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Abstract

Fifty cases of severe convective weather in the Netherlands have been analysed. According to their circulation type they can be classified in five classes. Accordingly five conceptual models of severe convective weather are presented including average circulation type, average value of surface potential wetbulb temperature (Θ_{sw}) and stability parameter (ΔT), a synthetical illustration of its causes and conditions for its occurrence. These conceptual models can be used as a basis for forecasting and also for understanding severe convective weather.

I. Introduction

Since severe convective weather (scw), such as tornadoes, big hail, heavy rain, gusts and lightning strike, may cause heavy damage, its causes and forecasting have been studied extensively.
Many cases of tornado in the Netherlands have been analysed since 1900, van Everdingen (1928), Wessels (1968), Roach and Findlater (1983) and Forbes (1985) analysed the strongest ones. Feteris studied the relations between the characteristics of thunderstorms and various meteorological parameters (1962) and statistical studies on thunderstorm situations in the Netherlands (1964).
Ivens (1987) set up a statistical method for the forecasting of maximum windvelocity in squalls. A framework for short-range forecasting of scw was developed by Heijboer, Timmerman and van der Hoek (1987) who designed an hourly nowcasting and very short-range forecasting system. Van Delden (1992) contributed to the understanding of scw in his study of the dynamics of meso-scale atmospheric circulations.
In the meantime conceptual models of scw are widely used in the United States and China. Scofield, Robinson and Du Yang (1990) presented a conceptual model of backward propagating mesoscale convective systems . Dang Renqing and others (1992) set up several conceptual models for forecasting mesoscale convective weather over the Changjiang Delta. These studies are very useful and very important in this field.
In order to understand and forecast convective weather in the Netherlands, a synthetical analysis of the cause and conditions of scw and the development of a conceptual model is highly needed. In this paper, conceptual models of scw in the Netherlands including its cause and conditions are presented. These models are based on an analysis of 50 cases (1925 - 1992), combined with other cases. These conceptual models show the circulation background and the processes causing severe convective weather. It turns out that the causes and conditions of scw in different circulation types are very different. For example, in a Tsw circulation (the Netherlands is ahead of an upper air trough, south-west flow aloft), the air mass is very warm and moist, the air stratification is very unstable and the buoyancy is very strong, so the strongest convective weather, such as tornado, heavy rain or big hail, often happened in this type. The average value of surface potential wetbulb temperature (Θ_{sw}) is 19.2 °C, the stability parameter (ΔT) is 3.7°C. But in the cold vortex type, the temperature is quite low, because it is in the cold air mass. The air is not very unstable and the buoyancy is not so strong, so only one small tornado was observed in this type. Big showers and big hail can occur in this type however. The average value of (Θ_{sw}) is 12.9°C and ΔT is 0.8°C, considerably lower than the value in Tsw type. All fifty cases can be assigned to five different circulation types. For every type the cause of and conditions for scw are identified. This analysis shows the close relationship between the value of (Θ_{sw}), ΔT and circulation type.
This study adds to previous research work.

Section 2 of this paper deals with the data and the method. It explains how the 50 cases of strong convective weather were selected and how these 50 cases can be classified according to five circulation types. From a period of 43 years (1950 - 1992), the strongest convective weather phenomena were selected. Tornadoes ≥ F2 (Fujita classification) or tornadoes that caused casualties were selec-ted. In addition, two other very strong cases were also selected. One is a tornado that occurred on August 10, 1925 in Borculo, 4 people being killed, 200 people wounded and 2000 homeless. The second was a case of heavy rainfall (208.0 mm) on August 3, 1948 in Voorthuizen.

Finally Section 3 presents the conceptual models on the basis of five circulation types. For each type the average circulation and conditions are illustrated.

II. Data and method

The data used in this study come from the same source as that used in the author's companion report "A synoptic climatology of convective weather in the Netherlands" (1993). From the 50 cases studied in these reports, 48 cases are identical. Two cases of Tsw type were left out because the convection was not very strong.
Two new cases are added, one case is a tornado which occurred on June 5, 1992 in Wielbergen. The circulation belongs to the Cvn type. Another case is a tornado which happened under a very strong upper air jet streak on August 17, 1992 in Ameland. This tornado caused heavy damage, one person was killed, several people were injured. The circulation type is Jet.

The 50 cases of sever convective weather were selected according to any of the following criteria:
1. Tornado ≥ F2 (Fujita-classification) or people being killed.
2. Big hail, size ≥ no. 4 (the diameter of the hail ≥ 21 mm.).
3. Heavy showers, the rainfall ≥ 25 mm/hour or ≥ 80 mm/day.

The circulation types corresponding to these 50 cases can be classified in the following five classes:

1. Upper air trough south-west flow aloft (Tsw).
2. Upper air jet streak (Jet).
3. North part of cold vortex (Cvn)
4. Shear line (Sl)
5. Cold vortex (Cv)).

Table 1 shows the relationship between circulation type and several types of convective weather. This table should be read as follows. In the second column the total number of cases for each circulation type is shown. For example, out of 50 cases 31 were Tsw. In the following columns the total number and percentage of several types of convective weather are presented. Information is not always available for all cases. For example, for only 28 out of 31 Tsw cases, it is known whether or not hail occurred. For only 17 of these cases the hail size is known. Percentages are calculated only if the number of cases is sufficiently large (≥ 6) for the percentage to have significance. Otherwise only the ratio is shown.

The following observations can be made from this table:
1. A different circulation type usually corresponds to different weather. Most tornadoes occurred in Tsw type. Among a total of 31 Tsw cases ,11 tornadoes happened; so the probability of tornado in this type is 35 percent. But in cold vortex type, the probability for tornado is only 8 percent. Meanwhile the strongest tornadoes, big hail and heavy rain also often took place in Tsw type.
2. Big showers or heavy rain happened in Sl and Tsw type.
3. Most severe convective weather phenomena, such as hail, big shower and lightning strike often occurred together and the probability is very high. So, each of these five circulation types can lead to many kinds of convective weather.

In order to develop a conceptual model of strong convective weather, we computed the upper air and surface circulation type for each case and paid attention to the circulation system which caused convective weather. Secondly, the surface potential wetbulb temperature (Θ_{sw}) and stability parameter (ΔT) are calculated.
The records of Θ_{sw} and ΔT during the period 1945 - 1965 were from KNMI's series of records "Thunderstorms and Optical Phenomena". As a third step, we analysed every one of these 50 cases to find out the causes and condition of convective weather. On this basis we developed conceptual models including the cause and conditions. Finally, these conceptual models were tested on other independent cases. This testing procedure led to final corrections and improvements.

weather/ type	total type	tornado	%	hail	%	hail size ≥ no.3	%	hail size ≥ no.4	%	heavy shower ≥ 10 mm/h or ≥ 25 mm/d	%	heavy shower ≥ 25mm/h or ≥ 50 mm/d	%	light-ning strike	%
Tsw	31	11	35%	25	89% (25/28)	15	88% (15/17)	14	82% (14/17)	29	94% (29/31)	17	55% (17/31)	16	94% (16/17)
Jet	1	1	(1/1)												
Svn	3	1	(1/3)	2	(2/2)	1	(1/1)	1	(1/1)	2	(2/3)	1	(1/3)	1	(1/1)
S1	3	0	(0/3)	2	(2/2)	1	(1/1)	0	(0/1)	3	(3/3)	3	(3/3)	3	(3/3)
Cv	12	1	8%	11	92% (11/12)	5	83% (5/6)	4	67% 4/6	8	67% (8/12)	6	50% (6/12)	8	100% (8/8)
total	50	14		40	(40/44)	22	(22/25)	19	(19/25)	42	(42/50)	27	(27/50)	28	(28/29)
%		28%			91%		88%		76%		84%		54%		97%

Tabel 1. Relationship between circulation type and convective weather

III. Conceptual model

1. Average circulation type

Figure 1 to figure 5 show the average upper air circulation and surface weather situation for each circulation type respectively. The time of the upper-air maps is 3-4 hours prior to the occurance of convective weather.
Each figure expresses a very clear image, i.e. which kind of background of circulation type and which kind of surface weather system could cause strong convective weather.

1.1 Tsw
A very deep upper air trough accompanied by very strong cold air is situated above the British Isles. The Netherlands is ahead the trough with south-westerly flow aloft. A very strong cold front is usually located along the coast of Western Europe. At the surface, ahead of the cold front, the temperature is quite high and the air is very humid. When the cold front passes the Netherlands, it often causes strong convective weather. Tsw type is a common type, 60 percent of the total 50 cases.

1.2 Jet
The main character of this type is a very strong jet streak on the 300 hpa level . The jet is over the Atlantic ocean and Western Europe. The maximum wind speed is more than 50 m/s, sometimes it can reach 75 m/s. When the Netherlands is under the exit region, especially under the left side of the exit region, the updraft could induce the occurrence of convective weather. Figure 2c is adopted from van Delden (1992). It explains the reason why this circulation may cause convective weather. Among the 50 selected cases this type occurred only once, on August 17, 1992 in Ameland, but actually another tornado case with a very similar circulation occurred on August 11, 1972 in Ameland. That tornado caused 4 casualties and 90 people were injured on the Island.

1.3 Cvn
In this type the Netherlands is located in the north part of a cold vortex. The east part of the Netherlands is often warmer than the rest of the country. When the warm front passes the Netherlands, it often causes a low level warming, the air becoming unstable, so many kinds of strong convective weather, heavy rain, big hail, even tornado may happen in this situation.

1.4 Sl
In this type, there is a line of directional wind shear in the upper air above the Netherlands. On the surface weather chart we find a front beneath the shear line. Strong convergence and updrafts induce severe convective weather, especially heavy rain often happens in this type.

1.5 Cv
A deep cold vortex is in the upper air above the Netherlands, the surface weather map also shows a low pressure area. The temperature is quite low. Sometimes a cold front passes the Netherlands. If no cold front passes, large scale upward motion causes convective weather.
The value of Θ_{sw} and ΔT are much lower than for the other four types. So the circulation type is more important than the

value of Θ_{sw} and ΔT. When the value of $\Delta T > 0$, it is often favourable for the development of convective weather.

2 Surface potential wetbulb temperature (Θ_{sw}) and Stability parameter (ΔT)

Tabel 2 shows the average value of Θ_{sw} and ΔT. Θ_{sw} is derived from the temperature T, dewpoint T_d and pressure at station level. ΔT is the temperature difference between the saturated adiabat through the cloud base and the clear air temperature at 500 hpa level. If ΔT is positive, the air is unstable which favours the development of convective weather.
Figure 6a and 6b show the relation between strong convective weather and Θ_{sw}, ΔT. From these figures some results can be found. In most cases in Tsw, Sl, Cvn, and Jet the value of Θ_{sw} is above 15°C and ΔT is positive. In figure 6a the percentage of these cases is 89 percent, in figure 6b the percentage is 93 percent, but the percentage for cold vortex is only 42 percent. It means that a classification of circulation type is very important: different circulation types should be dealt with in different ways. For cold vortex type, the value of ΔT is only positive. The percentage become 83 percent, the percentage of the total cases is 87 percent. This analysis improves previous results obtained by Feteris (1962, 1964).

Tabel 2. The average value of Θ_{sw} and ΔT per circulation

weather/ type	Θ_{sw} (°C)		ΔT (°C)		lift system
Tsw	19.2		3.7		cold front
Jet	18.0		3.0		divergence on upper air Convergence at low level
Svn	19.7		3.0		front or shear line
S1	18.8		3.0		warm front
Cv	12.9		0.8		Convergence or front

Θ_{sw} Surface potential wetbulb temperature
ΔT Stability parameter

3 Schematic illustration

3.1 Upper air trough (Tsw)

Figure 7 is a composite picture of Tsw type. In this circulation type the conditions for the occurrence of scw are as follows:

a. The deeper the upper air trough developes, the stronger the convective weather will be.
b. The difference of upper air temperature between St. Mawgan (03817, England) and De Bilt (06260, The Netherlands) indicates the intensity of cold air. The average value is 6°C, a growing difference of temperature implies stronger convective weather.
c. There is a jet streak on the 300 hpa level in most cases, the wind velocity for one third of the cases exceeds 50 m/s. The stronger the jet is developed, the more severe the convective weather will be. Among nine cases of Jet streak with wind velocities over 50 m/s, there are six cases with tornado, two cases with big hail, one case with heavy rain, so much attention should be paid to the occurrence of strong jet streaks.
d. Θ_{sw} is a function of temperature and humidity, the value is often higher than 15°C. The higher the value of Θ_{sw} the heavier the convective weather developes.
e. ΔT is an unstability index. A higher T is favourable for the development of convective weather.
f. If the central part of a cyclone is nearby the Netherlands (i.e. between 48° and 55°N and between 10W and 6E), then this is a condition for strong convective weather.
g. The surface temperature is usually very high in this type, often more than 25°C, even more than 30°C. The situation is favourable for the development of unstable weather. When the cold front approaches, we must pay much attention to strong convective weather.
h. The cold front causes upward motion. A strong cold front easily causes severe weather.
i. A warm and moist tongue at low level is very important: we should watch out for this and forecast the severe weather earlier.

3.2 Jet streak (Jet)

Figure 8 is a composite picture of the Jet type. The conditions are as follows:

a. The main character of this type is a very strong jet streak in the upper troposphere. The maximum wind speed is usually more than 50 m/s, sometimes can be over 75 m/s, wind direction west to south-west. The difference between Jet and Tsw type is that in the former case the accompanying trough is much weaker. Strong convective weather often occurred on the left side of the exit region of the jet streak, because of updraft in that region. Vertical motion and divergence on August 17, 1992 at three levels (850 hpa, 700 hpa, 300 hpa) in Western Europe show that there was updraft at three levels above Ameland where a tornado happened.
b. The value of Θ_{sw} is more than 15°C.

c. ΔT is positive. If the sea surface temperature is higher than the temperature on land, a tornado may develop over sea and pass through islands. Two tornadoes killed people in 1972 and 1992 in Ameland. Both occurred in the same situation.
d. The lift system on the surface is quite weak. The trough or low pressure zone may be shallow, the front may be only weak.

3.3 North part of cold vortex (Cvn).

Figure 9 is the synthetical illustration. The conditions are as follows:

a. When a cold vortex is the south of the Netherlands and a warm front is moving to the Netherlands from the east, then the circulation belongs to this type.
b. The value of Θ_{sw} more than 15°C.
c. ΔT is positive.
d. The warm front is the lift system. When it passes, low level becomes much warmer than high level, so the air gets very unstable. Two tornadoes happened in this circulation type.

3.4 Shear line (Sl)

Figure 10 is the synthetical illustration of this type. The conditions are as follows:

a. There is a shear line above the Netherlands at two or three levels (850 hpa, 700 hpa, 500 hpa). This shear line is different from the one observed in Cv: in Sl it is usually between two high pressure areas.
b. The value of Θ_{sw} is more than 15°C.
c. ΔT is positive.
d. A front or a shear line on the ground is a lift system, strong convective weather happened along the shear line.

3.5 Cold vortex (Cv)

Figure 11 is a composite picture of this type. The conditions are as follows:

a. The central part of a cold vortex is located nearby the Netherlands. Most cold vortices move slowly or are even stationary, so the convective weather can last for several days.
The Cv circulation type has a special and very important character. For instance, in the central part of a cold vortex the value of ΔT is negative; but still there may be strong convective weather.
b. The value of ΔT is the second index of this type. Most convective weather developes in this condition when ΔT is positive, but it remains possible at negative ΔT values.
c. The value of Θ_{sw} in this type is not very important, most cases of convective weather happened when Θ_{sw} was less than 15°C, sometimes less than 10°C.

d. The values of updraft at low and middle levels are useful: the vertical motion shows there is a close relation between updraft and convective weather.
e. Sometimes the cold front is the lift system. Sometimes the convergence is the lift system. The convective weather is scattered.

IV. Discussion and Summary

4.1 Strong convective weather often causes heavy damage, even loss of life. Forecasting and prevention are very important. In order to improve the prediction of convective weather, much research work needs to be done, including development of forecasting methods. Conceptual models are useful, but even a perfect conceptual model needs a period of refinement.

4.2 In this paper five conceptual models of severe convective weather are presented. Each conceptual model may correspond to several severe weather phenomena: big hail, heavy shower or heavy rain, lightning strike and sometimes tornado, because they often happen together. These models can also explain the cause of and conditions for convective weather and present a clear synthetical picture. They can be used as a background for weather forecasting. They should be combined with other data and methods such as satellite cloud pictures, radar echoes, numerical weather prediction and so on.

4.3 In this study, convective weather is classified into five different circulation types. For each type the cause and conditions which lead to the development of severe weather are very different. From table 2 the value of Θ_{sw} and ΔT are very different between cold vortex type and other types. This study improves earlier studies.

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References

. Dang Renqing, Tang Xinzhang and Zhang Jiacheng, 1992, Experiments in forecasting mesoscale convective weather over Changjiang delta.
Advances in Atmospheric Science, 9, pp. 223 - 230.

. Delden, A. van , 1992, The dynamics of meso-scale atmospheric circulations, Physics Reports (Special Issue), vol. 211, 6, pp. 251-376

. Delver, A., 1951, De windhozen van 23 Augustus 1950, (Veluwe) Hemel en dampkring, 49, pp. 121 - 129, 148 - 157

. Dong Hongnian, 1993, A synoptic climatology of convective weather in the Netherlands, KNMI Scientific Report. WR 93-04, De Bilt,

. Everdingen, E. van, 1925, The cyclone-like whirlwinds of August 10, 1925. Proc. Kon. Akad. v. Wetenschappen, Section of Sciences, 28, pp. 871 - 889

. Feteris, P.J., 1962, On the relations between the characteristics of thunderstorms and various meteorological parameters. Research Report 's-Gravenhage.

. Feteris, P.J., 1964, Statistical studies on thunderstorm situations in the Netherlands. Journal of Applied Meteorology, 4. pp. 178-185.

. Forbes, G.S., 1985, Tornadic vortex along the cold front of a baroclinic mesocyclone in the Netherlands, not accompanied by thunderstorms. AMS, prepr. 14 th conf. on severe local storms, Indianapolis Ind., Oct. 29 - Nov. 1, pp. 212 - 215. Boston, Mass.

. Heijboer, L.C., Timmerman H. and Hoek, A. van der, 1989, Description and performance of an hourly nowcasting and very short-range forecasting system. Q.J.R. Met. Soc. 115, pp 93 - 115.

. Ivens, R.A.A.M., 1987, Forecasting the maximum wind velocity in Squalls. Proc. symp. mesoscale analysis & forecasting, Vancouver, Canada, 17 - 19 august 1987. European Space Agency, pp. 685-686, Paris.

. KNMI, 1879-1881, Onweders in Nederland, waargenomen in ... Publ. 54 I, II.

. KNMI, 1882 - 1887, Waarnemingen van onweders in Nederland. Publ. 57 III - VIII

. KNMI, 1888 - 1895, Onweders in Nederland naar vrijwillige waarnemingen. Publ.69, IX - XVI.

. KNMI, 1896 - 1965. Onweders, optische verschijnselen, enz. in Nederland. Publ.81, XVII - LXXXI.

. Roch, W.T. and Findlater J., 1983, An aircraft encounter with a tornado. Meteorological Magazine, 112, pp. 29 - 49

. Scofield, R.A., Robinson, J., and Du Yang, 1990, A scheme for nowcasting heavy rainfall from mesoscale convective systems.
AMS, prepr. 16th Conf. on severe local storms. Kananaskis Park, Alta, Canada, October 22 - 26 1990,
J 13 - J 19. Boston, Mass.

. Wessels, H.R.A., 1968, De zware windhozen van 25 juni 1967 (Chaam, Tricht). Hemel en Dampkring, 66, pp. 155 - 178

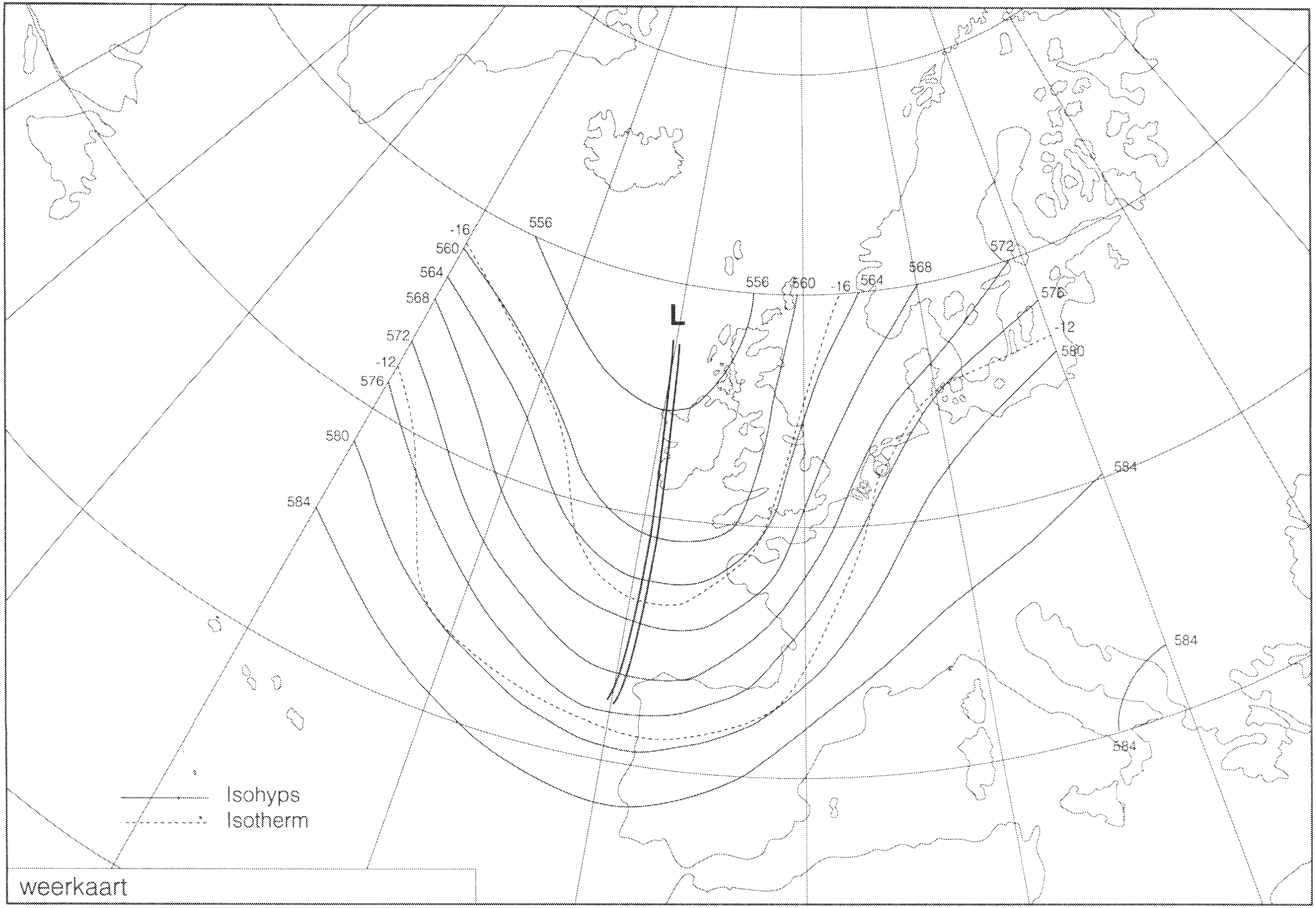


Fig. 1a Tsw 500 hPa average chart

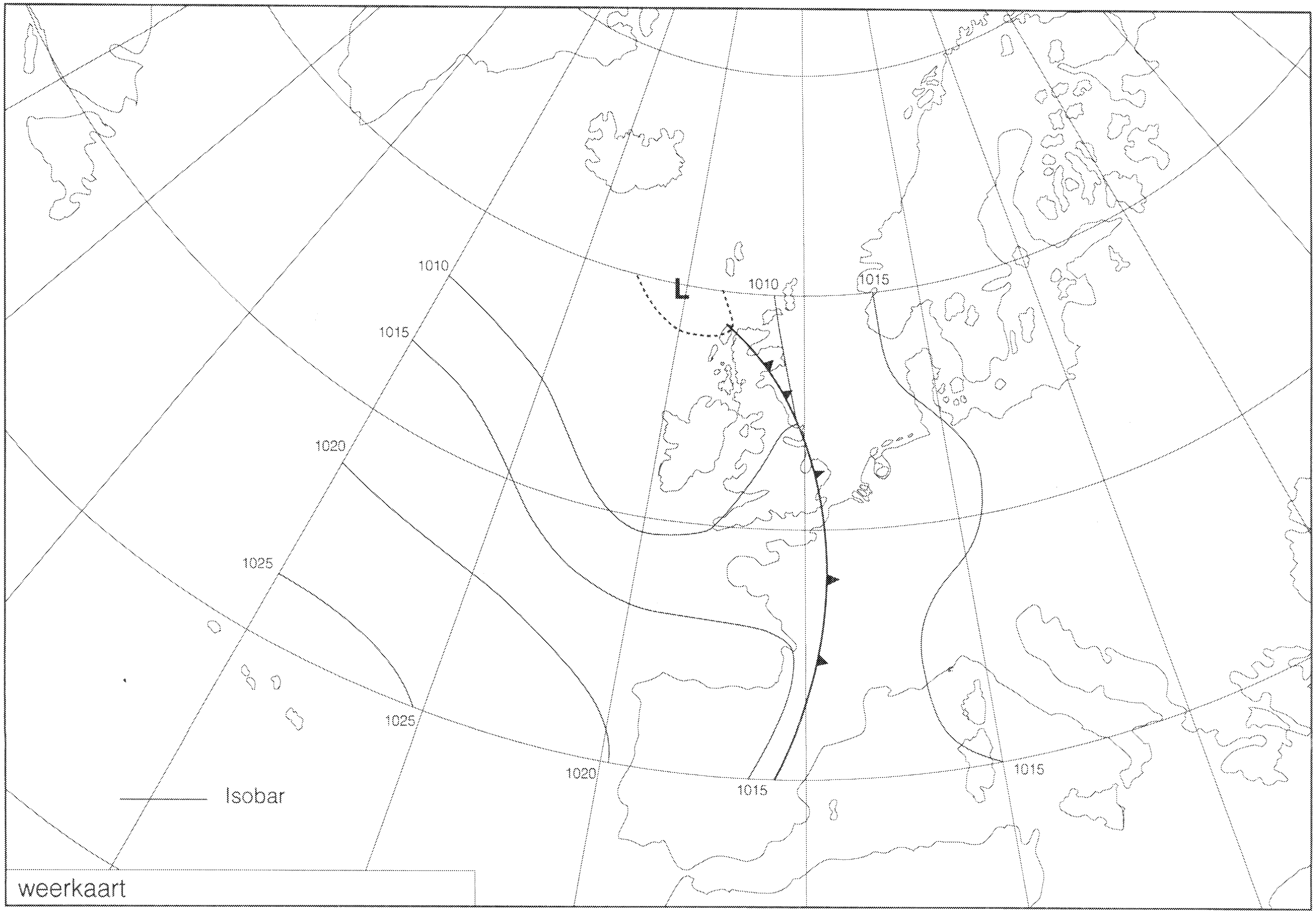


Fig. 1b Tsw surface average chart

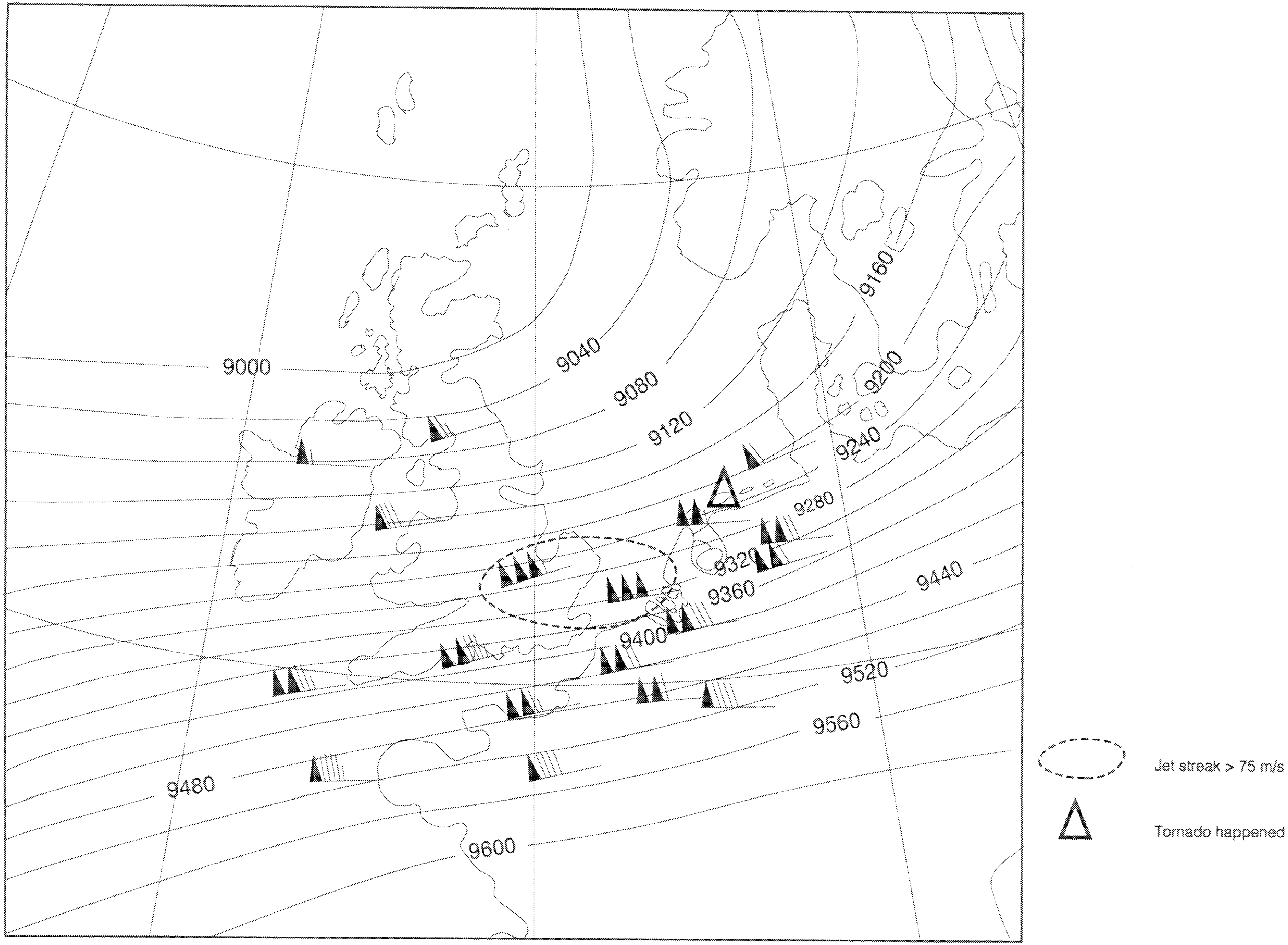


Fig. 2a A case of Jet type
300 hPa chart, 17 august 1992 12 UT

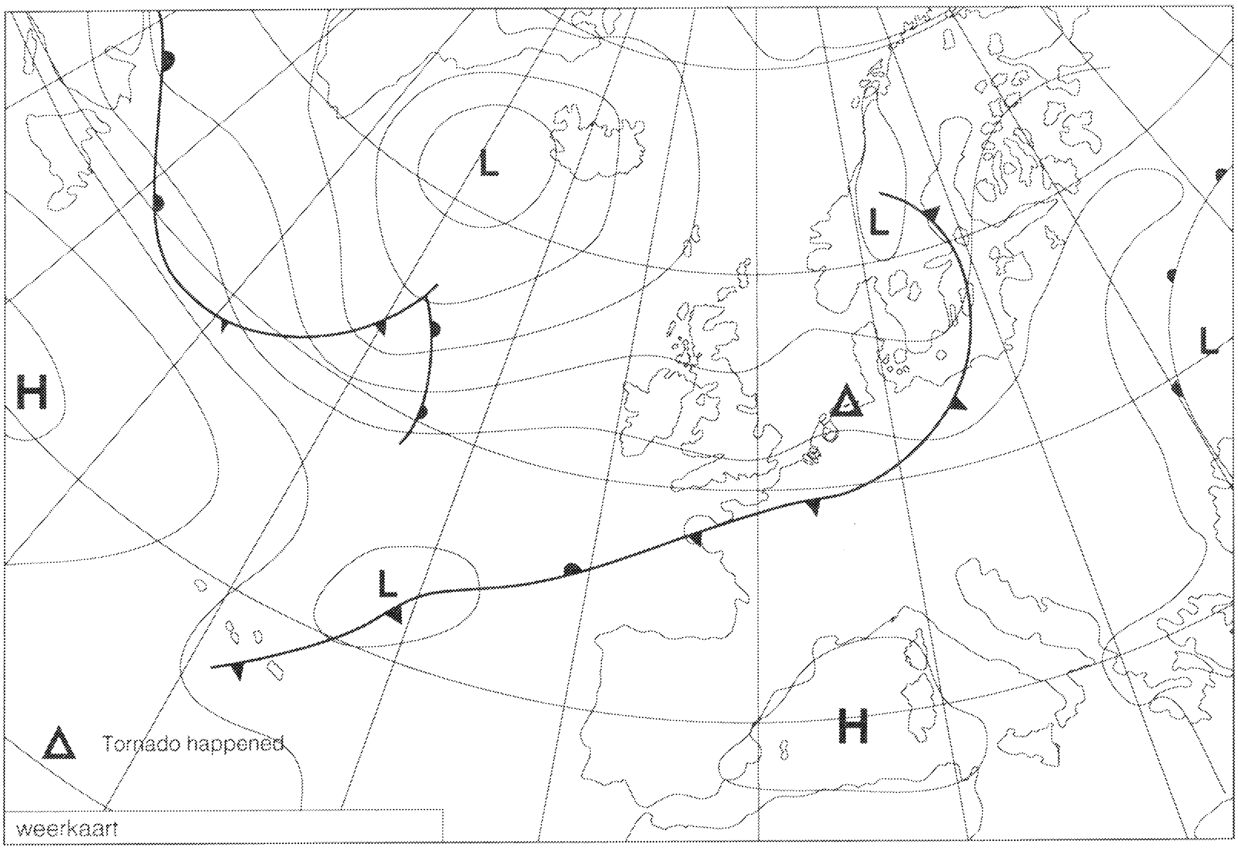


Fig. 2b A case of Jet type
surface chart, 17 august 1992 12 UT

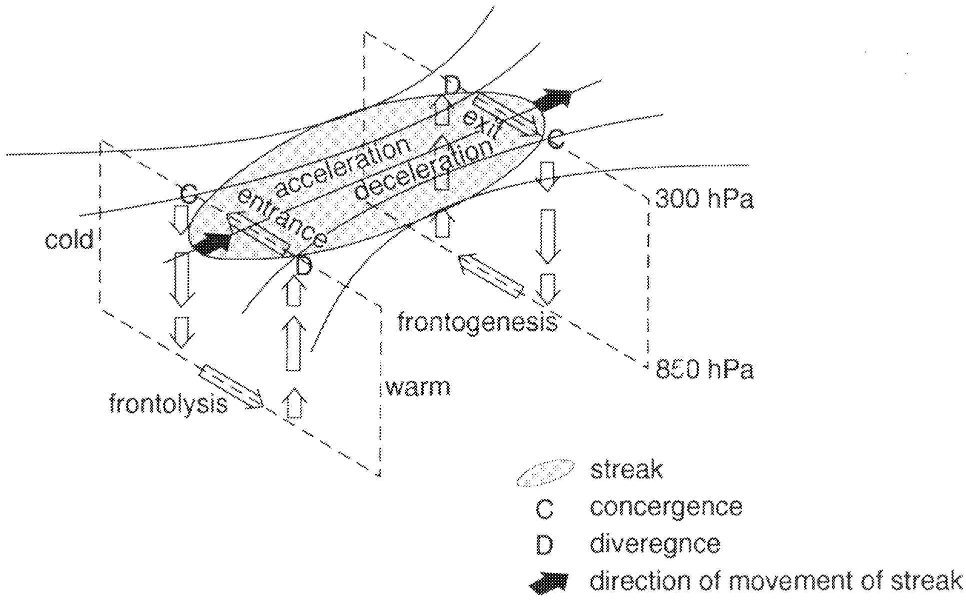


Fig. 2c. The geostrophically forced circulation in the vicinity of a jet streak in a baroclinic zone. Thin solid lines are streamlines. (adapted from Arnout van Delden, 1992)

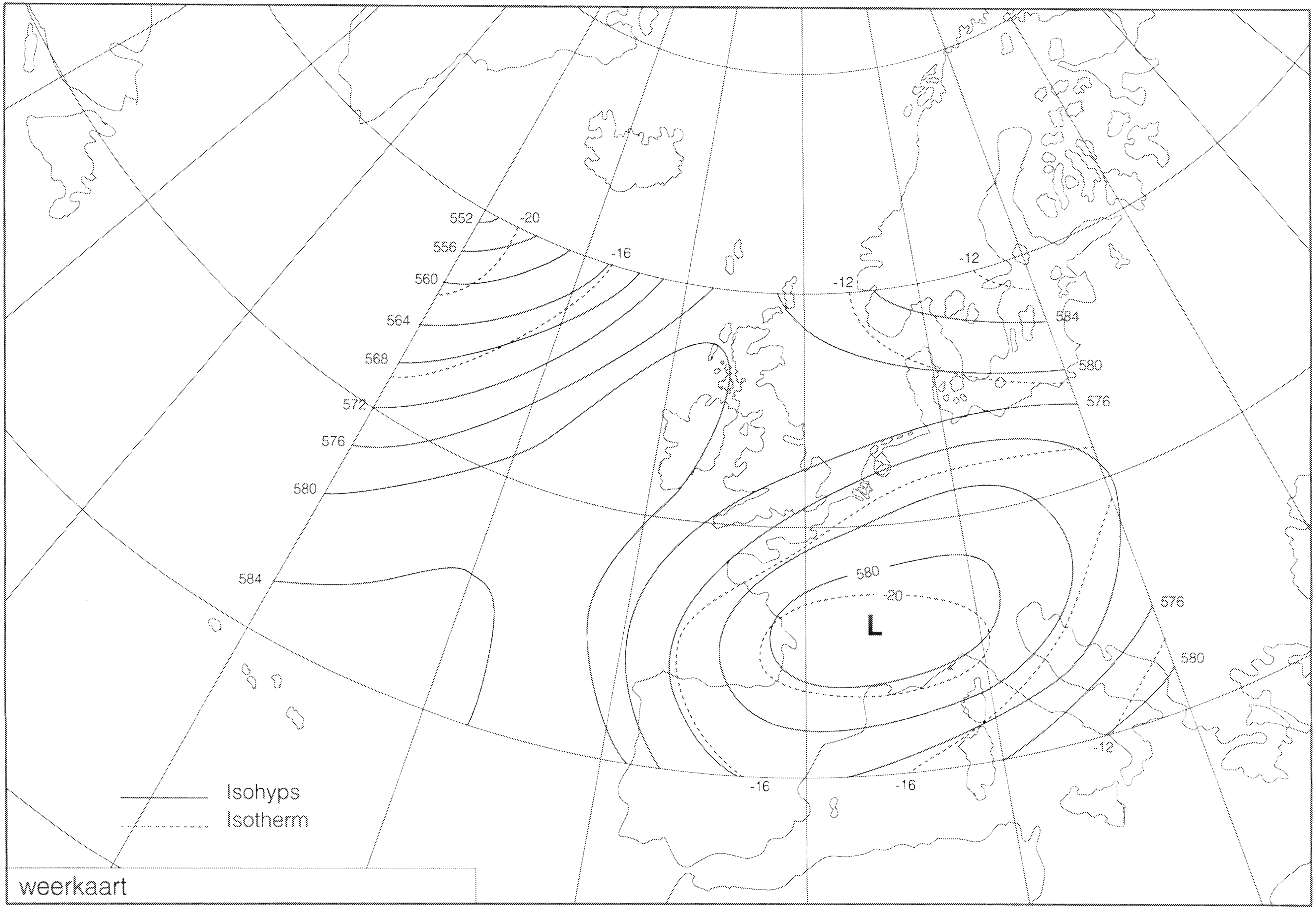


Fig. 3a Cvn 500 hPa average chart

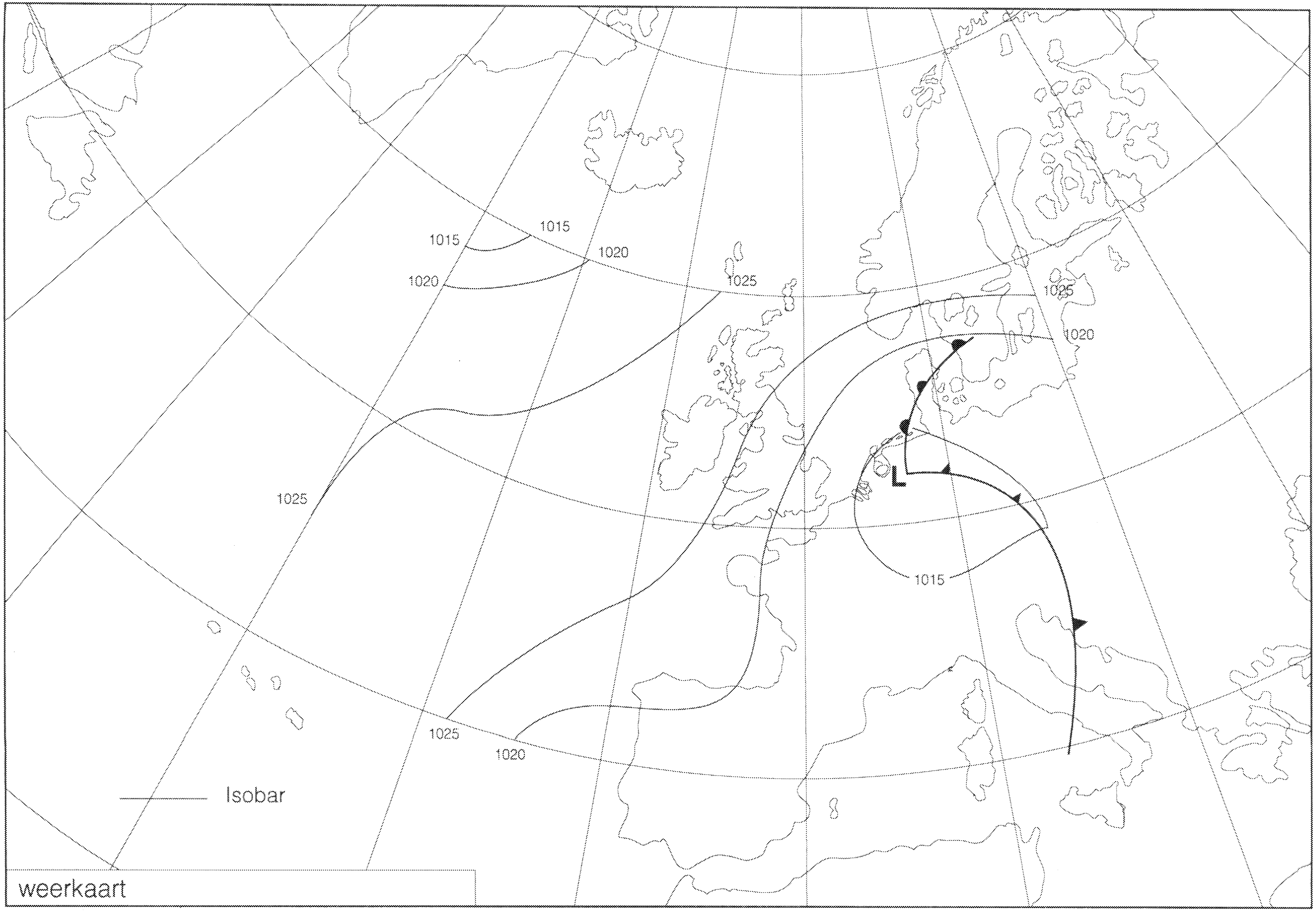


Fig. 3b Cvn surface average chart

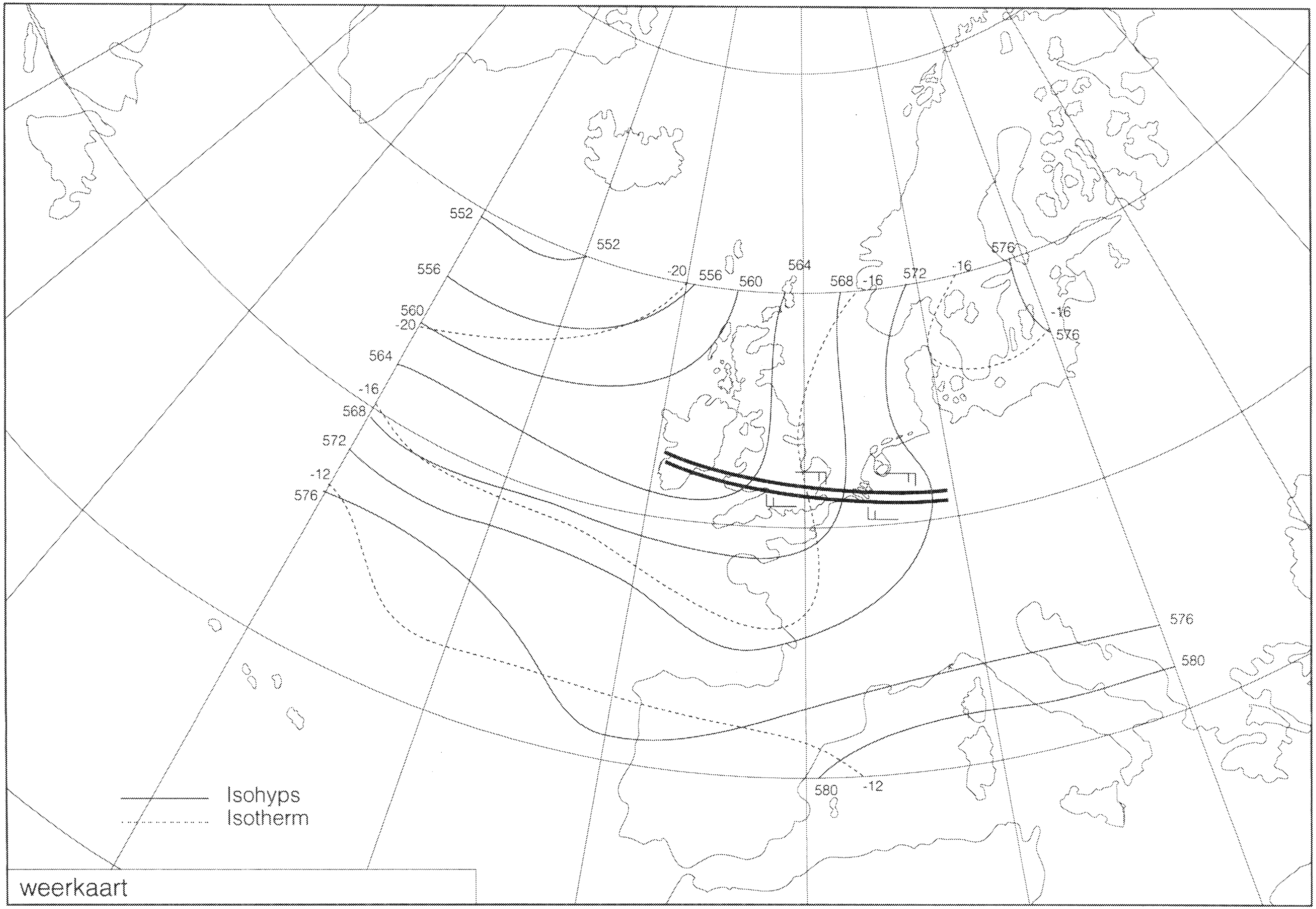
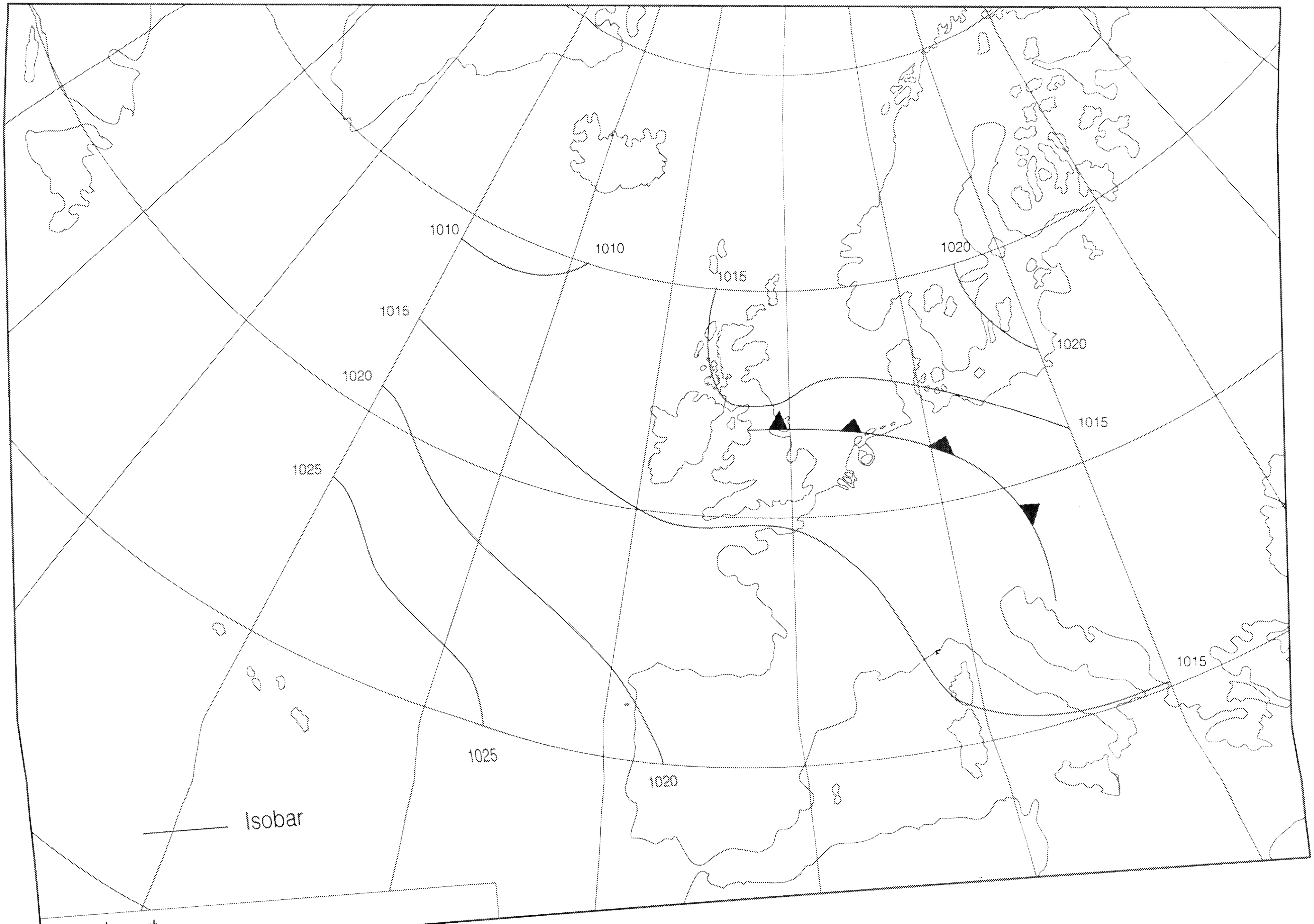


Fig. 4a SI 500 hPa average chart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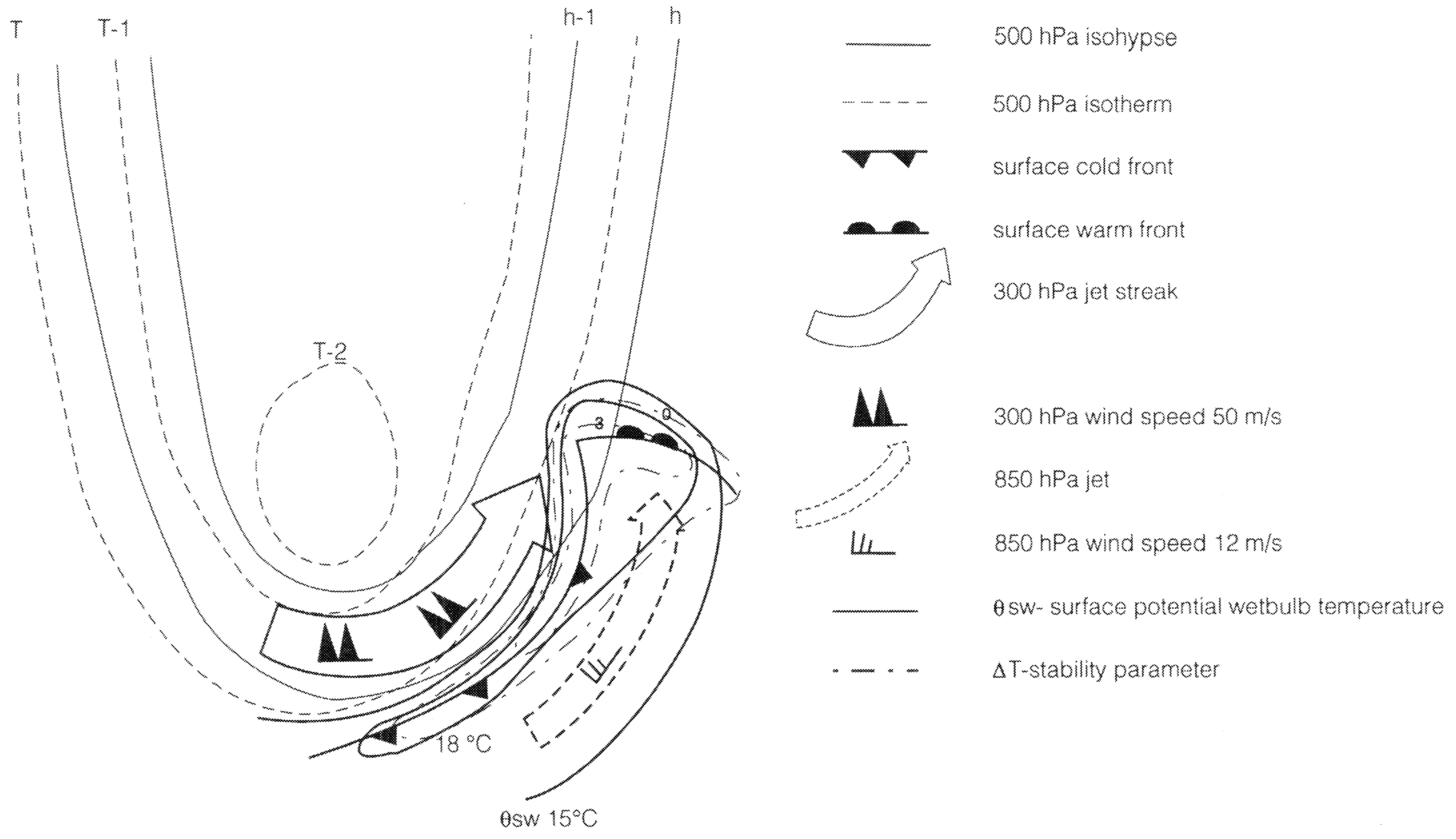

Figure 7. A synthetical illustration of Tsw type

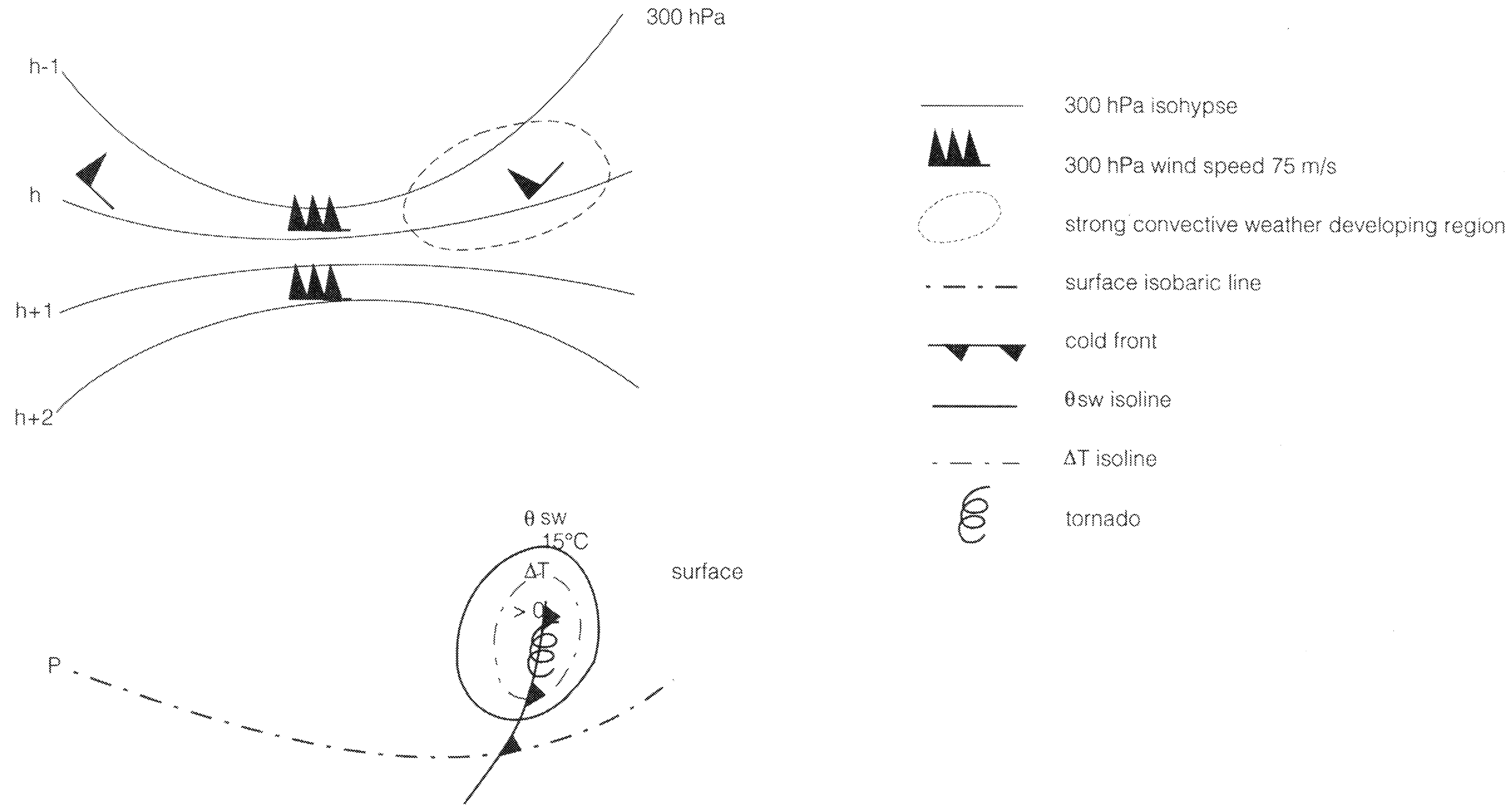

Figure 8. A synthetical illustration of Jet type

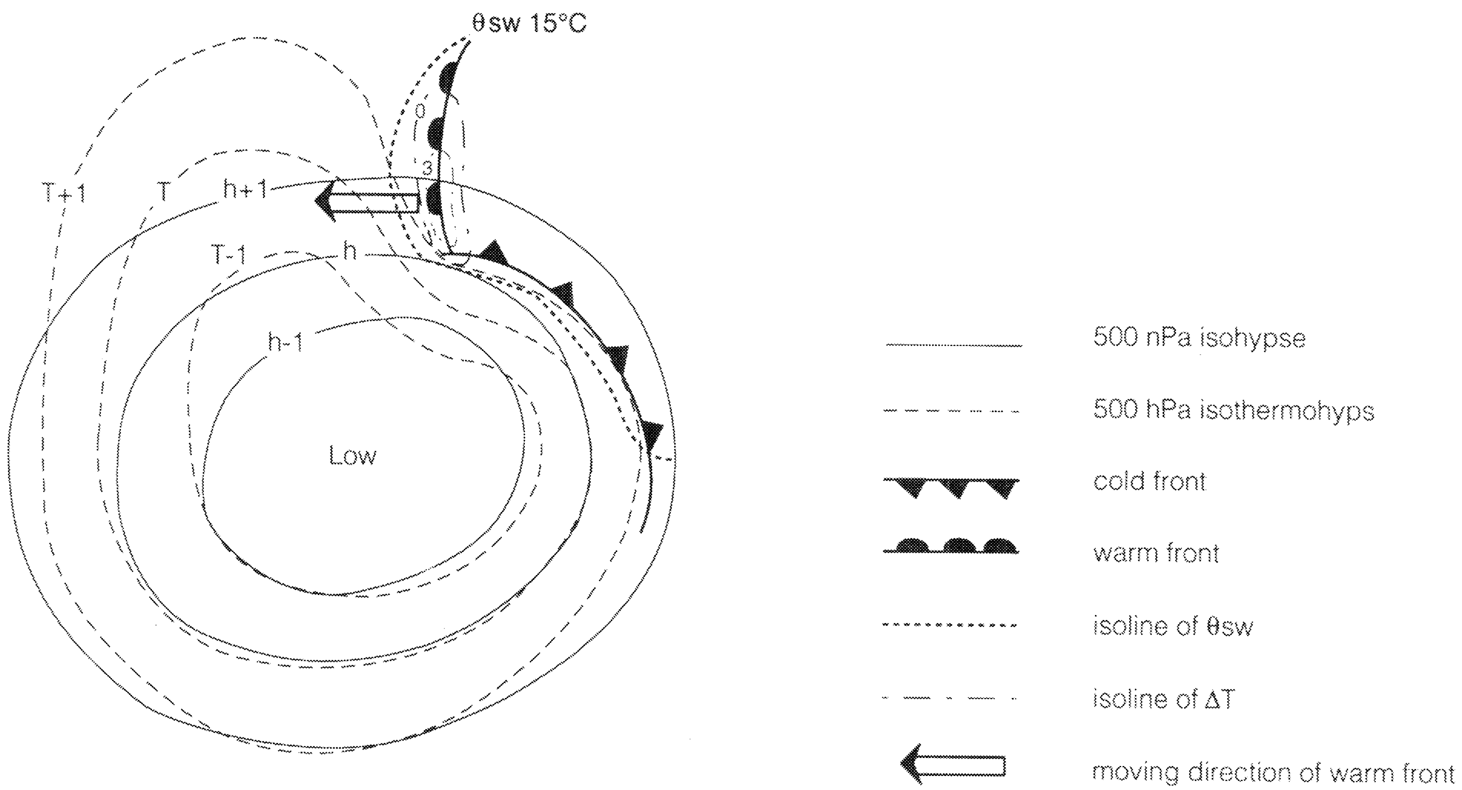

Fig. 9. A synthetical illustration of Cvn type

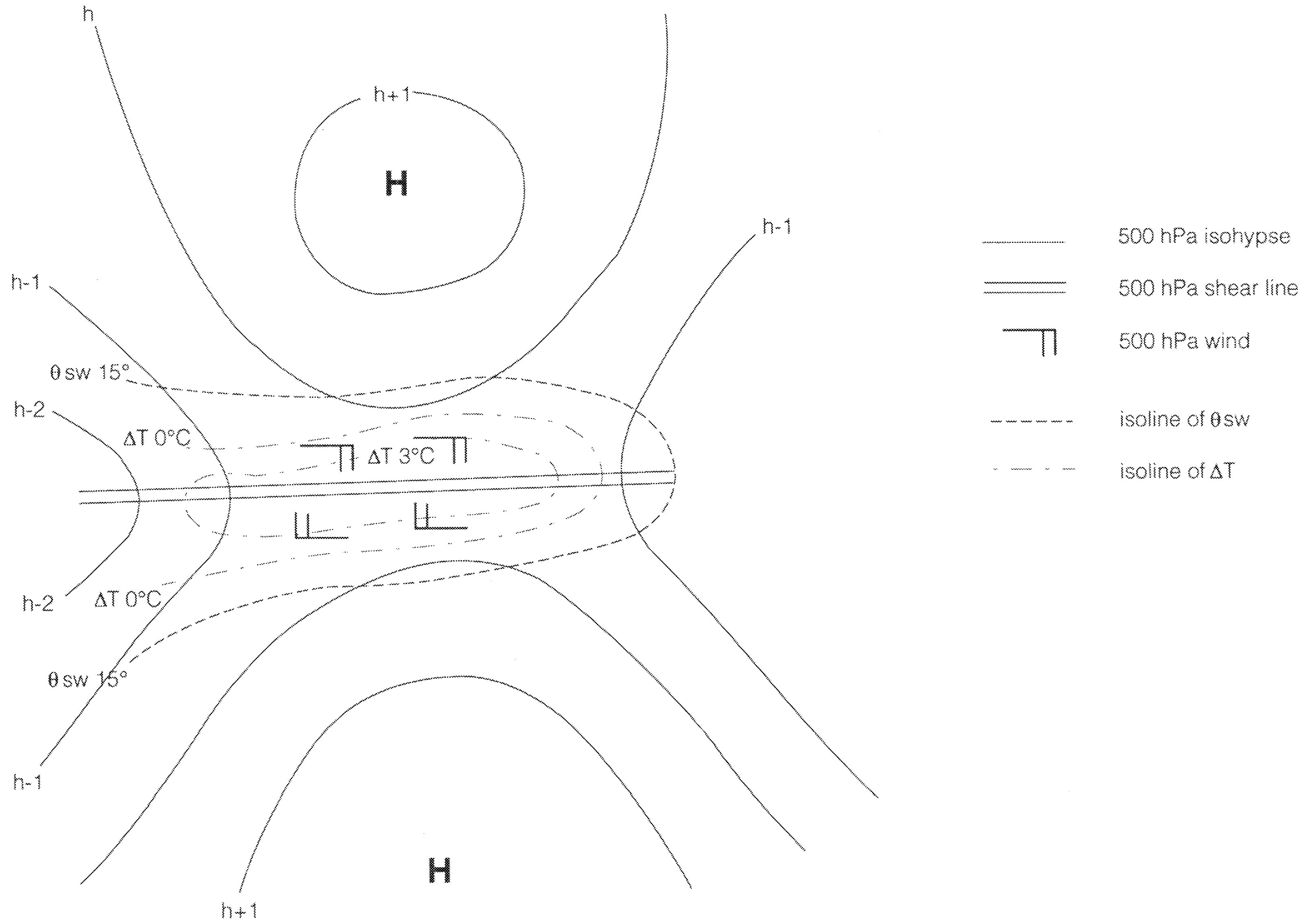

Fig. 10. A synthetical illustration of SI type

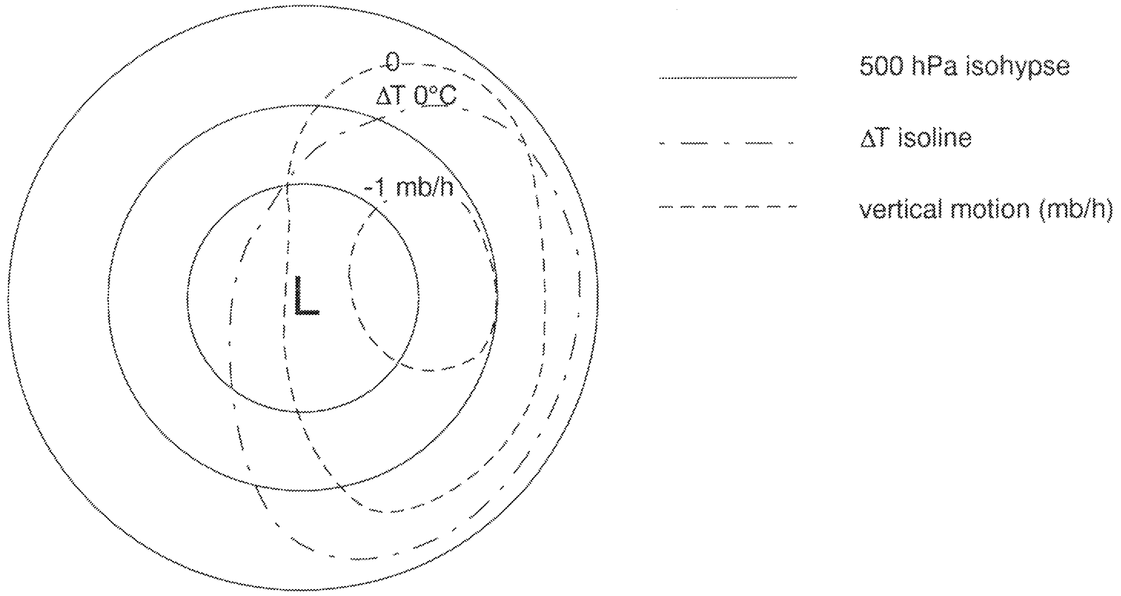

Figure 11. A synthetical illustration of Cv type