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Evaluation of the human thermal discomfort index in different phases of North-Caspian Sea Patterns (NCP) in southern coasts of Caspian Sea, Iran

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Abstract
Human thermal comfort is strongly dependent on climatic parameters variations. Variations of climatic parameters such as air temperature, precipitation, and wind speed under the effect of atmospheric teleconnection patterns can influence thermal conditions. Therefore, the main objective of this study is evaluating the effect of North-Caspian Sea Pattern (NCP) on Human Thermal Discomfort (HDI) in southern coasts of Caspian Sea. To do so, air temperature and dew point temperature data at 2 m, were extracted from the reanalysis of the ERA-Interim/European Center for Medium-Range Weather Forecasts (ECMWF) in monthly time scale during 1979-2018 with a spatial resolution of 0.125° × 0.125°. Then, different phases of NCP were extracted including positive, negative and neutral phases. Human thermal discomfort index was calculated during each phases. Also, influence of NCP's intensity on thermal conditions were analyzed for positive and negative phases regarding to neutral phase and ΔHDI were computed. Results illustrated that cold stress is predominate thermal conditions during the positive phases of NCP in studied region while negative phase of NCP cause more comfortable conditions especially in eastern coasts of Caspian Sea. Also, intensity of NCP can influence the thermal conditions of the region.

Introduction

Atmospheric circulation and its interaction with earth surface reflects weather patterns. The most significant interaction is recognized as atmospheric teleconnection patterns (Tatli 2007). These patterns, are characterized by variations of sea-level pressure (SLP) or geopotential heights in contiguous geographic regions (Rodionov et al. 2010; Nigam et al. 2015). The relationship between these patterns and climatic parameters such as temperature and rainfall is well documented in scientific literature (Bjerknes 1969; Carleton 2003; Tsonis 2008; Wang 2017; Wang 2018; Yoo et al. 2018; Ayala 2019). Chen et al. (1999) have reported temporal variation in temperature during NAO in Sweden. Ghasemi and Khalili (2006) have concluded the Arctic Oscillation (AO) strongly controlled mean winter temperature over Iran. Atmospheric teleconnection patterns also can affect the thermal comfort and public health of a region due to variations of air temperature, precipitation, relative humidity, and wind speed (Azevedo et al. 2015). Nonetheless, the relationship between NCP and thermal comfort has not yet been completely explored. Almendra et al. (2017) have studied The influence of the winter North Atlantic Oscillation index on hospital admissions through diseases of the circulatory system in Lisbon, Portugal. They have concluded that North Atlantic Oscillation (NAO) index has indirect impact on hospital admissions due to variations in CO, PM2.5, NO, and SO2 levels. Rodrigues Diniz et al. (2019) have evaluated human thermal discomfort in the period of El Niño-Southern Oscillation (ENSO) in Brazil. Their results illustrated that discomfort conditions increases during El Niño events due to the heat while La Niña decreases discomfort.

North-Caspian Sea Pattern (NCP) is one of the significant atmospheric pattern which can affect climatic and thermal conditions between North-Caspian Sea region. NCP is defined as upper level atmospheric teleconnection between 0º to 55º N and 10ºE to 55ºN for its north-western pole and 50ºE, 45ºN and 60ºE, 45ºN for its southern-eastern pole (Kutiel et al. 2002). Figure. 1 shows poles of the North-Caspian Pattern (NCP). NCP has three phases. Negative NCP (-) is defined for cases when standard score (zi) of the difference between two poles is $Zi \leq -0.5$. whilst positive NCP represent $Zi \geq +0.5$. NCP with values

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between -0.5 and 0.5 °C are considered neutral events (Kutiel et al. 2001).

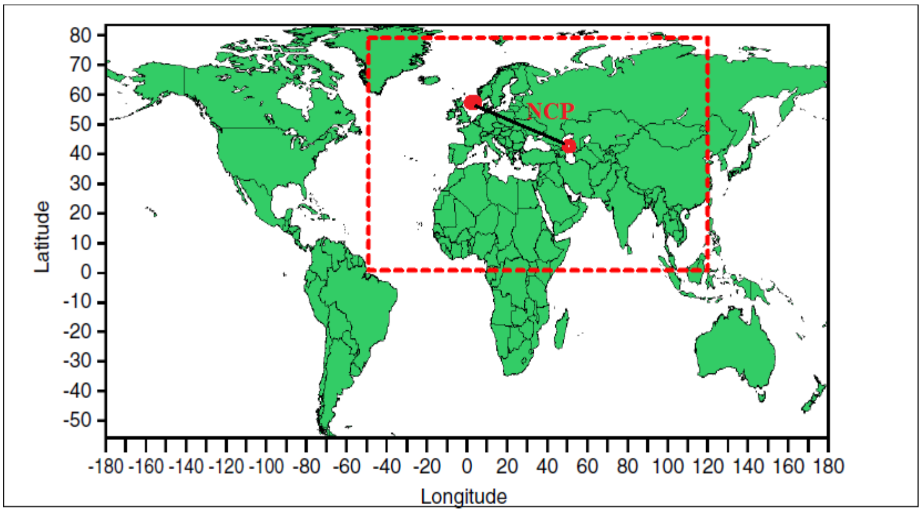

Figure 1. Poles of NCP.

Gunduz et al. (2005) have studied effect of NCP on surface fluxes of Euro-Asian Mediterranean Sea. They have reported that the NCP can significantly the Aegean and southern Black Sea heat fluxes. Ghasemi and Khalili (2008) have found out that the NCP is correlated with winter outgoing longwave radiation over Iran, negatively. Based on Kutiel et al. (2002) temperature values during NCP (-) is significantly higher than NCP (+). However, the influence of NCP on weather or thermal conditions is less documented in literature. Therefore, the main objective of this research is to evaluate the human thermal discomfort (HDI) during the negative and positive phases of NCP over southern coasts of Caspian Sea in Iran.

Material and Methods

Caspian Sea as the world's largest inland water body is located in north of Iran. It is surrounded by Kazakhstan to the northeast, Russia to the northwest, Azerbaijan to the west, Iran to the south, and Turkmenistan to the southeast. The climate of our study area is humid subtropical. The northern Caspian Sea lies in a moderately continental climate zone, while the middle (and most of the southern) Caspian Sea lie in the warm and dry continental belt (Moalvi-Arabshahi et al. 2016). People who live in southern coast of Caspian Sea experience special climatic conditions during the year due to its proximity to the sea. Hence, thermal conditions vary from month to month in this region. Besides, atmospheric general circulation and teleconnection patterns can affect thermal sensation and comfort of this region during the year. Figure 2 represents Caspian Sea and its southern coasts geographical position.

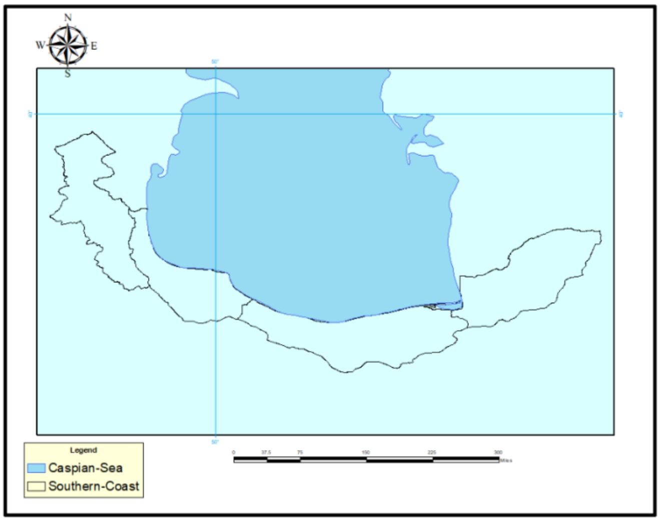

Figure 2. Geographical Location of Studied area.

To evaluate the NCP impact on thermal discomfort in the area, air temperature and dew point temperature data at 2 m, were extracted from the reanalysis of the ERA-Interim/European Center for Medium-Range Weather Forecasts (ECMWF) in monthly time scale during 1979-2018 with a spatial resolution of 0.125° × 0.125°. Then, Human Discomfort Index (HDI) was calculated for each phase of NCP by Eq.1:

$$HDI = 0.99Ta + 0.36Td + 41.5 \quad (1)$$

Where Ta is air temperature and Td is dew point temperature at 2 m.

Finally, the difference between positive/ negative and neutral phase of NCP was calculated as ΔHDI. Equation 2 and 3 represents ΔHDI for each phase:

ΔHDI= positive Phase-Neutral phase (2)

HDI= negative phase- Neutral phase (3)

The thermal conditions felt by the people were classified according to range of the human thermal discomfort index and NCP intensity in all three phases.

Results

HDI

Based on Table 1, 160, 153 and 150 cases of positive, negative and neutral phases were recognized during the statistical period (1979-2018). Among three intensities of positive phase 65, 55 and 40 cases were occurred during the weak, moderate and strong intensity of positive phase. Whilst 70, 50 and 33 cases of negative phase were occurred with weak, moderate and strong intensities, respectively (Table 1).

Table 1. Frequency of positive, negative and neutral phases of NCP with different intensity during 1979-2018.

Phase	Total Number	Weak intensity	Moderate Intensity	Strong Intensity
Positive	160	65	55	40
Negative	153	70	50	33
Neutral	150	*	*	*

*Neutral phase has no intensity (NCP <0.5

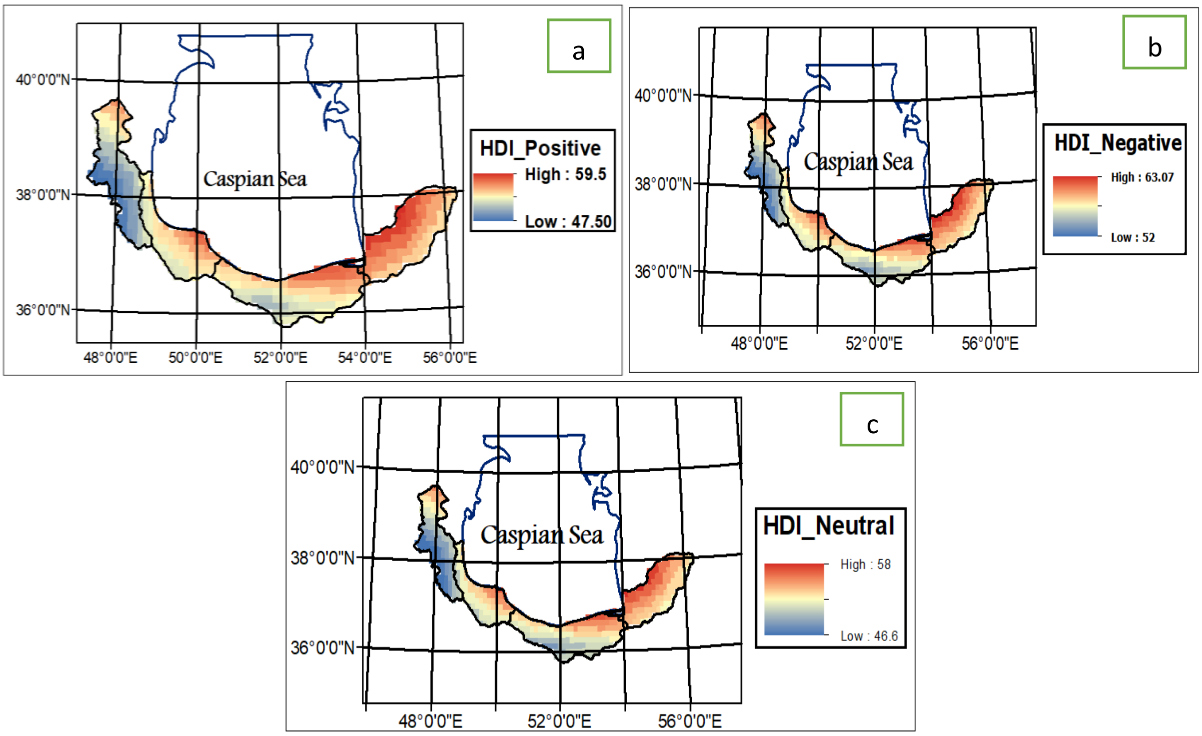

Figure 3. Composite of the index of human thermal discomfort from 1979 to 2018: (a) Positive (b) Negative (c) Neutral phases, respectively.

Generally, in the Caspian coasts the values of HDI is higher than the rest. However, during the positive phase cold stress is predominant due to the cold (55<HDI<60) and cold discomfort (HDI<55) especially in the southern and northwestern parts. Compared to positive phase, the cold discomfort is lower in negative phases so that the HDI varies between 55<HDI<60. Also, a small parts of the eastern coasts experience comfortable conditions during the negative phase of NCP with amount of 60-63. Similar to positive phase, the western coasts have more cold stress than eastern parts in negative phase as well. The neutral phase illustrates similar pattern as positive phase so that HDI varies between 46–58 during neutral phase with the highest cold stress in western and southern parts of the shores. All in all, no stress due to heat and heat discomfort conditions (HDI>65) were recognized during the all phases of the NCP in this region (Figure 3).

The composites of the difference between positive events and neutral years and negative and neutral years (Figure. 4) were plotted. It is possible to notice that during positive phase of NCP the maximum ΔHDI ca be observed in central and eastern parts of Caspian Sea with the highest amount of 2.2. in other words, there is an increase of the HDI throughout the Caspian Sea. In the western region, the HDI had a small increase that ranged from 0.5 to 1.5 while in the central to eastern parts of Caspian Sea the HDI increased between 1.5 to 2.2. In relation to negative phase, the similar trend was observed while the HDI had more increase in negative phase compared to neutrality. Figureure 5 represents composite of the HDI difference between periods of neutrality and negative phases (ΔHDI). As can be seen the HDI had a significant increase all over the Caspian Sea so that it ranged from 4.05 to 6.3. similar to the positive phase, the highest increase in ΔHDI is related to central and eastern parts with the amount of 5.03 to 6.3. The increase of HDI during the negative phase of NCP cause more comfortable conditions especially in eastern coasts of Caspian Sea. While during the positive phase the cold stress and discomfort due to cold conditions is more tangible especially in western coasts. In general, there was discomfort due to the cold during the three events in the West and South of the Caspian Sea, being greater in periods during which NCP is in positive phase. Moreover, it is important to note that there is no decreasing trend all over the shores. Therefore, it can be concluded that in both positive and negative phase of NCP, the HDI increases while it can produce comfortable conditions during the negative phase.

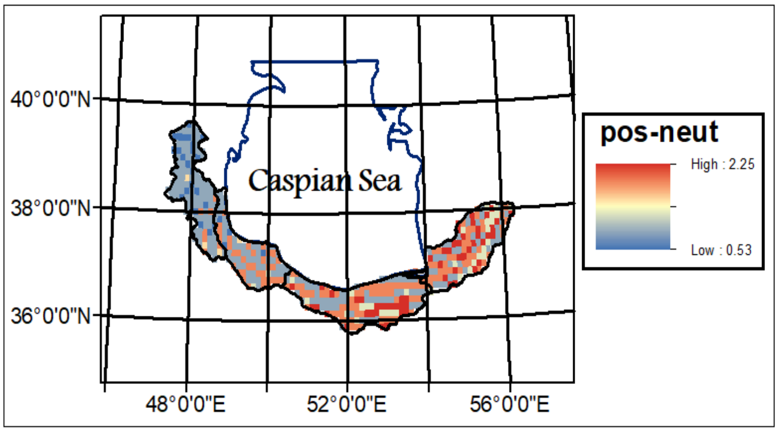

Figure 4. Composite of the HDI difference between periods of neutrality and positive phases (ΔHDI).

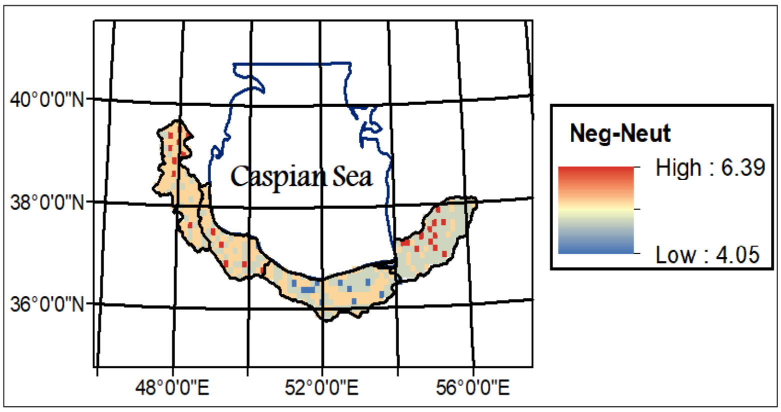

Figure 5. Composite of the HDI difference between periods of neutrality and negative phases (ΔHDI).

HDI for NCP intensity intervals

In order to determine the impact of the NCP intensity on human thermal sensation in southern coasts of the Caspian Sea, the HDI were calculated during the different intensity of NCP during both positive and negative phases. Generally, there were 65 months with positive and 70 months with negative phase of weak intensity, 55 months with positive and 50 months with negative phase of moderate intensity and 40 months with positive and 33 months of negative phase of strong intensity of NCP from 1979 to 2018. Figureure 4 presents human thermal discomfort index since1979 of the positive phases with intensity of 0.5 to 0.9 (Weak) and difference Neutral phase and positive phase with intensity of 0.5 to 0.9 (ΔHDI of Weak) (Figure. 6a, b). In positive phase of NCP with weak intensity, the maximum HDI was computed for the eastern coasts with amount of 48.6. However, the HDI increase was not enough to change the comfort of the region. From Figure. 6b, it is possible to observe small decreases in the HDI in relation to neutral periods (ΔHDI), as the intensity changes. The highest decreases were observed in western and eastern coasts of Caspian Sea ranged from -8.7 to -10.3. Therefore, the occurrence of weak intensity of NCP can increase the cold stress conditions of studied area especially in western and eastern parts.

During the positive phase of NCP with moderate intensity (1 to 1.4), the HDI varies between 93.3 to 106.3 (Figure. 7a) which shows a considerable heat discomfort (HDI>80) conditions all over the Caspian Sea coasts. The HDI increases in eastern parts are more tangible than the western. The difference between moderate intensity of positive phase with neutral phase (Figure. 7b) represents that the highest heat discomfort occurred in eastern coasts (ΔHDI> 47).

In positive events of NCP with strong intensity (NCP>1.5) (Figure 8-a), the HDI increases toward east coast of Caspian Sea so that it reaches 42.9 at the easternmost point. Comparison to neutral phase, the HDI decrease to -17 when the NCP is in strong intensity (ΔHDI<17) (Figure. 8b). In this way, events of positive of moderate intensity have more of an influence upon the increase of the HDI in Caspian Sea southern coasts. On the other hand, the lowest increase of HDI occurred during the weak intensity of positive NCP. Generally, during the positive phase of NCP, there is cold stress when the intensity is weak or strong. While in moderate intensity of NCP of positive phase the heat stress influences all over the Caspian shores.

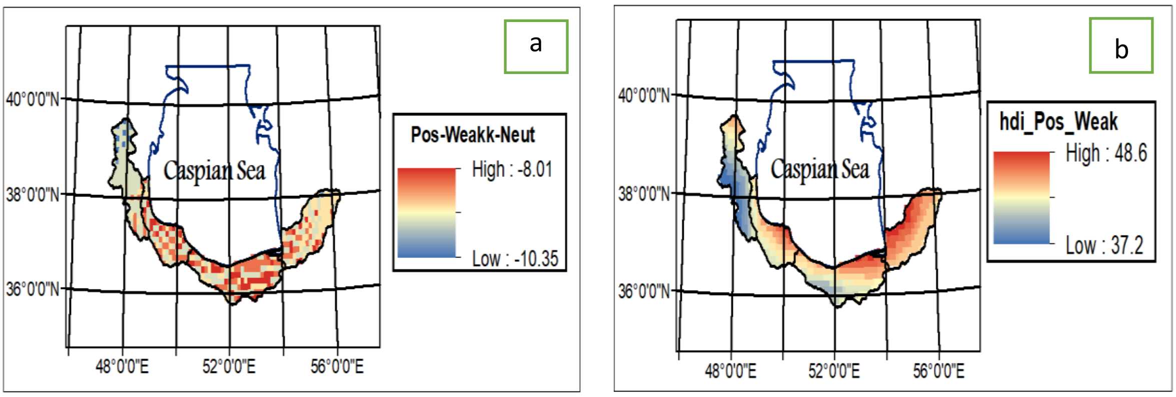

Figure 6. (a) Human thermal discomfort index since1979 of the positive phases with intensity of 0.5 to 0.9 (Weak); (b) Difference Neutral phase and negative phase with intensity of 0.5 to 0.9 (ΔHDI of Weak).

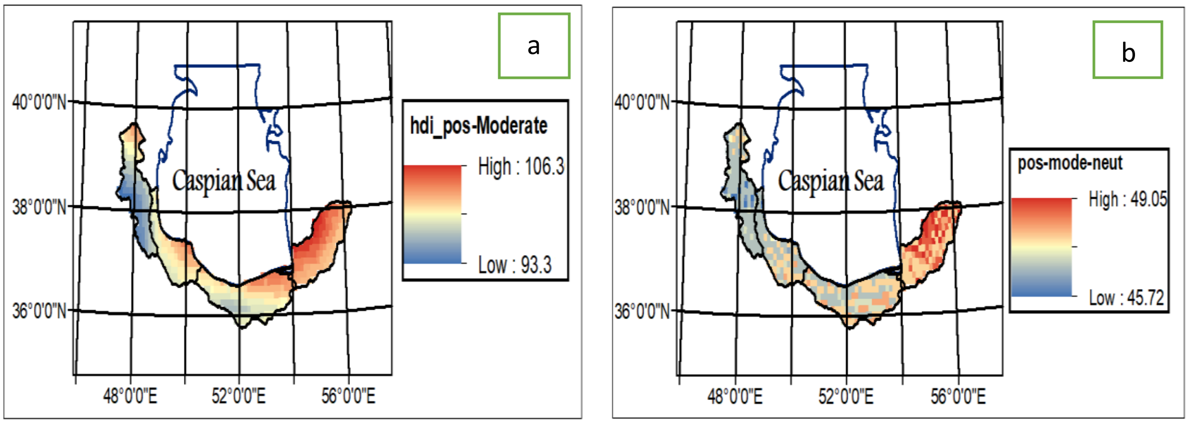

Figure 7. (a) Human thermal discomfort index since1979 of the positive phases with intensity of 1 to 1.4 (Moderate); (b) Difference Neutral phase and negative phase with intensity of 1 to 1.4 (Moderate).

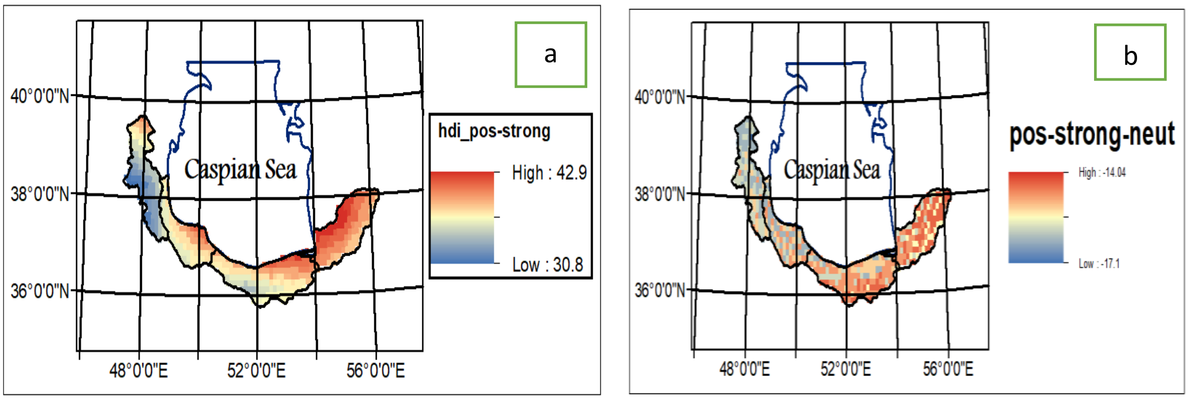

Figure 8a. Human thermal discomfort index since1979 of the positive phases with intensity of >1.5 (Strong). b Difference Neutral phase and negative phase with intensity of >1.5 (Strong).

Figures 9–11 show the HDI for the negative events according to the intensity and the difference of the HDI between neutral periods and negative in each intensity. As in positive events, in negative events, the HDI decreases during the weak intensity of NCP, but this decrease is small and is more noticeable in the Northeast and East regions (Figure. 9a, b). Generally, HDI is lower than 55 during the weak intensity of negative phase and stress due to the cold is common condition whole over the region. Although, compared to the neutral phase of NCP, occurrence of weak intensity of negative phase of NCP can decrease HDI between -4.8 to -6.5 all over the Caspian Sea coasts. But the thermal sensation during the weak intensity of negative phases generate cold stress and this decrease make it worse.

During the occurrence of negative phase of NCP with moderate intensity (-1 to -1.4) which is presented on Figure. 10a, the HDI is increase considerably and varies between 48.7 to 60.1. This increase can decline the intensity of stress due to the cold especially in eastern regions. Meanwhile, difference between moderate intensity and neutral phase (Figure 10-b) displays a small increase between these two phases which ranged from 1.8 to 3.1 Hence, the occurrence of moderate intensity of negative phase can reduce the cold stress over the region compared to the neutral phase. However, comparison with moderate intensity of positive phase (1 to 1.4), no heat stress occurred and the eastern parts of the studied regions have experienced thermal comfort during the moderate intensity of negative phase (-1 to -1.4).

Finally, similar to weak intensity, the HDI decrease when the strong intensity (<-1.5) of NCP occurs so that it ranges from 40.1 to 50.8 which represents stress due to the cold (Figure11-a). This condition is more tangible in western coasts of Caspian Sea and towards the east the HDI increase slightly. However, the most predominant thermal condition is "cold discomfort" all over the regions. Furthermore, the ΔHDI between neutral phase and strong intensity of negative phase represent decreasing trend of HDI. In other words, occurrence of strong intensity of negative phase (<-1.5) can decrease the HDI all over the Caspian Sea coast with the highest amount of -7.8 in east and southeast of Caspian Sea (Figure 11b).

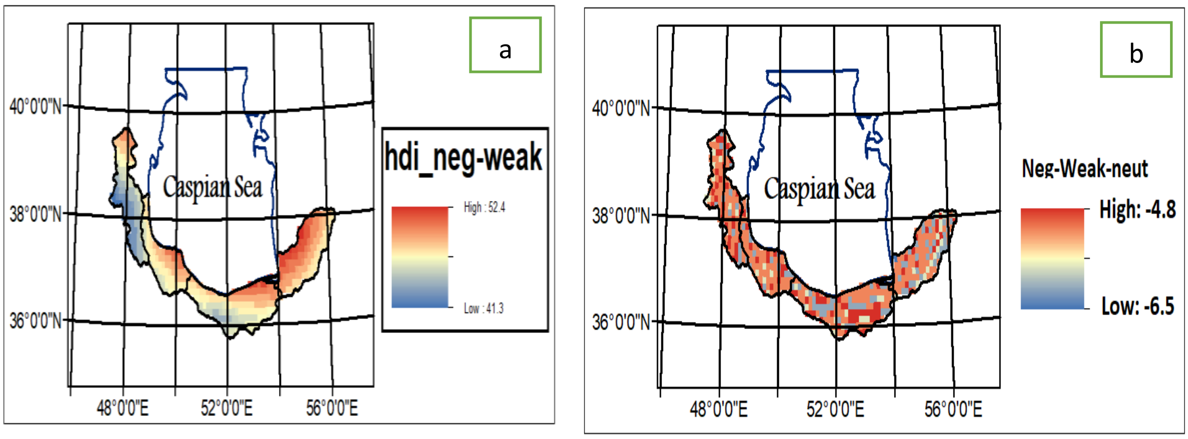

Figure 9a. Human thermal discomfort index since1979 of the negative phases with intensity of -0.5 to -0.9 (weak). b Difference Neutral phase and negative phase with intensity of -0.5 to -0.9 (weak).

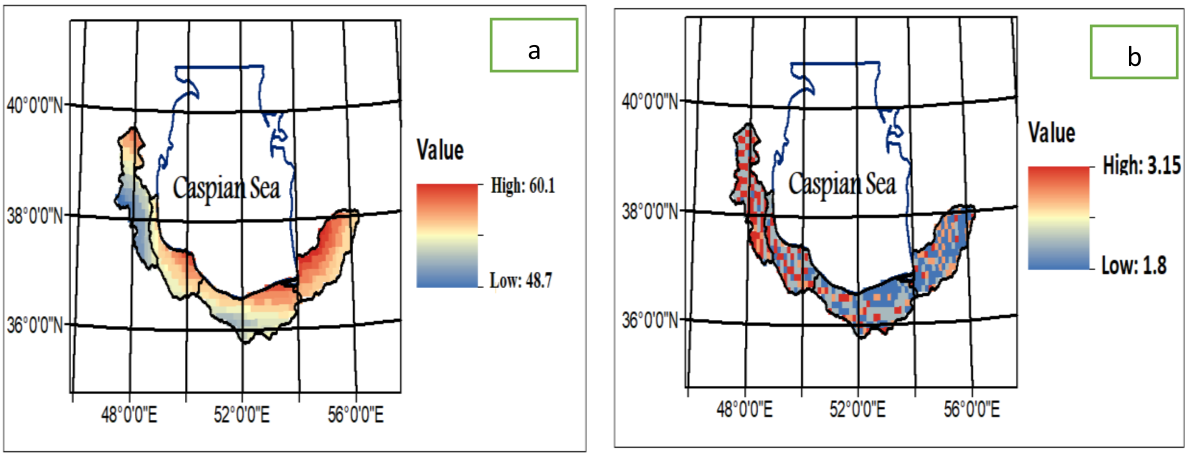

Figure 10a. Human thermal discomfort index since1979 of the negative phases with intensity 0f -1 to -1.4 (moderate). b Difference Neutral phase and negative phase with intensity 0f -1 to -1.4 (moderate).

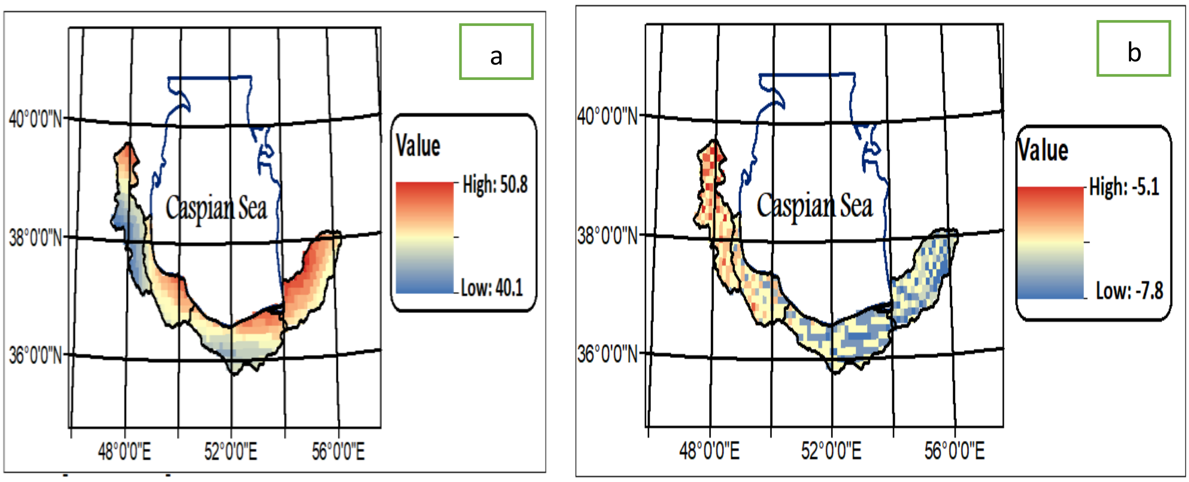

Figure 11a. Human thermal discomfort index since1979 of the negative phases with intensity 0f <-1.5 (Strong). b Difference Neutral phase and negative phase with intensity 0f <-1.5 (Strong).

Discussion

NCP is a climatic phenomenon that causes impacts on other region's climate by the upper level atmospheric teleconnection. The most observed impacts are variations in climatic elements such as air temperature and precipitation. However, it was confirmed by previous researches that the influence of the NCP will be less pronounced on the rainfall compared with its impact on temperature (Kutiel et al. 2002; Maheras et al 1999; Maheras and Kutiel 1999). These variations in temperature regime can impact human thermal sensation especially in coastal regions (Yan and Oliver 1996). In this study, it was observed that during the positive phase cold stress is predominant due to the cold and cold discomfort especially in the southern and northwestern parts. Compared to positive phase, the cold discomfort is lower in negative phases. Also, a small parts of the eastern coasts experience comfortable conditions during the negative phase of NCP. This pattern is due to the different variations of temperature during the negative and positive phase of NCP. Generally, the temperature of Caspian Sea regions increases during the negative phase while it is decrease during the positive phase. Hereupon, the HDI decrease and increase during the positive and negative phases, respectively. However, the intensity of the NCP represents that this pattern will be changed when the intensity of each phase is considered. Based on the intensity analysis, it was found out that during the weak and strong phase of positive phase the predominant thermal sensation is "discomfort" due to the cold stress. While the HDI can be increased during the moderate intensity of both positive and negative phases. However, the moderate intensity of negative phase has more increasing impact on HDI comparison with positive phase so that it can cause heat stress thermal conditions especially in eastern coasts of Caspian Sea. All in all, it can conclude that despite of the upper level atmospheric conditions under the effect of NCP, topography and geographical conditions of the studied area can influence the thermal conditions of the coastal regions of Caspian Sea. In this regards, the eastern coasts are more affected by heat stress and moderate cold stress during the negative and positive phase of NCP, respectively. Whilst the western parts are influenced more by cold stress and thermal sensation. This pattern is exactly consistent with the temperature regime of the region which it is increase toward the east. Therefore, the teleconnection indices such as NCP cannot determine the thermal conditions of the regions totally but can strengthen or weaken it.

Conclusion

This research investigated human discomfort in the periods of positive, negative and neutral phases of NCP in southern coasts of Caspian Sea from 1979-2018 statistical years, as well as the impact of NCP intensity on thermal comfort conditions. Results demonstrated that cold stress is predominate thermal conditions during the positive phases of NCP in studied region. Also, no stress due to heat and heat discomfort conditions (HDI>65) were recognized during the all phases of the NCP in this region. The increase of HDI during the negative phase of NCP cause more comfortable conditions especially in eastern coasts of Caspian Sea. While during the positive phase the cold stress and discomfort due to cold condition is more tangible especially in western coasts. Furthermore, the influence of NCP's intensity in positive and negative phases and its impact on thermal conditions was analyzed. Based on the results, in positive weak intensity NCP no changes in thermal comfort conditions was observed in the region. Whilst positive moderate intensity of NCP caused a considerable heat discomfort (HDI>80) conditions all over the Caspian Sea coasts. In positive strong intensity of NCP, the HDI decreased. On the other hand, in negative weak intensity of NCP a small decrease was observed in HDI. Negative moderate intensity of NCP has provided stress due to the cold especially in eastern regions. Finally, negative strong intensity of NCP represented stress due to the cold in the region.

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