Researches in Earth Sciences

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Research Article

A synoptic analysis of the northward displacement of the Mediterranean low-pressure tracks in Iran

Gholamreza Barati [1*], Negar Ghaderi[1]

1-Department of Physical Geography, Faculty of Earth Sciences, Shahid Beheshti University, Tehran, Iran

Received: 31 May 2025 Accepted: 24 Nov 2025

Abstract

Mediterranean low-pressure systems are among the most important rain-producing systems for Middle east and Iran during the cold half of the year. In this study, nearly 2,400 weather-maps at a level of 1000 HPA were downloaded from the NOAA website. The identification of the stages of these low-pressure systems, including their formation, strengthening, and tracking, was carried out over two decades and in four representative months of the seasons, including November, February, May, and August, respectively. The aforementioned identification was divided into two categories: low-pressures were towards Iran (LTI) and low pressures were towards other lands (LTO). Initial results showed that 418 low-pressure systems formed and moved over the Mediterranean Sea between 2003 and 2022. Of the 418 recovered tracks, 88 ones were LTIs and 330 ones were LTOs. Meanwhile, the 21% share of LTIs has been decreasing at a gentle rate over the last two decades. Marking the tracks on the base maps at three scales of months, years, and decades showed that these systems have diverged towards the east on three pathways, from the western and central northern Mediterranean areas. Pathway No. (1) passed through the southeastern part of the Hijaz in the first decade, but in the second decade it turned northward and crossed the southern provinces of Iran. Pathway No. (2) passed through the central lands of Iran in the first decade, and in the second decade, it left Iran with a significant northward turn, crossing the middle of the Caspian Sea towards the plains of Turan (Central Asia). Pathway No. (3) passed over the Black Sea at the highest latitudes during the first decade, but in the second decade, it went out of the map frame north of this sea. Overall, the decadal patterns showed that most of the LTIs and LTOs tracks were extended to higher latitudes during the years 2013 to 2022 (second decade) compared to the years 2003 to 2012 (first decade). Therefore, given the persistent and mild nature of precipitation resulting from Mediterranean systems, it is believed that as more southern systems such as Sudanese low-pressure systems replace them, it will become more difficult for planners to store and manage Iran's water resources.

Keywords: Mediterranean Sea, low-pressures, Northward displacement, Iran.

Citation: Barati, Gh.R. and Ghaderi, N., 2025. A synoptic analysis of the northward displacement of the Mediterranean, *Res. Earth. Sci:* 16(Special Issue), (210-217) DOI: 10.48308/esrj.2025.240213.1278

* Corresponding author E-mail address: g_barati@sbu.ac.ir

Introduction

In the mid-latitudes of the Northern Hemisphere, lands adjacent to the ocean, especially on the western side of the land, benefit more from ocean moisture and atmospheric precipitation. Gradually, as you move away from the coastline and eastward within the Eurasian continent, humidity decreases and the aridity coefficient increases (Kimura and Moriyama, 2024). In the Northern Hemisphere, the Mediterranean Sea is a large body of water that stretches east-west from the Atlantic Ocean, sandwiching three of the world's major continents: Asia, Europe, and Africa. During the warm period of the year, the southern mid-latitude lands are covered by subtropical high-pressure systems such as the North African Ridge (Blaga and Blaga, 2012), and this phenomenon causes weather stability and reduced precipitation. Meanwhile, the west-east direction of this sea for Southern Europe and during the cold season, there is a high chance that the northern, northeastern, and eastern lands around this sea will benefit from the moisture of rain-producing low pressures. Flocas et al. (2010) believe that these low-pressure areas form more in the western Mediterranean than in its eastern part. This sea, along with the Red Sea, also provides precipitation for the southwestern Asian continent and its large and small countries. Related to this issue, researchers have referred to the systems approaching Iran from the Red Sea as Red Sea lows (Pourkarim et al, 2023), warm and dry cT air masses (Heidarizad et al, 2019), North African trough (Lashkari, 2003), Red Sea trough (Qasemi and Khalili, 2008), or Sudanese lows (Sayad et al, 2021). As Mediterranean low-pressure systems move eastward and sometimes merge with Red Sea low-pressure systems (Reisi and Mahmoudi, 2023; Poorkarim et al, 2023), and then enter Iran, the amount of atmospheric precipitation increases. It seems that what researchers such as Asakereh et al. (2021) have mentioned with the term “Decrease in precipitation in Iran over the past 4 decades”, Aghapour Sabbaghi et al (2012) with the term “Reduction of 400 million cubic meters of groundwater”, and Sadeghi et al. (2022) with the term “The risk of recurrent droughts” is due to changes that have occurred in synoptic patterns, especially the track of precipitation systems from the Mediterranean Sea. In this study, an attempt is made to reveal these changes. Previously, Barati and Heydari (2010) determined the contribution of the Mediterranean Sea and the Red Sea in the transmission of rain-producing low pressures to Iran as 45 and 38 percent, respectively. Therefore, the aim of the current study was to design the track patterns of Mediterranean low-pressure systems and retrieve and analyze their frequency and latitude changes over a 21-year period, from November 2002 to August 2023, based on the months of November, February, May, and August. In this study, the mentioned months are considered to represent the autumn, winter, spring, and summer seasons, respectively.

Materials and Methods

Data and research methodology

In this study, the Mediterranean Sea was referred to as the water area between the three continents of Europe in the north, Africa in the south, and Asia in the west. The components of the Mediterranean Sea in the southern half include the Levantine Sea and the Gulfs of Gabes and Sidra, and the Ionean Sea in the northern half includes the Adriatic, Tyrrhenian, and Balearic Seas (Figure 1).

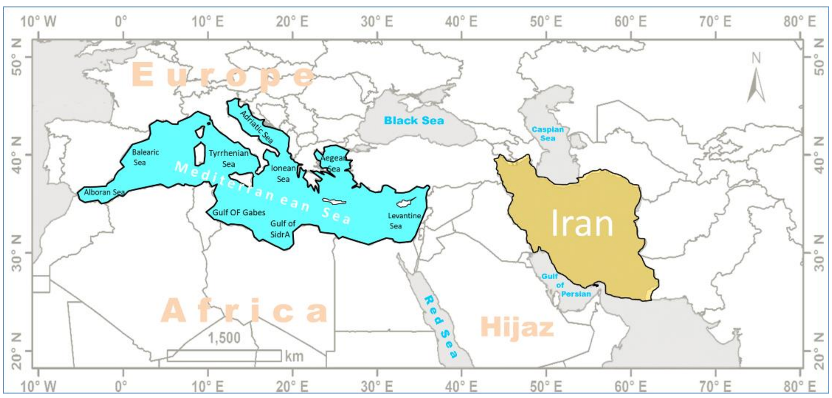

Fig. 1: Location of the Mediterranean Sea and the target land in the synoptic zone

To identify the Mediterranean Low-Pressure, daily weather maps at the 1000 hectopascal level were used. These maps were downloaded from the NOAA (Atmospheric Data Reanalysis Database) for the statistical period under study, i.e., 2003 to 2022, and were located in the latitude range of -10°W to 80°E and 20°N to 50°N. Their number was calculated based on the total number of days in the 4 representative months (Figure 2), 2400. The selection of 4 representative months out of 12 months of the year was done with the aim of reducing the frequency of the maps under study and achieving annual and decadal patterns of the Mediterranean low-pressure track.

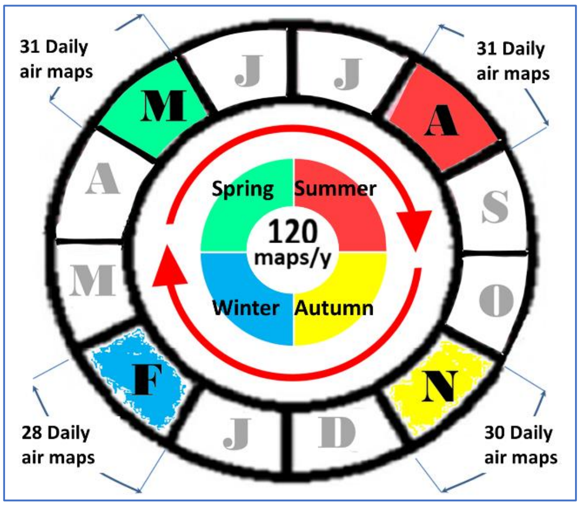

Fig. 2: Frequency of daily weather maps per year based on the position of representative months

In this study, Mediterranean Low Pressure (MLP) was defined as: "Any core or depression formed over the Mediterranean Sea or its coasts whose movement in longitude or latitude is monitored for at least two consecutive days." Figure (3) shows the method of retrieving and marking an MLP. During May 12, 2004, one MLP was restored in the western Mediterranean. This is while on May 11, the MLP was at more southern latitudes, over Africa, but since its center is not over the sea, the beginning of the its track is defined as May 12. During May 13, the MLP shifted more easterly and moved over northern Greece. Each month, the first MLP detected over the sea or on its coast was recorded with a colored circle and a specific number on the base area. The location of the identified MLP center was marked on the map with the same color and number during the following days until the last day. The last day was defined as the day after which either the MLP would move out of the map frame or weaken and disappear. The second, third, and ... MLPs were also recorded with consecutive numbers and other colors in the same base area. Using the innovative three-step technique, 120 maps were downloaded for each year, and 2,400 maps were downloaded daily for the entire 21-year period. After retrieving the tracks and plotting them, 84 monthly patterns were designed. The technique of distinguishing the number and color on each pattern was necessary because in some months the number of identified tracks was large and if different numbers were not used, counting the tracks would be difficult. Also, if different colors were not used, it would be difficult to connect the centers of each MLP on consecutive days in months when their frequency was high. Figure (3) shows the steps in designing a monthly synoptic model of the position and track of MLP in February 2003. For example, pattern (4 a) is drawn without using different colors. This pattern clearly shows the difficulty of distinguishing tracks, but in Figure (4 b), where the color difference technique is used, the tracks are easily distinguished. In Figure (4 e), the tracks are drawn based on the difference in color and number. Figure (4 d), which is the final stage, the numbers and circles have been removed, and the pattern of tracks for February 2013 has been finalized. These steps were designed to draw 83 more patterns, a total of 84 patterns for the years 2003 to 2022 (Figure 4).

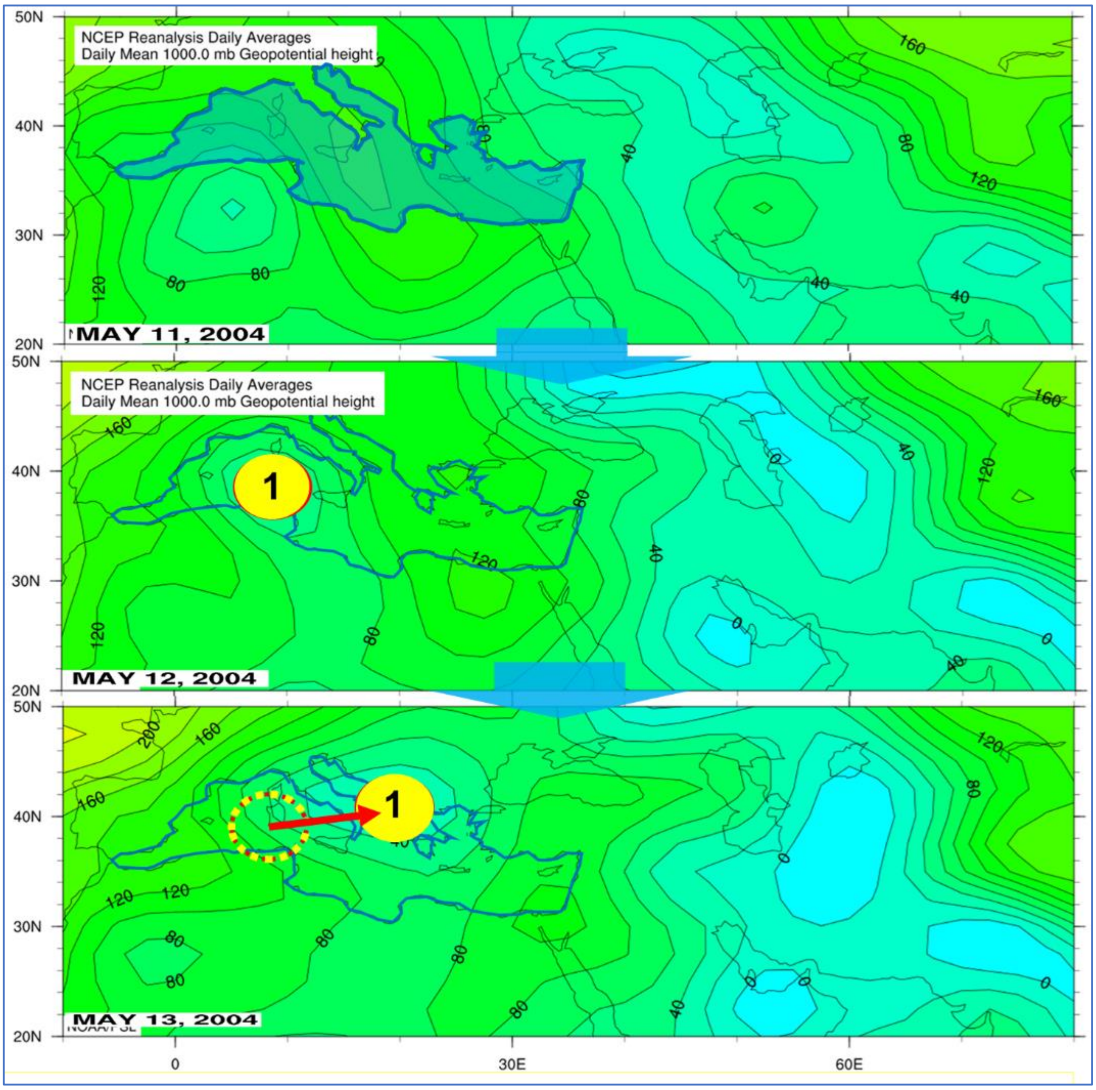

Fig. 3: Method of retrieving and marking MLP

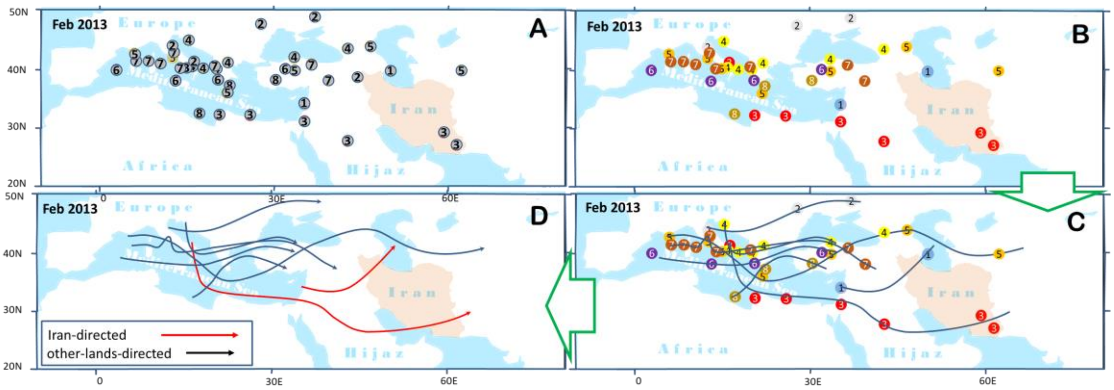

Fig. 4: Three-step technique for designing MLP tracks patterns and distinguishing between LTIs and LTOs tracks: daily position of MLP areas without color difference (a), with color difference (b), drawing the tracks of each low-pressure area based on the color difference and number (c), and drawing the final tracks (d).

In designing the patterns, the tracks that reached the geographical area of Iran were drawn in red and were called low towards Iran (LTI), and the tracks that did not reach the geographical area of Iran were drawn in black and were called low towards other lands (LTO).

In the last stage of this research, after the annual counting of tracks, a pattern of tracks sets was designed in two decades (2003-2012) and (2013-2022) to test the hypothesis of northward displacement of tracks.

Results and Discussion

Iran is located in the world's desert belt, with an average annual rainfall of 250 mm, which varies from less than 200 mm to more than 1000 mm in different regions (Heydarizad et al, 2019). Of all the seas surrounding Iran, the Mediterranean Sea plays an important role in generating precipitation systems for Iran during the autumn, winter, and spring rainy seasons (Barati and Heydari, 2010). Dayan et al. (2015) believe that moisture transfer from the Mediterranean Sea occurs mostly in the middle layers of the troposphere. Meanwhile, the first results of the current study indicate a gradual decrease in the arrival of Mediterranean rain-bearing low pressures in Iran during the autumn and winter seasons over the last two decades (Fig. 5). The filling of MLPs up to about 4 millibar from 1948 to 2009 has also been previously investigated by Rasouli et al. (2012). Given the hot, arid and semi-arid nature of Iran's climate, winter precipitation plays an important role in providing snow reserves in the main mountain ranges of Iran, especially the karst formations in the Zagros (Eshqi and Serveti, 2003). Winter rainfall is also important for rainfed agriculture, aquifer recharge, and water reserves behind dams. Therefore, these results alone are a warning for water resources planners in Iran.

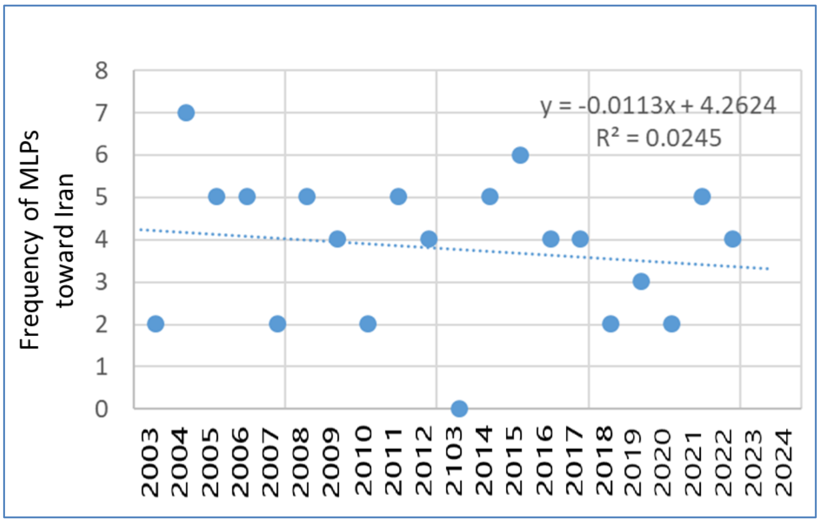

Fig. 5: Changes in the frequency of MLPs of the LTIs type over time

In this study, based on the definition provided for MLP, a total of 418 low pressure areas were identified and tracked. Of these 418 low-pressure areas, 330 of them left the sea and headed towards other lands, and 88 of them reached Iran. Also, of the 418 low-pressure areas mentioned, 12 arose from other lands, such as the African desert (Sahara), but from the day they entered the Mediterranean Sea and continued their track, they were considered MLP areas. A study of 84 designed monthly patterns showed that the contribution of LTOs dominates LTIs. In Figure (6), the contribution of both low pressures is indicated and in the two-month sample, the first month is presented with the maximum share of LTOs and the second month with the maximum share of LTIs. Pattern (6-a) shows the conditions in November 2010. This month, 100% of the time, the tracks have been LTOs, and Iran has not had any of the low-pressure areas. Pattern (6-b) shows the conditions in February 2003. Iran's largest share of Mediterranean low pressure in the entire statistical period was in February. Figure (6-e) shows the ratio of the total contribution of the LTIs and the LTOs.

The latest research findings related to the separation of tracks, both LTIs and LTOs, into two half-periods, including 2003 to 2012 and 2013 to 2023. If the length of the tracks from west to east is divided into three parts, the first part of the tracks is generally in the northern Mediterranean, and this issue has been mentioned by Hejazizadeh and Sedaghat (2010) for the month of January, but thereafter, the tracks exit the Mediterranean Sea in three main directions or pathways. In this study, we plotted the set of tracks from 2003 to 2022 in two half-periods, including the first half-period from 2003 to 2012 and the second half-period from 2013 to 2022. In the first half of the period, low pressures originated from the western

Mediterranean and traveled along pathways 1, 2, and 3 toward the southern Persian Gulf, central Iran, and the Black Sea, respectively (Figure 7-a), but in the second half of the period, the pathways show a clear shift. The three aforementioned pathways have been shifted to more northern latitudes, namely over the southern provinces of Iran, the middle of the Caspian Sea, and the northern Black Sea, respectively (Figure 7-b). These two patterns (Figures 7-b and 7-e) are consistent with the results of previous researchers (Alijani, 1995).

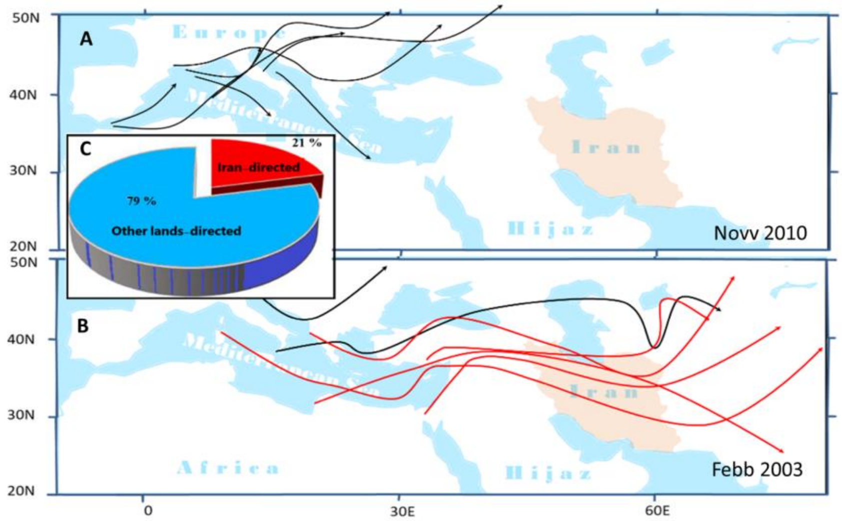

Fig. 6: Two examples of synoptic patterns related to the month with maximum LTO tracks (A), maximum LTI tracks (B), and their total contribution (C) to providing precipitation in Iran

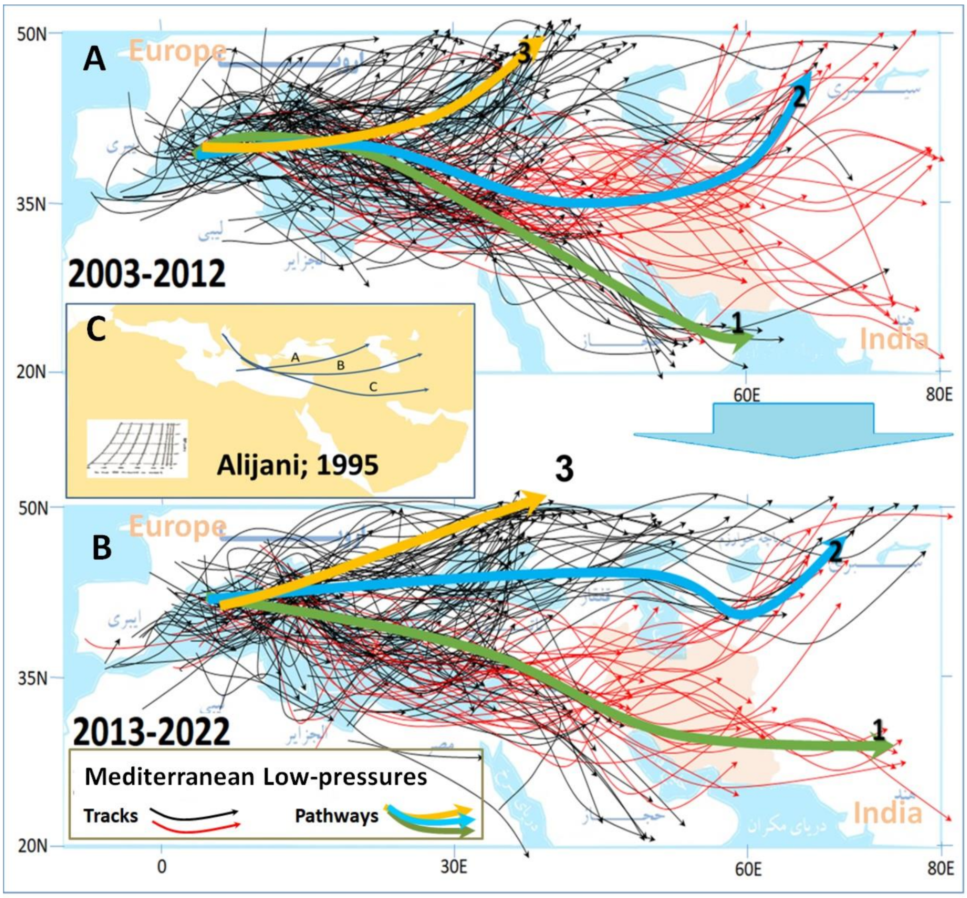

Fig. 7: The pattern of the tracks (narrow red and black ones) and pathways (thick yellow, blue and green ones) including LTIs and LTOs during: half-period 2003 to 2012 (A), half-period 2013 to 2022 (B) and its comparison with the general pattern drawn in previous research (C).

Is the current finding, the northward shift of the LTIs over the past two decades, related to the researchers' results on the expansion of the Hadley cell in the Northern Hemisphere? This question is important because Iran is located on the northern edge of this cell and every year it experiences the arrival of tropical systems from the southwest and southeast, respectively, including the Indian monsoon sequence during the summer (Habibi, 2000; Khoddam et al, 2015) and Sudanese low-pressure systems from lands such as northern Ethiopia (Movaghari and Khosravi, 2014) and the Arabian Sea (Mofidi and Zarrin, 2005). These precipitations have a convective mechanism and are sometimes torrential. Some studies have mentioned the northward expansion of the Hadley cell, with interpretations of the more northerly track of tropical cyclones (Lu et al, 2007) and their increasing risk at more northern latitudes (Sharmila and Walsh, 2018). Xian et al (2021) linked the increase in heat waves in Europe to the expansion of the Hadley cell.

Conclusion

In the current study, the emergence and movement of low-pressure areas over the Mediterranean Sea were investigated over a 20-year period (2003 to 2022). For this purpose, the Mediterranean Sea was defined from the Strait of Gibraltar at the westernmost point to the Gulf of Iskenderun at the easternmost point, and from the Gulf of Venice on the northernmost coast to the Gulf of Sidra on the southernmost coast. By conducting this synoptic survey, a total of 418 Mediterranean Low-Pressure (MLP) were tracked. Studying and recording the daily position of low-pressure systems on the daily air pressure maps revealed their eastward movement along three main pathways. Of the three main pathways along which Mediterranean rain-producing low pressures travel towards Iran, only two pathways passed through Iran in the first half of the period (2003 to 2012) and the other pathway crossed higher latitudes than Iran to the east. In the second half of the period (2013 to 2022), one of the two pathways mentioned has also moved to northern latitudes and exited Iran. Therefore, only one pathway, which is the southernmost pathway and previously tended to the countries south of the Persian Gulf, passes through Iran. Meanwhile, winter is the season when Mediterranean precipitation-producing low pressures have entered Iran more frequently than other seasons. Now, if the gradual decrease in the arrival of Mediterranean low-pressure systems in Iran continues or intensifies in the coming decades at the rate revealed in the current research, the country's agricultural sector and then urban water could face a serious crisis. The vastness of Iran, the distance of many of its regions from water sources, and their sheltered location behind the Alborz and Zagros Mountain ranges are factors that do not greatly enhance the hope of compensating for the water shortage through low-pressure systems in the Red Sea or the combined low-pressure systems of the Mediterranean and the Red Sea along the only remaining pathway in Iran.

Acknowledgment

There has been no support from any organization to carry out this project.

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