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Synoptic and Numerical Studies for Simulating Weather Instabilities that Affect The Kingdom of Saudi Arabia in Winter: I. The Synoptic Case Study

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ABSTRACT. A study of a weather phenomenon was carried out, where interaction between middle latitude and tropical waves had occurred. The goal of this study was to simulate the interaction using a numerical model. The phenomenon occurred under winter synoptic regime and could lead to wide spread showers over a band that cover most of the kingdom. A detailed synoptic description of a case, where the interaction had occurred over west Africa, was discussed. It was shown that the invasion of cold air to the south of 30ºN was a necessary trigger action for such interaction. In this case a south wind component was developed due to air mass thermal differences. The developed wind component caused a change in the direction of the subtropical jet from westerly to south-west. This caused northerly advection of moist air from the Inter Tropical Convergence Zone (ITCZ) where deep convective cells existed. When a polar frontal system passed through the subtropical region and came in phase with the axis of the advected moisture tongue, rapid development of the system had occurred. In this case an active cloud band was formed and extended from the tropics to the middle latitude wave.

1. Introduction

One of the main active weather phenomena that affect the Kingdom of Saudi Arabia is the interaction between tropical and middle latitude waves. This phenomenon is a winter type regime that occurs during late September to February. It is accompanied by active cloud band that extends from the tropical region (about 5°N) to the middle latitude (about 35°N). An examination of mid-tropospheric flow, during the phenomenon, indicated that it was markedly distorted by strong meridional regime. In this case, a warm ridge was located over eastern Atlantic and was extended to Europe. This ridging lied between two active troughs. Such flow caused important weather anomalies as warm air was transported northward and cold air southward.

The effect of the tropical disturbances on the development of some winter middle latitude cyclones is old (El-Fandy (1950). Real progress in understanding the phenomenon started after the launch of satellites. These provide current real time images of clouds in both visible and infrared spectrums. They also supply us with atmospheric images of water vapor patterns. Benefits of such images to operational and research activities are invaluable. Nowadays equipment which receive the satellite data and display it are essential tool in meteorological offices. In fact satellite photos are vital device for allocating systems especially in areas with no (or sparse) ground based stations. Previous work (Zohdy, 1989) was published on the lateral coupling between extratropical and tropical disturbances. The author studied 205 synoptic situations that occurred during six year period (1980 - 1985). He showed that these cases were accompanied with huge cloud bands that extended from the African subtropical regions to the Mediterranean where middle latitude cyclones existed. The characteristics of these bands indicated that their length vary from 3000 to 10000 km, and the width from 600 to 1400 km. Their lifetime ranged from one to eleven days.

One of the atmospheric features that accompanies the middle latitude-tropical interaction is a blocking situation (Charney and Devore, 1979). The main consequences of this blocking is the substantial north (south) advection of warm (cold) air and the abnormal departure of the atmospheric waves to a track north or south of the blocking anticyclone. Thus, it causes weather anomalies which are clearly recognized in both temperature and precipitation patterns. The regions under the influence of a “blocking” ridge experience prolonged periods of hot and drought weather (Perry, 1976; Miles, 1977). It is established that blocking activity favors certain geographical locations. The eastern north Atlantic and the eastern north Pacific are examples (Treidle *et al.,* 1981) . This is an indication that surface effect is the main driving force for such phenomenon. An evidence that the surface topography support specific locations for the blocking phenomenon is the climatological mean charts. These time-averaged charts are indication of the surface nature since dynamic atmospheric waves are canceled out by the time averaging procedure. Fig. (1) shows the 700 mb mean winter geopotential field based on 26-year period (Namias, 1978). Note the ridging over the north-east Atlantic and north-east Pacific. These features exhibit a seasonal variation with maximum frequency in late winter and during the spring. This seasonal variation reflects the surface response to the large scale surface radiation balance. Statistically the occurrence of the phenomenon can differ remarkably from year to year (Namias, 1978).

In the present study, a winter synoptic situation that exhibits middle latitude-tropical interaction with a blocking situation was discussed. The climatological features compared to that of the synoptic case study were also presented.

2. Synoptic Case Study

A synoptic situation was investigated, where interaction between middle latitude wave approaching north east Africa came in phase with a tropical disturbance that located over Atlantic at 35°W, 5°N. This situation developed during January, 1991. The data used was obtained from the European Center for Medium Weather Forecast (ECMWF).

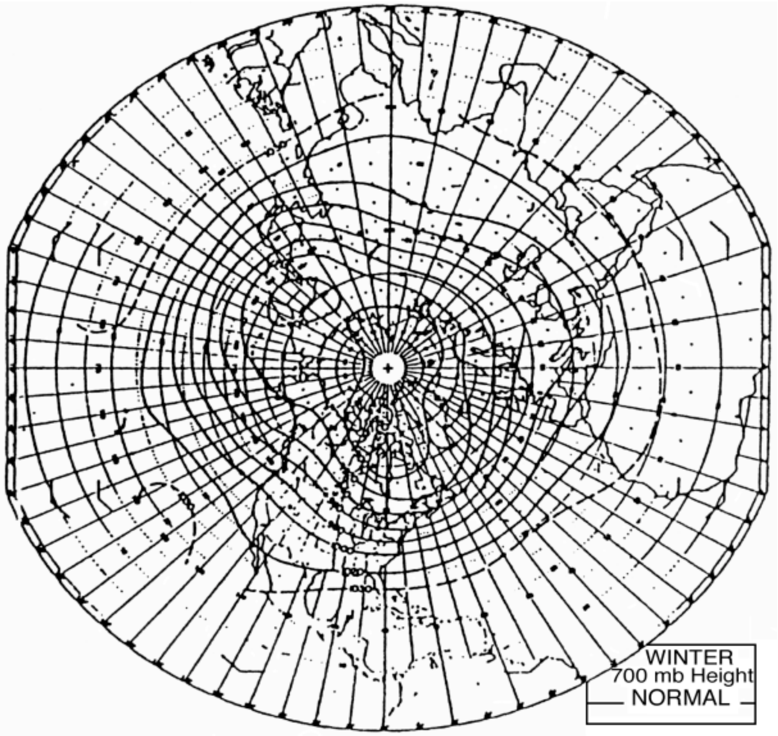

FIG. 1. Normal winter (December, January and February) 700 mb contours (in tens of feet) based on 26-year period, 1947-1972 (from Namias, 1978).

Figures (2)-(5) show the Meteosat infrared satellite cloud images for 21, 22, 25 and 26 of January 1991. On 21 January, Fig. (2), one could note the existence of a frontal system over the northern parts of Saudi Arabia with weak cloud extension over Africa at about 20°N. These clouds turned toward the ITCZ west of Africa at about 35°W, 5°N. The frontal system over Saudi Arabia represented an old polar front that was reinforced over Africa as a result of interaction between polar and tropical waves. On 22 January, Fig. (3), the frontal system moved over the Arabian Gulf and the cloud band, connected to the tropics, became very weak. The photo indicated also another cloud cluster over Spain and Morocco. This cloud assembly represented a frontal polar system that was approaching the area. . Unfortunately, the satellite images on 23 and 24 of January were not available. On 25 January, Fig. (4), the frontal polar system developed significantly with bright cloud band connected to the tropical disturbance over the Atlantic, which was located along the ITCZ. On 26 January, Fig.(5), The cloud band appeared weakened as the northern system separated from the tropical disturbance. The main concern, in this study, was to understand the development that occurred between 22 and 26 of January, 1991. Another paper will be dealt with the possibility of forecasting this development using a numerical model.

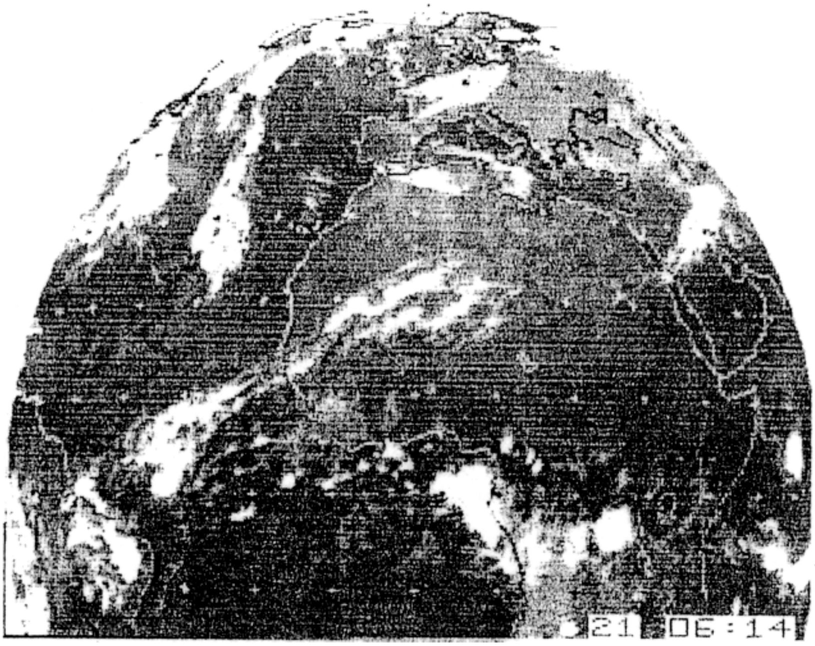

FIG. 2. Meteosat infrared satellite image on January 21, 1991 at 06: 14 GMT.

FIG. 3. Meteosat infrared satellite image on January 22, 1991 at 06: 14 GMT.

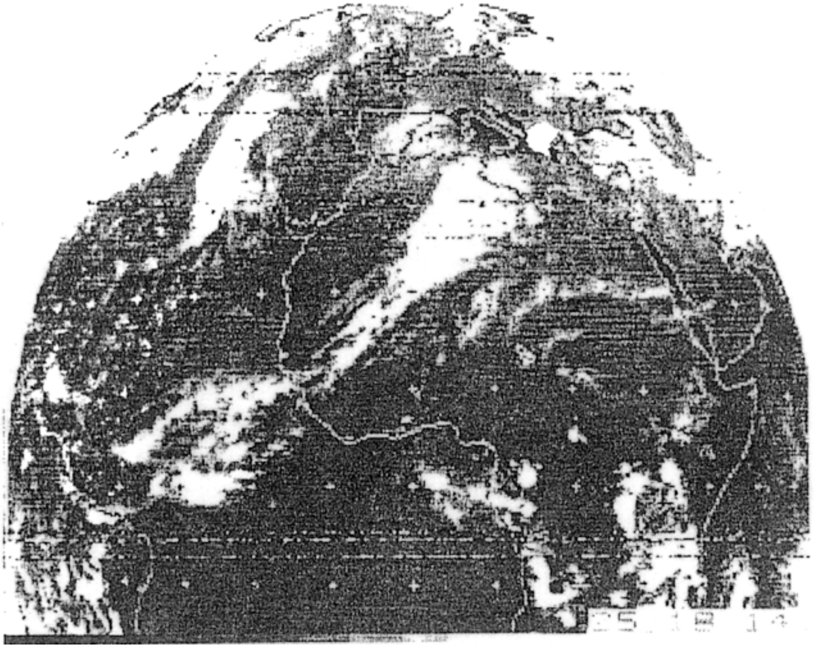

FIG. 4. Meteosat infrared satellite image on January 25, 1991 at 18: 14 GMT.

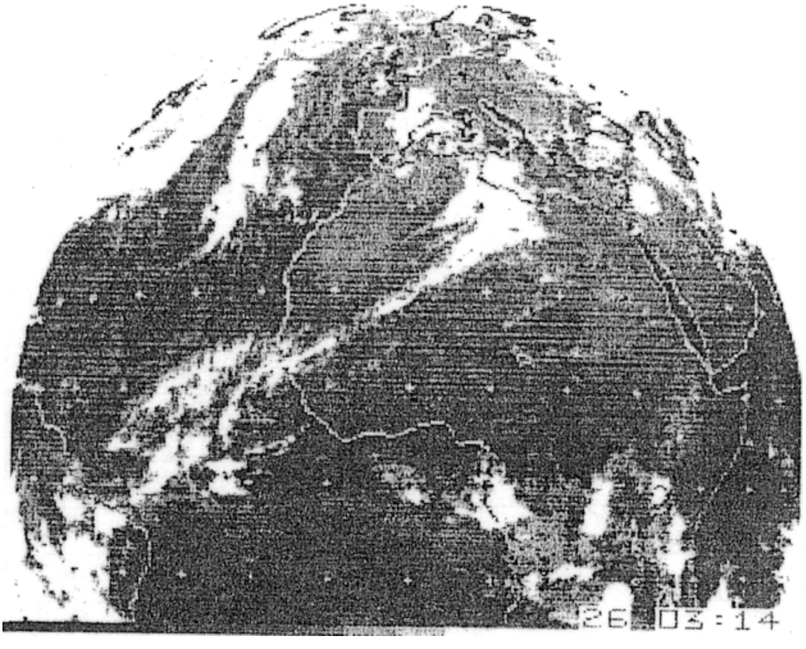

FIG. 5. Meteosat infrared satellite image on January 26, 1991 at 03: 14 GMT.

In the following discussion, weather charts from 22 to 26 January, 1991 are presented. For convenience, all charts are presented at 1200 GMT. Careful look at the cloud photos and synoptic charts indicated that the essential development occurred between 23 and 24 January. Figures (6)-(10) are the 850 mb geopotential analysis for 22 to 26 of January, 1991 respectively. On 22 January , Fig. (6), a distinct high pressure system appeared with its center located over England and a deep elongated ridge directed to the south-west at about 20°N and 42°W. This high pressure system forced the westerly waves that came from the west Atlantic to move on a track toward north of Europe. East of the high pressure, over Morocco and Spain, there was a weak low pressure system with center of 1530 geopotential meter (GPM). Also one could recognize along the African west coast a trough extended from the tropical region. On 23 January, Fig. (7), the Atlantic high pressure appeared deepened as a result of the warm advection by waves on the western side of the Atlantic anticyclone. Fig. (7) also shows that the low pressure area over Morocco and Spain was deepened to 1500 GPM with an extension to the south. On 24 January, Fig. (8), the African low had its minimum value of 1470 GPM with deep trough that extended to the tropical disturbance at about 35°W, 5°N. The consequent charts, Fig. (9) and Fig. (10), on 25 and 26 January respectively indicated an east movement of this wave with slight filling as shown by the decrease in the low pressure area over north-west Africa. The intensification of the high pressure on 23 January, as shown on Fig. (7), caused distinct advection of cold air on its east side as indicated by the extension of the high pressure to the tropical region. This could also be seen on the surface streamline chart of 23 January, Fig. (11), where flow north of Spain was directed to the tropics. On the upper air, 500 mb level, similar patterns were observed. Figures (12)-(14) are the 500 mb charts on 23 to 25 January respectively. On 23 January, Fig. (12), the north-west African cyclone was horizontally tilted to the east with center of 5520 GPM located over south-west Spain. On 24 January, Fig. (13), the tilt of this depression was directed to the south-west. On 25 January, Fig. (14), west movement of the cyclone with filling to 5580 GPM was observed.

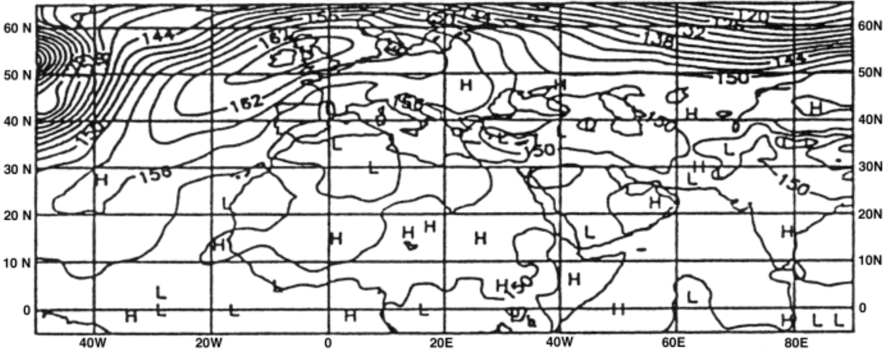

FIG. 6. 850 mb geopotential analysis on January 22, 1991 at 1200 GMT.

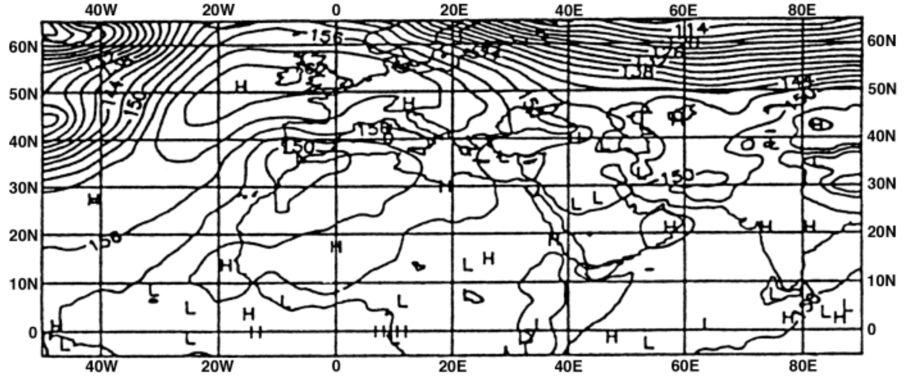

FIG. 7. 850 mb geopotential analysis on January 23, 1991 at 1200 GMT.

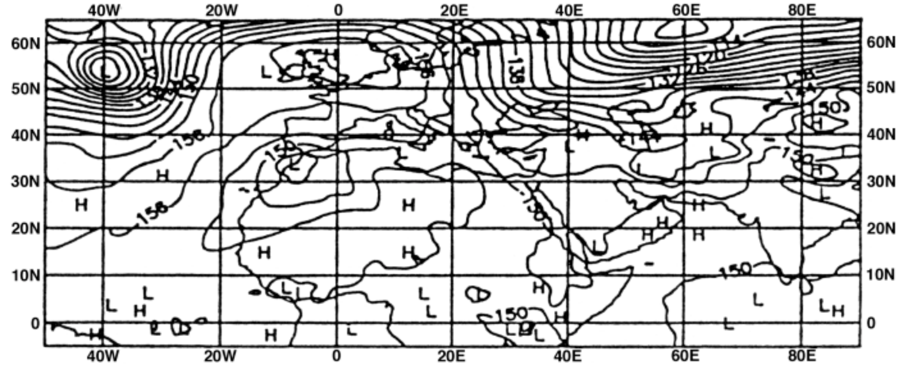

FIG. 8. 850 mb geopotential analysis on January 24, 1991 at 1200 GMT.

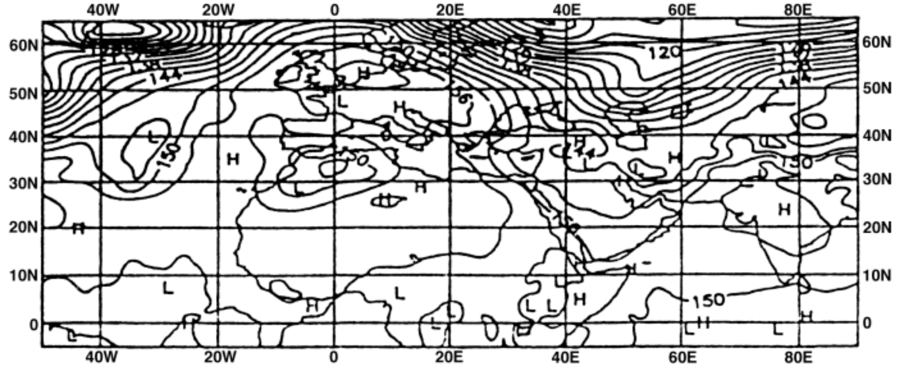

FIG. 9. 850 mb geopotential on January 25, 1991 at 1200 GMT.

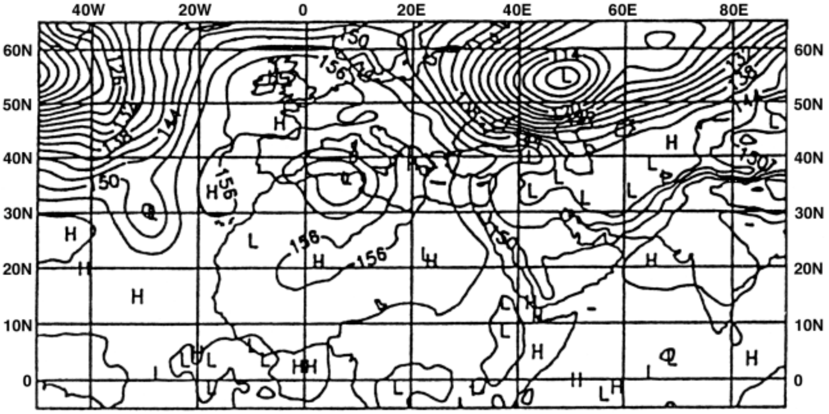

FIG. 10. 850 mb geopotential analysis on January 26, 1991 at 1200 GMT.

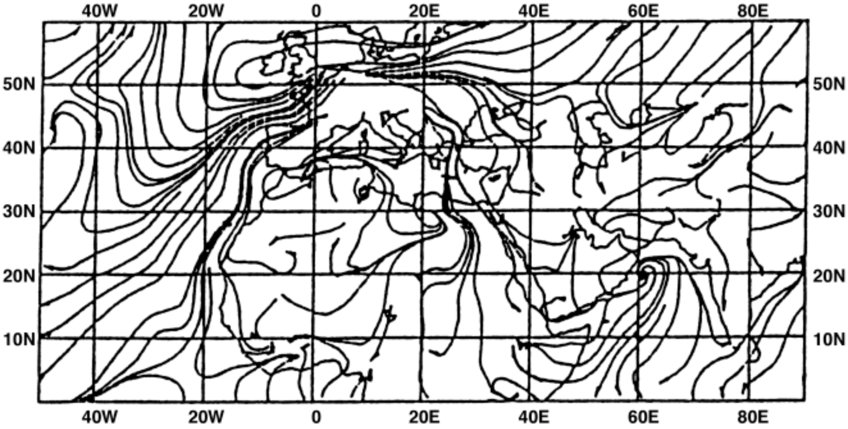

FIG. 11. Surface streamline analysis on January 23, 1991 at 1200 GMT.

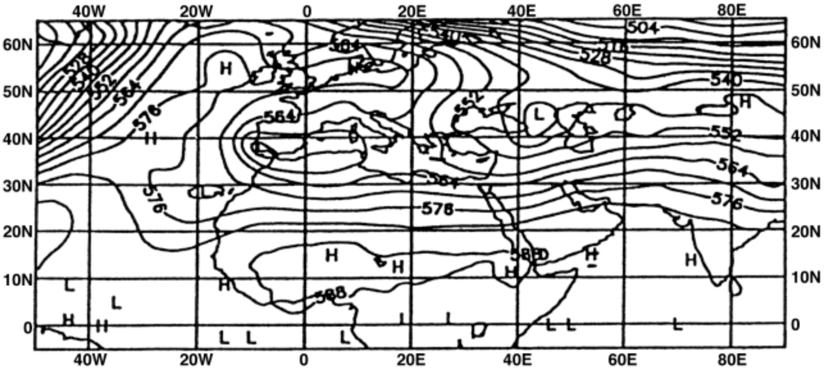

FIG. 12. 500 mb geopotential analysis on January 23, 1991 at 1200 GMT.

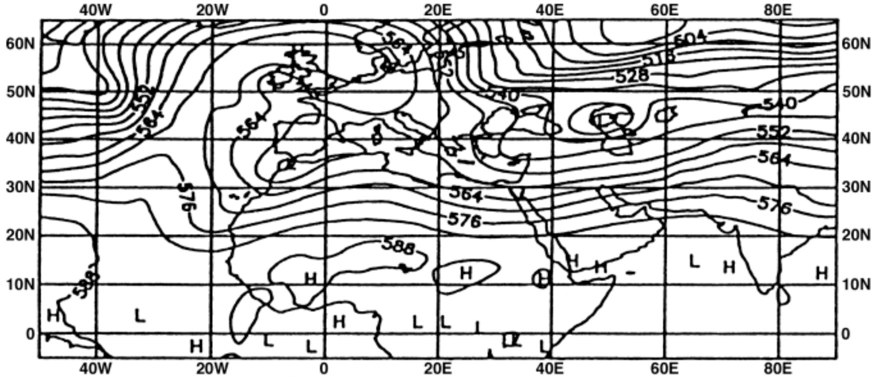

FIG. 13. 500 mb geopotential analysis on January 24, 1991 at 1200 GMT.

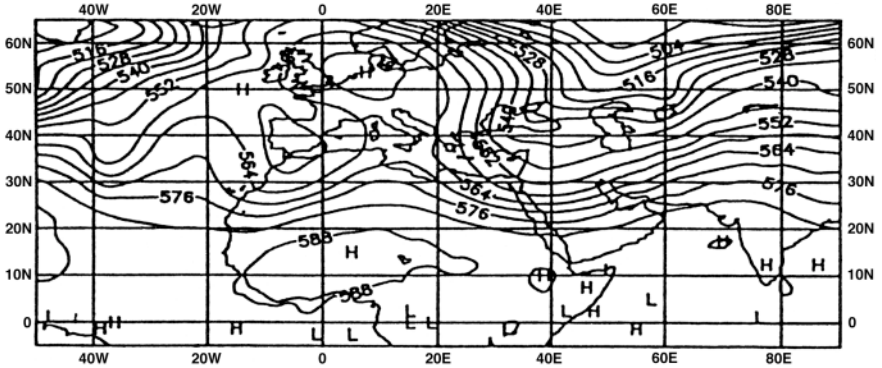

FIG. 14. 500 mb geopotential analysis on January 25, 1991 at 1200 GMT.

The above discussion confirmed that the development occurred between 23 and 24 January. Note that over north-west Africa there was a shallow warm (thermal) trough that had vertical depth of about 2 km. This trough extended from the tropics to Morocco. This was shown on the 1000 mb and the 850 mb geopotential charts, Figs. (15) and (7) respectively. The upper air flow over this area displayed a cold deep middle latitude trough, Fig. (12). The trigger action that led to this development seemed to be the advection of the cold air far to the south in the tropical region. In general two synoptic situations can lead to such substantial deep cold advection. Frontal passage associated with deep trough and the development of a high pressure system that had, on its east side, strong northerly wind component digging into the south. The latter case represents the present synoptic situation. This was an abnormal situation that was associated with a blocking high which deviated the track of the middle latitude waves north and (or) south of its normal path. Also such situation was generally marked with strong southerly (northerly) winds on the east (west) side of the blocking anticyclone, Fig. (11). The behavior of the subtropical and polar jets during the interaction nicely interpreted the development of the flow. Figures (16) to (20) display the isotachs at 300 mb from 22 to 26

January, 1991 respectively. On 22 January, Fig. (16), the maximum speed was 45m/s, and the streamline field, not shown here (see final technical report for project No. 168 / 412 of KAAU), indicated that the wind direction was zonal. This represented the subtropical jet. Also, northerly wind of speed 45 m/s was shown over Spain directed towards the subtropical jet. This was the polar jet associated with the middle latitude wave approaching the area. On the 23 January, Fig. (17), the polar jet approached near Africa and on the 24 January, Fig. (18), it was amalgamated with the subtropical jet. This resulted in a stronger subtropical jet with speed greater than 60 m/s, and backing in direction to be south-westerly instead of being westerly. This backing of wind with time is known to be due to cold advection. The change in direction was most probably the driving force for moisture advection from the towering clouds at the ITCZ towards the subtropical regions. On 25 January, Fig. (19), the maximum wind moved easterly and on 26 January, Fig. (20), it was noticed that the subtropical jet was almost back to its normal distribution in both speed and direction. It is known that the subtropical (polar) jet has its maximum speed around 200 mb (300 mb). The reason for displaying the 300 mb isotach field in the above discussion was to show the polar jet behavior during the development. The 200 mb isotach on the 23 January was displayed on Fig. (21). It was shown that the maximum speed of the subtropical jet was about 60 m/s. On 24 January, Fig. (22), after the amalgamation of both jets, the maximum speed increased to more than 75m/s.

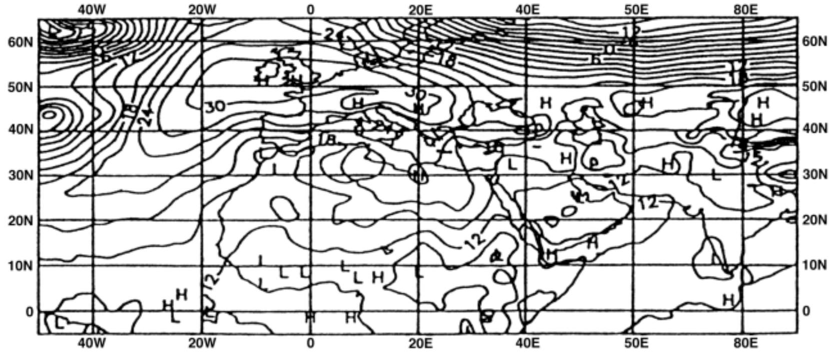

FIG. 15. 1000 mb geopotential analysis on January 23, 1991 at 1200 GMT.

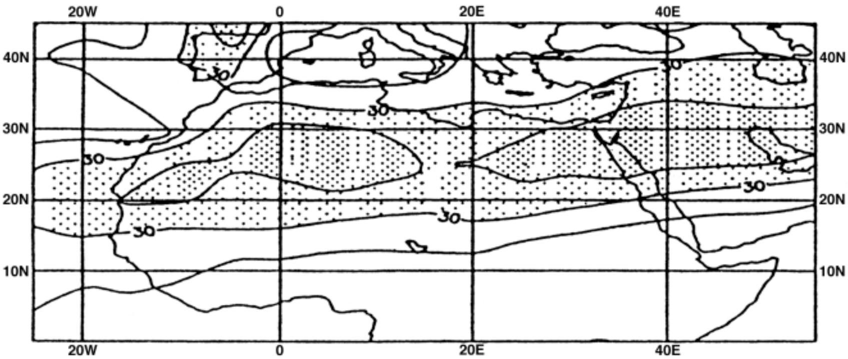

FIG. 16. 300 mb isotach (equal wind speed) on January 22, 1991 at 1200 GMT.

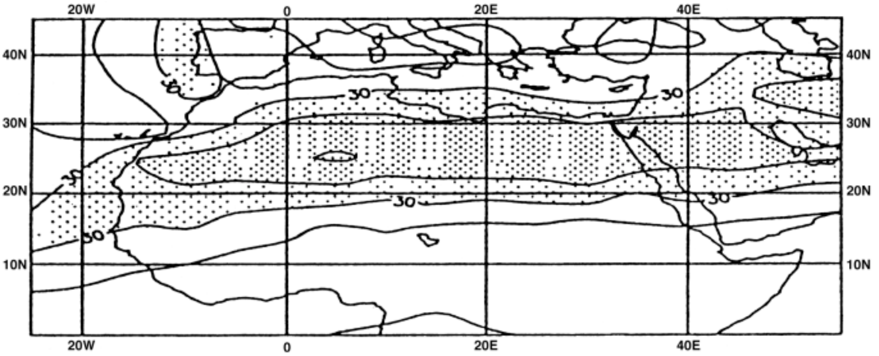

FIG. 17. 300 isotach (equal wind speed) on January 23, 1991 at 1200 GMT.

Thus, before interaction, the subtropical jet was westerly while the polar jet that appeared over Spain was northerly (a sign of cold air advection to the south). The interaction caused an increase in wind speed and a change in wind direction, of the subtropical jet, from zonal to south westerly flow over west Africa. Fig. (23) and (24) showed the relative humidity distribution on 24 January for the 1000 mb and 500 mb respectively. Note on the lower layer, 1000 mb, west Africa was dry while on the 500 mb level a moist tongue existed along the subtropical jet stream axis over west Africa.

3. Synoptic Versus Climatology

Figure (25) shows the climatological distribution of 1000 mb geopotentials for January. The chart indicates that near the surface the subtropical high pressure belt is well defined with centers located over Siberia, north Africa and Atlantic. Saudi Arabia is affected on its north region by a ridge from the Siberian high. The western region and the Red sea are affected by a trough from the Sudan low. The upper air flow, Fig. (26), reveals zonal stream with a ridge west of Africa. Figure (27) shows a warm ridge over east Atlantic. This is the warming effect of the ocean, in winter, on the surface air layer. Over Siberia and Sahara, the temperature distribution shows cold troughs. This suggests that the Siberian high and the Sahara high are cold and shallow while the Atlantic high is warm and deep. Also, the trough over the Red sea and the western region of Saudi Arabia, Fig. (25), is warm and shallow.

4. Deviation of the Synoptic Case Study from Climatology

The present case study of January, 1991 was remarkably deviated from the Climatology. Figure (28) showed the temperature distribution at 850 mb. on 24 January, 1991. Comparison between Figures (27) and (28), indicated that the warm ridge over east Atlantic was replaced by cold trough while the warm ridge appeared westward. The same configuration was shown on the 500 mb. temperature distribution, Fig. (29). The 1000 mb. geopotentials on 24 January, Fig. (30), were remarkably deviated from the climatological means, Fig. (25). A massive anticyclone was centered over England replacing the zonal flow in the climatological chart. This resulted in cold air advection west of Africa.

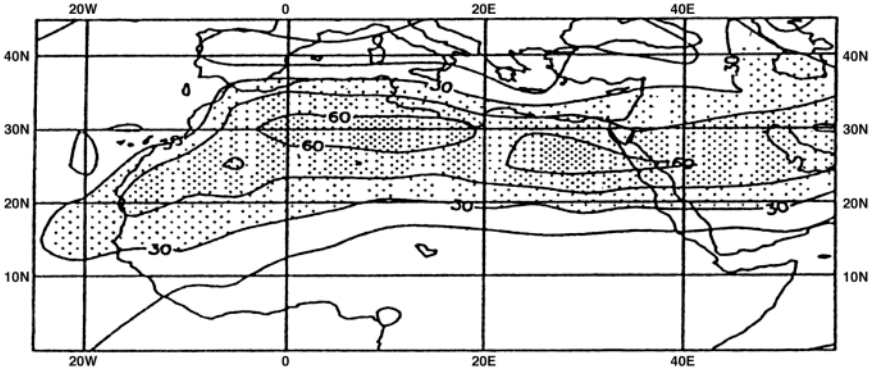

FIG. 18. 300 mb isotach (equal wind speed) on January 24, 1991 at 1200 GMT.

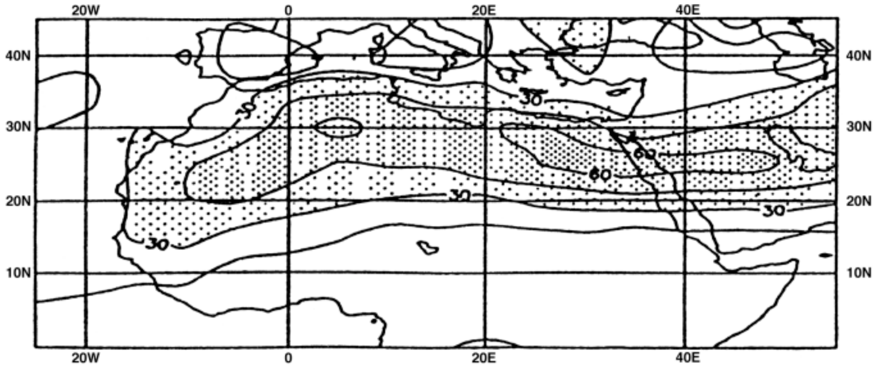

FIG. 19. 300 mb isotach (equal wind speed) on January 25, 1991 at 1200 GMT.

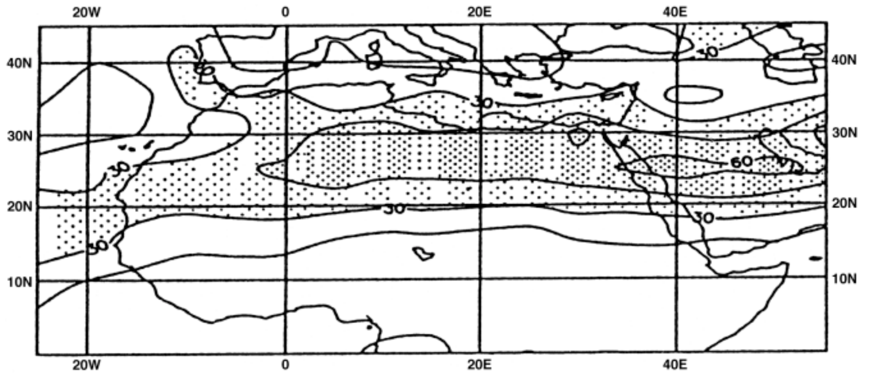

FIG. 20. 300 mb isotach (equal wind speed) on January 26, 1991 at 1200 GMT.

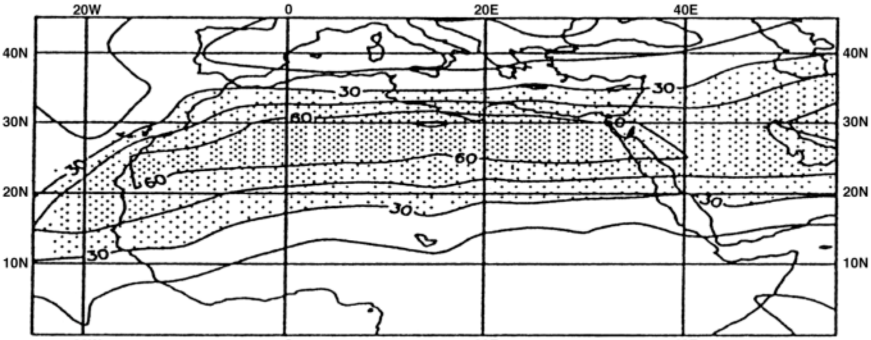

FIG. 21. 200 isotach (equal wind speed) on January 23, 1991 at 1200 GMT.

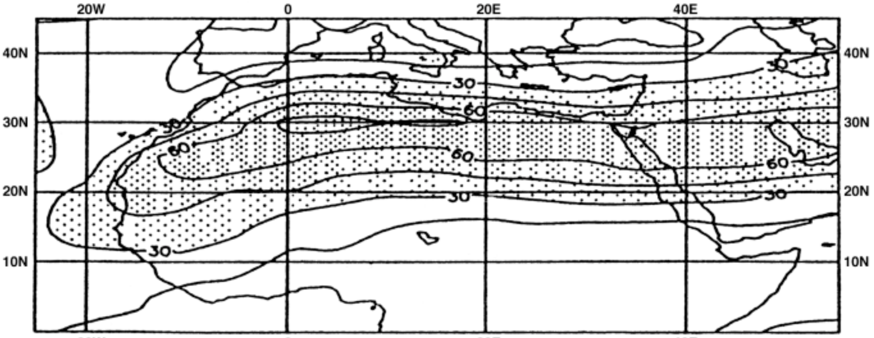

FIG. 22. 200 mb isotach (equal wind speed) on January 24, 1991 at 1200 GMT.

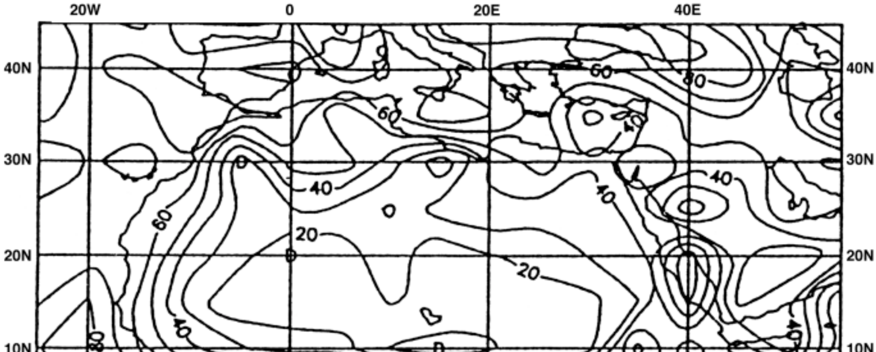

FIG. 23. 1000 mb relative humidity on January 24, 1991 at 1200 GMT.

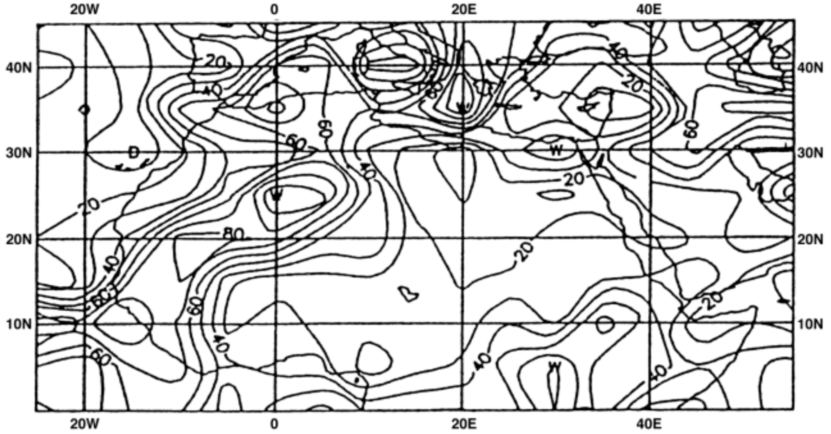

FIG. 24. 500 mb relative humidity on January 24, 1991 at 1200 GMT.

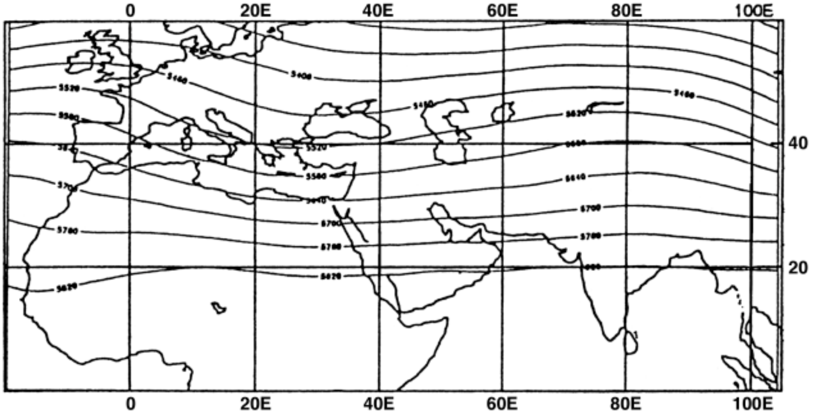

FIG. 25. Climatic 1000 mb geopotential field of January.

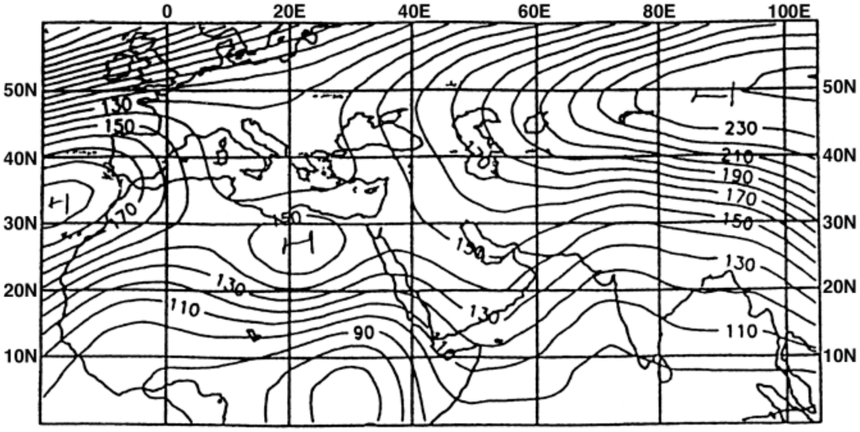

FIG. 26. Climatic 500 mb geopotential field of January.

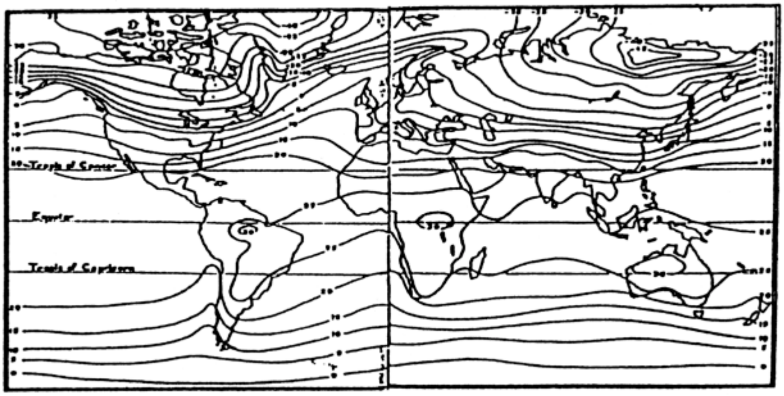

FIG. 27. Climatic mean sea level temperature field for January.

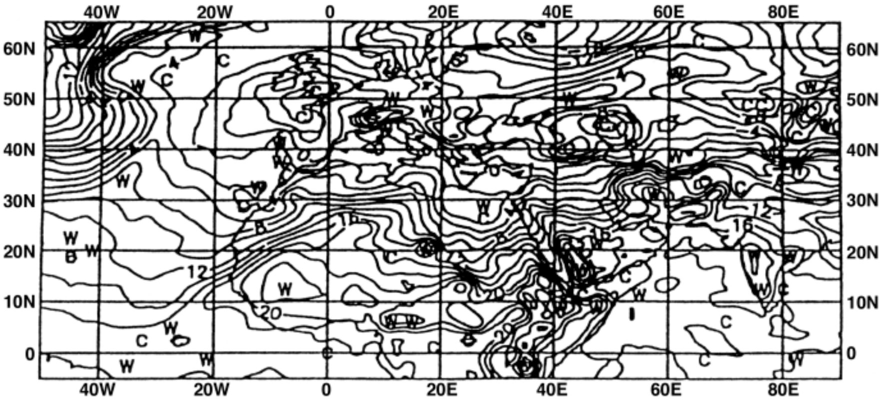

FIG. 28. 850 mb temperature analysis on January 24, 1991 at 1200 GMT.

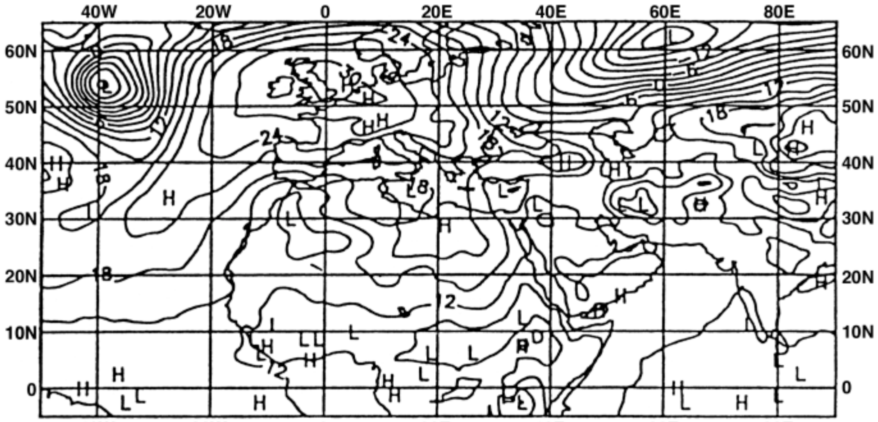

FIG. 29. 500 mb temperature analysis on January 24, 1991 at 1200 GMT.

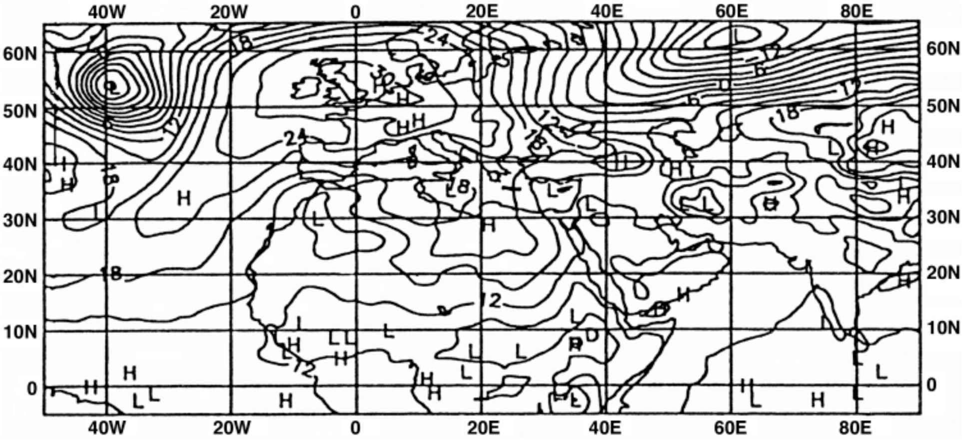

FIG. 30. 1000 mb geopotential analysis on January 24, 1991 at 1200 GMT.

5. Conclusion

A synoptic study was performed for a situation in which an interaction between a - middle latitude wave and a tropical disturbance was taking place. The interaction was developed during winter. The southerly advection of cold air west of Africa was the trigger action for the development of this lateral coupling. This invasion of cold air from the extratropical to tropical regions was taken place after the establishment of a blocking anticyclone with its center over Europe and extended to the north-east of the Atlantic ocean. The difference in temperature between the cold air mass advected west of Africa and the warm air mass over Africa created southerly thermal wind. This wind component caused backing of the prevailing subtropical jet to a south westerly flow. The new flow extract air from the tropical region where convective cloud cells existed along the ITCZ. This caused advection of huge amount of moist air toward the extratropical regions. The advection was revealed in satellite photos as medium and high clouds. The tongue of moist air was developed rapidly when a middle latitude trough came in phase with this cloud band. In this case, the convective clouds were rapidly developed along the band.

The favorable location for this interaction was over Atlantic at about 0 ºN and 30 ºW. The interaction took place when a blocking anticyclone existed over west Europe with a ridge extended over the Atlantic. East of this blocking anticyclone, cold air was advected from middle latitudes towards tropics. It was found that this was an essential process for the interaction to take place. The advected cold air created horizontal temperature difference with the subtropical air mass. As a result, south westerly thermal wind component was created and joined with the westerly subtropical jet with a resultant deviation of its path to south west. The subtropical and polar jets nicely showed this scenario. The polar jet accompanied the southward cold air advection. After amalgamation of both jets, a stronger subtropical jet resulted that had a south westerly direction. The satellite cloud photos revealed large amounts of moisture transfer directed from the ITCZ toward the subtropical regions.

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دراسة سينوبتيكية وعددية بغرض محاكاة عدم استقرار جوي يؤثر على أجواء المملكة العربية السعودية

١ – الدراسة السينوبتيكية

محمد أيمن عبد اللّه و مصطفى محمد إبراهيم

كلية الأرصاد والبيئة وزراعة المناطق الجافة ، جامعة الملك عبد العزيز

جدة - المملكة العربية السعودية

المستخلص . تمت دراسة الظاهرة الجوية الناتجة عن تفاعل بين موجات العروض الوسطى والعروض المدارية . تهدف الدراسة إلى محاكاة هذا التفاعل باستخدام نموذج عددي ، تتناول هذه الورقة البحثية الجزء الأول المتعلق بالدراسة السينوبتيكية لهذه الظاهرة التي تحدث خلال فصل الشتاء وقد تؤدي إلى تكون شريط ممطر من السحب يمتد من شمال المملكة إلى جنوبها .

تمت مناقشة تفصيلية لوضعية سينوبتيكية حدث فيها هذا التفاعل غرب أفريقيا ، اتضح أن الهواء البارد القادم من العروض الوسطى والذي يمتد جنوب خط عرض ٣٠° درجة شمالاً يعتبر العامل الهام والمحرك لهذا التفاعل ، ففي هذه الحالة تنشأ مركبة جنوبية للرياح الحرارية تتسبب في تغيير اتجاه التيار النفاث فوق المداري من الغربي إلى الاتجاه الجنوبي الغربي مما يسبب دفع لهواء رطب من منطقة التجمع الاستوائية (حيث تتواجد خلايا من السحب الركامية) إلى الاتجاه الشمالي . عند مرور جبهة هوائية قطبية بالمنطقة فوق المدارية واتحاد محورها مع محور لسان الهواء الرطب المدفوع شمالاً ، يحدث تطور سريع يتكون على أثره حزام هائل من السحب يمتد من منطقة التجمع الاستوائية إلى المنطقة فوق المدارية .