DIAGNOSIS OF ALPINE LEE CYCLOGENESIS – THE COMPLETE PICTURE

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1. INTRODUCTION

With northwesterly air flow across the Alps there is not only a descending motion and foehn along the lee flank, but often cyclogenesis takes place over northern Italy. This process has a great significance for weather and weather forecasting in Italy and the Mediterranean. The operationally used NWP models are nowadays able to simulate it satisfactorily well in advance.

Simulating a process with the aid of a NWP model, however, does not mean understanding it and its physics. Therefore conceptual models are needed not only to describe, but also to explain synoptic processes like the alpine lee cyclogenesis.

2. THE CONCEPTUAL MODEL OF MCGINLEY

After the investigation of some cyclonic developments in the lee of the Alps, Mc Ginley (1982) proposed a conceptual model of lee cyclogenesis which is strongly related to a frontogenetic effect caused by the Alps and the transverse circulation connected with it. In case of a northerly or northwesterly air flow directed towards the Alps there is always a strong tendency for a splitting of the flow into two branches passing the mountain barrier at its flanks. A cold front approaching the Alps experiences a strong frontogenetic effect in this diffluent stream field leading to an increase of the temperature gradient. Due to the frontogenesis a solenoidally direct circulation across the Alps is released with ascent of the warm air over northern Italy and descent of the cold air north of the mountain barrier, when the frontal zone crosses it. Since the ascent of the circulation is working above the orographically forced descending motion at the lee flank, the resulting vertical stretching leads to horizontal convergence and corresponding production of cyclonic vorticity below the level of the strongest upward motion. The whole process is shown by the schematic cross section in Fig. 1 taken from the paper of Mc Ginley.

3. DIAGNOSIS WITH THE AID OF THE Q VECTOR

A diagnosis of frontogenetic effects in the horizontal wind field and the related circulations can be made with the aid of the Q vector defined by Hoskins et al (1978). The Q vector describes the temporal change of the temperature distribution, a particle experiences within a geostrophic flow at a pressure level. One part of the change is the increase (or decrease) of the temperature gradient by deformation effects in the wind field which is called frontogenesis (or frontolysis) and which is indicated by the component of the Q vector transverse to the isotherms (Q_n). Frontogenesis is indicated when this component points towards the warmer air. And the divergence of it (FQ_n) describes the forcing of the vertical motions belonging to the transverse circulation released by the frontogenetic effect, that means ascent of the warmer and descent of the colder air. The orientation of Q_n and the resulting omega forcing at 700 hPa for a typical case of lee cyclogenesis south of the Alps is schematically given in Fig. 2. The distribution fully corresponds to the Mc Ginley scheme with the additional outcome that also across the Pyrenees a frontogenetic circulation is released whereas between Alps and Pyrenees an opposite, namely frontolytic effect wihin the flow has to be noted.

4. COMPLETION OF THE DIAGNOSIS

The model proposed by Mc Ginley is only two-dimensional and does not consider any effects working at the lateral flanks of the mountains. And there is indeed an important effect working there, namely that also due to the flow splitting forced by the Alps the cold air pushes much faster forward west and east of the Alps as across them giving rise to an increasing change of the direction of the isotherms and that differently along the frontal zone. The isotherms are deformed in a way that cold bulges develop at the flanks of the Alps whereas along it the isotherms assume an anticyclonic (or at least less cyclonic) curvature (Fig. 3).

This change of the direction (by vorticity and/or deformation) is exactly reflected by the component of the Q vector along the isotherms (Q_s) - at least for the geostrophic part of the wind field. If Q_s points in the direction of the thermal wind, it indicates a counter-clockwise rotation, otherwise a clockwise rotation of the isotherms. The direction of Q_s for a typical case of lee cyclogenesis is shown in Fig. 4. The divergence of Q_s also give rise to the forcing of vertical motions, here in the form of a succession of descent and ascent along the frontal zone with a forcing of descent in the developing cold bulges west and east of the Alps and of ascent in between as well as further eastwards.

5. THE COMPLETE PICTURE

Since the contributions to the omega forcing by divergences of the Q vector component along the isotherms (FQ_s) normally have a comparable magnitude as the forcing within the frontogenetic circulation across the frontal zone, the two-dimensional conceptual model originally proposed by Mc Ginley does not fully reflect the process of the lee cyclogenesis south of the Alps, but has to be completed by the third dimension, that means a consideration of the effects working along the frontal zone and reflected by Q_s and FQ_s, respectively. The contributions from both Q vector components to the total forcing of vertical motions partly compensate, but reinforce each other at some places. The latter is especially true for northern Italy where – as shown by Fig. 5 - FQ_n as well as FQ_s contribute to an ascending motion leading to the described cyclogenesis in the lee of the Alps immediately ahead of the cold front which crosses the mountains.

The influence of the effects working along the frontal zone also provides an explanation for the great variety the cyclogenetic effects south of the Alps show from case to case. Whereas the frontogenesis and the related cross-circulation is nearly always working when a cold front approaches the Alps from the north, the magnitude of the cold air advection at both sides of the Alps might be strongly different. If the advection is concentrated at the western side of the Alps, the contribution by FQ_s to the ascending motion over northern Italy is largest so that a deep cyclone may develop over the central Mediterranean. If, on the other hand, the cold air pushes forward mainly east of the Alps, the deformation of the isotherms over France and the western Alps remains small and that is true also for the related omega forcing by FQ_s. In such cases the cyclonic development in the lee will be rather weak, and is often limited to the immediate neighbourhood of the mountain range.

6. REFERENCES

McGinley, I.: A Diagnosis of Alpine Lee Cyclogenesis. Mon. Wea. Rev. 110 (1982), 1271-1287

Hoskins, B.J.; Draghici, I. and Davies, H.C.: A new look at the ω-equation. Quart. J.R. Meteorol. Soc. 104 (1978), 31-38

Figures see following page

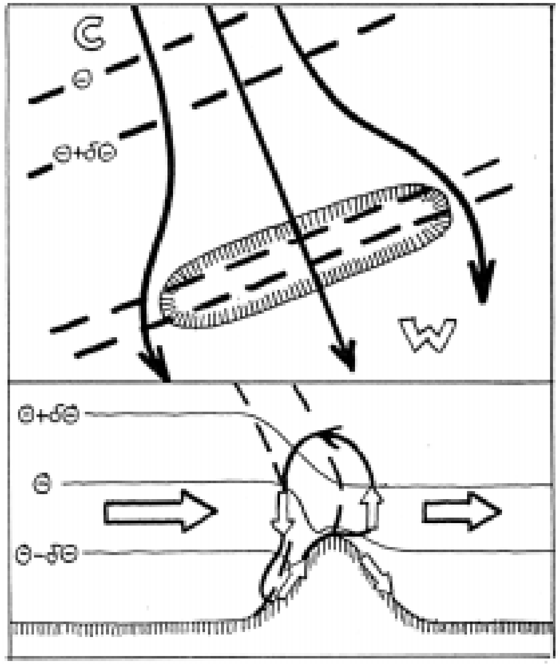

Fig. 1: Conceptual model of frontogenesis due to flow splitting forced by the Alps. Top: Horizontal streamlines (solid) and change of the isotherms (dashed) when approaching the Alps. Bottom: Transverse circulation superimposed over forced vertical motions at the flanks of the mountains (Partly after McGinley, 1982).

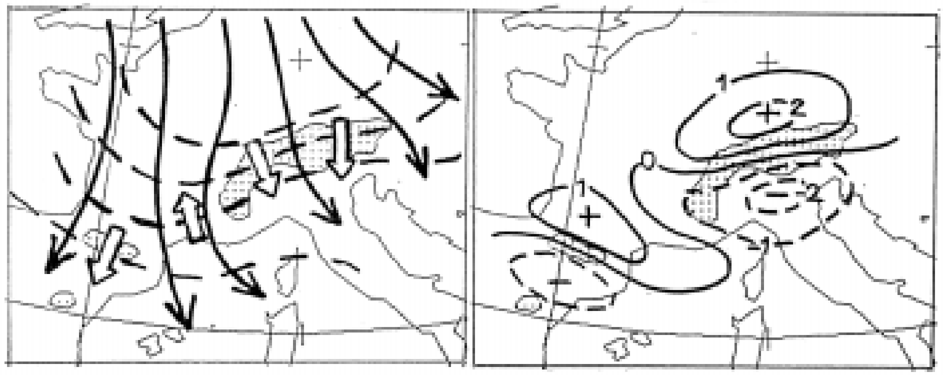

Fig. 2: Left: Streamlines (solid lines), isotherms (dashed lines) and Q vector component Qn at 700 hPa in case of lee cyclogenesis. Right: Related omega forcing (ascent dashed, descent solid lines)

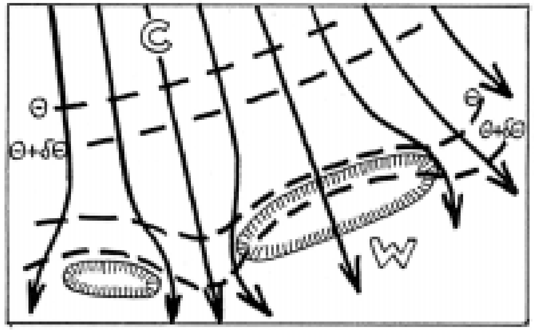

Fig. 3: Change of the direction of the isotherms at the lateral flanks of the Alps and Pyrenees in case of northwesterly flow.

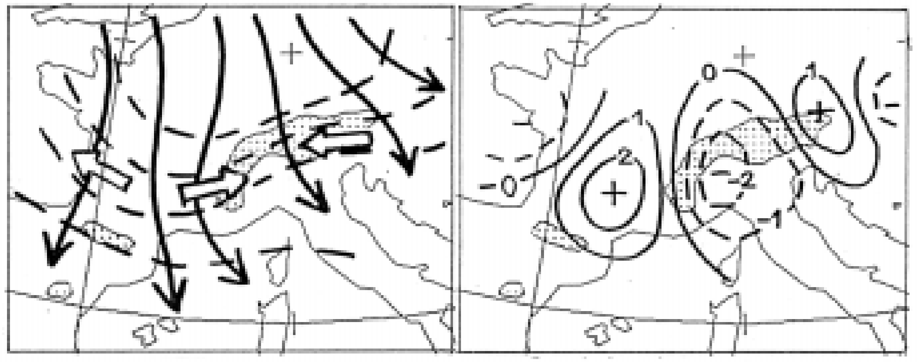

Fig. 4: As in Fig. 2 except for the Q vector component Qs and the related omega forcing

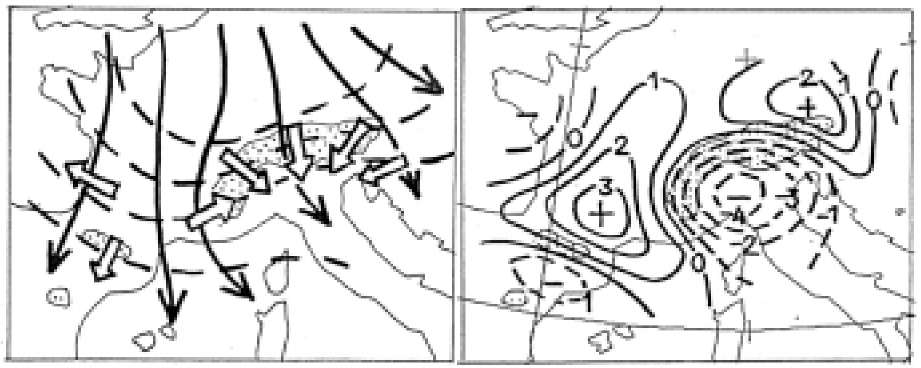

Fig. 5: As in Fig. 2 except for the Q vectors and the total omega forcing