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Full Length Research Paper

The role of the subtropical jet stream in cyclogenesis over the Central Mediterranean Sea: A case study of February 1974

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The Mediterranean Sea is recognized as one of the most important locations for cyclogenesis. In the course of this study, the role of subtropical jet stream in the formation of a deep cyclone over the central part of the Mediterranean Sea during 21 to 23, February 1974, was studied. The analysis based on NCEP data showed that there was a strong link between the presence of a subtropical jet along the African coast of Mediterranean Sea with the core speed of 60 to 70 ms^{-1} and its associated secondary circulation with the formation of that cyclone. Analysis also showed that there were strong positive vorticity advection at 500 hpa and divergence in horizontal wind field at 200 hpa surfaces that led to the occurrence of ascending motion maxima at the time of the formation of the cyclone.

Key words: Cyclogenesis, subtropical jet, divergence, positive vorticty advection (PVA).

INTRODUCTION

Some studies emphasis on the major role of the STJ (subtropical jet) streams or interaction PJ (polar jet) and STJ on the rapid development of cyclones over subtropical regions, United State, central part of the Mediterranean Sea and North Africa (Uccellini, 1987; Hakim and Uccellini, 1992; Prezerakos et al., 2006; Whitney, 1977; Kaplan et al., 1998; Prezerakos et al., 1997).

Idealized jet stream has shown that cyclonic vorticity advection and associated ascent can be collocated in the exit and entrance region of the jet (Reiter, 1972). According to the theory, observed divergence-convergence in the jet stream area develops due to the ageostophic ageostrophic circulation. Divergence which forms on the right side of the jet entrance and left side of the jet exit, resulting in large scale ascending motion and may trigger surface cyclone development.

The left side region of the jet stream axis is characterized by positive vorticity advection (PVA) with a maximum close to the western part of the cold front (Prezerakos et al., 1997).

Uccellini et al. (1984) focused on subtropical jet streaks and its role in the United States during pre-cyclogenesis period. They found maximum wind speed associated with STJ increased 15 to 20 prior to the development of the intense cyclone. Also, the divergence along the axis of the STJ increased as the wavelength of the trough-ridge system decrease.

In addition, upper level divergence is associated with upward vertical motion near the axis of the STJ. A transverse indirect circulation formed in exit of STJ, it can be formed upward motion between 400 to 700 hpa. In general, the vertical circulations have been related to cyclogenesis (Brill et al., 1985).

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Abbreviations: SJT, Subtropical jet; **PJ,** polar jet; **PVA,** positive vorticity advention.

Central Mediterranean Sea is one of the cyclogenesis areas in Mediterranean Sea

It has been recognized that Central and Eastern Mediterranean Sea cyclogenesis is usually forced by variety of upper-level troposhperic circulation features (Prezerakos et al., 1997). Some studies demonstrated that interaction between the PJ and STJ play major role in North African (Saharan cyclone) during cold season (Prezerakos et al., 2006; Prezerakos et al., 1997; Thorncroft and Flocas, 1997).

The approach of the PJ and the STJ to the central part of the Mediterranean Sea results in the strengthening of the upper-level wind field, the deepening of the height trough and the strengthening of the vorticity field to its maximum over the cyclogenesis area (Prezerakos et al., 1997).

However, the exact role of the interaction between PJ and STJ at the upper tropospheric levels on this type of cyclogenesis has not been fully determined (Reiter, 1972). In this study, cyclogenesis in February 1974 was considered because it seems that the STJ (not interaction STJ and PJ) has effective role in the cyclone development. The role of the upper level divergence associated with STJ during the various stages of cyclone development and the mechanisms responsible for the subsequent transformation of the initial relatively warm depression to a deep low pressure will be analyzed.

MATERIALS AND METHODS

The data used in this study was derived from the NCEP/NCAR archives of operational initialized analyses available every 6 h for the period of 22 to 26 February 1974. The data grid resolution is 2.5° × 2.5° and referred to the mean sea level and isobaric levels of 1000, 925, 850, 700, 500, 400, 300, 250, 200, 150 and 100 hpa.

The mean sea level pressure, geopotential height, wind speed were derived directly from NCEP data and the potential temperatures on 850 hpa, divergences on 200 hpa and vorticty advections on 500 hpa were calculated using a Fortran program based on NCEP data. The isopleths were plotted with the aid of Surfer software.

The dates and times referred to in the following sections have the format of *tt(UTC)dd* where *tt* stands for UTC time and *dd* for the day. The domain from 10 to 60°N and 0 to 60°E cover the study area. The central Mediterranean means from 15 to 22.5°E and 32.5 to 37.5°N, where is located between north of Libya and south of Italy.

The cyclogenesis selected in central Mediterranean was examine on the 21 to 24 February 1974, because It can be found by the analysis that the cyclone can progress only the presence of STJ not interaction STJ and PJ in central Mediterranean sea.

RESULTS

The cyclogenesis was initiated at 00(UTC) 21 February 1974 when the inverted pressure trough was extended to West-Northern Africa associated with the minor height trough at 500 hpa (not shown). The cyclone started to develop during the next hours and drop to minimum pressure 995 hpa at 00(UTC) 24. The figures were analyzed during 12(UTC) 21 to 12(UTC) 23 February with 24 h interval including cyclone formation and development process.

At 12(UTC) 21, the main axis of STJ with maximum speed value 62.5 ms^{-1} is directed from southwest to northeast, with its eastern edge being located at 25°N and its western extent at 30°N toward Northern Libya and Central Mediterranean Sea (Figure 1a). The surface pressure trough 1015 hpa has already developed from Africa toward northern Libya and Algeria is found beneath a STJ and divergence region at 200 hpa of $1 \times 10^{-5}\ s^{-1}$ (Figure 1a, c). At 500 hpa, low height is located over Western Europe which extended the weak height trough toward western Mediterranean Sea and northern Algeria (Figure 1b), while it is associated with the positive vorticity value $4 \times 10^{-5}\ s^{-2}$. The maximum upward motion 0.2 $pass^{-1}$ is seen ahead of positive vorticity but both of them are located beneath the upper-level divergence region at 200 hpa (Figure 1).

The 295 K contour is highlighted to show the pronounced cold advection that occurs during the next few days. Although, warm air is accompanied by inverted pressure trough which is defined as thermal pressure trough, the development and northward extended of thermal pressure trough initiates when the upper-level trough along with the accompanying cold advection and positive vorticity advection ahead approach to northwestern Africa (Figure 1b). The cyclogensis is started beneath upper-level STJ without PJ in this case.

Figure 2d shows vertical cross section along 12.5°E including isotachs, divergence field and upward motion. The upper-level divergence is located at 200 hpa left side STJ. In addition, surface convergence center is situated near 30 to 35°N exactly beneath the upper level divergence between them and weak upward motion occurred. Although, the PJ is in Figure 2d, it is located in high latitude far away inverted trough. It is found that PJ has no role in the extended pressure trough to northward.

In the following 24 h, maximum wind speed is increased to 70 ms^{-1} at 27.5 N over Algeria at the same time divergence value is increased to $1.5 \times 10^{-5}\ s^{-1}$ with eastward displacement located over Libya and near the exit of STJ (Figure 2a).

The cyclone is formed beneath upper-level divergence region and exit of STJ (Figure 2). It can be seen on the northern edge of a huge heat low that covers most of the north of Africa; a wavy pattern is formed that the western part of it turns to a deep dynamical low pressure over the middle of the Mediterranean Sea supported by STJ associated with divergence in its exit in 12 UTC 22 February. In this day, pressure at the center of that low pressure falls under 1005 hpa (Figure 2b); It can be confirm by Figure 2d that vertical cross section along 15°E, where the divergence field and upward vertical motion are intensified of left side STJ aloft developing surface cyclone. Also, there is no pronouncing PJ in Figure 2d.

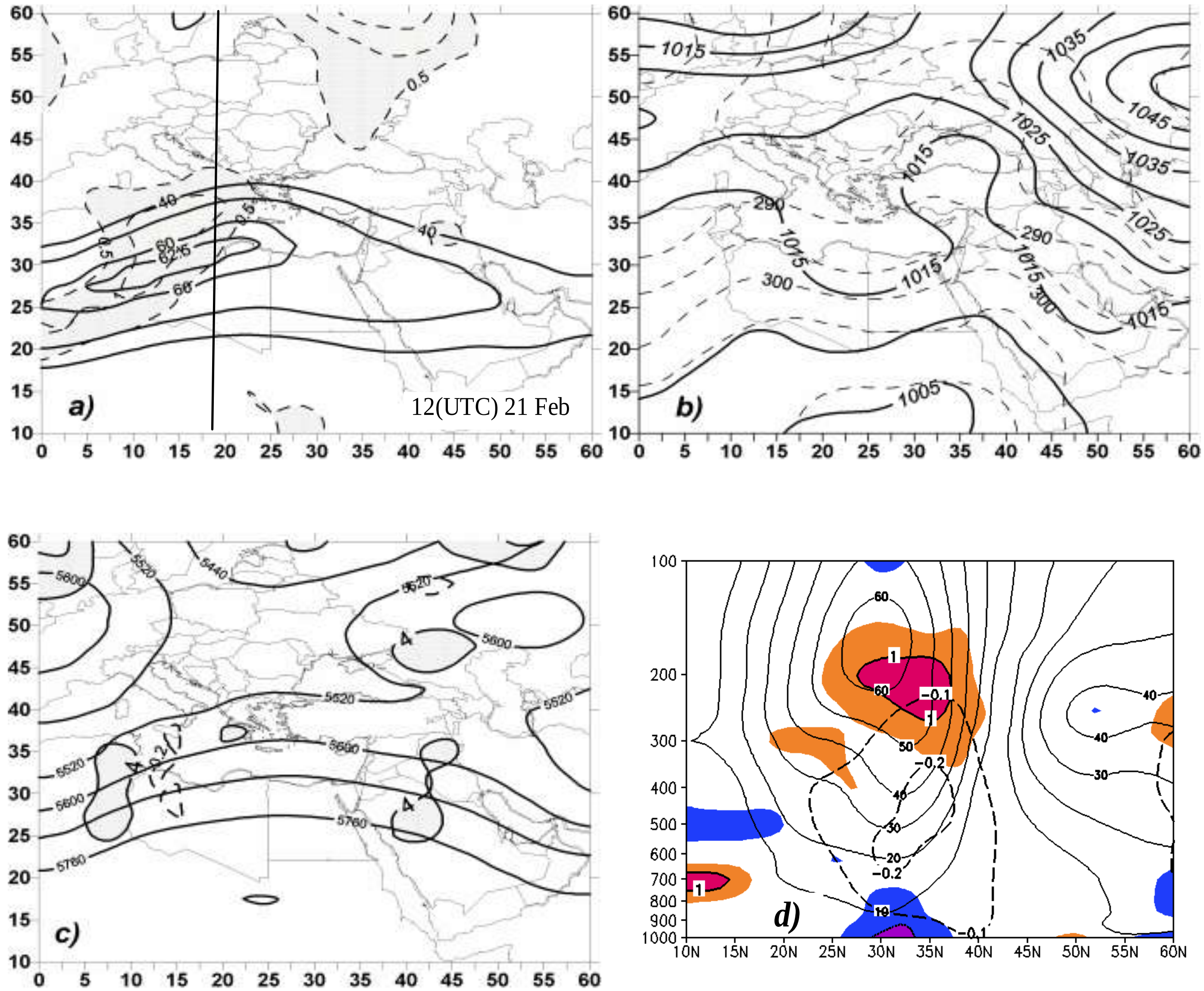

Figure 1. (a) maximum wind speed-isotach (ms-1-thick line), divergence (10^{-5} × s^{-1} -shaded area at 200 hpa level; (b) mean sea level pressure (hpa-solid line), potential temperature (K-dashed line) at 850 hpa level; (c) geopotentail height (m-thick line), ascending motion (pass^{-1} dashed line), positive vorticity advection (10^{-10} × s^{-2} -shaded area at 500 hpa; (d) vertical cross-section along 12.5°E, isotachs (ms^{-1}-solid line), horizontal divergence field (10^{-5} × s^{-1}-shaded area), upward vertical motion (pass^{-1} -dashed line); at 12(UTC) 21 February 1974.

Figures 1b and 2b, also, shows the potential temperature field in 850 hpa that is superimposed on the surface pressure field. Also, as the cyclone develops, there is pronounced cold advection behind and warm advection ahead of the cyclone. Southward cold advection is extended from Europe to Libya and warm advection Northward from Northeast Africa toward eastern Mediterranean Sea that is accompanied with pronounce height trough and ridge in 500 hpa (Figure 2b, c).

The potential temperature gradient increased between 12(UTC) 21 and 12(UTC) 22 February in North Africa. The observed patterns have indications of a well developed baroclinic disturbance associated with surface fronts.

It can be seen in Figure 2c, a small amplitude wave like disturbance over the Black Sea to the west of Mediterranean Sea and almost whole south coast of the Sea along the North of Africa. The 5520 m height contour reached into the North of Algeria and the height trough on 500 hpa surface coincides with low pressure in 12(UTC) 22 February (Figure 2c). According to Sanders and Gyakum (1980), this was not entirely favorable for low-level development since a majority of explosive cyclones originate with the axis of the 5520 m height contour in the

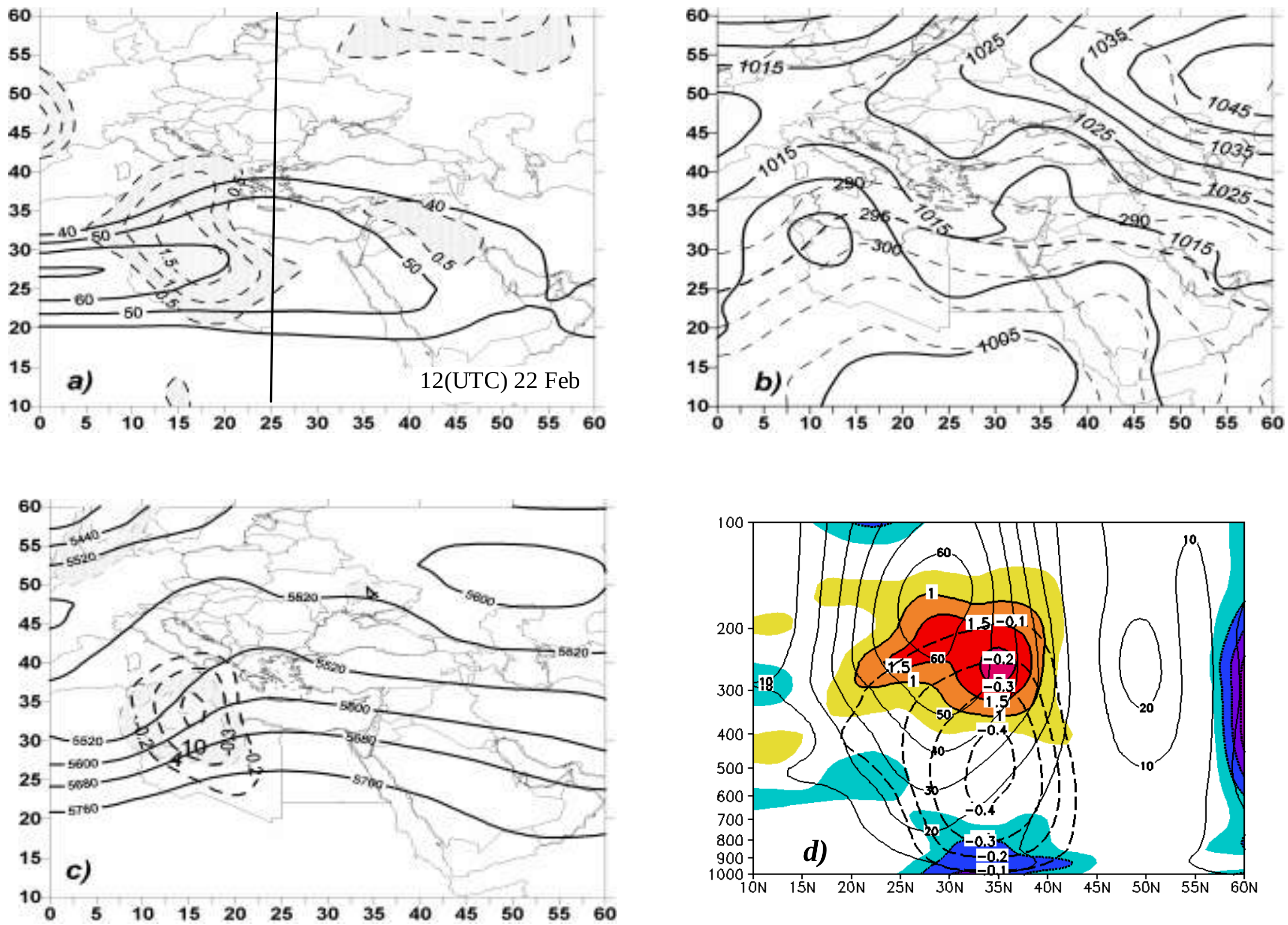

Figure 2. (a) Maximum wind speed-isotach (ms^{-1}-thick line), divergence ($10^{-5} \times s^{-1}$-shaded area at 200 hpa level; (b) mean sea level pressure (hpa-solid line), potential temperature (K-dashed line) at 850 hpa level; (c) geopotentail height (m-thick line), ascending motion (pass^{-1} dashed line), positive vorticity advection ($10^{-10} \times s^{-2}$-shaded area at 500 hpa; (d) vertical cross-section along 12.5°E, isotachs (ms^{-1}-solid line), horizontal divergence field ($10^{-5} \times s^{-1}$-shaded area), upward vertical motion (pass^{-1} -dashed line); at 12(UTC) 22 February 1974.

southwest quadrant of the surface low.

Also, the positive vorticity advection and upward motion are increased during the past 24 h as they coincided with each other located beneath the upper-level divergence and left exit of STJ, where the cyclonic curvature transformed to anticyclonic curvature (Figure 2a, c).

The deformation of wind field associated with increasing upper-level divergence and positive vorticity is caused increasing upward motion coincided with falling surface pressure.

The evolution of cyclone during the 24 h later to be followed

Comparing Figures 2a and 3a, significant change in wind field can be found so that maximum wind speed 70 ms^{-1} (STJ axis) is eastward shifted and located North-eastern Libya with southwest northeast direction between 25 to 30°N. The horizontal wind shear is intensified over central Mediterranean associated with strengthening cyclonic curvature. The maximum divergence value is $2.5 \times 10^{-5}\,s^{-1}$ in the left exit of STJ, where the horizontal wind shear is intensified. The divergence value is increased $1 \times 10^{-5}\,s^{-1}$ with wind field evolution in 200 hpa level during the past 24 h.

The intensification of divergence and upward motion associated STJ is shown by Figure 3d along 22.5°E that caused falling surface pressure and developing cyclone during past 24 h (Figure 3d) so that formed contour pressure 1000 hpa can moved to central Mediterranean (Figure 3b). At 500 hpa, evolution height shows close height contour with 5440 m over central Mediterranean Sea and south of Italy. The surface cyclone is located east of low height. Therefore, cold advection associated low height bring the decreasing temperature toward

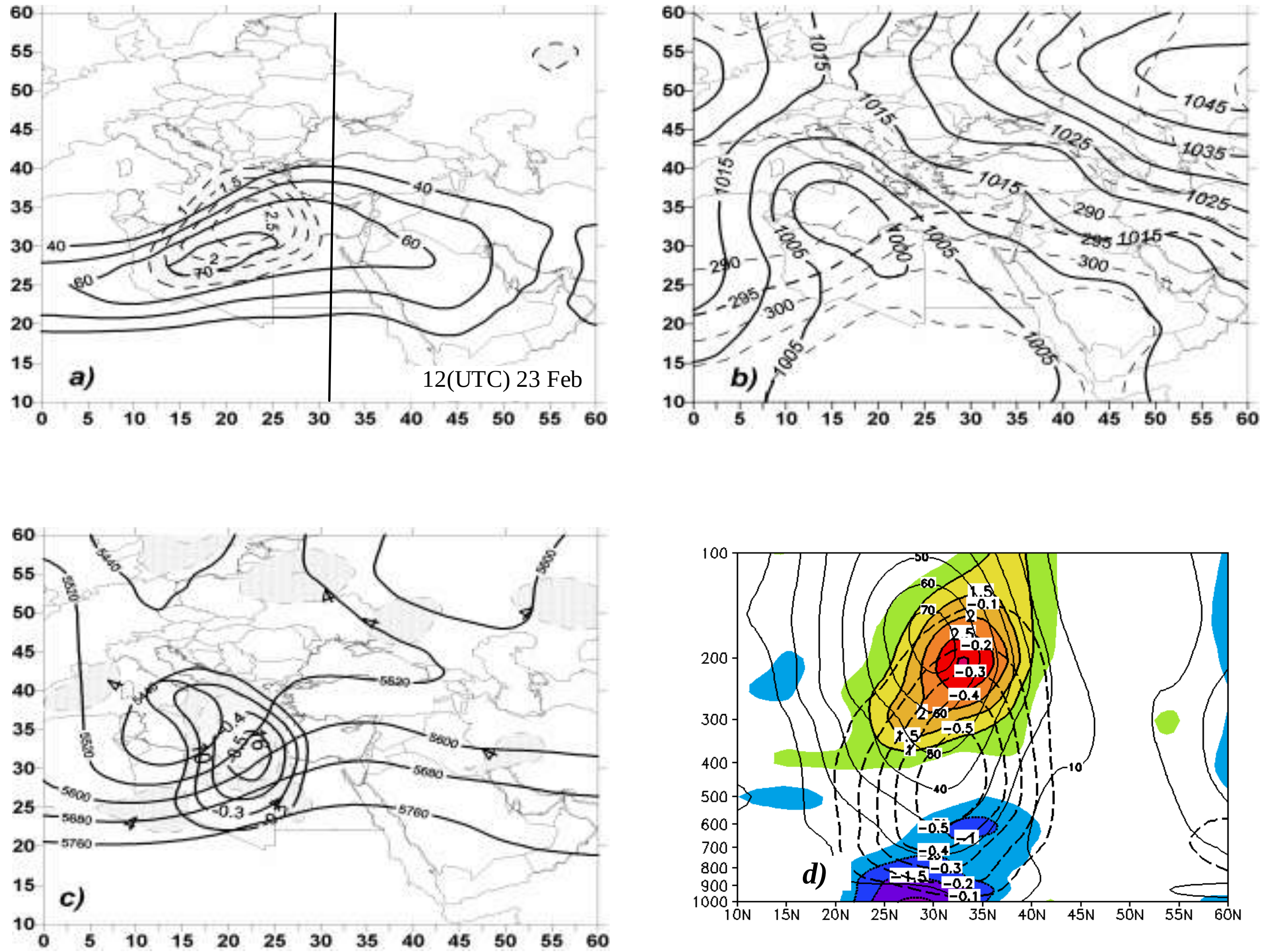

Figure 3. (a) maximum wind speed-isotach (ms^{-1}-thick line), divergence ($10^{-5} \times s^{-1}$ -shaded area at 200 hpa level; (b) mean sea level pressure (hpa-solid line), potential temperature (K-dashed line) at 850 hpa level; (c) geopotentail height (m-thick line), ascending motion (pass^{-1} dashed line), positive vorticity advection ($10^{-10} \times s^{-2}$ -shaded area at 500 hpa; (d) vertical cross-section along 12.5°E, isotachs (ms^{-1}-solid line), horizontal divergence field ($10^{-5} \times s^{-1}$-shaded area), upward vertical motion (pass^{-1}-dashed line); at 12(UTC) 23 February 1974.

Central Mediterranean Sea and North-western Africa, which is west of surface cyclone. On the other hand, warm advection (ridge height) has position to cyclone as the past 24 h (Figure 3b).

At 00(UTC) 24 February, the PVA maximum is located over north east of Libya and south of Greece and increases to 16 $\times 10^{-5} s^{-2}$ as the surface cyclone intensified (Figure 3c). The ascending motion increases to -0.5 Pa s^{-1} and moves to the east some where between Greece and Turkey at 12(UTC) 23 February (Figure 3c). At 12(UTC) 23 February, both ascending motion maxima and PVA maxima locations are in good agreement with the cyclogenesis and frontogenesis theories The sub-tropical jet stream intensified during the period of study and wind speed in its core increased to more than 70 ms^{-1} on the 23th of February. Cyclonic curvature and wind shear increased significantly between 12(UTC) 21 and 12(UTC)23. Jet direction, also, changed from the west to Northwest during its eastward movement with the surface weather system. At the same time, horizontal wind divergence field on the STJ left hand side exit increased from 1 $\times 10^{-5} s^{-1}$ on the 21 to 2.5 $\times 10^{-5} s^{-1}$ on 23 February.

DISCUSSION AND CONCLUSIONS

The cyclogenesis initiates in Northwestern Africa on the 21st of February, 1974, when a disturbance on the north western fringe of a huge depression over north of Africa starts to grow and move to the middle of the Mediterranean Sea. Study of the circulation patterns on the surface, 850, 500 and 200 hpa and their changes indicated that the development of the cyclone and its associated weather system fallow theory of cyclogenesis and frontogenesis, very well.

The heat pressure trough (North Africa) can evolution to dynamical cyclone in the beneath of STJ due to troposphric baroclinicity.

The study also shows that the subtropical jet stream, its cyclonic curvature and associated divergence field, that triggered a relatively high speed vertical motion in comparison with typical observed vertical motions in synoptic weather systems, have played a substantial role in the initiation and development of the under study weather system in the presence of distinct meridional temperature gradients.

The depression, being located in the zone of ascending motions resulting from indirect circulation in the STJ exists. Although, some studies found that North Africa depression developed due to the interaction of STJ and PJ; it realize progressing depression from 21 to 23 February 1974 was affected by STJ. The results of this study demonstrated that it is more necessary to consider how STJ or the interaction of STJ and PJ can cause development of North Africa cyclone.

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