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Identifying and Introducing Synoptic Patterns that Cause Storm Levels, Which are >50 cm in the South Coast of the Caspian Sea

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Abstract: In addition to seasonal and annual fluctuation, water level of Caspian Sea undergoes hourly and daily duration caused by the atmosphere circulation patterns. Sometimes, some of these fluctuations are so intense that impose irreparable damages on economic and social activities of the coastal areas. The aim of the study was a synoptic recognition of the elements, which cause storm levels in the Southern coast of the Caspian Sea, so that in an attempt to lessen damages, we could use the obtained information in environmental planning. This study was carried out in Southern coastal areas of the Caspian sea in 2009. Synoptic data and hourly statistics taken from CDC and tide gauge station in the area have been used. The study was carried out synoptically and descriptively in the region 20 W to 80 E and 20-70 N. The findings showed that storm levels, which are above 50 cm in the Southern coast of the Caspian sea are caused by the entrance of systems originating from the fallowing ten geographical regions: the Red sea, Western Mediterranean, Eastern Mediterranean, Siberian, North Africa, South of Northern Atlantic, Median of Northern Atlantic, North of Northern Atlantic, Black sea and the Arctic. These systems take the forms of saddle, cyclone and anticyclone, tongues of cyclone and tongues anticyclone on the synoptic maps. The study of the time and frequency of different systems that create storm levels and also the study of the source and direction of their movement show that the sea plays an important role as a source or reinforce of the system's energy and it is highly probable that the distance that these systems travel on the sea is related to the height of the storm levels.

Key words: Synoptic, sea storm level, saddle, cyclone, anticyclone, environmental planning

INTRODUCTION

During all the year in addition to the seasonal fluctuation, the water level of the Caspian Sea has experienced a sudden rise from its normal level with hourly or daily duration, as a result of which water occupies the coastal areas and damages the environment, industrial and harbor constructions and even the urban or rural foundations that are in the coastal areas and imposes great loss on the inhabitants and the economy of the country. By identifying the rate, frequency and time of the rise of water and environmental planning based on these data these damages can be eradicated or reduced to a great extent.

Variations and fluctuations of the water level when compared to mean sea level is diverse in different periods. For instance in historical periods, the rise and fall of the water last for about 300 years and the regular variations last about 80-100 years (Ghanghermeh and Malek, 2005). On the other hand, in the shorter span of time the rise and fall of the water in this sea are not periodic and are usually a result of the dominant climate condition of its different parts. Therefore, the daily and hourly changes of water can be determined by considering the factor that creates the climate conditions. These factors consist of atmospheric circulation patterns.

Among the methods of identification of atmospheric circulation patterns, the synoptic method is the most accurate of all, for it is multilateral and its data are measured several times a day by the National organization of aerology and its maps are drawn and announced by the national and international institutes. This method can be the most effective method of predicting events and reporting them to the related authorities and people before they happen. Therefore, the synoptic method is chosen for this study. Here by the storm level we mean sudden changes in the level of the water of the sea, which are caused by atmospheric factors. This phenomenon is called differently in different parts of the world. This is called by terms such as storm surge, storm tide, setup water level and wave run-up, etc. However, each of these terms has its own mechanism. For instance, storm surge is the raid of the water to the coast, which happens along with a raid of atmospheric pressure to the coast. The high

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velocity of the wind that is created by an atmospheric system imposes a pressure on the level of the water of the sea and this causes a rise in the level of the water that comes to the shore. Boon (2006) is defined a storm tide in as water level made higher by the combination of a storm surge, the change in water level due to the action of the storm, with the astronomical tide, the normal rise and fall of the water due to earth's gravitational interaction with the moon and sun (Fig. 1). Wave run-up is the rise of the water, which is cause d by the water that is near the shore. It should be mentioned that storm levels in coastal areas depend on the general Fig. 1 of the coastline and the topography of the seabed near the shore as well as the intensity, rate velocity and duration of the storm.

Sometimes the altitude of storm levels in the coastal areas of the Caspian sea reaches several meters. For instance in the coast of Kazakhstan the latitude of this level is shown to be about 4.5 m (Mansouri, 1995). In the Southeastern coast of the Caspian Sea, the highest altitude of these levels is above 1 m. The recording devices reported an altitude of 108 cm in the Southeastern shore on 19/03/1996. Figure 1 shows how storm surge affects sea level.

Most of the studies done on storm levels of the sea and of the Caspian Sea were statistical and usually limited by mathematical models than estimating the maximum of water levels in different periods and especially in periods of 100 years. Although, these studies can be used for planning and constructing places and structure of harbor, they are not appropriate for the prediction of events and warning the authorities and people before they happen.

Although, many studies have been carried out for the recognition of circulation systems and finding their direction all over the world namely the North Hemisphere, temperate zone and even in the country, Iran, less has been done on the effect of these systems on the disturbed coastal areas. Betts *et al*. (2004) reported that are Van Bibber's in 1882 study can be mentioned as one the first studies done on tracking these systems. Later, Hay in 1949, Sawyer in 1956 and Thomas in 1960 showed the cyclones, which affected Northwest Europe. These studies have been recently reviewed statistically. Furthermore, Alijani (2002) mentioned that lamb identified the direction of the entrance of the synoptic systems to Britain and direction of blow of atmospheric systems based on the position of high or low-pressure systems on or around Britain. Also, the cyclonic directions of the Middle East were identified by Alijani (1987).

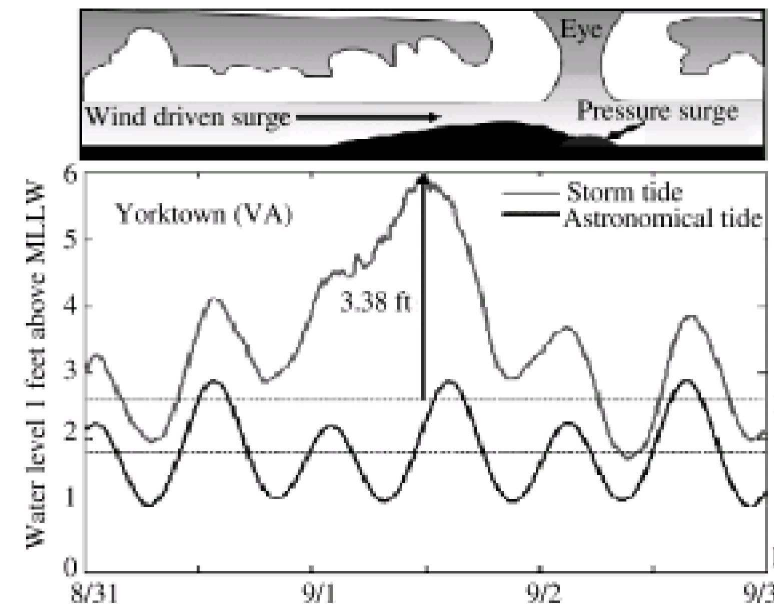

Fig. 1: The effect of storm tide on water level and astronomical tide

By analysis of surface and 500 hPa synoptic maps Davis *et al*. (1993) have described the synoptic climatology of extra tropical storms and associated wave climates that influence the mid-Atlantic coast barrier islands of the USA. Also, Holt (1999) examined storm tides of Irish Sea and the North Sea and proved that the atmospheric pressure was the only consistent element with the form of climate that caused storm tide and storm tide activities were a reflection of atmospheric activities and surge elevation a direct function of forcing energy. Betts *et al*. (2004) studied the winter storms that created storm tides in the East of the Atlantic Ocean having used the data of the pressure of the sea level and 500 hPa level, they examined a region from Southern to Northwest of France and Southwest of England and determined the directions and the intensity of cyclones that caused storm levels.

Khoshal and Ghaemi (1997) examined the effect of synoptic systems on the South coast of Caspian Sea. He recognized the effect of cyclonic and anticyclonic systems on water level and on the precipitation of >100 mm on this coast. Jahanbakhsh and Karimi (1999) studied the effect of Siberian's Anticyclone on the Caspian Sea and on the rainfall in Southwestern coast. However, no synoptic studies have been carried out on the effect of the atmospheric systems on storm levels of Southern coast of Caspian Sea. Thus, the present study is the first study on this subject.

The area studied in this research is the Southern coast of the Caspian Sea in the North of Iran and includes their provinces of Golestan, Mazandaran and Gilan. The areas in this region are 26 m lower than the level of open seas. The study region is between 36°34'-38°28' N latitude and 48°50'-54°02' E longitudes (Fig. 2).

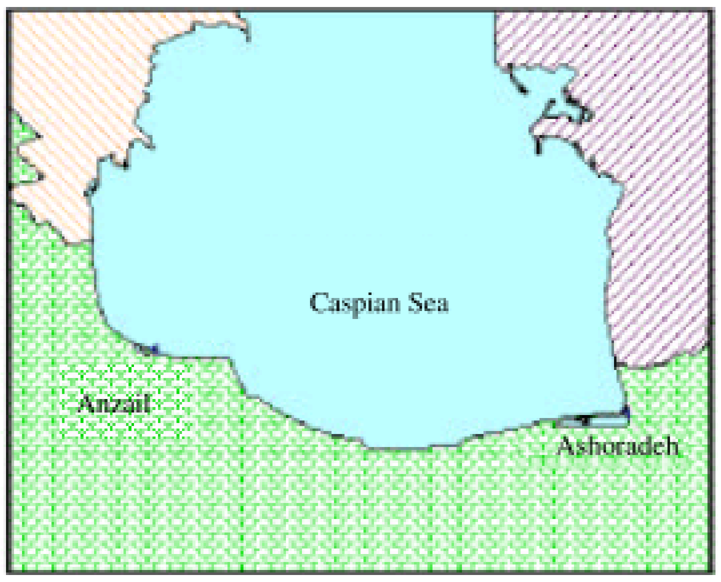

Fig. 2: The map of the region under the study and the location of the tide gauge station

MATERIALS AND METHODS

This research is done by using the synoptic method. First, the data of storm levels in tide gauge station of Ashoradeh (at 6:00, 12:00, 18:00 and 24:00 of local time) and Bandar e Anzali (at 6:00, 12:00, 18:00 and 24:00 of local time) were taken from the Data Bank of National Research Center of the Caspian Sea. As for the data of the circulation patterns of these levels, the data source of National Oceanic and Atmospheric Administration (2006) was used. The data consisted of the originating point of the circulation patterns and their direction to the end of their effect on the water level of the Caspian Sea in the region 20 W to 80 E and 20-70 N.

The calendar of the storm level of the tide gauge station was taken out because of the lack of important astronomical tide and also because of the studies by Malinin (1994) that said changes of shorter than 8 days are a result of daily atmospheric conditions (Fig. 3). The results obtained from taking out the calendar of storms higher than 50 cm showed that in the station of Bandar Anzali (1941-2005) 33 storm levels and in Ashoradeh station (1982-2003) 23 storm levels have occurred.

Then, using the analytic software of GIS, Surfer and Convertor (NOAA, 2006) were converted to synoptic maps of sea level and to the upper levels of the atmosphere for every 6 h. The centers of the synoptic figures (cyclones and anticyclones) were marked on these maps. Later, the centers were tracked from their source to the end of their effect on the water level. Then among the prepared maps of simultaneity maps, the time that the storm level occurred in a region between 35-65 E and 30-50 N was separated and categorized by cluster analysis. Finally, 6 patterns (clusters) were chosen as their indicators. Figure 4 shows the dendrogram of cluster analysis of these maps.

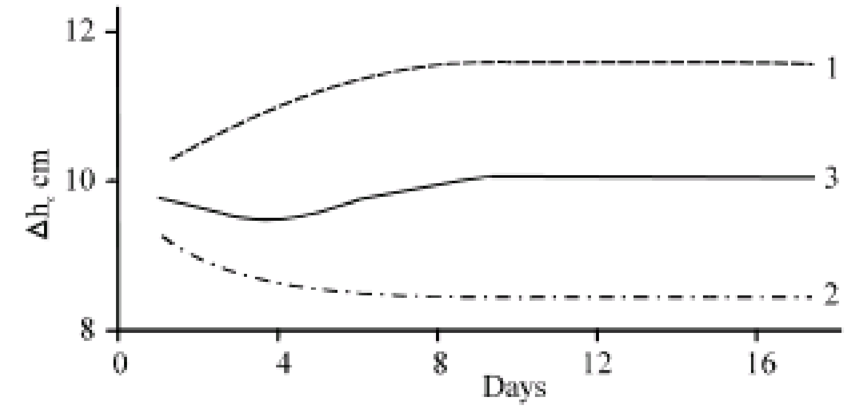

Fig. 3: The graph of the relation between the changes of water level (Δh_c) and the average period of primary data (Malinin, 1994)

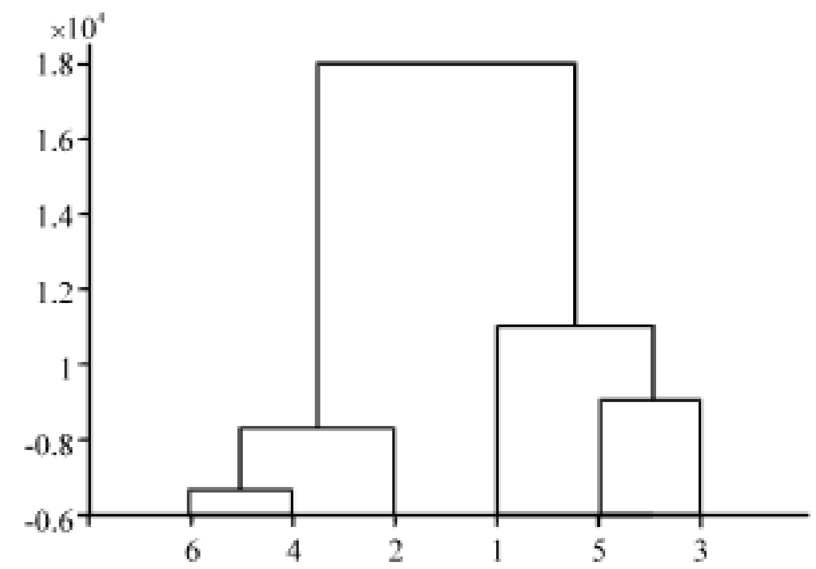

Fig. 4: The dendrogram of cluster analysis of synoptic maps of the occurrence time of storm levels >50 cm

RESULTS

The findings of their research are as follows:

- The highest frequency of the occurrence of storm levels is in the cold period of the year (Table 1)
- The systems that create storm levels above 50 cm in the Southern coast of the Caspian sea come from the following 10 geographical regions: the Red sea, Western Mediterranean, Eastern Mediterranean, Siberian, North Africa, North of Northern Atlantic, Median of Northern Atlantic, South of Northern Atlantic, Black sea and Arctic region (Fig. 5 and 6 and Table 2)
- Anticyclonic systems have the greatest frequency of systems that cause storm levels of >50 cm in the Southern coast of the Caspian sea (68% are anticyclone and 32% are cyclone)
- The Jetstreams of polar fronts can be shown in the maps of levels above 500 pH at the time that the systems causing storm levels of >50 cm take place in the Southern coast of the Caspian Sea (Fig. 7)

Table 1: The frequency of systems affecting the South coast of the Caspian Sea

	Bandar-e-Anzali		Ashoradeh		
Months	Cyclone	Anticyclone	Cyclone	Anticyclone	Sum
January	4	8	-	1	15
February	-	2	-	-	2
March	-	3	7	2	12
April	-	4	2	4	10
May	-	-	2	-	2
June	-	-	2	1	3
July	-	-	-	-	-
August	-	-	-	-	-
September	-	-	-	1	1
October	1	4	1	-	6
November	4	8	4	1	17
December	2	12	1	2	17

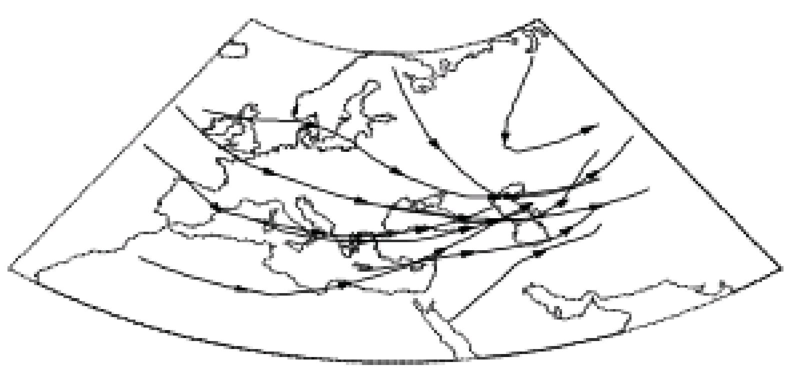

Fig. 5: The average of the main track of systems originating from 10 sources

- In the Southern coast of the Caspian Sea the cyclonic systems (the ratio of cyclone to anticyclone is 61%) and in the Southern coast the anticyclonic systems have the greatest number of systems that cause storm levels of >50 cm
- Patterns of systems that cause storm levels on the day that storms take place are categorized in six patterns (or clusters) and according to the mode of figures on the maps of 1000 hPa level. To make the analysis easier, we have categorized them as fellows: saddle forms, cyclone form, anticyclone form and vector forms

Saddle forms: This has two types, complete and in complete. As shown from the 6th cluster of 1000 hPa pattern in Fig. 8, a complete saddle is created in the maps and the anticyclonic parts of it are almost placed from the Southern to Northeast and the cyclone parts are placed from Northeast to Southeast and its fallen part is on the Caspian sea from the North to the South. In 500 hPa pattern of maps of this form, there is a trough in the West of the Caspian Sea on Caucasian and a ridge in the East of this sea whose axis are, respectively like the direction of anticyclone and cyclonic systems of the map of 1000 hPa level.

The wind pattern in 1000 hPa level of this form shows a great convergence from the North to the South on the Caspian Sea. The mean of storm levels in this form estimated 75 cm with the age 30 h (Table 3).

The second type is incomplete saddle. This form is shown in Fig. 8 of the first cluster. As can be shown in Fig. 8, the pattern of 1000 hPa of this type is the same as the first type. The difference is that the weakened saddle and the South cyclonic system is moved to the North and has extended the fallen among anticyclones. The pattern of 500 hPa of this type is the same as the first type; the only different is that the depth of the trough and the height of the ridge are lessened. Wind pattern in 1000 hPa level become different too and takes the form of a cyclone in the Southeast of the region. The mean of storm levels in this form estimated 64 cm with the age 41 h (Table 3).

Cyclone form: The 4th cluster in Fig. 8 shows this form. On the map pattern of 1000 hPa level, a strong cyclone is placed from the Southwest to the Northeast on the Caspian Sea and drives away the Asian anticyclonic systems toward the Northeast. In a map pattern of 500 hPa, there is a strong ridge in the East of the Atlantic Ocean and the West of the Europe and strong trough in the West of the Caspian Sea in Caucasian in a way that the Caspian Sea from North to South is placed on the front part of this trough. Also, the wind pattern in 1000 hPa level forms a cyclone movement exactly at the place of the said cyclone in this level and in the Western coast, winds become convergent. The mean of storm levels in this form estimated 56 cm with the age 29 h (Table 3).

Anticyclone form: As can be shown in third cluster in Fig. 8 in the 1000 hPa map of this form, there is a wide and strong cyclone in the Northeast of the Caspian Sea and its vector is located in the Northeast to Southwest on the Caspian Sea. In 500 hPa level of this form, there is a strong trough in the West of Mediterranean and there is a ridge almost from the southwest to the Northeast and the Caspian Sea. The wind patterns in this level almost flow from the Northeast to the southwest. The mean of storm levels in this form estimated 57 cm with the age 44 h (Table 3).

Vector form: This form affects the creation of storm levels in two ways of cyclone vector and anticyclone vector. In the first type, as can be shown in second cluster (pattern) in Fig. 8, a strong cyclone is formed in the Northeast of the Caspian Sea above 60 N whose vector comes towards the Caspian Sea from the Northeast to the Southwest and is spread on this sea towards the South. In 500 hPa map pattern, strong trough is spread from the North to the South whose axis passes the North of the Caspian Sea and is placed in the West of the sea. This trough is exactly in the place of the cyclone, which was on the map of 1000 hPa level. Also, the wind pattern in

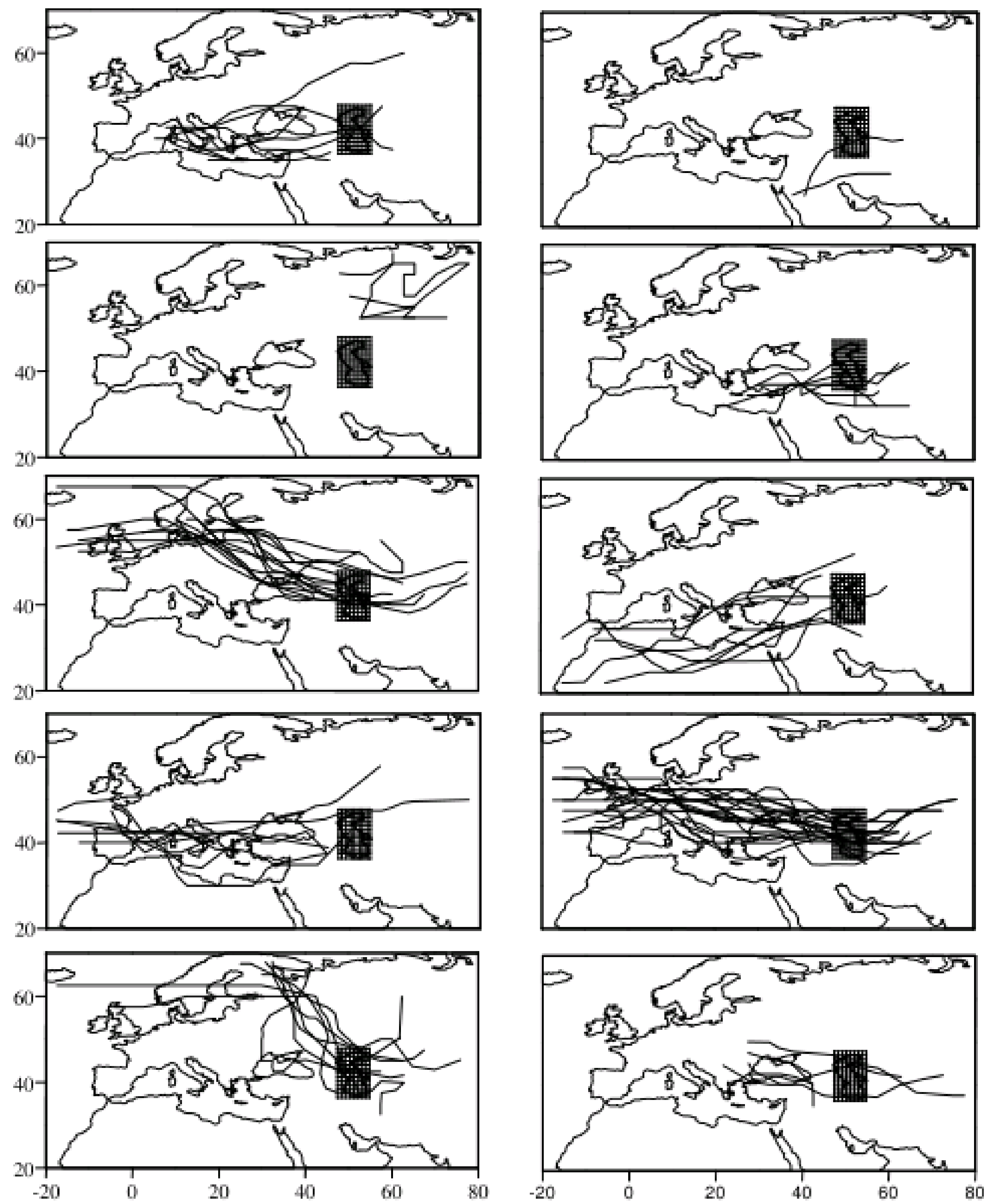

Fig. 6: Ten paths of systems affecting storm levels of >50 cm in South coast of the Caspian Sea

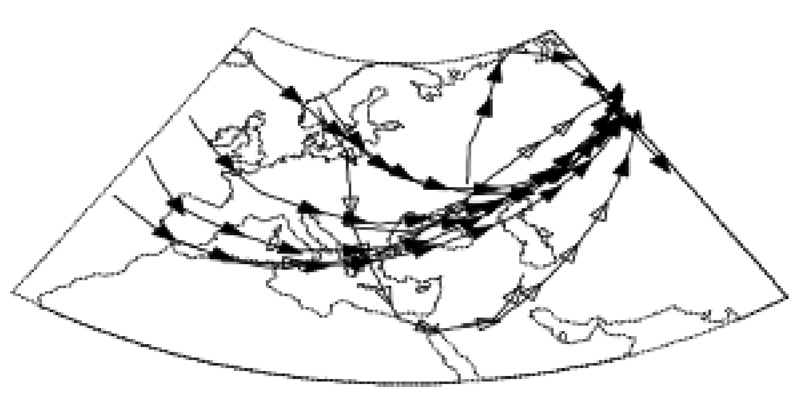

Fig. 7: The average of the main paths of 500 hPa Jetstreams

Table 2: The source and frequency of climate systems affecting storm levels in the Southern coast of the Caspian Sea

Geographical regions	No. of cyclone	No. of anticyclone
Red sea	2	-
Western Mediterranean	6	2
Eastern Mediterranean	5	1
Siberian	-	3
North Africa	2	5
South of Northern Atlantic	5	10
Median of Northern Atlantic	5	16
North of Northern Atlantic	2	5
Black Sea	1	4
Arctic	2	6
Sum	30	52

1000 hPa level shows a week cyclone movement in the Southeast of Caspian Sea. The mean of storm levels in this form estimated 57 cm with the age 37 h (Table 3).

The second type is the anticyclone vector. As shown in Fig. 8 of the 5th cluster map pattern of 1000 hPa, a strong anticyclone vector is spread from the East on the Caspian Sea and drives away the Northeast trough to the Southwest of the Northeast cyclone of 60 N toward the West of the Caspian Sea. On the 500 hPa map pattern, a ridge from the South, around 50 E comes up toward the northwest up to the Caucasian region and the Black Sea and drives away the Northeast trough of 60 N toward the middle part of the Caspian Sea. The map of wind pattern shows the existence of anticyclone movements in the

Table 3: Remarkable features of storm level, frequency of effective system and peculiarities of the direction of the movement in each cluster

	Storm levels in the South coast of Caspian Sea			Duration (h)			The length of tracking systems and moving speed			
Cluster	Average (cm)	CV (%)	Maximum	Average	CV (%)	System (%)	Average (km)	Max. (km)	Min. (km)	Speed (km h^{-1})
1st	64	16/8	108	41	45	26	4289	7122	1382	33
2nd	57	11/8	76	37	44	21	3957	5561	2012	44
3rd	57	8/4	74	44	39	22	4591	7958	2736	38
4th	56	10/5	69	29	33	11	3951	8138	2559	31
5th	55	5/9	63	29	38	15	4329	5615	2455	47
6th	75	20/0	102	30	30	5	3982	5797	2054	33

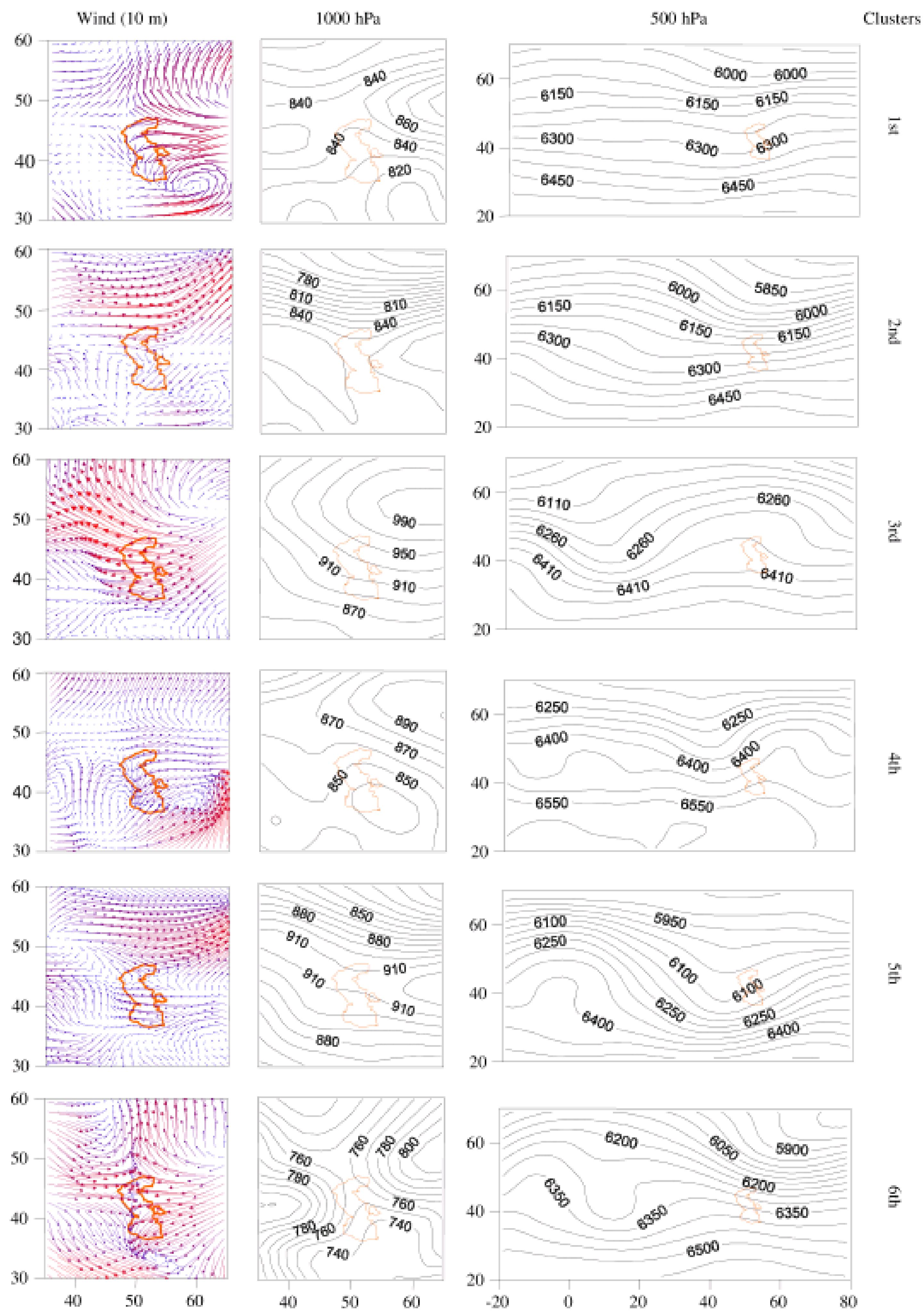

Fig. 8: Circulation patterns of 500 and 1000 hPa level affecting storm levels of >50 cm in the Southern coast of the Caspian Sea

Southeast of the Caspian Sea up to the middle part of this sea. The mean of storm levels in this form estimated 55 cm with the age 29 h (Table 3).

DISCUSSION

Table 1 shows the time distribution of storm levels of Southern coast of the Caspian Sea. As can be shown in Table 1, the greatest numbers of this storm are in the cold months of the year. A comparison of the occurrence of storm levels in the stations of Bandar Anzali and Ashoradeh shows that in Ashoradeh station, the ratio of cyclone to anticyclone is about 61%, while in Bandar Anzali station this ratio reaches 21%. In other words, in Bandar Anzali station, anticyclones are more important than cyclones. Probably, the reason for the greater number of effective cyclones in the Southeast and the effective anticyclones in the Southwest is the direction of their movement on the sea, for, as we know the cyclones move from the southwest to the Northeast and usually anticyclones move from the Northeast to the southwest in the Northern hemisphere. Therefore, the cyclones that come from the Southwest will be weak in the Southwest of the Caspian Sea because their movement on the water is short but where they move from the West to the East, they swell and become stronger. The reverse of this is true for anticyclones because their movement on the Caspian Sea is from the East to the West. Therefore, when they reach the Southwest, the resulting sea breeze front is reinforced, leading to a stronger disturbance.

Table 2 shows the source of the systems that cause storm levels in the Southern coast of Caspian Sea during 1951-2006. As shown in Table 2, 86 systems caused 56 storm levels, which were above 50 cm. In other words, some levels are created as a result of 2 or 3 consecutive systems. The sources of these systems were the following ten geographical regions: the Red sea, Western Mediterranean, Eastern Mediterranean, Siberian, North Africa, North of Northern Atlantic, Median of Northern Atlantic, South of Northern Atlantic, Black sea, 0-Arctic region.

Figure 7 and 8 shows the source and direction of the movement of these systems during a statistical period. As shown from this Fig. 7 and 8, the cyclones mostly moved from the Mediterranean and the Red sea to the Caspian Sea and anticyclones mostly moved to the Caspian Sea from the rest of the regions.

The study of Jetstreams at the time of the presence of the atmospheric systems, which cause storm levels, shows that all these systems were formed at the same time that Jetstreams were present. Figure 5 shows the average direction and the position of Jetstreams when the systems that cause storm levels are there. As we know, cyclones become strong in the North of Jetstreams and anticyclones become strong in the West of them. By considering the direction of Jet streams in the region under the study, it becomes clear that these Jet streams are of the polar front type (Alijani, 1994).

Table 3 shows the categorization of frequency and height of the storm level, the number of systems, the length of the movement and the velocity of the systems that create storm levels. As can be shown in Table 3, the average height of the storm level in the first and 6th clusters were the highest of all, i.e., 65 and 75 cm respectively. Also, the coefficients of their changes are 16/8 and 20%, respectively. In other clusters, these altitudes are very close to each other and their difference is only 2 cm.

CONCLUSION

Based on what mentioned above, it can be found out that the factors that cause storm levels of the Southern coast of the Caspian Sea are the circulation patterns, which affect the level of the sea. Since all the places that these patterns were formed and their directions are indicated in this research, the experts and weather forecasters of meteorological institutes can predict the coming storm levels. By using the result of this study, they can predict storm levels when they recognize the first signs of the said system in weather maps and understand how they move and then they can report it to the related authorities.

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