Mesoscale overview of Lothar storm (26 December 1999)

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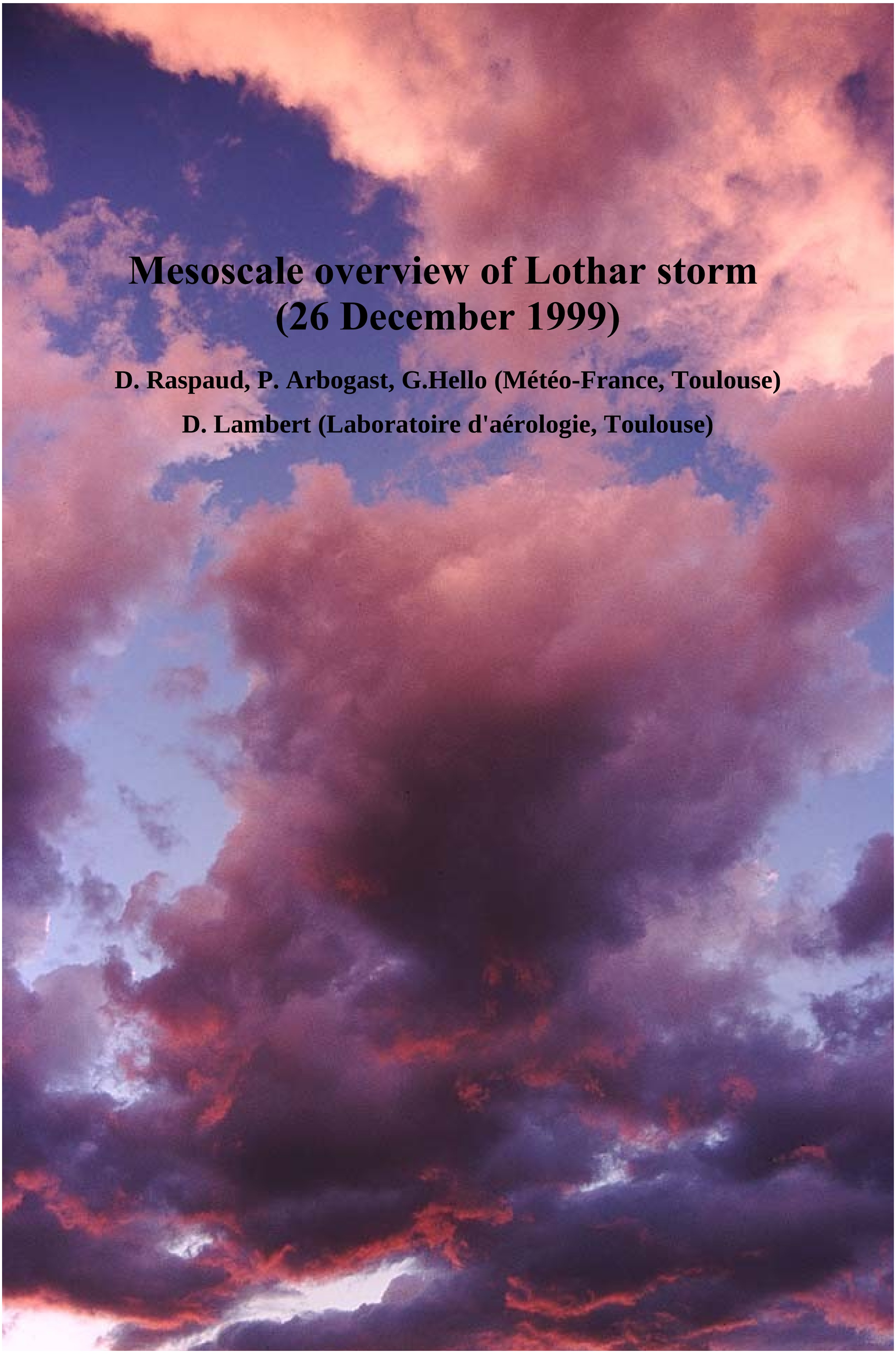

1. Summary

The dynamics of the main growing phase of the 26 December 1999 storm is characterized by smaller horizontal and time scales than what is currently observed for mid-latitude cyclone developments. It seems therefore interesting to characterise the dynamical mechanisms using mesoscale simulations. This is done here using ALADIN simulations at 10km horizontal resolution. Then dynamical diagnoses are applied to the simulations in order to characterize mechanisms that are involved in the development of the storm.

2. The ALADIN simulations of the Lothar storm

The domain of the simulation is made such as the center of the domain corresponds to the location where the strengthening of the storm is maximum on the 25 of December at 21UTC. The simulation is starting on the 25 of December at 18UTC to end on the 26 of December at 06UTC. The period is covering the explosive development of the Lothar storm. The geographical domain is shown on the figure 1. Except from the geographical aspects, the configuration of the ALADIN model is the same as the one used currently in operation at Météo-France.

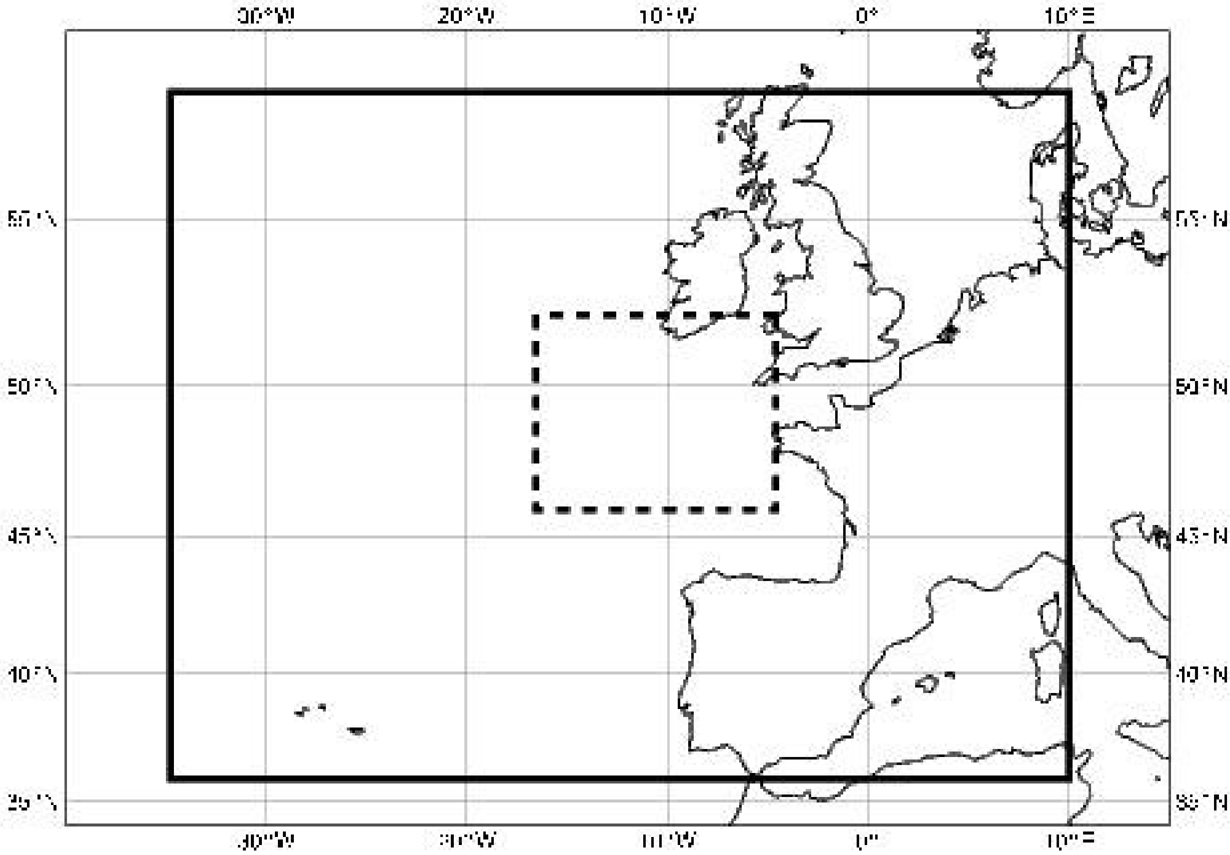

Figure 1: Geographical domain covered by the ALADIN simulations (in plain lines)

The upper level jet plays a major role in the development of the storm. It is well-simulated by the ALADIN model speaking in terms of location as well as in terms of depiction of its unusual intensity (Figure 2). The comparison of the ALADIN forecast is done when the cyclone is over the land on the 26 of December at 06UTC (Figure 2 bottom panel). The pressure field forecast by ALADIN (12 hours forecast) locates the surface cyclone on the west side of the Paris area. In reality, at this time the center of the storm is located a little more westerly on the normandy area. The value at the center given by the 12 hours forecast is of 976 hPa as the observed value is around 960 hPa. The low level winds given by the forecast show maximum values in the south part of the cyclone of 27 ms^{-1} which can be compared to the observed mean wind. In conclusion the ALADIN model forecast correctly the upper level dynamics and the location of the surface cyclone. The intensity of the deepening is not well forecast as it is also the case for the ARPEGE model.

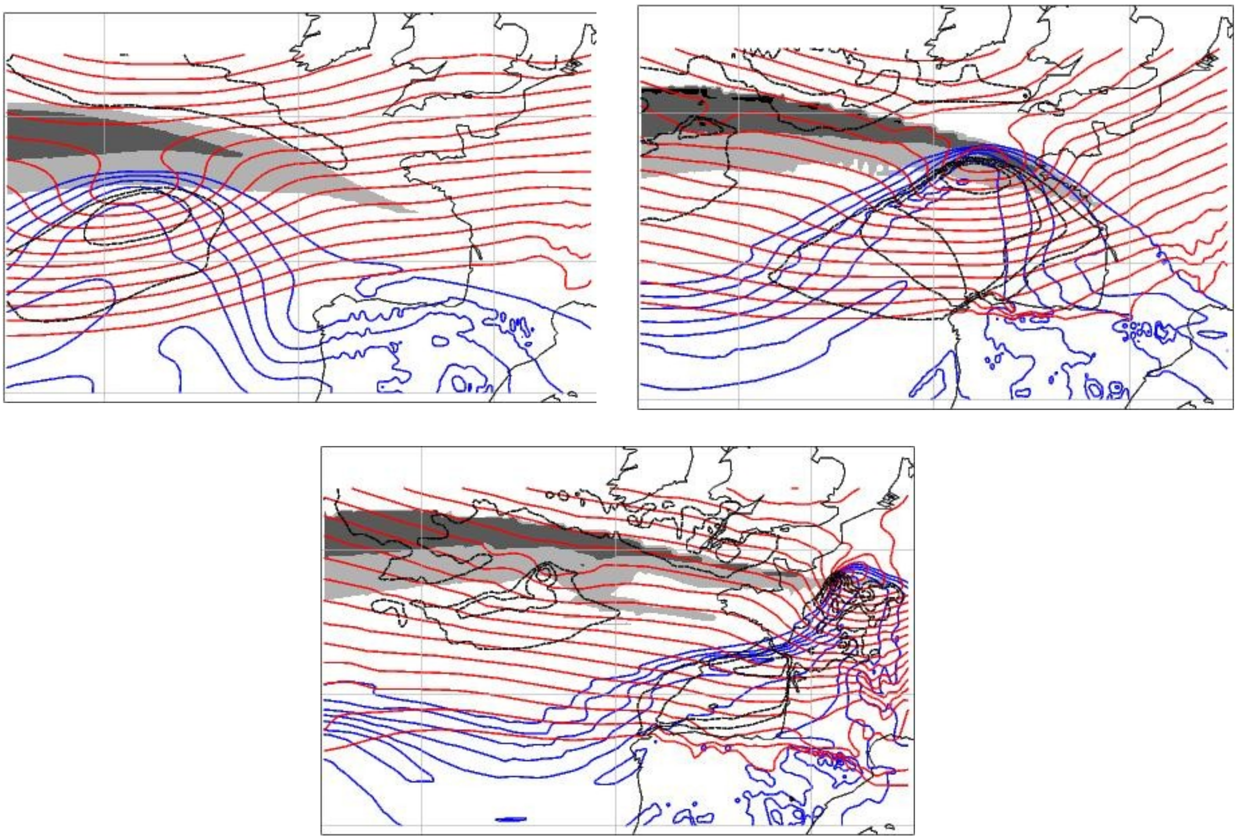

Figure 2 : ALADIN forecast. Upper left: analysis on the 25 of December 18UTC. Upper right: 6 hours forecast on the 26 of December 00UTC. Bottom: 12 hours forecast on the 26 of December 06UTC. In red, mean-sea-level pressure every 2 hPa for values lower than 1015 hPa. In blue θ'_w (K) at level 850 hPa , isolines every 1K for values greater than 283K. In shading mode, the intensity of the wind, every 10 m/s for values greater than 80 m/s. The dot lines show the intensity of the low level wind at level 20 meters, every 25m/s for values greater than 17 m/s.

3. Results

3.1 Energetics study

The first stage of this study is to split the model outputs into two parts: the first one is the time mean of the simulation over 12 hours (from 18UTC 25 December 1999 to 06UTC 26 December 1999) and the second part is the departure from this time mean. The first part will be called large scale environment whereas the second part may be associated with the storm itself. Then barotropic and baroclinic interactions between the storm and the large scale environment are studied using local energetic conversions.

To put on light barotropic interaction between the storm and its environment a superimposition of the deformation axis of the environment and the vorticity of the storm is shown at 23UTC 25 December 1999 (Figure 3, Left-hand side panel). If the wind associated to the large scale environment tends to make the vorticity maximum less elongated and more circular, i.e. the deformation axis is orthogonal to the main axis of the vorticity maximum, then the storm is able to extract some kinetic energy from its environment. Although the deformation field is not systematically orthogonal to the vorticity maximum main axis, the barotropic conversion has two maxima, the first one along the northern edge of the vorticity maximum and the second one along the southern edge making the vortex more circular. Therefore the barotropic interaction between the vorticity maximum and its environment is one factor helping the cyclogenesis process.

The right-hand side panel of figure 3 suggests that baroclinic mechanisms dominate the growth of the storm. The baroclinic conversion displayed on the figure is proportional to ω'θ' where ω is the vertical velocity, θ the potential temperature and denotes the departure from the time average. The magnitude of the local internal conversion maximum is about seven times the maximum of barotropic conversion showing the predominance of the baroclinic mechanisms for the growing phase of the storm.

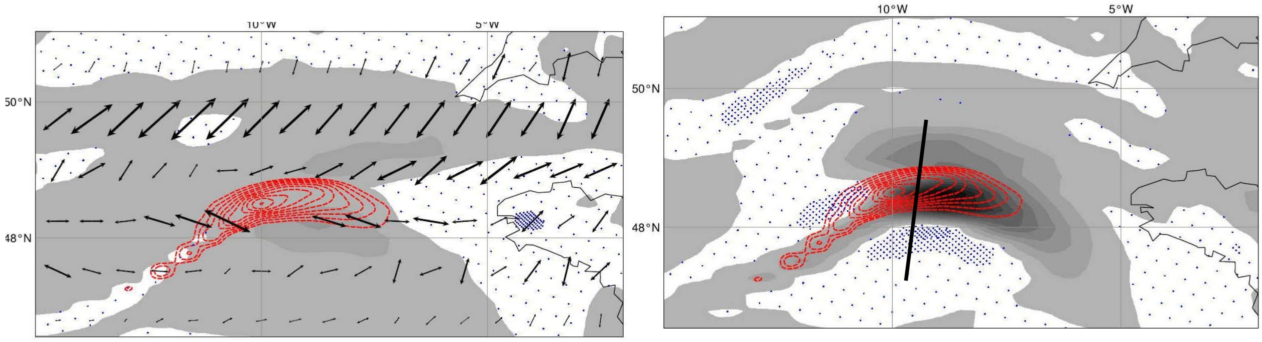

Figure 3: Energetic conversions at 23UTC 26 December 1999. Left: high-frequency relative vorticity associated to the cyclone (red contours every 0.5 10-5 s-1 for values > 1.5 10-5 s-1), deformation associated to low-frequency wind field (the length of each arrow is proportional to the strengh) and barotropic conversion (grey shading for value > 16 W/m2, blue shading for negative values). Right: same as left for the red contours, shading is for baroclinic conversion (maximum: 110 W/m2)

3.2 Balanced vertical velocity diagnoses study

The vertical velocity field has two different origins: a dynamical one and a physical one. The dynamical mechanisms associated to the interaction of potential vorticity/potential temperature perturbations of finite amplitude embedded within a baroclinic environment (here a very strong and sharp jet stream) infer vertical velocity preserving the balance between the mass and wind fields. Such mechanisms are a key feature of baroclinic development. The physical mechanisms as latent heat release may also infer vertical velocity. After some balance assumptions -here the Alternative Balance (Davies-Jones, 1991) - it is possible to express the vertical velocity variable as solution of the following equation:

$$\mathscr{L}(\omega)=Q_{dyn}+Q_{dia}$$

where $\mathscr{L}$ is a second-order partial derivative operator, Q_{dyn} is the baroclinic forcing function of the "q-vector" divergence and Q_{dia} is the diabatic forcing computed using the time tendency contribution of the physical parametrizations of the ALADIN physics. The dynamical vertical velocity is characterized by a dipole below the tropopause which is consistent with the classical configuration below a jet exit (Figure 4, left-hand side panel). The low-level vorticity maximum during its displacement towards the northeast will meet the ascending motion pattern. Then the deepening of the storm will be sustained by vorticity stretching.

However the diabatic contribution (Figure 4, right-hand side panel) presents features at the horizontal scale consistent with the cyclone itself and maximum four times the dynamical counterpart. The fact that the diabatically induced vertical velocity dominates the vertical velocity field supports the conclusion of Wernli *et al.* (2002). It may be inferred from this result that the forecast skill is not only determined by the initial conditions but also by a proper representation of subgrib scale physical processes.

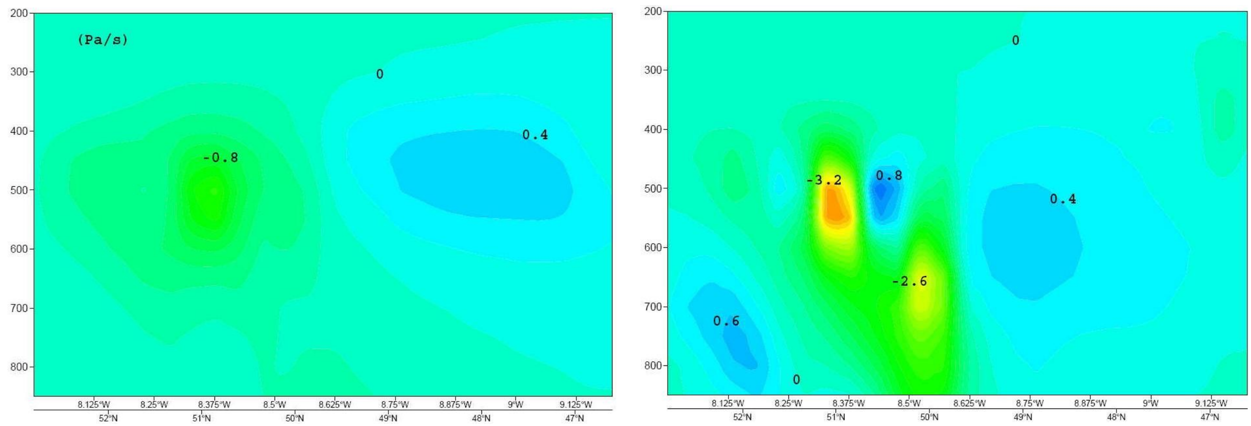

Figure 4 : 23UTC 25 December 1999. Vertical sections of dynamic (on the left) and diabatic (on the right) contributions to the vertical velocity field (in Pa/s) along the axis displayed on the previous figure. Green to red shading is for upward motion, cyan to blue for downward motion.

4. References

Davies-Jones, R., 1991: The frontogenetical forcing of secondary circulations. Part I: the duality and generalization of the Q vector. *J. Atmos. Sci.*, **48**, 497—509.

Wernli, H., S. Dirren, M. A. Liniger and M. Zillig, 2002: Dynamical aspects of the life cycle of the winter storm 'Lothar' (24-26 Decmber 1999). *Quart. J. Roy. Meteor. Soc.*, **128**, 405—429.

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