INFLUENCE OF THE APENNINES ON TRACK DEFLECTION OF GENOA CYCLONES

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Abstract: Observations of the MAP special observing period reveal two different track patterns for Genoa cyclones as they impinge on the Apennines. In some cases, the cyclones appear to be completely blocked by the orography and are deflected southward (e. g. IOP-1). In other cases, the cyclones do cross over the Apennines, but experience a period wherein two surface cyclones exist, one on the upstream side and a new, secondary cyclone on the downstream side of the mountains. Aloft, the system propagates without stalling. With time, the upper level trough phases with the secondary cyclone and the secondary cyclone becomes the dominant feature. Such a track is referred to as a discontinuous, but not blocked track for the purposes of this research. One such case during MAP belonging to this category is IOP-8. The aim of this study is to understand the control parameters that dictate whether a cyclone is blocked and deflected or if it is discontinuous, but not blocked. Examination of observations as well as ECMWF reanalysis data shows there is a dependency on the vortex Froude number (F_{vortex}) with smaller values of F_{vortex} indicating a greater likelihood for cyclone blocking and deflection. However, numerical sensitivity experiments indicate there are other, more important control parameters that dictate the degree of track deflection.

Keywords *- Genoa cyclone, Adraitic cyclone, twin cyclones, secondary cyclones, Apennines, Alps*

1. INTRODUCTION

When a cyclone crosses over a mesoscale mountain range, its track can be significantly deflected by the topography. This may dramatically modify the flow circulation and, consequently, the amount, location, and pattern of its associated precipitation: a potentially serious problem for quantitative precipitation forecasting. Track deflection has been noted to occur as Genoa cyclones, which are cyclones that typically form in the general vicinity of the Gulf of Genoa, impinge on the western side of the Apennines (Morelli and Berni 2003). During the Mesoscale Alpine Program (MAP), one case of a deflected Genoa cyclone has been identified: IOP-1. An additional case of a Genoa cyclone impinging on the Apennines during MAP has also been observed: IOP-8. However, in this case, significant track deflection did not occur. Rather, as this system impinged on the orography, a secondary cyclone formed to the lee of the Apennines at the surface. This secondary cyclone later went on to become the dominant surface feature while the original surface cyclone decayed. The tracks for this system was, more-or-less, undeflected or straight.

Lin et al. (2005) found that the tendency for tropical cyclones passing over the Central Mountain Range in Taiwan to be deflected was dependent on the vortex Froude number which is given by

$$F_{vortex} = \frac{V_{max}}{Nh} \qquad (1)$$

where V_{max} is the maximum tangential wind speed of the cyclone, N is the Brunt-Väisälä frequency upstream of the orography, and h is the mountain height along with other parameters (e. g. U/Nh). In this paper, we will examine to what extent this control parameter dictates whether Genoa cyclones are deflected as they impinge on the Apennines. We will accomplish this goal through comparison of two of the above mentioned cases: IOP-1 and IOP-8.

2. TRACK DEFLECTION AND FLOW CIRCULATION: OBSERVED DATA

Let us first consider the behavior of the IOP-8 cyclone. The IOP-8 Genoa cyclone initially developed between 00 UTC and 06 UTC 21 October 1999. Figure 1 shows sea-level pressure and surface winds from 12 UTC 21 October 1999 (10/21/12Z) to 10/22/12Z. These analyses are based on the ECMWF 0.5° resolution data. At 10/21/12Z (Fig. 1a), the cyclone (marked as L1 in Fig. 1a) was situated just west of Corsica. During the following 12 h, the cyclone moved eastward, toward the Italian Peninsula and the Apennines. At 10/22/00Z (Fig. 1b), the cyclone was centered over the western coast of Italy. By this time, a secondary cyclone (marked as L2 in Fig. 1b) had developed over the eastern coast of Italy, on the lee side of the Apennines. Between 10/22/00Z and 10/22/12Z, the secondary cyclone phased with the upper level low and became the dominant surface feature. Figure 1c shows that by 10/22/12Z, the original cyclone no longer existed.

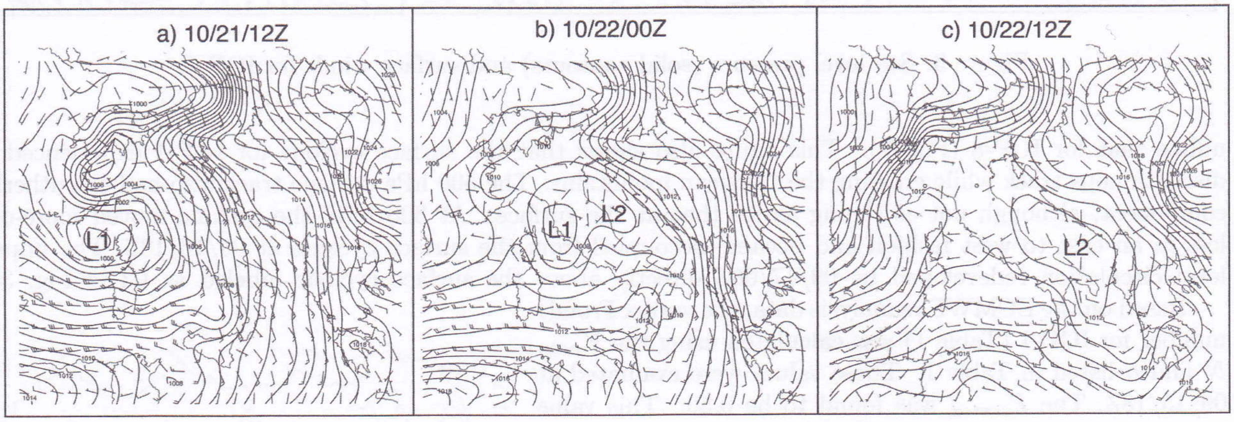

Figure 1: Sea level pressure (solid contours) and surface winds for IOP-8.

A more complete assessment of cyclone track can be gained through inspection of Fig. 2 which shows the cyclone position at the surface, 500 hPa and 300 hPa. The surface cyclone track shows that 10/22/06Z, there were two cyclones present. At 500 and 300 hPa, the track was continuous. For IOP-8, the cyclone track was essentially oriented east to west.

The surface cyclone for IOP-1 developed between 09/15/00Z and 09/15/06Z. The sea-level pressure and surface winds for IOP-1 are shown in Fig. 3. Figure 3a shows that at 09/15/18Z, the cyclone was positioned just west of Corsica. By 09/16/12Z (Fig. 3b), the cyclone had moved past Corsica and was just west of the Italian coastline. To the lee of the Apennines, a secondary cyclone, the so-called Adriatic cyclone, had developed. The Genoa cyclone and Adriatic cyclone (labeled as L1 and L2, respectively in Fig. 3) coexisted for 18 h. Rather than continue eastward over the Apennines, the Genoa cyclone was deflected toward the south during the following 12 h. Figure 3c shows the Genoa cyclone was just north of Sicily at 09/17/06Z. Also at this time, a new cyclone, labeled as L3 in Fig. 3c, had developed just south Italy. Similar analyses at later times (not shown) indicate this cyclone, L3, phased with the upper level trough and went on to become the dominant surface cyclone while the original cyclone, L1, decayed.

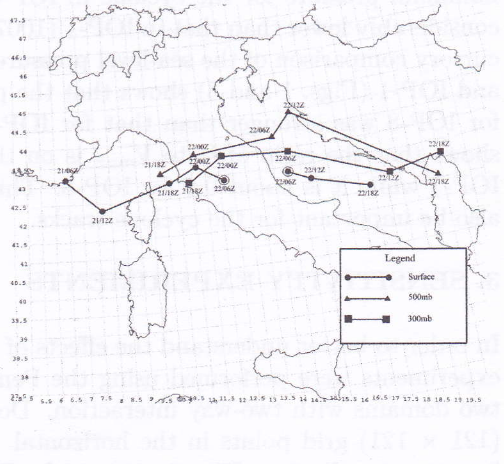

Figure 2: Cyclone track for IOP-8 at the surface, 500 and 300 hPa (see legend in figure).

The cyclone tracks at the surface, 500, and 300 hPa are shown in Fig. 4. This figure shows the track for the surface cyclone had a strong southerly component,

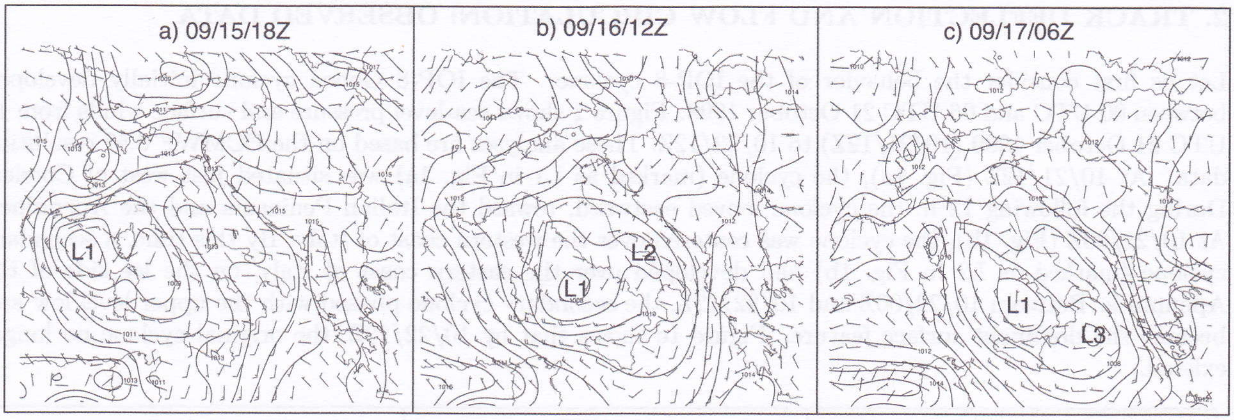

Figure 3: Sea level pressure (solid contours) and surface winds for IOP-1.

unlike that for IOP-8 (Fig. 2). This figure also shows that the surface cyclone for IOP-1 experienced a discontinuous track while crossing the Corsican mountains. The 500 hPa cyclone track also had a southerly component, although not as strong as for that at the surface. At 300 hPa, the cyclone moved more-or-less in an east to west fashion and became decoupled from the surface cyclone at 09/16/18Z. The upper level circulation redeveloped by 09/17/06Z directly above the surface cyclone labeled as L3 in Fig. 3c.

Based on the ECMWF reanalysis data, the vortex Froude number for IOP-1 (Table 1) was calculated using the V_{max}, N and h listed in Table 1. These values were evaluated at 09/15/18Z. The F_{vortex} was found to be 0.50. This value is very small compared to the minimum F_{vortex} necessary for non-deflected cyclone tracks. The vortex Froude number (F_{vortex}) for IOP-8 calculated at 10/21/06Z is 1.16. This value is large compared to the minimum F_{vortex} noted in Lin et al. (2005) for a discontinuous, not deflected cyclone track and, therefore, supports the notion that F_{vortex} may be an important control parameter dictating whether or not Genoa cyclones are deflected by the Apennines. There are a couple of additional points of interest in Table 1. First, the minimum pressure for the cyclone in IOP-8 (994 hPa) was considerably lower than that in IOP-1 (1007 hPa). In fact, a cursory comparison of the sea-level pressure fields for IOP-8 and IOP-1 (Figs. 1 and 3) shows that the pressure gradient for IOP-8 was stronger than that for IOP-1. Table 1 also shows that the ratio of U to V_{max} is on the order of 1 for IOP-1 while it is about 0.6 for IOP-8. This difference may also be important for the cyclone tracks.

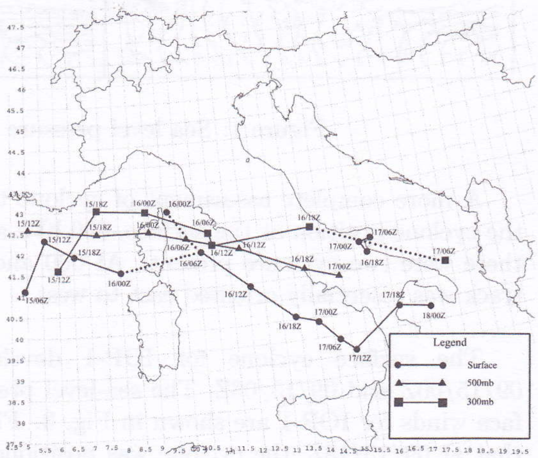

Figure 4: Cyclone track for IOP-1 at the surface, 500 and 300 hPa (see legend in figure).

3. SENSITIVITY EXPERIMENTS

In order to better understand the effects of orography on the cyclone tracks for IOP-1 and IOP-8, numerical experiments were performed using the Pennsylvania State/NCAR MM5. These experiments incorporated two domains with two-way interaction. Domain 1 (2) used a grid spacing of 45 km (15 km) with 91 × 85 (121 × 121) grid points in the horizontal. The vertical grid spacing was stretched with 45 vertical levels in $\sigma - p$ coordinates. The time steps for Domains 1 and 2 were 90 and 30 s, respectively. All simulations were initialized with ECMWF ERA40 2.5°×2.5° reanalysis data. The IOP-8 experiments were initialized at 10/17/00Z while the IOP-1 experiments were initialized at 09/14/00Z.

Control simulations were performed for each case. These simulations agree well with the observations and reanalysis data on the cyclone track and strength of the cyclones (not shown).

Table 1: Flow and orographic control parameters estimated at 10/21/06Z for IOP-8 and 09/15/18Z for IOP-1. The meanings of the symbols are as follows: U is the basic state wind speed, V_{max} is the maximum tangential speed of the vortex, R_{max} is the maximum radius of the vortex, P_{min} is the minimum pressure of the cyclone, h is the height of the Apennines, and N is the Brunt-Väisälä frequency (assumed to be 0.01 s^{-1}

	U	V_{max}	P_{min}	h	U/Nh	V_{max}/Nh
IOP-8	10.84 m s^{-1}	17.5 m s^{-1}	994 hPa	1500 m	0.72	1.16
IOP-1	6.5 m s^{-1}	7.5 m s^{-1}	1007 hPa	1500 m	0.43	0.50

In order to determine whether track deflection is dependent on F_{vortex}, sensitivity experiments were performed wherein the height of the Apennines was set to zero. In the IOP-8 sensitivity experiment, the surface cyclone crossed over Italy without experiencing a discontinuous track. Aloft, the motion of the system was comparable to that in the control experiment and observations. In the IOP-1 sensitivity experiment, the surface cyclone still appeared to be deflected to the south. This suggest that F_{vortex} is not the only parameter that dictates whether mid-latitude, mesoscale cyclones experience track deflection.

4. SUMMARY

In this study, whether or not F_{vortex} dictates if a mid-latitude, mesoscale cyclone's track will be deflected by orography has been examined through a comparison of two Genoa cyclones that occurred during MAP IOP-1 and IOP-8. Both cyclones in these cases formed over the Gulf of Genoa, propagated eastward, and impinged on the Apennines over the Italian Peninsula. The surface cyclone associated with IOP-8 stalled on the upstream side of the Apennines while a secondary cyclone developed to the lee of the Apennines. As the upper level wave passed over the Apennines, it phased with the secondary cyclone. The secondary cyclone subsequently strengthened while the initial cyclone dissipated. This cyclone has been classified as a discontinuous but not blocked cyclone. During IOP-1, the surface cyclone appeared to be blocked by the Apennines and deflected southward. Although a cyclonic circulation was detected to the lee of the Apennines for this case, the upper level trough did not phase with this circulation and the initial cyclone remained the dominant surface feature. Calculation of F_{vortex} shows that IOP-8 had a much higher F_{vortex} than IOP-1, a finding that is consistent with that of Lin et al. (2005). However, the sensitivity experiments do not corroborate this finding. Rather, these experiments indicate that there are likely other control parameters not accounted for here that dictate the track of a cyclone impinging on orography. Future work will attempt to uncover these parameters.

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