

SUPPLEMENT No. 403

The m/s ESTONIA accident. Weather conditions on September 27th
and 28th 1994.

Swedish Meteorological and Hydrological Institute.

Norrköping 1995.

1995-12-04

Board of Accident
Investigation,
Sweden

STATENS HAVERIKOMMISSION	
Ink	1997 -10- 0 8
Dnr	ESTONIA
Aktbil. nr	C 35

The m/s ESTONIA accident;

Weather conditions on September 27th and 28th 1994

General

The weather conditions on the 27th was dominated by an intense and large low pressure area with several sub lows, covering northern Scandinavia and the Norwegian Sea. Refer to the weather chart over Europe in figure 1 (bilaga 1) from 12 UTC Sept. 27th.

One of the sub lows intensified on the 27th and rapidly moved eastward via southern Norway and eastern Sweden to southern Finland. The low became relatively intense and was located over Oslo on Sept. 27th at 12 UTC with pressure 995 HPA, on Sept. 28th at 00 UTC over the southeastern part of Sea of Bothnia with 980 HPA and on Sept. 28th at 12 UTC over eastern Finland with 985 HPA. A warm front, associated with the low, together with an area of rain, moved quickly eastward during the evening of the 27th over the northern Baltic sea. South and southwest of the low the wind shifted from southwesterly to westerly, the westerly becoming very gusty.

THE WEATHER CONDITIONS ON NORTHERN BALTIC SEA AND GULF OF FINLAND SEPTEMBER 27TH

The weather can be described with a map of observations from different places. In figure 2 to 6 (bilaga 2-6) these maps are shown for the period of interest. Weather observations are made simultaneously every third hour, beginning at 00 UTC. Swedish time is equal to UTC-time plus 1 hour. Finnish and Estonian time is equal to UTC-time plus 2 hours. In this report, Swedish time, called L.T. (UTC time plus 1 hr) is used unless indicated otherwise. In some of the figures, the time notation Z is used, which is equal to UTC.

The winds on the chart is denoted by an arrow flying with the wind. The arrow has short and/or long cross bars indicating the wind speed. One short bar means 2.5 m/s, one long bar means 5 m/s.

For example:

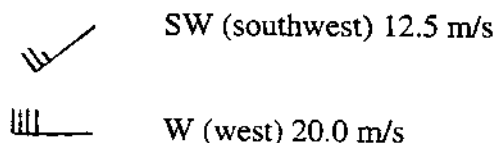


Figure 7 (bilaga 7) shows a map of selected observation sites which have been found representative to present the weather conditions on northern Baltic sea: Söderarm, Svenska Högarna, Bogskär, Utö, Russarö, Bagaskär and Ristna.

Observations are also made in Tallinn, however those are impaired by lee wind effects. For instance, no wind speed over 7 m/s were reported from Tallinn during the period of strong winds which occurred on Sept. 27-28th.

In figure 8 (bilaga 8), the weather observations from the above mentioned sites are listed in table form for each third hour during the period of interest.

DEFINITION OF WIND

The wind is defined by an international agreement (WMO), used by all countries, as the mean wind registered on a height of 10 meters over the ground during a period of 10 minutes preceding the observation occasion. The wind is, in most cases, measured with the help of an instrument called anemometer.

In Sweden, the maximum mean wind during the last 3-hour period is also noted. The Finnish lighthouse, Bogskär, is equipped with an automatic weather station which also measures maximum mean wind and gust-winds.

Also on the Estonian site Ristna, maximum and gust winds are measured. Refer to figure 8 (bilaga 8).

The variation of the wind hour by hour as registered by Söderarm and Svenska Högarna (copies of original registrations) are shown in figure (bilaga) 9 and 10. Note that the time is UTC. Clearly, the maximum winds occurred after the accident of Estonia.

COMMENTS TO THE TABLE OF THE WEATHER CONDITIONS

The wind observations from the listed observation sites are relatively representative for open sea area although some reduction is always present even at a lighthouse close the coast. Additionally, at some lighthouses, the lee effect is significant from certain wind directions. Observations from Bogskär and Ristna is estimated to be the most representative in this weather situation.

In order to better assess the winds at sea, SMHI is using a computer model which takes into account the actual weather observations, effects on the wind due to topography over land and coastal areas and over the sea. Included in the model is also sensitivity to the actual type of air mass and water temperatures. The physical relationships are well known and by running this weather model one enhances the assessment of the winds in different areas of the sea. The figures (bilaga) 11-14 depict such computer generated maps valid 19, 22, 01 and 04 hours L.T. on Sept. 27-28th.

WAVES

DEFINITION OF WAVES

The wave height of a single wave is defined as the vertical distance from bottom to top. According to international agreements, measurements are done using significant wave height and maximum waves. The significant wave height is defined as the mean value of the highest third of all waves. This concept has been introduced as a way to achieve a better relationship between waves measured by instruments and manually assessed wave heights. It is known that a human eye tends to over-estimate the "mean wave height". The concept "significant wave height" then provides a better relation between manual observations and those made by instruments.

The concept maximum wave height is introduced because waves, which interferes with each other, occasionally form waves considerably higher than the significant wave height.

Statistically, every 500th to 1000th wave will become generally 70-80% higher than the significant wave height and in some extreme cases, 100% higher. On this occasion, it is estimated to have happened between every second and every third hour.

In the cases of waves passing over shoals, the frequency of the above described interference phenomena increases. This also occurs when the wind direction shifts more than 45 degrees, lasting for at least a couple of hours. Wave fronts will then intersect and interfere with each other.

Wave measurements were missing at the occasion in the northern Baltic sea. The only measurements made routinely in this area are made at Almagrundet. Due to technical problems this station has not been in use for some time. However, on this occasion, wave measurements from Almagrundet would not have been representative for the area from the western part of the Gulf of Finland to south of Utö, in particular not with wind directions from south and southwest followed by west.

The daily wave forecast, used by SMHI, is produced by a numerical wave model which uses the speed, direction and duration of the wind, plus the sea depth, in its calculations. The dynamic processes are well known, and the model has been verified to be very accurate in both Germany and Sweden. The result is presented as significant wave height.

In order to calculate the wave conditions on the occasion as accurate as possible, SMHI has used the above mentioned numerical weather model to produce the initial weather conditions as input in the wave model. The outcome being waves based on the actual wind conditions during Sept. 27-28th in the area of interest.

Figure (bilaga) 15-17 shows calculated waves at 19, 01 and 07 L.T., based on the numerical weather model.

This report also includes a theoretical study of wave heights and an assessment of probabilities for some extreme wave heights which may have occurred on the occasion. See figure 18 (a-b).

AIR TEMPERATURE

The air temperature at sea varied between 11 and 13 degrees during the day on the 27th. Behind the narrow front which passed eastward during the evening, the temperature sunk to 10-11 degrees. The temperature dropped to 8-9 degrees after the wind had shifted to west during the later part of the night.

SEA SURFACE TEMPERATURE

Daily maps of the sea surface temperature of surrounding seas are produced by SMHI. Data is acquired from measurements made by ferries and merchant vessels and from satellite measurements made with infrared sensors.

The sea surface temperature in the the area of interest during the night between 27-28th was between 12-13 degrees. From the 28th the temperature sunk to 10-11 degrees. Refer to figure (bilaga) 19.

CURRENTS

Sea current measurements are not made on a daily basis in the Baltic sea. However, a numerical model which calculates currents is run daily at SMHI. This information is mainly used for oil discharge fighting and rescue operations. Since the weather conditions entirely steer the sea currents in the Baltic sea, it is possible, as in the wave height case, to calculate the sea current conditions with the help of weather models.

These calculations, which in this case shows the current at 5 m depth, does not reveal any strong currents along the route of m/s Estonia in the beginning of evening.

Shortly before midnight the current is calculated to have increased to about 0.5 knots towards the direction between east and northeast. From 02-03 L.T. shifting toward southeast, still around 0.5 knots.

REPORTS FROM EYEWITNESSES

Information about wind and waves have been gathered from:

- * The ferries Silja Europa and Mariella, which run almost parallel to Estonia. They arrived to the place shortly after the loss.
- * The ferry Finnjet, which was located about 25 n.m. behind Estonia, arriving to the place at 02.20 L.T.
- * The ferries Silja Symphony and Isabella, which departed from Stockholm toward Helsinki and estimated to have passed the place of the loss 2-3 hours after it happened.

- * Two Swedish merchant vessels, Westön and Ingrid Gorthon, arriving to the place of accident 3-4 hours after it happened.
- * Helicopters from the Air Force and the Navy , which participated in the rescue operation and arrived 3-5 hours after the loss.

Wind and waves

Vessels

All vessels reported the mean wind in the beginning of the evening (Sept. 27th) to about south 10-15 m/s. Later, further increasing to south 15-20 m/s. Then 2-3 hours before midnight shifting to southwest 15-20 m/s. From the later part of the night, that is after the loss, about west 20-25 m/s with gusts up to 26-30 m/s. During the early morning decreasing to west about 20 m/s, later in the morning 15 m/s.

The wave height has been estimated to 4-5 m, with occasional maximum waves 6-7 m before the accident, after the accident 5-6 m with occasional waves up to 7-8 m.

The wind gauge instruments on the ferries are placed between 40-50 m over the sea surface but the wind speed readings are reduced to be valid at a height of 10 m. After many years of experience, the general opinion among the crew on board the vessels is that this reduction of the wind very well corresponded to the real conditions.

Observations of wind and waves on merchant ships are always estimated. The captains on board these vessels point out that according to their experience, the wave height was at the most 5-6 m, compared to 6-10 m which has been figured in the press.

Helicopters

The Swedish helicopters from the Air Force and the Navy which arrived to the site of the loss between 02.50 and 05.00 L.T. have made the following estimates:

Wind about west 25 m/s, gusts up to 30 m/s. One helicopter reported gusts of up to 40 m/s.

Concerning the wave heights, the range varies more than for the wind. The majority reports 5-6 m or 6-8 m. One helicopter reported 6-9 m, another 6-10 m.

One helicopter even reported a gigantic wave of 12 m.

Comments to observations from vessels and helicopters

The wind and wave conditions of interest are those which occurred before the accident. There is a close agreement between observations from the different meteorological

stations, observations made on vessels and the numerical model calculations of the wind and wave conditions. Close agreement remains also after the accident except for wave height reports from helicopters. It may prove difficult to evaluate the different observations, but SMHI wants to comment on those since there have been speculations about extreme conditions in the press.

Wind

Before the accident, reports were available from ferries and merchant ships. There is close agreement here about the southwest wind 15-20 m/s, also supported by meteorological observations and computer models.

After the accident, i.e. the late part of the night and the early morning, both vessels and helicopters were generally in agreement of wind speed west 20-25 m/s, gusts up to 30 m/s.

One helicopter reports gusts up to 40 m/s.

These reports are generally supported by observations made by meteorological stations as well as computer models, which indicated gusts of up to 30-34 m/s.

Significant wave height

There is close agreement between observations and calculations on the wave height 3.5-4.5 m before the accident. During the time after the accident, there is significant difference between the reports from the vessels, which report 5-6 m, and the helicopters, which report wave heights from 5-6 m to 6-10 m.

One has to assume that reports from helicopters do not distinguish between significant and maximum waves, which result in the large range of wave heights.

Since observations of significant wave height from ferries and merchant vessels before and after the accident is in close agreement with numerical calculations and theoretical studies, the conclusion made by SMHI is that is most likely that the wave height before the accident was 3.5-4.5 m and 2-3 hours after the accident had increased to 5.0-6.0 m.

Maximal wave height

The maximal wave height, both observed by vessels and theoretical, are also in close agreement here. Occasional maximal waves occurring before the accident is estimated to about 7 m, but statistically, an 8 m wave could have occurred every second hour. A couple of hours after the accident, the expected maximum wave is 8-9 m, possibly with some extreme wave up to 10 m. This wave may have been observed by the helicopter which reported the 12 m wave.

As a comparison, the highest waves ever measured in the Baltic Sea since 1976 is from Almagrundet with a significant wave height of 7.8 m, maximum height 12.8 m and from Svenska Björn with a significant wave height of 8.1 m, maximum height 12.2 m. Both of these readings are made during a long lasting southerly storm during January 13-14th 1984.

During the rescue operation later in the night, the waves must have been experienced as very difficult due to the fact that "old" waves from southwest with longer period were superimposed by waves from the west with shorter periods, forming a confused sea state.

THE CONDITIONS FOR M/S ESTONIA

An attempt is made here to retrospectively give the most probable wind and wave conditions which m/s Estonia experienced during her last voyage, based on observations and calculations referred to earlier in this report.

The magnitude of the force of the gusts are estimated from both observations and theoretical calculations made on the present weather situation.

Note that the significant wave height is calculated while the maximal wave height is based on theory, statistics and eyewitnesses.

The time is referred to as Swedish time. The vessel's speed is based on the normal time table/speed normally used according to EstLine including information from Officer Kukk to media and m/s Mariella.

Estimated conditions on m/s Estonia's last voyage:

* 18.00-19.00 L.T. Tallinn roadstead - point just west of Naissar. (Speed 19-20 knots?)
Wind S-SW 8-10 m/s. Gusts up to 13 m/s.
Waves 1.0-1.5 m, max 2.0 m.

* 19.00-20.00 L.T. Point just west of Naissar - line Pakri/Jussarö. (Speed 16 knots?)
Wind S 10-13 m/s. Gusts up to 16 m/s.
Waves 1.5-2.0 m, max 3.0 m.

* 20.00-21.00 L.T. line Pakri/Jussarö - abeam of Osmussar. (Speed 15 knots?)
Wind S 11-15 m/s. Gusts up to 18 m/s.
Waves 2.0-3.0 m, max 4.0 m.

* 21.00-22.00 L.T. Abeam of Osmussar - line Tahkuna/Russarö. (Speed 14 knots?)
Wind S-SW 13-17 m/s, gusts up to 24 m/s. (At the front shortly strong gusts.)
Waves 2.5-3.5 m, max 5.0 m.

* 22.00-23.00 L.T. Line Tahkuna/Russarö - abeam of Bengtskär. (Speed 14 knots?)
Wind SW 13-17 m/s. Gusts up to 21 m/s.
Waves 3.0-4.0 m, max 6.0 m.

* 23.00-24.00 L.T. Abeam of Bengtskär - abeam of Ristna. (Speed 13 knots?)
Wind S-SW 14-18 m/s. Gusts up to 21 m/s.
Waves 3.5-4.5 m, max 6.5 m.

* 00.00-00.30 L.T. Abeam of Ristna - point just east of the accident. (Speed 12 knots?)
Wind SW 16-20 m/s. Gusts up to 23 m/s.
Waves 3.5-4.5 m, max 7.0 m.

At the sight of the loss:

* 00.30-02.00 L.T.
Wind SW 16-20 m/s. Gusts up to 24 m/s.
Waves 4.0-5.0 m, max 7.5 m.

* 02.00-06.00 L.T.
Wind W 20-25 m/s. Gusts up to 30-34 m/s.
Waves 5.0-6.0 m, max 9.0 m, possibly an occasional wave up to 10 m.

* 06.00-08.00 L.T.
Wind W 17-22 m/s. Gusts 26 m/s.
Waves 4.0-5.0 m, max 7.0 m.

FORECASTS

Presentation of forecasts valid on the occasion of the accident including the customized forecast which was sent to m/s Estonia.

The General Weather Forecast for Sea areas

In the general weather forecast for sea areas transmitted on the Swedish radio P1 on the 27th at 08.00 L.T. and the forecast transmitted in English via Coastal Radio Station and NAVTEX on the 27th at 06.56 UTC, it was indicated that the wind from SW 10-13 m/s would be increasing to 17-22 m/s, during the night further increasing to westerly storm 20-25 m/s. Refer to figure (bilaga) 20 and 21.

The following reports transmitted during the day and evening of the 27th, repeated this forecast. Refer to figure (bilaga) 22-25.

Customized Forecast

Like many other ferries, m/s Estonia subscribed to a daily forecast service from SMHI via fax. These forecasts are customized to a specific route and offer relevant information. The forecast was sent by fax and acknowledged by m/s Estonia in the afternoon on the 27th is shown in figure (bilaga) 26.

Besides a detailed wind forecast for separate stretches along the route, a wave forecast is included, based on the earlier mentioned numerical wave model.

Forecast preparation

The data used by SMHI for making 72 hour forecasts is provided by a numerical weather model which is run on a main frame computer four times a day. Longer forecasts of up to 10 days are calculated on a co-European weather model twice a day, but the space and time resolution in the latter model is not as high.

In cases of technical problems and for reasons of comparison, SMHI also receive numerical weather models from Great Britain, Germany and the United States.

All available information about the present weather condition on a global basis from the surface, the atmosphere and through satellite sensors are continuously transmitted into these models. The data is also supervised directly by meteorologists on screens and maps in order to closely follow the weather development.

The weather development on Sept. 27-28th was well predicted by SMHI's weather model and supported by the rest of the above mentioned weather models. The meteorologist on duty at SMHI during Sept. 27-28th had access to a reliable forecast and was able to issue a storm warning already Tuesday morning for the upcoming night on northern Baltic Sea.

The operational wave model, which uses winds from the numerical wind model as input, produced maps of waves which, although slightly smaller, relatively well corresponded to the actual wave heights.

FINAL COMMENTS

Weather and wave conditions

As mentioned earlier, the conclusion is that the hardest winds and windshift to a westerly storm force, with corresponding heavy sea, occurred not until 1-2 hours after the accident and then continued 3-5 hours in the morning.

The weather on Sept. 27-28th is not extreme in any way, instead a rather 'normal' autumn storm occurring a number of times during the autumn and winter periods, statistically 5-15 times per year.

Forecasts

SMHI's opinion about the general forecasts, which were transmitted on Swedish radio station P1, coastal radio station and NAVTEX, is that the weather development was well predicted on the evening of the 27th and morning of the 28th on the northern Baltic Sea. Additionally, the customized forecast sent to and acknowledged by m/s Estonia, must have matched the expected quality requirements, although the waves in the forecast were underestimated to some degree, especially the maximal waves.

Up until the accident the wave height was in the forecast 2.5-3.5 m, max 5.5 m. In the analysis of this report the actual wave height is estimated to have been 3.5-4.5 m, max 7.0 m before the accident.

SMHI finds no physical or topographical conditions in the sea which may have caused any extreme waves over 7 m before the accident.

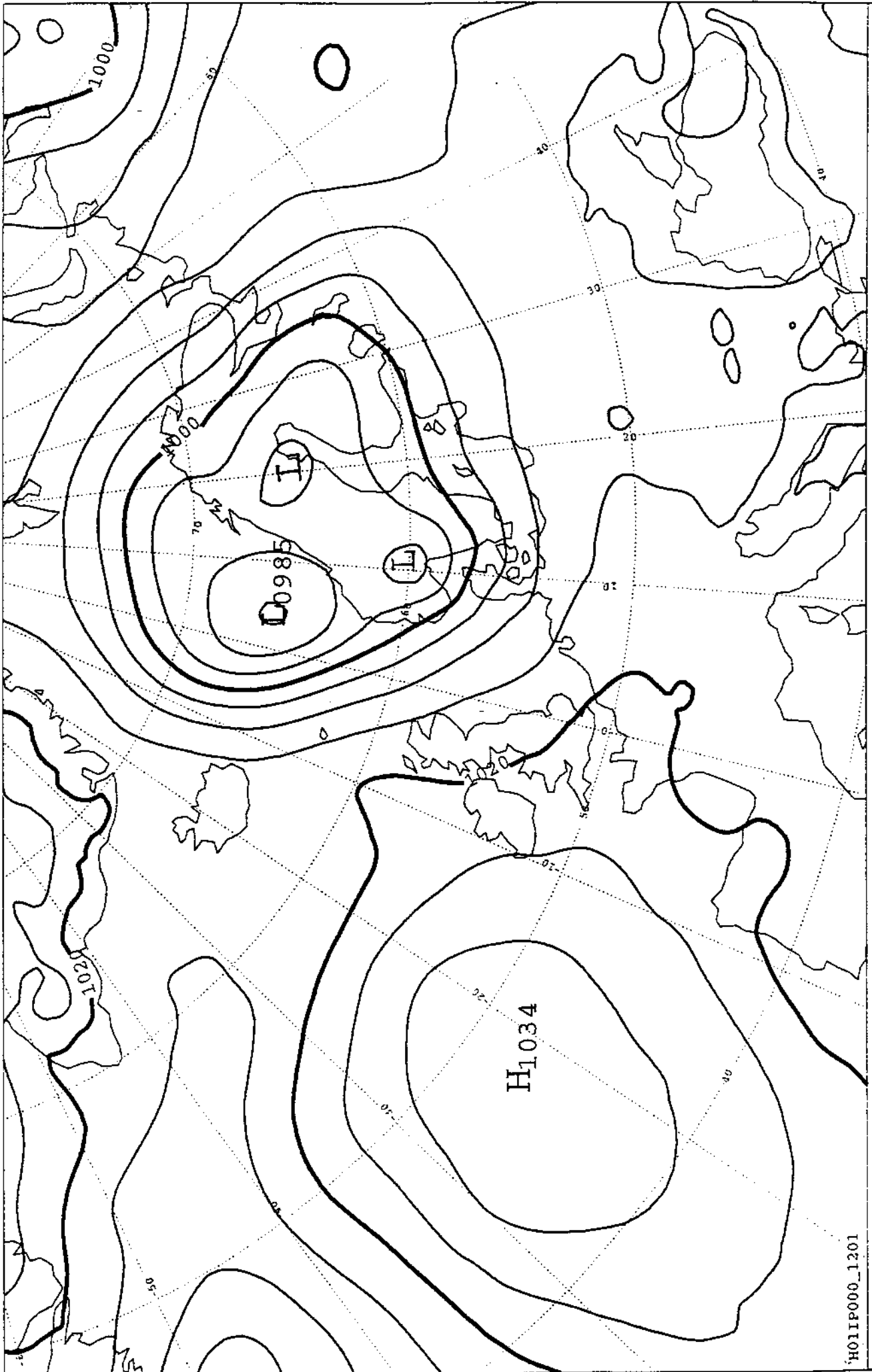
The conditions after the accident with waves 5.0-6.0 m, max 8-9 m, occurring 2-6 hours later in the morning on the 28th, would never have been experienced by m/s Estonia if the vessel had continued westward with 14-16 knots, since the wave height decreases toward the lee shore further westward.

This is why the customized forecast from SMHI for the period 04-07 Estonian time (03-06 L.T.) indicated decreasing waves, although the wind was predicted to increase to west 18-25 m/s.

SMHI's opinion is that the forecast in this case did not have a deterrent effect to the officers on m/s Estonia, since these conditions are experienced a number of times each year on the northern Baltic Sea, and at times even worse.

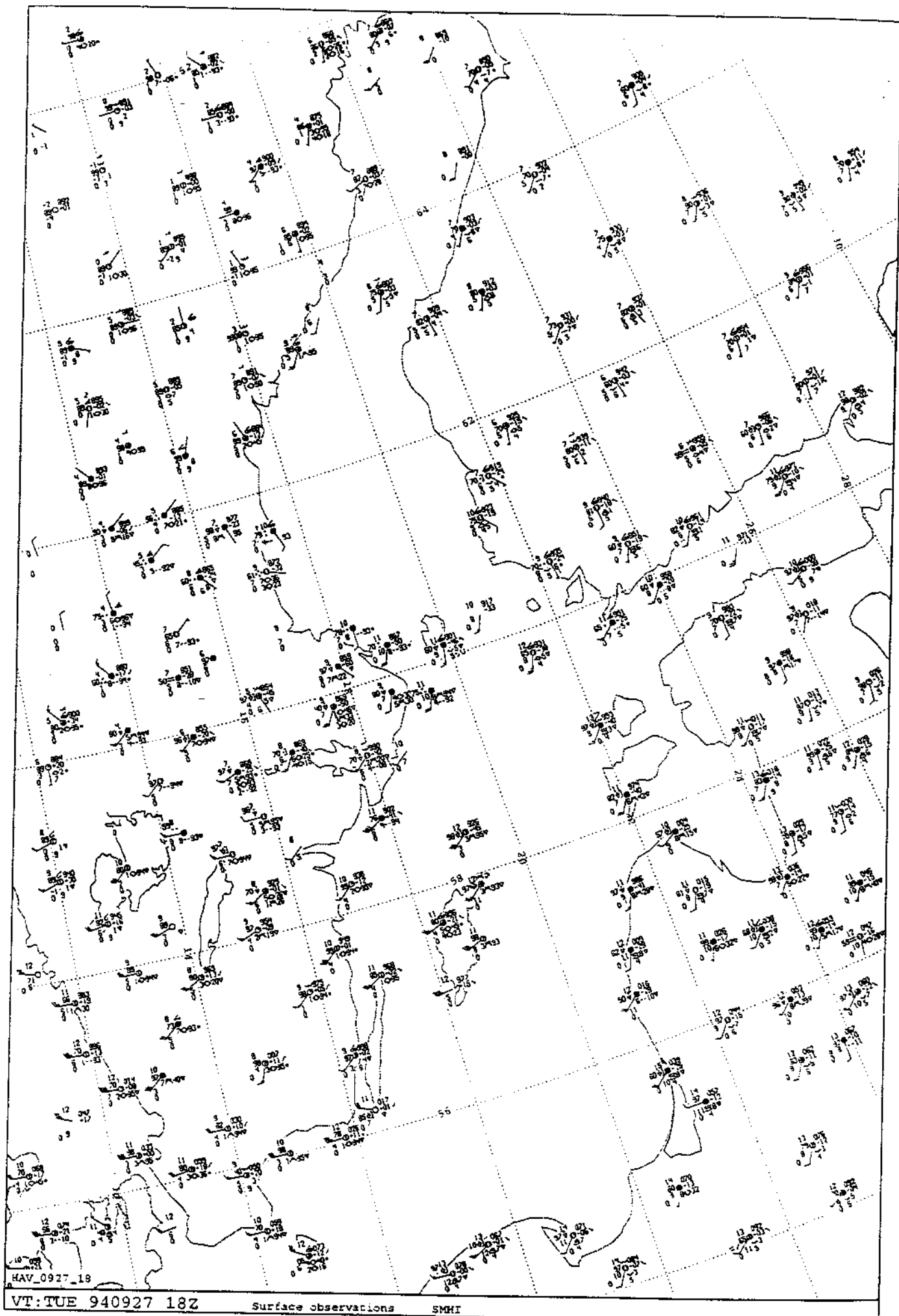
For SMHI

Svante Andersson
Head of SMH I -Marine Services



H01P000_1201

HIRL 940927 12Z+000 VT:TUE 940927 12Z Pressure M.S.L.

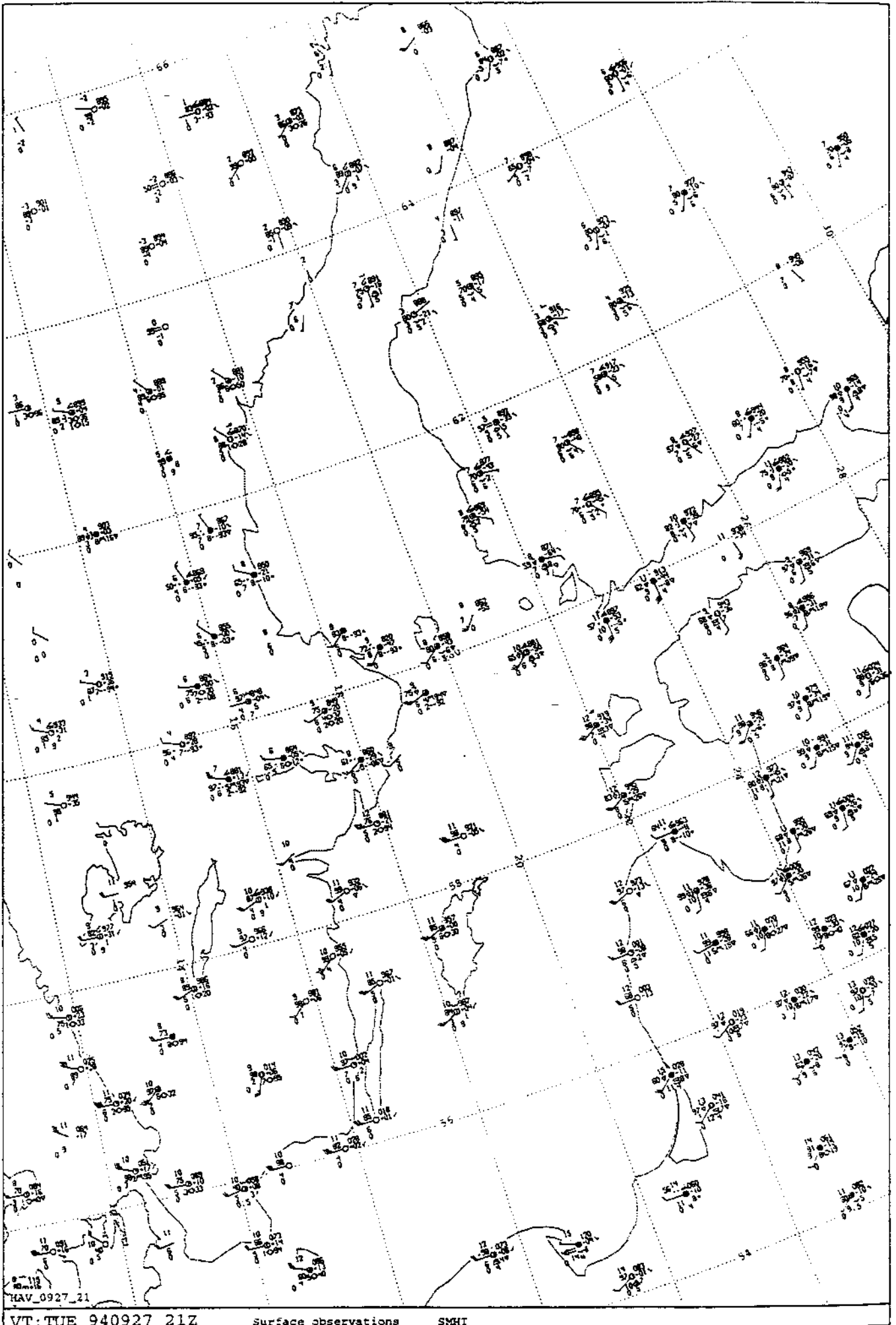


HAV_0927_19

VT:TUE 940927 18Z

Surface observations

SMHI

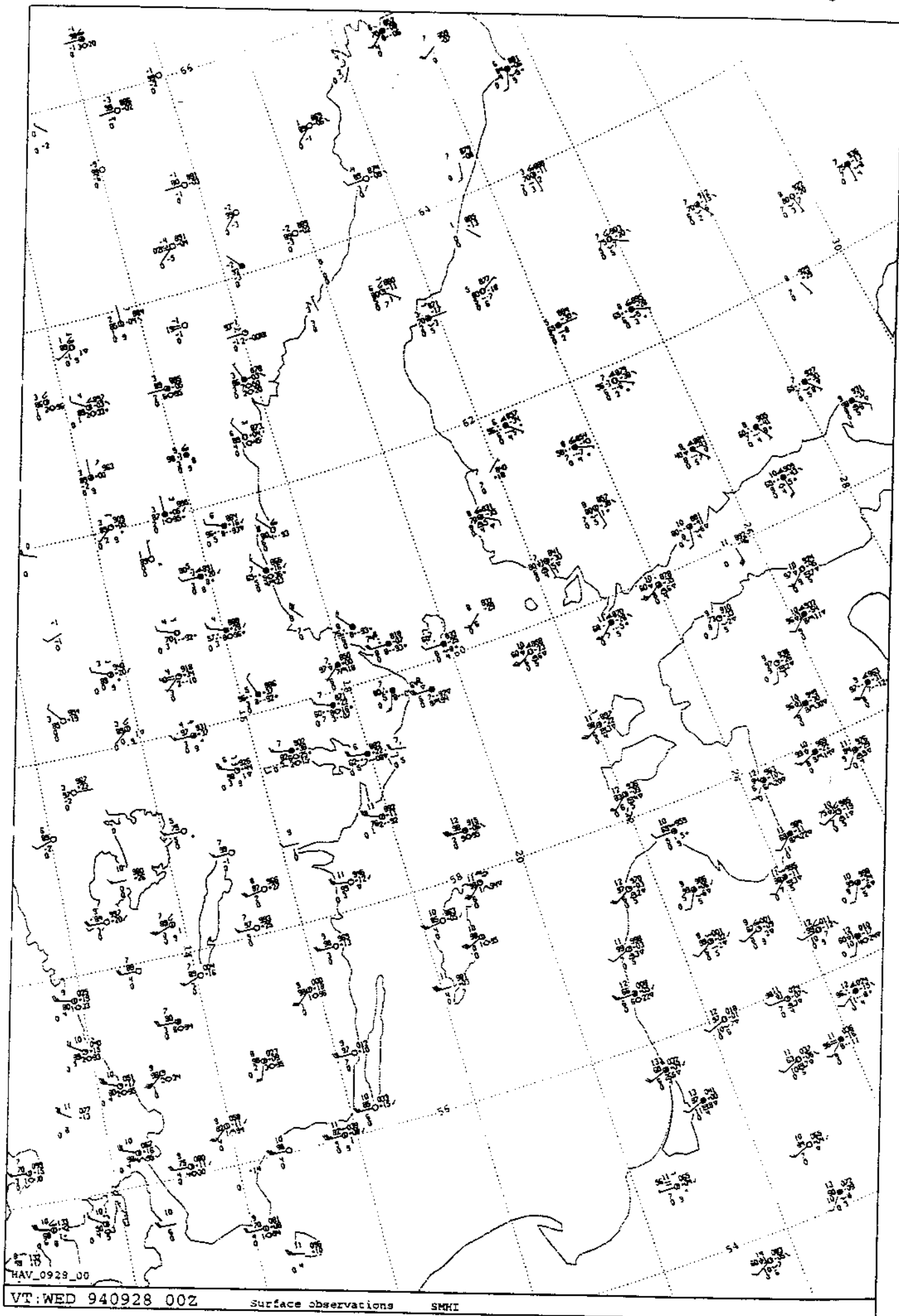


HAV_0927_21

VT:TUE 940927 21Z

Surface observations

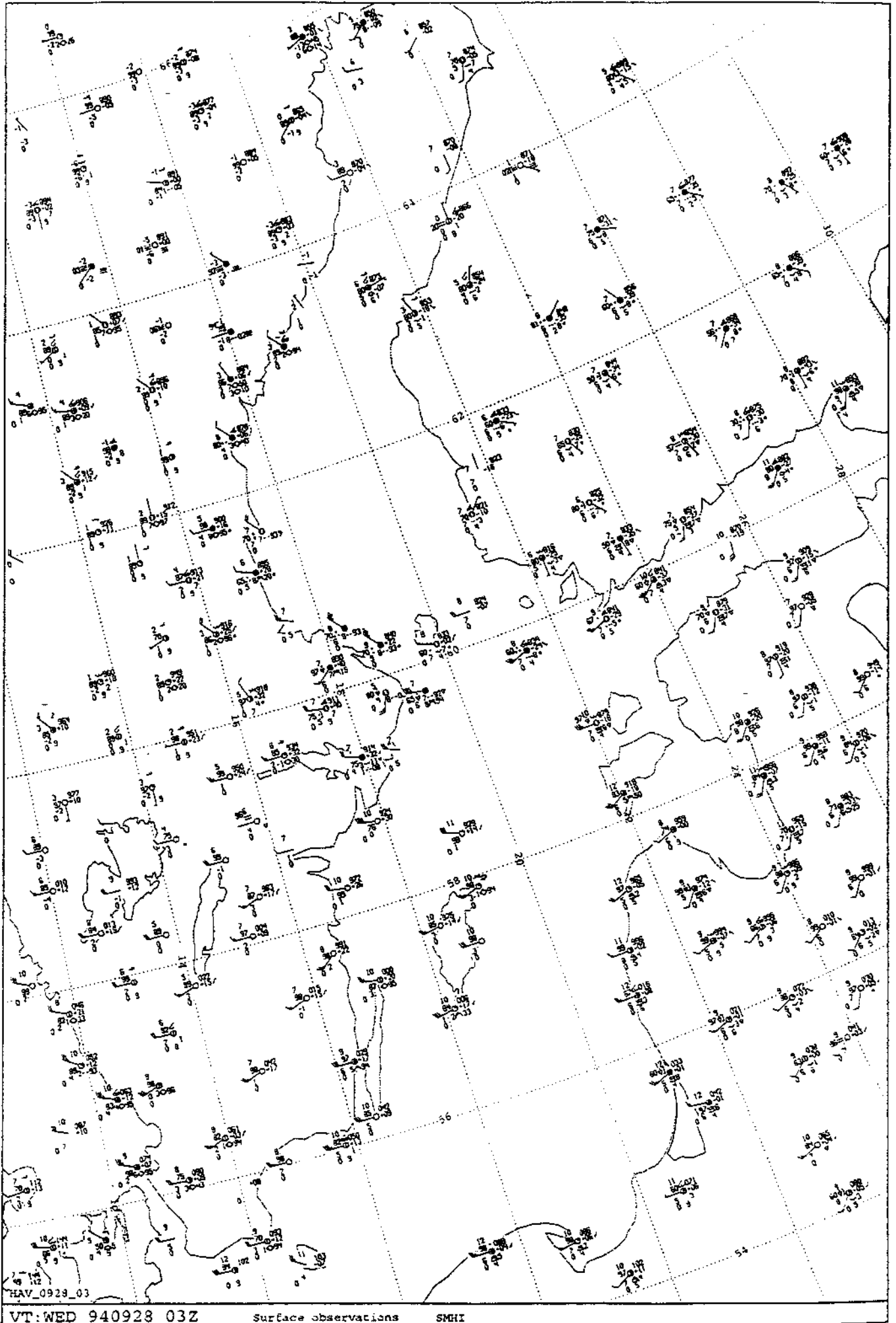
SMHI



HAV_0929_00

VT:WED 940928 00Z

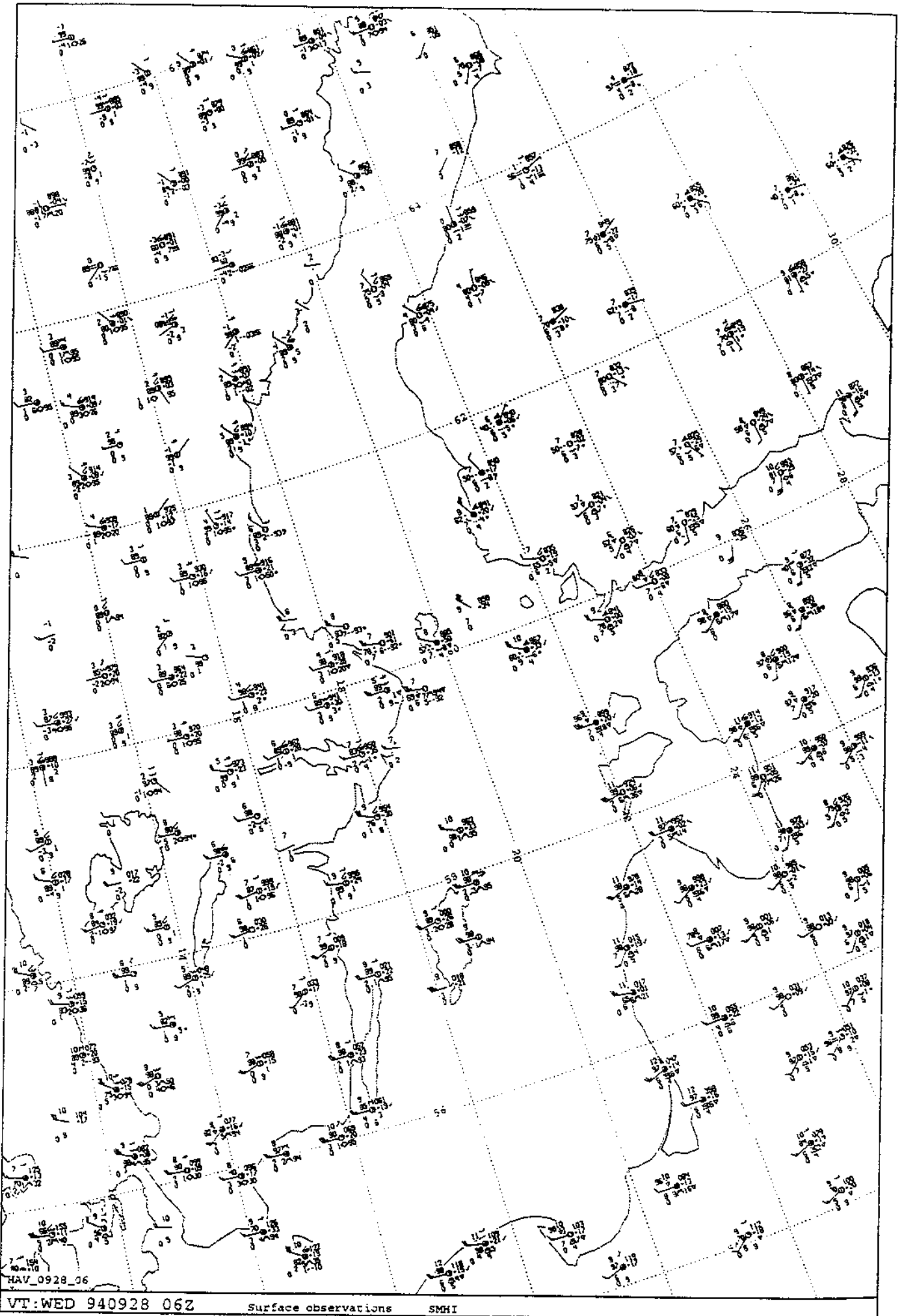
Surface observations SMHI



HAV_0928_03

VT:WED 940928 03Z

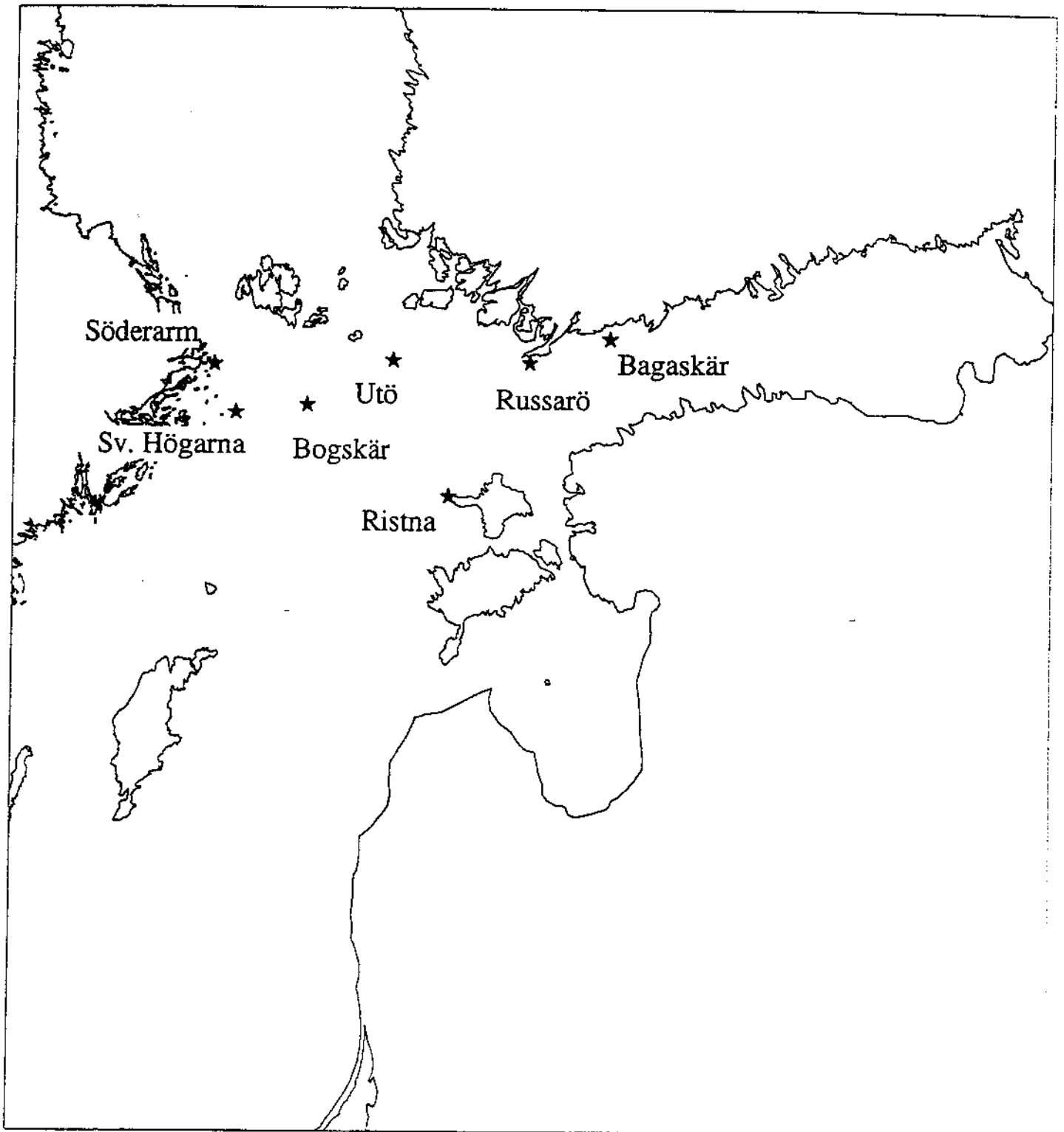
Surface observations SMHI



HAV_0928_06

VT:WED 940928 06Z

Surface observations SMHI



OBSERVATIONER

Nedan visas de observationer av medelvind till riktning respektive hastighet som noterades 27-28 september.

Endast de svenska stationerna plus den finländska automatstationen Bogskär anger vilka maximala medelvindar man noterat sedan förra observationen, 3 timmar tidigare. Notera att man aldrig mäter vindhastigheten i byarna vid någon av dessa stationer förutom vid Bogskär och Ristna.

Tiden är svensk vintertid.

Dag/ kl	Söderarm riktning medel/max (m/s)	Svenska Högarna	Bogskär byvindar, se Not.	Utö	Russarö	Ristna / bymax	Bagaskär
27/kl 16	SW 09 /12	SW 12 /14	SW 13 /14	SW 09	WSW 09	SW 08 /12	SW 12
27/kl 19	SW 11 /13	SSW 14 /16	S 14 /17	SSW 13	SW 08	SSW 08 /14	SW 09
27/kl 22	S 13 /17	SW 16 /18	SW 17 /18	SW 15	S 16	WSW 16 /21	S 15
28/kl 01	SW 14 /15	W 17 /18	SW 20 /21	SW 15	SW 12	WSW 15 /22	SW 16
28/kl 04	W 20 /20	WNW 24 /24	W 19 /22	WSW 15	WSW 12	W 18 /29	SW 18
28/kl 07	WNW 17 /20	WNW 18 /25	WNW 21 /24	WNW 13	WNW 09	W 17 /26	W 04
28/kl 09	WNW 12 /17	WNW 14 /18		W 15	WNW 11	W 12	W 10

Not.

Bogskär uppmätte de högsta byvindarna:

27 september kl 22.46 till 24.6 m/s.

28 september kl 06.25 till 27.7 m/s.

Däremellan var bymax betydligt lägre.

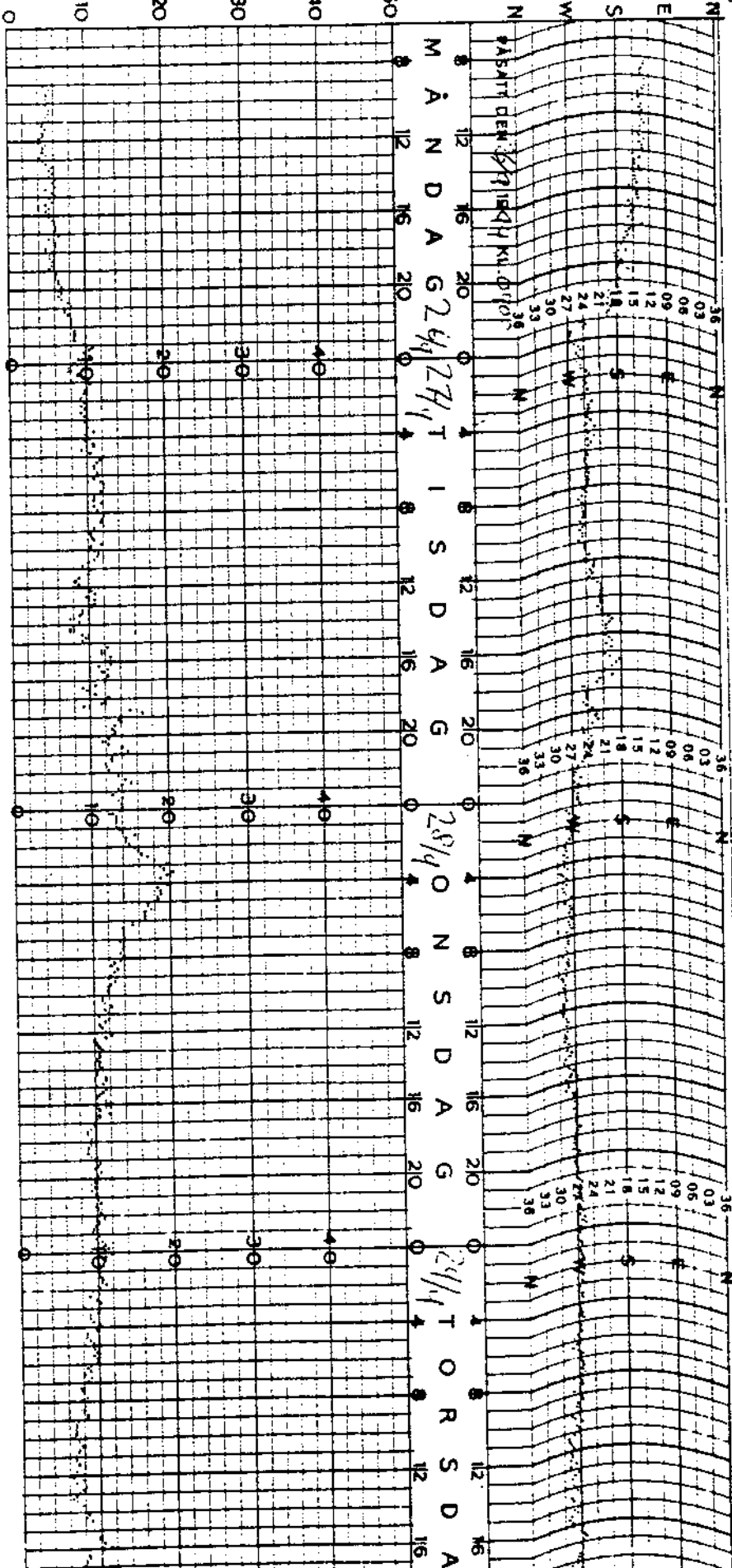
SÖDERARM

Mo 1989.08.1600 LÖFFSET Norrboing

SMHI 4315

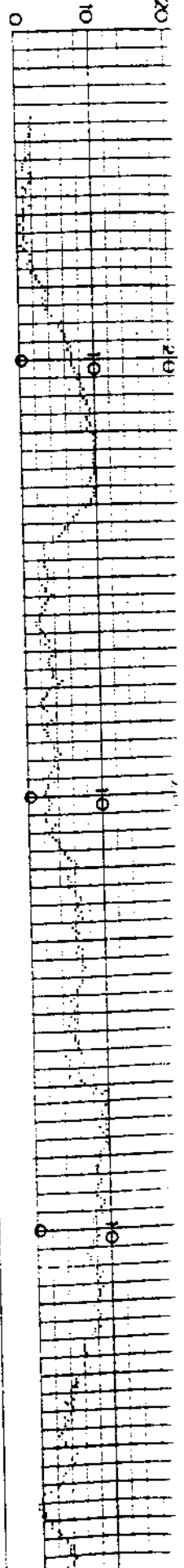
Tidskorrektion

STATION NR 134 NAMN Söderarm
 VINDHASTIGHET I M/SEK. VINDRIKTNING

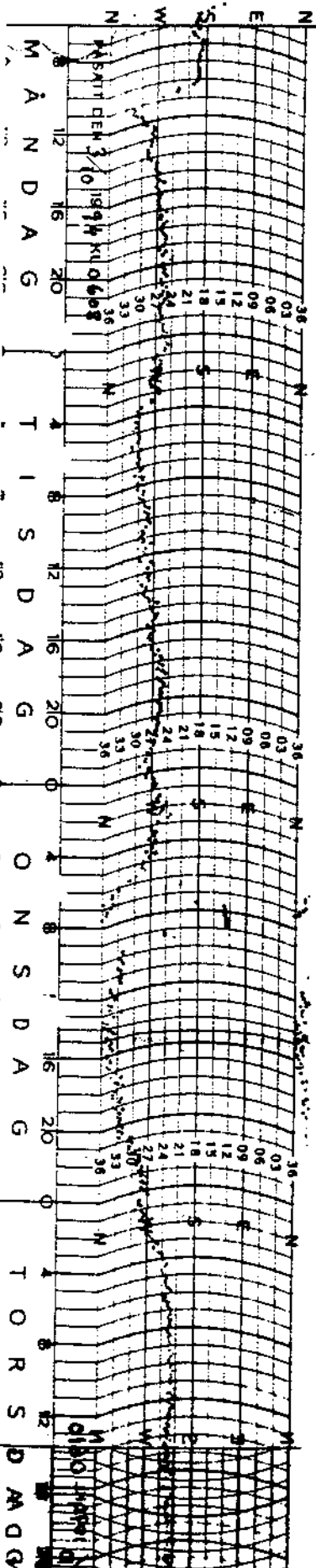


Tidskorrektion

STATION VINDHASTI



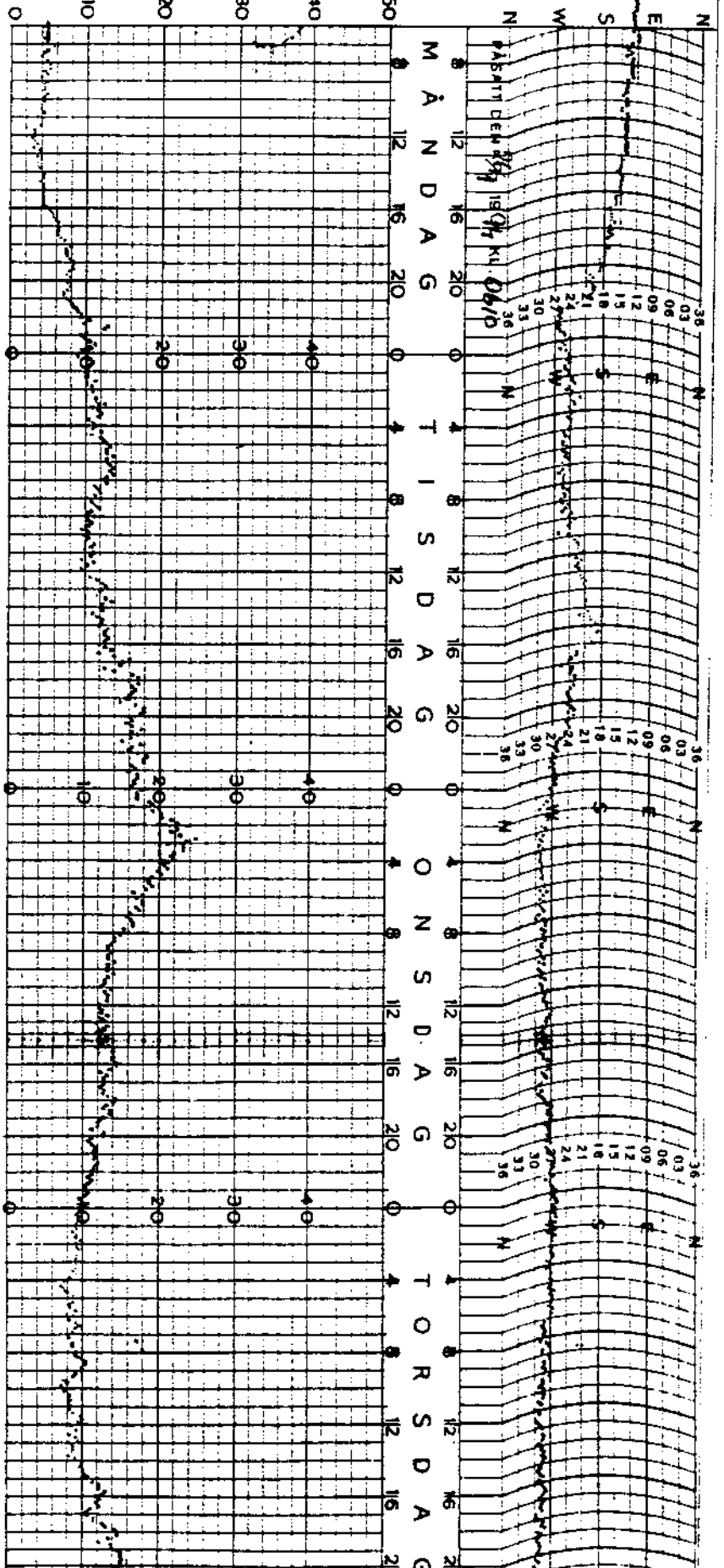
SVENSKA HÖGARNA
VINDRIKTNING



Tidkorrekction

Tidkorrekction

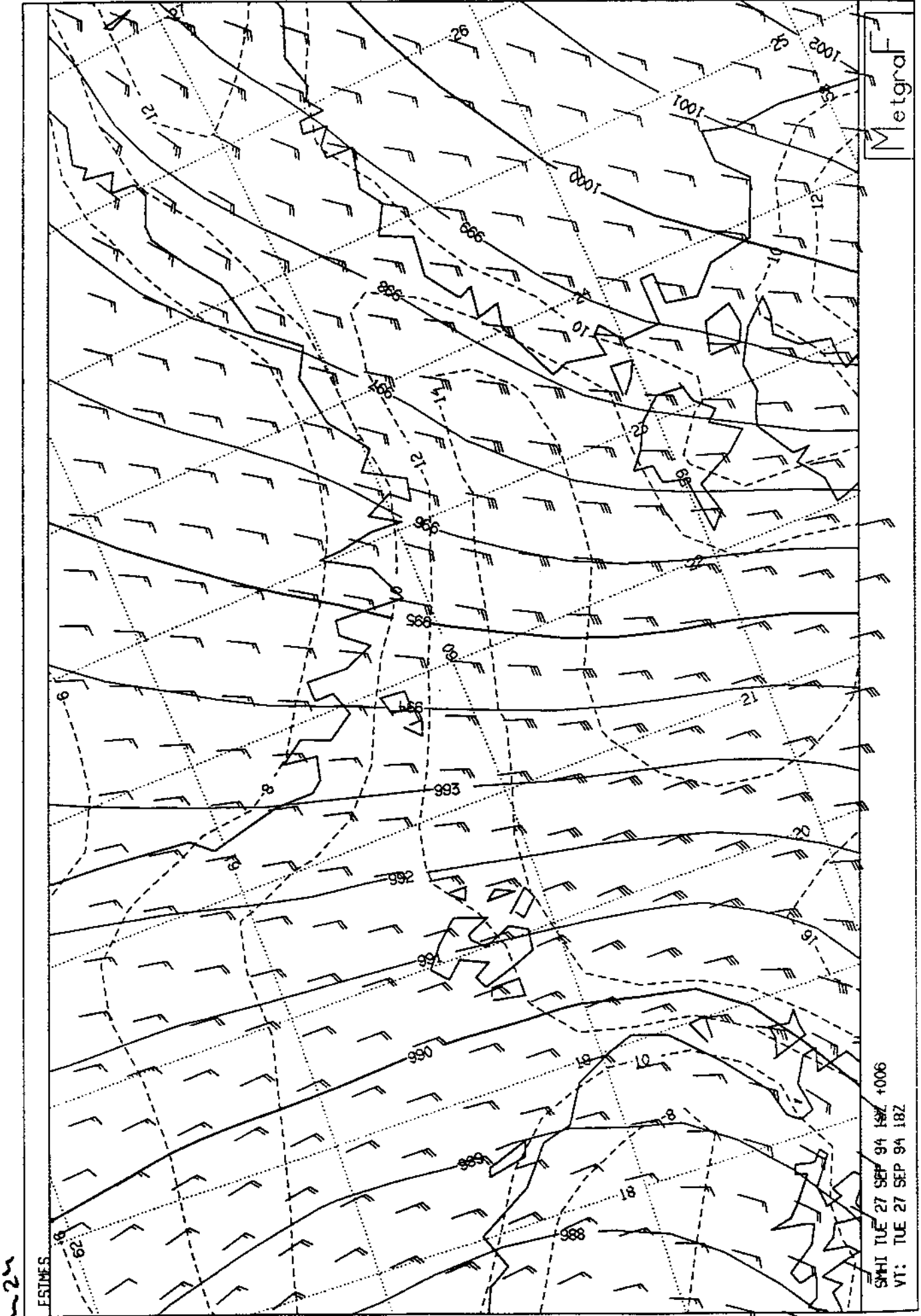
STATION NR 496 NAMN SVENSKA HÖGARNA
VINDHASTIGHET I M/SEK.

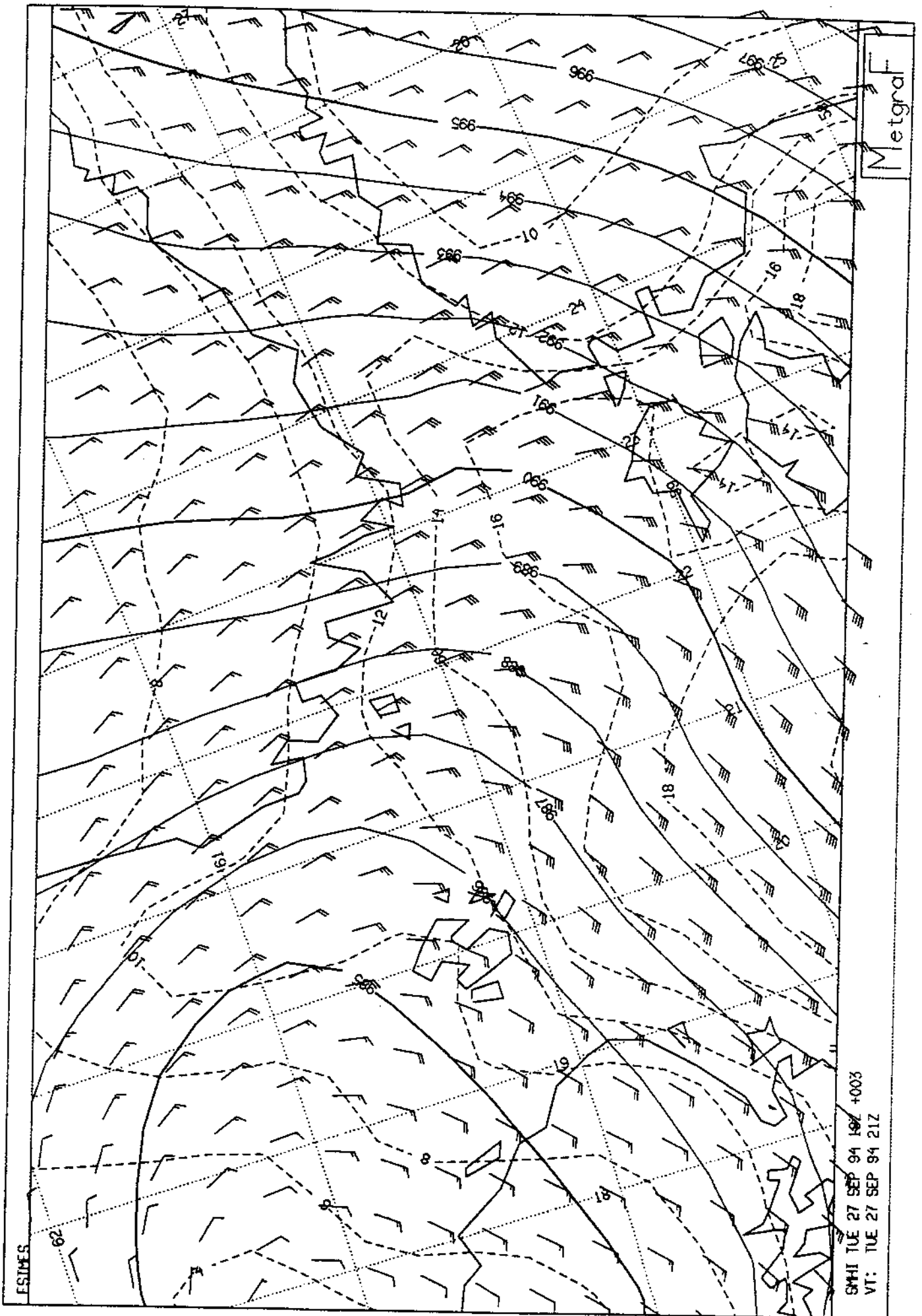


SVENSKA HÖGARNA
VINDRIKTNING

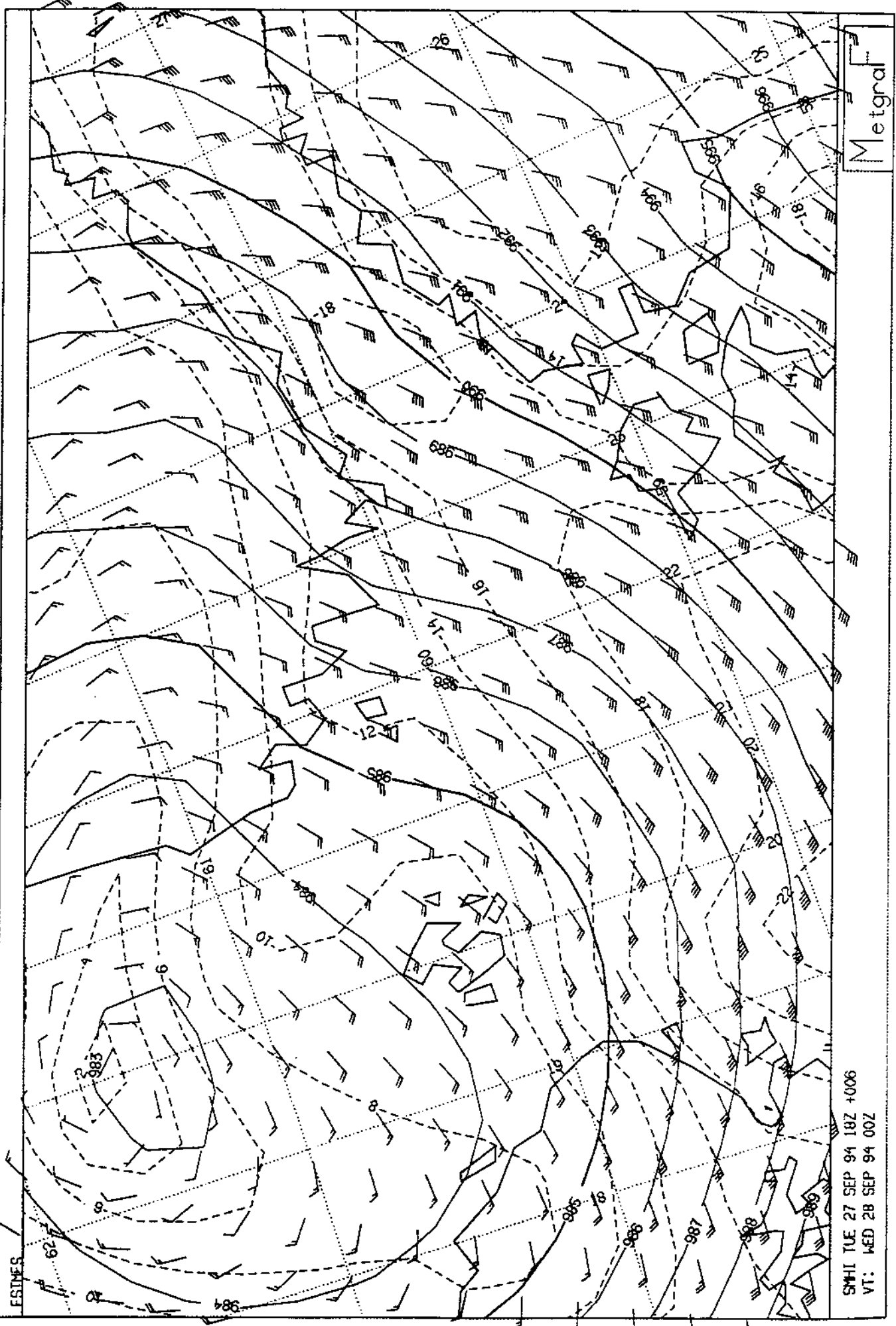
Tidkorrekction

Datorbaserad tolkningsmodell kl 19.



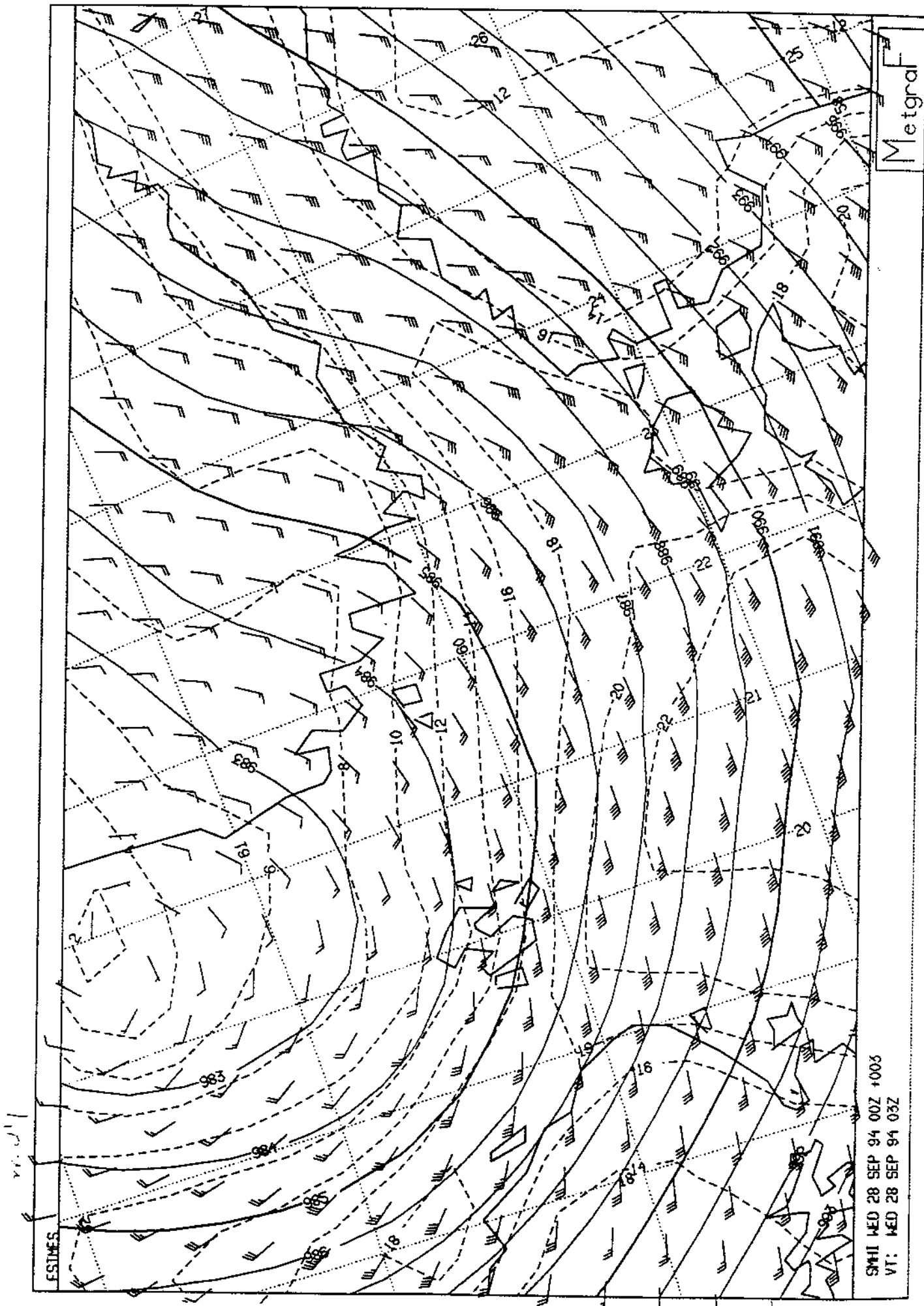


11 21



Metgraf

SMHI TUE 27 SEP 94 18Z +006
VT: WED 28 SEP 94 00Z



Metgraf

FSTINES

SMII MED 28 SEP 94 00Z +003
VT: MED 28 SEP 94 03Z



SMHI TUE 27 SEP 94 06Z + 12
VT: TUE 27 SEP 94 18Z



SMHI TUE 27 SEP 94 06z + 18
VT: TUE 27 SEP 94 24z



SMHI TUE 27 SEP 94 06z + 24
VT: WED 28 SEP 94 06z

A theoretical studie of the wave conditions in the northern Baltic with S-SW winds 15-20 m/s.

Definitions

The wave height and wave length depends primarily on the wind speed, but very important is also the duration of time of the wind speed and the fetch (how wide/long the open area is from which the wind blows).

The wave length is the distance from wave top to wave top.

Wave period is the time between two wave tops.

The significant wave height is the average height of the 33% (1/3) of the highest waves.

Wave heights and wave lenghts in the northern Baltic at S-SW 17-18 m/s.

A wind speed of 17-18 m/s generates wave heights up to 5.0-5.5 m over open water.

However it takes more than 24 hours with this wind speed and a fetch of over 1000 km (500 nm) before this wave height is reached.

As an example we can study the area from Gotland to the Gulf of Finland, with a fetch of 300 km (150 nm). With a wind of S-SW of 17 m/s, this condition must remain for more than 10 hours before it creates significant waves of 4.0 m.

Before a radical change in the wind direction or a radical increase of the wind speed has modified the waves in order to create the maximum wave height and wave length, it would take at least 6-8 hours.

A situation with rather "new" waves, which means short and moderate waves, is experienced as very rough when old waves (swell) penetrates into this area after a radical change in the wind direction has occurred.

If we have a condition with winds of 17 m/s and wave heights of around 4.0 m in the northern Baltic, measurements and theoretical calculations gives a wave period of about 8 s and a wave length of about 100 m.

How different wave systems can interact and create extreme waves.

The wave systems at sea are normally not an area with uniform waves. Instead different wave systems often are mixed so that the sea becomes confused, sometimes chaotic, with short and long waves. Due to this interaction between different "wave trains" more extreme waves rather frequently are formed. These maximum waves are normally 70-80 % higher than the significant wave height, at times even 100 % higher, but the waveperiod and wavelength does not change. Measurements and theoretical studies have shown that when one extreme wave occur, there are normally at least two further extreme waves following.

The shallow water influence on storm waves.

At some places the wave direction always changes and creates extreme waves. If the water depth is less than 1/4 of the wave length, the bottom will have influence on the waves. The most notable thing is that the wave speed reduces.

For example around a shallow water area/shoal bank this is normal and the waves are interfering in lee of the bank where high or extreme waves will be formed.

This phenomenon is caused by the fact that the waves passing over a shoal will reduce its speed and the wavelength shortens, while the waves on both sides changes direction and propagates around the bank.

If the waves penetrates into a larger shallow water area, the wave height increases and the wave length decreases. For example, if waves with a wave length of 100 m from S-SW reaches the shallow water area south of Åland, the wave height increases where the depth is less than 25 m. In these grounder areas the wave conditions also becomes more chaotic due to refraction from the shore.

Theoretical estimation of the waves at the location of m/s Estonia's accident.

Around the position N59.25 E21.42 there are no known ground areas at all on the available nautical charts. The theoretical studies gives that the waves at the time of the accident, in this area should have been the same as in the rest of the area of northeasternmost Baltic, i.e. round 4 m with possibilities of some maximum waves up to near 8 m.

However 5-10 nm north of this area, there are several places with water depths of 20-30 m, and in this area there would have been more unregular sea with higher waves.

During the night the 28th the wind changed (after 01.00, swedish time) from S-SW to around W and increased later on up to near 24 m/s.

After 1 hour (02.00) waves from W of about 1.5 m may have superimposed onto the "old" SW-sea of still near 4 m. After about 3 hours (04.00) the W-ly waves would be up to 3.5 m, but at this time the old SW-sea already must have been rather much reduced.

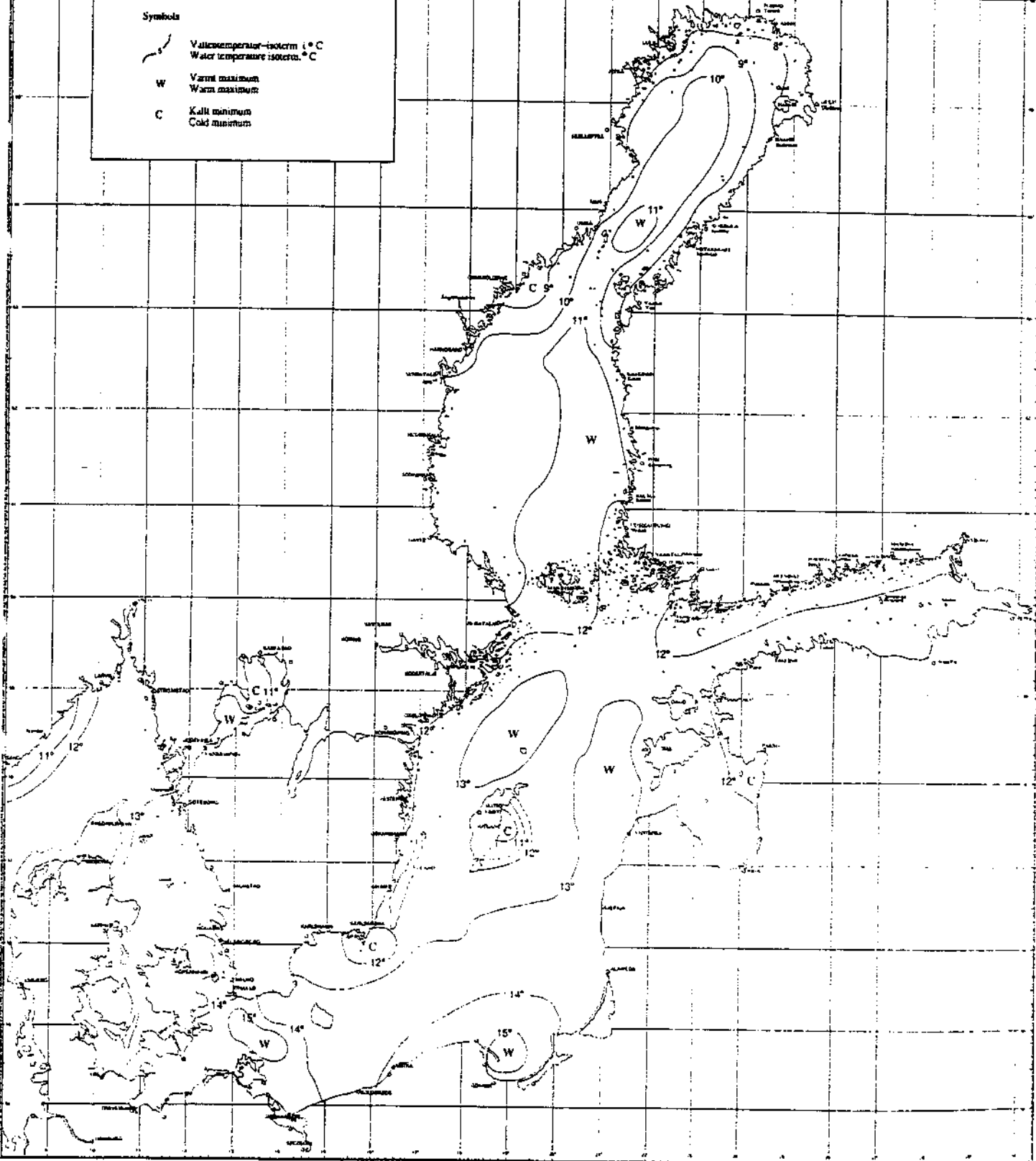
If m/s Estonia the last 1-2 hours had a significant wave height of 4.0 m, the statistical wave theory gives that every 10 minute she should have experienced a wave height of about 6.5 m, and every 2nd or 3rd hour (2 hours 40 min) a wave of about 8.0 m.

SMHI
YTVA FLENTEMPERA TUNGR
SEA SURFACE TEMPERATURES
1994-09-28

©

Symbols

- Vattemperatur-isoterm 1°C
Water temperature isotherm 1°C
- W Varmt maximum
Warm maximum
- C Kallt minimum
Cold minimum



Prognostiker	Uppläsare	Datum	Sändningstid
Gu	LF	94-09-27	8:05

VÄDERÖVERSIKT

- Anslutning till storm 25
 Storm- och kulingvarning är utfärdad för SKAGERACK, KATTEGATT, VÄNERN, ÖRESUND OCH BÄLTEN, HELA ÖSTERSJÖN, ÅLANDSHAV OCH SKÄRGÅRDHAVET.

Utsikter till Onsdag morgon

SKAGERACK:

m/s
 Byig väst kuling 14-18 ökande, i ~~kväll~~ ^{e.m} 18-22, i natt långsamt avtagande.

KATTEGATT, VÄNERN, ÖRESUND
 OCH BÄLTEN, SYDVÄSTRA
 ÖSTERSJÖN, SÖDRA ÖSTERSJÖN:

- följigen storm 25
 Byig väst 12- kuling 16, på Kattegatt i eftermiddag och i kväll upp till 20. I natt långsamt avtagande.

SYDÖSTRA ÖSTERSJÖN, MELLERSTA
 ÖSTERSJÖN, NORRA ÖSTERSJÖN,
 ÅLANDSHAV OCH SKÄRGÅRDHAVET:

Ökande sydväst, från i eftermiddag kuling 14-17, i natt byig väst 18-22, på norra och mellersta Östersjön storm 25.

BOTTENHAVET, NORRA KVARKEN:

Syd eller sydväst 8-12.

BOTTENVIKEN:

m/s
 Sydost 9-13, i eftermiddag syd och något avtagande.

STORM- OCH KULINGVARNING FÖR

SKAGERACK: Väst 14-18 m/s, i kväll 18-22, i natt långsamt avtagande.

KATTEGATT, VÄNERN, ÖRESUND OCH BÄLTEN, SYDVÄSTRA ÖSTERSJÖN, SÖDRA

ÖSTERSJÖN: Väst 14-18, på Kattegatt i em. och i kväll ca 20.

SYDÖSTRA ÖSTERSJÖN, MELLERSTA ÖSTERSJÖN, NORRA ÖSTERSJÖN, ÅLANDSHAV OCH

SKÄRGÅRDHAVET: Från eftermiddagen sydväst 14-17, i kväll ytterligare ökande, i natt ca 20, på MELLERSTA och NORRA ÖSTERSJÖN STORM 25 m/s.

(Ingen nedisningsvarning)

SMHI NORRKPING - 1994-09-27 06:56 UTC

WOSN42 ESMI 270700
SWEDISH GALEWARNINGS 0700 UTC

SKAGERRAK:

WESTERLY 14-18 M/S. THIS EVENING 18-22. TONIGHT SLOWLY DECREASING.

KATTEGAT. LAKE VAENERN. THE SOUND AND THE BELTS. WESTERN BALTIC.
SOUTHERN BALTIC:

WESTERLY 14-18. IN KATTEGAT THIS AFTERNOON AND EVENING 20.

SOUTHEASTERN BALTIC. CENTRAL BALTIC. NORTHERN BALTIC. SEA OF AALAND
AND AALAND ARCHIPELAGG:

FROM AFTERNOON SOUTHWESTERLY 14-17. THIS EVENING FURTHER INCREASING.
TONIGHT 20. IN CENTRAL AND NORTHERN BALTIC 25 M/S.

REMAINING AREAS NIL.

Prognostiker
HaUppläsare
HaDatum
94-09-27Sändningstid
13:00

VÄDERÖVERSIKT

Ett intensivt lågtryck vid Oslotrakten rör sig österut under fördjupning. I morgon drar det bort över Finland.

~~Storm- och kulingvarning är utfärdad för:~~

STORMVARNING för mellersta och norra Östersjön.

KULINGVARNING för övriga delar av Götalands farvatten, Svealands farvatten och sydligaste Bottenhavet.

Utsikter till Onsdag kväll

SKAGERACK, NORRA KATTEGATT:

Omkring väst kuling 17-23 m/s, i morgon avtagande till 10-13. Måttlig till god sikt.

SÖDRA KATTEGATT, ÖRESUND och
BÄLTEN, SYDVÄSTRA ÖSTERSJÖN:

Omkring väst, ökande till 13 till kuling 17. I morgon på dagen något avtagande. Mest god sikt.

VÄNERN:

Omslag till väst eller nordväst 13 till kuling 17, i morgon avtagande till c:a 10. Måttlig till god sikt, till en början regnskurar.

SÖDRA, SYDÖSTRA, MELLERSTA
och NORRA ÖSTERSJÖN:

Sydväst 10-13, ökande till kuling 17-22, i natt väst, på mellersta och norra Östersjön STORM 25, under dagen avtagande. Måttlig sikt, regnskurar.

ÅLANDSHAV och SKÄRGÅRDHAVET,
SYDLIGASTE BOTTENHAVET:

Sydväst 7-11, i kväll tillfälligt växlande, därefter nordväst 13 till kuling 18, senare under dagen något avtagande. Måttlig sikt, efterhand regn eller regnskurar.

NORRA BOTTENHAVET, NORRA
KVARKEN:

Sydväst 4-7, ikväll växlande, i morgon väst eller nordväst och ökande till 10-13. God sikt.

BOTTENVIKEN:

I de norra farvattnen till en början sydost, i övrigt sydväst 4-8 m/s, i morgon något ökande. Måttlig sikt, upphörande regn.

STORM- OCH KULINGVARNING FÖR

SKAGERACK, NORRA KATTEGATT: Omkring väst 17-23 m/s, i morgon avtagande.

NORRA KATTEGATT, ÖRESUND OCH BÄLTEN, SYDVÄSTRA ÖSTERSJÖN: Väst 14-17, i morgon avtagande.

VÄNERN: Väst eller nordväst 14-17, i morgon avtagande.

SÖDRA OCH SYDÖSTRA ÖSTERSJÖN: Sydväst, ökande till 17-22, i natt väst och på dagen avtagande.

× MELLERSTA ÖSTERSJÖN, NORRA ÖSTERSJÖN: Sydväst, ökande till 17-22, i natt väst 25 m/s, därefter avtagande.

ÅLANDSHAV OCH SKÄRGÅRDHAVET, SYDLIGASTE BOTTENHAVET: I natt nordväst 14-18 m/s, under dagen avtagande.

(Ingen nedisningsvarning)

FPSN72 ESWI 271400

Prognostiker Ha'	Uppläsare EWA	Datum 94-09-27	Sändningstid 15:55
---------------------	------------------	-------------------	-----------------------

~~VÄDERÖVERSIKT~~

Ett intensivt lågtryck - med centrum över Värmland - rör sig nästan rakt österut. I morgon drar det bort över Finland.

~~Storm- och kulingvarning~~ är utfärdad för
STORMVARNING för mellersta och norra Östersjön.
KULINGVARNING för övriga delar av Götalands farvatten, Svealands farvatten och sydligaste Bottenhavet.

Utsikter till Onsdag kväll

FLADEN, DOGGER:	Nordväst 12 till kuling 15 m/s, något avtagande, i morgon sydväst. Måttlig till god sikt.
TYSKA BUKTEN, FISKEBANKARNA, SYD UTSIRA:	Nordväst kuling 16-22, i natt avtagande, på dagen sydväst 8-13. Måttlig sikt, till en början regnskurar, i morgon övergående regn.
SKAGERACK, NORRA KATTEGATT:	Väst eller nordväst kuling 17-23, i morgon avtagande till 8-13 och efterhand sydväst. Måttlig till god sikt.
SÖDRA KATTEGATT, ÖRESUND och BÄLTEN, SYDVÄSTRA ÖSTERSJÖN:	Omkring väst 13 till kuling 17, i morgon på dagen 7-12. Mest god sikt.
VÄNERN:	Nordväst 13 till kuling 17, i morgon väst och avtagande till 7-10. Måttlig till god sikt.
SÖDRA, SYDÖSTRA, MELLERSTA och NORRA ÖSTERSJÖN:	Sydväst 10-13, ökande till kuling 17-22, i natt väst, på mellersta och norra Östersjön STORM 25, under dagen avtagande. Måttlig sikt, övergående regn, därefter regnskurar.
ÅLANDSHAV och SKÄRGÅRDHAVET, SYDLIGASTE BOTTENHAVET:	Sydväst 6-10, i kväll tillfälligt växlande, därefter nordväst 13 till kuling 18; senare under dagen något avtagande. Måttlig sikt, regn eller regnskurar.
NORRA BOTTENHAVET, NORRA KVARKEN:	Tillfälligt växlande 3-6, i morgon väst eller nordväst och ökande till 10-13. God sikt.
BOTTENVIKEN:	Omkring sydväst 4-8 m/s, i morgon något ökande. Måttlig sikt.

~~STORM- OCH KULINGVARNING FÖR
SKAGERACK, NORRA KATTEGATT: Omkring väst 17-23 m/s, i morgon avtagande.
NORRA KATTEGATT, ÖRESUND OCH BÄLTEN, SYDVÄSTRA ÖSTERSJÖN: Väst 14-17, i morgon avtagande.~~

Prognostiker
ÅB

Uppläsare
EWA

Datum
94-09-27

Sändningstid
21:50

~~VÄDERÖVERSIKT~~

Ett djupt lågtryck över inre Svealand fortsätter österut. Ett annat lågtryck söder om Island rör sig snabbt mot sydligaste Skandinavien, men blir inte lika intensivt som dagens lågtryck. Ett tredje lågtryck förskjuts åt nordväst över nordligaste Skandinavien.

~~Storm- och kulingvarning~~ är utfärdad för
STORMVARNING för mellersta och norra Östersjön.
KULINGVARNING för övriga delar av Götalands och Svealands farvatten och för sydligaste Bottenhavet.

Utsikter till Onsdag kväll

FLADEN, FISKEBANKARNA, SYD
UTSIRA,

Omkring väst 10-kuling 15 m/s, tillfälligt avtagande till 6-10, i de norra farvattnen sent under onsdagen växlande. God sikt, under dagen tidvis regn.

DOGGER, TYSKA BUKTEN,

Omkring väst 7-12, från middagen ökande till 10-kuling 15. Måttlig eller god sikt.

SKAGERACK, NORRA KATTEGATT:

Omkring väst kuling 15-20, långsamt avtagande till 5-10, onsdag kväll möjligen växlande. Mest god sikt.

SÖDRA KATTEGATT, ÖRESUND och
BÄLTEN, SYDVÄSTRA ÖSTERSJÖN:

Omkring väst 10-kuling 15, på dagen 7-12. Mest god sikt, sent i morgon regn.

VÄNERN:

Väst 12-kuling 17, under dagen avtagande till 4-8. Mest god sikt.

SÖDRA OCH SYDÖSTRA ÖSTERSJÖN,

Väst kuling 15-20, under dagen avtagande till ca 10. Mest god sikt.

MELLERSTA ÖSTERSJÖN, NORRA
ÖSTERSJÖN,

Omkring väst kuling 17-storm 25, under dagen långsamt avtagande till 8-13. God sikt.

ÅLANDSHAV och SKÄRGÅRDHAVET,
SYDLIGASTE BOTTENHAVET,

Omslag till väst eller nordväst, ökande till 13-kuling 20, blåsigast i södra farvattnen, under dagen långsamt till ca 10. Förbättring till god sikt men någon regnskur.

BOTTENHAVET UTOM DEN
SYDLIGASTE DELEN, NORRA
KVARKEN:

Växlande 5-10, från morgonen väst 9-13. Mest god sikt.

BOTTENVIKEN:

Syd 4-8 m/s, i morgon väst eller nordväst och något ökande. God sikt.

Vindutsikter för Torsdagen

I samtliga farvatten vind mellan väst och nordväst, på många håll kuling.

SMHI NORRKÖPING - 1994-09-27 18:56 UTC

WOSN42 ESMI 271900
SWEDISH GALEWARNINGS 1900 UTC

NEW:
SOUTHERNMOST PART OF BOTHNIA

SKAGERRAK, NORTHERN KATTEGAT:
AROUND WEST 15-20 M/S. SLOWLY DECREASING .

LAKE VAENERN:
WESTERLY OR NORTHWESTERLY 14-17. DURING THE DAY DECREASING.

SOUTHERN KATTEGAT, THE SOUND AND THE BELTS, WESTERN BALTIC:
WESTERLY. AT FIRST 15.

SOUTHERN BALTIC, SOUTHEASTERN BALTIC:
AROUND WEST 15-20. DURING WEDNESDAY DECREASING.

CENTRAL BALTIC, NORTHERN BALTIC:
AROUND WEST. TONIGHT 17-25. LATER DECREASING.

SEA OF ÅLAND AND ÅLAND ARCHIPELAGO, SOUTHERNMOST PART OF SEA OF
BOTHNIA:
FROM LATE TONIGHT WESTERLY OR NORTHWESTERLY 14-20 M/S. TOMORROW
DECREASING.

REMAINING AREAS NIL.

To: m/s ESTONIA
Att: MASTER

Fax: 010 - 261 98 08

CC: 08-666 60 52 ATT: BENGT BRYUNGS

Issued: 1994-09-27 1311 LT

TALLINN - STOCKHOLM

Stretch	Time	Mean wind speed on 10 m level (svensk kl) m/s	Prob. for mean wind >15 m/s in %	Wave height sign (m) max (m)	Remarks
Naisaar-N Osmusaar	⁽¹⁹⁻²¹⁾ 20-22	S-SW 10-15	20	1,0-2,0	3,0
N Osmusaar-S Bogskär	⁽²¹⁻⁰³⁾ 22-04	SW-W 15-20	70	2,5-3,5	5,5
S Bogskär-Sandhamn	⁽⁰³⁻⁰⁶⁾ 04-07	W-NW 18-25	90	3,5-2,0	5,5

COMMENTS: INTENSE LOW NEAR OSLO MOVING E-WARD VIA SOUTHERN SEA OF BOTHNIA TO SUOTHERN FINLAND. IT WILL CAUSE INCREASING SW- LATER W-NW. FROM TO NIGHT GUSTY WIND. AT DEP. RAIN WITH MOD VIS. LATER SOME SHORT SHOWERS.

BEST REGARDS/