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The "Papal Front" of 3 May 1987 – Mesoscale Analyses of Routine Data

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Abstract:

The weather development associated with a double cold front over southern Germany is analyzed for the period 2 May 1987, 12 UTC to 3 May 1987, 21 UTC by means of routinely collected data. The first front was well forecast and analyzed in the regular weather charts, but had no significant weather attached to it. The second, the 'papal front', followed at the leading edge of an area of rapidly intensifying precipitation. North of the Alps it propagated four times faster than the first front; eventually, both merged in the Salzburg area. In cross-sections perpendicular to the fronts the first one appears as a backward sloping zone of distinct gradient in potential temperature, while the latter is marked by a steep transition zone in equivalent potential temperature.

Zusammenfassung: "Papstfront" vom 3. Mai 1987 – mesoskalige Analysen von Routinedaten

Die Wetterentwicklung, die mit der Passage einer doppelten Kaltfront über Süddeutschland einher ging, wird für den Zeitraum 2. Mai, 12 UTC bis 3. Mai 1987, 21 UTC auf der Basis von routinemäßig gewonnenen Daten analysiert. Die erste Front, in den üblichen Wetterkarten gut vorhergesagt und analysiert, war von keinen markanten Wettererscheinungen begleitet. Die zweite, die "Papstfront", folgte am Vorderrand eines Gebiets mit rasch zunehmendem Niederschlag. Sie bewegte sich nördlich der Alpen viermal schneller als die erste und holte sie im Raum Salzburg ein. In Querschnitten senkrecht zu den Fronten erscheint die erste als nach hinten geneigte Zone eines ausgeprägten Gradienten in der potentiellen Temperatur, während die zweite von einem steil aufgerichteten Übergangsbereich in der äquivalent-potentiellen Temperatur markiert wird.

1 Introduction

During the preparation phase for the German Front Experiment 1987 (Hoinka and Volkert, 1987) a very active cold front crossed southern Germany on 3 May 1987 six hours after the passage of a well forecast, but inactive first front. We named the second one 'papal front' because of the memorable, though non-meteorological fact that the helicopter transfer from Munich to Augsburg for pope John Paul II had to be cancelled due to severe wind gusts and heavy precipitation.

This study aims primarily at the documentation of the event based on routine data. In contrast to previous case studies of frontal passages over southern Germany (Kurz, 1982, 1984a, 1984b; Ragette, 1984), emphasis is place on those mesoscale features, which cannot be resolved by the regular radiosonde network. In our case, all hourly reports from synoptic stations and airfields, and continuous registrations at the meteorological tower in Garching are considered besides the radiosonde data.

There are a few studies in the literature, which deal with the influence that orographic barriers exert on the development and propagation of fronts. Steinacker (1987) describes how a surface front gradually encircles the entire Alps, Shapiro et al. (1985) document a very sharp and dry front propagating along the Rocky Mountains, while Colquhoun et al. (1985) present case studies of the southerly buster, an abrupt form of cold front that moves along the eastern side of the Australian Alps. Accordingly, we look for evidence for any orographic influence during the evolution of the 'papal front'.

2 Synoptic scale development

On 2 May 1987 the large scale weather situation began to change over Central Europe from an anticyclonic to a cyclonic type. The 850 hPa map of 3 May 1987 at 00 UTC (Figure 1) illustrates that two surges of cold air approached the continent from the northwest. A first cold front, from now on referred to as 'front 1', replaced the subtropic warm air (mS), which influenced the weather over most parts of Central Europe during the previous days. This front passed over southern Germany in the morning hours of 3 May. On its wake

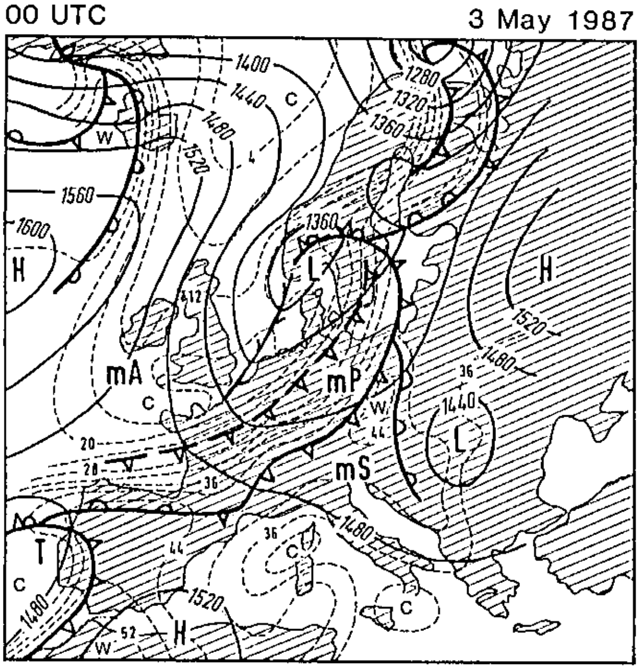

Figure 1 850 hPa map of geopotential height in m (full lines) and equivalent potential temperature in °C (dashed lines). The analysis of fronts and air masses (mA: maritime arctic cold air; mP: maritime polar cool air; mS: maritime subtropic warm air) was adapted from the 'Berliner Wetterkarte', issued by the Institute of Meteorology at the Free University of Berlin.

a polar cool air mass (mP) originating over the Atlantic penetrated eastwards.

Along the eastern edge of the Atlantic high pressure zone, colder air of arctic origin (mA) pushed forward crossing the Norwegian Sea southbound. It was separated from the polar cool air by a second cold front (,front 2'), which had crossed the British Channel by 00 UTC on 3 May.

According to the analyses, which are made on a routine basis by the European Centre for Medium Range Weather Forecasts (ECMWF) at 6 hour intervals, the following development took place during the period 00 to 12 UTC on 3 May. In the upper troposphere (300 hPa level), the distinct trough tightened and its axis moved eastbound from a line western North Sea – Bay of Biscay to a line central North Sea – Barcelona. For a characterization of the mid-tropospheric situation, we use the diagnosed field of vertical motion directly rather than quantities as advection of vorticity or warm air, which can contribute to synoptic scale upward motion. At 00 UTC three isolated cells of upward motion in excess of −10 hPa/h were present in both the 700 hPa and the 500 hPa level. One was centred over Bordeaux; the second lay above the Pyrenees (above the wave of front 1 in Figure 1); and the third stretched roughly along the line Ulm – Livorno mostly within the mS air mass of Figure 1. Six hours later we find a single, enlarged region of stronger upward motion (in excess of −20 hPa/h at 700 hPa and 500 hPa) above the Pyrenees and an area of uplift over Southern Germany, centred over Munich in the 700 hPa level and over the Upper Rhine valley in the 500 hPa level (well over −10 hPa/h in both regions). During the six hours until 12 UTC a considerable development took place, as by that time a vertically consistent area of well pronounced uplift was diagnosed. It extended from northern Italy to southern Germany and peaked in −35 hPa/h over western Austria in the 500 hPa level.

In the northern part of that region of midtropospheric uplift strong precipitation developed in southwestern Germany and northern Switzerland (here a release of potential instability lead to thunderstorms). The evaporation of rain drops in the arctic cold air may have been responsible for a further cooling and the sharpening of the cross frontal temperature gradient. Such an effect is discussed by Kurz (1982).

In general, unsaturated air can be cooled by evaporating rain until its wet bulb temperature is reached. If vertical motion is present the equivalent potential temperature (θ_e) is an appropriate measure of the lowest temperature, which can be reached at the ground. Accordingly, an air mass must be characterized by $\theta_e \leqslant 19\,°C$ to allow a cooling down to +2 °C at a pressure level of 950 hPa, as it was observed over southern Germany. Figure 1 reveals that such conditions are encountered within the arctic cold air. A further indication for this thermodynamic process can be seen from the west-east cross sections from Camborne (United Kingdom) to Budapest (Hungary) at 12 UTC on 3 May 1987. They show the vertical distribution of potential temperature θ (Figure 2) and of equivalent potential

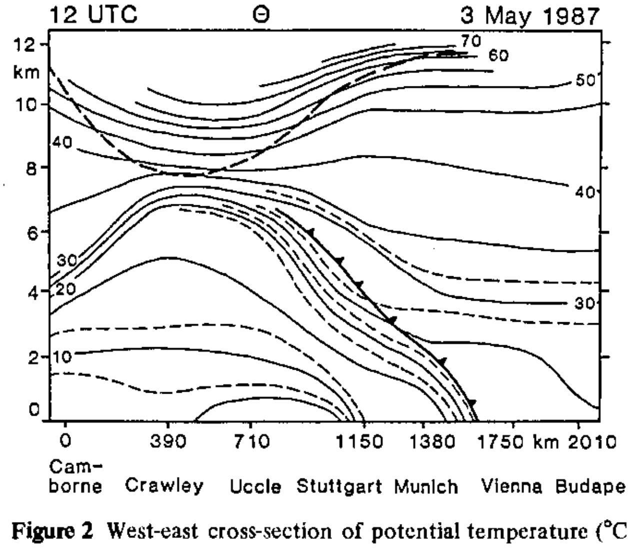

Figure 2 West-east cross-section of potential temperature (°C). The positions of front 1 (thick line with frontal symbols) and the tropopause (dashed line) are indicated.

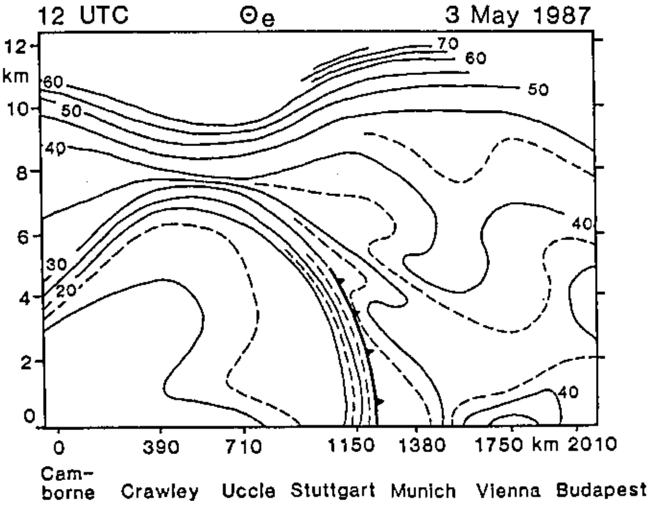

Figure 3 West-east cross-section of equivalent potential temperature (°C). The position of front 2 (thick line with frontal symbols) is indicated.

temperature θ_e (Figure 3). The centre line of the west European trough coincides with a maximum vertical extension of the arctic cold air over Crawley (U.K.). Here, the tropopause has dropped down to 8 km above mean sea level. The positions of the frontal layers can be derived from the distributions of either θ or θ_e. Front 1, which has passed Munich already, is clearly discernible by the gradient of θ, but it does not show up in the field of θ_e above the boundary layer. On the other hand, cold front 2 is evident up to 4 km through a sharp gradient of θ_e in the region of Stuttgart, where a gradient of θ is encountered only near the surface. This supports the assumption that the evaporation of rain drops removed sensible heat from the air on the rear side of front 2. Such a process does not affect the equivalent potential temperature ($\partial\theta_e/\partial z \simeq 0$), whereas the potential temperature increases with height according to a wet adiabatic lapse rate. We consider the different appearance of fronts 1 and 2 in the fields of θ and θ_e and their separation at the surface of about 400 km to be exceptional; at least, we are not aware that a comparable situation has been described before.

3 Surface front propagation across southern Germany

Surface observations and imagery from polar orbiting satellites are the only source of routine data which allow inferences on the evolution of a frontal passage on a scale finer than the mean distance between aerological stations. Here, we reconstruct via careful manual analyses the positions of cold front 2 at the leading edge of an area of intense precipitation that crossed southern Germany between 09 and 18 UTC on 3 May.

Table 1 Surface characteristics of the airmasses separated by fronts 1 and 2.

Element \ Air-mass	Suptropic warm air	Polar cool air	Arctic cold air
Day temperature (°C)	≃ 20	12 to 16	≃ 5
Pressure tendency (hPa/3h)	−2 to −4	−1 to −3	2 to 8
Wind direction	variable	NE to NW	NW to W
Wind velocity (kn)	below 5	below 10	up to 25
Precipitation	none	hardly any	intense with showers, thunderstorms, partly snowfall

The network consists of between 85 and 130 reporting stations (more stations report at synoptic times, only fewer every hour) between longitudes 7° E and 14° E and latitudes 47° N and 51° N. They comprise synoptic stations and civilian and military airports. The reports are plotted on charts following the plotting scheme of the German Weather Service. Figure 4 depicts a sample of such a mesoscale weather chart in reduced size together with an analysis of the pressure and pressure tendency fields, and the positions of front 1 (in the east) and front 2 (in the middle). The shifts in pressure tendendy and wind direction are used for the positioning of front 2, together with the time of passage taken from the Garching registrations (see Section 4) and the cloud information from a satellite image. Note the distinct mesoscale high centred west of Lake Constance, the pronounced pressure rise area at its eastern side and the strong pressure gradient towards the south and the east. The surface characteristics of the air masses separated by the two fronts are quantitatively summarized in Table 1. The triangles at front 2 indicate the direction of progression of the front, which is obviously due to the continuous deepening of the mesoscale depression over southern Germany (surface winds followed the isallobars rather than the isobars).

Now, we briefly summarize the development from 09 to 18 UTC. At 09 UTC front 1 had just passed Munich while front 2 appeared along the Rhine Valley. Pressure decreased over large parts of southern Germany, but rose behind front 2. During the following hours the pressure dropped considerably ahead of front 2, which penetrated eastwards and was followed by an area of distinct pressure rise. In this area contiguous precipitation took place with embedded thunderstorms around Lake of Constance; over the highlands of southwestern Germany the precipitation turned into snowfall. At 15 UTC the horizontal pressure contrast had increased to 18 hPa per 230 km (Salzburg – Lake of

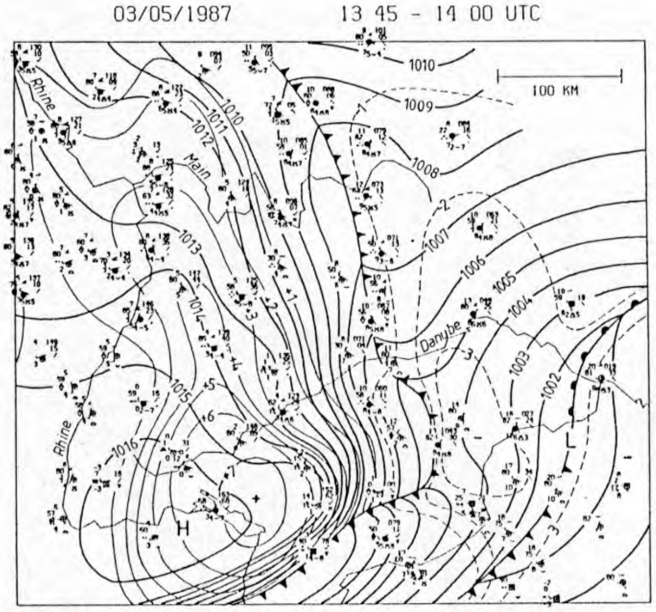

Figure 4 Surface chart for southern Germany, 3 May 1987, 14 UTC. Surface fronts, pressure field (in hPa; full lines) and pressure tendency (in hPa/3 h; dashed lines) are analysed from the reports of 86 stations. The area is bounded by longitudes 7° E and 14° E and latitudes 47° N and 51° N. The triangles at the front indicate the direction of propagation.

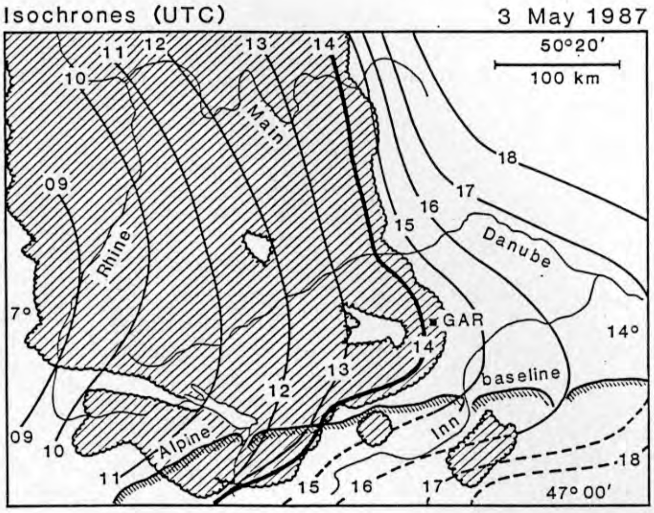

Figure 5 Isochrones of surface positions for the period 09 to 18 UTC on 3 May 1987 (full lines); the 14 UTC position (thick line) corresponds with cold front 2 of Figure 4 and roughly coincides with the leading edge of the area with cloud top temperatures below −40°C (hatched; see Figure 6).

Constance). The speed of front 2 increased to 50 km/h, which is four times faster than front 1. This resulted in a sharpened temperature contrast (20°C in Salzburg, +2°C in Munich over a distance of 130 km). By 18 UTC front 2 caught front 1 east of Linz (Austria). The postfrontal pressure rise amounted to 8 hPa/3h.

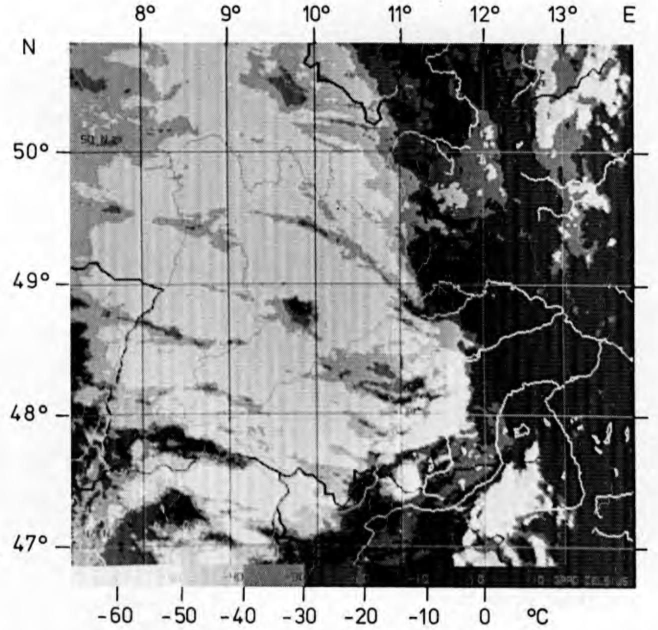

Figure 6 Cloud top temperatures derived from channel 4 (wavelength: 11.5 μm) of the NOAA-9 satellite for southern Germany, 3 May 1987, 1415 UTC.

The precipitation complex behind front 2 had enlarged; in the area south of the Danube and west of Munich snowfall reached the ground.

Figure 5 displays the hourly isochrones of the surface front position from 09 UTC, when front 2 became apparent in the Rhine Valley, until 18 UTC when it had caught front 1 near Linz (outside the region displayed). During the afternoon an acceleration along the Alpine baseline and a retardation at the Bayerischer Wald was well-pronounced. The frontal analysis in mountainous terrain south of the baseline remains questionable (dashed lines in Figure 5).

The same figure displays the cloud mass with top temperatures below −40°C (equivalent to cloud tops above 8 km). A comparison with the surface chart of 14 UTC (Figure 4) reveals the coincidence between the surface front and the leading edge of the deep cloud mass. The complete satellite image is shown in Figure 6. The very sharp gradient at the eastern edge of the large area with temperatures below −40 °C stands out. In that region the contiguous cloud mass extends to much higher levels than further to the east or to the west. It roughly occupies the area for which strong precipitation was reported from the stations given in Figure 4. The curved rim of the deep cloud mass south of the Danube coincides with the acceleration of front 2 above the Alpine foreland (see Figure 5).

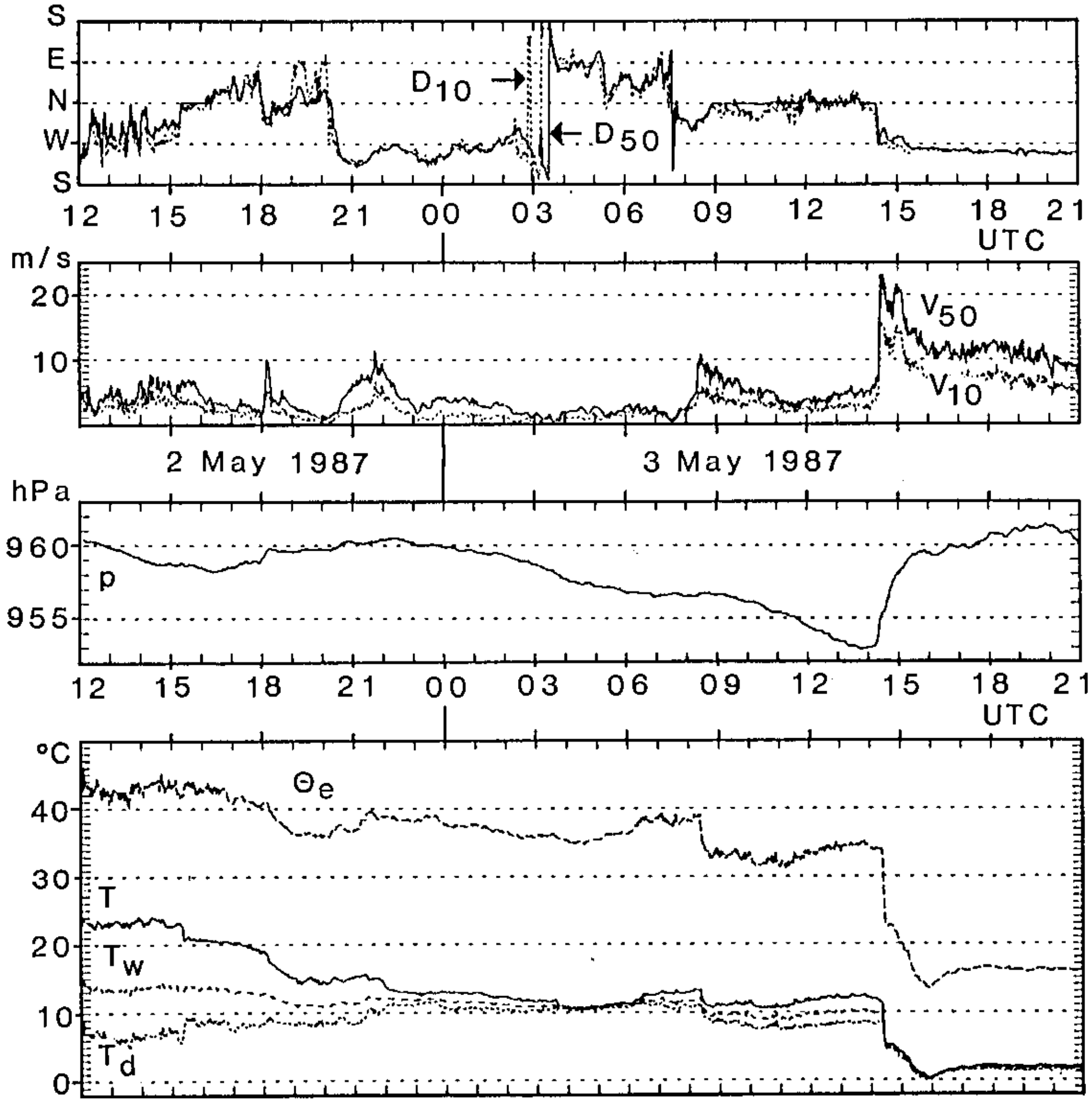

Figure 7 High resolution time series recorded at Garching during the period 2 May 1987, 12 UTC to 3 May 1987, 21 UTC. The symbols stand for (from top to bottom): wind direction in 10 and 50 m (D_{10} and D_{50}); wind speed in 10 and 50 m (v_{10} and v_{50}); pressure (p); equivalent potential (θ_e), dry (T), wet bulb (T_w) and dew point temperatures (T_d) in 2 m above the ground.

Table 2 Value and duration of change for several meteorological elements during the frontal passages in Garching on 3 May 1987; T, T_w, θ_e: dry, wet bulb, and equivalent potential temperatures; p: pressure; v_{50}, D_{50}: wind speed and direction in 50 m; RR: precipitation.

	Front 1		Front 2			
			short term		total	
Period (UTC)	0820 to 0826		1420 to 1426		1420 to 1600	
ΔT $/\Delta t$	−2.0 K	/6 min	− 6.2 K	/6 min	−12 K	/100 min
ΔT_w $/\Delta t$	−1.9 K	/6 min	− 4.8 K	/6 min	− 9 K	/100 min
$\Delta \theta_e$ $/\Delta t$	−4.5 K	/6 min	−12 K	/6 min	−21 K	/100 min
Δp $/\Delta t$	0.2 hPa	/6 min	1.8 hPa	/6 min	6.5 hPa	/100 min
Δv_{50} $/\Delta t$	6 ms^{-1}	/8 min	16 ms^{-1}	/8 min	4 ms^{-1}	/100 min
ΔD_{50} $/\Delta t$	20°	/8 min	90°	/8 min	115°	/100 min
RR $/\Delta t$		0	3.1 mm	/6 min	11.3 mm	/100 min

4 High resolution time series at a single station

The third source of data available for this study consists in time series recorded at the meteorological tower in Garching (15 km north of Munich; operated by the Meteorological Institute of Munich university with a normal sampling rate of 120 s).

Figure 7 gives a complete overview of the 33 hour period between 2 May, 12 UTC and 3 May, 21 UTC. Four small, but distinct steps of temperature decrease are evident, which coincide with periods of increasing wind speed or pronounced shift in wind direction (1520, 1810 [1 hPa pressure rise], 2155 [0.5 mm precipitation], 0350 UTC [0.5 mm precipitation]). As the time series of the equivalent potential temperature does not exhibit significant changes, we conclude that outflows from thunderstorms south of Munich caused the stepwise temperature reduction rather than an air mass change.

At 0820 UTC on 3 May the cold front 1 passed Garching. All elements except pressure and precipitation show distinct variations as listed in Table 2. The drop in equivalent potential temperature of nearly 5 K within 6 minutes characterizes an air mass change without precipitation.

At 1420 the front 2 passed Garching. The short term variations given in Table 2 suggest the passage of a gust line (abrupt increase of wind speed, distinct temperature fall, significant precipitation). These abrupt variations within 6 to 8 minutes are followed by a period of one hour and a half, during which the temperature reaches the freezing point, the precipitation turns into steady snowfall. The pressure fell until the passage of front 2 and rose by nearly 7 hPa afterwards, which could suggest that front 2 coincides with the pressure trough; but Figure 4 shows the pressure minimum at this time along front 1. This finding points to an ongoing deepening of the mesoscale depression, and also explains the uncommon anticyclonic wind shift during the passage of front 2. The wind speed registration shows two distinct maxima, separated by 30 minutes or approximately 25 km. In Garching the 'papal front' exhibited short term changes close to the ones observed during the passage of a dry cold front in Boulder, Colorado on the 19 September 1983 (Shapiro et al. 1985, Figure 15).

The data from Garching are compared with values taken in Karlsruhe (KfK-tower; 10 min averages) and Salzburg (TEMPIS network; 30 min averages). In the Karlsruhe traces only front 2 shows up; time of passage was 0940 with a decrease in temperature of 4.3 K/h, an increase in wind speed from 3.7 to 7.0 m/s in a height of 40 m and the begin of a gradual pressure rise during the following 6 hours. Front 1 must have passed in the early morning hours, but its effect is obviously buried under the diurnal variation. From Salzburg only temperature and wind data are available. They indicate a single, quite distinct discontinuity between 1600 and 1630. Temperature dropped from 18.8 to 8.1 °C; the mean wind speed increased from 2.5 to 10.9 m/s with maximum gusts of 22.6 m/s and a change in wind direction from SE to SW.

5 Conclusions

This paper documents a significant double cold front on its passage across southern Germany. Cross-sections normal to the fronts reveal their different nature. Front 1 appears as a temperature discontinuity with no significant weather attached to it; front 2 defines the eastern edge of an area of precipitation which strengthened along its eastbound path. The comparison of time series from Karlsruhe, Garching and Salzburg suggests that local frontogenesis must have taken place between Karlsruhe and Garching during the period 09 to 14 UTC.

The hourly isochrones of the positions of front 2 point to an acceleration in the region close to the Alpine baseline. Comparisons with similar cases along the Pyrenees (Hoinka and Heimann 1987) and along the Australian Alps (Colquhoun et al. 1985) show evidence of an orographic influence during the propagation of the 'papal front', probably due to the blocking effect of the mountains. A hindcast of the development with a fine mesh numerical model might strengthen the hypothesis of an orographic influence on the along ridge acceleration of the surface front.

At the end of our study, we note that we adopted the common practice in using the term 'front' for lines of pronounced discontinuities without proper definition. Fronts 1 and 2 appear to be embedded in a synoptic scale zone of baroclinicity, probably have mesoscale baroclinic belts around them, but exhibit quite different types of weather. It is hoped that the coordinated effort during the German Front Experiment 1987 with spatially and temporarily denser observations leads to more insight regarding such lines of discontinuity in general and the influence that Alps exert on them in particular.

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