P2.11 STUDY OF TROPOPAUSE PERTURBATION AND EFFECTS ON CYCLOGENESIS USING POTENTIAL VORTICITY INVERSION METHOD

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1. INTRODUCTION

The Fronts and Atlantic Storm-Track EXperiment (FASTEX) was an international field project which took place in January and February 1997 to make detailed observations of extratropical cyclones over the North Atlantic. The FASTEX intensive observation period 18 was devoted to the study of a cold air cyclogenesis (over the Labrador Sea) that involved a major tropopause disturbance. The mesoscale study by Donnadille et al. (2001: FASTEX IOP 18 : a very deep tropopause fold. Part I : Synoptic study and modeling. *submitted to Q. J. R. Meteorol. Soc.*) shows that the cyclogenesis goes in two steps : *i)* triggering and decay of a polar low by the baroclinic interaction with a coherent tropopause disturbance at the limit between the sea ice and the open ocean, and *ii)* development of the final surface low by the baroclinic interaction of both the Coherent Tropopause Disturbance (CTD) and its associated tropopause fold. This work is aimed at completing the previous study with other larger-scale aspects using a quasi-geostrophic potential vorticity (PV) inversion method coupled to the ARPEGE† model.

2. SOME PV INVERSION EXPERIMENTS

We use the quasi-geostrophic PV inversion method (Chaigne E. and P. Arbogast, 2000: Multiple potential-vorticity inversions in two FASTEX cyclones. *Q. J. R. Meteorol. Soc.* **126**, pp. 1711-1734) coupled to the french model ARPEGE with T95 spectral resolution and 19 vertical levels. PV inversions performed at the initial time of the model simulation aim at testing the impact of the presence or the absence of a PV structure during the course of the model simulation. PV inversions are also used like an attribution method, for instance by diagnosing the difference fields of vertical velocity in experiments with and without a PV structure. A first experiment consists in showing the triggering role of the CTD on the surface low development by comparing a reference forecast and another one in which the CTD struture has been removed at the initial time. A second experiment investigates the sensitivity of the triggering role of the CTD to the presence of a mobile ridge over the United States 3 days prior to the explosive cyclogenesis over the Labrador Sea. Again, a reference forecast is compared to one in which the mobile ridge has been removed at the initial time. The last experiment completes the sensitivity study by investigating the role of surface temperature and boundary layer stability at the limit between sea-ice and the open ocean. A couple of simulations are performed, the reference one and another with a modified surface temperature field. The PV inversion method is then used in an attribution-like mode to evaluate the vertical motion field associated with the CTD and to analyze its modifications when the surface temperature field is modified.

3. THE RESULTS

Figures 1a and 1c present vertical and isentropic sections of the CTD at 0000 UTC 21 February. Figure 1e is the reference 36 hours forecast valid on 1200 UTC 22 February of 1000 hPa geopotential field. This forecast agrees with the 4Dvar ARPEGE analysis. The surface low is well developped south of Greenland. On the right side of Fig. 1 are displayed the same fields but in the experiment for which the CTD has been removed (Figs. 1b, 1d). In this PV-modified forecast (Fig. 1f), there is no surface low. So, the surface cyclogenesis is completely associated to the evolution of the coherent tropopause disturbance.

Figure 2a presents 300 hPa PV at 0000 UTC 19 February. The CTD is located about 70 N 85 W and a well defined ridge (hereafter RR) is over The Rockies. Donnadille et al. (2001) show that this mobile upper level ridge rapidly prop-

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agates eastwards and enters in phase with the CTD. The resulting increase of confluence triggers vertical transverse circulations that contribute to the tropopause folding process. The PV inversion method is applied to remove this ridge adding a minimum amount of PV. Figure 2b is a difference field of upper level wind between the modified initial state and the starting analysis of the reference forecast valid on 0000 UTC 19 February. It shows the wind perturbation that is added to the reference forecast with the objective to decrease the confluence between the upper level ridge and the CTD. Figure 2c is the potential temperature difference on the 2 pvu[‡] surface valid on 0000 UTC 22 February (72 hours forecast). The dipole over the Labrador shows that the CTD in the modified forecast lags behind the one in the reference forecast, which suggests that the presence of the upper level ridge influences the CTD movement, and consequently the surface low development over the Labrador Sea. Figure 2d is the 84 hours PV-modified forecast (valid on 1200 UTC 22 February) for geopotential at 1000 hPa. Compared to the reference forecast (Fig. 1e), the surface low is more to the west and more intense. The difference in the location of the surface low agrees with the CTD lagging behind. The synoptic and zonal jet (over 50N) in the reference forecast has also changed its orientation in the PV-modified forecast under the effect of the removal of the upper-level ridge, as indicated by large differences of potential temperatures along 50N (Fig. 2c): the zonal dipole of potential temperature differences indicates that the exit region of the jet at 55W is more to the north in the PV-modified forecast than in the reference forecast. It may put the surface low in more favorable conditions to deepen, i.e. downstream of the CTD and in the exit region of the synoptic jet.

Results of an experiment realized to test the importance of surface fluxes that are especially strong over the open sea of Labrador are now discussed. Figure 3a corresponds to a 36 hours forecast from 0000 UTC 21 February in an experiment in which the global surface temperature field is set to 238 K (the "238 K" forecast hereafter), which corresponds to the surface temperature north of Canada. Compared to the reference (Fig. 1e) the surface low has nearly the same position but is twice lesser intense. The very stable boundary layer that develops in the "238 K" forecast would inhibit the cyclogenetic action (vertical stretching and thermal advection) of the upper level forcing at low levels. It suggests that the baroclinic interaction of the CTD maintains the surface low from 21 February but that surface conditions do no allow further development. To investigate further this hypothesis, PV-inversion experiments are realized at the end of the reference forecast and the "238 K" forecast to evaluate the vertical motion associated with the dynamics of the CTD in a given environment. A diagnostic computation of vertical velocity fields is then performed using the Alternative Balance omega equation (Davies-Jones, 1991: The frontogenetic forcing of secondary circulations. Part I: the duality and generalization of the Q vector.*J. Atmos. Sci.* **48**, 497-509) , on the four final stages: let's W1 and W2 be the vertical velocity fields associated with the reference forecast with and without the CTD, and W3 and W4 be the vertical velocity fields associated with the "238 K" forecast with and without the CTD, respectively. Fields of the differences of either (W1-W2) or (W3-W4) present a dipole of vertical velocity (not shown) characteristic of the upper level forcing of the CTD. The subsidence patterns of (W1-W2) and (W3-W4) upstream of the CTD are quasi-identical and correspond to the adiabatic part of the vertical circulation. Differences between (W1-W2) and (W3-W4) are only significant downstream of the CTD in the region where the surface low is deepening. Figure 3b shows the difference field of vertical velocity ((W1-W2)-(W3-W4)). The main ascending vertical velocity pattern that is displayed locates over the surface low and over the developing cold surface front at the southeast. This vertical velocity ascent difference shows that the action imposed by the upper level forcing of the CTD is made easier in the favorable surface environment of the reference forecast, compared to the "238 K" surface configuration.

4. CONCLUSION

Quasi-geostrophic potential vorticity inversion experiments are applied to a case study of a cold air cyclogenesis over the Labrador Sea. The precursor role of a Coherent Tropopause Disturbance (CTD) is demonstrated. A study of the sensitivity of the triggering of the cyclogenesis by the CTD shows two other important factors: *i)* the presence of an upper level ridge that increases the confluent flow south of the CTD, and *ii)* the boundary layer change from stable to neutral conditions at the limit between the sea ice and the open ocean that modifies the penetrating depth of the upper level forcing.

[‡] $1pvu = 10^{-6}\ Km^2s^{-1}kg^{-1}$

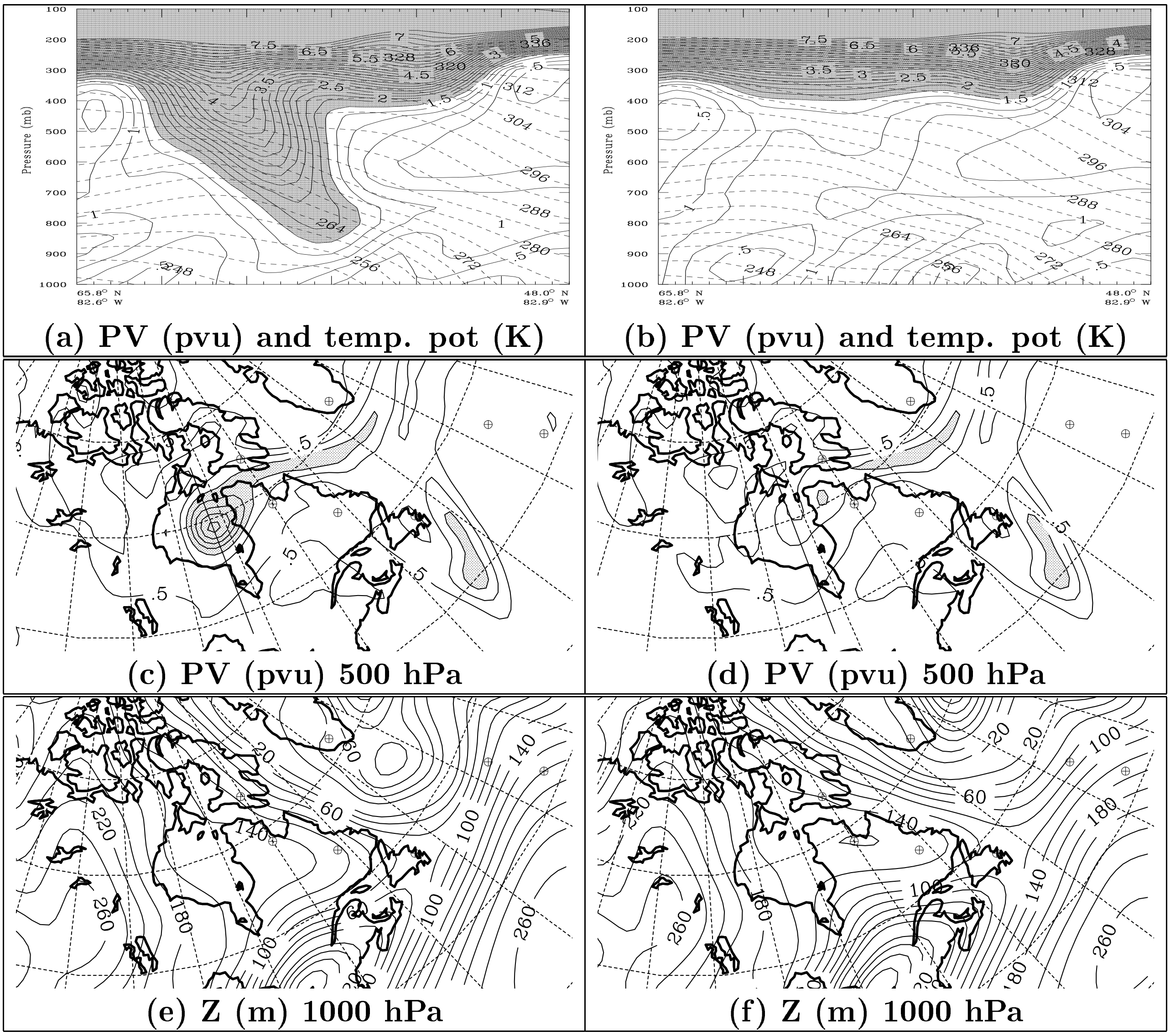

Figure 1: (a, b, c, d) are ARPEGE reanalysis at 0000 UTC 21 February. (e, f) are 36 hours ARPEGE forecast. Left part of Fig. 1 (a, c, e) is for non modified atmosphere. Right part of Fig. 1 (b, d, f) is for the CTD removed experiment. (a, b) are vertical cross section for PV (pvu) (solid lines, every 0.5 pvu, shaded from 1.5 pvu) and potential temperature (K) (dashed lines, every 4 K). (c, d) are 500 hPa PV (pvu) (every 0.5 pvu, shaded from 1.5 pvu). The straight line on (c) and (d) represents location of the vertical cross-section displayed on (a, b). (e, f) are 1000 hPa geopotential (m) (every 20 m).

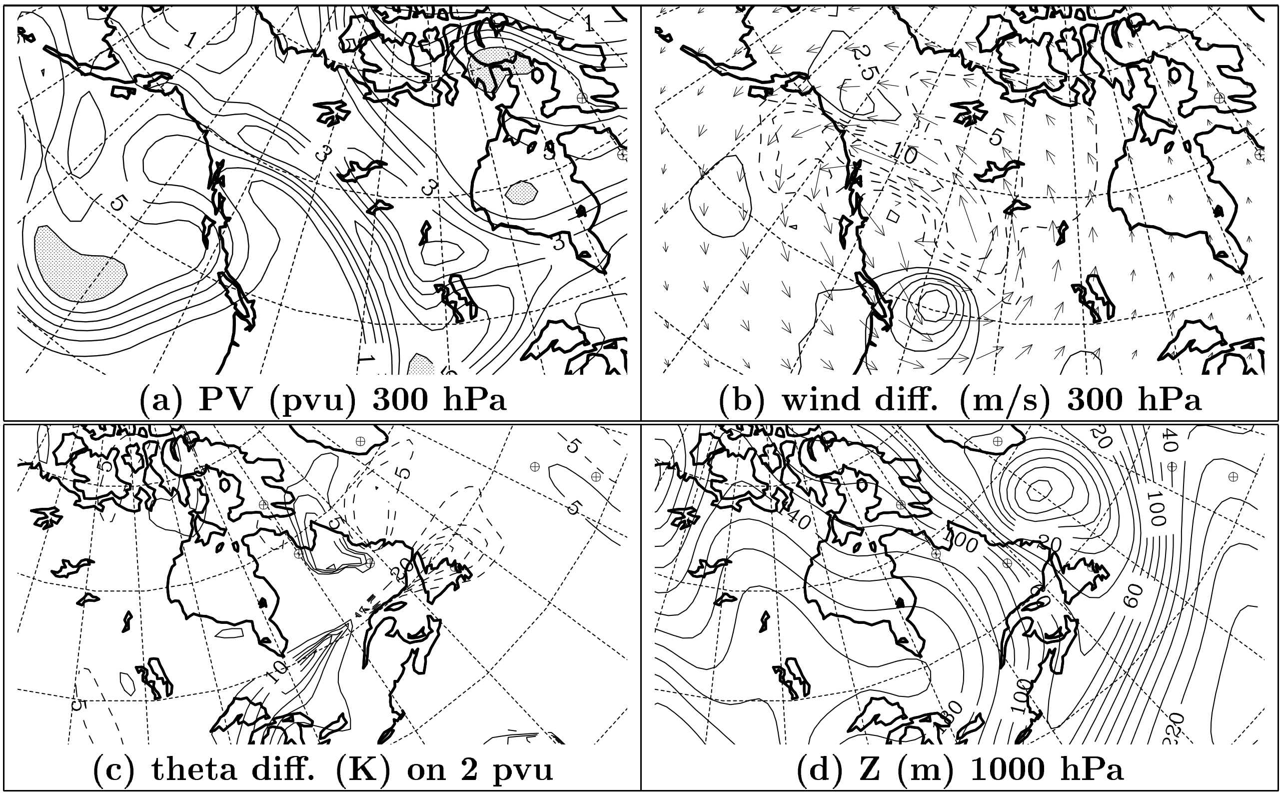

Figure 2: (a, b) are ARPEGE reanalysis at 0000 UTC 19 February. (c, d) are respectively 72 hours(valid on 0000 UTC 22 February) and 84 hours (valid on 1200 UTC 22 February) ARPEGE forescats from 0000 UTC 19 February. (a) is 300 hPa PV (pvu) every 1 pvu, shaded from 6 pvu. (b, c) are respectively 300 hPa wind field ($m.s^{-1}$) (every 2.5 ms^{-1}) with wind vectors and potential temperature (K) on 2 pvu surface (every 5 K) difference field maps between real atmosphere and PV-modified experiment (solid lines represent positive values, dashed lines are negative ones). (d) is 1000 hPa geopotential (m) (every 20 m).

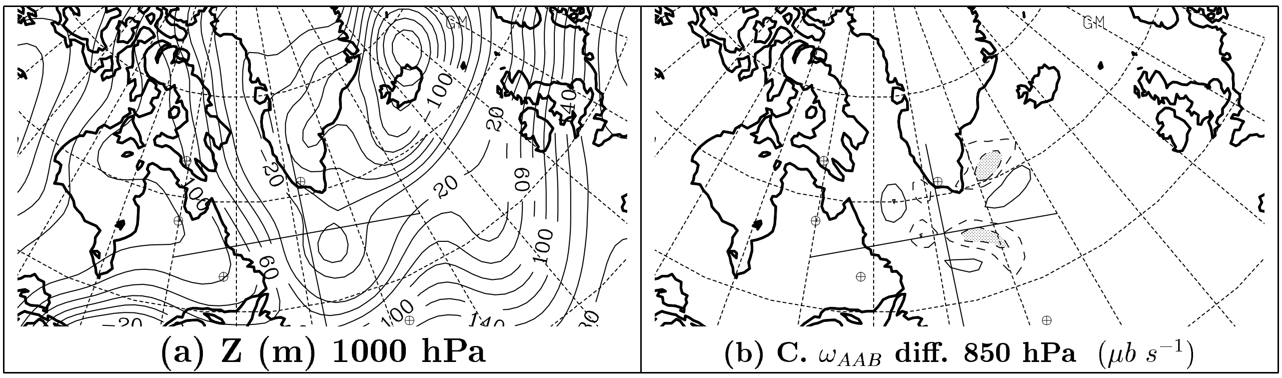

Figure 3: 36 hours ARPEGE forecast from 0000 UTC 21 February. (a) is 1000 hPa geopotential (m) (every 20 m) over a 238 K surface temperature. (b) is a 850 hPa complete AAB vertical velocity ($\mu b\ s^{-1}$) (every 0.5 $\mu b\ s^{-1}$) difference map. See text for precisions.