of a belt of high pressure, which lasted from 9 to 11 August, a westwind drift set in from 12 to 13 August in the Baltic area. This drift was dispersed during the period of 14 to 19 August by a high over northern Scandinavia.





<u>Temperature</u>

	IV	V				
	0m	0m	5m	15m	Cd	Cs
16.8.80	16.6	16.6	16.6	16.6	320	0.2

16.8.80, 10.08 h, CZCS, Channel 3

The extent of the appearance of masses of blue-green algae in the western Baltic is presented in this scene (Horstmann et al. 1981). Eddies can be observed south of Bornholm and Rügen. One notes the presence of an outflow system.

16.8.80, 14.54 h, TIROS N

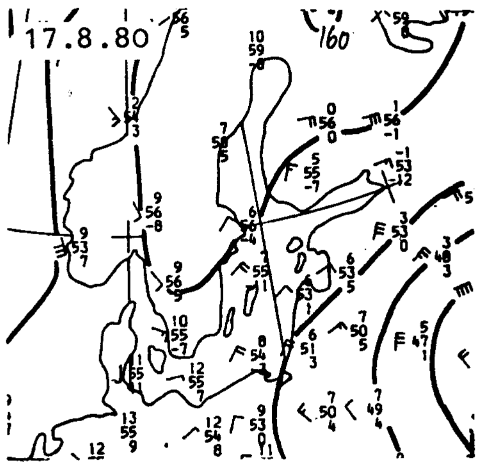
In this scene, which unfortunately lies along the scanning periphery, colder water can again be discerned in the area west of Rügen.

16.8.80, LANDSAT 2 MSS 4 (500 to 600 nm), Orbit No. 208,
Frame 22 and 23

This recording, composed of 2 scenes obtained from the LANDSAT 2-satellite and scanned at almost the same time as the NIMBUS G scene on p. 48, reveals through its better resolution (75 m per reproduced point instead of 1100 m with NOAA and TIROS and 800 m with NIMBUS, all in the nadir) congregations of blue-green algae in the surface waters of the Baltic. The white patterns, which appear to be located in the Hanö Bay, northeast of Bornholm and in the southern region of the Bay of Pomerania, are clouds. In the Greifswalder Bodden as well as in the area at the mouth of the eastern arm of the River Oder situated in the Bay of Pomerania one can make out suspended material in the water (see also pp. 48 and 54).


17.8.80 10.26h


55
18.9.80 13.40h
19.9.80 13.29h
20.9.80 14.58h
21.9.80 14.46h



Temperature

	IV	V				
	0m	0m	5m	15m	Cd	Cs
17.8.80	16.9	16.7	16.7	15.5	140	0.2

17.8.80, 10.26 h, CZCS Channel 3

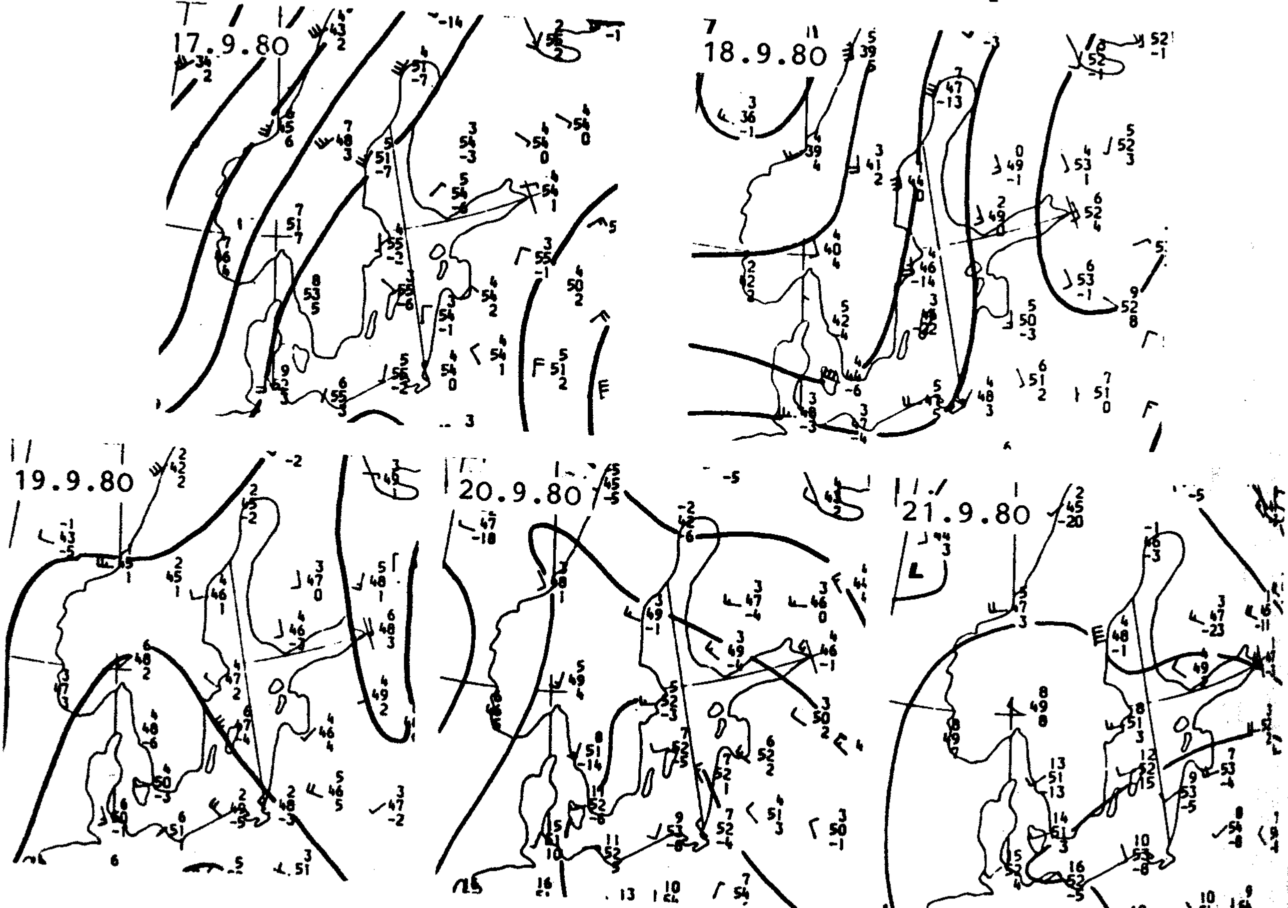
This scene was recorded on the day succeeding that corresponding to the scene on p. 49, at which time only the structures distinguished by blue-green algae were recognizable through the cloud cover. By observing the movements of the fronts and eddies west of Bornholm one perceives a drift towards the northwest in the direction of the Öre Sound.

17.8.80, 2.24 h, NOAA 6 IR

In this scene one can, again, distinguish the dimension of a cold waterbody west of Rügen, in this case recorded 4 days after a change from a system of inflow to the Baltic to that of outflow.

18 to 21 September 1981

Following a high lasting until 8 September over central Europe, low pressure troughs crossed over the Baltic in rapid successior from 9 to 18 September as a result of a powerful westwind. From 19 to 21 September central Europe lay at the western flank of a high pressure area located over eastern Europe.

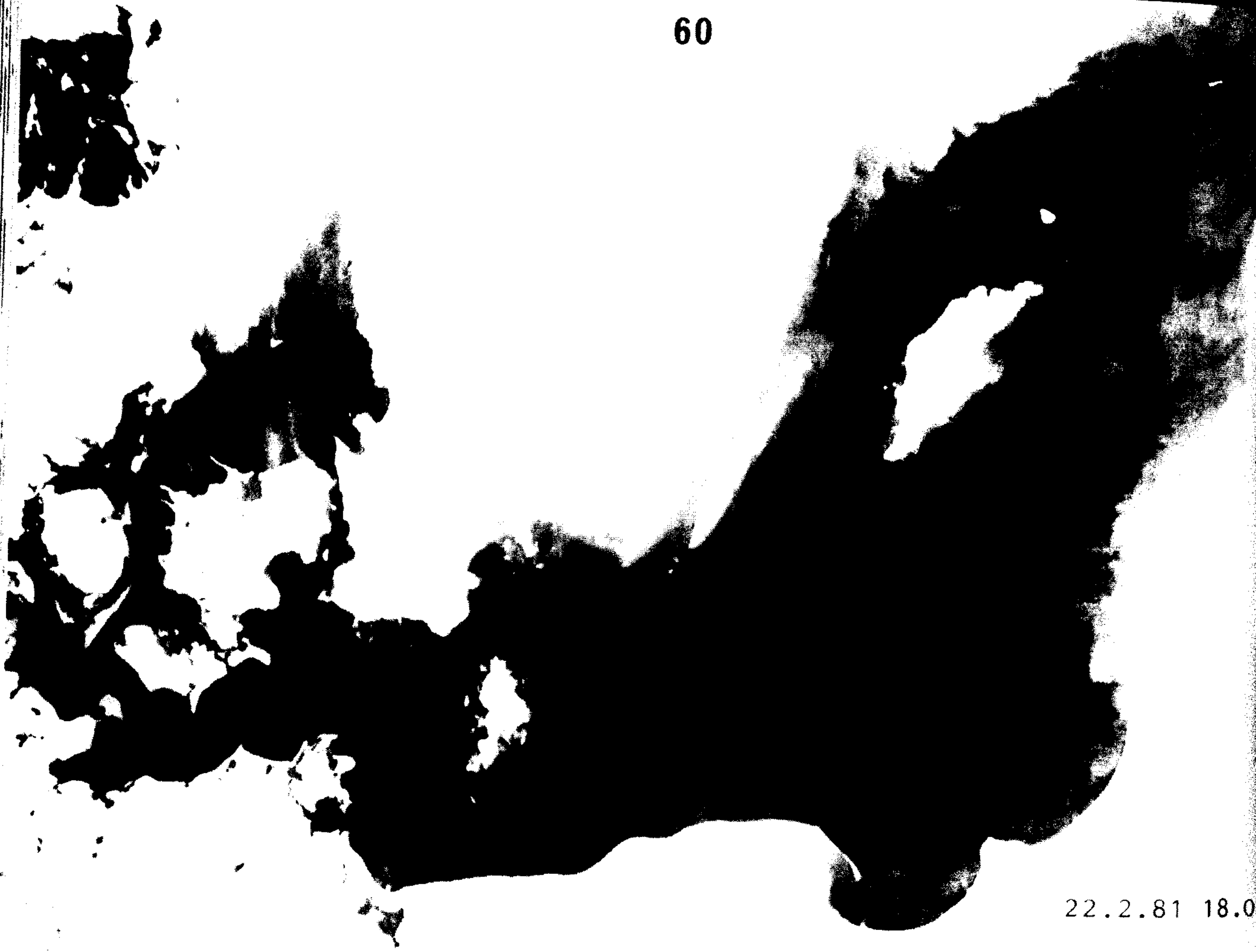


Temperature

	IV	V				
	0m	0m	5m	15m	Cd	Cs
18.9.80	14.0	12.8	12.8	13.2	270	0.4
19.9.80	14.2	13.1	13.1	13.0	360	0.3
20.9.80	14.1	12.6	12.6	12.1	360	0.3

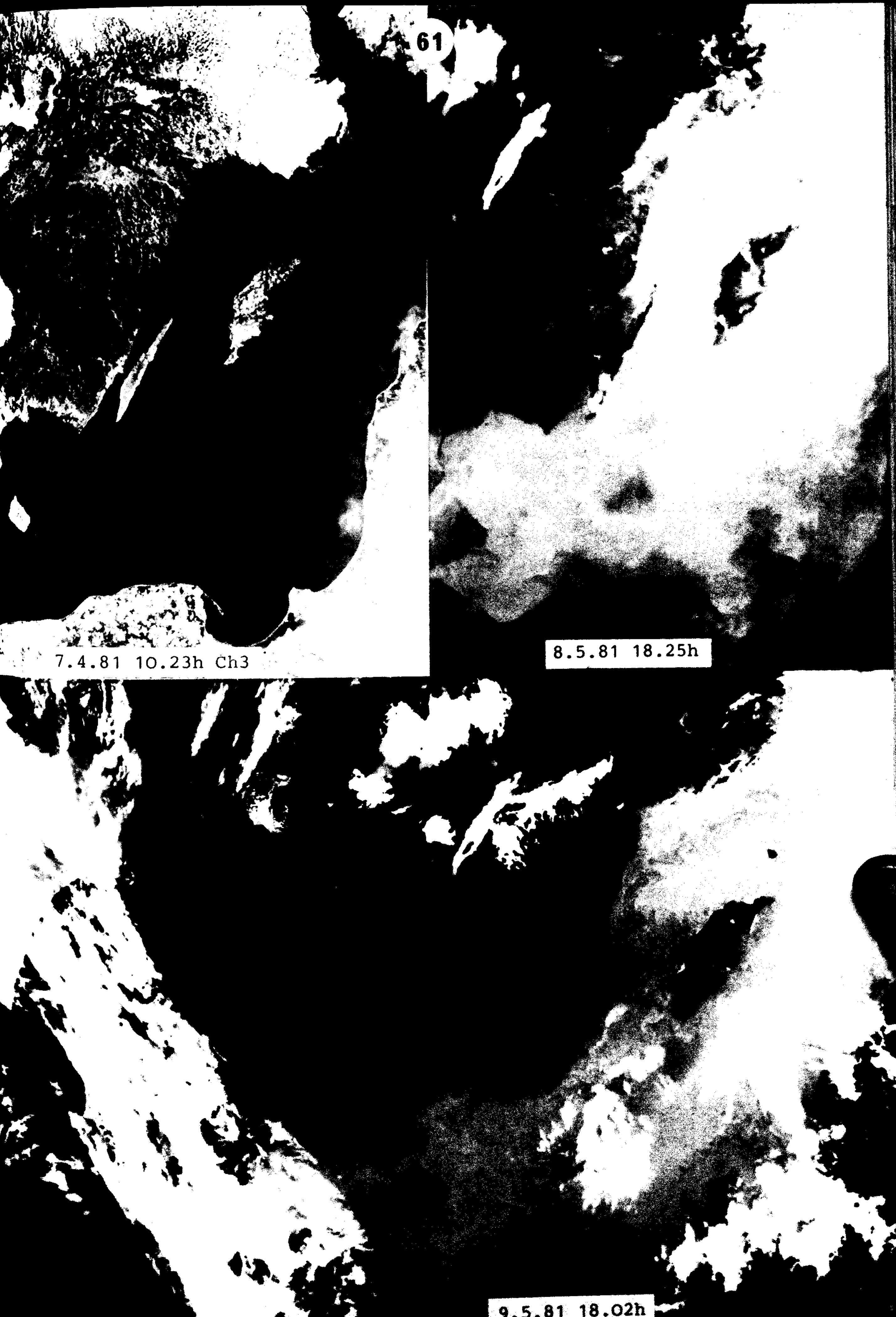
18.9.80, 13.40 h, 19.9.80, 13.29 h, 20.9.80, 14.58 h and 21.9.80, 14.46 h, all TIROS N IR

This series of 4 successive scenes displays the drifting behaviour of the cold water arising from the areas east of Öland in the Hanö Bay and south of the Öre Sound.



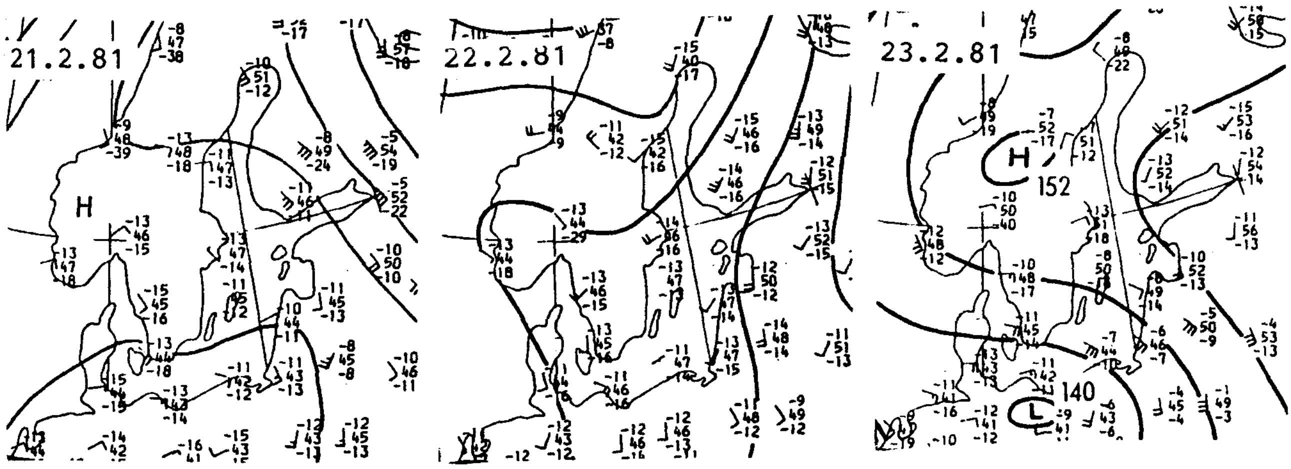
22.2.81 18.0

22.2.81 17


61
7.4.81 10.23h Ch3
8.5.81 18.25h
9.5.81 18.02h

22 February 81

From 14 February to 21 February a number of troughs crossed Europe with intermediate high pressure areas on 14 and 17 February. On 22 February another high was a weather determinant over the Baltic Sea.



Temperature

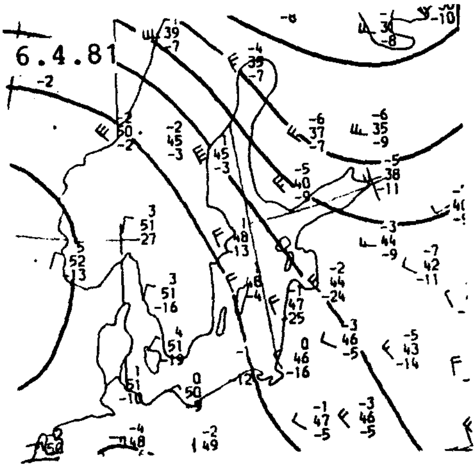
	IV	V				
	0m	0m	5m	15m	Cd	Cs
22.2.81	2.1	1.8	1.8	1.9	20	0.4
23.2.81	1.7	1.6	1.5	1.5	270	o.3

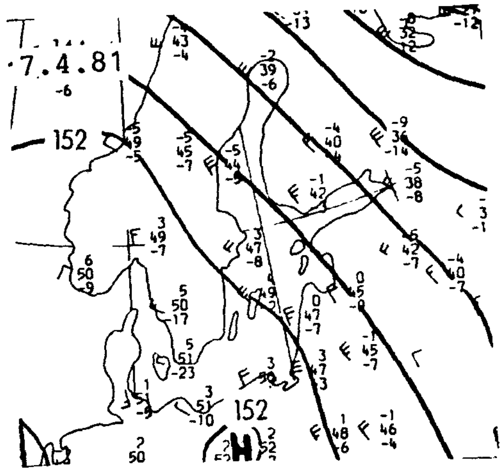
22.2.81, 18.ol h and 23.2.81, 17.39 h, both NOAA 6

As noted so far, for all of the winter images of the Baltic, the scenes from these 2 successive days reveal cold water lining the coast throughout the Baltic. It is surprising how quickly alterations in the structures of colder water occur within a period of 24 hours. Along the coastline of islands there is discernable a similar, narrower fringe of colder water.

7 April 1981

From April 2 to 4 there was a high pressure area over northern Scandinavia, and from 5 to 6 April a high lay over the British Islands.





Temperature

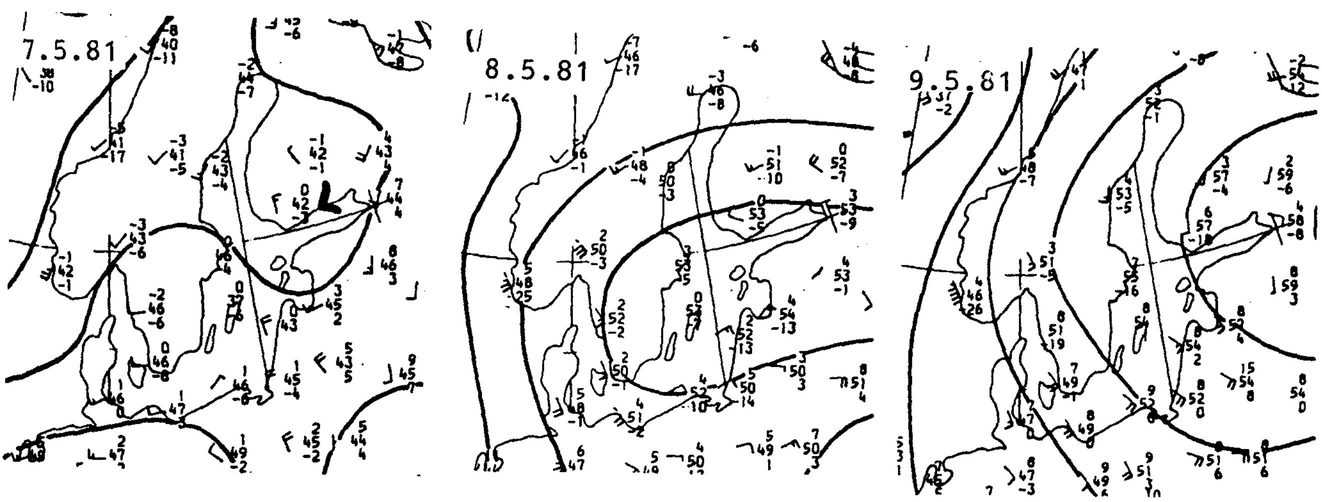
	IV
	0m
7.4.81	2.5

7.4.81, 10.23 h, CZCS, Channel 3

In the eastern region of the Baltic structures attributed to suspended material are clearly seen. Structures at the northern outlet of the Courland lagoon specifically, at the Nemunas River and in the vicinity of the mouth of the Windau River are especially distinct (see also 12 April 79, pp. 6 and 7). The view of the western part of the Baltic is impaired by haze.

8 and 9 May 1981

From 1 May to 5 May depression areas moved from the northwest over the Baltic. From 6 to 9 May southerly winds predominated, and from 10 May onwards there was a high pressure area over northern Scandinavia.



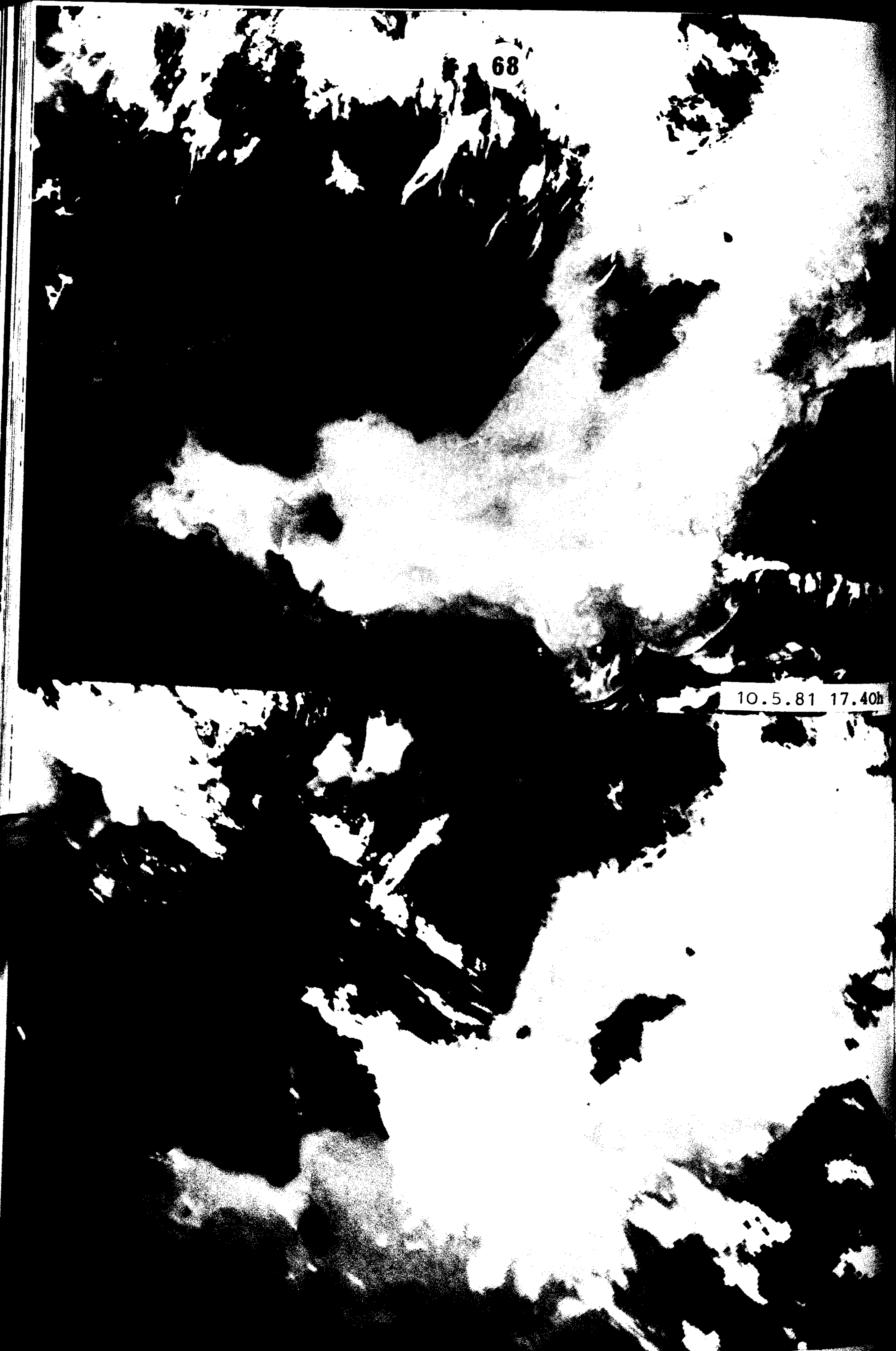
Temperature

	IV	V				
	0m	0m	5m	15m	Cd	Cs
8.5.81	4.4	5.8	5.7	5.2	320	0.4
9.5.81	4.9	5.5	5.5	5.2	320	o.3

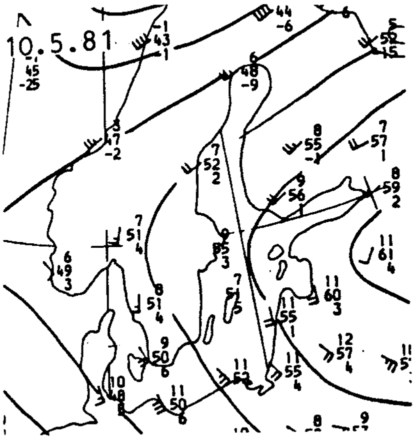
8.5.81, 8.25 h and 9.9.81, 18.02 h, both NOAA 6

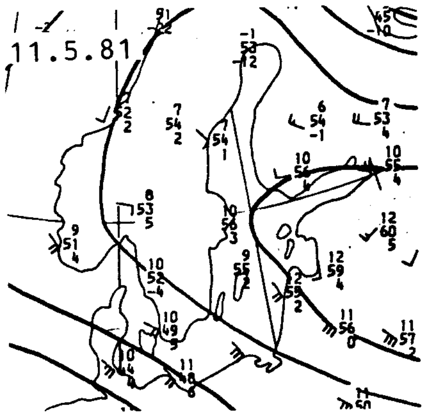
The two infra-red images supplement each other as to a sky without cloud covering. Warm water can be seen along the coasts in the southern Baltic extending towards the north in the Bay of Danzig (see also 10 June 80, p. 30 and 22 May 81, p. 69). Characteristic is the patch of warm water southwest of Bornholm and the vortex row north of Öland.

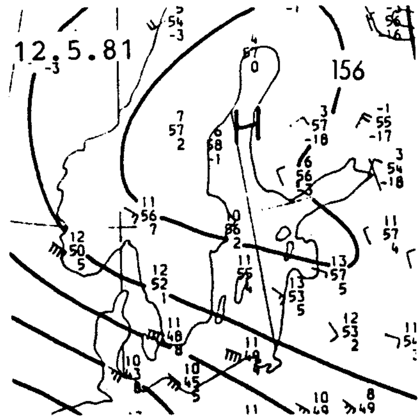
In addition, warm water is visible west of Bornholm corresponding to the contours of the Rönne Bank. The vortex row stretching from east of Stockholm almost up to Bornholm is characteristic (see also 28 July 80, p. 42 and 13 June 80, p.31).


68
10.5.81 17.40h


69
22.5.81 18.08h
23.6.81 17.42h







Temperature

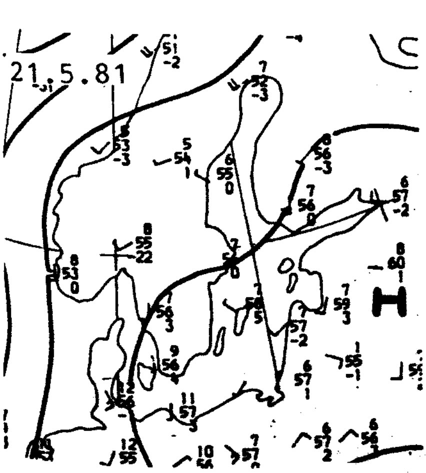
	0m	0m	5m	15m	Cd	Cs
10.5.81	5.1	6.2	5.6	5.5	320	0.3
12.5.81	5.7	6.6	6.6	6.5	50	0.3

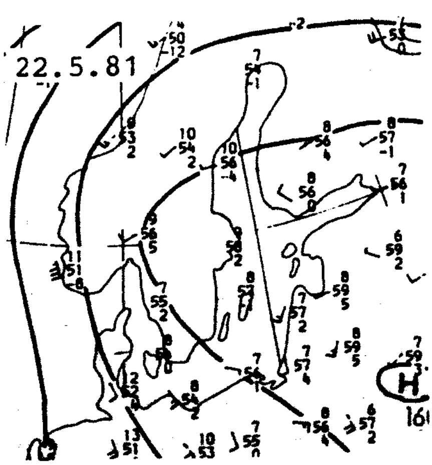
10.5.81, 17.40 h and 12.5.81, 18.08 NOAA 6

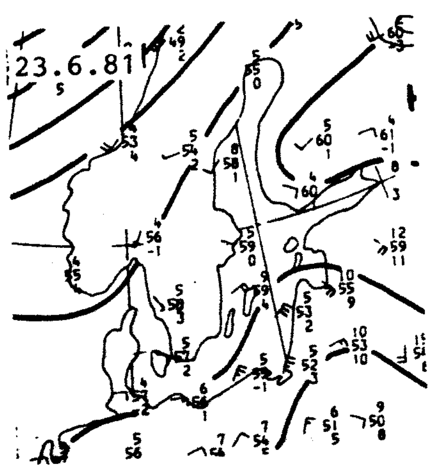
The scenes reflect the distribution of warmer surface water in the coastal vicinity of the southern Baltic. Warmer water is also perceptible along the coast of Latvia and Lithuania and in the southern region of the Gulf of Riga. A system of outflow dominates in the Belt Sea.

22 and 23 May 1981

The high pressure area over northern Europe lasted up to 17 May. From 18 May to 21 May depression areas crossed the southern Baltic from south to northeast.







Temperature

	IV	V				
	0m	0m	5m	15m	Cd	Cs
22.5.81	8.8	8.8	8.8	7.0	320	0.2

22.5.81, 18.08 h, NOAA 6 IR

This scene displays the extension of warmer water in the southern Baltic. Furthermore, warm water is visible along the coast of Öland and the southeastern coast of Sweden. Characteristic is the vortex row identifiable by its warm water quality in the region west of Bornholm; in this scene it does not coincide with the Rönne Bank southwest of Bornholm.

23 June 1981

On 21 June the last of a series of troughs went from northwest towards northern Europe, from 22 to 25 June a high influenced the weather over the Baltic.

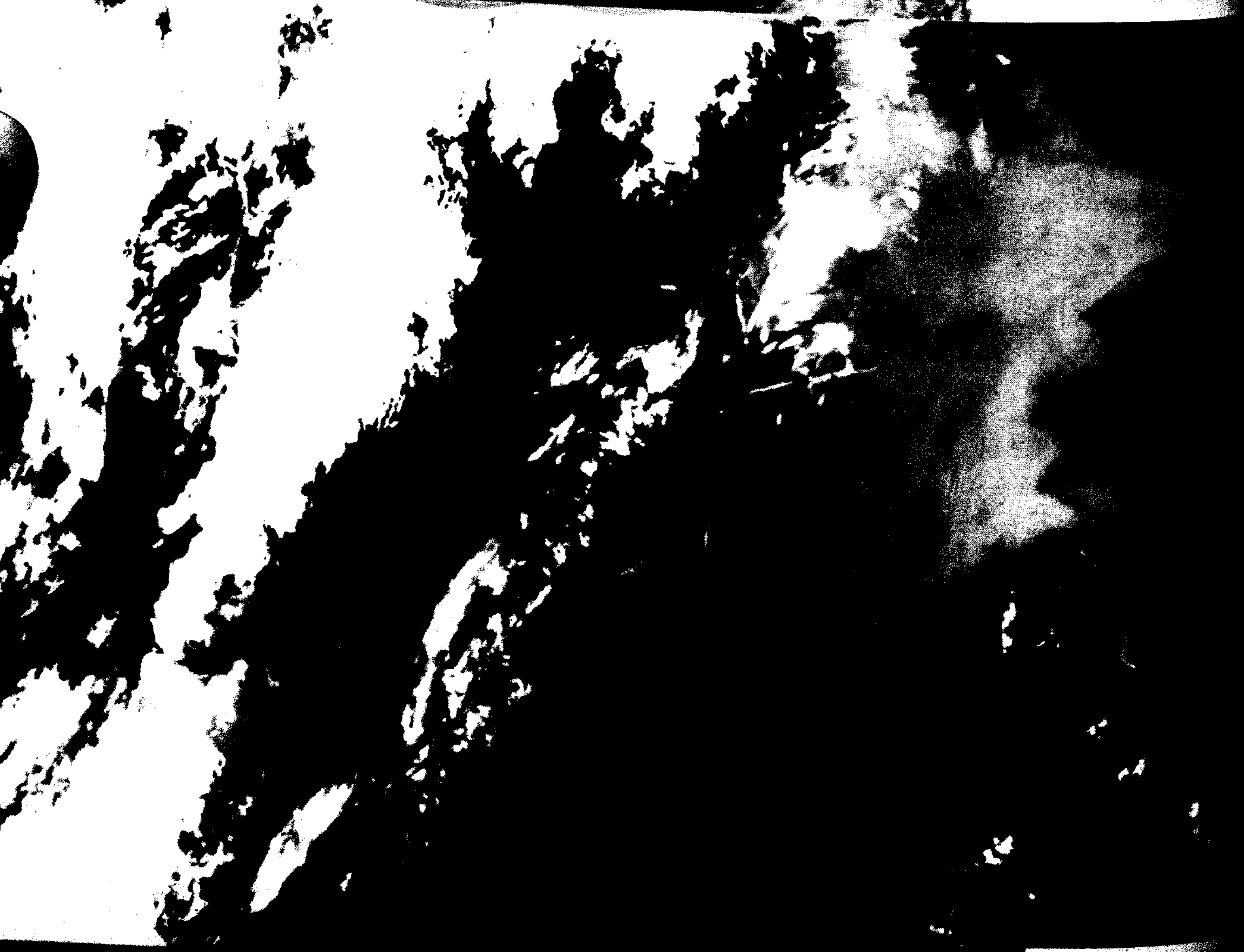
Temperature

	0m	0m	5m	15m	Cd	Cs
23.6.81	11.9	12.9	12.7	13.3	320	0.3

23.6.81, 17.42 h, NOAA 6 IR

The recording reveals a system of outflow from the Baltic into the Belt Sea. Characteristic structures are recognizable west of Fehmarn. From the Öre Sound cold water extends towards the Kattegat. Furthermore, a narrow band of colder water is indicated along the northwestern coast of Gotland. Despite disturbance by cloud cover colder water also appears to be located in the coastal vicinity of the USSR. A narrow margin of warmer water is discernable along the Polish coast. The dark structures in the Hanö Bay on 25 July are attributable, as depicted in the scene from 26 July, to atmospheric causes. From a careful comparison of the water colour scenes to the infra-red scenes, one can see that many structures distinguished through blue-green algae superpose with those of the temperature scenes. On 26 July an upwelling of cold water west of Rügen is, again, indicated.


74
5.7.81 18

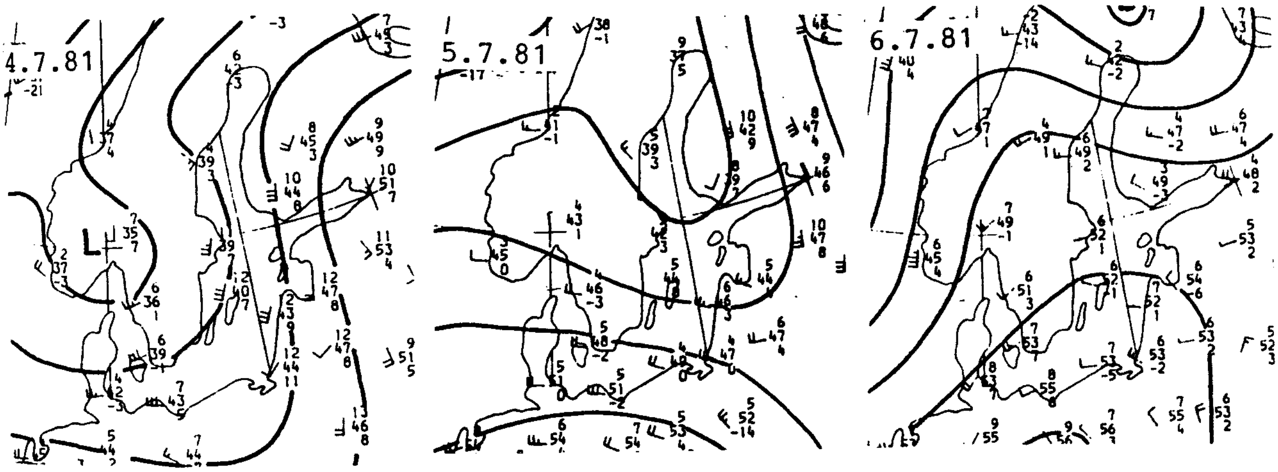



7.8.81 10.10h CH3


7.8.81 13.52 h

2 to 7 July 1981

From 2 July to 4 July a depression area slowly moved over Europe from west to east.



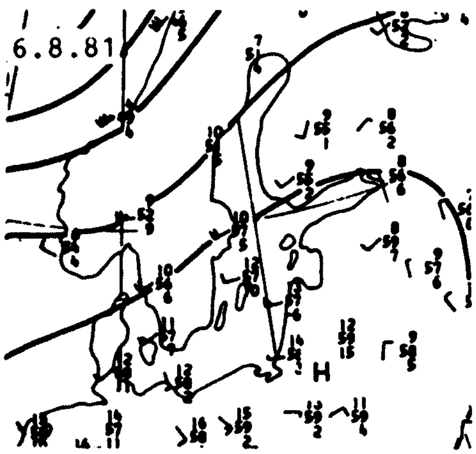
Temperature

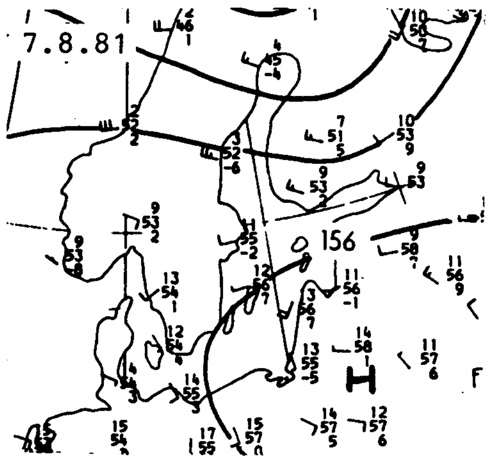
	IV	V				
	0m	0m	5m	15m	Cd	Cs
5.7.81	12.2	12.7	12.7	13.1	270	0.2
6.7.81	13.0	13.2	12.2	9.0	320	o.2

5.7.81, 18.08 h, NOAA 6 and 6.7.81, 17.46 h, NOAA 6

The images depict warm water along the southcoast of Poland and the westcoast of Lithuania, Latvia and Estonia and colder water southwest of Gotland and Öland as well as in the Hanö Bay and along the Swedish southcoast.

From 3 August to 6 August there was a high pressure bridge over the southern Baltic





Temperature

	IV	V				
	0m	0m	5m	15m	Cd	Cs
7.8.81	17.4	16.9	16.8	8.0	320	0.3

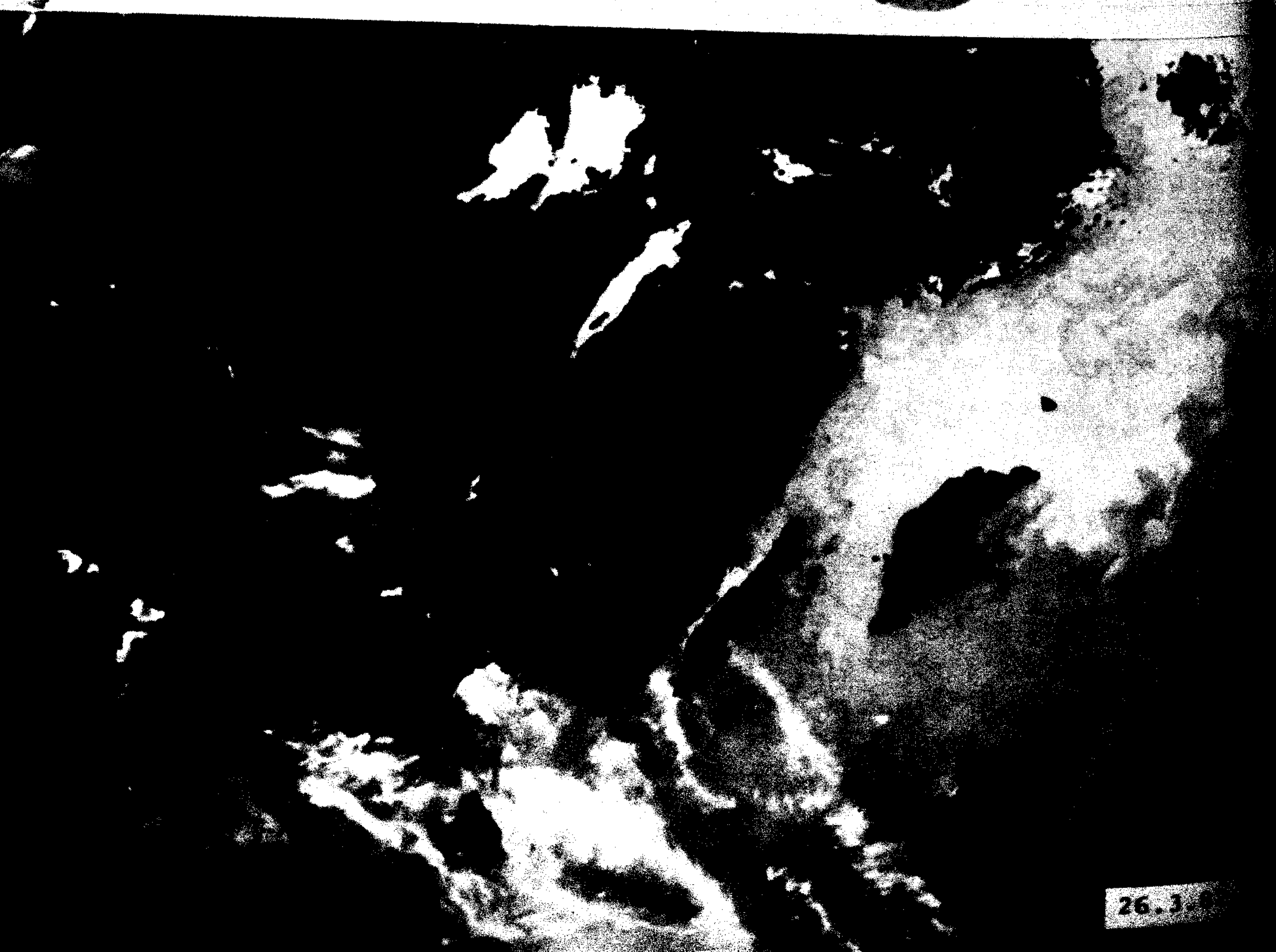
7.8.81, 10.10 h, CZCS, Channel 3

The scene shows the distribution of blue-green algae in the surface layer of the central and southern Baltic. Particularly noteworthy is the intensity of the reflection of suspended material in the Courland Lagoon. The phenomenon is first noted at the northern outlet of the lagoon and apparently drifts in the form of a narrow band along the coast northwards (see also 12.4.79, pp. 6 and 7 and 7.4.81, p. 61). The paler structures southeast of Rügen are caused by the atmosphere. A vapour trail extends from Estonia towards Bornholm.

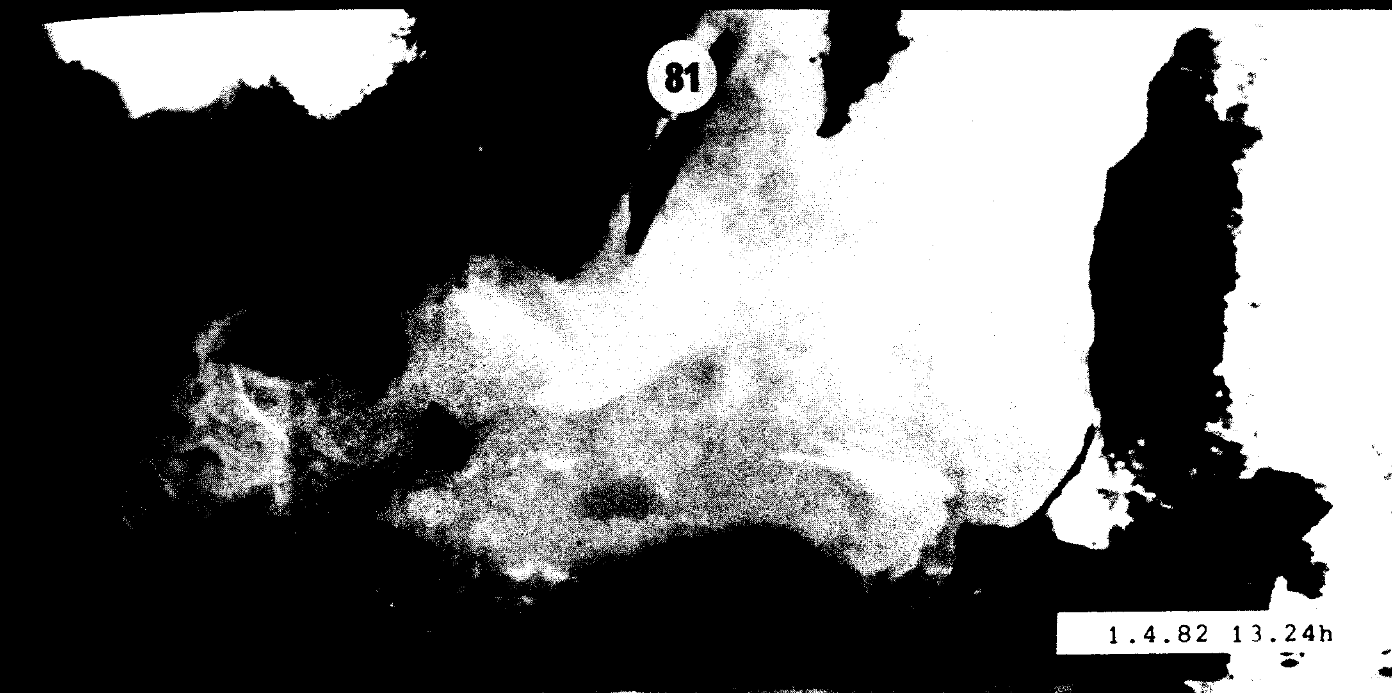
7.8.81, 13.25 h, NOAA 7

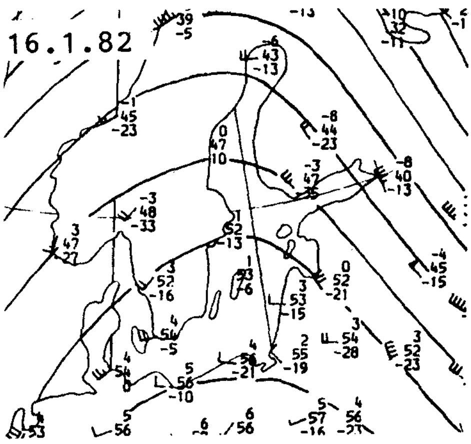
This image unfortunately lies along the scanning periphery and is, therefore, of lesser quality. Cold water is recognizable in the eastern sector of the Hanö Bay and southeast of Öland. At the Sill of Darss northwest of Rügen cold water can be seen on the surface.

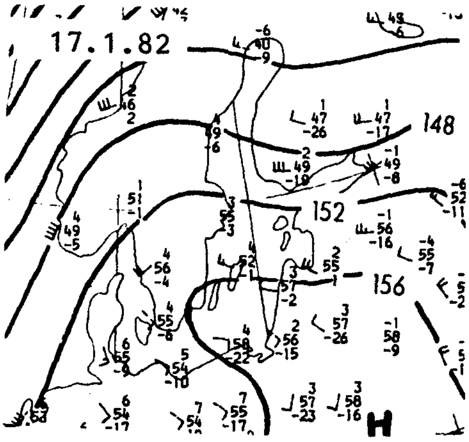

17.1.82 12.4


26.3.

81





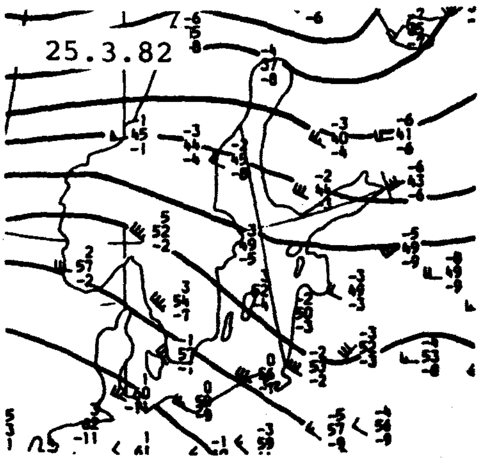


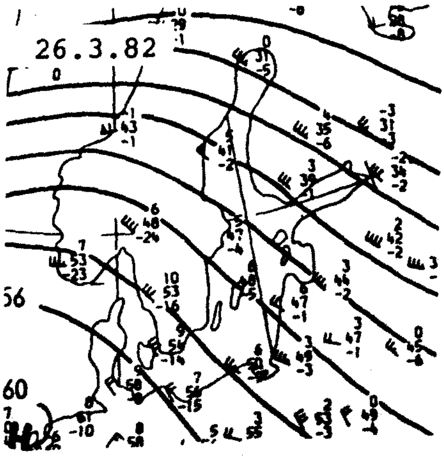
Temperature

	IV
	0m
17.1.82	1.2

17.1.82, 12.49 h, NOAA 7 IR

The satellite scene depicts ice-patches along the Polish coast and in the Kattegat in the middle of January. Cold water generally dispersing along the coast stretches from the eastcoast of central Sweden in a southeasterly direction and from the southeastern coast of Gotland southwards (compare also 22. and 23.2.81, p. 60).





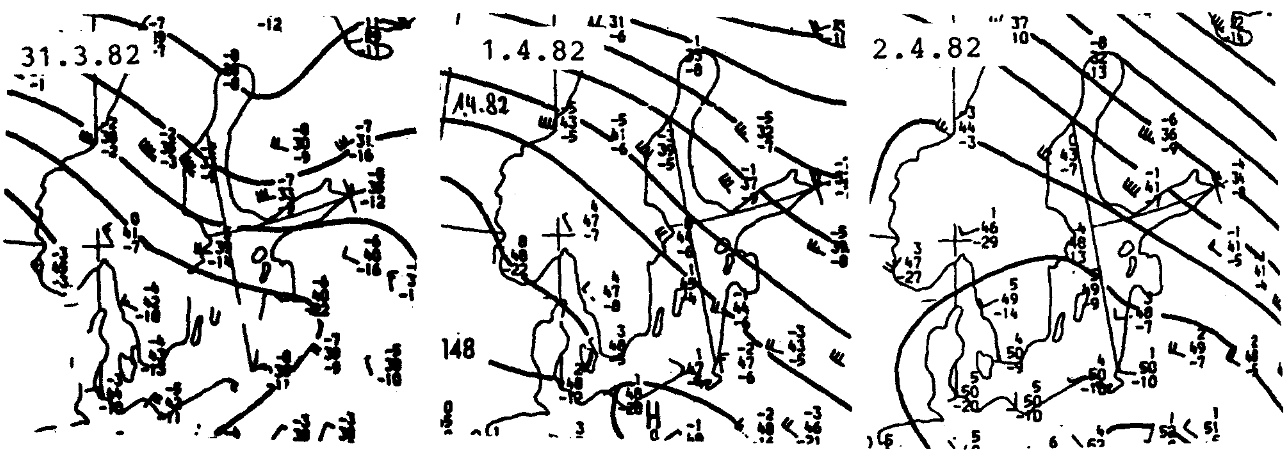
Temperature

	VI		
	0m	5m	15m
26.3.82	2.6	2.6	2.7

The infra-red image shows patterns of warmer water southeast of Rügen in the Bay of Pomerania. Warmer water is also visible along the coast of Lithuania, southeast of the islands of Öland and Gotland as well as along the Swedish mainland coast. An extended area of colder water lies north of Gotland.

1 to 2 April 1982

From 21 to 28 March a high pressure bridge lay over the southern Baltic. Low pressure troughs crossed the area on 29 March and after 30 March a high pressure area over Great Britain influenced the weather in northern Europe.



Temperature

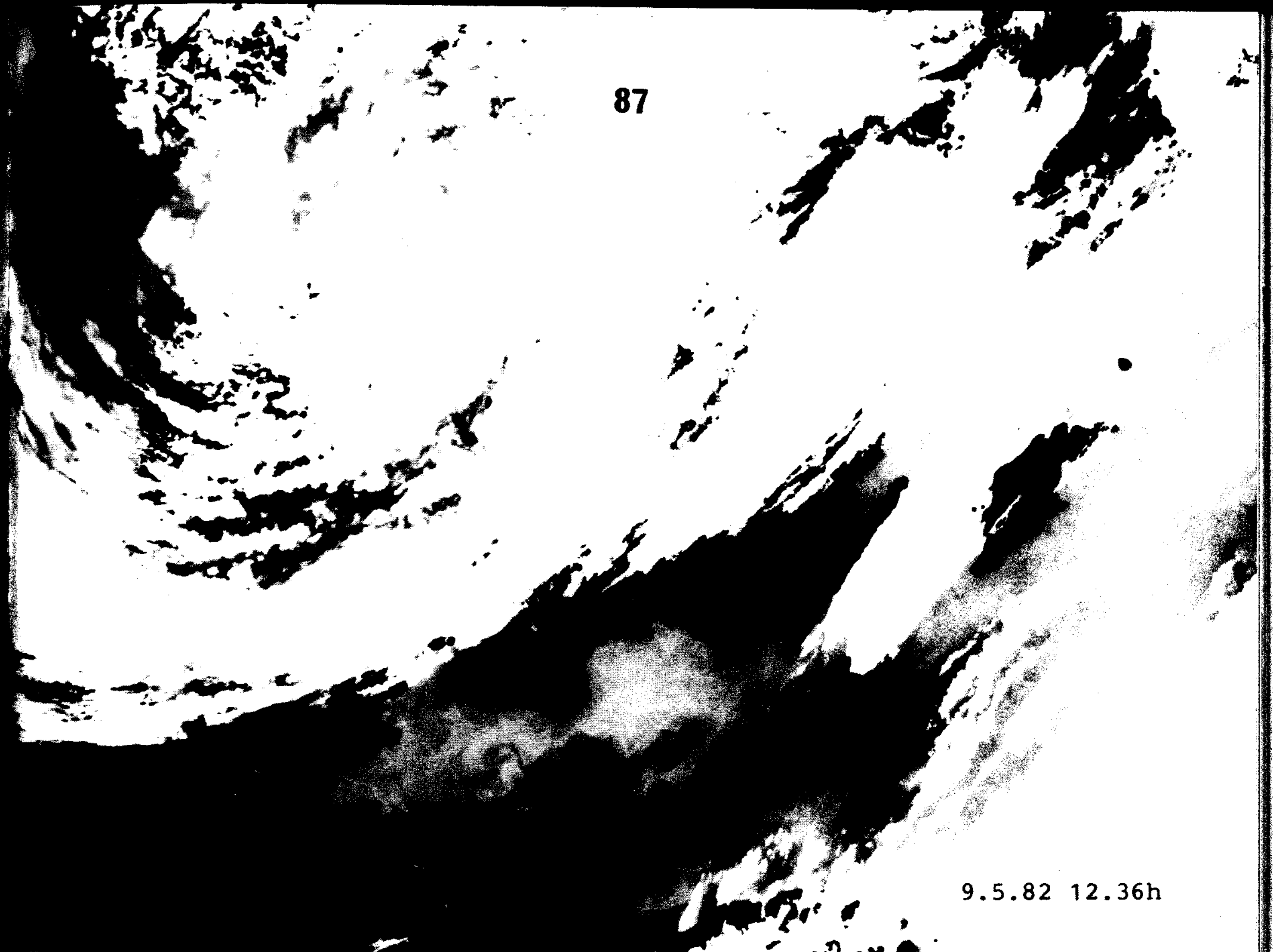
	III		IV	VI		
	0m	5m	0m	0m	5m	15m
1.4.82			1.6	3.6	3.6	3.5
2.4.82	1.8	1.8	2.0	3.8	3.5	3.1

1.4.82, 13.24 h, 2.4.82, 3.17 h and 2.4.82, 13.12 h all NOAA 7 IR

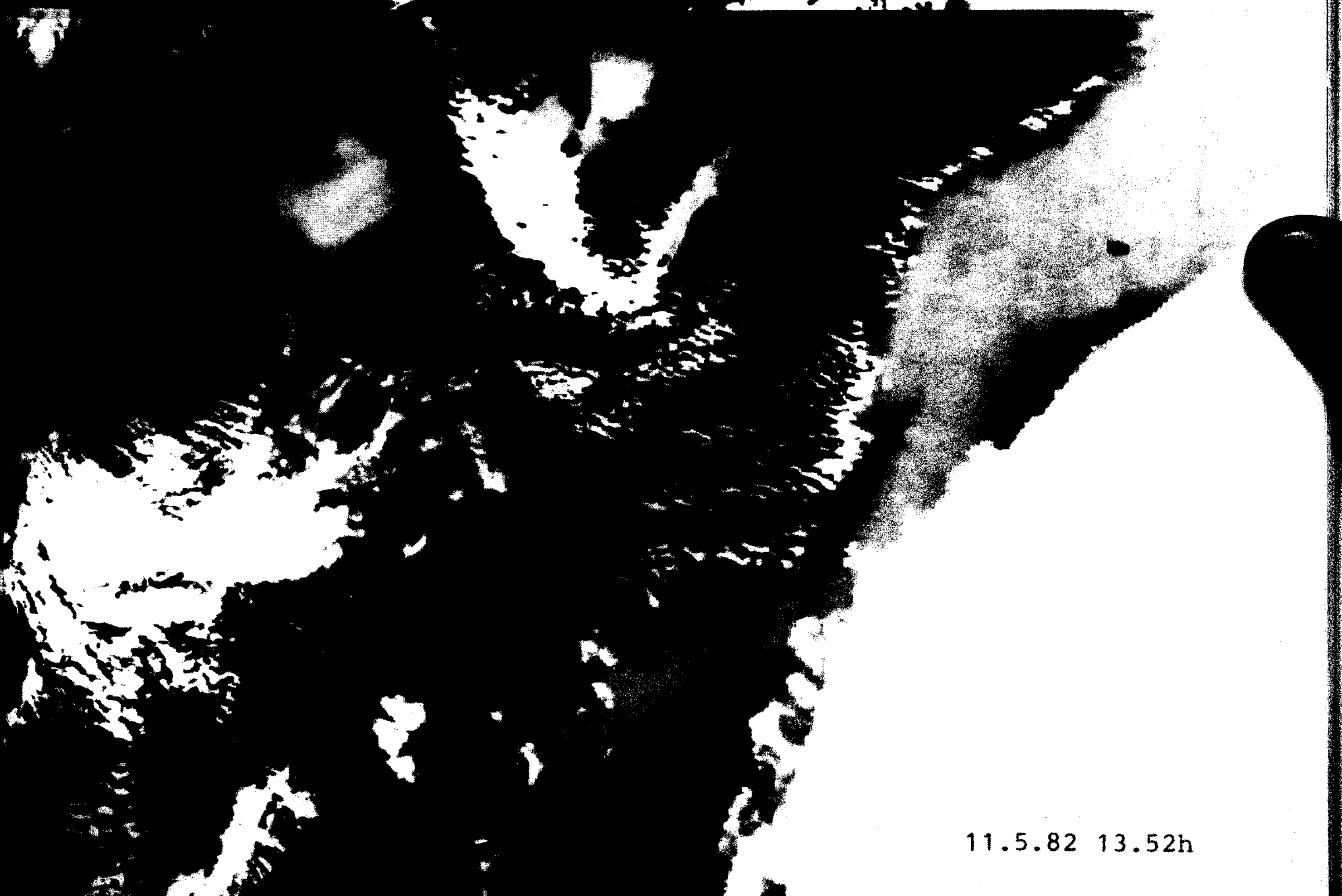
In the scenes of 1 and 2 April colder water is noticeable north of Gotland and in the Gulf of Riga. Warmer water is located along the coast of Latvia, in the southern section of the Gulf of Riga, in and southeast of the Bay of Danzig extending towards the north and southeast of Rügen. Furthermore, as shown in the infra-red night scene warm watermasses also occupy small strips along the southeastern coast of Gotland and Öland as well as along the coast of the Hanö Bay. Clearly visible is a series of eddies and fronts in the Arkona Sea and in the southern region of the Öre Sound.


27.4.82 3.23h


27.4.82 10.05h



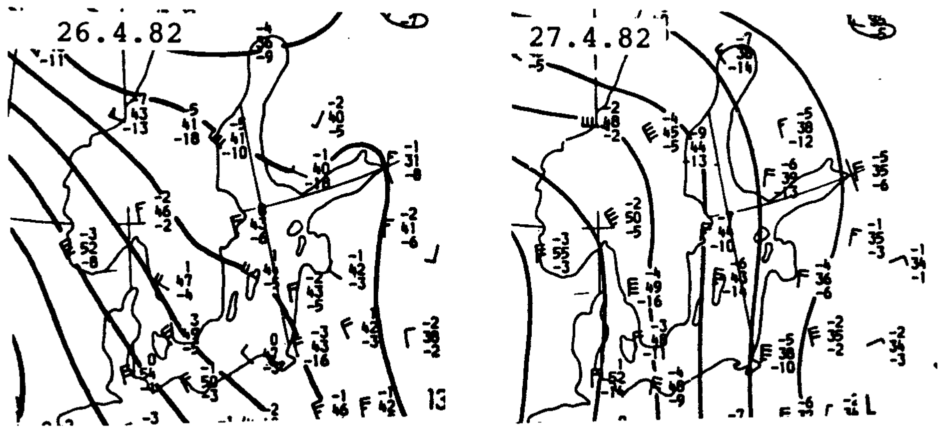
9.5.82 12.36h



11.5.82 13.52h

27 April 82

An extensive high pressure system influenced the weather in Europe since 14 April. On 27 April strong northerly winds dominated.



Temperature

	I	II		III		IV	V				
	15m	5m	15m	0m	5m	0m	0m	5m	15m	Cd	Cs
27.4.82	2.0	3.1	3.1	3.2	3.1	3.7	12.6	12.5	8.9	140	o.2

27.4.82, 3.23 h, NOAA 7

The infra-red scene indicates a relatively uniform surface temperature in the central Baltic. In the Bay of Pomerania and along the northcoast of Poland a body of warm water is perceptible. Furthermore, a narrow band of warm water is conspicuous in the coastal vicinity of the northern tip of the island, Hiiumaa.

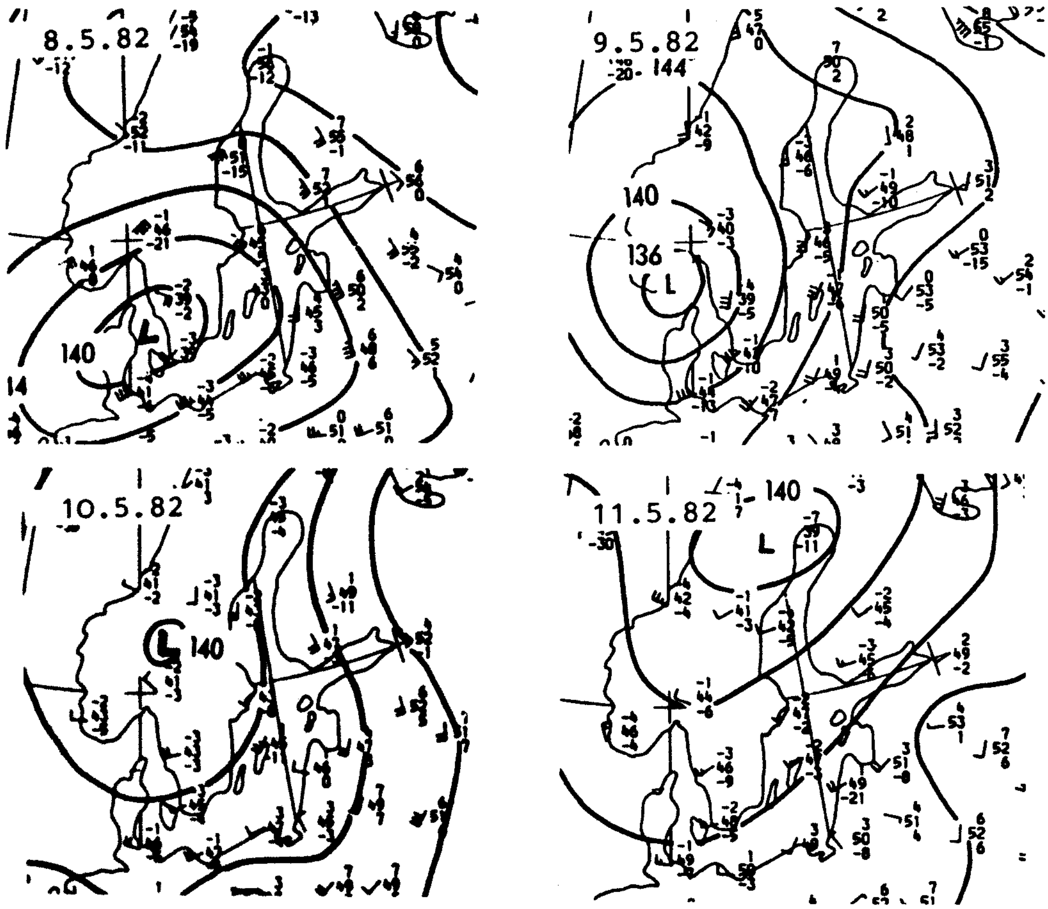
27.4.82, 10.05 h, CZCS, Channel 3

The image reveals the contours of the Oder Bank (water depth 6 - 9 m) southeast of Rügen, indicating strong penetrating effects of the light. This implies that at least in this area the spring phytoplankton bloom had already come to a close and phytoplankton has disappeared from the water column. Suspended material, very likely phytoplankton, is, nevertheless, recognizable in the central Baltic and, especially, along the eastern section of the Polish coast and the coast of Latvia and Lithuania. (Compare also 12.4. 79 page 6, 13.5.80 page 12 and 7.4.81 page 61.)

It can be assumed that mineral nutrients somehow enter the euphotic zone and cause increased phytoplankton development. The water depth in those areas does not permit the perception of reflected light from the sea floor. Unfortunately at 3.23 h when the NOAA 7 IR scene was recorded the westcoast of Lithuania and Latvia was covered with a heavy cloud layer, so that structures in the channel 3 of the CZCS cannot be compared with temperature data.

9 to 11 May 1982

From 3 May up to 10 May depression areas moved repeatedly over Europe from southwest to northeast. From 11 May onwards a high pressure area lay over southern Europe.



Temperature

	IV	V				
	0m	0m	5m	15m	Cd	Cs
9.5.82	4.7	5.3	5.3	4.9	360	0.3
11.5.82	5.3	5.9	5.8	5.6	360	0.2

9.5.82, 12.36 h and 11.5.82, 13.52 h both NOAA 7

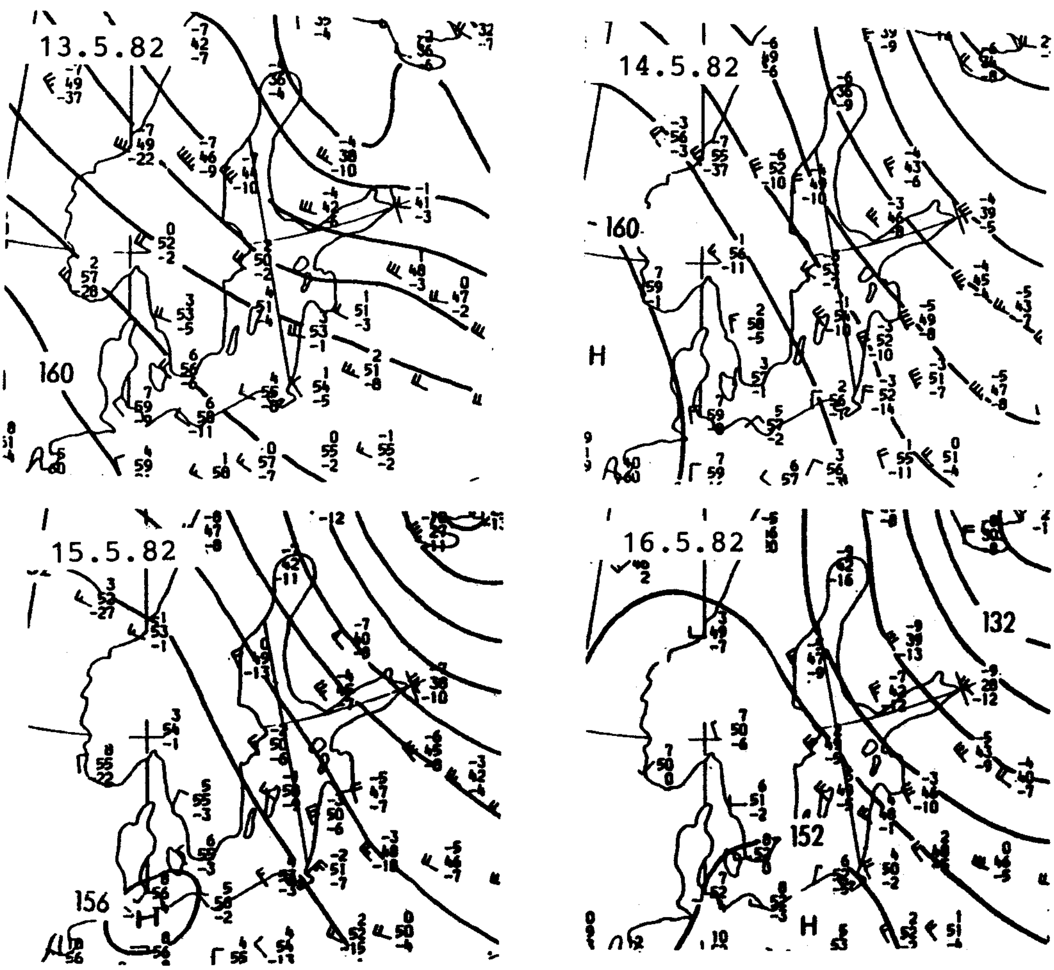
The scenes of 9 and 11 May disclose cold watermasses which apparently move north of Bornholm westwards towards the northern Arkona Sea, creating distinct patterns of eddylike structures west of Bornholm. In the Bay of Pomerania and towards its northern extension warmer water can be recognized. On 11 May a characteristic row of vortexlike patterns can be seen to extend from the sea areas east of Stockholm towards the south of Öland.


14.5.82 13.17h


15.5.82 13.05h

14 May to 16 May 1982

Following the repeated crossing of low pressure areas from the southeast over the Baltic in an easterly direction from 2 May to 10 May, a high pressure area was situated from 11 May to 15 May over central Europe.



Temperature

	IV	V					VI		
	0m	0m	5m	15m	Cd	Cs	0m	5m	15m
14.5.82	5.4	6.9	6.8	5.9	230	0.2	8.4	8.6	6.9
15.5.82	5.5	7.5	7.0	5.7	360	0.2	8.1	8.0	7.2
16.5.82	5.2	8.3	6.9	5.7	320	0.2	8.9	9.1	7.0

14.5.82, 13.17 h, 15.5.82, 3.11 h, 15.5.82, 13.05 h and 16.5.82, 12.53 h all NOAA 7 IR

There is a clearly regonizable succession of fronts and eddies in the western Baltic. Southwest of Fehmarn on 14 May there is a weak front visible, which by the night of 15 May has evolved into a well developed front. This front, in turn, develops into an eddy migrating in a westerly direction. North-northeast of Rügen an S-shaped double eddy can be recognized, whose more northern part migrates southwestwards in the course of the next 3 days, and whose southern section migrates about twice as quickly in a more westerly direction. At the inlet of the Öre Sound one can discern another weakly developed eddy, which moves northwards. Finally, south of Bornholm lies an eddy, which has 2 centres on 14 May and moves northwestwards (see Fig. 2). From the series of scenes one can distinctly make out the manner in which cold water from the Baltic advances into the Belt Sea and Kattegat. A colder body of water is recognizable on 14 May near the southeastern tip of Fehmarn and at the northern tip of Fehmarn in the night on 15 May. The watermass already extends another 15 km northwards by noon of the same day. This corresponds to a current velocity of 1.2 m per second, which is the value reported by the light vessel in the Fehmarn Belt. The frequently appearing zone of cold water northwest of Rügen on 16 May is, again, conspicuous.

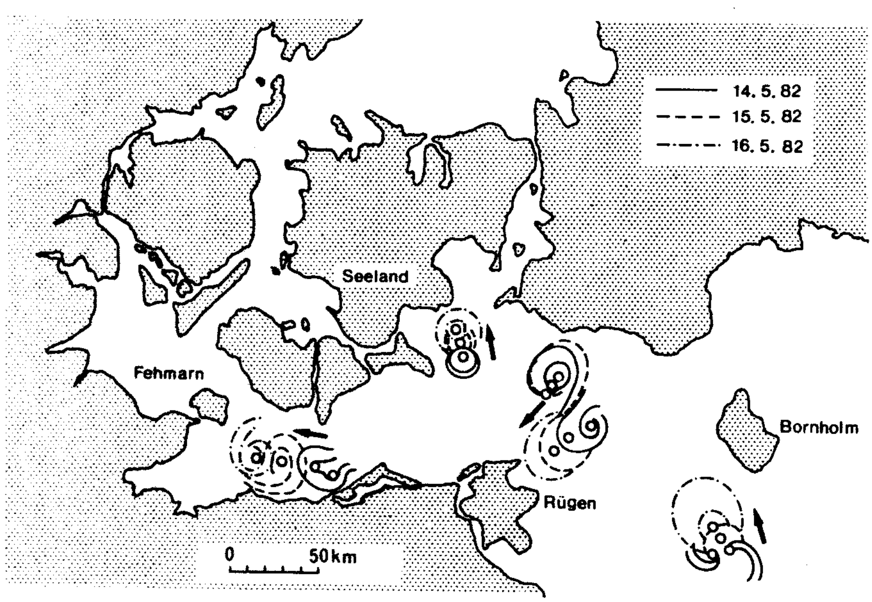


Fig.2: Migration of eddies in the western Baltic, from 14.5.1982 to 16.5.1982

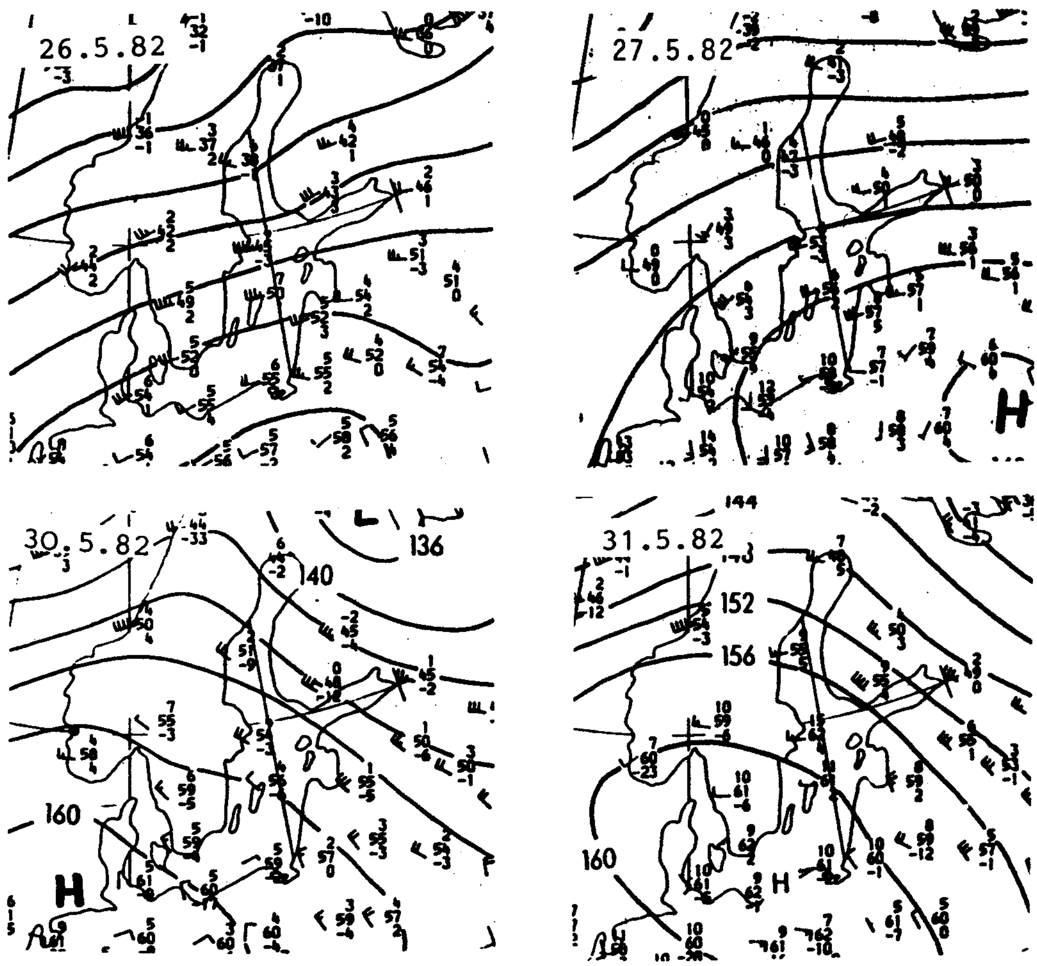

98
27.5.82 15.43h
31.5.82 13.16 h


1.6.82 3.09h


1.6.82 13.04h

27 May 82 to 1 June 1982

Low pressure troughs extended from the southwest out over the central Baltic from 16 to 24 May. From 24 to 28 May a high pressure belt crossed the Baltic area from west to east, which developed into a high pressure area in the next few days. On 26 and 27 May strong westerly winds dominated over the Baltic.



<u>Temperature</u>

	IV	V					VI		
	0m	0m	5m	15m	Cd	Cs	0m	5m	15m
27.5.82	8.0	9.2	9.2	6.3	290	0.1	12.5	11.0	7.6

27.5.82, 15.43 h, TIROS N IR

<u>Temperature</u>

	IV	V					VI		
	0m	0m	5m	15m	Cd	Cs	0m	5m	15m
1.6.82	11.0	12.0	11.3	6.3	270	0.3	13.5	13.5	7.3

A sequence of scenes of the western Baltic could be recorded during the period from 27 May to 3 June 82. On 27 May the scene presented lay along the scanning periphery but, nevertheless, reveals 2 distinct eddies north of Rügen and the evolution of another eddy in the Kiel Bight. As can be seen from the accompanying time series the dark sections in the Bay of Pomerania and along the northcoast of Poland are, in fact, not atmospheric disturbances but a body of warm water repeatedly observed in that area (see also 9.6.80, p. 30, 9.5.81, p. 61, 5.7.81, p. 74 and several others).
The white 'spots' west of Fehmarn are, indeed, atmospherically induced.

Temperature

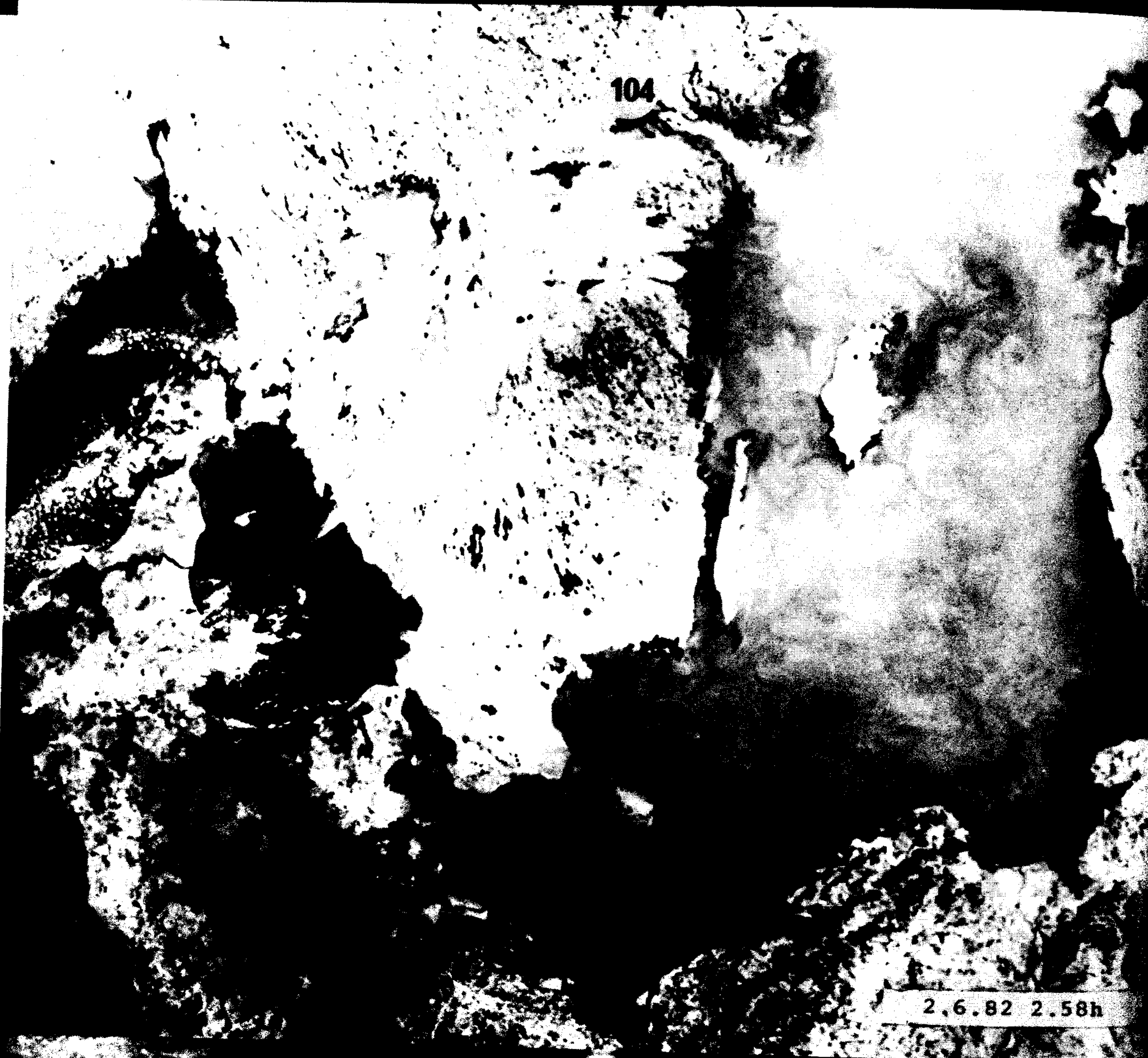
	V					VI			VII	
	0m	5m	15m	Cd	Cs	0m	5m	15m	0m	15m
31.5.82	11.0	10.4	6.8	0	0	14.2	12.2	10.0	11.5	9.6

31.5.82, 13.16 h, NOAA 7 IR

This scene depicts a whole succession of well developed eddies, whose migration can be observed in the following 5 images (see Fig. 3, p. 107). The dark region south of Bornholm is doubtlessly attributable to atmospheric influences, as is also true for the dark 'spot' west of Bornholm on 1 June 82.

1.6.82, 3.09 h and 1.6.82, 13.04 h, both NOAA 7

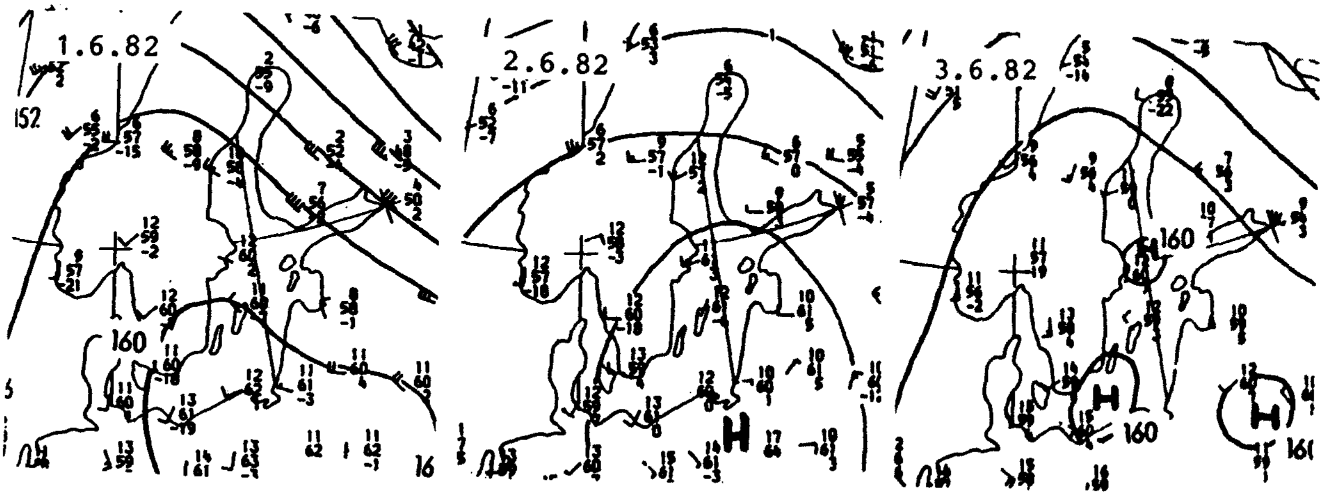
As in the period from 14 May to 16 May this series reveals the onset of a system of eastwinds following a short westwind period on May 27 and 28.
Prominant, again, is the warmer water east of Rügen extending up to the Rönne Bank (see night image from 2 June). In the Danzig Bay and along the coast of Latvia there is also warm water at the surface. The appearance of colder water northwest of Rügen is again discernable.


2.6.82 2.58h


2.6.82 12


3.6.82 2.46h


3.6.82 12.41h



Temperature

	I	II		III		IV
	15m	5m	15m	0m	5m	0m
2.6.82	6.2	10.0	8.3	11.4	9.5	12.8
3.6.82	8.4	10.3	8.5	13.0	8.9	14.0

	V					VI			VII	
	0m	5m	15m	Cd	Cs	0m	5m	15m	0m	15m
2.6.82	12.0	11.3	6.3	320	0.3	13.0	12.5	7.8	13.0	13.1
3.6.82	13.2	11.7	4.9	320	0.3	14.0	13.6	8.9	14.9	13.2

2.6.82, 2.58 h, 2.6.82, 12.52 h, 3.6.82, 2.46 h and 3.6.82, 12.41 h, all NOAA 7 IR

The scenes of 2 and 3 June clearly show warmer water along the coasts facing towards the west and north. In the image recorded during the night colder Baltic water can easily be traced as it moves through the Bornholmgatt and northern Arkona Sea into the Belt Sea (see Wessel 1971, map of average surface current of the Baltic) and, finally, into the Kattegat.

North of the Bay of Danzig a rarely observed anticyclonic eddy can be made out. The images recorded during daytime are of poor quality due to waves of warm air. The scenes, however, reveal the development of a cold waterbody near the Sill of Darss and the Hela Peninsula.

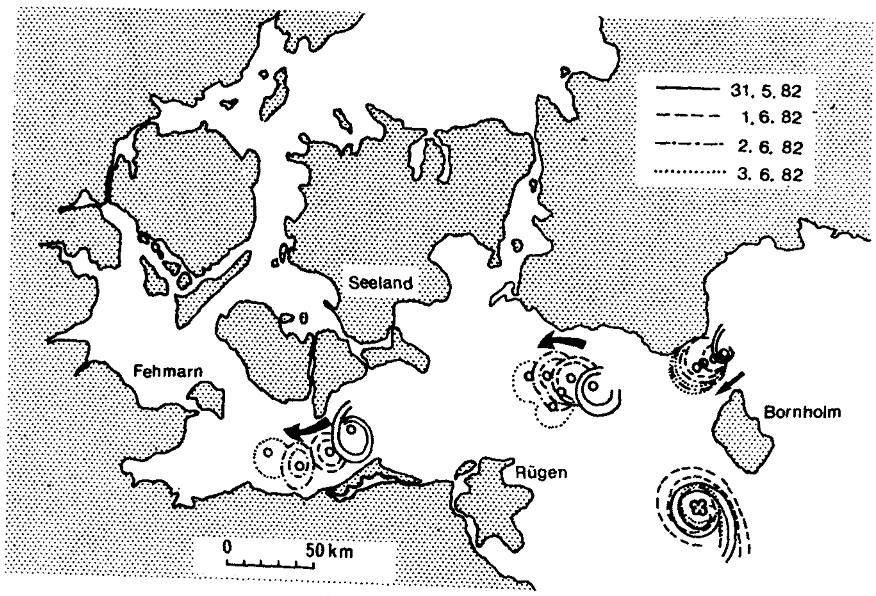


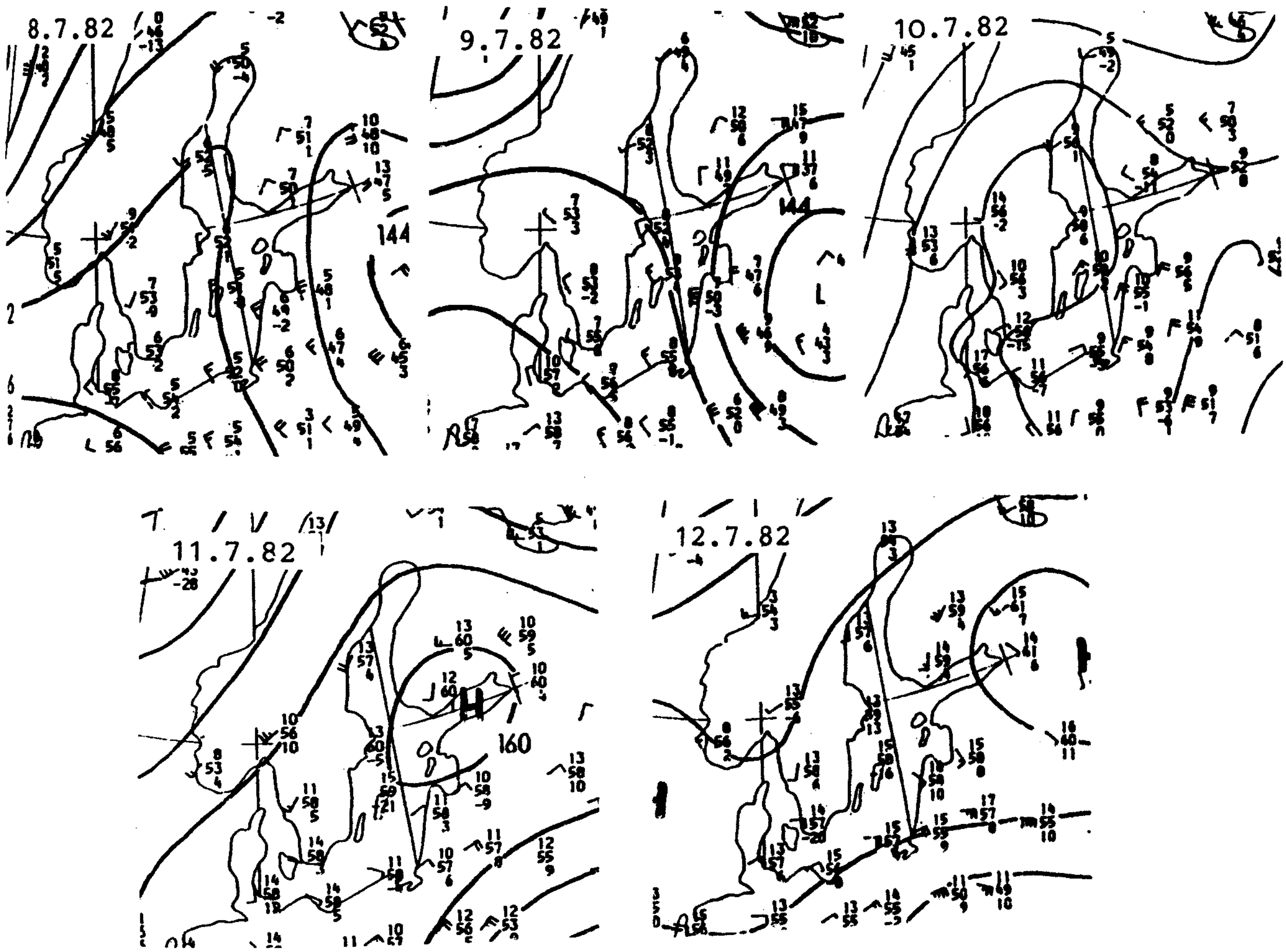
Fig. 3: Migration pattern of eddies in the western Baltic from 31.5.1982 to 3.6.1982


9.7.82 13.54h
10.7.82 13.42h
11.7.82 13.30h
12.7.82 13.19h


111
15.7.82 12.44h
16.7.82 12.32h

9 to 16 July 1982

From 4 July to 7 July low pressure troughs stretched eastwards over the southern Baltic.

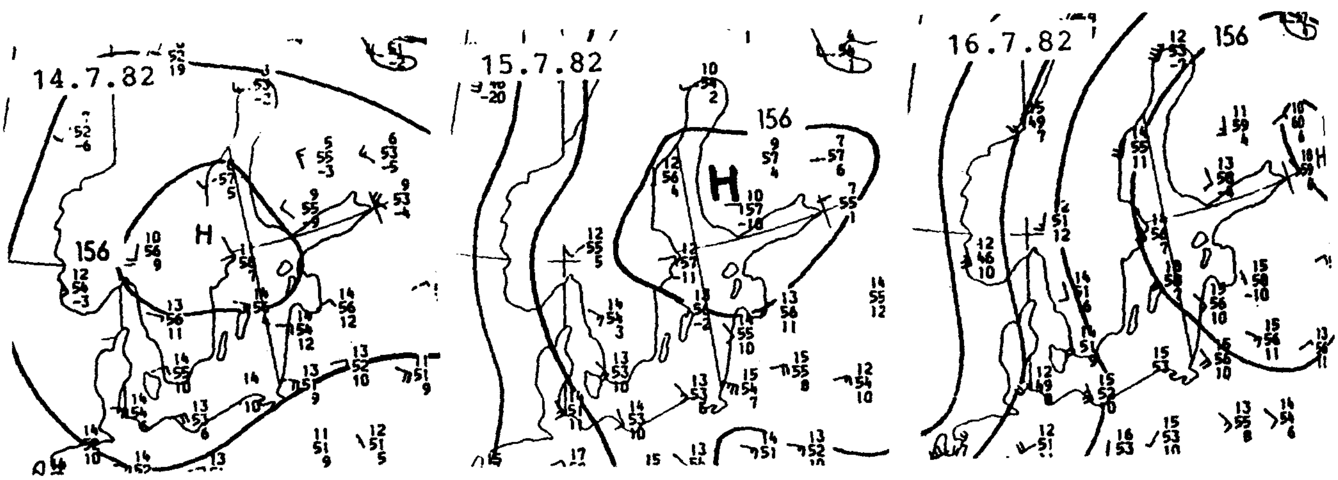


Temperature

	IV	V					VI		
	0m	0m	5m	15m	Cd	Cs	0m	5m	15m
9.7.82		14.8	14.8	9.2	270	0.8	15.2	15.5	13.6
10.7.82	14.2	15.6	15.6	6.4	270	0.6	16.5	15.8	14.4
11.7.82	14.9	15.1	15.0	12.0	320	0.4	17.5	15.2	8.7
12.7.82		15.6	15.6	6.8	320	0.4	17.3	15.9	14.9

9.7.82, 13.45 h, 10.7.82, 13.42 h, 11.7.82, 13.30 h and 12.7.82, 13.19 h, all NOAA 7

The series of 4 recordings displays the development of the migration of eddies in the Arkona Sea. Furthermore, the appearance of cold water northwest of Rügen on the 3rd day following a change in prevailing weather conditions (a shift from a westwind to an eastwind system) is clearly perceptible. In this series the velocity of migration of the eddies southeast of Fehmarn amounts to 14 km in 24 hours from east to west.



Temperature

	I	II		III		IV
	15m	0m	5m	0m	5m	0m
15.7.82	9.1	15.9	15.8			
16.7.82	9.0	15.8	15.1	16.1	16.0	14.6

	V					VI			VII	
	0m	5m	15m	Cd	Cs	0m	5m	15m	0m	15m
15.7.82	16.0	16.0	7.4	320	0.2	18.0	18.0	17.7		
16.7.82	15.8	15.8	0.0	340	0.2	17.7	17.8	10.6	19.6	18.6

15.7.82, 12.44 h and 16.7.82, 12.32 h

The two scenes demonstrate the extent of the upwelling northwest of Rügen. Along the northern coast of Poland, on the coast of Lithuania and Latvia and in the Gulf of Riga a weak band of cold water is identifiable. The same phenomenon is observed at the northernmost point of Öland and Gotland. Along the northern coast of Estonia structures of cold water are particularly distinct. The dark patterns in the southeastern Baltic and northwest of Gotland are of atmospheric origin.

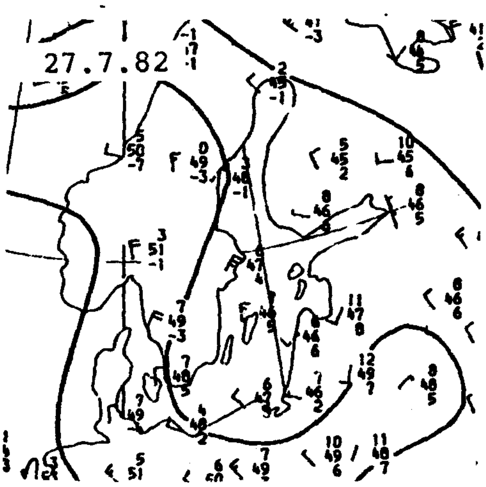

116
28.7.82 10.41h CH3
28.7.82 13.29h


1.8.82 10.10h CH3


1.8.82 12.41h

28 July

From 19 July to 30 July a high over Great Britain influenced the weather in northern Europe.

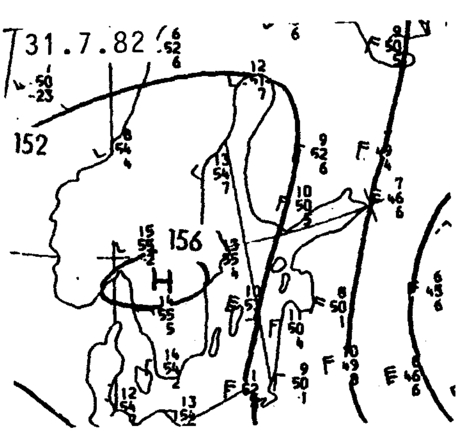


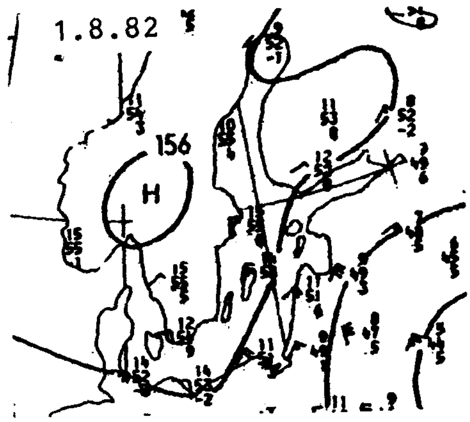
Temperature

	IV	V					VI			VII
	0m	0m	5m	15m	Cd	Cs	0m	5m	15m	0m
28.7.82	18.2	18.8	18.7	11.8	230	0.5	19.3	19.2	13.0	19.5

28.7.82, 10.41 h, CZCS and 28.7.82, 13.29 h, NOAA 7

The CZCS-scene of channel 3 reveals structures, which are attributable to the presence of blue-green algae in the surface waters of the western Baltic (ships' observations). These structures are also discernable from channels, 1, 2, and 4 but to a much lesser degree (not inlcuded here). Very distinct are 4 characteristic eddies west of Bornholm (see also 26.7.80, p. 37, 1.4.82, p. 81, 2.6.82, p. 104 and 1.8.82, p. 117). The infra-red recording made approximately 3 hours later depicts one of the eddies of the CZCS-scene very clearly, whereas the others are only slightly indicated. The pale colouration along the southern coast of Sweden is probably of atmospheric origin.





Temperature	I	II		III		IV
	15m	5m	15m	0m	5m	0m
1.8.82	15.6	19.2	16.7	18.8	17.7	19.6

	V					VI			VII	
	0m	5m	15m	Cd	Cs	0m	5m	15m	0m	15m
1.8.82	20.1	20.1	12.2	350	0.3	2040	20.4	15.2	20.5	17.5

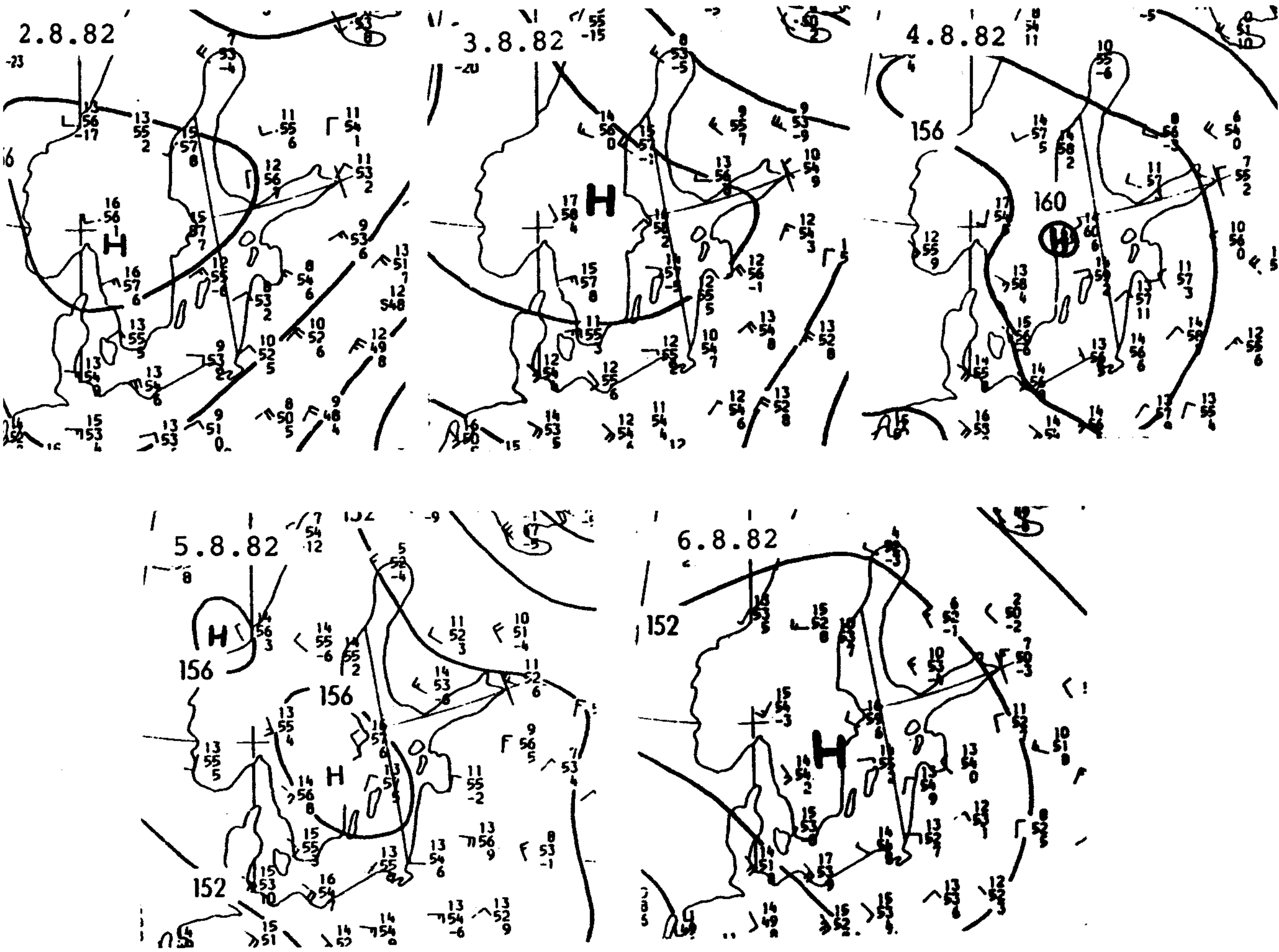
1.8.82, 10.10 h, CZCS, Channel 3 and 1.8.82, 12.41 h, NOAA 7

The CZCS-scene from 1 August shows, again, the distribution of blue-green algae in the surface layer of the Baltic. Furthermore, it is observed that in various zones of the Baltic completely different structures traceable through blue-green algae at the surface appear, south of Stockholm, in the central Baltic, in the Danzig Bay, along the northern coast of Poland as well as in the southern Belt Sea. The fact that the water column is relatively poor in suspended material is indicated by the appearance of the bottom-structures of the Oder Bank southeast of Rügen. The structures along the coasts of Lithuania and Latvia are probably not attributable to surface drifting blue-green algae. As revealed in the infra-red image colder watermasses are dispersed along the coasts of Latvia, Lituania and the islands of Saaremaa and Hiiumaa, and, also, along the northwestern coast of Gotland. These masses doubtlessly originate from deeper water layers due to Ekman upwelling. Note, also, the cold water northwest of Rügen and along the Polish coast.


122
1.8.82 12.41h
2.8.82 14.10h


123
4.8.82 13.46h
5.8.82 13.34h
6.8.82 13.22h

From 1 August to 6 August a high pressure area with its centre situated over Sweden determined the weather over the Baltic Sea.



<u>Temperature</u>	I	II		III		IV
	15m	5m	15m	0m	5m	0m
2.8.82	14.9	19.1	18.5	19.1	18.8	20.4
3.8.82	15.0	20.4	17.9	20.2	20.3	20.2
4.8.82			15.4	20.7	20.1	20.4
5.8.82	15.3	21.4	18.1	20.8	19.9	20.6
6.8.82	14.9			21.2	20.8	20.7

	V					VI			VII	
	0m	5m	15m	Cd	Cs	0m	5m	15m	0m	15m
2.8.82	19.8	19.8	8.2	360	0.2	20.8	20.5	14.0		
3.8.82	20.1	20.1	20.0	320	0.2	20.1	20.0	13.9	21.2	19.4
4.8.82	20.4	20.4	14.1	270	0.2	19.6	19.6	13.1	21.6	19.2
5.8.82	20.6	20.5	13.9	270	0.2	19.5	19.4	16.8	22.2	19.7
6.8.82	20.6	20.5	15.6	230	0.2	19.4	19.5	12.8	22.3	19.9

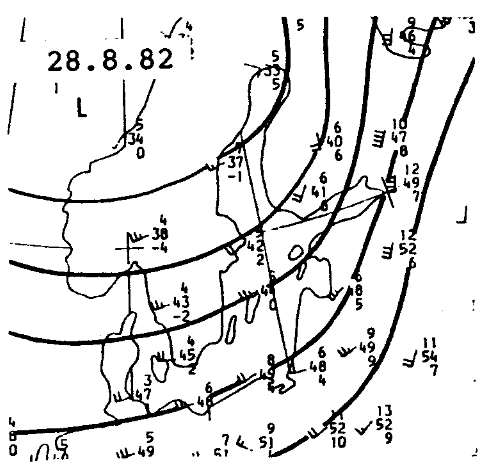
This series of images demonstrates the appearance of cold water in the southern Baltic. After a brief period of westwinds at the end of July eastwinds coincide with an outflow of Baltic water and, two days later, the appearance of cold water at the Sill of Darss can be observed (see also 9.-12.7.1982, p. 110). The cold water area visible on 1 August along the coast of Lithuania and Latvia can be regarded to be Ekman upwelling due to northerly winds in this area at this time. As a consequence of eastwinds on 2 and 3 August upwelling appears along the coast of Poland.

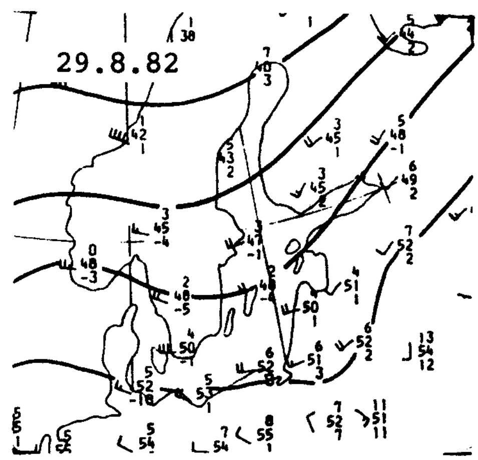

128
29.8.82 13.49h


129
19.9.82 13.08h
21.9.82 12.36h
26.9.82 13.17h

29 August 1982

From 14 to 27 August troughs of low pressure repeatedly crossed northern Europe in the form of a strong westerly drift. Only from 28 to 30 August was there a high pressure region over central Europe.





Temperature

	15m	5m	15m	0m	5m
29.8.82	15.6	12.6	11.1	11.6	11.5

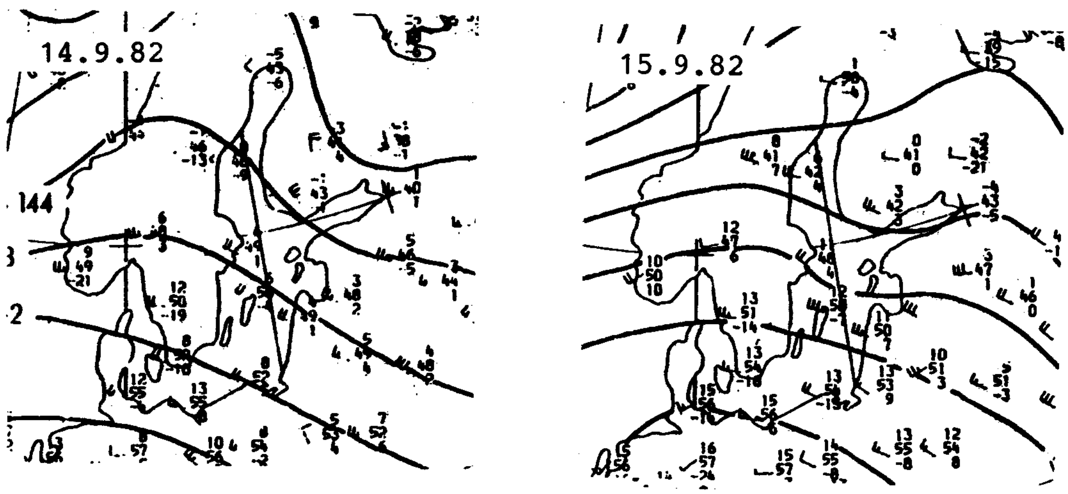
	VI			VII	
	0m	5m	15m	0m	15m
29.8.82	16.2	16.2	15.1	16.4	16.6

29.8.82, 13.49 h, NOAA 7

In the scene from 29 August 82 cold water is discernable along the Swedish eastcoast from Stockholm into the Hanö Bay. Along the east-coast of Öland and the southeastern coast of Gotland as well as the coast of southeastern Saaremaa there is cold water at the sur-face due to upwelling caused by southeasterly winds. A band of warmer water extends from the Bay of Danzig towards the northeast.

15 September 1982

From 5 to 8 September low pressure areas accompanied by troughs crossed the central Baltic in a westerly drift. On 8 September a high pressure wedge from the Azores determed the weather, and from 9 to 14 September a high pressure belt formed over central Europe developing into a region of high pressure on 15 September.



Temperature

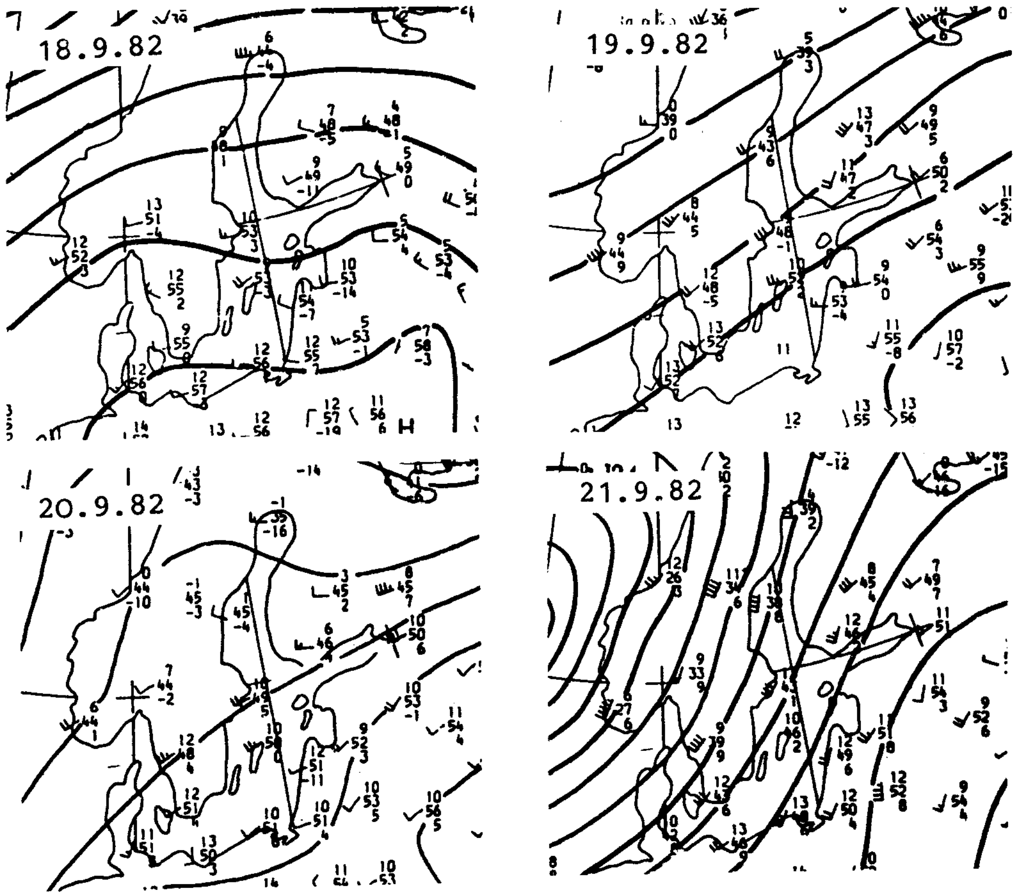
	IV	V					VI		
	0m	0m	5m	15m	Cd	Cs	0m	5m	15m
2.6.82	15.0	15.0	14.9	14.9	90	0.1	15.6	15.6	14.1

15.9.82, 13.47 h, NOAA 7

As already observed on 29 August, colder water along the Swedish eastcoast is clearly perceptible. Isolated cold water fronts have penetrated from south of Gotland and Öland far into the central Baltic. Cold water fronts are also discernable west of Bornholm in the Arkona Sea. The eastern Baltic lies under cloud cover.

19 September 1982

From 18 to 20 September the centre of a high pressure area shifted slowly towards eastern Europe and, consequently, low pressure troughs from the southwest extended out over the central Baltic.



Temperature

	V					VI			VII	
	0m	5m	15m	Cd	Cs	0m	5m	15m	0m	15m
19.9.82	15.4	15.4	14.8	320	0.2	16.0	16.0	16.0	15.1	15.5

19.9.82, 13.08 h, NOAA 7

Still weak on 18 September but stronger on 19 September southwesterly winds may well be considered to be the cause for the appearance of cold water along the eastcoast of Sweden.

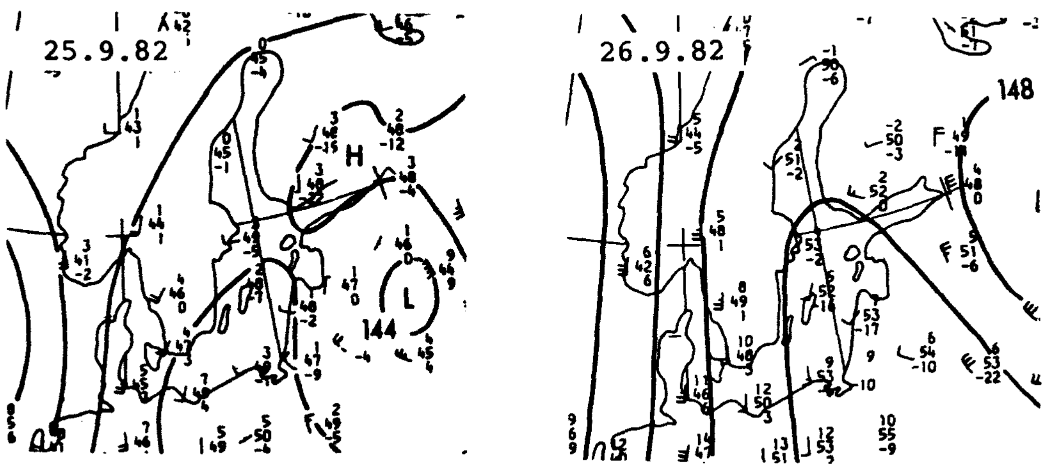
21 September 1982

Disturbances in a west wind drift crossed over central Europe from 21 September to 24 September. Included were troughs which moved from southern England to Scandinavia.

Temperature	V					VI			VII	
	0m	5m	15m	Cd	Cs	0m	5m	15m	0m	15m
21.9.82	15.6	15.6	15.3	140	0.3	16.0	16.0	14.6	15.1	16.8

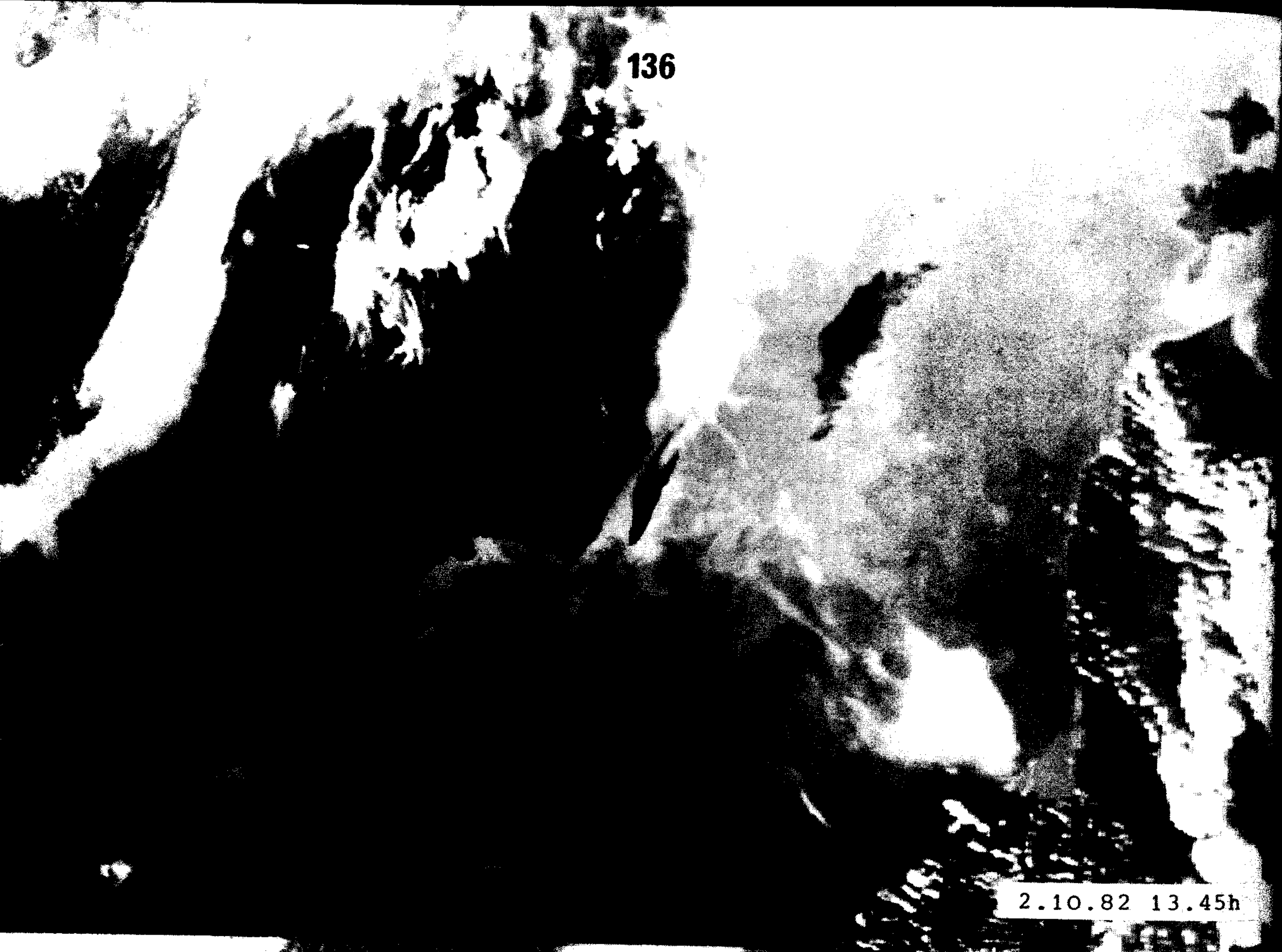
21.9.82, 12.36 h, NOAA 7
Strong winds from the southwest induce the upwelling of cold water along the southeast coast of Sweden especially in the area south of Stockholm and along the island of Öland. The colder water in the northern region of the Gulf of Finland could also be considered as Ekman upwelling. No considerable water temperature differences are recognizable in the area surrounding Gotland.

26 September 1982
From 25 to 30 September troughs of low pressure moved across Northern Europe from the southwest. On 26 September southerly winds dominated over the Baltic.



Temperature	V					VII	
	0m	5m	15m	Cd	Cs	0m	15m
2.6.882	14.9	14.9	14.4	320	0.3	4.5	14.4

26.9.82, 13.17 h, NOAA 7
Colder water is still discernable in the Hanö Bay and in that part of the eastcoast not covered by clouds. Clearly visible is a ribbon of colder water along the Hela Peninsula in the northern Bay of Danzig. Its development could already be observed on 19 September. In the western region of the northcoast of Poland cold water at the surface also becomes visible. One can recognize that colder water surrounded by warmer watermasses extends from the area north of the Bay of Danzig northwards.


2.10.82 13.45h

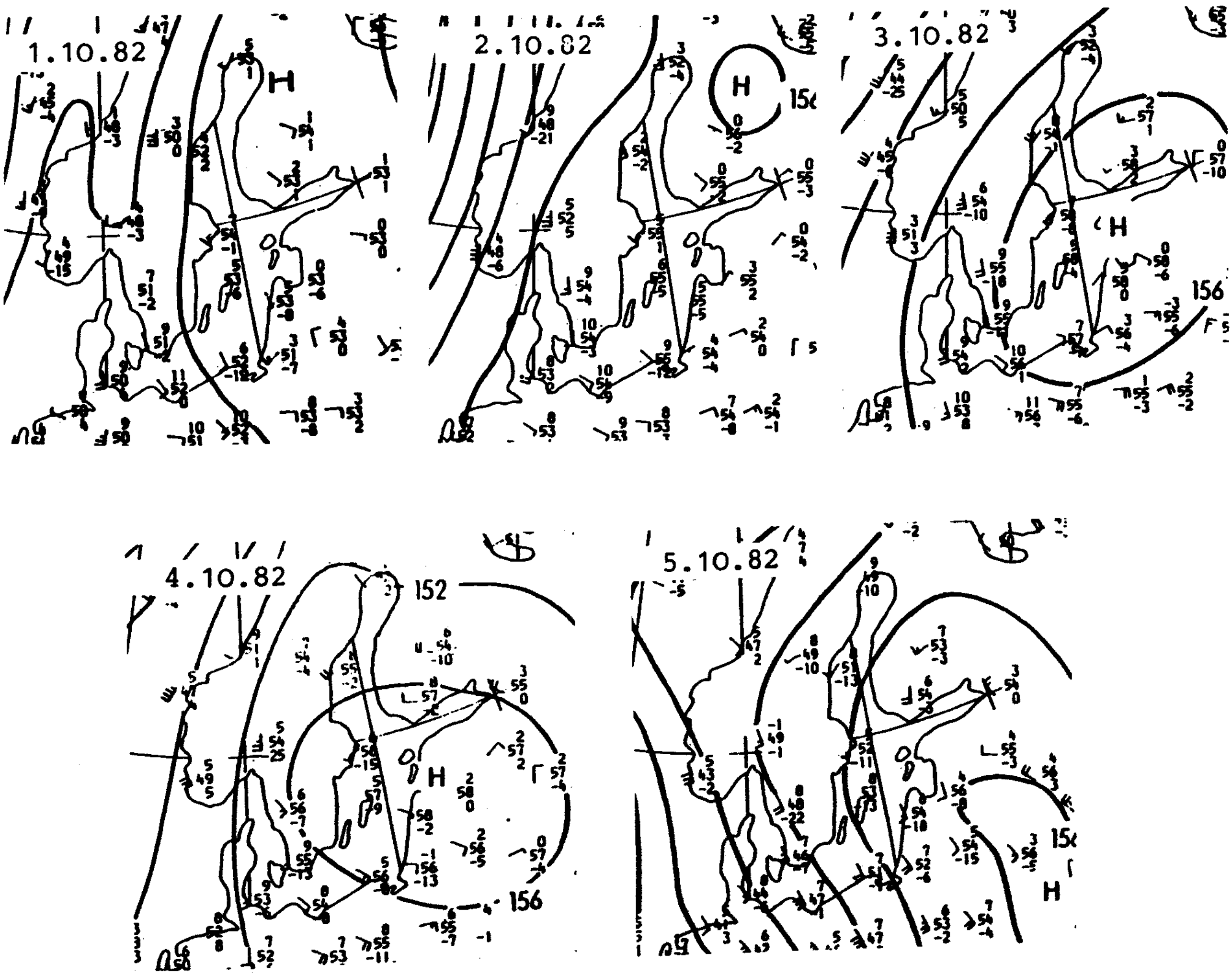

3.10.82 13.33h

4.10.82 13.21h

5.10.82 13.09h

2 October 1982

From 25 to 30 September low pressure troughs displaced by a ridge of high pressure from 27 to 29 September cross the Baltic. Thereafter, from 1 October on, a high pressure system determines the weather conditions over the Baltic.



<u>Temperature</u>

	V					VI		
	0m	5m	15m	Cd	Cs	0m	5m	15m
2.10.82	14.5	14.5	12.6	90	0.2	15.0	15.0	12.6
3.10.82	15.0	15.0	14.2	110	0.2	13.9	13.8	12.4
4.10.82	14.4	14.4	14.2	340	0.2	14.3	14.3	13.5
5.10.82	14.3	14.3	14.3	90	0.1	14.8	13.8	13.7

2.10.82, 13.45 h, 3.10.82, 13.33 h, 4.10.82, 13.21 h, 5.10.82, 13.09 h, all NOAA 7

On 2 October colder water in the Hanö Bay and around the southern point of Öland is still detectable. At the northern promontory of Latvia colder water is seen at the surface. Colder watermasses along the western stretch of the Polish northcoast have expanded and, as so often observed, cold water is present at the surface northwest of Rügen. In this sequence of 4 scenes a series of characteristic transport processes can be observed: in the southern Belt Sea a small front of cold water originating in the area west of Rügen wandered from Fehmarn (2 October) up to the northern tip of Langeland (3 October). A tongue of warmer water northeast of Rügen advances in a northerly direction and breaks up on 4 October. The upwelling of colder water along the northcoast of Poland west of Rügen as well as that located north of the Hela Peninsula intensifies within the next 4 days and exerts a considerable influence on the southwestern area of the Baltic. In the southwestern region of the Hanö Bay an eddy indicated cold water arises and moves southeastwards. In the eastern part of the Hanö Bay near Klipp Bank one can make out another eddy of cold water, which advances slowly northwards in the next 4 days. Simultaneously, in the east, on the far side of a warm water front moving northwards, there is a small colder eddy migrating towards the south. Unfortunately, on 2 and 3 October the eastern section of the Baltic is recorded in the scanning periphery and, consequently, the picture quality suffers. The stronger contrast on 4 and 5 October is of a technical nature. Nevertheless, it is clear that the cold water upwelling near the Hela Peninsula intensified, and a small eddy of cold water, which apparently degenerated northwest of Hela on 2 October, wanders towards the northeast on 3 October and then assumes a strictly easterly course. As determined from photographic enlargement the rate of migration is 9 km per day. Clearly observable is the progress of 2 cold water eddies, which arise off the northwestern coast of the Gulf of Riga and wander in a northeasterly direction.

DISCUSSION

The aim of this study is to indicate the importance of satellite imagery for Baltic oceanographers. It is not meant to give a detailed discussion on processes inducing patterns visible in the satellite images. However, some of the most striking features especially those indicating vertical transport or mixing processes are commented upon in this volume.

Upwelling:

Except for the spring and autumn periods during which warmer water can be found beneath a cooled surface layer in the Baltic (see temperature recordings appended to the respective scenes) pale structures corresponding to colder water can indicate upwelling in the Baltic.

Upwelling during offshore winds is observed several times, whereby along almost all Baltic coasts water from deeper layers is dispersed in a windward direction (see 8.6.80, p. 25 or 15.7.82, p. 111). Much more effective is the upwelling with coast-parallel winds. When the coast is situated to the left relative to coast-parallel winds, a drift to the right at a 90° angle to the wind's direction forms, and consequently, according to the Ekman theory induces upwelling. Very clear examples of this phenomenon are depicted on 1.8.82, p. 117, 29.8.82 and 15.9.82, p. 128, as well as 19.9.82, p. 129, and also from 2.10. to 5.10.82, pp. 136 and 137. It is repeatedly documented in literature that upwelling along the Swedish southeastern coast plays an important role for the vertical nutrient transport in the Baltic (Kullenberg, 1974, Jansson, 1978). Svansson (1975) cites that out of 20 measurements at different occasions about half showed upwelling in that area. On the satellite images of the last 3 years, however, upwelling was distinct only in late summer and autumn 1982 (see pp. 128, 129 and 136). A period of slight upwelling in the Hanö Bay and further northeast can be made out in September 1980, p. 55 and in May 1981, p. 69. Nevertheless, the appearance of upwelling along the Estonian and Latvian westcoast with northerly winds, and along the German-Polish coast during periods of eastwinds is shown to play an important role in the vertical nutrient transport in 1980, 1981 and 1982.

One may object that satellite images of the cloud-free Baltic are rather a subjective selection as to wind situations, since westerly winds usually cause a cloudcover over the Baltic. This is to a certain extent correct. The presented selection of images, however, shows quite a few cloud-free scenes accompanied by a westwind. However, there are also a number of images showing the Baltic right after the change from west to eastwinds. In these cases upwelled water can be expected to be visible several days later, once it differs in temperature from surface water.

Distinctly visible and remarkably frequent is the upwelling area northwest of the Island of Rügen (compare pp. 30. 42, 54, 93, 104 , 123 and 137). As is evident in the various series of satellite recordings cold water can influence the southern Belt Sea up to a point within the Kiel Bight and thus considerably affect the nutrient balance in this region. From the comparison of the presented series of images with weather data and current direction data from the lightships Fehmarn Belt and Mön SE, it is observed that in 6 out of 7 cases demonstrated above the appearance of cold water at the Sill of Darss occurs 2 to 3 days after a change from a westwind to an eastwind situation with the consequent change from a system of inflow into the Baltic to that of outflow. Moreover, this phenomenon of upwelling is intensified considerably within the next few days in each case. Kielmann (1981) postulated through his numerical model, that outflow in deeper waterlayers (layer 2, 15 - 20 m) is interrupted at the Sill of Darss and must result in a vertical transport mechanism. It would be interesting to determine from which depth this water actually originates.

Eddies and their migration in the western Baltic

Among the most characteristic structures observed on satellite images are the eddies in the central and western Baltic. Such eddies, the theory of which is discussed more extensively by Kielman (1981) and Aitsam and Elken (1981) can exist as two different types of waves in the Baltic: firstly, as internal Kelvin waves with a wave length of less than 10 km along narrow sections of the coast, and secondly, as topographic Rossby waves appearing as eddies with a diameter of 30 - 40 km and advancing along the isobaths (Aitsam and Elken 1982, Kielmann 1981, Svansson 1975). The eddies identified on the satellite images through temperature anomalies, change in water colour or accumulation of blue-green algae at the water surface vary considerably in their sizes. The

eddies in the western Baltic are mostly from 18 to 25 km in diameter, but they are also observed to attain a diameter of up to 35 km. At the southern outlet of the Öresund in the Lübeck Bay eddies of only 10 km are perceived. Aitsam and Elken (1982) state that the typical horizontal dimensions of the eddies in the Baltic are on the order of 2 to 6 times the Rossby radius (CR_d = 10 km). Almost all eddies in the Baltic show cyclonic circulation (exception see p. 104).
From some examples of series of satellite images, especially in the western Baltic, it can be seen how eddies dissociate from fronts and then continue migrating (see pp. 13, 9 2, 98). Aitsam and Elken (1982) conclude from their hydrographic surveys, that the observed eddies may originate from baroclinic instabilities due to vertical shears. Differing migratory speeds and directions can be determined for different locations in the western Baltic (see Fig. 2, p. 96 and Fig. 3, p. 108). As documented by the comparison of the directional movements of 2 series (14 to 16 May 82 and 31 May to 3 June 82) the eddies migrate in completely different directions, although the movements are within the same region. The eddies' rate of migration in the Arkona Sea and south of Bornhom are different and vary at the different occasions observed. Some are almost stationary (within 4 days of observation), others move 3, 4, 6 or 11 km per day, while a rate of 14 km per day is evidenced in three recorded situations in the Mecklenburg Bay (see Figs. 2 and 3). Aitsam and Elken (1982) found migration speeds of a few cm/sec. From the continual surveillance of eddies by means of satellite images it can be determined that in contrast to Aitsam's and Elken's (1982) observations, the eddies observed on the satellite images in the western Baltic do not migrate along isobaths. It is, therefore, questionable, whether free topographic waves are actually involved or not. Nevertheless, especially as a result of the Baltic current, an advection of the surface structures may alter the direction of pattern originally induced by topographic Rossby waves. The characteristic structure of the vortex row extending from east of Bornholm into the Lübeck Bay, as observed on 28 July 82 and on 1 May 82, could be explained through barotrophic instabilities arising from a shear.

The implication of eddies for vertical mixing and, hence, for the input of nutrients to the surface region from deeper layers as has been emphasized by Svansson (1975), Kielmann (1981) and Aitsam and Elken (1982) can be considered important for the primary production in the Baltic. Their degree of importance, however, is still to be determined. Vertical velocities below and between eddies are calculated by Kielman (1981) in his mathematical 3-dimensional model. The model postulates maximum vertical velocities of 10^{-4} cm per second at a depth of 50 m in an eddy induced east of Bornholm. Aitsam and Elken (1982) found that the vertical synoptic scale displacements of the isopycnals in eddies can be more than 20 m. The existence of vertical movements beneath eddies and the respective transport of nutrients was substantiated by Kahru et al. (1981) and Kahru (1982) in the BOSEX region of the Gotland Basin.

Though only a few exciting phenomena observed on the satellite images have been mentioned, there is much more information in the presented scenes requiring systematic evaluation. For this, however, sea truth data are indispensible. Quite a number of such data do exist from the Baltic for the years 1980 to 1983, and some of them can be attributed to one or the other scene presented. However, more ship data are needed and should be correlated with the satellite data.
If this compilation of satellite images has given an indication of where to look in the Baltic for what processes and at what times, it has served its purpose.

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