A Cyclogenesis south of the Alps

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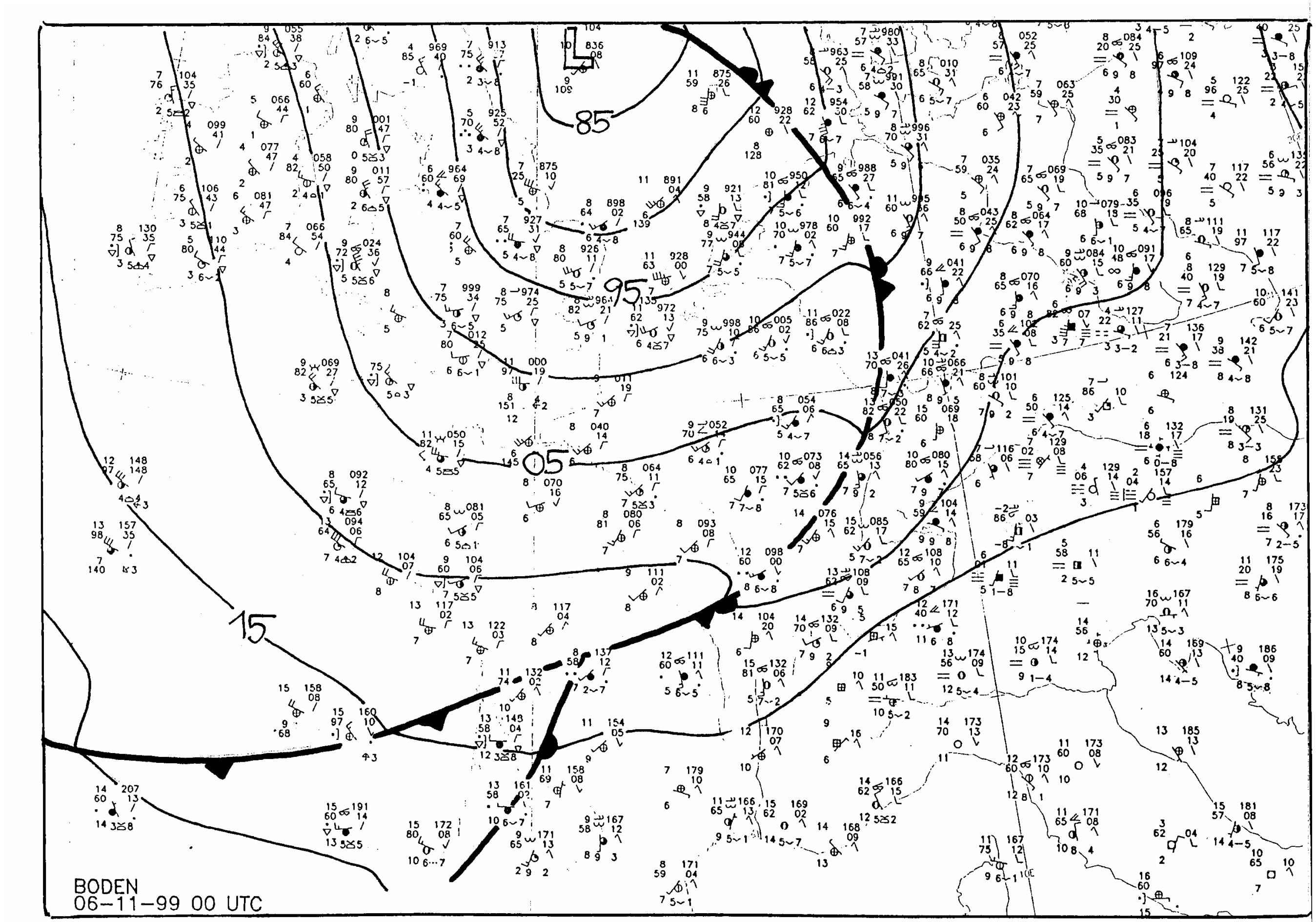
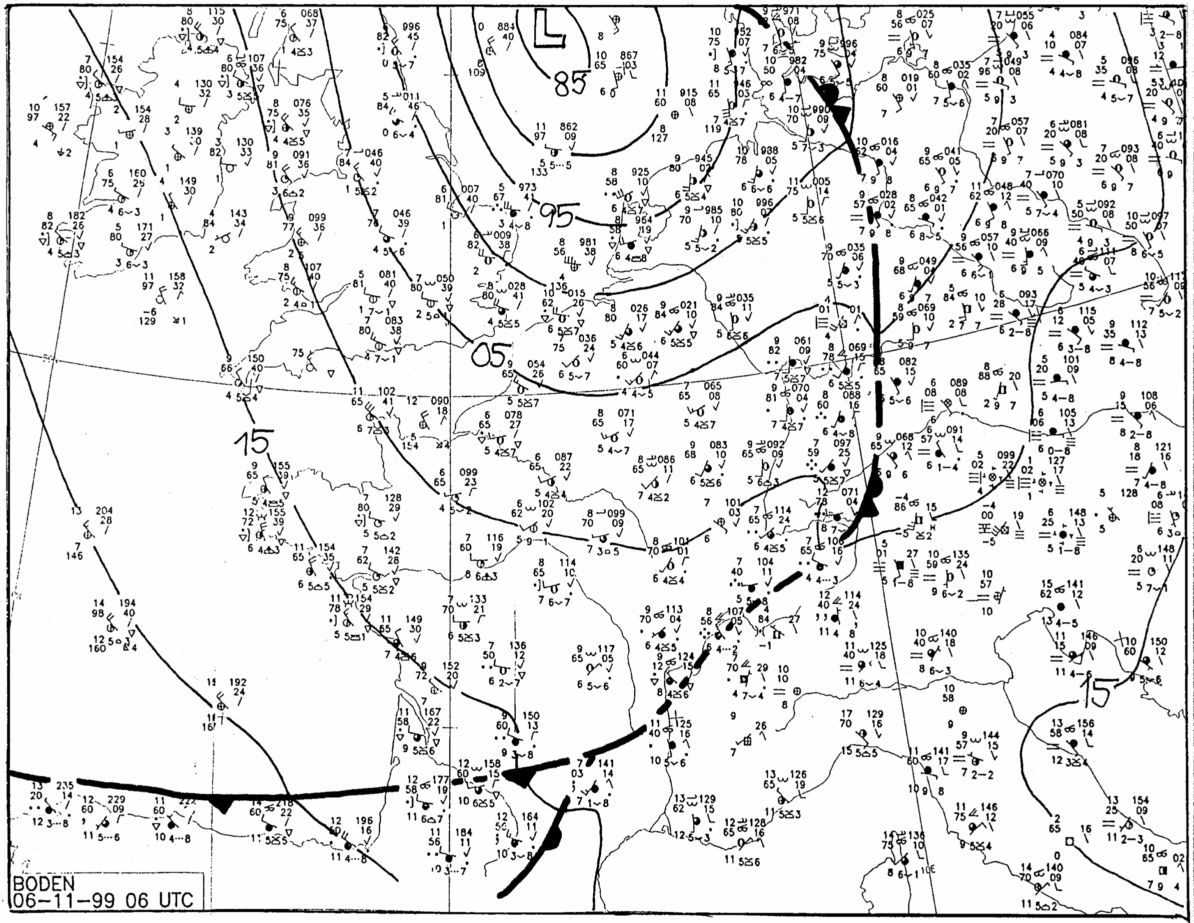
Surface maps

06-11-99,
00 UTC



The occluded frontal system of a quasi-stationary low above the North Sea extends from the German Bight above western Germany and the mid of France towards the Biscay. It is embedded in a frontal trough of the pressure field and accompanied by continuous cloud and some rain. Behind the front a broad trough with showers follows. Northern Italy is covered by a warm and moist air mass with a very weak pressure gradient.

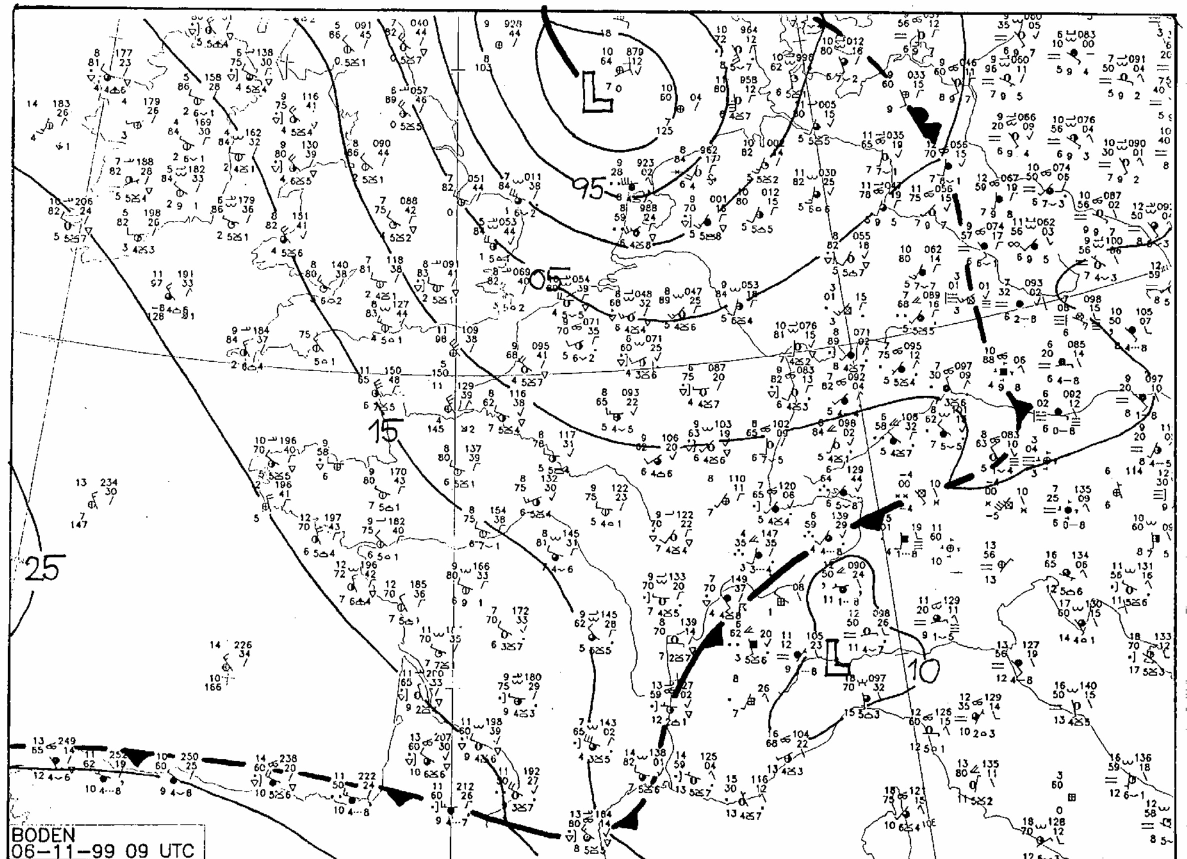
06 UTC



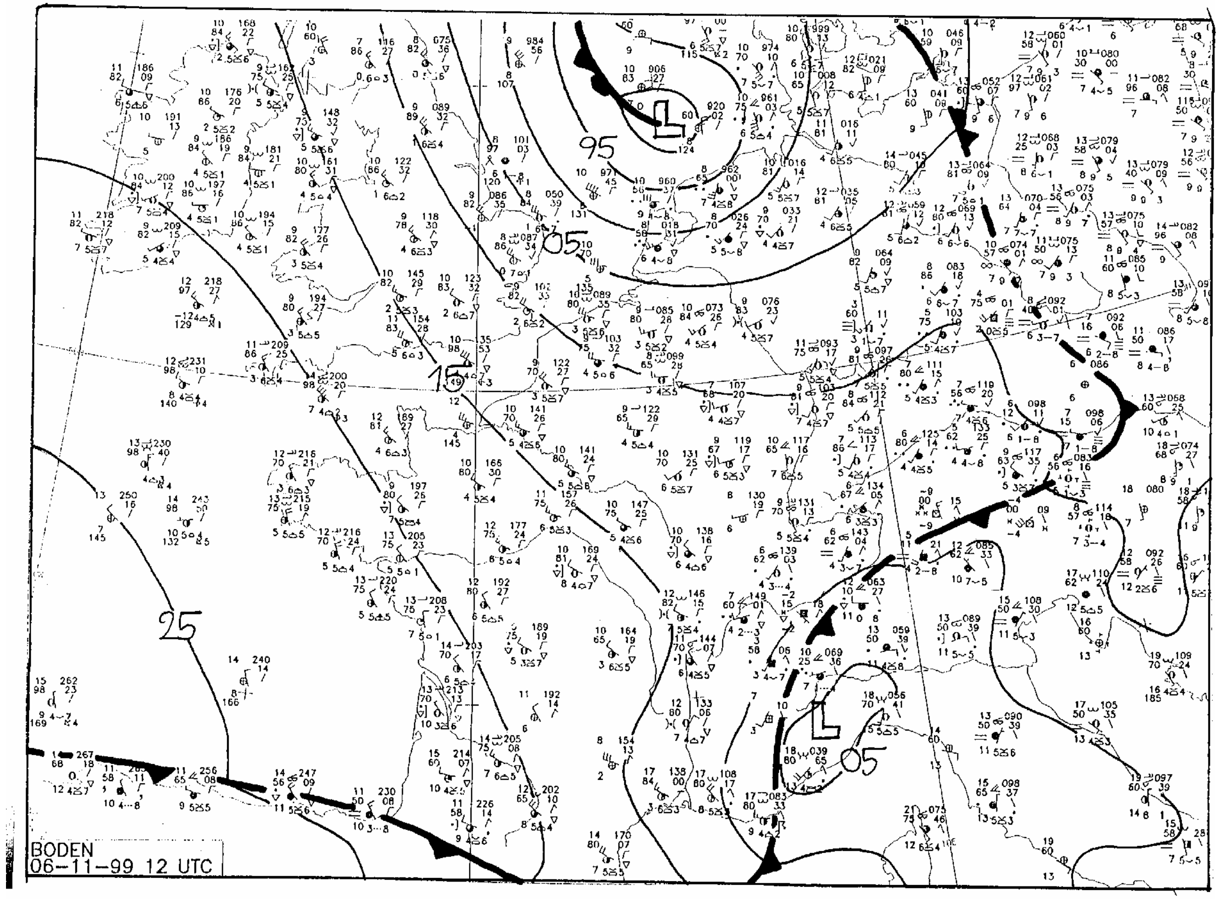
The front has crossed the mid of Germany and the Massif Centrale in France. A deformation of the front ahead of the western Alps becomes visible. The weather activity of the front west and north of the Alps has significantly increased with partly heavy rain mainly at the cold side of the surface front. This points to a frontogenetic effect working at this part of the front.

Above northern Italy the pressure has continuously lowered and a flat low centre can be analyzed above the western part. It is important to note that it has a position well ahead of the approaching front.

09 UTC

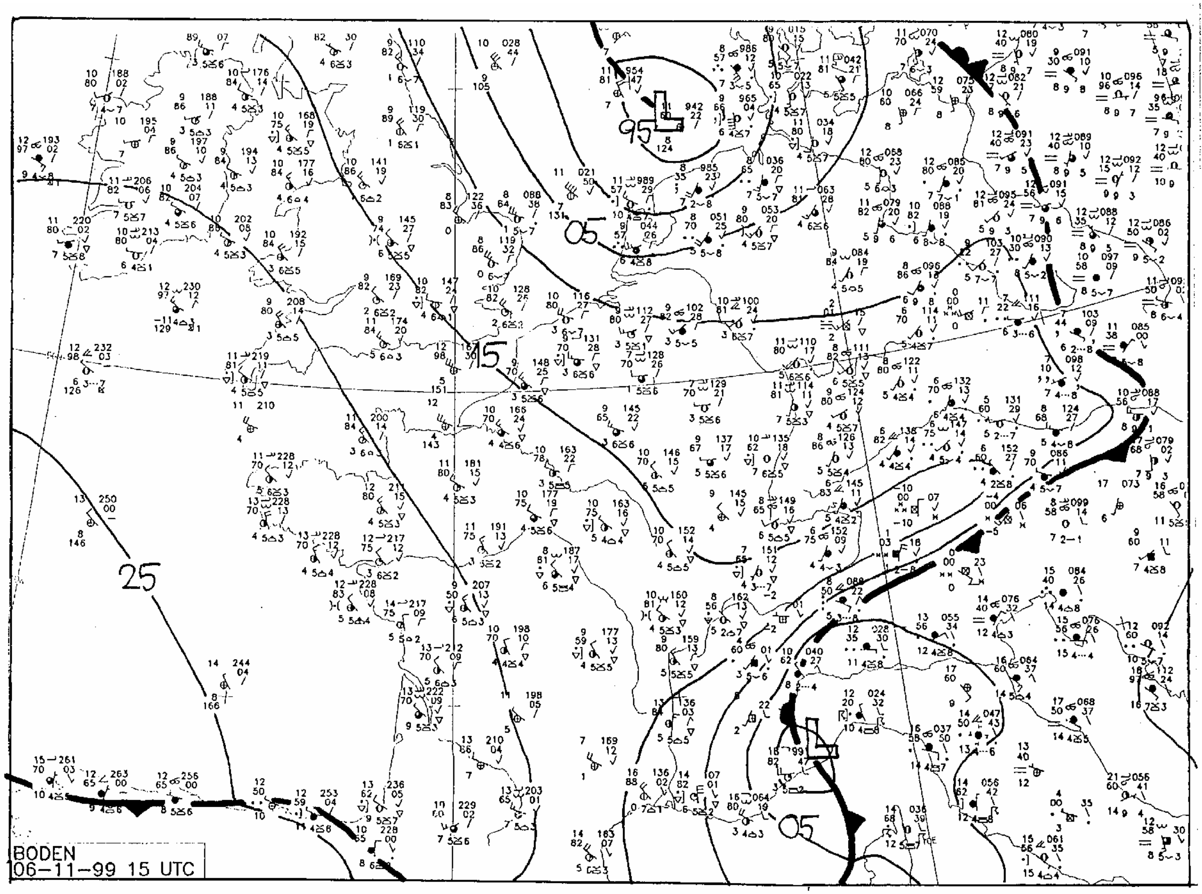


12 UTC

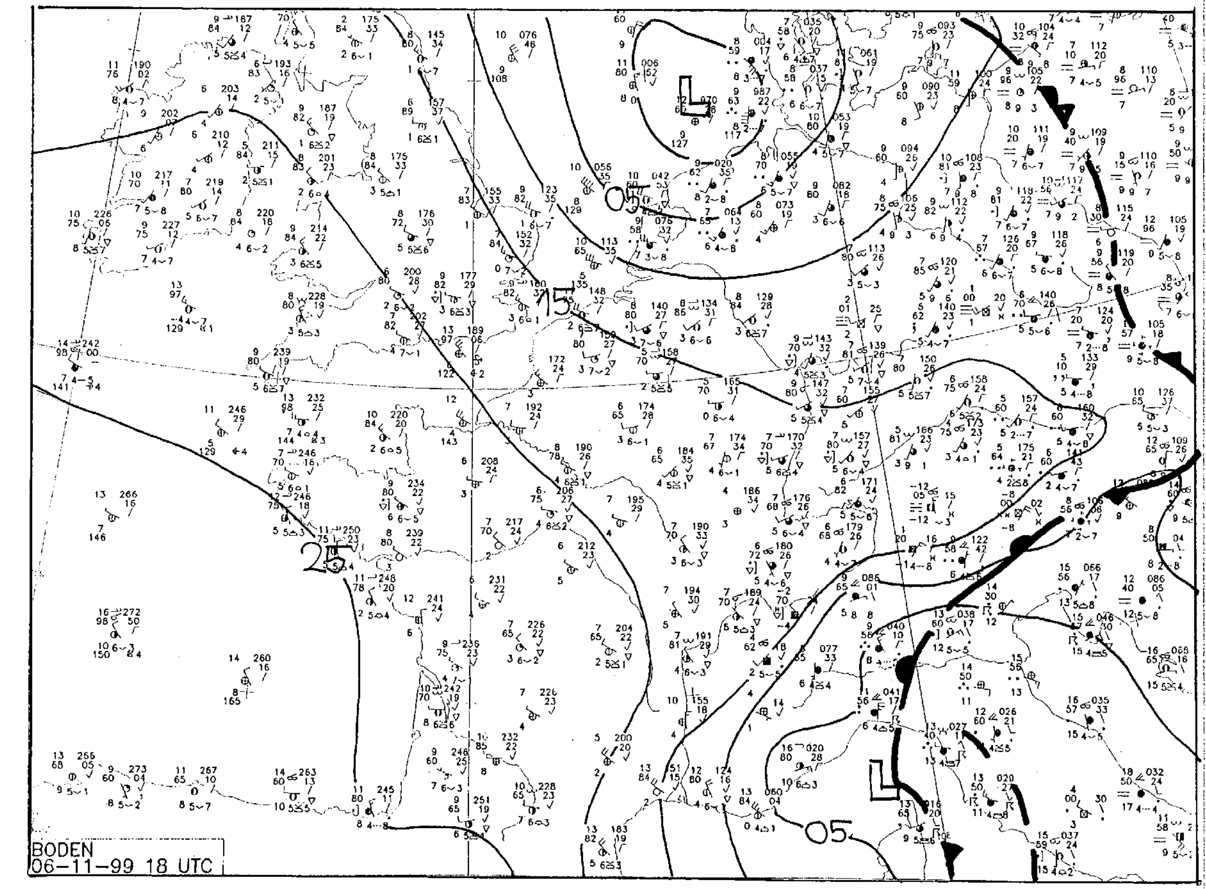


The cold air behind the front pushed forward north of the Alps and between Alps and Pyrenees towards the Gulf of Lion whereas its movement across the Alps was strongly hindered. Therefore the deformation of the front increased. The low ahead of the front above northern Italy has further deepened and moved a little bit south-westwards. There is widespread precipitation now also ahead of the front in the Alps and north of the Po-valley. Even some thunderstorms were observed. Contrary to that, the forward march of the cold air towards the western Mediterranean is accompanied by a quick disappearance of the cloud.

15 UTC



18 UTC



The low south of the Alps deepened more and more whereby its centre of gravity moved towards the Gulf of Genova. The cold front pushed from west into the centre of the low and crossed Corse. Ahead of the front a line of thunderstorms formed.

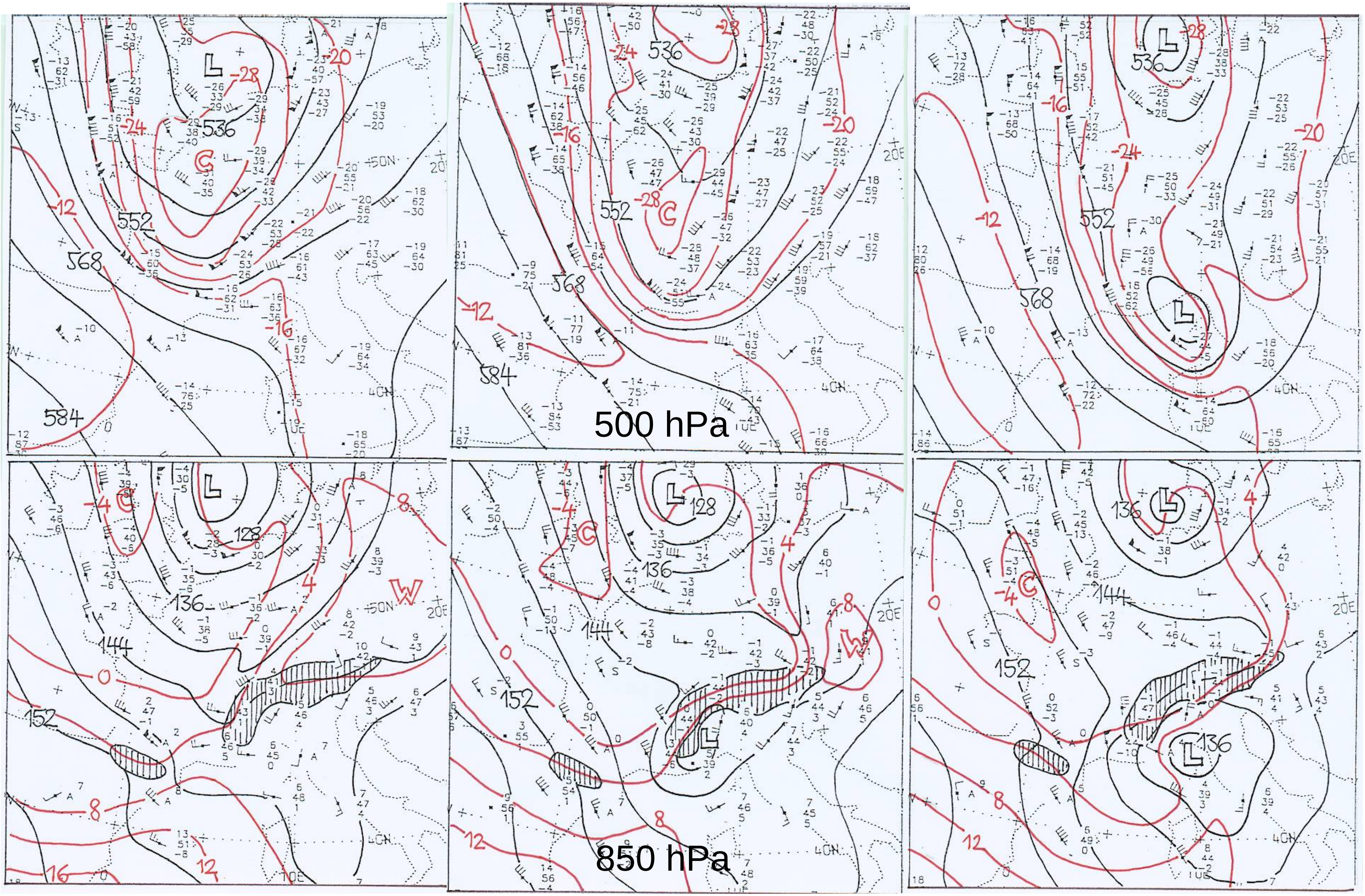
North and north-east of the low the movement of the low across the Alps was slow as before. According to synoptic convention, the front was there analyzed as a warm front, but it moved in reality as a cold front – although with a small speed.

The weather south of the Alps

	06	09	12	15	18	21	00	03
Locarno	NNW1	WSW1	WNW3	ESE2	ENE1	ESE2	SE 1	SW1
	drizzle	drizzle	shower	rain	--	--	--	--
	12/11	12/11	12/11	8/5	9/5	13/-2	12/-1	9/1
Torino	C	NE1	WSW1	NW2	S1	SW2	C	W2
	mist	mist	rain	--	--	--	--	--
	10/8	11/9	10/7	10/8	8/6	8/5	7/5	6/-9
Milano	NE1	ENE1	ENE2	ESE1	NW4	NW1	C	C
	mist	mist	rain	rain	rain	rain	rain	--
	11/11	12/11	13/11	12/11	9/8	9/8	10/9	10/8
Verona	NE1	E1	ENE3	ENE2	ENE4	NNE2	NNW3	ESE1
	mist	mist	p.rain	rain	p.rain	rain	rain	rain
	10/8	11/9	13/11	13/12	13/12	10/9	11/7	10/9

A cyclogenesis south of the Alps

Upper air charts



06 UTC 12 UTC 18 UTC

850 hPa

- The changes of the temperature distribution at 850 hPa between 06 and 18 UTC clearly reflect the impact of the Alps on frontal zones in the lower troposphere. Due to the barrier effect the cold air is forced to deviate and to push forward along the northern Alps (06-12 UTC) and between Alps and Pyrenees towards the western Mediterranean (12-18 UTC). The cold air, however, also crossed the Alps, but with distinctly smaller speed. Altogether, a S-like deformation of the isotherms resulted at both flanks of the mountain chain. In addition, a strong frontogenesis was effective at the front north of and across the Alps, whereas a frontolysis took place between Alps and Pyrenees.
- The isohypses at 850 hPa show the development of the low in the warm air above the westernmost part of northern Italy. It is important to note that there was no foehn effect during the origin of this low, but southerly winds against the mountain barrier at this level. The winds shifted to northerly direction only with the advent of the cold front at the southern flanks of the Alps and the displacement of the low southeastwards.

500 hPa

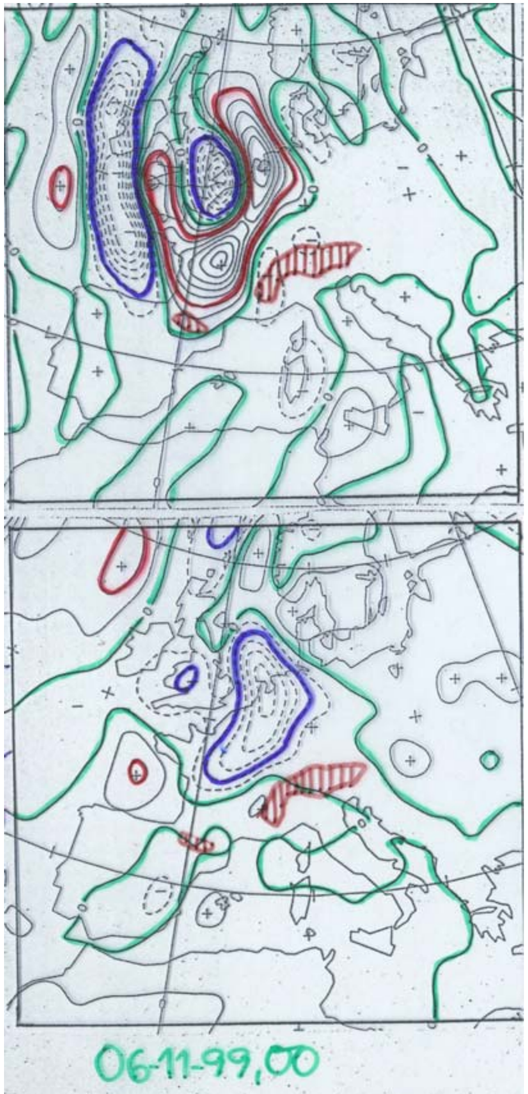
- The analyses for 500 hPa show the extension of the upper trough to the south and finally the cut-off of an upper low south of the Alps just above the surface low. The formation of the surface low took place immediately ahead of the deepening upper trough.
- At the beginning the frontal zone ahead of the trough has at 500 hPa a position slightly behind the frontal zone in the lower troposphere. But 6 hours later there is a great distance between both since the upper frontal zone did not follow the fast movement of the lower one along the northern Alps towards the east. Afterwards the cold air pushes forward to the south at both levels – west of the Alps and mainly by advection at 850 hPa, but crossing the western Alps and mainly due to cooling by ascending motion at 500 hPa.
- A significant feature of the 500 hPa-temperature distribution is the existence of a well developed frontal zone immediately behind the trough with partly very great temperature gradient and very strong winds at its warm flank.

A cyclogenesis south of the Alps

Diagnostic maps

Conventional QG-diagnosis

- Following the conventional quasi-geostrophic diagnosis, the analyses of vorticity advection at 500 hPa and thickness advection between 500 and 1000 hPa should be considered first. According to the omega-equation, a forcing of ascent in the mid troposphere and connected with that a cyclogenetic effect in the lower troposphere has to be expected in areas with PVA (positive vorticity advection) aloft and/or maximized WA (warm advection). Contrary to that, a forcing of descent and an anticyclogenetic effect in the lower troposphere results in areas with NVA (negative vorticity advection) aloft and/or maximized CA (cold advection).

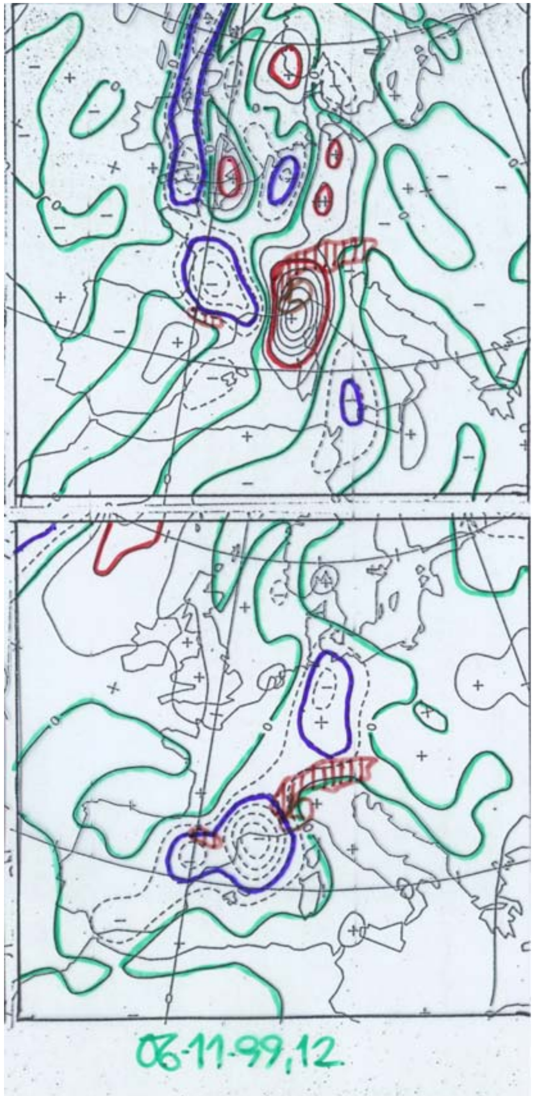


Top: Vorticity advection at 500 hPa; bottom: Thickness advection 500/1000 hPa

06-11-99, 00 UTC:

At the beginning there is significant PVA aloft ahead of the upper low and trough with two maxima above the Netherlands and mid France, respectively. This points to a movement of the trough to the east and a simultaneous extension southeastwards. The cyclogenetic effect of the upper PVA for the lower levels, however, is to a great extent compensated by the CA being effective behind the surface cold front.

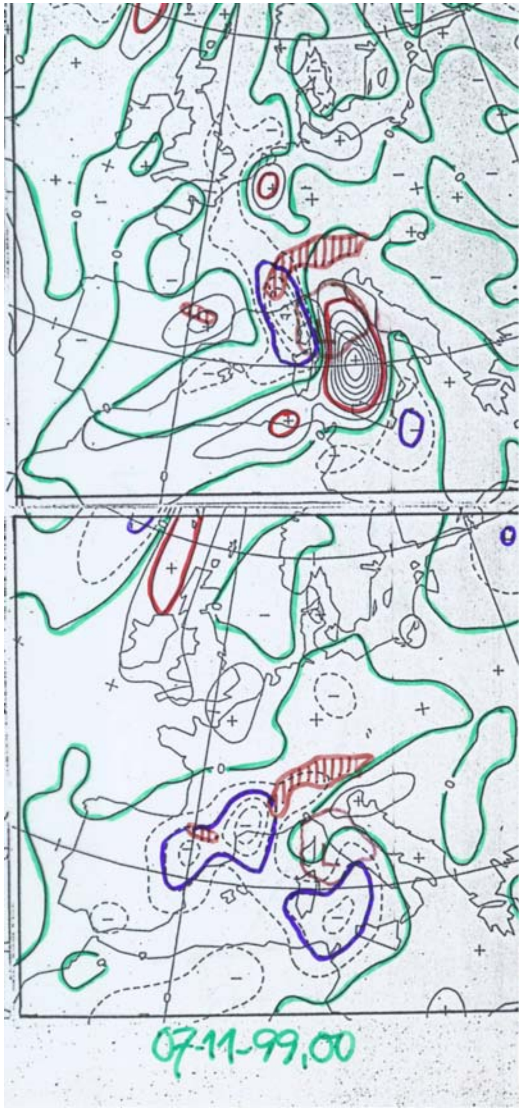
Only above southern France the PVA works already ahead of the CA so that together with some WA a forcing of ascent can be expected there. This would explain the increasing precipitation along the front observed in this region in the hours after midnight.



06-11-99, 12 UTC:

The compensation between PVA aloft and lower CA is still effective above Germany. Further south a new maximum of CA appears between Alps and Pyrenees where the cold air pushes accelerated forward to the western Mediterranean. The southern part of the PVA-area ahead of the trough has meanwhile crossed the western Alps and has now a position above the western part of northern Italy and the Gulf of Genova. There its cyclogenetic effect could not be compensated by CA and therefore led to the formation and deepening of the surface low.

The lower CA, on the other hand, is effective directly below the upper trough and should give rise to an intensification of the cyclonic vorticity of the trough.



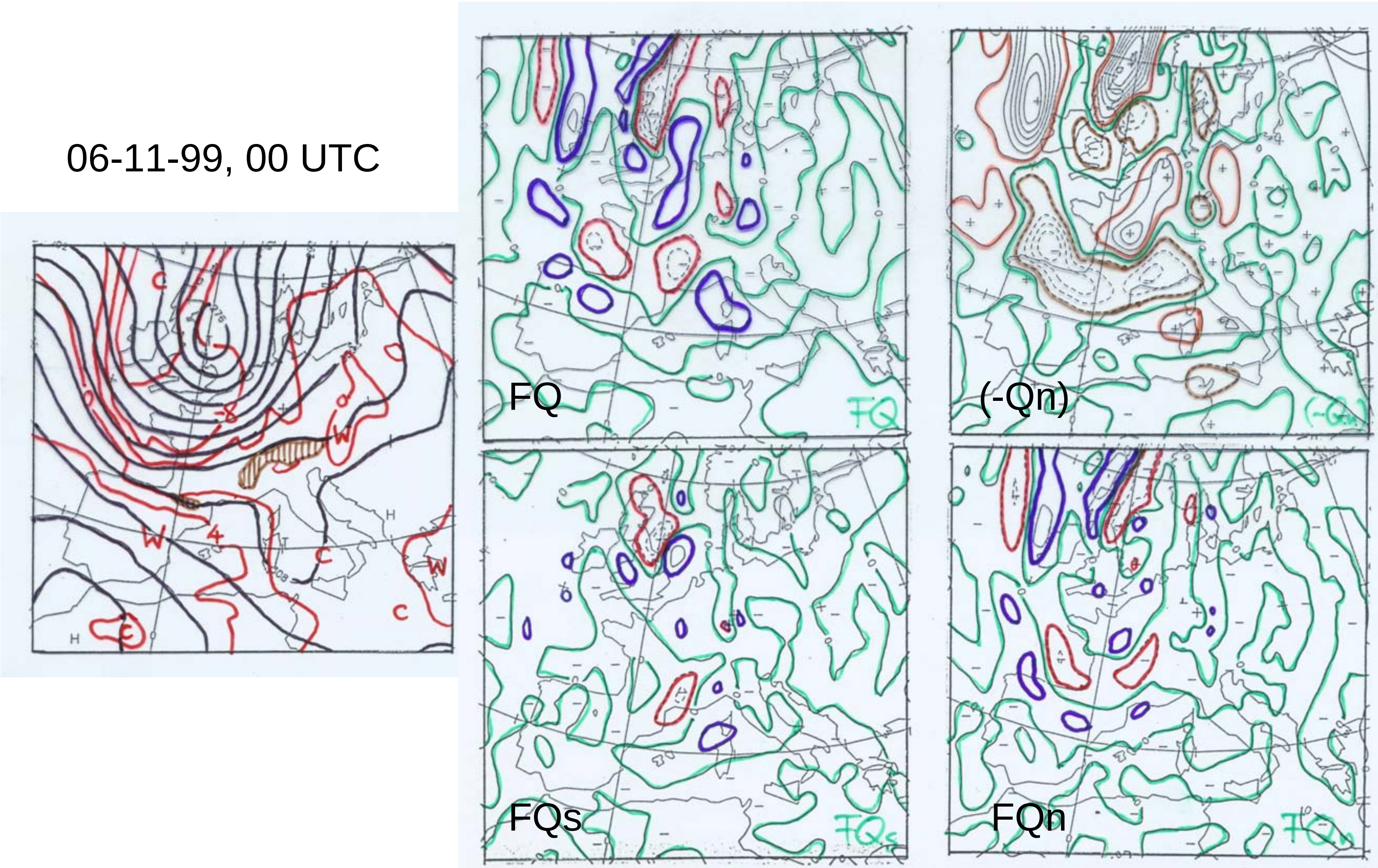
07-11-99, 00 UTC:

Since meanwhile a closed low has also formed at 500 hPa lying directly above the surface low at midnight, the upper PVA works now southeast of it and contributes to the displacement in this direction. There is, however, again a compensation with CA in the lower troposphere behind the surface cold front. Both forcing functions have the same sign northeast of the low so that the ascending motion should be maximized there.
The orographically fixed CA between Alps and Pyrenees Is still effective.

Q-vector diagnostics

- Using the Q-vector as diagnostic tool, the forcing of vertical motions and the related cyclogenetic effects can be easily and un-ambiguously computed. A forcing of ascent results in areas with convergence, a forcing of decent in areas with divergence of the Q-vectors (FQ).
- In addition to that, the Q-vector allows a direct estimation of frontogenetic of frontolytic effects in the geostrophic wind field shown by the parameter (-Qn) and of the forcing (FQn) of circulations across the frontal zones subjected to these effects. Frontogenesis is connected with a direct circulation with ascent of the warmer and descent of the colder air, frontolysis with an indirect circulation with opposite vertical motions.
- The remaining part of the forcing (FQs) is related to the temperature changes caused by the rotatory component of the winds and is to a great extent identical with the so-called Sutcliffe-forcing given by the vorticity advection with the thermal wind. Ascent (descent) is forced by positive (negative) advection along the isotherms.
- The Q-vector diagnostics was performed for 700 hPa.

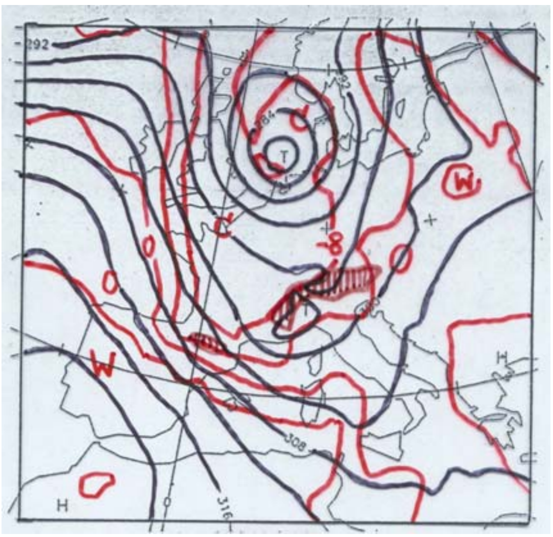
06-11-99, 00 UTC

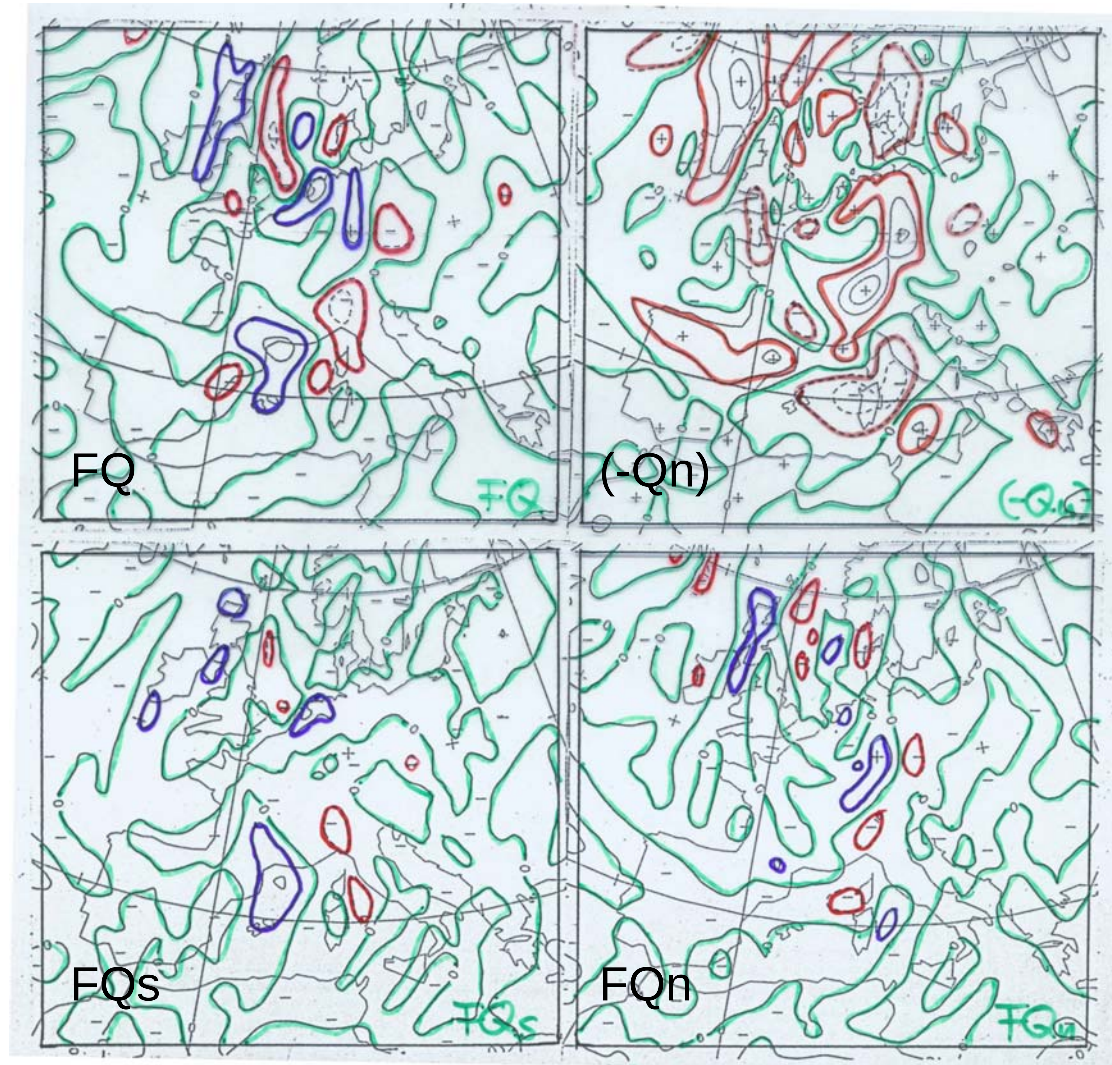


06-11-99, 00 UTC

- The diagnosis shows a forcing of ascent along the frontal zone of the cold front above southern France and western Germany followed by descent in the colder air. In the context of the classical QG-reasoning given before, the ascent is obviously mainly forced there where the upper PVA works ahead of the CA and is supported by some WA.
- On the other hand, the diagnosed forcing can also be partly traced back to the distinct frontogenetic and frontolytic effects being effective in the geostrophic wind field and giving rise to circulatory vertical motions – either in solenoidally direct or indirect sense.
- The rotatory part of the forcing provides an additional contribution to ascent above the Rhone valley where the vorticity decreases along the isotherms and positive advection is effective by the thermal wind.

06-11-99, 12 UTC

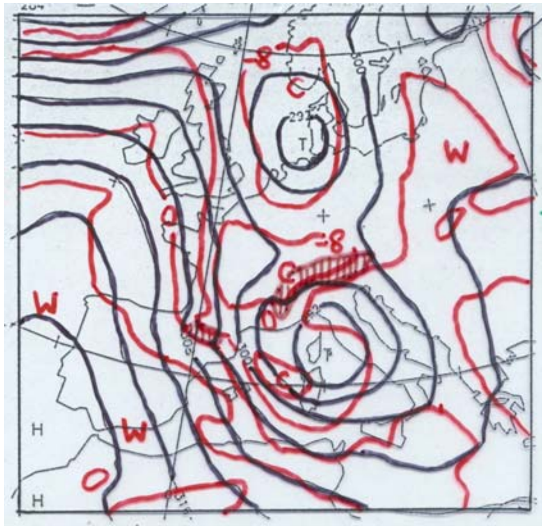


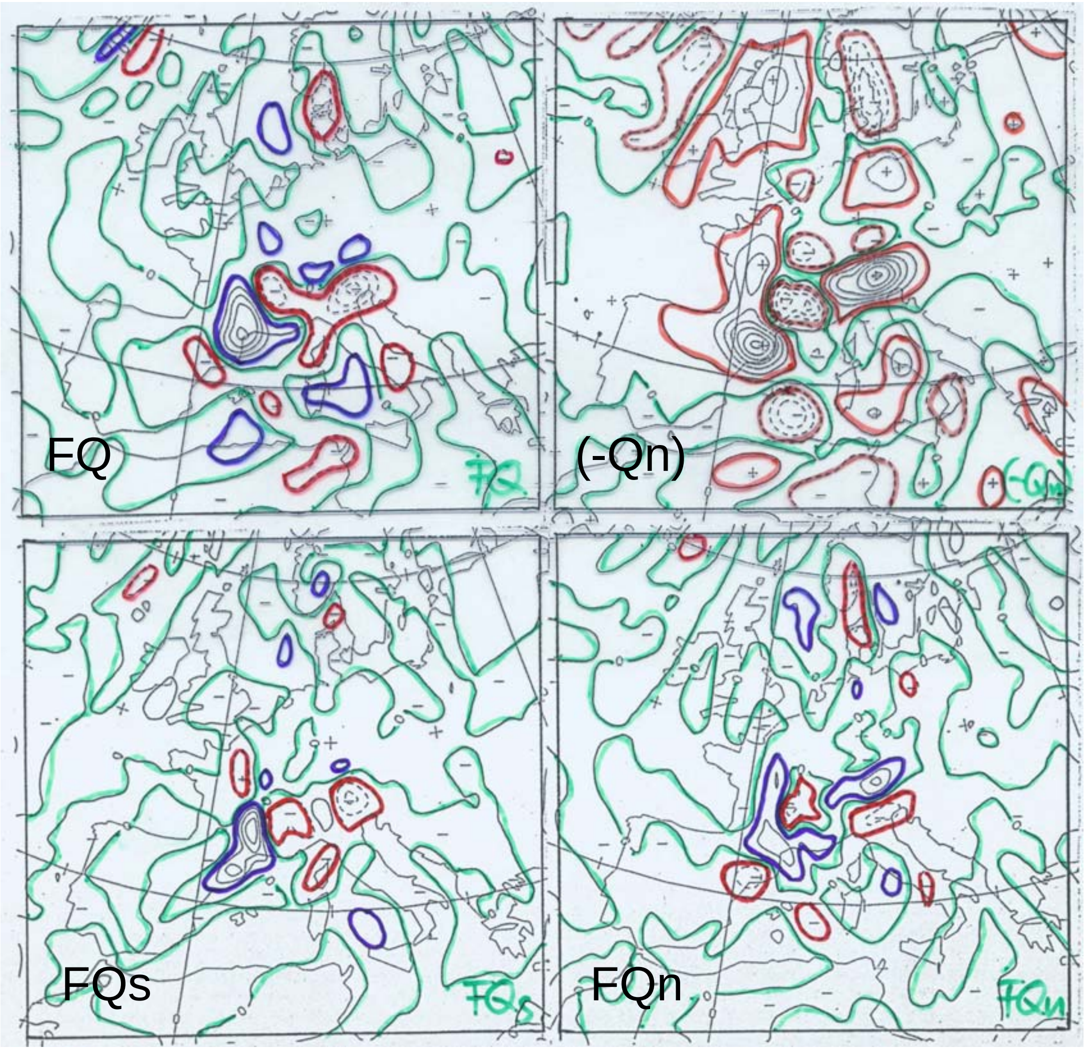


06-11-99, 12 UTC

- The dominant features of the forcing are the ascent above the western part of northern Italy and the Gulf of Genova and the descent centred above the Gulf of Lion. They are well correlated with the upper PVA and the lower CA, respectively, working in these areas as described above.
- The forcing of ascent and descent side-by-side above mid Europe, however, cannot be satisfyingly explained by the qualitative reasoning with vorticity and temperature advection. It can be easily understood when considering the frontogenesis parameter. Since the frontal zone is still subjected to frontogenesis, a direct circulation is released the vertical motions of which dominate the total forcing.
- Due to the orographic effects the frontogenesis is especially strong above the Alps so that the ascent of the warmer air within the circulation contributes by roughly one half to the ascending motion being effective above northern Italy and leading to the formation of the surface low there. The other half is provided by FQs due to positive vorticity advection by the thermal wind ahead of the trough and the already existing low at 700 hPa. The descent above the Gulf of Lion is mainly forced by FQs due to negative vorticity advection along the isotherms which is identical with CA by the real winds in this case.

07-11-99, 00 UTC



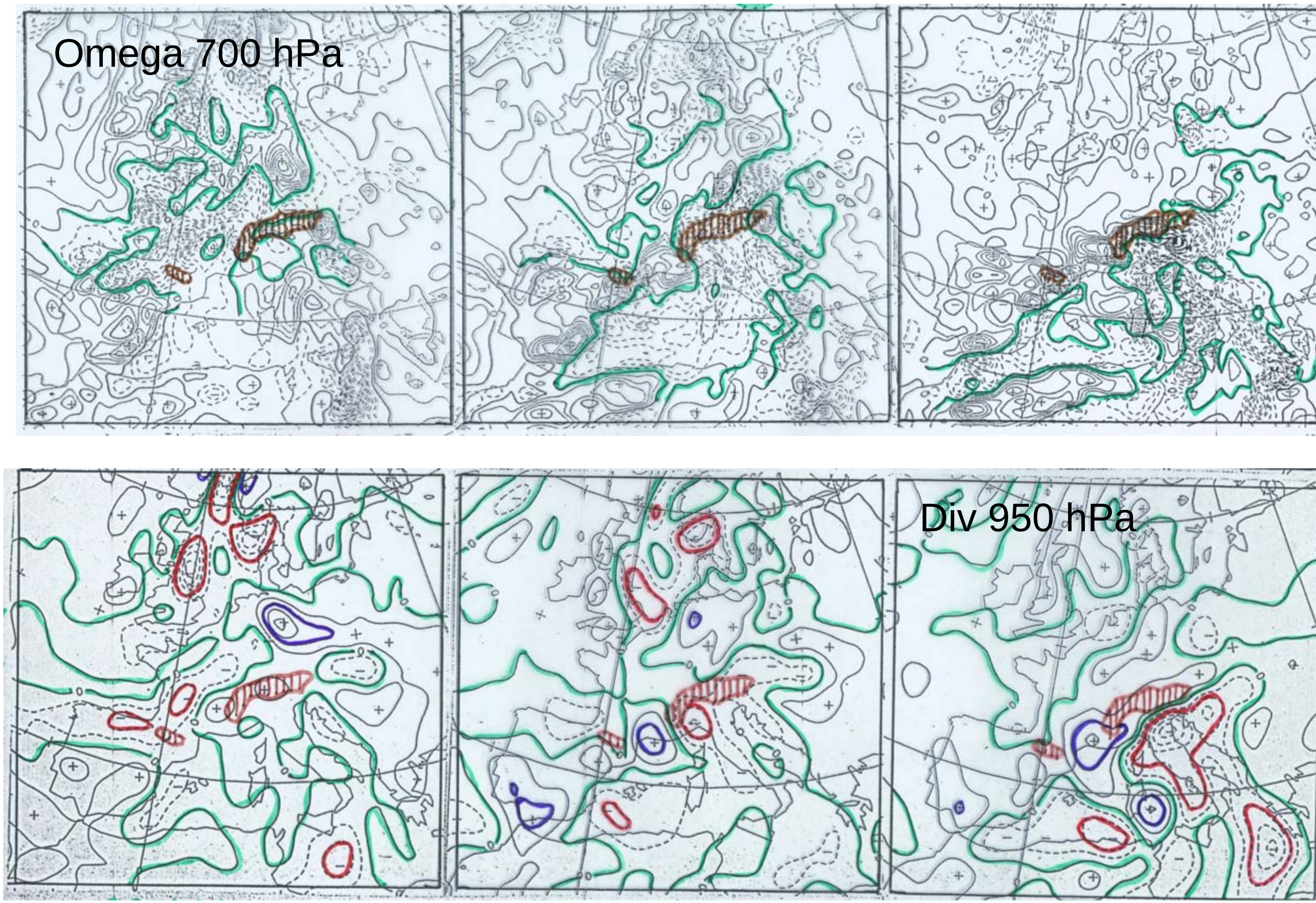


07-11-99, 00 UTC

- Around the low above the Mediterranean there is ascent north and northeast of the low centre where PVA and WA are effective, descent due to dominating CA south of it and strong descent above the southernmost part of France also well correlated with the origraphically forced CA there.
- The frontogenesis parameter indicates strong frontogenesis above Alps and Pyrenees and frontolysis in between so that the vertical motions of two direct and one indirect circulations significantly contribute to the total vertical motion regime.
- The contributions by FQs have the same strength with concentrated descent above southern France and a wide area with ascent above the Alps, northern Italy and the area near the low centre. The sharp transition from descent to ascent in easterly direction across the Rhone valley can be understood when taking into account that the vorticity distribution at 700hPa shows relative high cyclonic values just between Alps and Pyrenees (see below).

A cyclogenesis south of the Alps

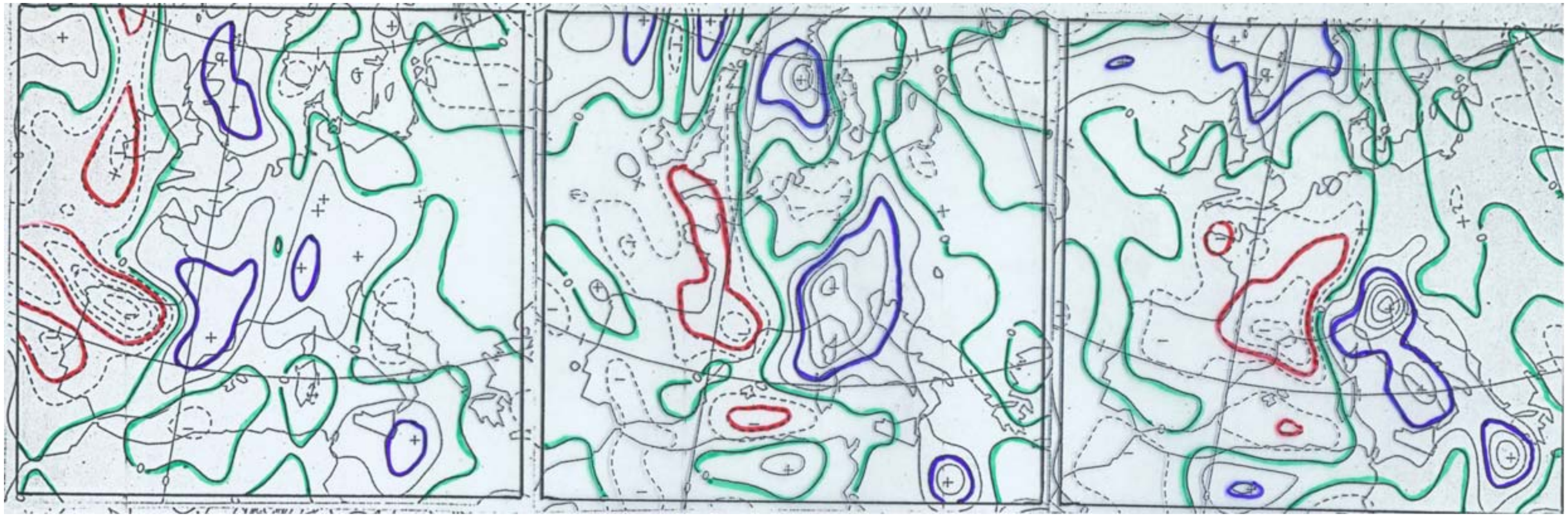
Further diagnostic parameters



06-11-99, 00 | 06-11-99, 12 | 07-11-99, 00

Model omega and lower divergence

- The main features of the quasi-geostrophic forcing correspond relatively well with the model omega and the divergence computed from the model winds. The analyses of 700 hPa-omega and 950hPa-divergence show at first the belt with ascent and lower convergence along the frontal zone, then the dipole of ascent above the Alps and northern Italy and descent between Alps and Pyrenees connected with convergence and divergence, respectively. At the end there is agreement with regard to strong ascent and convergence northeast of the surface low and descent with divergence south of it as well as above southern France. The area of ascent, however, has a somewhat more southerly position than in the diagnoses and the extension towards northwest is missing. These differences might be due to the direct impact of the orography on the model fields which is, of course, not included in the quasi-geostrophic diagnosis.



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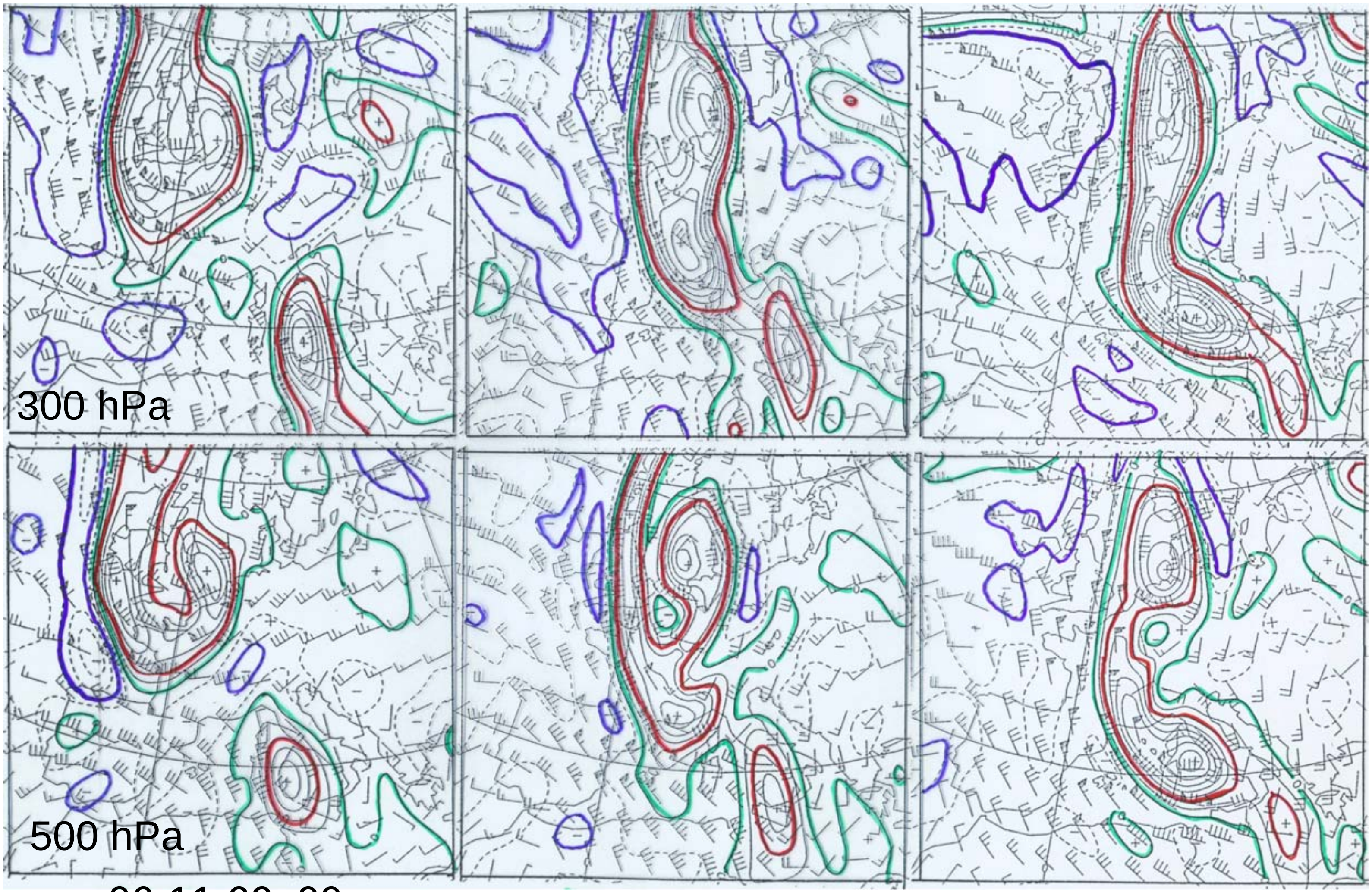
300 hPa-divergence

Upper divergence

- The distribution of the divergence at 300 hPa partly corresponds to the vertical motions at 700 hPa and the related divergence at lower levels, but also show some deviating features. At the beginning the area with upper divergence ahead of the trough is much larger than the area with lower convergence. Above northern Spain an area with upper convergence is indicated nearly directly above the belt with lower convergence. Since it is not possible that convergence works at all tropospheric levels, there must be a more complex vertical distribution of convergence and divergence in this area than the simple scheme with one change of the sign of divergence in the vertical only.
- This scheme is realized, however, during the cyclogenesis south of the Alps ahead of the approaching upper trough. Upper divergence, ascending motion and lower convergence are well correlated. In spite of that there is at first no direct response at 300 hPa to the lower descent and divergence in the area with CA between Alps and Pyrenees.
- Altogether there is a good correlation between divergence and PVA and convergence and NVA at 300 hPa.



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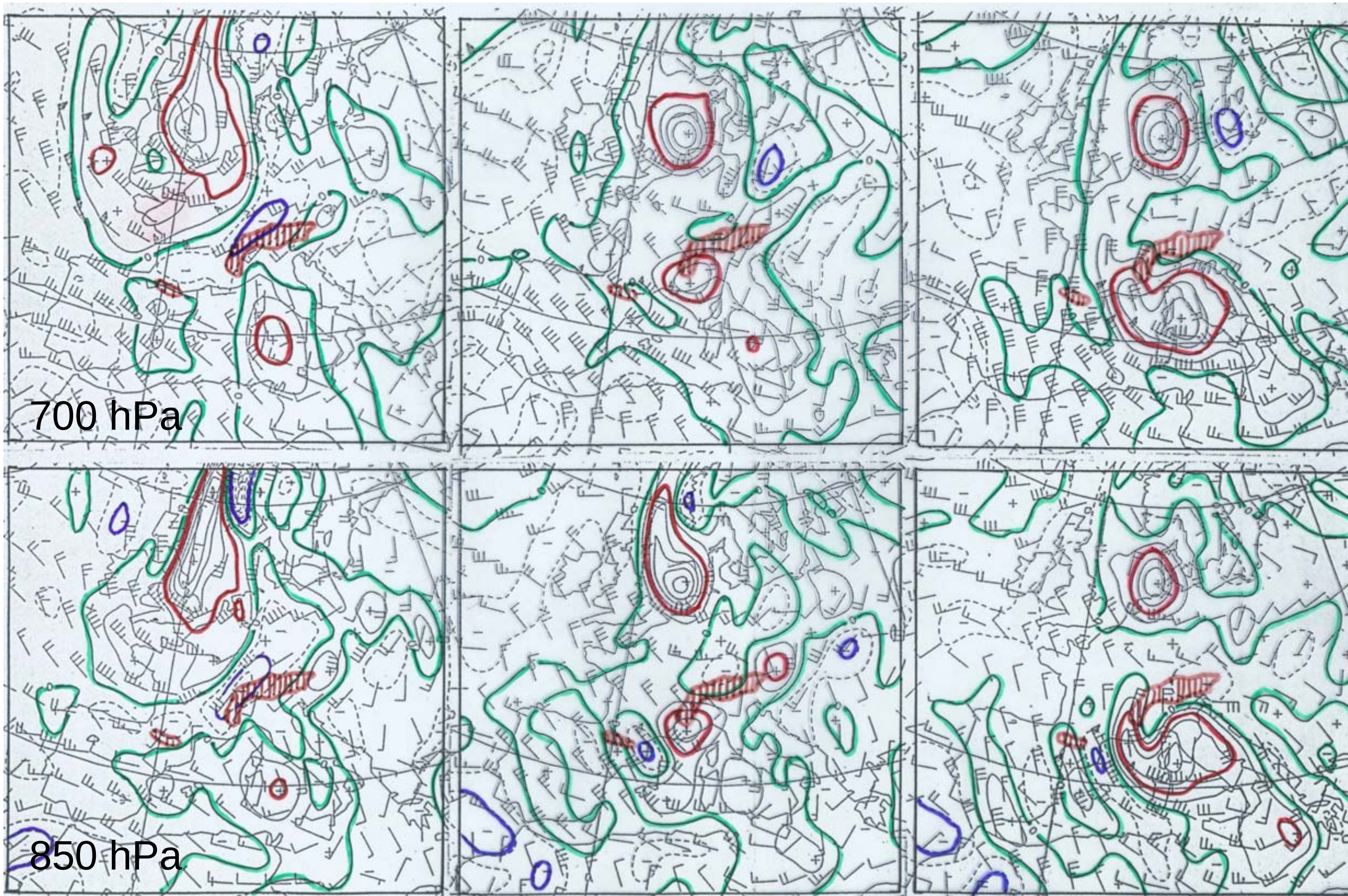
Vorticity at 300 and 500 hPa

- The vorticity analyses for 300 and 500 hPa reflect an interesting structure at the beginning. There is no one single vorticity maximum in the upper trough coinciding with the centre of the upper low, but two – one east of the low centre above the North Sea, the other one west of it at the cyclonic flank of the strong northwesterly jet at the rear of the trough. The easterly maximum moves slowly east or north-eastwards whereby it takes on a position inside the low centre. The westerly extremum is quickly displaced south-eastwards with a speed of roughly 50 kn. In doing so the maximum at 500 hPa moves al little bit faster and reaches a position south of the 300 hPa-maximum at noon. That is surely due to the convergence working now above the area with descent between Alps and Pyrenees. It also leads to an increase of the vorticity of the trough. Afterwards the vorticity extremes are further displaced in southerly direction, but with lesser speed, and reach a position above the surface low at midnight.



06-11-99, 00 06-11-99, 12 07-11-99, 00

Vorticity at 700 and 850 hPa (I)

- At 700 and 850 hPa the vorticity distribution shows at the beginning the vorticity maximum in the low above the North Sea and a cyclonically bent belt of cyclonic vorticity along the frontal zone above Low Countries, mid France and Biscay. Around the Alps the distribution reflects the impact of the orography with westerly winds: Due to shear there is an area with anticyclonic vorticity west and north of the Alps and an area with cyclonic vorticity south-east and east of it.
- 12 hours later the analyses show the newly developed maximum of the low south of the western Alps. It becomes significantly larger and more intense during its movement south-eastwards due to the convergence working in this area. A belt of cyclonic vorticity extends from the centre towards the western Alps accompanied by a belt of anticyclonic vorticity west of it which is especially pronounced at 850 hPa. This structure is due to the shear at the flanks of the strong northwesterly winds between Alps and Pyrenees and reflects the primary “vorticity banner” which are regularly observed at the flanks of mountain chains.

Vorticity at 700 and 850 hPa (II)

- At 850 hPa the analysis show further bands of cyclonic and anticyclonic shear vorticity, respectively, over Spain.
- Connected with the forwards march of the cold air north of the Alps the vorticity minimum is also displaced eastwards whereas the easterly maximum is intensified by convergence before it moves away north-eastwards.

Conclusions (I)

- The described case is a typical example for a cyclogenesis south of the Alps without a direct cyclogenetic effect of the mountains. There was no northerly flow across the Alps in the lower troposphere which could have led to the formation of a lee trough as starting point for the cyclonic development.
- The impact of the Alps on the development was rather due to the slow down of the movement of the cold front across the mountains so that the PVA ahead of the approaching upper trough was not compensated by any CA south of the Alps and could initiate the formation of the low. The concentrated CA between Alps and Pyrenees, on the other hand, influenced movement and intensity of the upper trough.

Conclusions (II)

- The cyclogenesis took place in the warm and moist air lying above northern Italy. It was accompanied by increasing cloudiness followed by rain. Later on also thunderstorms were observed.
- In the afternoon and evening the cold front crossed northern Italy from west and north causing a drop of temperature and a shift to northerly winds. This wind shift, however, did not cause any weather improvement for the middle and eastern parts of the area since the strong ascent due to upper PVA and WA northeast of the low maintained for a while so that the rain also continued there.
- Only in the western parts of Italy and in Ticino the precipitation stopped and the sky became partly clear due to the macro-scale descent by NVA and CA. The relatively high temperatures combined with low dew-points observed at some stations point to the fact that also foehn was effective in this region.