Phenomenological examination of 'Lothar Successor' - the forgotten storm after Christmas 1999

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Abstract

The majority of scientific research to the notorious storms in December 1999 focuses on 'Lothar' and 'Martin' causing most of the damage to properties and fatalities in Central Europe. Few studies have been performed in the framework of the passage of storm 'Lothar Successor' (introduced in a case study of the *Manual of synoptic satellite meteorology* featured by ZAMG) between these two events being responsible for some gusts in exceed of 90 km/h between Northern France, Belgium and Southwestern Germany. The present study addresses to the phenomenology and possible explanations of that secondary cyclogenesis just after the passage of 'Lothar' and well before the arrival of 'Martin'. Facing different theories and findings in several papers it will be shown that the storm possessed a closed circulation and a fully developed frontal system. That key finding is especially in contrast to the analysis of the German Weather Service which suggested that solely a 'trough line' crossed Germany. The point whether a warm or a cold conveyor belt cyclogenesis produced the storm could not be entirely clarified. Finally, reasons are given for which 'Lothar Successor' had not become a 'second Lothar', amongst others the unfavourable position between two jetstreams with lack of sufficient cyclonic vorticity advection.

1. Introduction

The motivation for reviewing the events from late December 1999 is mainly due to personal experience between the passage of 'Lothar' (26.12.1999) and 'Martin' (28.12.1999) in Lower Franconia close to Miltenberg (at the river Main between Frankfurt and Wuerzburg). Back then, I had not internet and was dependent on radio, television and teletext. In the forenoon hours, the radio told something about a windstorm crossing Paris with gusts about 150 km/ha and severe damage. The pressure of my barometer rapidly descended. At noon, it became rather windy but without any severe gusts (I would have estimated 70-80 km/h). The sky was very impressive with racing clouds from different directions within few hours (I later found out that my hometown was situated exactly in the center of the storm), and it cleared up in the afternoon. Simultaneously, the pressure strongly rose and the media reported about 'Lothar' causing damaging wind gusts in France, Switzerland and Southern Germany. Meanwhile, I constated a pressure drop in the evening, again, initially without any knowledge of what was the reason. The radio announced - according to the *Germany Weather Service (DWD)* - a 'trough line' which was expected to cross the south-central parts of Germany during the night. However, the passing storm has been much more vigorous in Hesse and Franconia than 'Lothar' and produced two losen tiles at our house, just above my roof-light (prompting a scared sight). Anyway, neither the DWD nor further studies of the 'Christmas storms 1999' dealed with 'Lothar Successor', a denomination I read many years later in the *Manual of synoptic satellite meteorology (abbreviated as MSSM as follows)* featured by the Austrian Central Agency for Meteorology and Geodynamics - ZAMG).

In general, the december 1999 is well known for its three devastating storms brushing past Northern Germany and Denmark ('Anatol' on 4.12.1999), France, Switzerland and Southwestern Germany ('Lothar' on 26.12.1999), and France and Italy ('Martin' on 28.12.1999). A lot of studies have been performed to examine the generation of such violent cyclones which can be all attributed to a classic 'rapid cyclogenesis' (defined as a pressure drop of 24 mb in 24 hours). **Ulbrich et al. (2001)** addressed himself to all three windstorms, **Baleste et al. (2001)** focused on 'Lothar' and 'Martin', **Santurette and Georgiev (2005)** applied satellite water vapor imagery and potential vorticity analysis to 'Martin', and **Wernli et al. (2002)** considered dynamical aspects of the life cycle of 'Lothar' using a 3-dim potential vorticity perspective. A remark to the unusual deepening of 'Lothar' can be gleaned from **Le Blancq and Searson (2000)**, e.g. the extreme pressure change in Caen (France) on 26.12.1999, with 28 mb falling between 03 and 06 UTC, and 29 mb

rising between 06 and 09 UTC. A quite exciting retrospective of 'Lothar' and 'Martin' is provided by **Pearce et al. (2001)** focusing on the effects of both storms on France.
Further explanation approaches are presented by **Fourrié et al. (2003)** who depicts the upper-level precursors with help of TOVS observations, and **Descamps et al. (2007)** redeveloping the idea of precursors in terms of amplified singular vectors, applied to the case of 'Lothar'. In contrast to the findings from Wernli et al. (2002), the recent paper from **Rivière et al. (2010)** exhibits that the timing and location of the rapid intensification stage can be reproduced with suppressed latent heat release and dissipation terms, but the intensity is overestimated. Key finding is the coupling between surface cyclone and upper-level jet which can be easily modelled without moist processes. As far as forecasting these storms is concerned, **Hello and Arbogast (2004)** proposed two different methods to correct the initial conditions applied to the storm 'Martin'. Another potential improvement to forecasts is discussed by **Leutbecher et al. (2002)** for 'Anatol' and 'Martin'.

Case studies to 'Lothar' and 'Martin' which are written on websites or in forums exist in the following links:

- Marco Puckert (DWD), Unvergessen: Meine Beobachtung von 'Lothar'
- Pierre Bessemoulin (MeteoFrance), L'évolution des tempêtes en France sour le XX^{è} siècle
- MeteoFrance, Le point sur les deux ouragans qui ont traversé la France du 26 au 28 décembre 1999
- Muenchner Rueckversicherung, Wintersturme in Europa (II), Schadensanalyse 1999 - Schadenpotenziale

Useful satellite imagery animations can be taken from

- MeteoFrance - (4,6 MB, GIF)
- Eumetsat - (1,6 MB, GIF)
- MET FU Berlin - (10 MB, MPEG-Video)

A remark to a possible third storm in the context of the Christmas storms 1999 exists in the case study by Matthias Jaeneke [1]mentioning an ominous structure further upstream of 'Lothar' designated only as a 'flare-up'. A step further has been made in the MSSM by ZAMG who carried out a case study with aid of satellite imagery [2]. The conclusions to 'Lothar Successor', which obviously never existed in german case studies and only appears as a 'pertubation' in the Bulletins Climatiques Quotidiens France [3] of 26. and 27.12.1999, are the following ones:
"For "Lothar successor" there is a distinct juxtaposition of **small to meso scale WA and CA maxima** during the whole phase; but, as for Lothar, the WA is superimposed on the frontal cloud band and only partially on the cloud head of "Lothar successor"

"From 26/00.00 UTC, a **PVA maximum** centred on the jet core is superimposed on the low cloud head; only 12 hours later does a clearer relationship appear between cloud head, PVA maximum and left exit region."

"For Lothar successor the **surface low** moves during the whole period from the anticylonic side to the cyclonic side of the jet. Only from 26 December/12.00 UTC does the relationship with an exit region becomes more distinct. This is also the point in time where some signs of a Rapid Cyclogenesis (e.g. darkening in the WV imagery) occur. Until this time the rather weak features in the surface trough and the poor relationship with an exit region can be reasons for the lack of a rapid development."

"There is a **upper level PV maximum** protruding downward to around 450 - 500 hPa until 26 December/00.00 UTC"

"[...] there is a **very broad baroclinic zone**"

"[...] there is an intensification of PV in the northernmost part of the baroclinic zone"

"In contrast to the other two cases, the PV = 1-2 maxima **ascends rather** than descending further in the phase where rapid development could be considered possible."

Summarizing, the article underlines that a third storm developed within a baroclinic zone and superimposed upper-level jet. The surface low was temporarily placed under a PVA maximum and exhibited a dark stripe of a beginning dry intrusion, but the extensive deepening stage like with 'Lothar' did not occur. The low has been characterized by a comma-like occlusion band - without developing a coil-up like 'Lothar'. Another hint of a low between 'Lothar' and 'Martin' is given in the Climate Status Report of the DWD 1999 [4] on pg. 13 displaying the pressure process at the DWD station Karlsruhe in the Upper Rhine Valley. Three pronounced pressure drops at 26.12., 27.12. and 28.12.1999 suggest the passage of three lows.

The present study aims to illustrate the appearance of 'Lothar Successor' with additional satellite imagery and surface weather charts. Moreover, the mechanisms leading to this rapid and somewhat surprising development - in the context of missing media reports and meager case studies - are examined using ecmwf archiv data as well as maps and figures from other papers. Section 2 deals with the synoptic development including surface weather charts to prove the existence of a closed circulation with 'Lothar Successor', section 3 addresses to the classification of 'Lothar Successor' and different explanation approaches are proposed. Section 4 provides several satellite images in different stages of the storm as well. Finally, in section 5 a remark about 'Lothar' and 'Martin' regarding their complex nature is given. The case study is completed by a summary and discussion.

2. Synoptic development of 'Lothar Successor'

For simplicity, the following abbrevations will be used now: 'Lothar' = L1, 'Lothar Successor' = L2, 'Martin' = L3, 'Martin 2' = L3-B (explanation see section 5). To describe the large- and meso-scale weather situation, the ECMWF archive data visualized by the Institute for Meteorology and Geophysics Innsbruck (IMGI) are used. The combination of both circumpolar maps is applied in the 'weather discussion' of the IMGI for several years. Current analysis and forecast maps in this stlye are only available at IMGI.

2.1 Northern Hemisphere

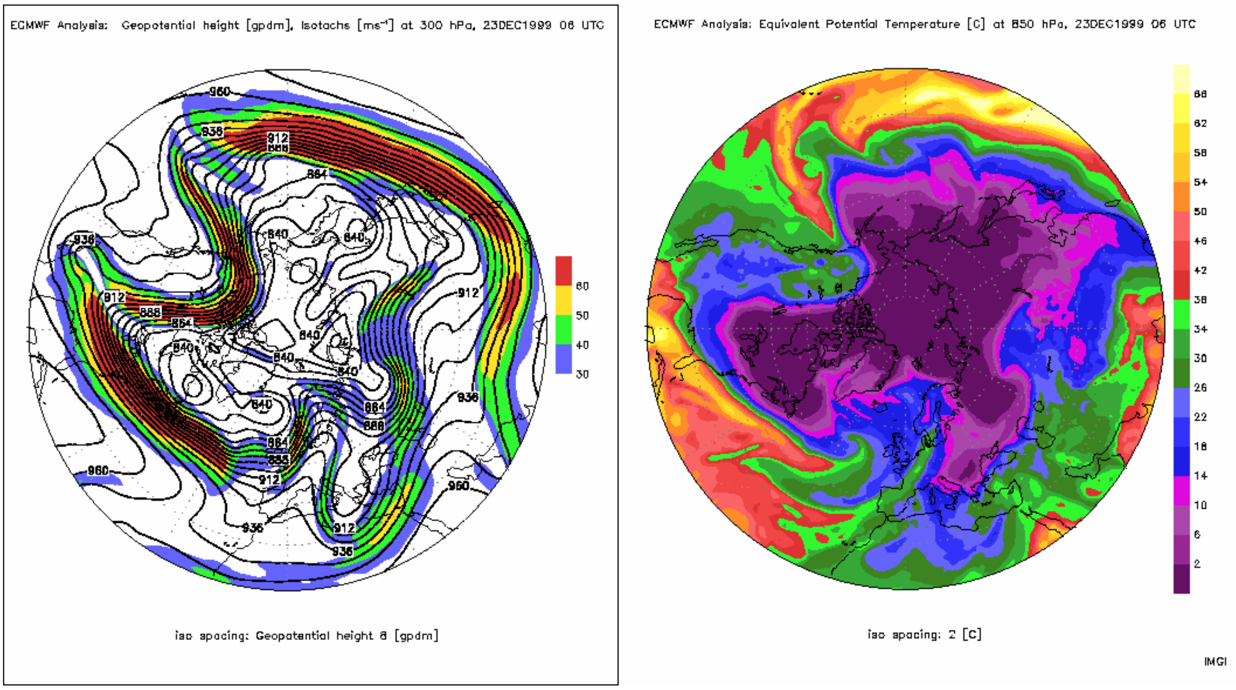


Fig.1: 300 hPa geopotential height [gpdm] + Isotachs [m/s], 850 hPa equivalent potential temperature [C] on 23.12.1999,06 UTC

Three days before the arrival of L1 the northern hemisphere is characterized by two longwaves with large zonal extent, one over North Pacific, the other one over USA and North Atlantics. A pronounced longwave ridge builts up over Western USA which in return triggers the development of a quite deep trough over central and southern USA. As a result, a zonal upper-level flow runs from Texas to the Azores. Farther downstream, a blocking situation dominates in Europe, consisting of a strongly amplified shortwave ridge over Central Europe and flanking troughs over the Balkans and North Atlantics. However, a classic omega high situation was not present for which reason anticyclolysis rapidly starts with the oncoming zonal upper flow.

Large temperature differences exist in the Northwestern Atlantics: a tongue of 54°C reaches eastward from Florida while 0°C are present over Newfoundland. A narrow warm air tongue is associated with the ridging over Europe, farther upstream a coiled-up occlusion front moves up. It belongs to deep low 'Kurt' which later acts as a steering low whose 'satellite lows' will become L1 and L2.

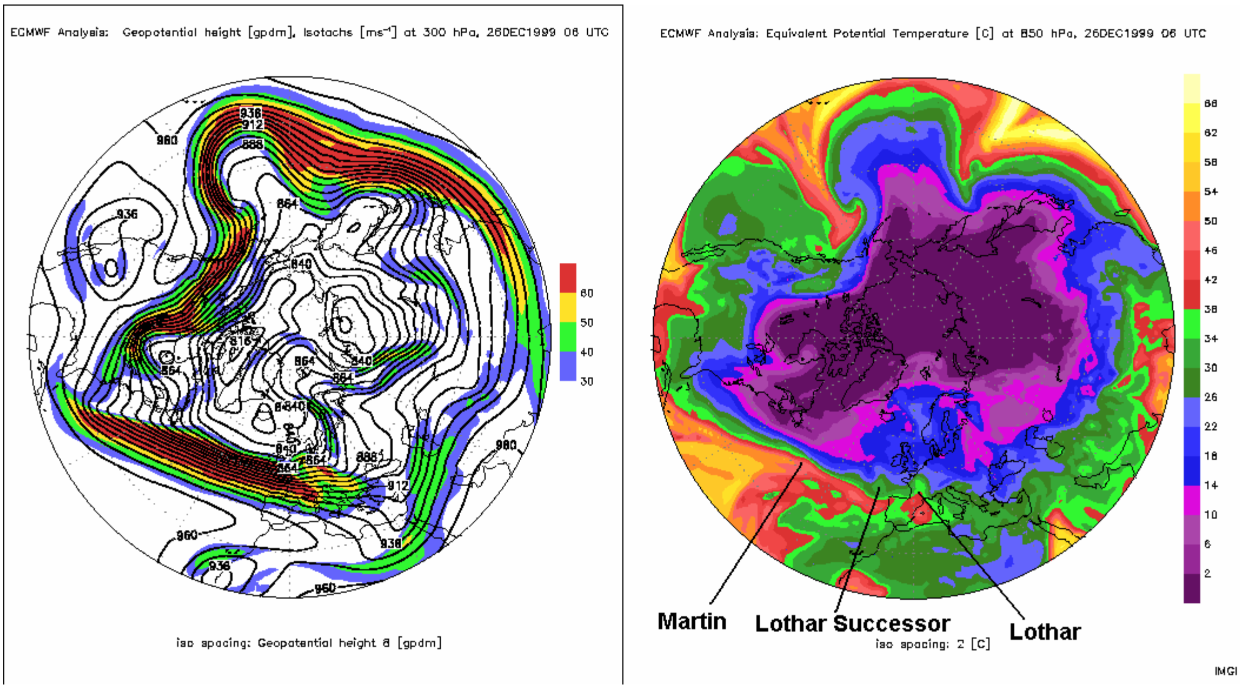


Fig 2: Same as fig.1, but for 26.12.1999, 06 UTC

On 26.12.1999, L1 already arrives onshore, L2 starts maturing and L3 is announced by a strong baroclinic zone. The polarfront jet moved to the North Atlantics extending to Italy and the Balkans. The jet splits over Central and Southern Europe due to the explosive development of L1. Being typical for rapid cyclogenesis the frontal waves form in the left exit region of the jet with strong cyclonic shear vorticity. The high-over-low-situation over North America and East Pacific pushs the polarfront jet far northward. The strong amplifying trough over the North Pacific eventueally allows for a clear weakening of the vigorous jet upstream of Europe.

Note the relative low model resolution smoothing the real air mass distribution.

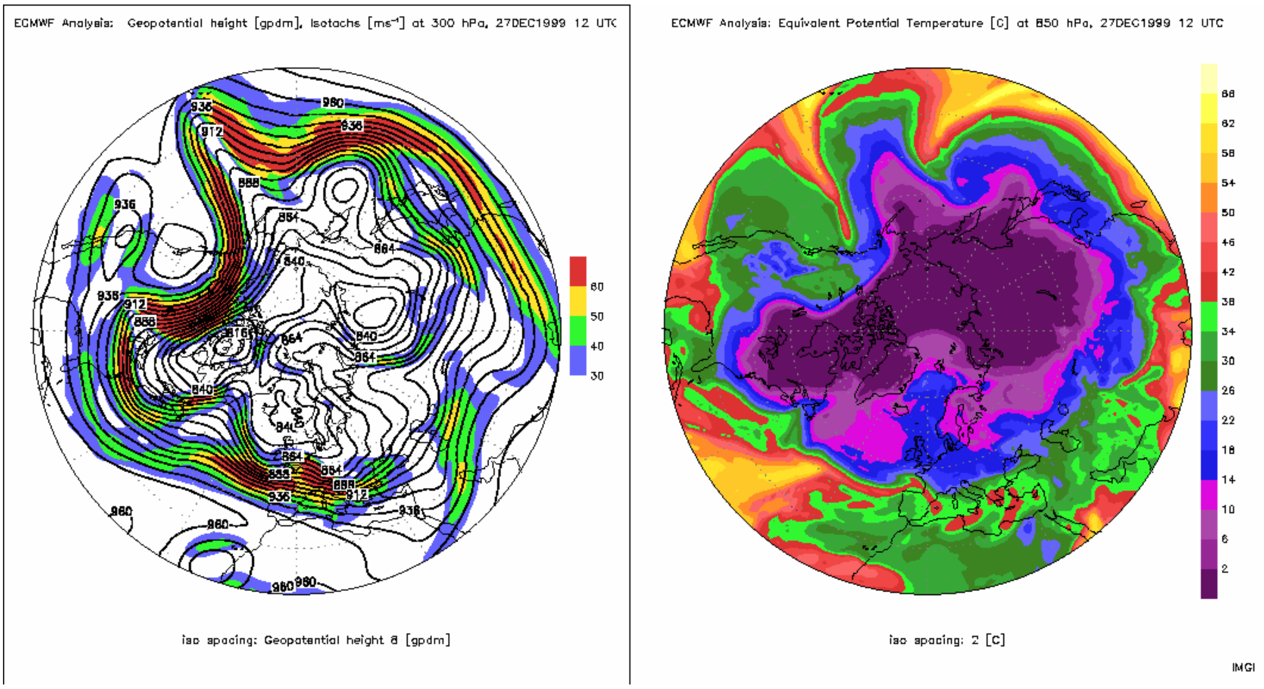


Fig 3: Same as fig.1, but for 27.12.1999, 12 UTC

On 27.12.1999 noon, the North Pacific trough markedly deepened, leading to an amplifyed longwave ridge over Western USA. Downstream, the supergeostrophic jet created another deepening trough which in turn caused a strong wavy polarfront jet. L3 now enters France as another severe windstorm, situated well ahead of the shortwave trough. In opposition to the former windstorms, L3 possesses much more curvature vorticity and respectively slows down with its eastward propagation. Since L3 is linked to the "main" trough, the storm series ends with L3.

2.2 Atlantic and Europe

The next figures show the development of L2 in the context of 500 hPa geopotential and relative vorticity.

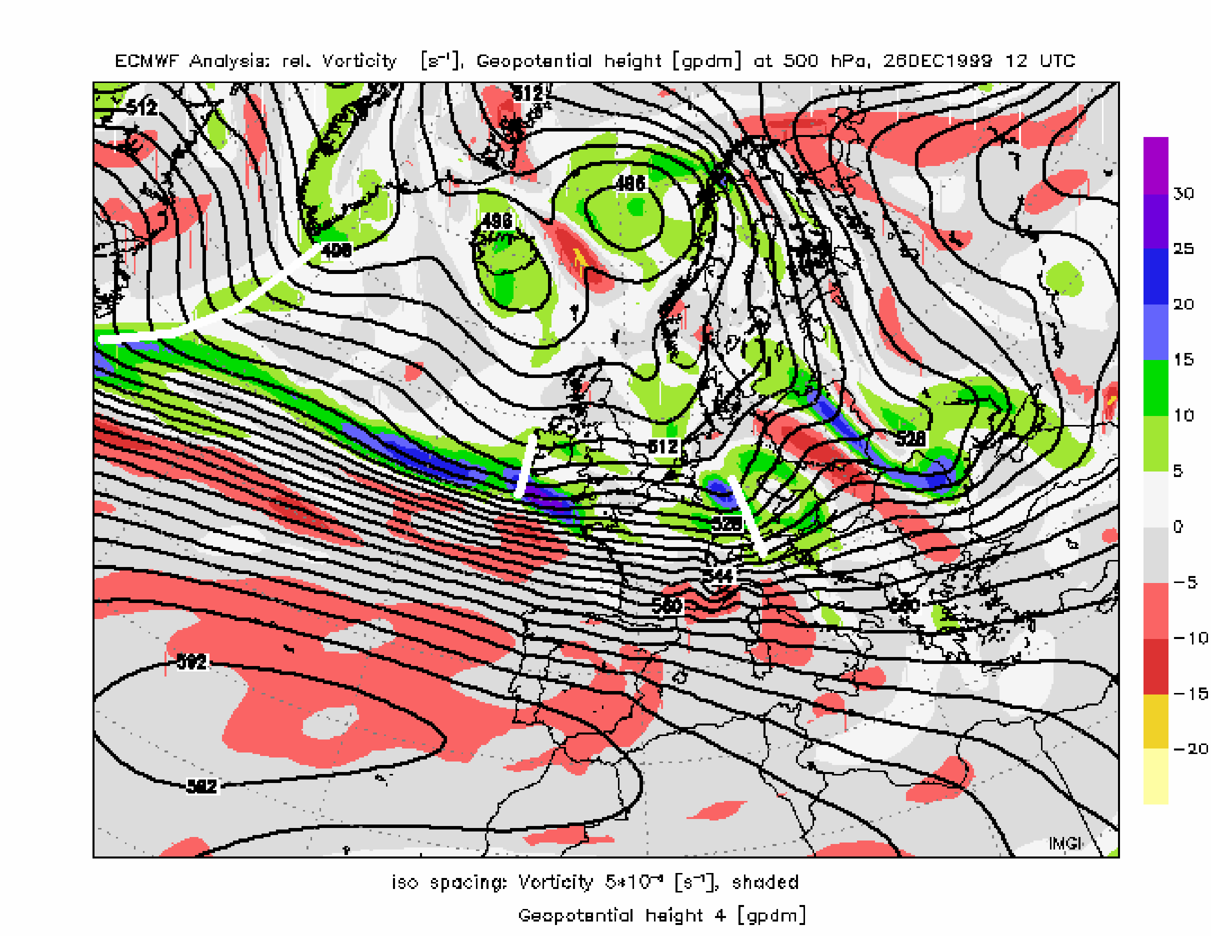


Fig.4: ECMWF Analysis: relative Vorticity [1/s], Geopotential height [gpdm] at 500 hPa, 26.12.1999, 12 UTC, trough axes associated with the storms are marked white

A violent upper-level flow dominates over wide parts of the Atlantic and Europe. The shortwave trough associated with L1 crosses Southern Germany. Upstream, another shortwave trough with weaker amplitude and laterally-aligned maximum of relative vorticity follows. The orientation of the relative vorticity suggests that it consists more of shear vorticity than of curvature vorticity. However, as the absolute values of relative vorticity do not increase over a larger north-south aligned area, the developing windstorm could not ingest enough differential cyclonic vorticity advection (DCVA) to become as violent as L1 before. L3 is located far upstream ahead of the main trough axis but more towards the jet axis with vanishing DCVA.

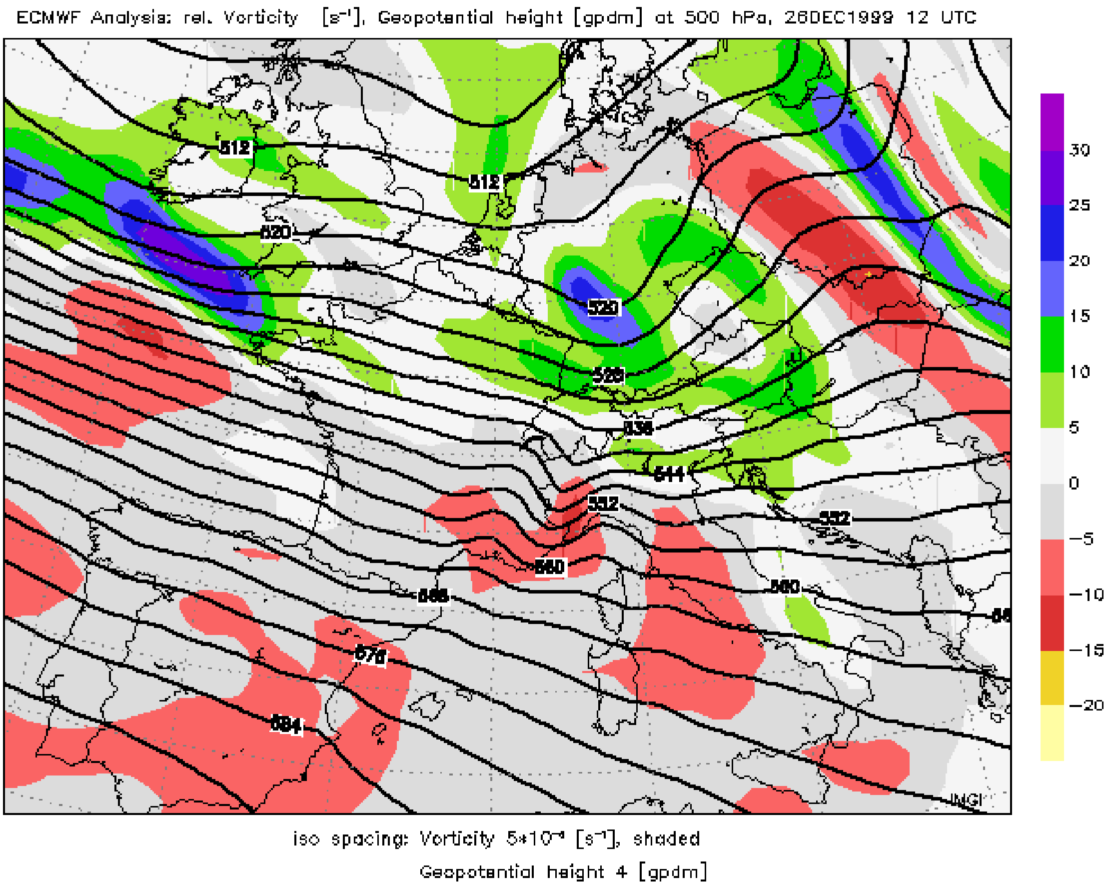


Fig.5: same as Fig.4, but closer look to Europe

A closer look to the situation in Europe reveals the larger portion of curvature vorticity associated with L1 and the larger portion of shear vorticity associated with L2. The lowest pressure of L2 is just ahead of the trough axis in the Celtic Sea, with slightly increasing DCVA.

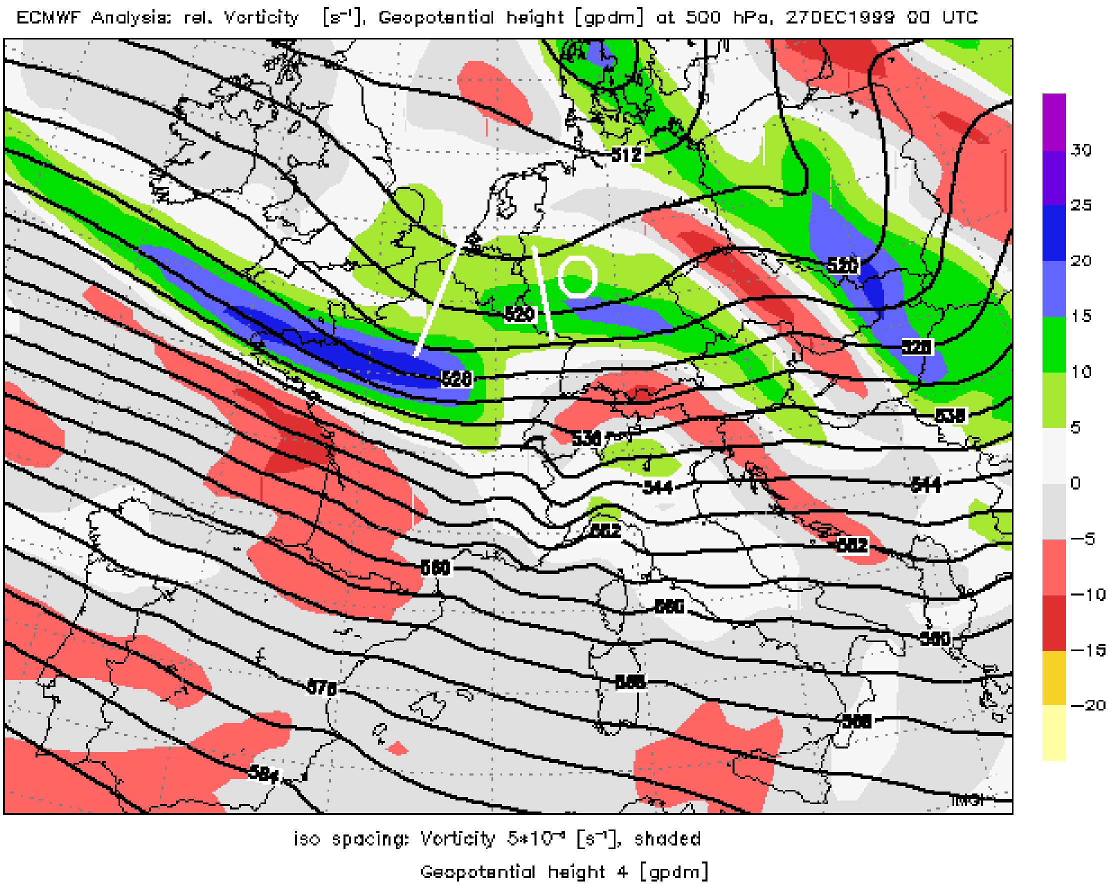


Fig.6: same as Fig.4, but for 27.12.1999, 00 UTC, the position of L2 (surface pressure) is illustrated by a white circle

At midnight, the reason for the weaker development of L2 is visible: the relative vorticity (respectively the trough) splitted in two branches, with a weaker primary maximum over Southern Germany and a stronger secondary maximum over Northern France. The lowest pressure of L2 is observed in the vicinity of the weaker maximum just ahead of the primary weaker trough axis. It can be easily seen that the secondary maximum is too far to the south to maintain the DCVA. With decreasing values of relative vorticity upstream of the primary maximum, the low is expected to fill up which actually happened thereafter.

2.3 Central Europe

The synoptic overview will finish with a series of surface pressure analysis. At first, the ECMWF analysis and synop observations (see bewow) will be compared to prove the reliability of the following ECMWF analysis charts. For this reason, the synop with the lowest pressure was taken. Since the data net is too sparse to solve the small-scale pressure field of L2, the pressure tendency of the used synop is added.

Date (in UTC)	ECMWF (hPa)	Synop (hPa)	Error (hPa)	Pressure Tendency Synop (hPa)
26.12.,12	987,5	987,3	0,2	00
26.12.,18	985,0	984,1	0,9	-2,4
27.12.,00	985,0	983,1	1,9	-2,9
27.12.,06	987,5	984,0	2,5	-0,9

Result: The ecmwf analysis slightly underestimated the deepening of L2.

The series below reaches from 26.12.1999, 06 UTC, to 27.12.1999, 12 UTC, covering the deepening stage of L2.

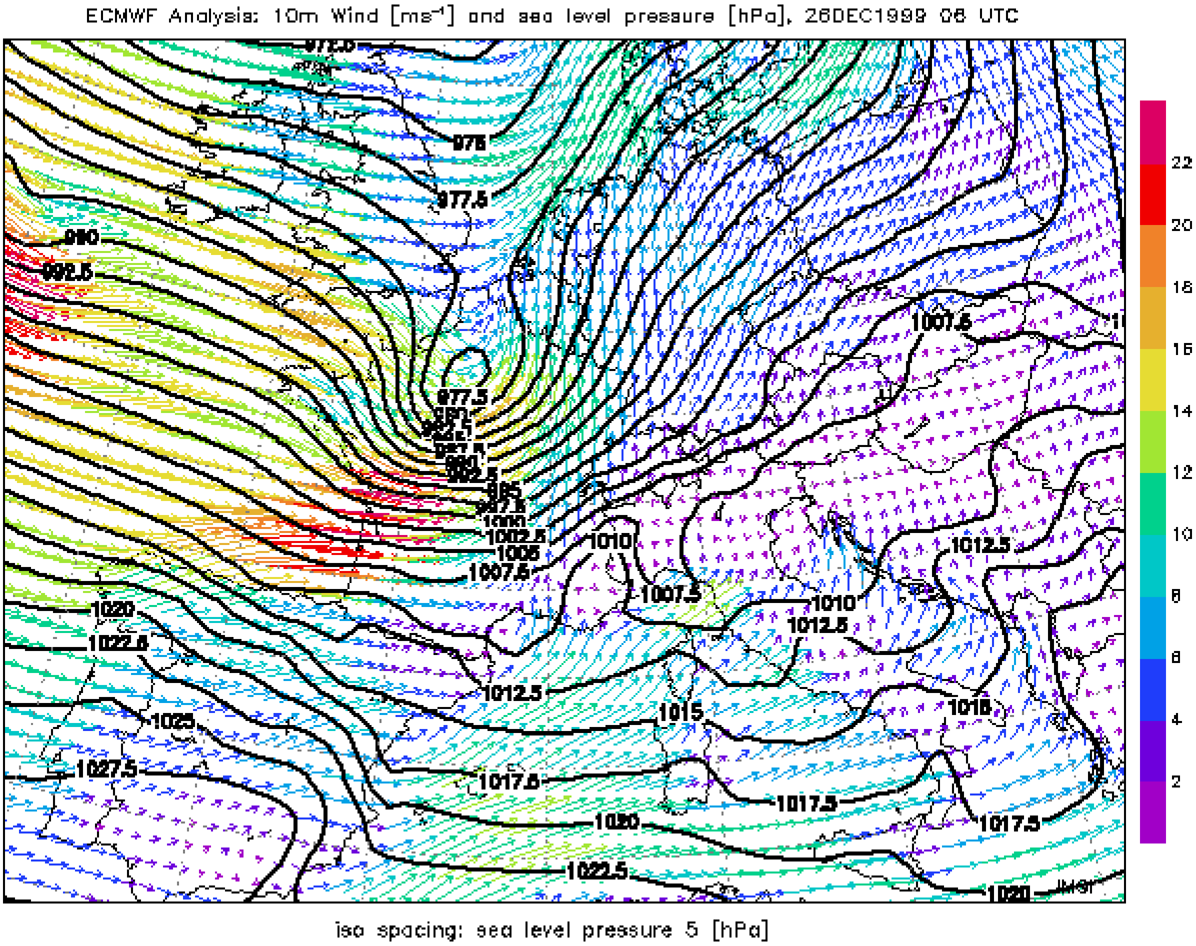


Fig.7 26.12.1999, 06 UTC, surface pressure [hPa] in 2,5 hPa isolines and 10 m average winds [m/s]

L1 crosses Northern France in the morning hours accompanied by violent pressure gradients and average winds in exceed of 22 m/s at the surface. The genesis of L2 is indicated to the southwest of Ireland where the pressure gradient sharpens again and a cyclonic curvature of the isobars is present.

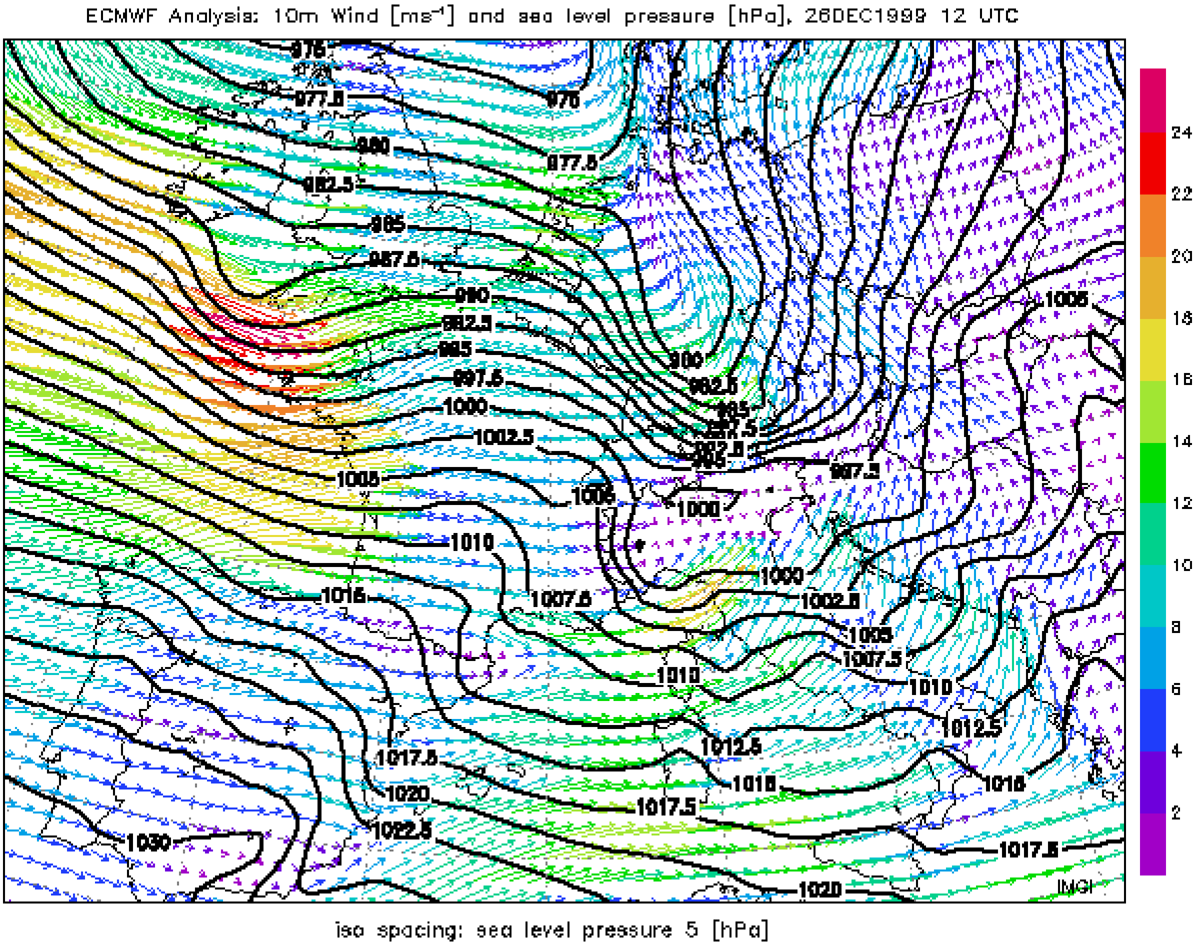


Fig.8 26.12.1999, 12 UTC, caption see Fig.7

The center of L1 is located over Northern Franconia (the surface weather charts will reveal that the center lies exactly over my hometown at this moment), with strongest winds on the southern flank. A weak surface ridge shifts northward over France developing ahead of L2 lying over the Celtic Sea. The cyclonic dent becomes stronger - first indication of a possibly closed circulation there. Notice also the strengthening winds northeast of the Gulf of Genua where an inactive lee cyclogenesis takes place. That secondary cyclogenesis as a result (amongst others) of orographic flow descent will - again - occur with L3 (see section 5).

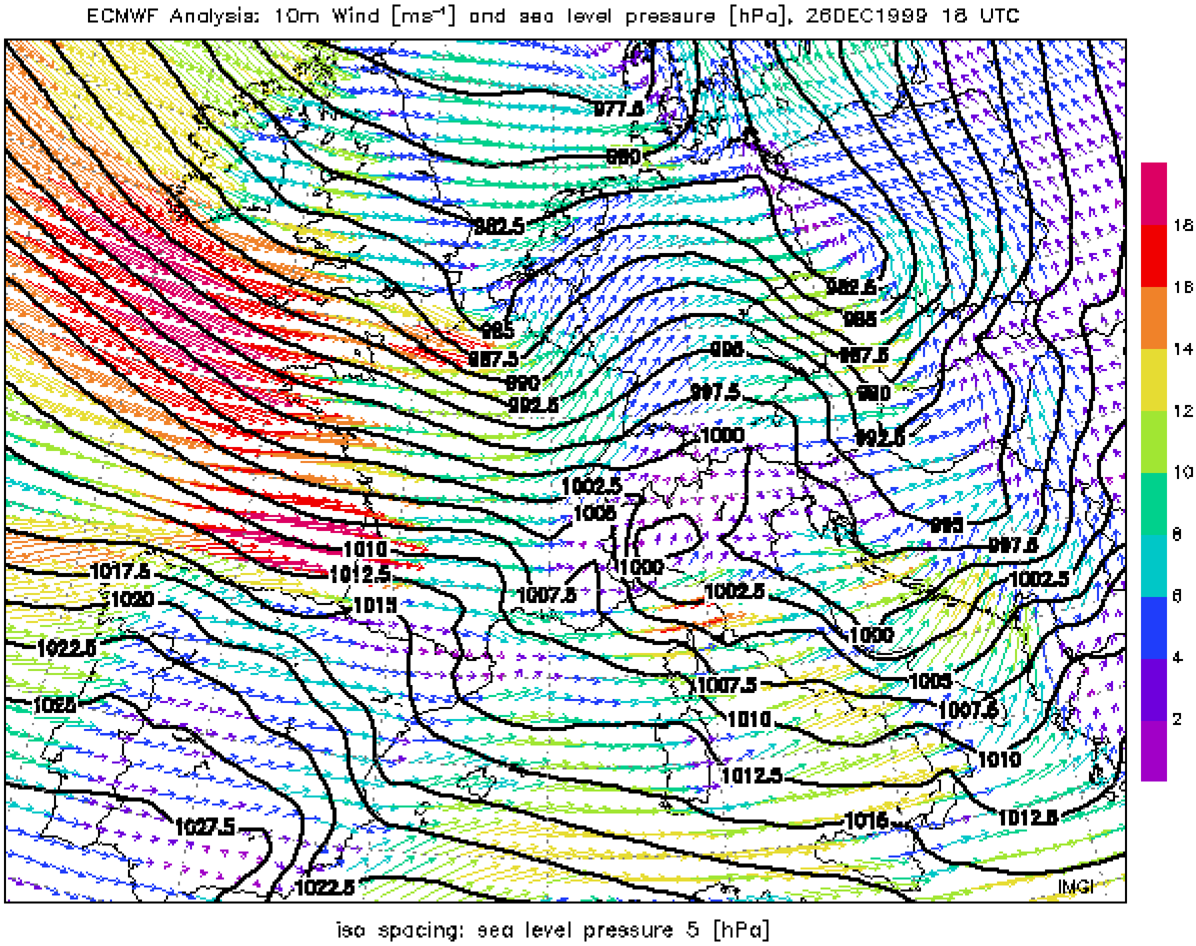


Fig.9 26.12.1999, 18 UTC, caption see Fig.7

L1 fills up east of Germany over Poland while L2 approaches the Benelux States from Northern France. The surface ridge increased its amplitude somewhat and L1 possesses a strong curvature of the 985 hPa isobar. The wind field of L2 becomes more cyclonic, with the maximum winds southwest of the center. Farther upstream, offshore, the wind field generally increased as a result of enhanced gustiness in the wake of the oncoming upper-level cold pool.

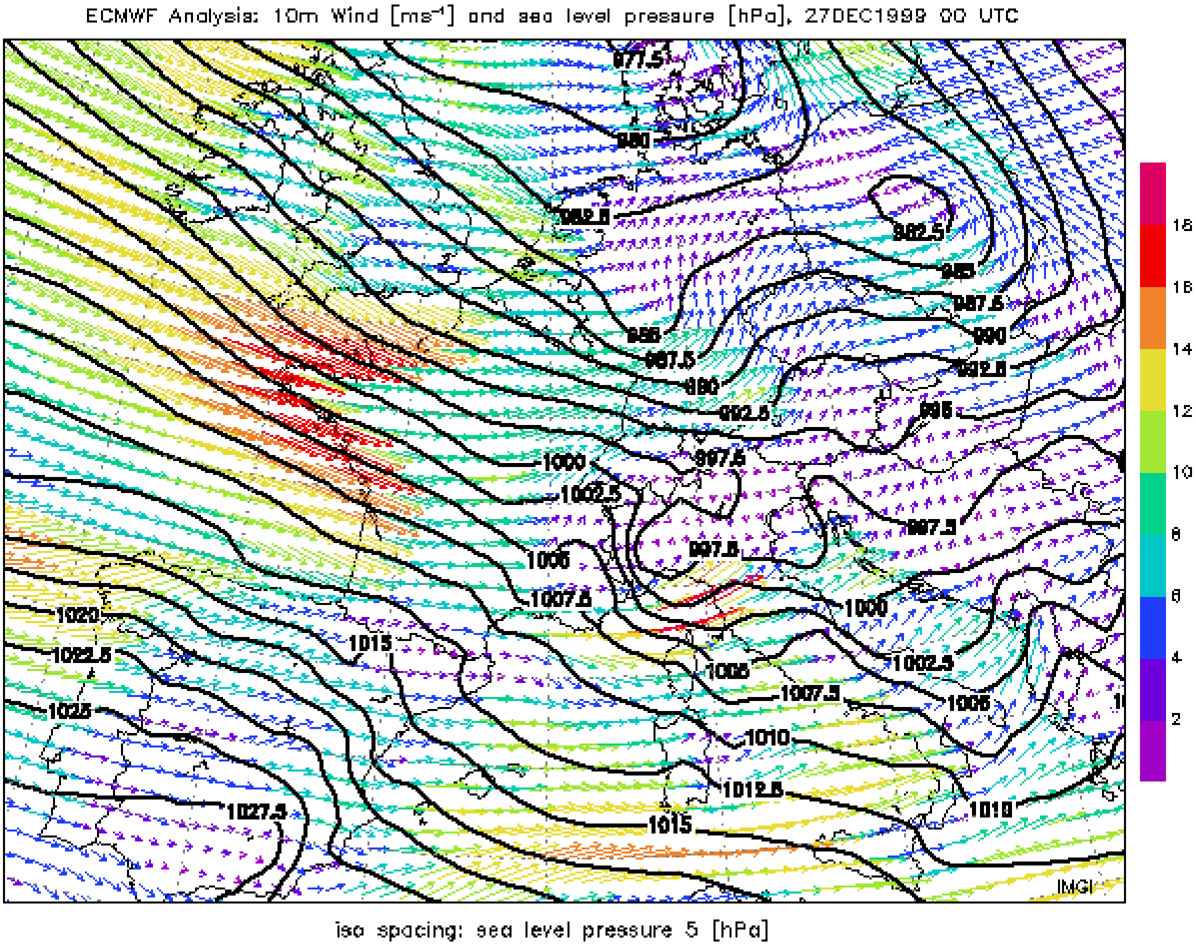


Fig.10 27.12.1999, 00 UTC, caption see Fig.7

Midnight, L2 brushs past my hometown producing the strongest gusts in exceed of 90 km/h. The wind field is much weaker than with L1, but still 'sensible'. Another reason for the comparatively weak winds is not only the higher pressure of the low's center but also the lack of rapid pressure ascent upstream of the low. Respectively, the isallobaric pressure change has been much smaller than with L1. In contrast, with a weakly-curved surface trough the pressure will persist at low levels after the passage of L2. Consider again the deepening south of the alpine main crest as a consequence of lee cyclogenesis.

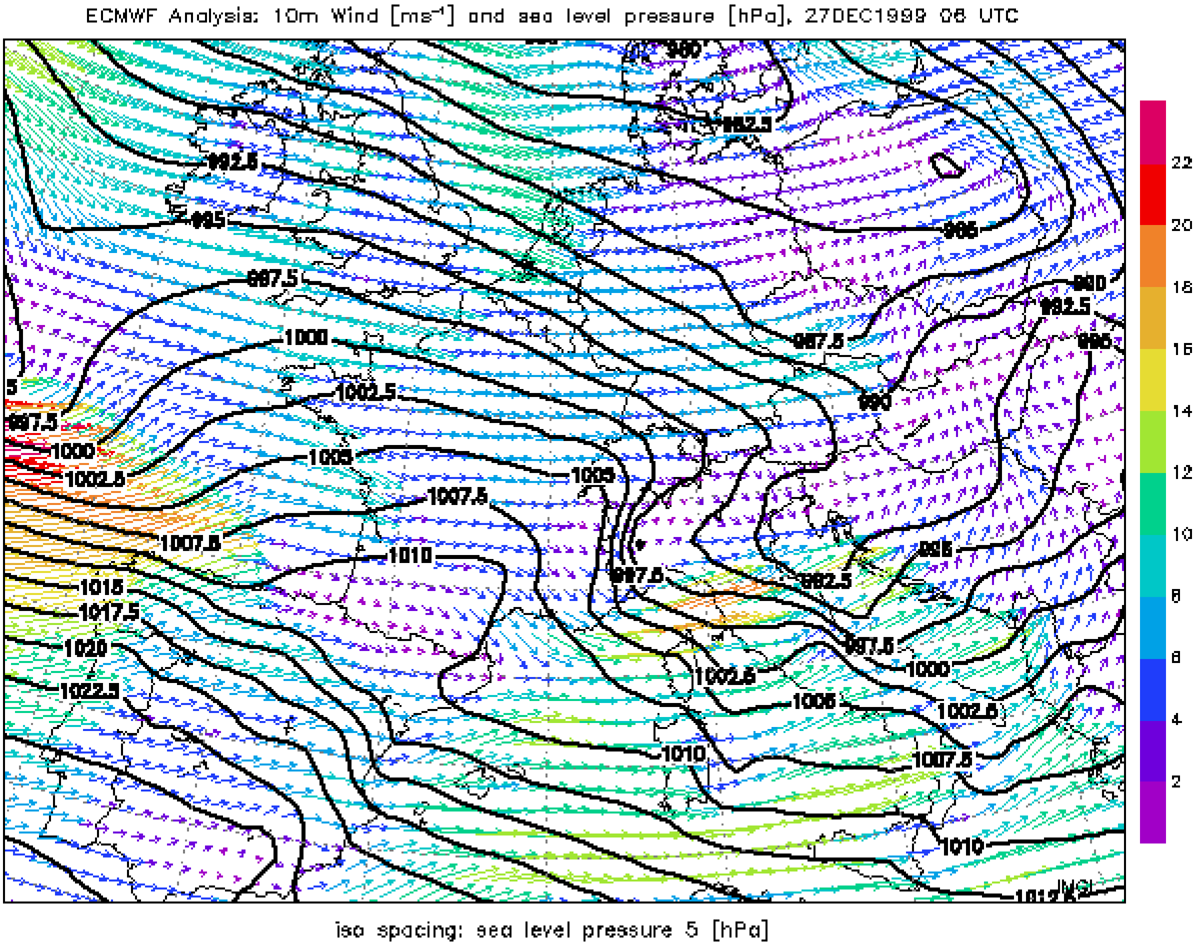


Fig.11 27.12.1999, 06 UTC, caption see Fig.7

At morning, L2 is situated over Czechia, with clearly rising pressure values. Indeed, ECMWF analysis overestimated the fill-up process of L2. Nevertheless, the time of L2 is supposed to be over - mainly due to the approach of L3 over the Biscaya. The warm air advection of L3 rapidly strengthens the development of the surface ridge upstream of L2, and simultaneously, the jetstream split continues. Subsequently, L2 gets into the cyclolytic side of the jet respectively the trough and accelerates its fill-up process.

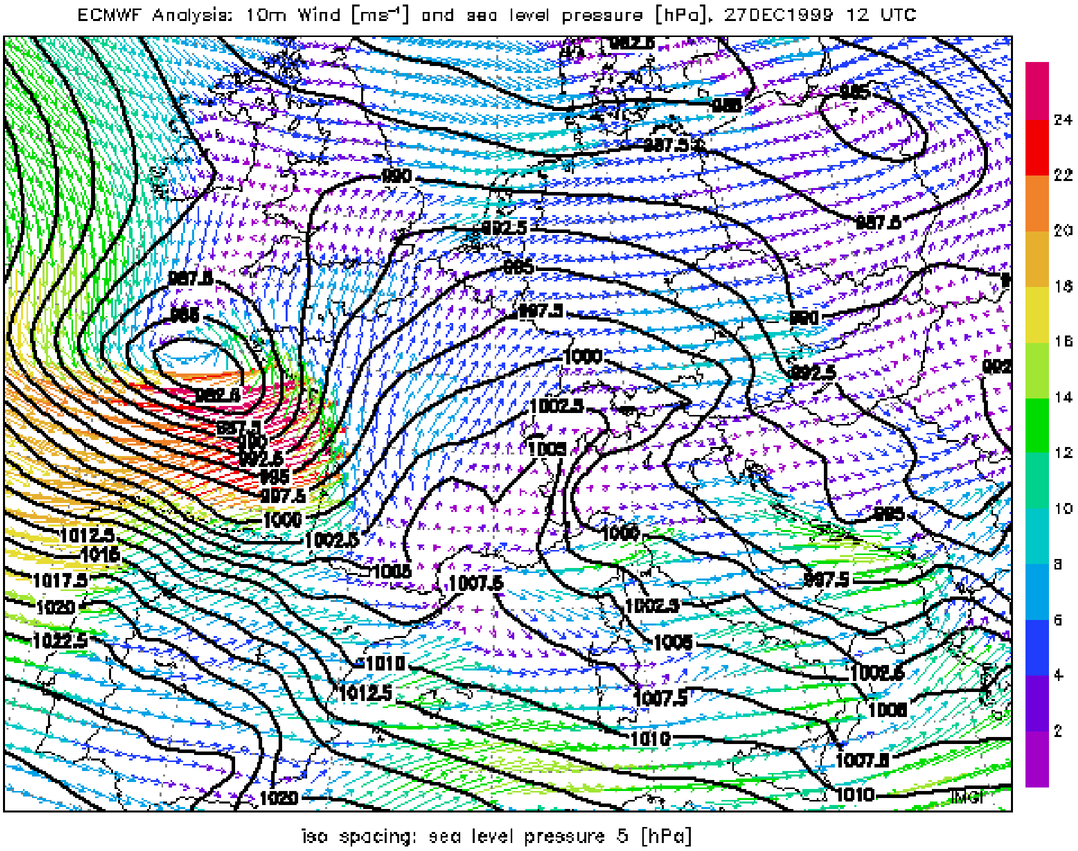


Fig.12 27.12.1999, 12 UTC, caption see Fig.7

At noon, L2 only exists as a well-curved 990 hPa isobar and slightly stronger winds south of the center (over Eastern Austria). Upstream, a pronounced surface ridge built up announcing the onset of L3 whose wind field exhibits extremely direction and speed convergence at the warm front.

3.4 Surface weather charts

The following surface weather charts stem from the Institute for Meteorology and Geophysics Innsbruck, reaching from 26.12.1999, 12 UTC until 27.12.1999,06 UTC. Red circles indicate observations of interest in determining the location of the surface pressure core.

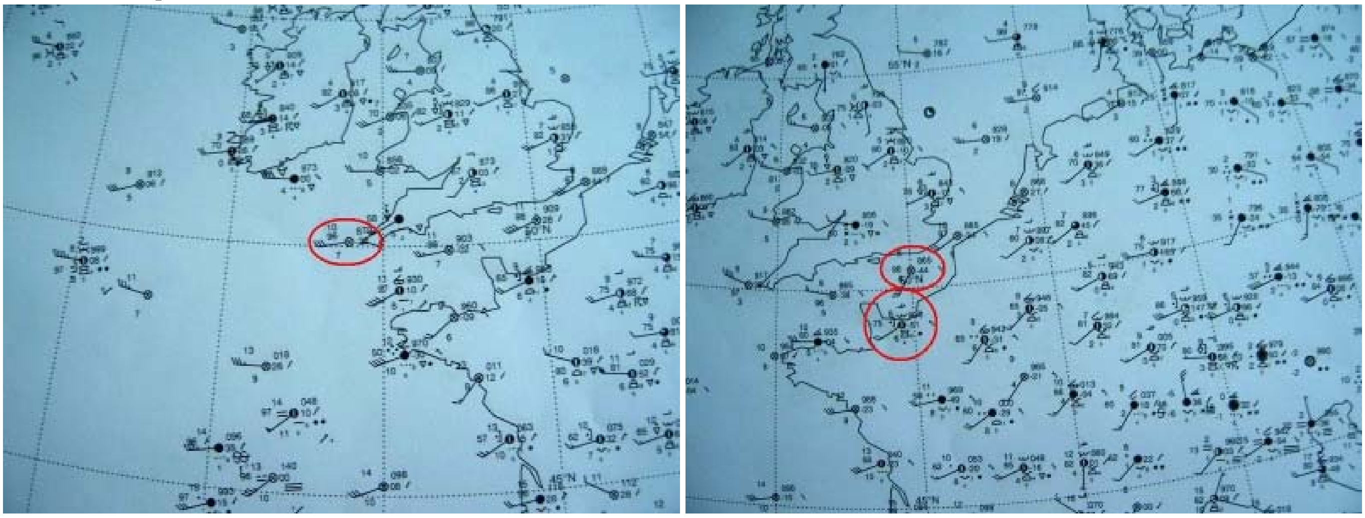


Fig 13,14: 26.12.1999 12 UTC (left) and 26.12.1999, 15 UTC (right)

Initially, the idenfication of L2 is not simple due to the sparse density of data and the uniform westerly winds at the surface. Indications of a new development are given by the marked synop at the southern tip of England where the pressure falls strongest with 2,2 hPa in 3 hours compared with the observations in the vicinity.

At 15 UTC, the pressure fall strengthened with tendencies of 4,4 respectively 5,1 hPa. The wind field becomes more cyclonic with southwesterly winds in the marked area and westnorthwesterlys farther upstream (English Channels reports 50 Knotes in average).


Fig 14,15: 26.12.1999 18 UTC (left) and 26.12.1999, 21 UTC (right)

At 18 UTC, the surroundings of L2 reveal a distinct cyclonic wind field. The pressure falls with 5 hPa southeast of the low's center, thus a southeastward propogation of L2 can be expected.

At 21 UTC, northerly winds as well as southerly winds are observed indicating a closed circulation between Belgium, Netherlands and Western Germany. The relative pressure minimum reaches **981,4 hPa** and a pressure fall of 5,3 hPa.

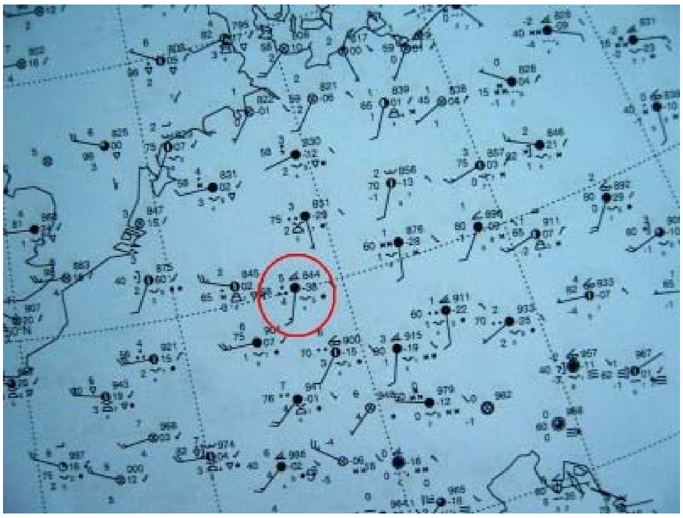
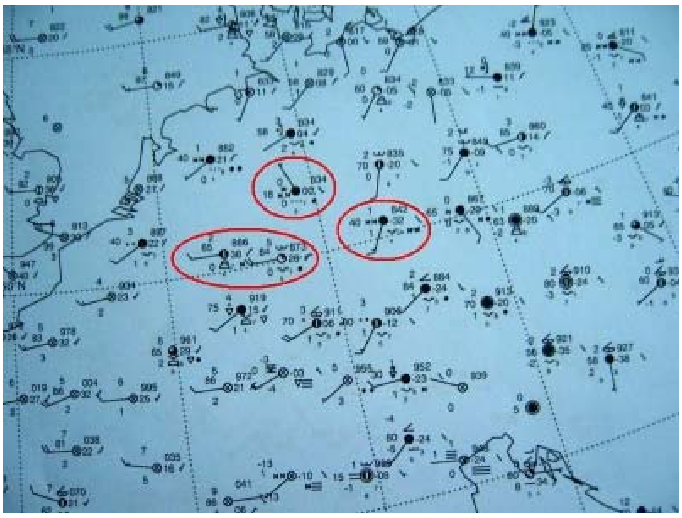



Fig 16,17: 27.12.1999 00 UTC (left) and 27.12.1999, 03 UTC (right)

At 00 UTC, a northerly wind component temporarily lacks (possibly due to the data hole northwest of the marked synop), but the marked synop shows a southerly wind with 3,8 hPa pressure fall and a weak pressure rise with westerly winds west of that synop. The cyclonic wind field still exists. The lowest pressure of L2 is 983,1 hPa, with 2,9 hPa falling.

A better overview with drawn fronts gives the surface weather chart of the 'Berliner Wetterkarte':

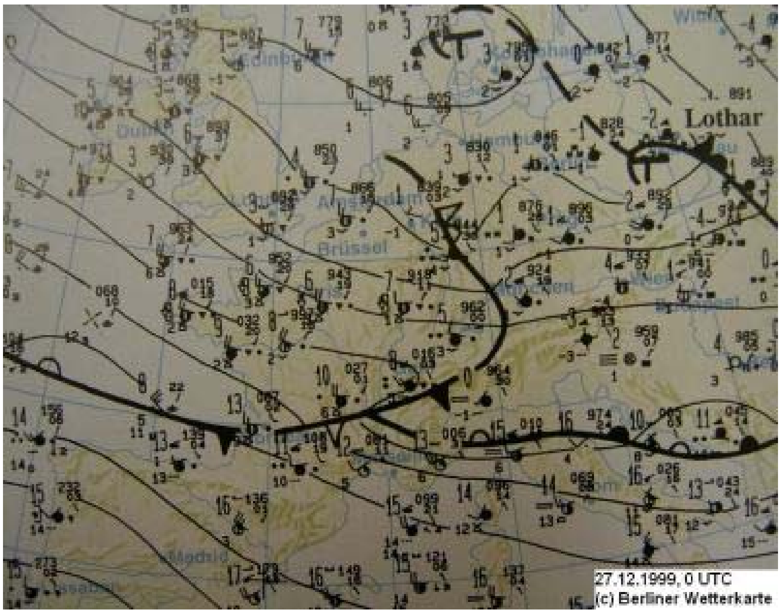


Fig.18: Surface weather chart at 27.12.1999, 00 UTC, with courtesy of Berliner Wetterkarte

The analysis of Berlin exhibits an upper occlusion front reaching from the low's center (note that there is only a cyclonic curvature of the isobars, no closed isobar) southward and ending with a cold front between the Western Alps and the Biscaya. Moderate snowfall and rainfall are observed with the upper occlusion front.

The surface weather chart at 03 UTC (figure 17) shows anew a northwesterly component and the lowest pressure with 983,4 hPa.

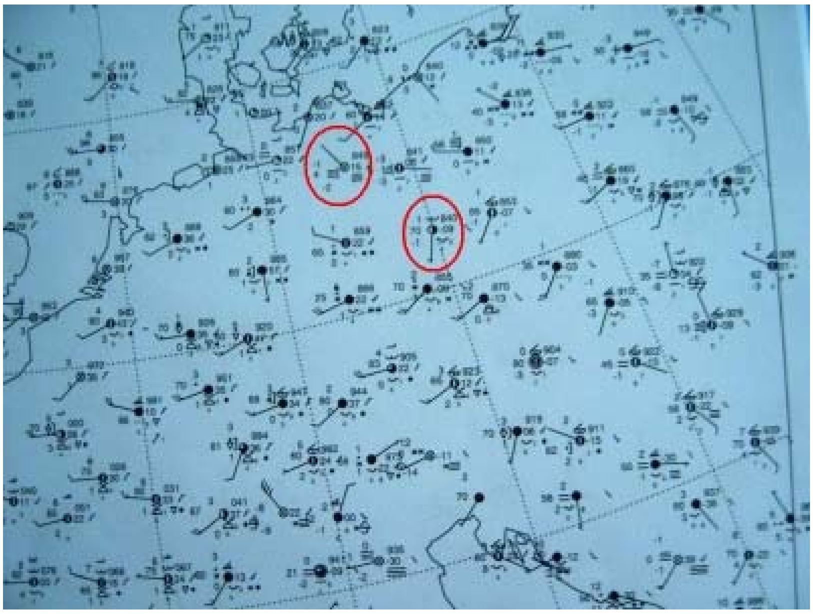


Fig. 19: 27.12.1999, 06 UTC

L2 appears the last time with a closed circulation at 06 UTC with northwesterly winds in Northeast Germany and southerly winds farther southeastward. where - again - a relative pressure minimum with 984, 0 hPa exists. The pressure fall tendencies are weaker than the rise tendencies indicating the dominating cyclolysis with L2.

Summarizing there is evidence that a closed circulation of L2 has been present between 26.12.1999, 18 UTC and 27.12.1999, 06 UTC. The denotation 'trough line' does not appear to be appropriate for this stage of L2's development.

3. Classification of L2

In this section, numberous case studies - all attributed to L3 and/or L1 - and descriptions of the storms are scoured for hints of the existence/generation of L2.

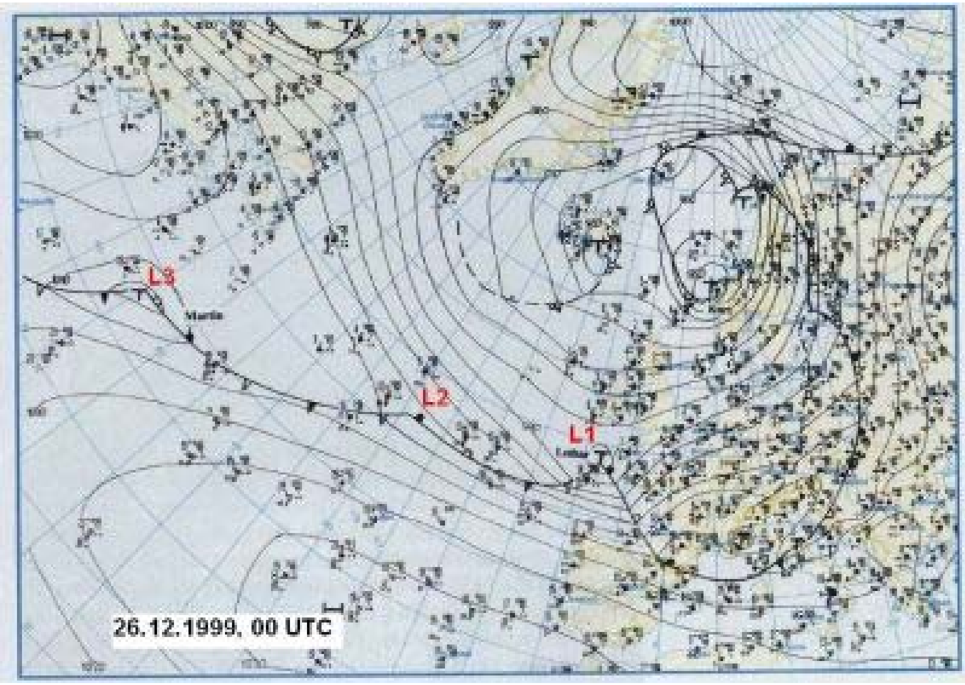
3.1 Vollmer und Boettcher

The review's authors [5] indirectly mention L2 as follows
"Auf dem Abendbild sieht man, dass Orkan Lothar bereits nach Tschechien abgezogen ist. Statt dessen sind neue Wolkenpakete über dem Südwesten aufgezogen. Sie bringen erneut Sturmböen, die aber deutlich hinter der Stärke von Lothar zurückbleiben werden. "

The image of the evening shows that windstorm 'Lothar' already moved to Czechia. New cloud packets captured the southwest [of germany]. They bring again gale-force winds which are, though, clearly weaker than 'Lothar'.

3.2 Kraus and Ebel (2003)

The following figure is displayed in Kraus and Ebel (2003), pg. 194 (chapter 6, cyclones of mid-latitudes):



`Fig. 20: Berliner Wetterkarte at 26.12.1999, 00 UTC, with courtesy of 'Verein Berliner Wetterkarte - http://www.berliner-wetterkarte.de, the three storms are additionally labelled with L1, L2 and L3.`

The authors write

"[...] drei Wellentiefs, die über den Atlantik nach Osten ziehen. Die östlichste dieser Mesozyklonen mit Namen "Lothar" führte zu den starken Weihnachtsstürmen in Frankreich, Süddeutschland und der Schweiz am 26.12.1999. Die übernächste Welle wuchs auch wieder zu einem Sturm heran. Er hieß "Martin" [...]"

[...] three wave cyclones moving eastward over the Atlantic. The easternmost of these mesocyclones named 'Lothar' leads to strong Christmas storms in France, Southern Germany and Switzerland on 26.12.1999. The next but one wave grew to a windstorm again. It is labelled 'Martin' [...].

Note the orientation of the frontal zone. L1, L2 and L3 all moved in a row with one frontal band after another. That analysis looks reasonable regarding the satellite imagery at this time (see section 4).

3.3 German Weather Service (DWD)

The DWD has published few (available) information to the Christmas 1999 storms. The title 'trough line' probably bases upon the following surface weather chart.

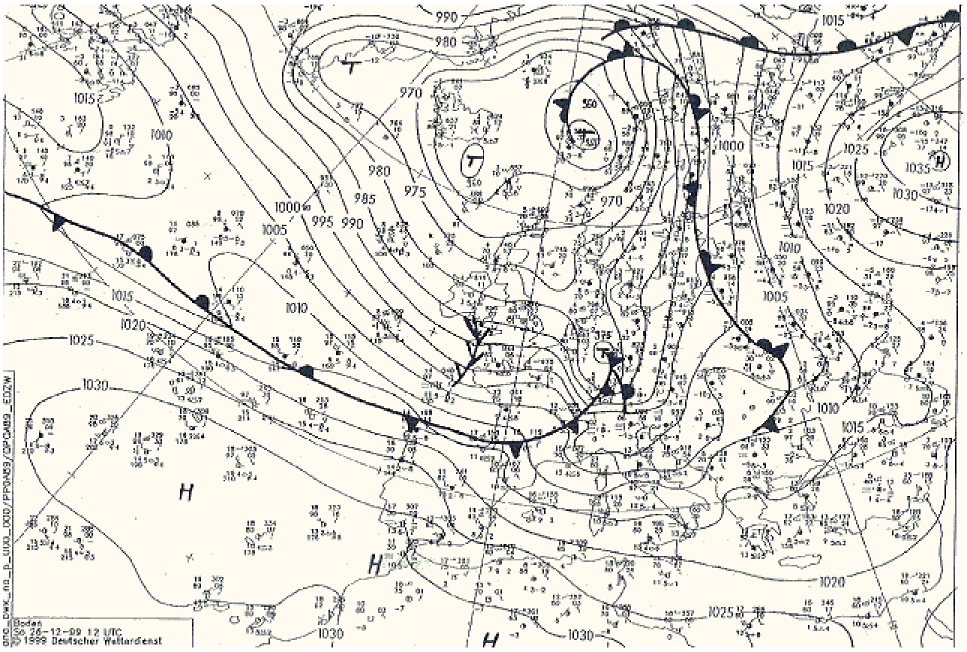


Fig. 21: Surface weather chart, DWD, valid for 26.12.1999, 12 UTC

In opposition to the 'Berliner Wetterkarte' above, the frontal zone solely links L1 with L3 far upstream. L2 is denoted as surface convergence line.

3.4 Matthias Jaeneke (DWD) alias 'Wetterfuchs'

The author of 'Lothar 26.12.99 : Nowcasting mit Satellitenbildern' [1] is a pensionary meteorologist of the DWD who has written a lot of case studies about notorious windstorms in the past, provided in the german 'Wetterzentrale Forum'.

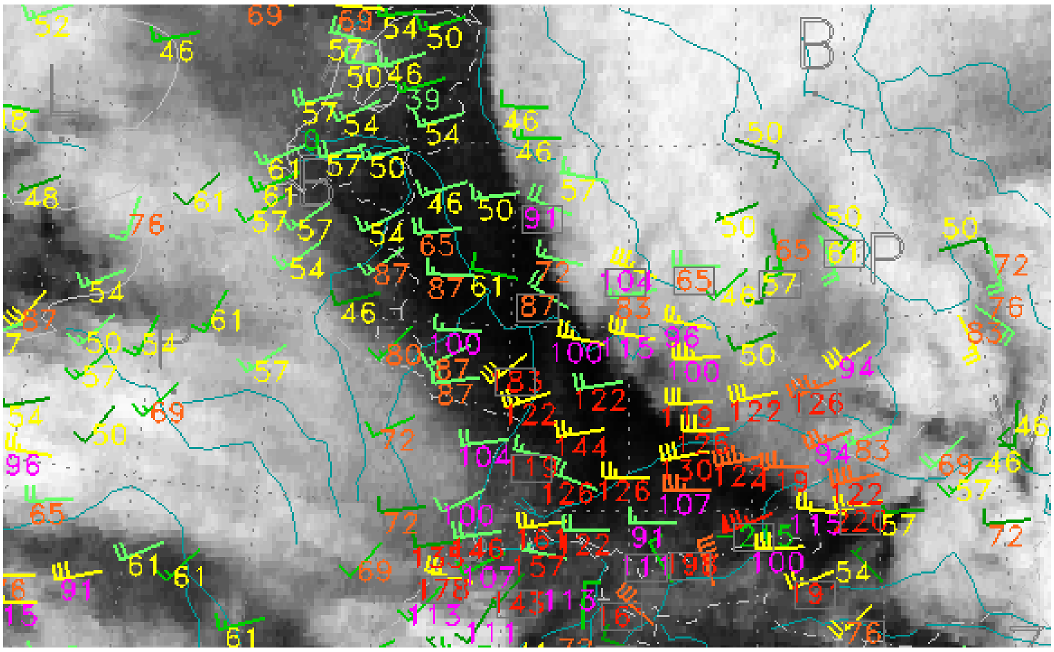


Fig. 22: Water vapor satellite image + maximum wind gusts + surface winds, 26.12.1999, 15 UTC

In the context of figure 22 in its case study he wrote:

"[...] Eine abschließende weitere Bemerkung zu dem letzten WV-Bild : Wie unschwer zu erkennen, näherte sich vom Ärmelkanal erneut eine "ominöse" Struktur mit Dry Slot. Da gleichzeitig dort auch der Wind schon wieder stärker geworden war, bestand kurzzeitig eine Irritation darüber, ob die Geschichte ein zweites Mal losgehen würde. **Es war nur ein kurzes Aufflackern**, sehr bald danach wurde klar, da passiert nichts mehr (zumindest nicht an diesem Tag, denn Orkan "Martin" ließ den Franzosen noch etwas Zeit) passieren würde. [...]"

A concluding further remark about the last water vapor image: As it can be easily seen, another 'ominous' structure with a dry slot drew near from the English Channel. As the wind speeds increased simultaneously, temporary irritation arose whether the story will start a second time. **It was just a short flare-up**. Soon it was obvious that nothing will happen anymore (at least not this day because windstorm 'Martin' give the French some time).[...]

3.5 NWS-North Atlantic Surface analysis (NCEP)

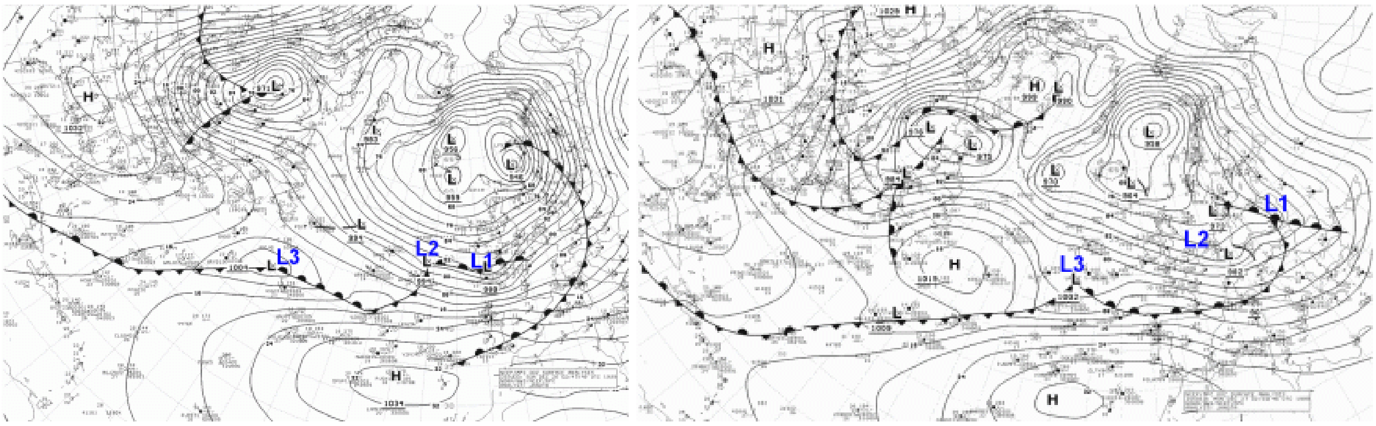


Fig. 23,24: NWS-North Atlantic Surface analysis. 26.12.1999 00 UTC (left), 27.12.1999 00 UTC (right)

The surface analysis is provided by the National Weather Service of the USA (NWS), and contains observations with superimposed isobars from model analysis. The combination of observations and model calculation likely explains the inconsistency of L2 which is initally denoted as a frontal wave and later on as a trough line.

3.6 NCEP Reanalysis maps

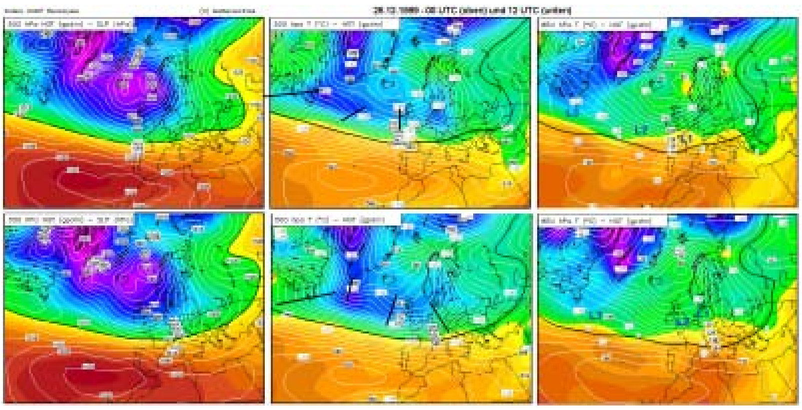


Fig.25: NCEP Reanalysis, 26.12.1999, 00 (above) und 12 UTC (below), with 500 hPa geopotential heights + surface pressure (left), 500 hPa geopotential heights and temperature (center), 850 hPa geopotential heights and temperature (right), trough axes are coloured, positions of the storms are labelled.

NCEP Reanalysis data being available on 'Wetterzentrale' show a strong baroclinic zone below a violent upper-level flow (tightened isohypses). At 00 UTC, L1 lies in the entrance region of the English Channel, L2 follows upstream and L3 is characterizied by a larger-scale frontal wave swimming on the jet stream (no significant deepening at this time).

12 hours later, L3 still swims with the jet, with slightly enhanced temperature wave. L1 crosses Germany, just below the trough axis (mature stage). L2 enters the English Channel marginally ahead of the trough axis. The peak of the temperature wave is displaced downstream of the trough axis , that is, it benefits from DCVA. This is the main difference to comma lows which are placed under the trough axis respectively the maximum values of curvature vorticity.

3.7 Manfred Spatzierer (Ubimet)

Manfred Spatzierer (personal communication) proposed an instant occlusion process as a possible explanation refering to the satellite imagery below

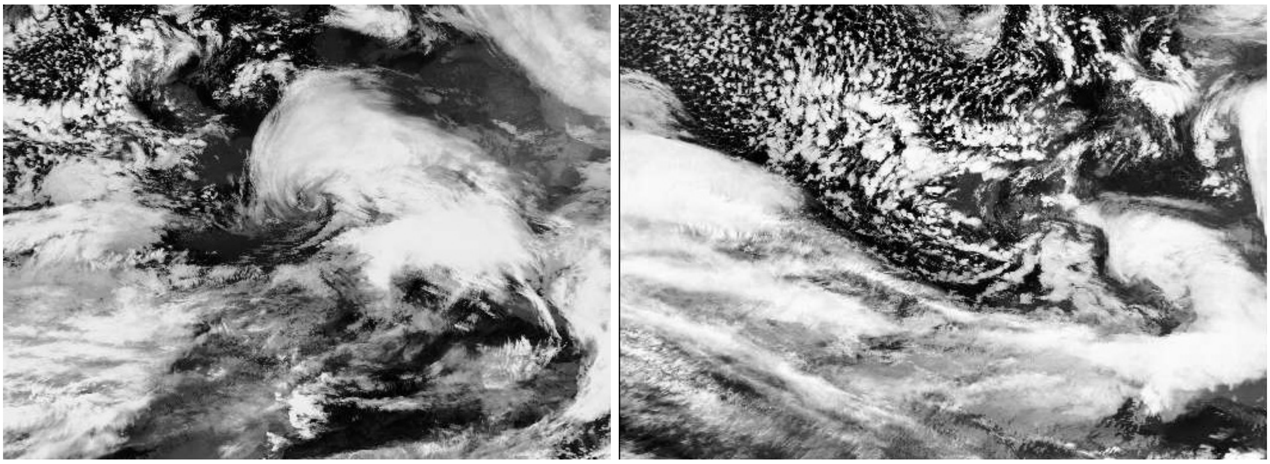


Fig. 26,27: IR-Satellite image from NOAA, 26.12.1999, 07:54 UTC (left) and 19:24 UTC (right)

The image on the left side shows the mature stage of L1, with a distinct occlusion wrapped around the low's center and a mesoscale cold front with "ribbed" convective cells. L2 approaches farther upstrem with slightly warmer cloud tops of the cloud head north of a narrow, but deep cloud band (baroclinic leaf?). The cloud head is situated within a well-mixed polar air mass yielding markedly defined deep moist convection. However, the cloud head appears to be less convective than its surroundings and the comma structure formed only later (see fig. 27) as the baroclinic leaf merged into the cloud head. The main convective activity took place well behind the frontal passage. As seen above (fig.5), the relative vorticity predominately consisted of shear vorticity and not of curvature vorticity being typical for comma lows.

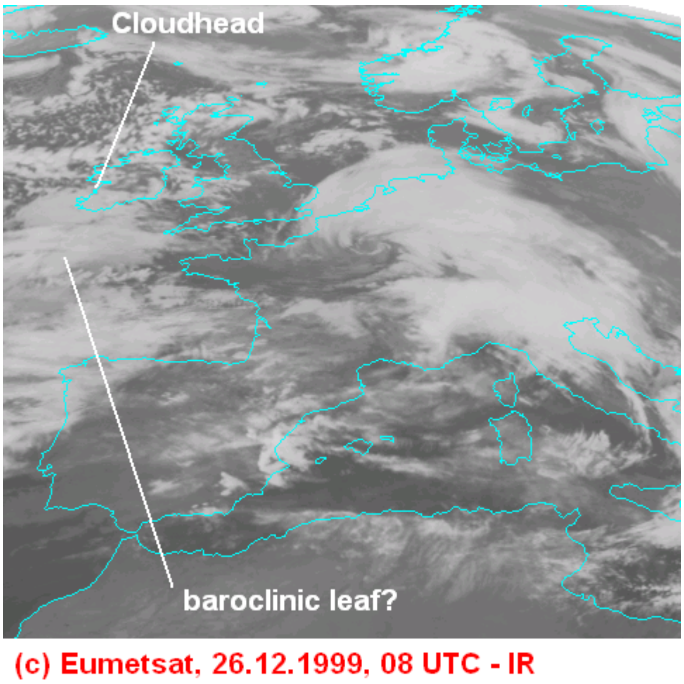


Fig.28: Eumetsat IR-Image, 26.12.1999, 08:00 UTC

The Eumetsat satellite image valid for the same date seem to corrobate that an instant occlusion process is rather unlikely as the stratiform appearance of the cloud head is clearly visible.

3.8 Wernli et al. (2002)

Main focus of this study is the dynamic evolution of L1 with respect to the 3-dim isentropic potential vorticity perspective. Some figures also indicate the presence of L1, for example figure 3d on page 410 where the accumulated precipitation and surface pressure are displayed. Upstream of L1, there is another small-scale surface trough (L2).

A more illustrating picture is given on page 416 in figure 7

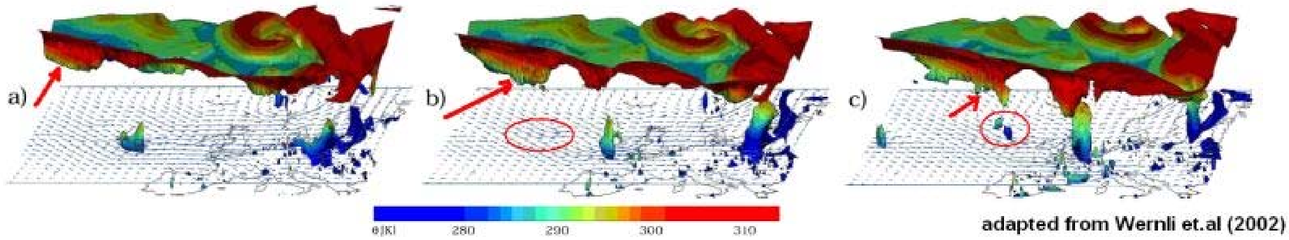


Fig. 29: IPV-Perspective with the 2-PVU surface of the moist HRM-Simulation at a) 25.12., 18 UTC, b) 26.12., 00 UTC and c) 26.12., 06 UTC. Surfaces are coloured with the potential temperature. The horizontal wind vectores are plotted for 850 hPa (the length of the maximum wind vector is 43,5 m/s); red circle indicates the position of L2, red arrows point to the descent of the tropopause associated with L2 (adapted from Wernli et al. (2002), fig. 7, pg. 416

The series of 3-dim figures illustrates the differences between L1 and L2:

In a) L1 is already present as a pronounced low-level potential vorticity anomaly (LL PV anomaly) while there is no sign of a secondary cyclogenesis save a clear descent of the tropopause fold (= UL PV anomaly) above a LL wind convergence. In b) L1 grows upward with simultaneously descending UL PV anomaly. The UL PV anomaly of L2 descends further and the LL convergence slightly strengthens. In c) the LL pv anomaly of L1 grows to a 'tower' and finally connects to the UL PV anomaly in the mature stage of the cyclogenesis. For the first time, L2 is visible in the shape of a small-scale, ill-structured LL PV anomaly with a relative far downward descended UL PV anomaly.

Conclusion:

L1 developed as a pre-existing LL PV anomaly later connecting to a UL PV anomaly (so-called "bottom-up intensification"). The absence of an initial upper-level precursory disturbance is typical for mid-latitude cyclones (Hoskins et al. 1985). L2 went the opposite way with a pre-existing tropopause fold exciting a LL PV anomaly which is often found with secondary cyclogenesis (e.g. Hoskins and Berrisford 1988).

The authors concluded that the development of L1 was mainly due to an unseasonably strong upper-level jet and a distinct LL PV anomaly created by the release of latent heat (directly affecting the growth of the LL PV anomaly and indirectly affecting the growth of the UL PV anomaly by adjusted balance) and unusually high sea surface temperatures.

3.9 Descamps et al. (2007) and Rivière et al. (2010)

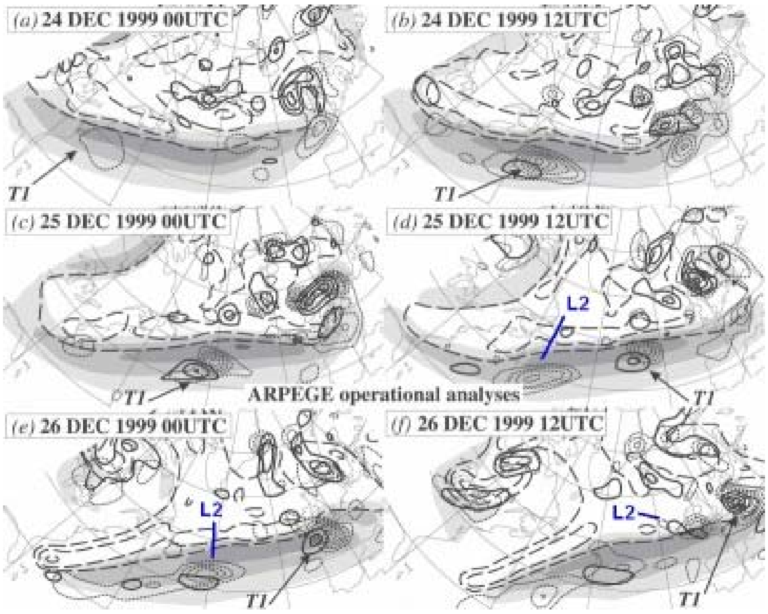


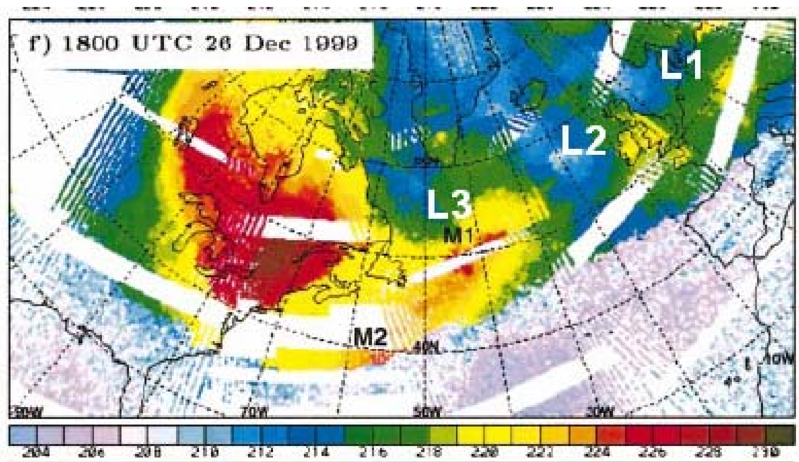
Fig.30: Evolution of L1 in the framework of 850 hPa positive relative vorticity (bold solid lines, contur interval of $5*10^{-5}s^{-1}$), geopotenial heights of the 1,5 PVU-surface (dashed lines, contur interval of 200 gpdam, below 800 gpdam), 600 hPa ascending vertical motion (dotted lines, contur interval of 0,2 Pa/s) and wind speed (1,5 PVU-surface, grey shades, interval 20 m/s above 40 m/s), adapted from Descamps et al. (2007), figure 1 on page 4290; blue line indicates the position of L2

On 25.12.1999, 12 UTC, L2 manifests itself as upward vertical motion in the right entrance on the anticyclonic side of the jet. In contrast to T1 (L1), relative vorticity and vertical motion are not coupled. The coupling takes place at 26.12.1999 00 UTC, ascending vertical motion is placed ahead of the vorticity maximum, again in the right entrance. Within 12 hours the disturbance L2 moves into the left exit region and reduces its extent. Some similarities to L1 are visible, but the intensity and inclination of the axis are different.

The same picture can be recognized with **Rivière et al. (2010)**

3.10 Fourrié et al. (2002)

Fourrié and Co-authors examined the preconditions of L1 with aid of TOVS-derived temperatures in the lower stratosphere (TLS). TOV is an abbrevation for TIROS (Television Infra-Red Observing Satellite) Operational Vertical Sounder measuring TLS. Strong warming in the lower stratosphere indicates a tropopause fold (with isentropic descending air masses).



adapted from Fourrié et al. (2002), Fig. 6

Fig. 31: TOVS-derived temperatures for the lower stratosphere, valid for 26.12.1999, 18 UTC, adapted from Fourrié et al. (2002), fig. 6 f), the position of the three cyclones is denoted with L1, L2 and L3.

Figure 31 shows with each cyclone patches of warming TLS. In the case of L3, the warming is most pronounced. The soundings support the theory that L2 was favoured by a discrete tropopause fold.

3.11 Leutbecher et al. (2002)

Different surface analyses with respect to L1 are provided by Leutbecher et al. (2002) in figure 7 of their paper. The control analysis of ECMWF (48h-forecast) as well as the random distribution scheme (RDS), especially in 7 i), k) partially show a closed low over the Celtic Sea on 26.12.1999, 12 UTC.

3.12 Hello and Arbogast (2004)

The study of Hello and Arbogast (2004) proposes two different methods to correct the inital conditions applied to the storm 'Martin'. However, it is quite interesting to look at the figures 2 b) and 3 a) (figure 32,33 in the present work) to locate the exact position of L2.

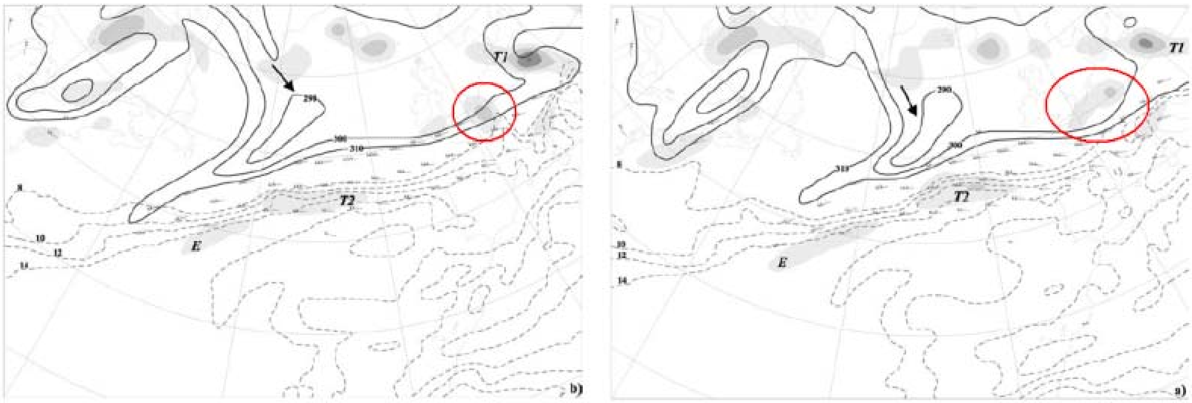


fig 2 b) fig 3 a) adapted from Hello and Arbogast (2004)

Fig. 32,33: 26.12.1999, 18 UTC (left) and 27.12.1999, 00 UTC (right); 850 hPa vorticity (grey shades), every 0,5 x 10^{-4} 1/s, wet-bulb temperaturebetween 8°C and 14°C, every 2K in 850 hPa (dashed), wind field in Knotes by 100 Knotes at 1,5 PVU, potential temperature at 1,5 PVU from 290 K to 310 K (solid lines), adapted from Hello and Arbogast (2004), red circles indicate the area of interest (L2).

There is a distinct vorticity maximum passing Germany with T1 (L1) and a weaker vorticity maximum with T2 (L3). Between L1 and L3 there is a more pronounced vorticity maximum pertaining to L2 which is situated in the left exit region now.

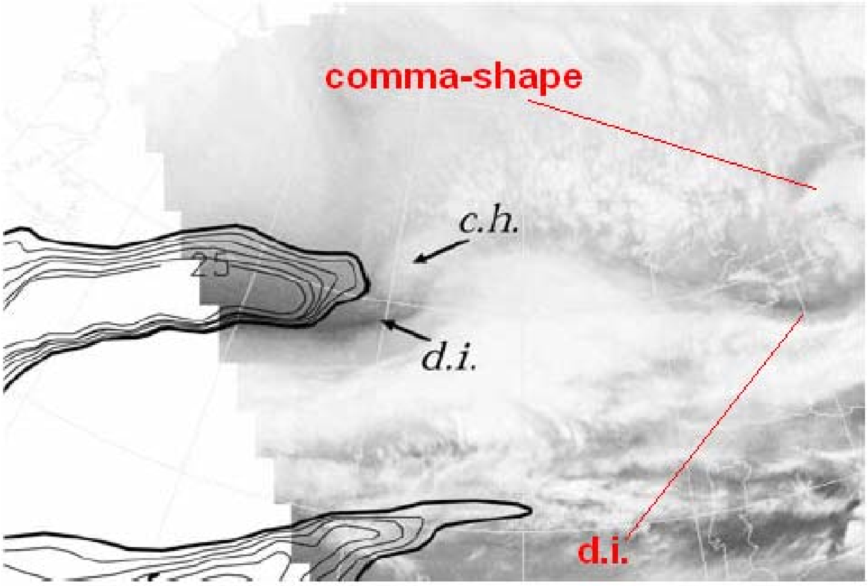
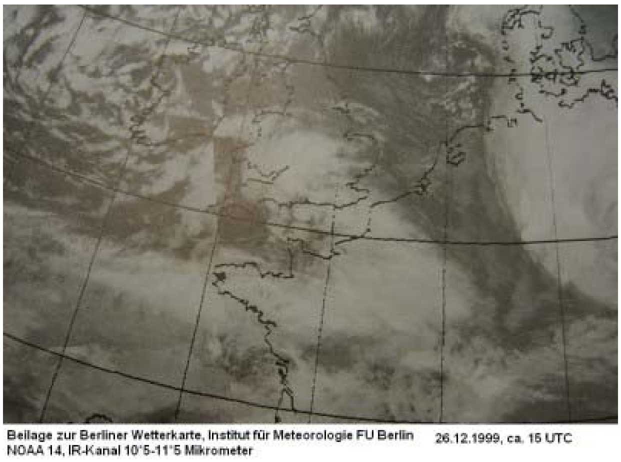


Fig. 34: Reference run basing upon the operational analysis of 26.12.1999, 12 UTC. Meteosat water vapor image and 12 h forecast of the synthetic brightness temperature (contur interval = 1K between 24 3K and 248 K), d.i. = dry intrusion, c.h. = cloud head valid for 27.12.1999, 00 UTC

Just look at the water vapor signatures of figure 34 where windstorm L3 already possesses a well-defined warm conveyor belt, a hook-shaped cloud head and a narrow tongue of dry air protuding between the cloud head and the cold front. A dry intrusion process also exists downstream east of the English Channel. The dry slot descends in the rear of the cold front of L2. A comma-shape cloud head wrappes around the center of L2.

3.13 Attachments of the 'Berliner Wetterkarte'

Recently, I found the following IR satellite images (attachments of the 'Berliner Wetterkarte') in the archive of Institute for Meteorology and Geophysics Innsbruck



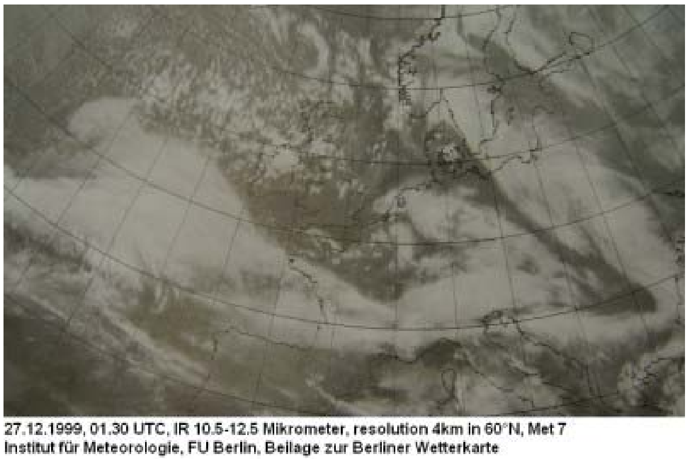


Fig. 35,36: Legend see below the images.

Figure 35 on the left side shows the already fully developed windstorm L2 in the entrance region of the English Channel. The coiled-up cloud head is convectively-riddled, with rather violent convective cloudiness close to the center of L2. The deep moist convection is likely caused by the overrunning dry slot. Archive soundings from Ready NOAA (NCEP archive data) indicate at least equilibrium levels of about 500 hPa. A few hours later in figure 36, L2 is decaying with an ill-structured cloud vortex over Northern-Central Germany. The convective elements upstream are less distinctive than before due to the approaching wave cyclone L3 whose warm air advection stabilizes the atmosphere layers. It is the speed of approaching L3, its horizontal extent and its vertical influence (stability, strength and location of the jetstream) which reduces the possibility of L2 to develop into another violent windstorm.

Comparing figure 26 with figure 36 there is an obvious similarity between L1 and L2 concentrating on the alpine region: both storms show a compact and deep cloud shield south of the low's center which already developed in the early stage of the cyclogenesis. It is likely due to the warm conveyor belt which was possiblystrengthened in the passage of the alpine region by orographic lift.

3.14 Preliminary conclusions

The figures 20-35 all show a wave cyclone developing alongside a strong baroclinic zone with superimposed tropopause fold. As the tropopause fold descended, a low-level disturbance evolved. L2 showed a comma-shape occlusion front and a vortex structure during the decay process. Similar to L1, L2 was characterized by deep moist-convection in the vicinity of the low's center, however, a pronounced cold front did not form in the mature stage of L2, possibly due to the advanced occlusion process. According to the presented figures and satellite imagery, the term 'trough line' or just 'comma low' does not seem to be appropriate as a typical cold-air feature in absence of a frontal zone did not exist. The presence of a dry intrusion process and the phase shift of upper-level vorticity maximum and corresponding ascending vertical motion field also indicate a cyclogenesis of the type as it happened before with L1 and thereafter with L3.

4. Chronological evolution of windstorms in satellite imagery between 24.12. and 29.12.1999

The following description deals with the series of frames taken from the MeteoFrance Infra-red satellite imagery loop. The respective images illustrate the development of the parent cyclones 'Juergen' and 'Kurt' and the subsequent daughter cyclones L1, L2, L3, respectively.

4.1 Parent cyclones 'Juergen' and 'Kurt'

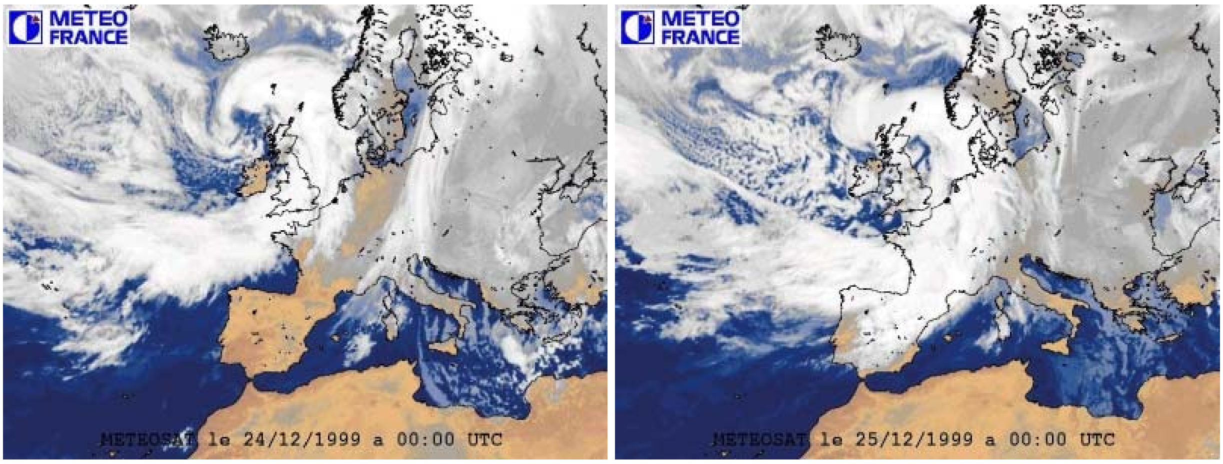
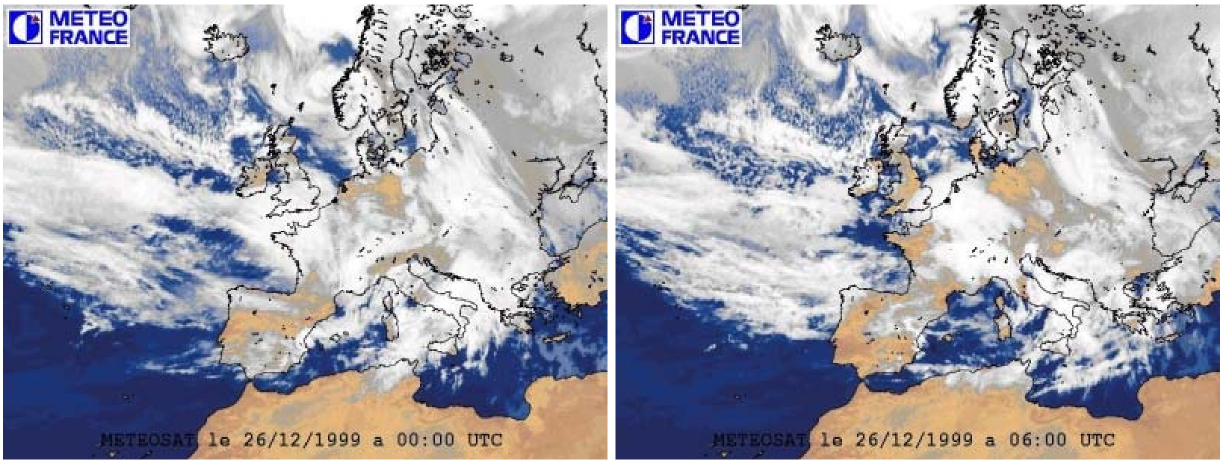


Fig.37,38: 24.12.1999 00 UTC and 25.12.1999 00 UTC

On 24. December, the intense low-pressure system 'Juergen' dominates Europe with an extensive frontal system and a well-defined warm conveyor belt. Quiet conditions prevail below a weak ridge and relative high geopotential heights between Spain, Germany and the Baltic Sea. The cold front of 'Juergen' exhibits a pronounced swelling west of the Biscaya: a secondary cyclogenesis takes place.

On 25. December, secondary low 'Kurt' developed to a deep low with hurricane-force winds and displaced 'Juergen'as steering low. The warm conveyor belt invariably persists with widespread upper-level and mid-level cloudiness. As already happened with 'Juergen', the cyclogenesis of its successor 'Kurt' is of the *warm conveyor belt (WCB) type*. On the cyclonic side of the jet - stretching from the Atlantic to the English Channel - deeply unstable polar air masses are advected southeastward. The vigorious contrast between the extremely tempered air masses (-15°C vs. -40°C in 500 hPa and +10°C vs. -7°C in 850 hPa) was significant for the generation of such a heavy upper-level flow. On the left side of the image, a deep cloud shield appears initally located below the jet axis. The sounding ascent of Camborne (England) 25.12. 18.00 UTC, shows maximum values of 315 km/h in 300 hPa (8770 m). Respectively, the forming wave rapidly moved eastward and the time frame for anticipating the impending windstorm was quite short.

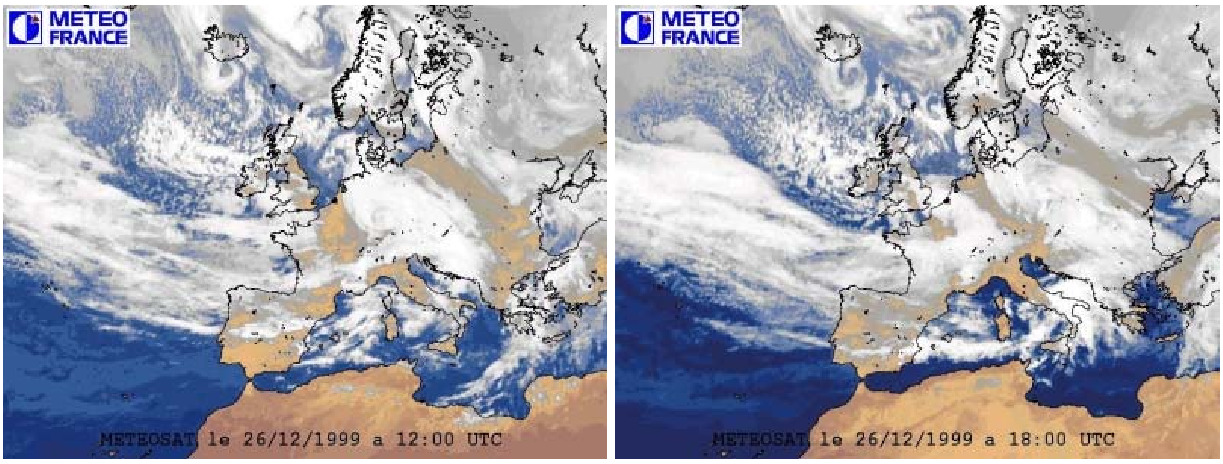
4.2 Daughter Cyclones L1 and L2



`Fig.39,40: 26.12.1999 00 UTC and 26.12.1999 06 UTC`

On 26.12. 00 UTC, the wavy cloudiness of L1 already reached the English Channel and falling pressure tendencies of 27,7 hPa in three hours at the French Coast (Caen) are observed (and subsequently, a rise of 29,0 hPa in the same time). We should concentrate on the upstream cloud field of L2 alongside the jet axis.

On 26.12. 06 UTC, the mature stage of L1 begins with the dry slot protuding between cloud head and WCB. Naturally, everyone stared on this extraordinarily violent cyclogenesis whereas the begin of L2 remained undetected. The jet streak reached 350 km/h during the 06 UTC ascent of Cambourne, that is, the secondary wave development L2 propogates faster than its precursor. In this stage, L2 consists of a ill-structured frontal wave and a better organized cloud head extending into the cold side of the jet stream. As the tops of the cloud head seem to be lower than of the frontal clouds, the initial phase of L2 resembles a *cold conveyor belt (CCB)* type cyclogenesis.



`Fig.41,42: 26.12.1999 12 UTC and 26.12.1999 18 UTC`

On 26.12. 12 UTC, L1 crosses Germany as a fully developed windstorm. In contrast to former windstorms, L1 possesses a deep cloud field even in the interior where the dry intrusion usually evaporates the upper- and mid-level clouds. The discrepancy probably arises due to the strong release of latent heat in the deepening stage of L1. Meanwhile, L2 enters England and the English Channel with a longitudinally-aligned wave front linked to the cloud head over the Celtic Sea. Another low cloud field follows southwest of Ireland pertaining to a secondary maximum of relative vorticity (see figure 4 upstream of the trough axis).

On 26.12. 18 UTC, the originally pronounced cloud structure of L1 clearly decays. L2 moves farther inland, with falling pressure tendencies in my hometown, and has developed a comma-like frontal cloud band. It is impossible for me to derivate the type of L2 in this stage of cyclogenesis: The former cloud head did *not* have lower cloud tops than the other parts of the frontal system which might indicate a WCB type. However, the cloud head was initially located on the cold side of the jet stream with lower cloud tops than the (assumed) baroclinic leaf which is typical for the CCB type. From a current point of view, that question has to remain without answer. L3 is much easier to determine because the cloud head appears as a considerably lower cloud shield than the adjacent baroclinic leaf: a textbook-like CCB type.

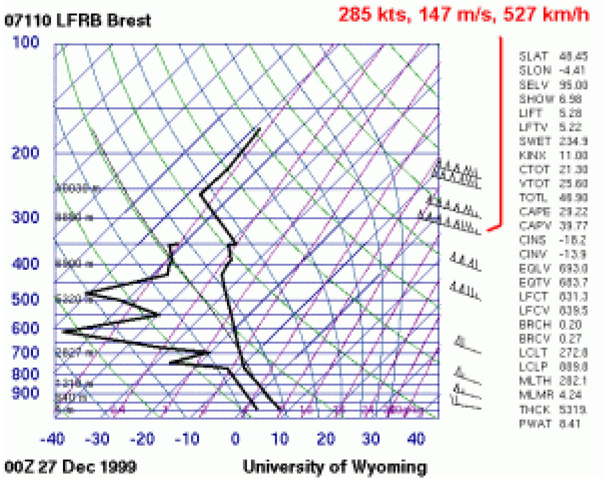


Fig. 43: Sounding ascent Brest, 27.12.1999, 00 UTC

At midnight of 27.12.1999, the sounding of Brest measured incredible 285 Knotes (527 km/h) in 300 hPa (8800 m). Due to the drifting characteristics of the sounding balloon, the location of the highest wind value should have been well downstream close to the circulation of L2.

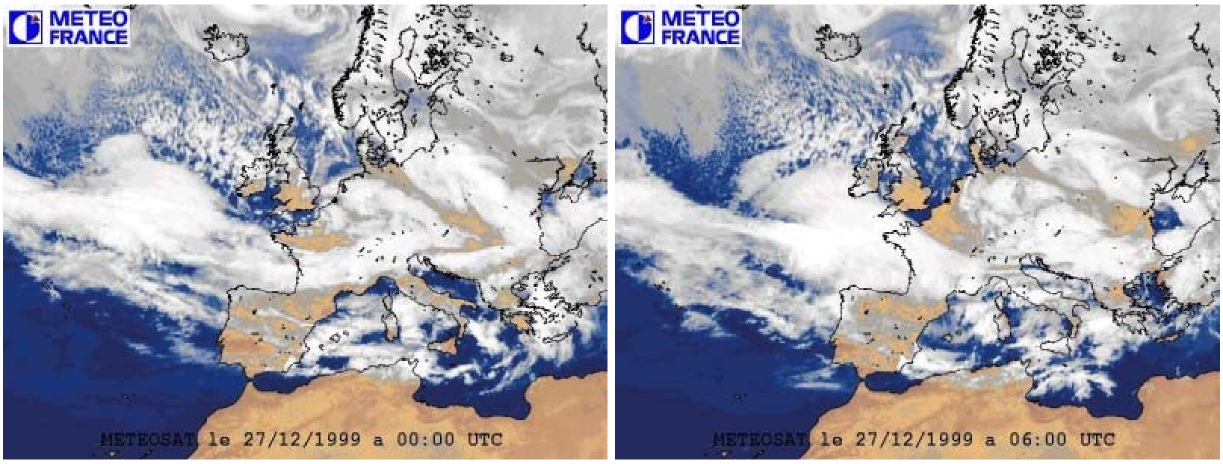


Fig.44,45: 27.12.1999 00 UTC and 27.12.1999 06 UTC

On 27.12. 00 UTC, L2 passes Germany with severe wind gusts. The unfavourable conditions within the jet stream lead to rapid decay of L2. The remnants of L1 are still visible east of L2 stretching from the western Baltic Sea to the Black Sea. L3 becomes larger as the cold conveyor belt pulls the cloud head backward.

On 27.12. 06 UTC, the leftovers of L3 are completely unstructured although a closed surface circulation has been present until that date. The upper-level flow ultimately reaches extreme velocities, with 150 Knotes (277 km/h) in 300 hPa. Respectively, L3 races to France, and a dry slot develops simultaneously being visible as a rather narrow nearly cloud-free stripe north of the longitudinally-aligned cold front. As L3 is sticked to the main trough axis which developed a larger amplitude than the shortwave troughs before, L3 slows down and the violent winds of L3 only hit France with hurricane force. Given a weaker amplitude of the trough a faster running cyclone could have been generated, with larger (wind) influence on Central Europe. In this case, the southward pushing upper-level cold pool meanders the jet stream resulting in a loss of velocity and potential for another fast running cyclone.

4.3 Daughter Cyclones L3 and L3-B

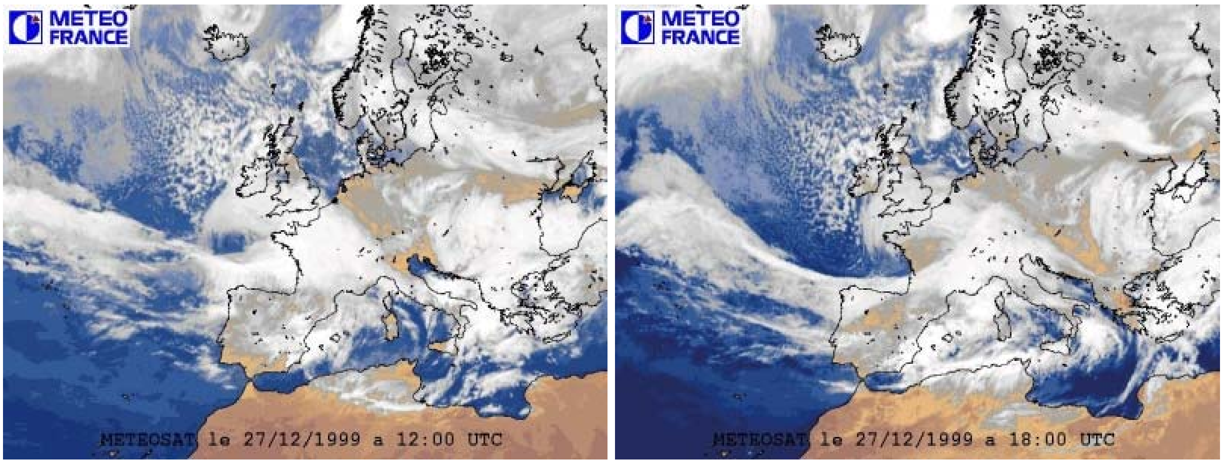


Fig.46,47: 27.12.1999 12 UTC and 27.12.1999 18 UTC

On 27.12. 12 UTC, the dry slot of L3 became more distinctive and a back-bent occlusion formed.

On 27.12. 18 UTC, a synop at the western coast of France observed falling pressure tendencies of 26, 3 hPa/ 3 hours while the center of L3 come onshore. The changing direction of the frontal zone is clearly seen in the meandering cirrus bands stretching from the Azores across Southern Spain to the south of Sicil. Respectively, L3 moves more eastward and does not affect Central Europe with such strong winds as its precursor. The back-bent occlusion wrappes around the low's center. Upper-level cold air protudes wedge-shaped with deep moist convection south of Ireland supporting the amplifying trough.

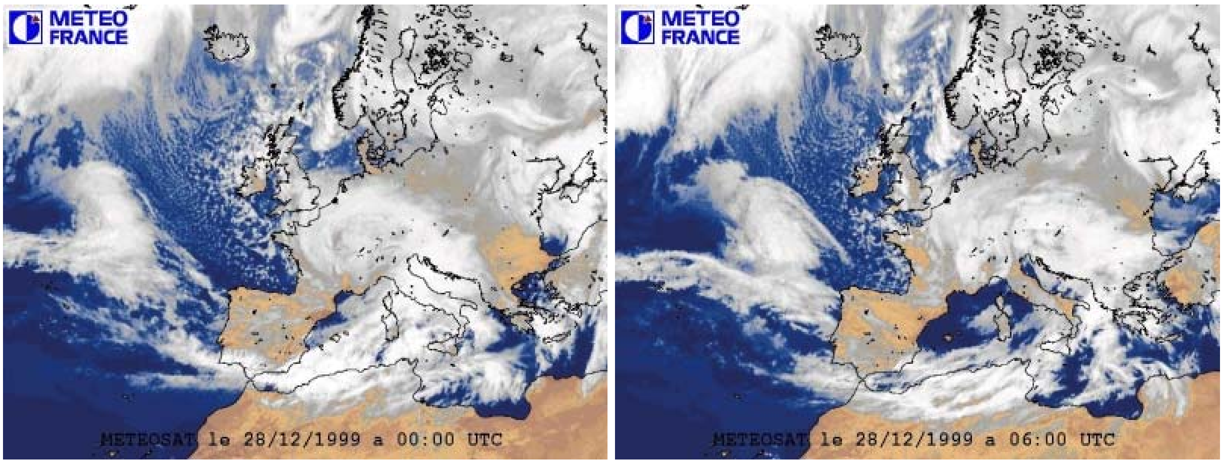


Fig.48,49: 28.12.1999 00 UTC and 28.12.1999 06 UTC

The next few images will reveal that the term 'Martin' did not describe sufficiently the low development as a secondary cyclogenesis - in the shape of a semi-dynamic lee cyclogenesis - replaced 'Martin' then. That secondary low will be denoted as 'L3-B'.

On 28.12. 00 UTC, windstorm L3 culminates over France with a completely wrapped-around occlusion front. L3 looks like windstorm 'Klaus' in this stage. The cold front of L3 went to the Northern Mediterranean while the WCB continues downstream of the Strait of Gibraltar over the Tyrrhenian Sea to the Adriatic Sea and the Balkans. The triple point lay in the vicinity of Vienna where heavy snowfall has been reported. Strong falling pressure in the Gulf of Genua indicates the aforementioned secondary cyclogenesis.

On 28.12. 06 UTC, L3 decayed mostly and the lowest pressure according to the synop observations is situated between Friuli and Istria. Remarkable pressure tendencies occurred with the lee cyclogenesis as the pressure falls with 19 hPa in 18 hours, fulfilling the definition of a rapid (lee) cyclogenesis. The lowest pressure of L3-B was 976,3 hPa at 09 UTC at

Udine. However, the IR satellite images do not suffice to detect a secondary low because an aesthetic vortex is not visible.

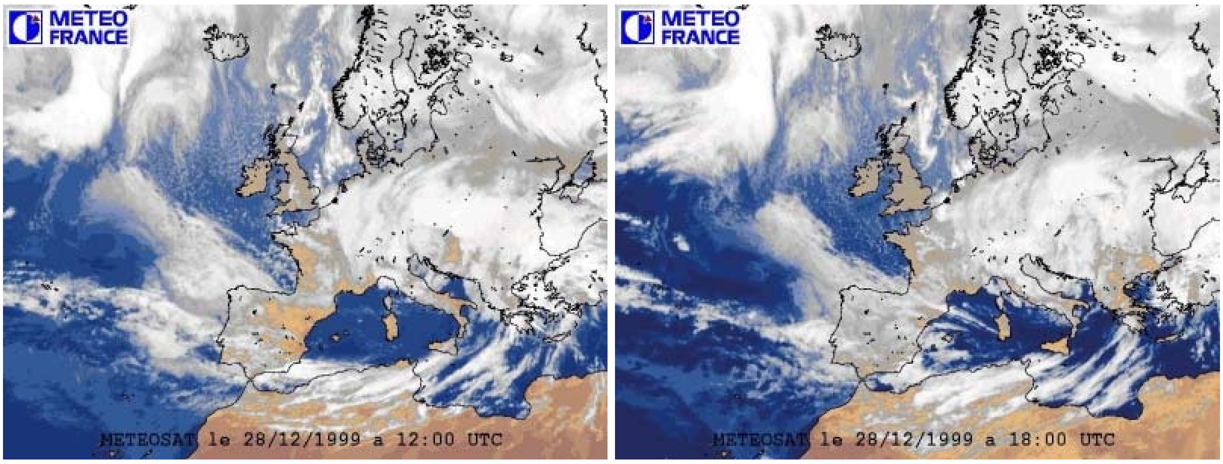


Fig.50,51: 28.12.1999 12 UTC and 28.12.1999 18 UTC

On 28.12. 12 UTC, L3 solely exists as ill-structured cloud field which is however responsible for the continuation of snowfall with northerly winds in Southern Germany and farther eastward. L3-B is located north of the Dinaric Alps. Strong southerly winds produce clearing skies downstream of the Dinaric Alps.

On 28.12. 18 UTC, L3-B gradually fills up, but still causes widespread solid precipitation in Central and Eastern Europe.

5. Special characteristics of L1 and L3

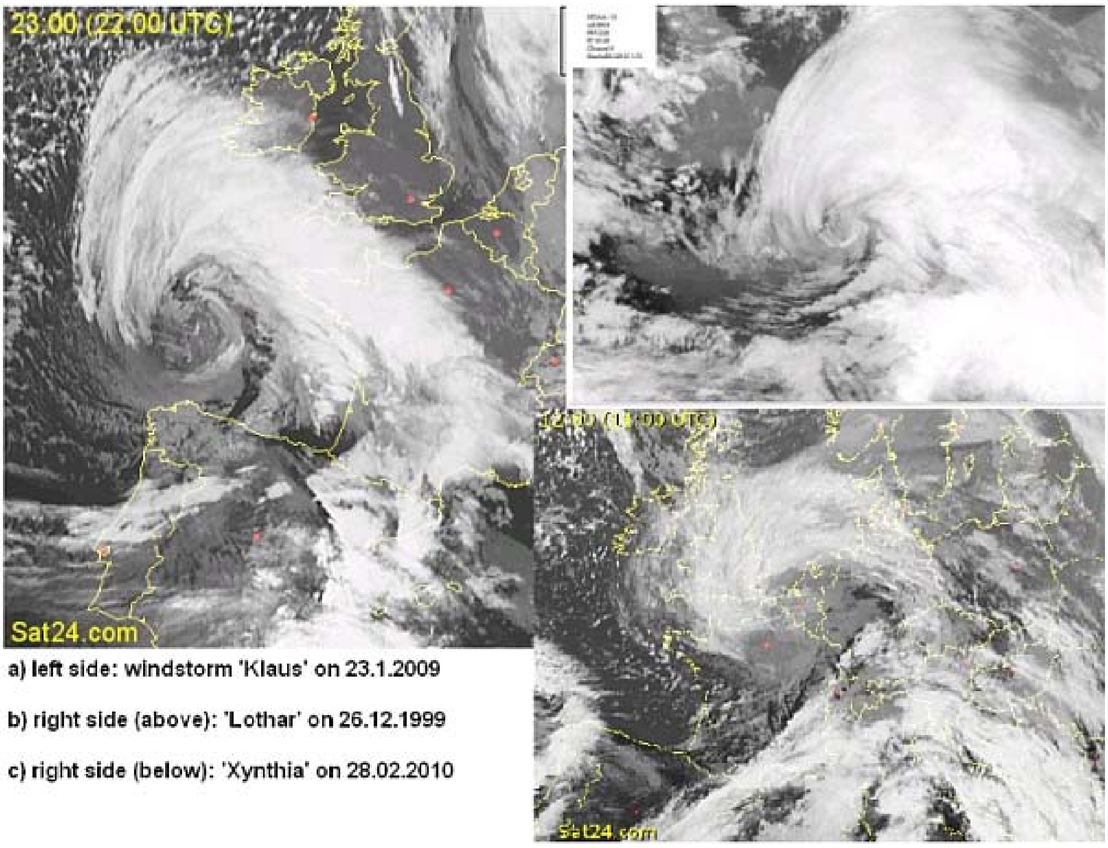


Fig.52: Comparison of L1 with windstorm 'Klaus' (2009) and 'Xynthia' (2010), IR-satellite image from Sat24 and NOAA

The comparison of recent windstorms like 'Klaus'[6] and 'Xynthia' ,which affected Western Europe with maximum wind gusts in the order of L1, suggests that different types of cyclogenesis occurred. While L1 developed as a classic rapid cylogenesis in the framework of the Norwegian model (NM), developed in the early 1920s by **Bjerknes and Solberg (1922)**, 'Klaus' and 'Xynthia' evolved as Shapiro-Keyser (SK) cyclones (**Shapiro and Keyser 1990**). The greatest difference between both cyclone models is the lack of a distinct occlusion process with SK cyclones and - in both presented cases - a weakly active cold front whereas L1 formed a small-scale, but intense cold front.

Both 'Klaus' and 'Xynthia' were accompanied by a sting jet (see e.g., **Browning 2004**, **Browning and Field 2004**, or **Baker 2008**) that developed at the tip of the back-bent occlusion and warm front, respectively. The presence of a sting jet is indicated by the evaporating cloud head of both cyclones which has been overrunned by a wedge-shaped dry slot. Vigorous wind gusts have been observed in the range of the significant lower cloud tops with strong evaporative cooling. In the case of L1, the lowering of the cloud tops was much weaker and most intense wind gusts were associated with the passage of the cold front, but extremely severe wind gusts have been also reported ahead of the cold front due to the intense isallobaric changes. In retrospect, the passage of windstorm 'Kyrill' on 18.1.2007[7] and windstorm 'Emma' on 01.03.2008[8] exhibited more similarities to 'Lothar', regarding the intensity of their cold fronts, despite the fact that the spatial scale of 'Kyrill' and 'Emma' (both NM) was rather in the order of 'Klaus' and 'Xynthia'.

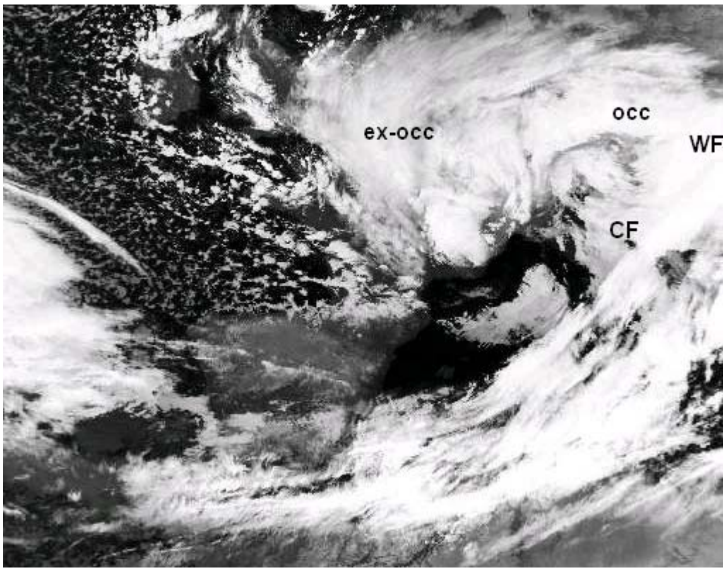


Fig.53: L3 and L3-B on 28.12.1999, 04.14 UTC, IR satellite image NOAA, Channel 4

In the stage of figure 53, L3-B already replaced L3. The new low pressure center lies east of the Apennin, with a new back-bent occlusion front and eastward moving triple point. The remnants of L3 cover most parts of Central Europe.

A closer look at the metamorphosis stage of L3 into L3-B is possible with the surface analysis maps:

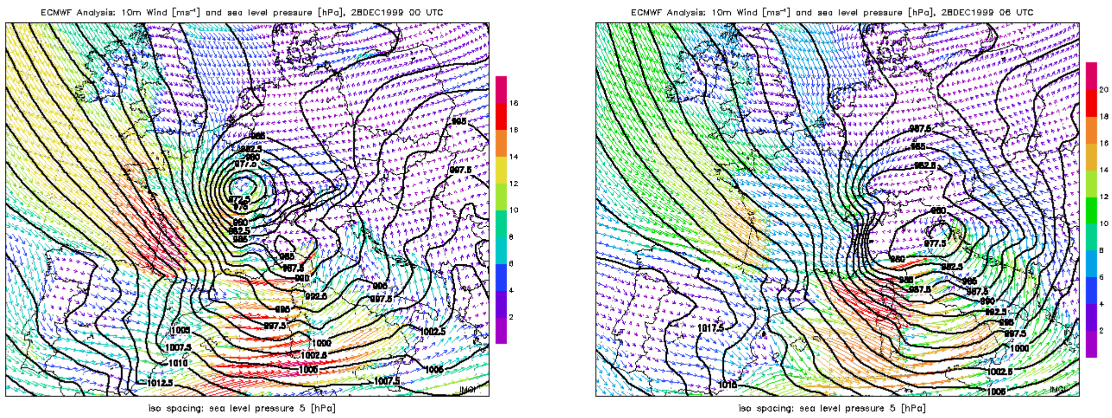


Fig.54,55: 28.12.1999 00 UTC and 06 UTC, surface pressure [hPa] in 2,5 hPa isolines and 10 m average winds [m/s]

During midnight, L3 moved to Eastern France, with the strongest wind field southwest of the low's center. Due to the simultaneously occurring lee cyclogenesis with minus 10 hPa in 6 hours, the pressure gradient across the alpine main crest is not as strong as with L1 where the strongest wind gusts in Switzerland partially were observed with south foehn winds ahead of the cold front [9]. The unusual path of L1 bouncing against the Western Alps leads to a rather seldom metamorphosis of a deep low - mainly on account of these three reasons:

- strong northwesterly flow across the western alps favours the development of a lee cyclogenesis
- southward propagation of the upper-level flow with corresponding vorticity maximums support a secondary cyclogenesis under dynamic aspects.
- pre-existing air mass differences south of the Alps create a baroclinic zone and ongoing cyclogenesis

Another six hours, the changing of the guard (of the Alps) is perfect: the original low pressure center northwest of the Alps filled up from 972,5 hPa to 982,5 hPa while L3-B deepened from 985 hPa to 977,5 hPa. To my knowledge, such a wind field has not been analyzed in the last twenty years, with a weakening cyclonic pressure field north of the alps, and a strenghtening cyclonic pressure field south of the Alps. Situations with such a low pressure in this region may occur ahead of upper-level troughs protuding in the western Mediterranean, but as a successor of a severe windstorm - that's the *real* striking point within the scope of windstorm 'Martin'.

6. Summary and Discussion

The present study revealed that a secondary fastrunner between 'Lothar' and 'Martin' crossed Western and Central Europe between the late afternoon of 26.12.1999 and early forenoon of 27.12.1999. The synop observations documented the existence of a closed circulation with 'Lothar Successor' between 26.12.1999, 21 UTC and 27.12.1999, 06 UTC. As underlined by ecwmf model archiv data and numberous figures of other studies, the storm formed in the left exit region of a violent jet stream below a well-developed tropopause fold. Due to the presence of a strong baroclinic zone, it belongs to a classic cyclogenesis of the mid-latitudes (according to the Norwegian model). Therefore, the term 'trough line' appears misleading in the stage of a closed circulation and fully-developed frontal system.

'Lothar Successor' reached only a pressure minimum of 983,1 hPa which is well below that of 'Lothar' (960 hPa). However, in a bounded path from Eastern France over southwesterly Germany, the storm brought severe wind gusts in the order of 90 km/h - and likely more in my hometown considering the damage. The reason for the lack of a vigorous deepening of 'Lothar Successor' can be found in the upper-level flow. While the storm moved eastward, the jet stream splitted in two branches leading also to a separation of the vorticity maxima. The storm then was situated in the rear flank of the weaker primary vorticity maximum where differential anticyclonic vorticity advection is present. Furthermore, the time frame for a rapid cyclogenesis was quite short because of the strong upper-level flow (in exceed of 300 km/h, later in exceed of 500 km/h!) and the approaching third windstorm 'Martin' whose warm air advection weakened the downstream shortwave trough.

The case study emphasized also the complex nature of windstorm 'Martin' which underwent a clear metamorphosis bouncing against the western alpine region. The primary surface low vanished north of the Alps while a secondary surface low formed south of the Alps as a result of lee cylogenesis, propagation of the jet stream and corresponding vorticity maximum with a low-level baroclinic zone. That secondary low is remarkable concerning the rapid pressure fall (- 10 hPa in 18 hours) in the sort of a lee cyclogenesis. 'Martin 2' was responsible for strong snow fall in Austria and the northern Balkans.

Finally, a remark was made regarding the cyclone typ of 'Lothar' in comparison with former windstorms, namely 'Klaus' and 'Xynthia' representing 'Shapiro-Keyer'cyclones, and 'Kyrill' and 'Emma' representing the 'Norwegian model'. The placement of 'Lothar' in the left exit region and the development of a pronounced cold front bringing the most intense wind gusts hint at the Norwegian model.

In general, all three windstorms developed in a strongly sheared environment with extreme upper-level winds and propagated rapidly eastward. 'Lothar' and 'Lothar Successor' were linked to small-scale shortwave troughs while 'Martin' pertained to the larger-scale main trough. During the metamorphosis stage of 'Martin' into 'Martin 2', the storm slowed down as the trough became more amplified.

The point to which type of conveyor belt the windstorms belonged cannot be entirely clarified. The outside appearance of 'Martin' suggested that a cold conveyor belt dominated. 'Lothar' resembles more a warm conveyor belt with deep cloudiness from the occlusion front to the warm front and 'Lothar Successor' should be attributed to the cold conveyor belt as the occlusion band and its vicinity, respectively, consisted of convective cloudiness. However, in the case of

'Lothar' and 'Lothar Successor' a clear distinction between warm and cold conveyor belt type does not seem to be easy with the used satellite imagery.

It would be of further interest to perform numeric simulations regarding 'Lothar Successor' in a 3-dim IPV perspective by focusing on the reasons for which the storm did not develop to another devastating windstorm. Moreover, it could be stated to what extent the environment of the adjacent windstorms affected the development and decay of 'Lothar Successor', for example, whether the release of latent heat with 'Lothar' left the atmosphere too stable, or in what way the bulge of the downstream shortwave ridge of 'Martin' favoured the splitting jet stream.

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Please note: I worked on this study in my spare time as the topic of my diploma thesis goes in another direction (anomalous valley winds in mountainous terrain). The review of this case pursued me since the event happened - it has been a kind of a 'life-task' for me which is now finished apart from (I hope so...) minor corrections. Due to the lack of further time I cannot convert this study in AMS style, but I hope some interested readers will find some new findings and possible ideas for further studies in the framework of the Christmas storms in December 1999.

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Appendix

A Footnotes related to websites

-- 1: Lothar 26.12.99: Nowcasting mit Satellitenbildern

-- 2: STORM CATASTROPHE 25 - 28 DECEMBER 1999 - LOTHAR AND LOTHAR SUCCESSOR by ZAMG

-- 3: Bulletins Climatiques Quotidiens France

-- 4: Klimastatusbericht DWD 1999 (PDF, 136 pg.)

-- 5: Stuermische Zeiten. Weihnachtsorkan loest Streit um Rolle des DWD aus

-- 6: Windstorm 'Klaus' on 23/24.01.2008 - a synoptic review, by Felix Welzenbach (2009) - in german

-- 7: Windstorm 'Kyrill' on 18.1.2007 - synoptics of a destructive low-pressure system, by Felix Welzenbach (2007)

-- 8: Windstorm "Emma" and secondary low "Fee" on 01./02.03.2008, by Felix Welzenbach (2008) - in german

-- 9: Report about windstorm 'Lothar' from MeteoSchweiz

B Source of figures

-- **Fig. 1-19,54,55:** ECMWF model analyses - available for scientific purposes - with friendly permission of Georg Mayr, Institute for Meteorology and Geophysics, Innsbruck

-- **Fig. 18,20,35,36:** Berliner Wetterkarte

-- **Fig.21:** Wetter3- surface chart archive DWD

-- **Fig.22:** see footnote [1]

-- **Fig.23-25:** Wetterzentrale - NCEP Reanalysis

-- **Fig.26,27,53:** Satellite imagery from NOAA (Channel 4), Copyright NERC, Satellite Receiving Station, Dundee - free registration necessary

-- **Fig. 28:** Winter Storm 'Lothar' over Europe as seen in Meteosat Images

-- **Fig. 29:** Wernli et al. (2002)

-- **Fig. 30:** Descamps et al. (2007)

-- **Fig. 31:** Fourrié et al. (2002)

-- **Fig. 32-34:** Hello and Arbogast (2004)

-- **Fig. 37-42, 44-51:** Le point sur les deux ouragans qui ont traversé la France du 26 au 28 décembre 1999

-- **Fig. 43:** Wyoming Soundings

-- **Fig. 52:** Sat24 and Dundee