The synoptic setting of thunderstorms in Western Europe

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Thunderstorm frequency

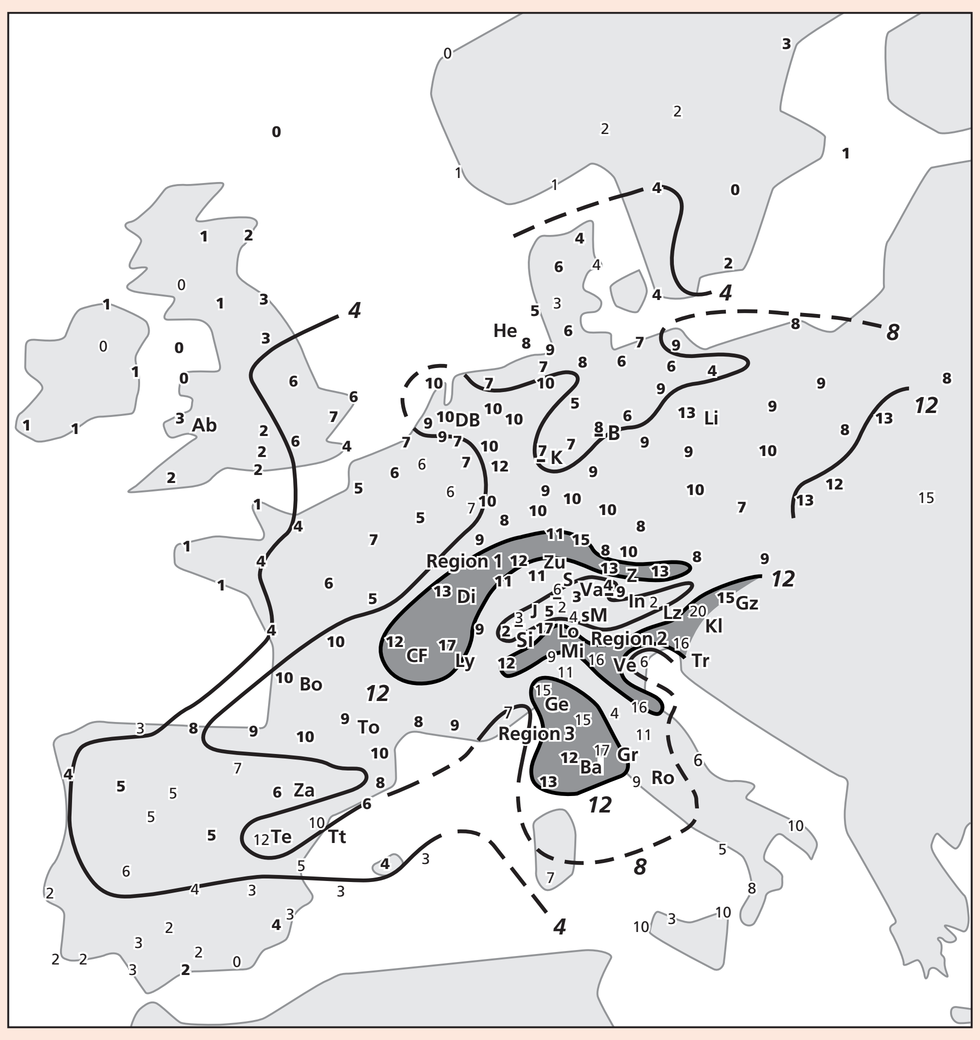

Figure 1. Thunderstorm frequency at more than 200 synoptic weather stations in western Europe for the period April to October of the years 1996-1999 (00, 06, 12, and 18 UTC). The thunderstorm frequency is defined as the total number of thunderstorm reports divided by the total number of weather- reports in promille. A weather-report is counted as a thunderstorm report if thunder is heard and/or lightning is observed with precipitation one hour before, or at, observation time. The frequency is printed in bold if the dataset at the particular station contains more than 3000 observations (at least 88 % of the maximum amount possible), whereas it is printed in plain text if it is based on a series containing between 2000 and 3000 observations. ***Three preferred regions for severe thunderstorms are identified. The location of these regions is strongly related to the orography (regions 1 & 2) and to high sea surface temperatures in the autumn(region 3).***

The names of several stations are indicated in the map with the following two-letter abreviations. Ab: Aberporth; Ba: Bastia; Bo: Bordeaux; CF: Clermand Ferrand; DB: De Bilt; Di: Dijon; Ge: Genua; Gr: Grosseto; Gz: Graz; He: Helgoland; In: Innsbruck; Kl: Klagenfurt; Li: Lindenberg; Lo: Locarno; Ly: Lyon; Lz: Lienz; Mi: Milan; Ro: Rome; Si: Sion; sM: St Moritz; Su: Sundsvall; Te: Teruel; To: Toulouse; Tr: Trieste; Tt: Tortosa; Ve: Verona; Za: Zaragoza; Zu:Zurich. Mountain top stations are indicated by one capital letter, i.e. B: Brocken (1142 m); J: Jungfraujoch (3580 m); K: Kahler Asten (834 m); S: Saentis (2490 m) and Z: Zugspitze (2962 m).

An example

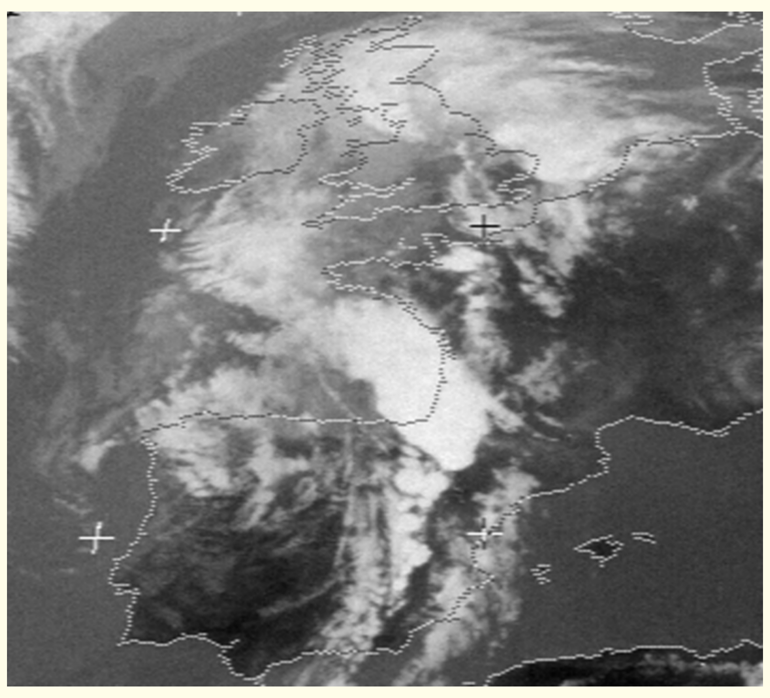

Figure 2: Meteosat image (infrared) corresponding to Auygust, 8, 1992, 1530 UTC. ***Many severe thunderstorms arise over the Northern Iberia or South-western France in a south-westerly flow.***

Confluence line

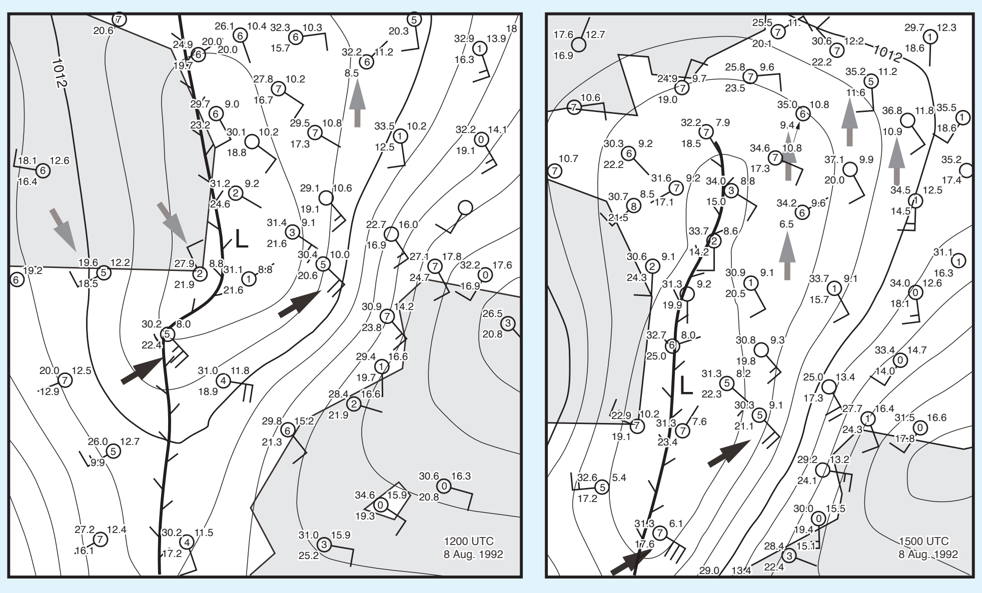

Figure 3. Surface weather maps corresponding to 1200 (left) and 1500 UTC (right), August 8 1992. The position of a surface station is indicated by a circle. The number inside the circle indicates the cloudiness (in octas). Also indicated are the temperature (¡C) (upper left), the dew point (¡C) (lower left) and the pressure (hPa-1000) (upper right). The hooked thick solid line indicates the position of the confluence line. The upward pointing gray arrows highlight the relatively low dewpoints in the north eastern quarter of the thundery low (marked by the letter L). The slanting upward pointing black arrows highlight high wind speeds. The slanting downward pointing gray arrows highlight the cool humid air flowing towards the east along the steep north coast of Iberia and the hot, very humid air over south western France. Sea level isobars are drawn every 1 hPa. ***The confluence line is embedded in the thundery low*** *(figure 4).*

Moisture flux convergence

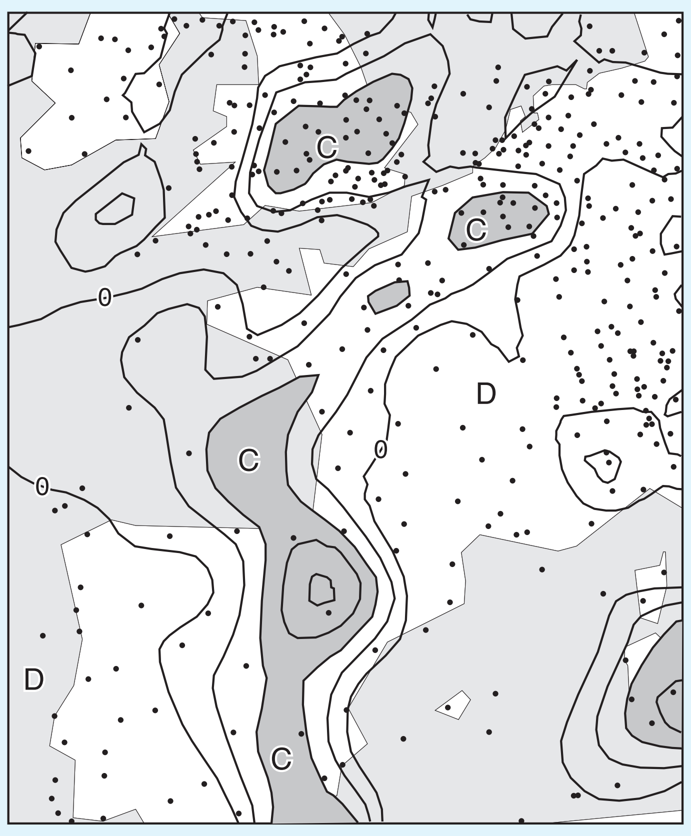

Figure 4. Horizontal moisture flux divergence near the earth s surface before the formation of the squall lines on 8 August 1992 between 0900 and 1200 UTC. Only negative values are contoured. The zero contour is also drawn. The contour interval is 10^{-7} kg $m^{-3}s^{-1}$. Regions where the mean moisture flux convergence is greater than $2x10^{-7}$ kg $m^{-3}s^{-1}$ are shaded. The letters C and D denote moisture flux convergence and moisture flux divergence, respectively. The black dots indicate the locations of the measuring stations on which the analysis is based. ***Enhanced moisture flux convergence is observed over North-eastern Iberia, exactly where the storm forms*** *(figure 2).*

Large-scale flow: deep trough over the eastern Atlantic

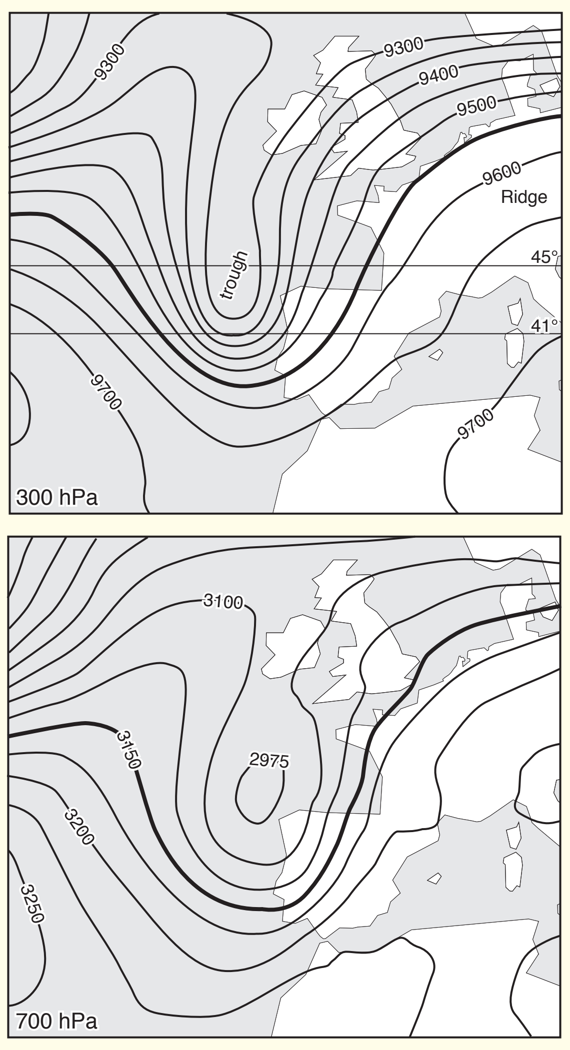

Figure 5. Analysis of the 300 hPa height and the 700 hPa height for August 8 1992, 00 UTC. The 41¡ and 45¡ latitude circles are shown for reference in Figures 6 and 8.

Jets and fronts

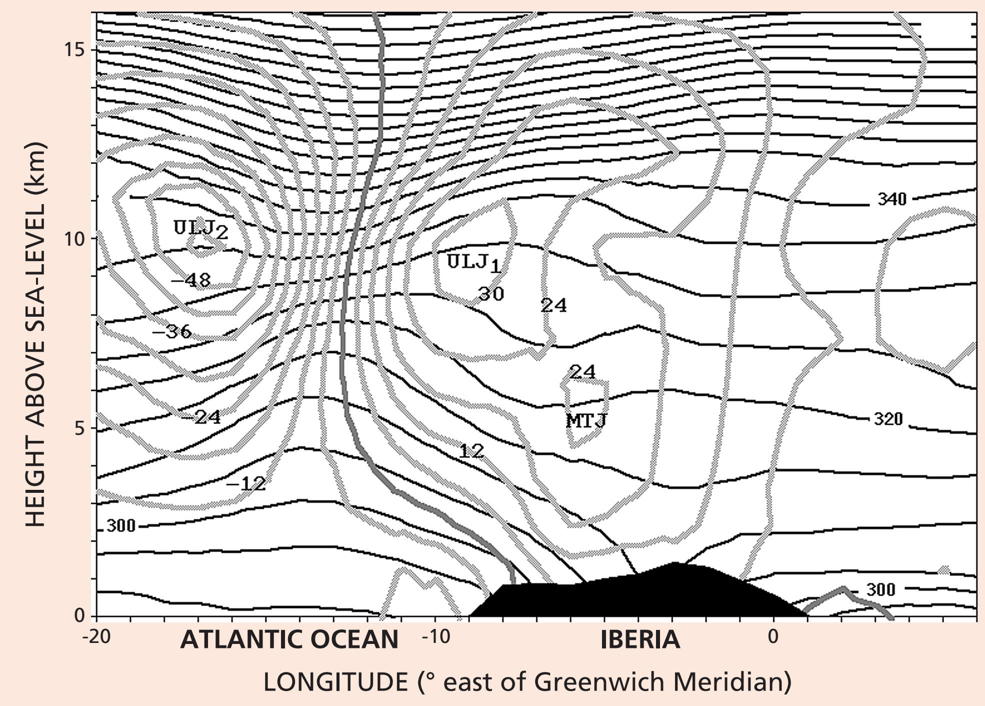

Figure 6. The potential temperature and the meridional component of the wind velocity as a function of height and longitude for the latitude 41¡N, on August 8, 1992, 0000 UTC, according to the ECMWF analysis. Black lines are isentropes drawn every 5 K. Gray lines are isotachs of the meridional wind (v) drawn every 6 m s^{-1}. The orography of Iberia, smoothed as in the ECMWF analysis/model, is also shown. ***The jets labeled ULJ1 and ULJ2 are related to the upper level trough. The jet (streak) labeled MTJ is related to an intense low level front over Iberia, which forms due to confluence of hot air originally located over the Iberian plateau and cool air approaching from the Atlantic Ocean.***

Jet streak

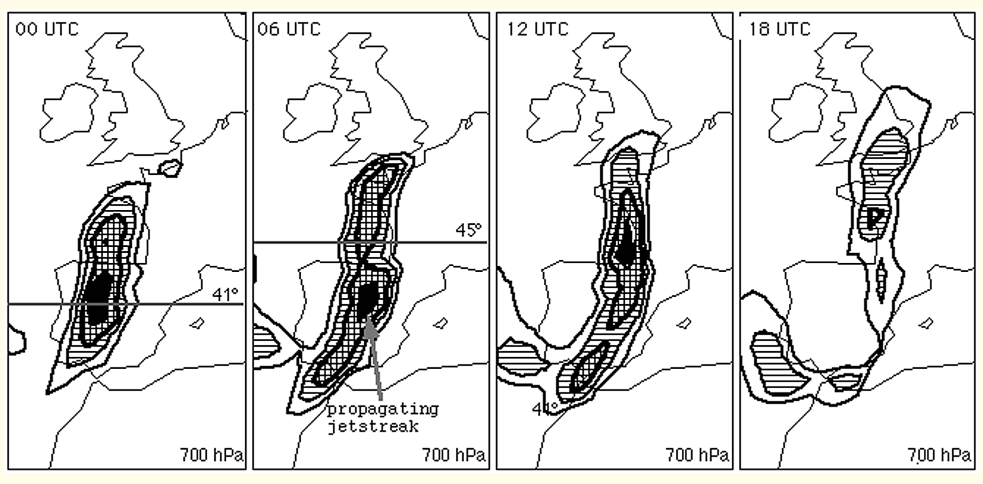

Figure 7. Analysis of the absolute windspeed at 700 hPa on 8 August 1992, 0000, 0600, 1200, and 1800 UTC. Isotachs are drawn every 2.5 m/s, starting at 15 m/s. Areas where the windspeed is greater than 22.5 m/s are shaded in black. ***The jetstreak forms over Iberia and propagates towards the north.***

Cross-frontal circulation

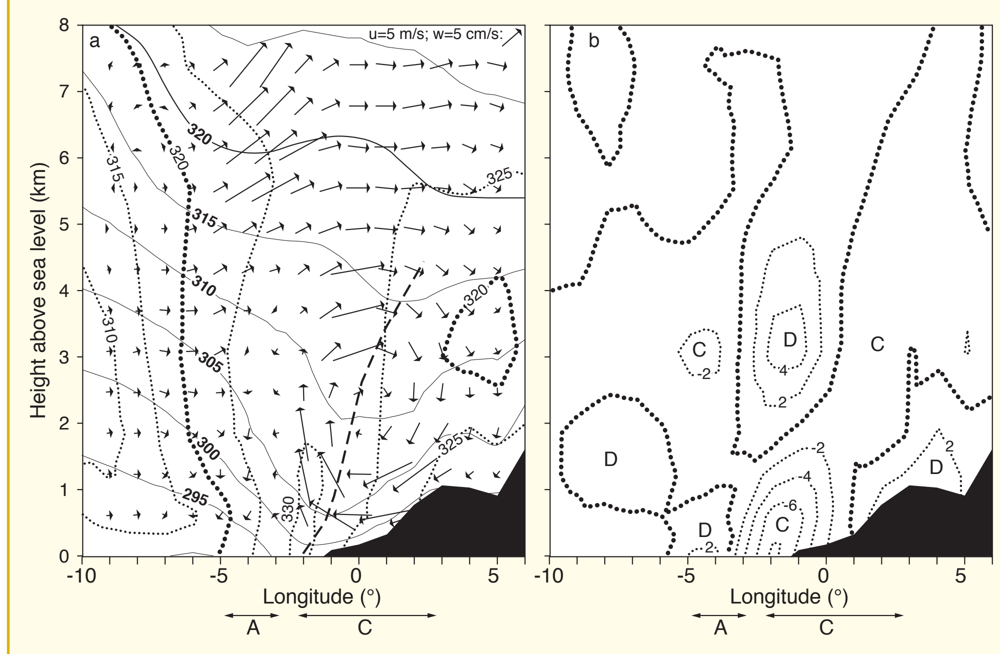

Figure 8: Vertical section 45¡N (latitude) corresponding to August 8, 1992, 0600 UTC. The orography of France, smoothed as in the ECMWF-model, is also shown. Left panel (a): potential temperature (thin solid lines, labeled in K), equivalent potential temperature (dotted lines, labeled in K) and the component of the wind vector in the plane of the cross section. The dashed line indicates the position of the axis of the warm plume of air from Iberia. The letters A and C below the horizontal axis indicate the position and extent of the anticyclonic cross-frontal circulation and the cyclonic cross-frontal circulation, respectively. Right panel (b): horizontal divergence (dotted lines, labeled in units of 10^{-5} s^{-1}). The letter C indicates convergence (negative values); the letter D indicates divergence (positive values). ***The confluence line at the earth s surface (figure 3) is the footprint of the cross-frontal circulation.***

Tilted front

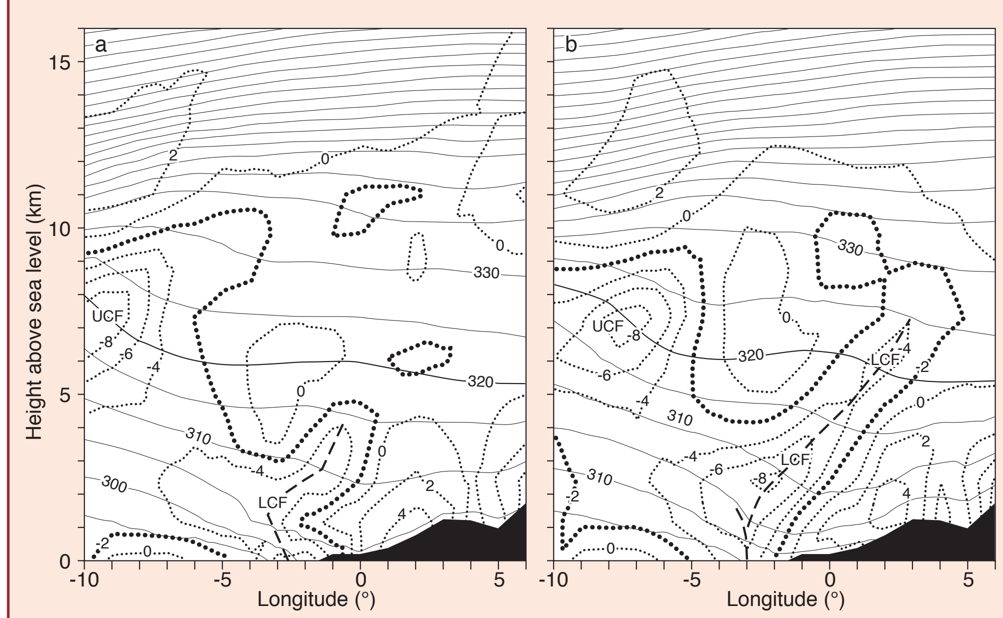

Figure 9: Vertical section of the slope of isentropes, $(\partial z/\partial x)_\theta$, along the 45¡N latitude circl. (a) August 8, 1992, 0000 UTC; (b) and 0600 UTC. The orography of France, smoothed as in the ECMWF-model, is also shown. Isentropes are indicated by thin solid lines (labeled in K), and isopleths of $(\partial z/\partial x)_\theta$ re indicated by dotted lines, labeled in units of 10^{-3}. The dashed line indicates the axis of the lower cold front (LCF). The upper cold front is labeled UCF. ***The LCF is tilted forward with height and intensifies significantly. Associated with this the troposphere at midlevels becomes potentially more unstable. Along the axis of the confluence line, the warm humid air near the earth s surface is lifted to the lifting condensation level thereby releasing the potential instability.***

Concluding remarks

The three factors determining thunderstorm-formation are: (1) high levels of potential instability, (2) a supply of moisture and (3) forced lifting. Forced lifting is associated with frontogenesis and with upslope flow. High levels of potential instability are created beneath the forward sloping front or in the lee of mountains when cold air impinges on the mountain range, blocking occurring only at low levels (this is a reason for the high thunderstorm frequency in the Po Valley). A supply of moisture is found in regions with significant meso-scale convergence related to frontogenetically forced or thermally forced circulations.

Note: The analyses in Figures 5-9 are based on the ECMWF-analysis.

References

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