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Investigating atmospheric instability indices coinciding with hails of moderate to severe size diameters: case study: Synoptic station in Bandar Abbas

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Abstract

Hail phenomenon is one of the hazardous weather phenomena that can make the highest amount of damage to farms, gardens, cars, rooftops, etc. in a very short time (a few minutes), depending on the diameter of the particles. One of the best ways to study this devastating climatic phenomenon is the use of atmospheric instability indices. The indices which are calculated with the help of radiosonde data give a fairly comprehensive vision regarding the occurrence of such phenomenon. In this study, the incidence of moderate to severe hail is investigated in the period of 1990-2010. First, the atmospheric codes related to hail phenomena were applied to extract the data, then radiosonde data in intended time were received and applying the RAOB software, the physical status of atmosphere was studied. In the studied period, two hail examples were reported on November 27, 2008 and December 5, 2008. In the first instance of hail that occurred on November 27, 2008, the status of some indicators was calculated and it was found that LCL was at an altitude of 284 meters, CCL at an altitude of 1582 meters, LFC at an altitude of 6230 meters, the ice surface at an altitude of 3278 meters, the LI index was -0.2, the K index was 25.7 ° C, and PWC was 28 mm. In the above mentioned conditions, there was a hail with a diameter of 25.4 mm. In the second instance of hail that occurred on December 5, 2008, the status of some indicators was calculated and the results showed that LCL was at an altitude of 280 meters, CCL at an altitude of 1762 meters, LFC at an altitude of 2271 meters, the ice surface at an altitude of 2771 meters, the LI index was -1.4, the K index was 27.1 ° C, and PWC was 23.6 mm. In the above mentioned conditions, there was a hail with a diameter of 3.6 mm. Given that in many ways, the status of most atmospheric indicators in the two above examples of hail were close to each other, it turns out that in similar circumstances, the greater the distance the ice level gets to the summit of cloud, the greater is the probability of hails larger in diameter. The value of this distance for November 27, 2008 was at approximately 6384 meters and for December 5, 2008, it was at about 5012 meters.

Key words: *instability indicators, hail, Skew-T, Bandar Abbas station.*

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Introduction

The phenomenon of hail is caused by severe thunderstorms. Such storms can make tornadoes, strong winds with speeds in excess of 25 meters per second and hails with more than 1.9 cm in diameter (Bluestein, 1993: 448). So that in the case of August 2, 1981 hailstorm that occurred in southeastern Montana, vertical speed was increased to up to 50 meters per second (Bluestein, 2013:113). In order for hails to be the size of a golf ball, they should remain inside the cloud for about 5 to 10 minutes (Ahrens, 2001:132). This is considered as one of the main causes of damage to crops, wealth and property when the particles are large (Barry and Chorley, 2010: 131). The damage caused by hail depends on the size of particle diameter so that more destructive hails have a diameter of over 20 mm (Mohammadi, 2009: 52). The size of severe hail diameter is greater than 5 mm and it often creates serious damage. This phenomenon usually occurs in middle latitudes and its incidence decreases towards the poles and the equator (Wixon, 2005: 400). Observations show that only a very small part of any severe thunderstorm can cause large types of hail; this phenomenon usually starts suddenly and ends a few minutes to less than a half of an hour (Saha, 2010:56).

The United States is divided into 13 regions in terms of intensity and frequency of hail phenomenon (Allaby, 2007:206). Studies show that the damages caused by hail phenomenon amount to hundreds of millions of dollars every year to various sectors such as machinery, roofs of houses and streets of the United States of America (Ahrens, 2009:184 Ahrens and Samson, 2010:159). In addition, damages caused by hail phenomenon alone among all climatic factors in Montana amount to about 27.7 percent of America's total loss between 1947 and 1967 (Thompson and Perry, 1997:254).

Few studies have been conducted in connection with hail phenomenon which are mentioned briefly here based on the most important results obtained. Generally, the swing of two high pressure subtropical components and polar vortex during warm and cold seasons have caused the most instances of hail in the cold season in the South West of the country and in the warm season in the North West (Hejazizadeh, 2000). The spatial distribution of hail events in Iran was in areas of West and North West and the temporal distribution was more in March and April (Farajzadeh and Mostafapour, 2012). Studies in Tabriz indicate that the more the distance between the ice level and the cloud summit, the more is the probability of hail and as the level becomes less, than 3000 m the probability of hail becomes less (Mirmousavi and Akbarzadeh, 2009). The temporal distribution of hail in the North East of the country shows that the maximum time frequency was between 9 and 15 (local time) and maximum monthly frequency was in March, April and December, respectively (Lashkari and Amini, 2009). Most thunderstorms in Isfahan were in the period from 1990 to 2008, which has been associated with heavy rainfall and hail in the transitional seasons of fall and spring; in such thunderstorms the greatest source of moisture was provided by the warm seas of the southern Persian Gulf, Sea of Oman and the Arabian Sea (Khazaee et al. 2004). Given that the hail phenomenon occurs in convective clouds and the temporal and spatial distribution of this phenomenon is very limited, one of the best ways to study this devastating climatic phenomenon is the use of instability indices. Therefore, in this study instability indices will be used to identify situations for the development and intensification of this destructive phenomenon.

Data and methodology

In this study, moderate to severe hail in Bandar Abbas synoptic station with the latitude of 27° 13 minutes north, longitude of 56°, 22 minutes east, and with a height of 9.8 meters above sea level, has been studied over the period of 1990 to 2010. First, the codes of hail on rainy days were extracted (Table 1), then, the upper at-

Codes of phenomenon	The description of phenomenon
27	Hail or hail along with the rain, during the last hours.
87	Light rain and small or soft hail, with or without rain or mixed with rain or snow
88	Moderate or severe hail storm or soft hail, with or without rain or mixed with rain and snow
89	Soft hail, with or without rain or mixed with rain or snow
90	Moderate or severe hail storm, with or without rain or mixed with rain and snow
93	Snow or mixed rain and snow or hail accompanied by lightning during the last hours
94	Snow or mixed rain and snow or hail accompanied by soft or severe lightning during the last hours
96	Lightning accompanied by severe or soft hail
99	Lightning accompanied by severe hail

Table 1. Codes related to hail phenomenon (WW)

The probability of thunderstorm	SI index
It is expected in some areas	>3
The likelihood of thunderstorm increases quickly	-1 to 2
Severe thunderstorm	-3>
The possibility of tornado	-6>

Table 2. the relation between SI index and thunderstorm severity (air service weather, 1990: 35)

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mospheric data for the two recorded hail for 00:00 O'clock were got from the University of Wyoming and the status of indicators such as LCL, LFC, K, SI and PWC in considered days were drawn applying the RAOB software and they were analyzed in details.

Instability indices

Lifting Condensation Level (LCL)

Lifting Condensation Level is defined as the height at which an air parcel will reach saturation by dry adiabatic lifting. At this level, the relative humidity is 100% and the cloud base in formed. To obtain LCL, first a line is drawn from the point of drying temperature at ground level parallel to dew point then a line is drawn from the dew temperature point at ground level parallel to mixing ration until it intersects the first line; the intersect point is called the Lifting Condensation Level (air weather service, 1990:13).

Level of free convective (LFC)

If the environmental temperature degradation exceeds the moist adiabatic lapse rate, the air parcel is forced to continue its ascending to reach a level where floating of air packages becomes more than the surroundings. In this situation, the air parcel would rise freely and this level is called the LFC (Holton, 2004: 290). LFC is calculated through the following approach:

From the LCL level, a line is drawn parallel to adiabatic saturation lines so that it crosses the environmental temperature degradation curve; the intersect point is called the LFC. From this intersect point upward, the floating of air packages is positive and it ascends freely.

SI index

This index was proposed by Showalter in 1953. The index, which is based on the concept of potential instability, is calculated by

the possibility of thunderstorm occurrence in %	K index
Close to 0	<15
20	15-20
20-40	21-25
40-60	26-30
60-80	31-35
80-90	36-40
Close to 100	40<

Perceptible water content index

$$PW = g^{-1} \int_{p500}^{p0} dqp$$

g: Acceleration of gravity

q: Special Nam

P_0: Ground level pressure

P_{500}: Pressure level of 500 m b

Table 3. the relation between K index and the possibility of thunderstorm occurrence (Air service weather, 1990: 38)

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lifting a parcel dry adiabatically from 850mb to its LCL, then moist adiabatically to 500mb, and comparing the parcel versus environmental 500mb temperatures. As the size of this index becomes smaller in quantity, the instability severity becomes more. The index is calculated from the following equation:

SI = T500 - T^’

To calculate this index from the Skew-t graph, we act as follows:

First from the dry point at 850b, a line is drawn parallel to dry adiabatic, then from the dew point at 850mb, a line is drawn parallel to the mixing ratio so that it crosses the previous line. From the intersect level, a line is drawn parallel to adiabatic saturation to reach the 500mb level, Table 3 shows the relation between SI index and thunderstorm severity.

K instability index

This index was proposed by George in 1960. Three levels of 850, 700 and 500 HP are used to calculate this index. The thunderstorm index is based on decreasing temperature rate, low atmospheric moisture content and vertical expansion layer. The K index is calculated using the following equation:

K = (T850-T500) +Td850- (T700-Td700)

In the above equation:

T is the temperature; D is dew point temperature in Celsius degrees at pressure levels of 850, 700 and 500mb. In calculating this index, the high temperature degree and dew point shows the moisture in the low-level. As the temperature difference between 850mb level and 500mb level increases, the decrease in the vertical temperature and dew point temperature at 850mb is more visible; in addition, the difference between temperature and dew point temperature at 700mb shows the moisture amount. In other words, as the temperature difference increases, the moisture content and moisture amount decreases and conversely, as the temperature and dew point temperature at 700mb become closer and have less difference, the moisture amount at this level increases and the possibility of thunderstorm occurrence increases. Table 4 shows the relation between K index and the possibility of thunderstorm occurrence.

As Figure 1 shows, the rising air density level is located at an altitude of 284 meters. At this very low height, the relative humidity is 100%

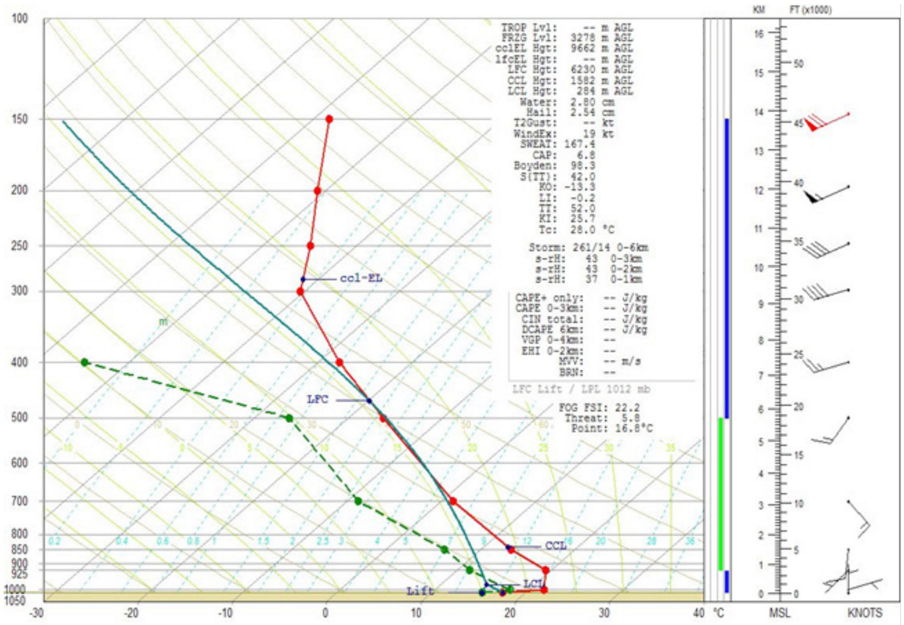

Figure 1. The Skew-T diagram of November 27, 2008 at 00:00 o'clock in Bandar Abbas station

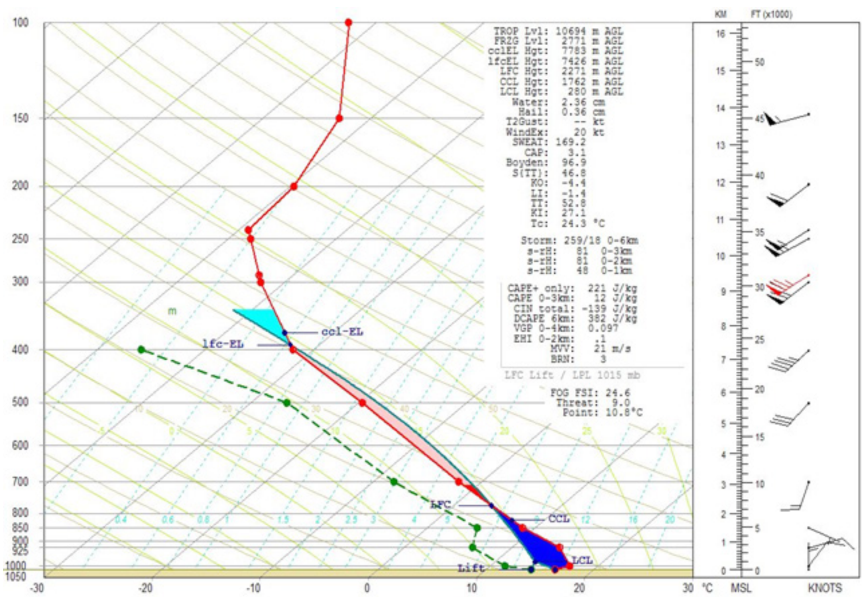

Figure 2. The Skew-T diagram of December 5, 2008 at 00:00 o'clock in Bandar Abbas station

and cloud base is formed. Also, the convective condensation level is located at a relatively low height of 1582 meters. LCL and FCL low-altitude levels have made air very humid and too thick and consequently to have high latent heat release. The free convection level in this day is at an altitude of 6230 meters. From this level to the high altitude, the air pack earns enough energy to climb and without the need for other rising factors, it freely ascends in the vertical direction with the release of its latent heat. In this day, a Thunder cloud peak is located at 9662 meters altitude. So, the thickness of super-thunder in Bandar Abbas station is approximately 9380 meters. The freezing level at this super-thunder starts at an altitude of 3278 meters. The height of this level indicates that about two-thirds of the upper part of super-thunder is formed of ice droplets. In addition, the LI negative value index which shows that

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the air pack climbs is -0.2° C and the SI index was 0.26. Considering the low negative values and low positive values of SI index, it becomes clear that most of the energy for ascend of super-thunder in that day has been obtained from the release of latent heat. In addition, the value of K index shows that moisture in the super-thunder was about 25.7 ° C. The amount of perceptible water in that super-thunder was 28 mm. Finally, with regard to availability of all conditions in terms of moisture and instability, this super-thunder could create a devastating hail with a diameter of 25.4 mm.

Figure 2 shows the humidity and instability conditions in December 5, 2008 at 00:00 o'clock in Bandar Abbas station. It is observed that the rising air density level is located at an altitude of 280 meters in this thunderstorm. Also, like the previous thunderstorm (November 27, 2008), the convective condensation level is located at a relatively low height. In addition, convective condensation level is located at 1762 meters altitude. LCL and FCL low-altitude levels shows better moisture conditions at lower levels of this super-thunder. The vertical transmission level of air packages is at an altitude of 2271 meters. Given that the level of free convection is located at low altitude, it is found that a moisture condition in the lower levels is well prepared for the super-thunder. The summit of this super-thunder is at the height of 7426 meters, thus the thickness is 7146 meters. The thickness of this thunderstorm is 2230 meters lower than the thunderstorm of November 27, 2008 and this has caused the precipitation water in this super-thunder to be 23.6 mm which is about 4.4 mm less than the thunderstorm occurred in November 27, 2008. The ice surface in this thunderstorm is at an altitude of 2771 meters. The LI index value, which represents the dynamic instability of the atmosphere, was about -1.4°C and the SI index was -0.4. The K index was about 27.1°Celcius. All conditions have caused this super-thunder to create hails with a diameter of 3.6 mm.

Conclusion

Hail is one of the hazardous atmospheric phenomenons which occur during the cold season, particularly in southern areas. Extreme weather instability, along with plenty of moisture in these areas has led to hail event in some parts of the created cumulonimbus clouds. Given that the hail phenomenon lasts a few minutes and in many cases the resulting instability usually lasts less than a few hours and on the other hand, the upper atmospheric data are reported twice a day, at 00:00 and 12:00 (upper atmospheric data in Bandar Abbas is reported once a day), there are many limitations in investigating short-lived phenomena such as hail, which is formed quickly and destroyed. Thus, in many cases that the hail occurs at time distant from 00:00 and 12:00, studying instability indices alone cannot show the state of the atmosphere well. In the studied period, two hail examples were reported on November 27, 2008 and December 5, 2008. Given that in many ways, the status of most atmospheric indicators in the two above examples of hail were close to each other, it can be concluded that in similar circumstances, the greater the distance the ice level gets to the summit of cloud, the greater is the probability of hails larger in diameter. The value of this distance for November 27, 2008 was approximately 1372 meters more than the hail in December 5, 2008. As the distance between this level and cloud summit increases, the amount of moisture available for the release of latent heat and extreme weather climbs is provided and it allows vertical development of cumulonimbus clouds to create hails with larger diameters.

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