The role of blocking in the structure of Mediterranean cyclones which affect Middle-East and Iran

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Abstract

Blocking can affect atmospheric motions and the formation and track of pressure systems. The Mediterranean Sea is one of the important centers of cyclogenesis in the Northern Hemisphere, and most of the cyclones affecting the Middle-East region during autumn and winter originate over the Mediterranean Sea. Therefore, investigating the impact of blocking on Mediterranean cyclogenesis would help understand the dynamics and characteristics of these systems and, hence, forecasting the weather conditions. Thus, the role of blocking in the structure and life cycle of Mediterranean cyclones is studied here. Mean sea level and upper level synoptic maps in recent years were used to select two cyclones (one in the presence and another in the absence of blocking). The Meso-scale Model Version 5 (MM5) was used to simulate the two cyclones. The study region covered eastern North Atlantic, Europe, the Mediterranean and Iran (30°W - 90°E, 15°N - 65°N). The MM5 outputs were investigated by comparing the following physical, dynamical and thermodynamical fields: horizontal components of the wind speed, vertical motion, relative vorticity, potential vorticity, temperature, potential temperature and relative humidity. Results show that blocking (1) produced a negative anomaly in the zonal and a positive anomaly in the meridional components of wind (2) intensified the relative and potential vorticity and (3) increased vertical motion, relative humidity and precipitation amount. Furthermore, blocking intensified and increased the life span of the cyclone and changed its direction towards lower latitudes. Although this subject deals with scales larger than the general soaring scales, it is necessary to first understand the large scales.

Nomenclature

E	East
NE	Northeast
SW	Southwest
GFS	Global Forecast System
NCEP	National Centers for Environmental Prediction
hPa	hecto-Pascal
MM5	Meso-scale Model Version 5
N	North
RH	relative humidity, *%*
T	temperature, *K*
u	zonal component of wind speed, *m/s*
v	meridional component of wind speed, *m/s*
w	vertical component of wind speed, *m/s*
W	West
ξ	vertical component of relative vorticity, *1/s*
θ	Potential temperature, *K*
UTC	Coordinated Universal Time
ϕ	geopotential height, m^2/s^2
σ	static stability parameter
PV	potential vorticity, *pvu*$(Km^2/kg.s)$
ρ	density, g/cm^3
ς_a	absolute vorticity, *1/s*
MSL	mean sea level

Introduction

Synoptic scale disturbances are sometimes associated with alterations in the planetary-scale circulation through the formation of blocking systems. Whether all planetary-scale blocking circulations are associated with antecedent synoptic-scale cyclones, however, has not been resolved. Conversely, it is not known how frequently synoptic-scale cyclones are linked with future blocking systems.

The relationship between atmospheric blocking and antecedent, upstream cyclone activity has been a matter of considerable scientific interest since this possible relationship was first suggested[1]. The onset of blocking flow following upstream cyclogenesis has been documented in case studies[2, 3, 4] and in climatological analyses.[5, 6, 7, 8] In particular, Konrad and Colucci[6] note that the onset of persistent, synoptically defined blocking patterns is preceded by an upstream rapidly intensifying[9] surface cyclone associated with a northeastward-moving mid-tropospheric trough. It is assumed that the trough moves with the background planetary-scale flow. This finding suggests that a necessary condition for the onset of blocking might be the occurrence of rapid surface cyclogenesis downstream of a planetary-scale trough such that the midtropospheric planetary-scale flow over the surface cyclone is southwesterly. Whether cyclone-scale processes are responsible for blocking onset or are only coincidentally related to blocking development through some other mechanisms has not been unambiguously established.

Basic locations for the formation of atmospheric blocking in the Northern Hemisphere are the Atlantic and Pacific Oceans and Europe.[10, 11] The Mediterranean Sea is considered to be one of the most cyclogenetic areas in the World[12, 13] usually favoring development of weak low-pressure systems. However, occasionally the region is subjected to deep cyclogenesis that causes a series of severe weather events as they advect throughout the Mediterranean area. Deep Mediterranean cyclones cause considerable winds and rainfalls. Most of the cyclones that affect Iran and the Middle-East are generated over the Mediterranean or intensified in this basin.[14]

The purpose of the work reported here is to qualitatively investigate the role of blocking on cyclogenesis over the Mediterranean Sea. To do this, blocking versus non-blocking events during synoptic-scale cyclogenesis are considered through a concurrent examination of surface cyclones in the winter time over the Mediterranean Sea and its nearby region. The possible impacts of blocking on cyclone properties, such as structure, life span and direction are investigated.

Data and methodology

Using 500 hPa geopotential height and MSL pressure synoptic maps at 0000, 0600, 1200 and 1800 UTC, cyclogenesis events during the winter seasons (December, January and February) from December 2004 through February 2007 over the Mediterranean Sea were identified. Two cyclones (one in the presence of blocking and another in the absence of blocking) were chosen among the numerous blocked and non-blocked cyclogenesis events that occurred in the identified period. The properties of these cyclones such as their structure, life cycle and path of movement were analyzed. Then the MM5 was run for the periods of these cyclones using the NCEP GFS data as the initial and boundary conditions.

The physical and dynamical model outputs, including zonal and meridional components of horizontal wind speed, temperature advection, vertical motion, temperature and potential temperature, vertical component of relative vorticity and relative humidity were analyzed and compared for the two events.

Region of study

The domain includes 15°N - 65°N and 30°W - 90°E. This region consists of the cyclogenetically active eastern Atlantic Ocean and Europe (location of blocking), the Mediterranean Sea (where cyclogenesis is investigated) and the Middle East and Iran (where cyclones affect).

Events of study

The period of interest was divided into two events, each corresponding to the life cycle of a surface cyclone. In this section the surface and 500 hPa features of the two cyclones are synoptically evaluated and compared.

Event 1

The first cyclone event began on 26 January 2006 while at the same time a surface low-pressure system appeared over the west of the Mediterranean Sea. This event, which occurred in the presence of a 500 hPa ridge, corresponds to an Omega-type block observed over Europe at the beginning of the period. In this blocking structure, two troughs were observed with a ridge in between, each trough associated with a surface cyclone: one over the eastern Atlantic Ocean and the other over central Europe. This Omega-type block was well established over the Atlantic Ocean, with an anticyclonic vortex at high latitudes and two cyclonic vortices at middle latitudes. On 26 January 2006, a cut-off low was formed over the west of the Mediterranean Sea by spreading the western low pressure of the Omega pattern.

This cyclone intensified and migrated eastward over the southern coast of the Mediterranean (Fig. 1). The most significant intensification occurred on 1 February. The 544 dm contour at 500 hPa in the mature stage of this event was observed in the region (Figure not shown). The corresponding MSL map is illustrated in Fig. 2a. The 500 hPa geopotential height and surface pressure maps show decaying stage of the cyclone and it entirely disappeared on 5 February.

Event 2

The second event occurred during 8-14 February 2007 in the absence of blocking. In this event, the 500 hPa synoptic–scale trough associated with the surface cyclone evolved into an intense cyclonic vortex. There was no intensification or retrogression of the Atlantic blocking ridge during this event. The cyclone was formed on 8 February 2007 and followed a path along the northern coast of the Mediterranean (Fig. 1) and migrated eastward over this basin. It intensified over a period and the maximum of intensification happened on 11 February (Fig. 2b). Then, the cyclone started to weaken and it disappeared on 14 February.

It is concluded from the analysis of the synoptic maps that a blocking episode can affect the cyclone properties such as its path of movement and life span. The ridge of the block pattern forces the cyclone to change direction and to migrate over lower latitudes. In addition, the quasi-stationary property of the block expands the life time of the event.

Physical and dynamical analyses

Horizontal wind speed

Figures 3 and 4 show the 300 hPa simulated zonal and meridional components of the horizontal wind (u and v) at 0000 UTC on 1 February 2006 and 11 February 2007, which are the mature stages of the two cyclones. Corresponding to these fields, there is a larger v component in the blocked cyclone. Also, the u component is negative in the presence of blocking. In other words, there is a concurrent weakening of planetary-scale westerlies, relative to normal, and amplification of planetary waves leading to the development of anomalously large meridional (i.e., southerly) flow near and prior to block onset. Therefore, blocking, in these cases, caused the wind to become eastward which led to more intense southerlies. Intensification of v happened because the atmospheric flow tends to follow the Omega pattern of the block. Also, because the block episode is quasi-stationary, it caused u to change to easterly or weak westerly flow.

Vorticity

The vertical component of the relative vorticity is calculated as:

$$\xi = \left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \right) \quad (1)$$

As discussed above, there is greater v and weaker u associated with the blocked cyclone than the non-blocked one. Therefore, we expect a greater ξ over the region in the presence of blocking. This point is confirmed in the simulated 500 hPa vorticity fields in Figs. 5a and 5b.

Temperature advection

The equation of temperature advection is given as:

$$-V.\nabla T = -\left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} \right) \quad (2)$$

As was shown before, u is negative and v is greater in the blocked event than the non-blocked event. Also, the second term in the right-hand side of Eq. (2) is negative because temperature generally decreases with latitude. Therefore, corresponding to Eq. (2), we expect more intense warm advection in the presence of blocking. The simulated temperature advection fields (not shown) support this fact.

Temperature

Model simulated 850 hPa temperature fields at the mature stage of the two cyclones (not shown) reveal little difference between temperature fields of the two cyclones. It seems that blocking did not affect temperature in these events. Further studies are needed before this conclusion can be generalized.

Potential temperature

Cross-sections of potential temperature in a NE-SW direction (Fig. 6) at 0000UTC on 1 February 2006 and 11 February 2007 are illustrated in Figs. 7a and 7b. As seen in these figures, in the presence of blocking, the potential temperature gradient in the upper levels is greater than this quantity in the absence of blocking. Therefore, the static stability ($\sigma \propto \partial\theta/\partial z$) is greater in the blocked cyclone.

Potential vorticity

The NE-SW cross-sections of *PV* in the mature stages of cyclones are presented in Figs. 7c and 7d: there are sharp gradients in *PV* contours which are augmented for the blocked cyclone. The sharp gradients of *PV* in the upper levels correspond to sharp gradients of potential temperature.

The equation for *PV* is written as[15]:

$$PV = \frac{1}{\rho}\varsigma_a.\nabla\theta \quad (3)$$

Equation (3) states that *PV* is directly proportional to static stability. Therefore, an intense *PV* anomaly is expected where the static stability is large.

Tropopause folding, which penetrates the stratospheric *PV* into the troposphere, occurred in the mature stages of the two cyclones. But, the folding is more intense in the presence of blocking.

Vertical motion and relative humidity

Figures 7e and 7f show the cross-section of vertical motion (w) in NE-SW direction in the mature stages of cyclone events: there were anomalies in the w cross-sections in both cyclones. However, there was greater w and a more intense anomaly in the blocked cyclone. A similar pattern was observed in the cross-sections of *RH* (not shown). In the presence of blocking the anomaly is larger. It can be expected that increased relative vorticity and static-stability increases w and *RH*, leading to increased rainfall for the cyclones associated with blocking.

Conclusions

The effects of blocking on cyclogenesis over Mediterranean Sea has been qualitatively examined for two surface cyclones (one, in the presence and another in the absence of blocking) during winter seasons but in different years.

Analysis of synoptic maps shows that the blocked cyclone had a longer period than the non-blocked one. Also, blocking made the cyclone migrate in the lower latitudes; it migrated over the southern coast of the Mediterranean, while the non-blocked cyclone followed a path over northern parts of the Mediterranean.

It is concluded from the MM5 simulated fields, that the most significantly different feature between the blocked-cyclone and non-blocked one was the anomalously weaker westerlies over the blocked cyclone. The weakened westerlies has been reported previously[16, 17]. For example, Shutts[18] obtained block development in a barotropic model through eddies interacting the westerlies. In addition, in our simulations, blocking made the vorticity, warm advection, static stability and *PV* increase while the temperature fields of the two cyclones were similar. Additionally, blocking intensified and increased the life span of the simulated cyclone and changed its direction towards lower latitudes.

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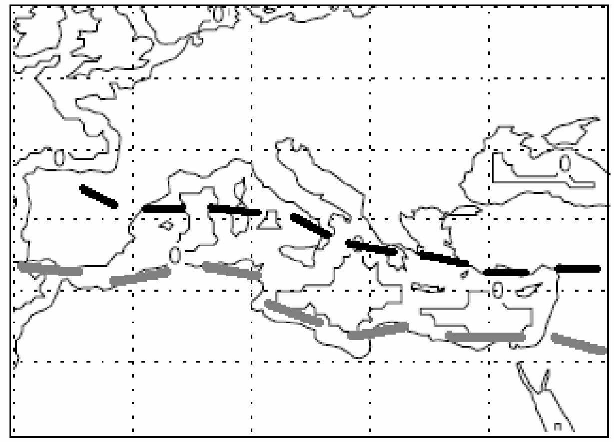

Figure 1 Path of movement of the blocked cyclone (gray dashed line) and the non-blocked cyclone (black dashed line).

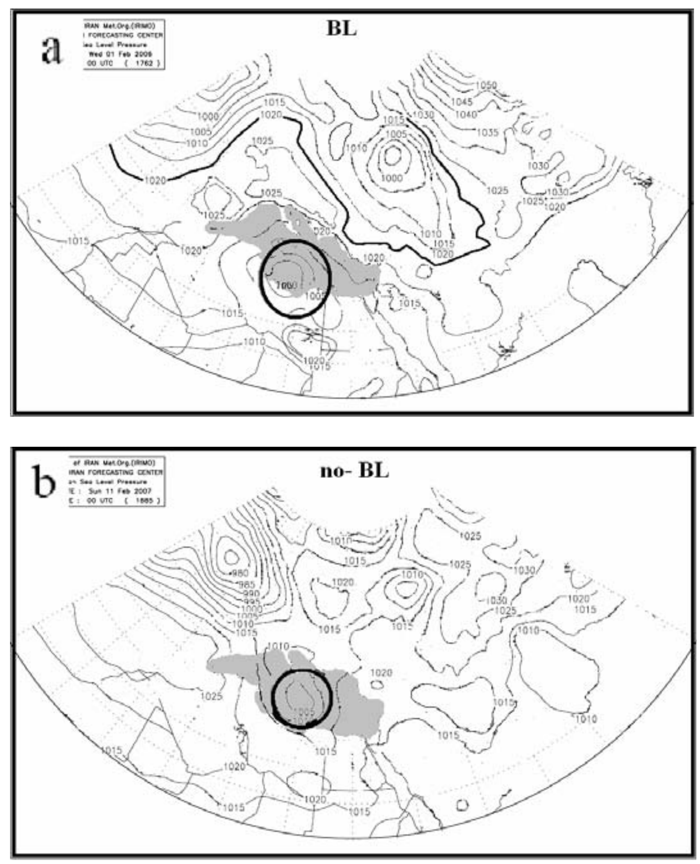

Figure 2 Pressure (5 hPa contour interval) actual maps at Mean Sea Level at 0000 UTC on (a) 1 February 2006 (blocked cyclone) and (b) 11 February 2007 (non-blocked cyclone). The Mediterranean Sea and center of cyclone are shown, respectively, with the gray shaded area and the black circle. The Omega block is shown with the black line on (a).

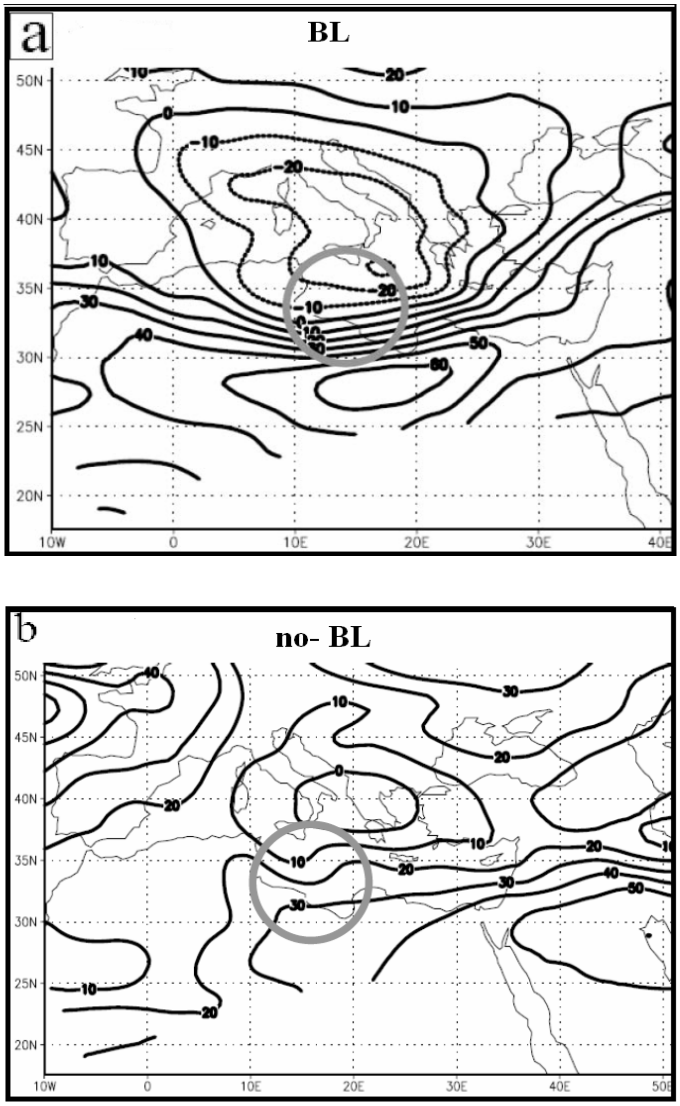

Figure 3 Zonal component of the simulated wind speed (solid lines with 10 m/s contour interval) at 300 hPa at 0000 UTC on (a) 1 February 2006 (blocked cyclone) and (b) 11 February 2007 (non-blocked cyclone). The center of the cyclone is shown with the gray circle.

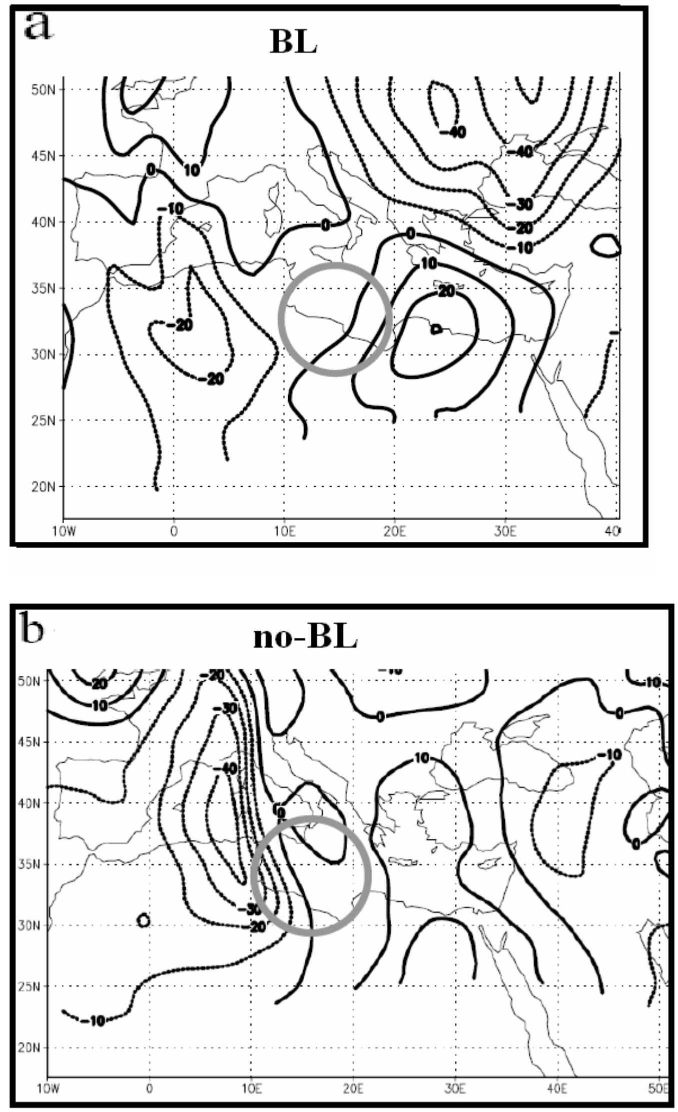

Figure 4 Meridional component of the simulated wind speed (solid lines with 10 m/s contour interval) at 300 hPa at 0000 UTC on (a) 1 February 2006 (blocked cyclone) and (b) 11 February 2007 (non-blocked cyclone). The center of cyclone is shown with the gray circle.

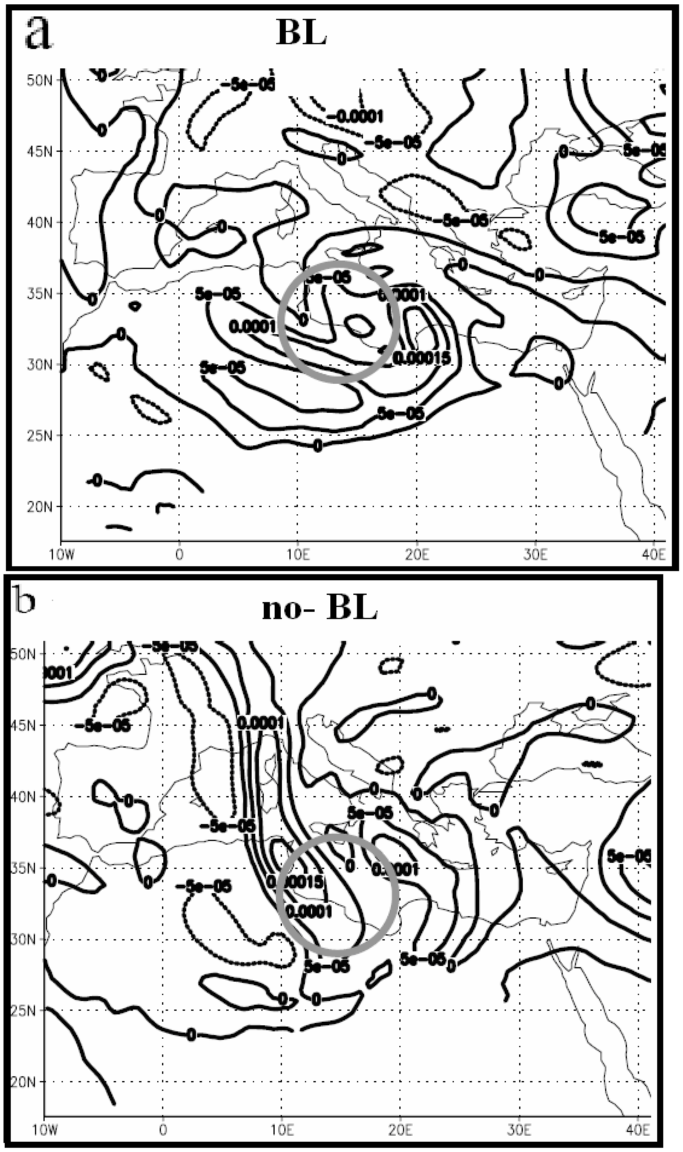

Figure 5 Vertical component of the simulated relative vorticity (solid lines with 5e-5 1/s contour interval) at 500 hPa at 0000 UTC on (a) 1 February 2006 (blocked cyclone) and (b) 11 February 2007 (non-blocked cyclone). The center of the cyclone is shown with the gray circle.

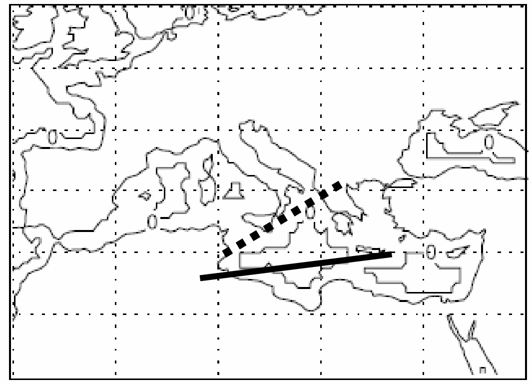

Figure 6 Location of the cross-sections shown in Fig. 7 on 1 February 2006 (solid line) and 11 February 2007 (dotted line).

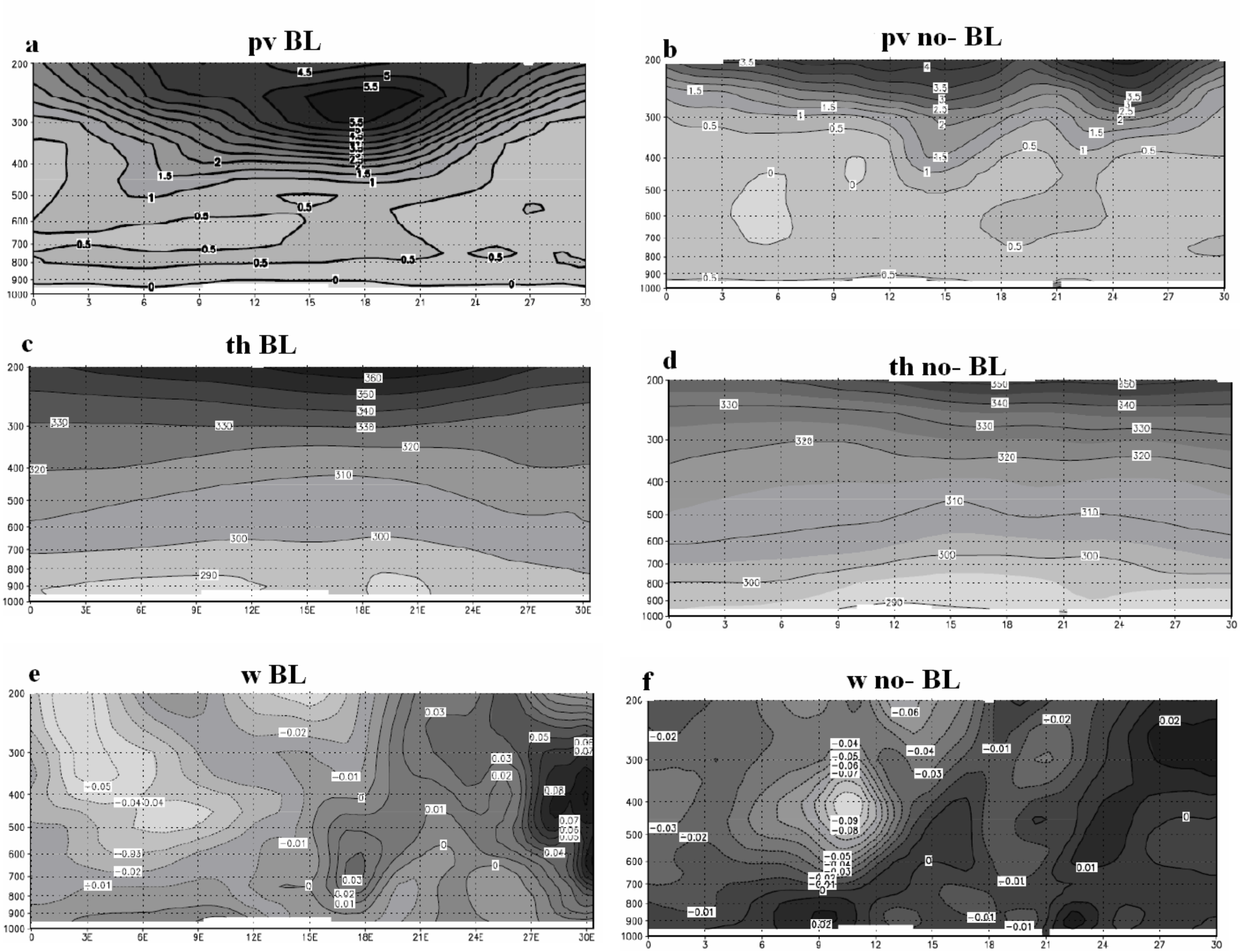

Figure 7 (a) *PV* (gray shaded with 0.5 pvu contour interval), (c) potential temperature (gray shaded with 10 K contour interval) and (e) *w* (gray shaded with 0.01 m/s contour interval) NE-SW cross-section at 0000 UTC on 1 February 2006 (blocked cyclone) and (b) *PV* (gray shaded with 0.5 pvu contour interval), (d) potential temperature (gray shaded with 10 K contour interval) and (f) *w* (gray shaded with 0.01 m/s contour interval). NE-SW cross-section at 0000 UTC on 11 February 2007 (non-blocked cyclone).