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Study of Convective Instabilities in Tehran Area

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Abstract: In this research, a number of convective instability indices during a 5-year period (1999-2003) for thunderstorms in Tehran area which have been accompanied with at least one lightening by means of thermodynamic diagrams analysis are calculated. These indices include precipitation water of cloud (PWC), Showlter index (SI), and convective available potential energy (CAPE). Average precipitation of Mehrabad, Chitgar, Aghdasieh, Geophysics, Doushantapeh, and Aminabad stations was measured and using the best regression curve between the calculated values of indices in flood days as the independent variable and mean precipitation of the selected stations in Tehran as the dependent variable, thresholds have been estimated for probability of flood generation. Values of these thresholds for CAPE, PWC and S indices have been found 1000J/kg, 26mm, 35^0C and -2, respectively. Values of these thresholds in warm seasons due to more thickness of convective clouds are usually slightly greater.

Key words: precipitation water of cloud (PWC), Showlter index(SI), convective available potential energy (CAPE).

INTRODUCTION

Stability is a state of atmosphere in which vertical movement does not exist or is limited. Instability is the opposite of the defined state for stability in which there is accelerating vertical movement inside the atmosphere. Degree of stability and instability effect can be identified and examined from vertical distribution of environment. Given the temperature difference between the air package vertical movement and environment at each given level and considering definition of atmosphere's stability and instability, final result can be obtained. Atmosphere's stability and instability relative to environment is a function of the amount of temperature drop which allows decrease or increase in floating power in the air package vertical movement. For convective instability, meteorologists have given the explanation that a layer will turn into convective instability when potential temperature equal to the height decreases throughout the layer.

Amongst phenomena which are generated as a result of convective instability, it can be referred to thunderstorms. Structural thunderstorms are in small scale and have a rapid growth and are accompanied with plenty of lightening and sometimes with strong winds or hail formation. This phenomenon often leaves destructive and harmful effects behind.

Anthes *et al*., (1996) research in North America, every 12 hours hemispherical maps have been drawn. By means of these maps, geopotential, vertical velocity, precipitation water of cloud, humidity and convective available potential energy (CAPE) have been studied. This research showed that CAPE increase is accompanied with increase in PWC and this in turn give rise to increased clouds soaring (ascending) speed and eventually increased rainfall.

In another research, Simoenov and Georgiev (2001) investigated the storms accompanied with hail stone in Sophia (Bulgaria) during 1997-2001 and calculated instability indices for them and for convective available potential energy and soaring speeds, they have obtained high values.

Costa *et al*., (2001) investigated three groups of storms with different intensities accompanied with hail and heavy rains which had occurred in north of Italy and by calculation of instability indices for all the three groups they looked for the best index with necessary storm forecasting power. According to the carried out investigations, they reached the conclusion that K index was not able to detect the type of storm. However, with Showlter index, if the temperature is obtained at -3^0C, it indicates tornado and at lower than -3^0C it indicates rainfall and at above -3^0C it indicates hail. For tornado and storms accompanied with hail, they obtained a high value for CAPE and for showers (cloudbursts) they obtained a low value for CAPE.

Monkam (2002) researched in North Africa and Atlantic Ocean (tropical zone), relationship between CAPE and rainfall in center and west of Africa during summer 1985 was investigated and correlation coefficient of CAPE and the region's rainfall indicated that these two parameters around Inter Tropical Convergent Zone have a good correlation.

Manzato and Morgan (2003) in this research in an area in Venice of Italy calculated convective indices for 5050 registered events during 1995-2001 and for each index they found a suitable threshold in order by means of which to be able to forecast boundaries of convective activity. According to these investigations, indices such as soaring speed, precipitation water of cloud, and CAPE for prediction of formation of thunder storm, and level

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free convection (LFC) and K index for prediction of thunder storm in the region under study have been suitable indices.

MATERIALS AND METHODS

4-1. Thunderstorm Structures:

Most of the thunder storms are accompanied with Cumulonimbus clouds and time period for their growth and activity takes only few hours.

All the thunderstorms for formation need a muggy soaring (ascending) air from cold front slope or mountain. Exit-less ascending cooling leads to saturation and condensation and consequently to release of the hidden heat for provision of buoyancy power. Convective instabilities in thunder storm strongly depend on buoyancy and in fact initiation of this process is formed by existence and reinforcement of buoyancy power.

All storms have a nearly similar life cycle. Thunderstorms are seen more frequently in the afternoon and evenings, because by temperature increase in the afternoon, instability increases and more thunderstorms are formed (Lutgens, 2004).

In general, it can be said: all the thunderstorms are together with a lot of lightening or strong winds or hails with a diameter of several centimeters. Thus, storms due to condition difference can be divided in to 2 groups:

1. Tropical Storms which are accompanied with muggy weather.
2. Thunderstorms which are formed as a result of strong soaring power and cold front passing.

4-2 Data:

In Tehran, there are pluviometers stations in north, south, east, west and center. For north of Tehran, Aghdasieh station, for west of it, Mehrabad and Chitgar stations, for its center, Tehran University Geophysics Station, for west of it, Doushantapeh, and for south of it, Aminabad station have been used. Registered rains in the stations were used to obtain and study the stations' mean rainfall on the intended days.

Considering the large extent of Tehran, the stations' statistical difference may be considerable which seems natural, because this research is about thunderstorm (local and mid-scale phenomenon) and it is possible that in west of Tehran this phenomenon occurs while in east of Tehran we may have a clear sky. Since only Mehrabad station in Tehran has high atmosphere data, it is more likely that the research carried out in Mehrabad station to yield better results.

In this research, high atmosphere data (Skew-T maps) concerning Mehrabad station are used and the desired indices are extracted and analyzed and the best index for forecasting existence of thunderstorms are obtained.

4-3 Instability Indices:

4-3-1 Showlter Index:

This index is one of the oldest indices which were suggested by Showlter (1953). This index is environment air package temperature difference at 500mb but by assuming that initial package lies at 850mb, SI is calculated as follows:

$$SI = T_e @ 500 - T_p @ 500 \quad (1)$$

In which, $T_{e@500}$ is environment at 500mb level and $T_{p@500}$ is air package temperature at 500mb level while Lifting Condensation Level (LCL) has been obtained from 850mb level.

When air package temperature at 500mb level is less than environment temperature, environment is stable and positive values are obtained for S index, whereas if air package temperature is greater than temperature of its environment, air package will be lighter and negative values are obtained from SI. Thus, it can be said that negative values of SI can represent atmosphere instability. Calculation method of SI by skew-T diagram is as follows:

To calculate this index, the temperature and dew point temperature at 850mb level is used and LCL is obtained then the LCL parallel to exit-less line over the increased saturation up to 500mb level is cut.

Temperature difference of environment and air package at that level represents SI. SI negative index indicates that atmosphere is instable because negative value indicates the fact that Planetary Boundary Layer relative to mesosphere is more instable and is a favorable environment for convection. Also, negative S value can be explained that temperature difference of air package and environment represents, in a sense, amount of flotation power $\left(B = g\frac{T_p - T_e}{T_e}\right)$. Thus, the positive the amount of flotation power is, the stronger the atmosphere's instability will be.

This index, if there is a strong thermal inversion between layers of 850mb and 500mb, cannot be a good index for instability.

4-3-2 Convective Available Potential Energy (CAPE) Index:

Convective available potential energy was suggested by Moncrieff and Green (1972) and was defined as follows: "the work which flotation power should do on the package in order to move upward from LFC level to EL level", while above that level, the package becomes heavier than its surrounding environment. CAPE is calculated from the below relation:

$$\text{CAPE} = \int_{Z_{lfc}}^{Z_{EL}} B\,dz \quad (2)$$

4-3-3 Precipitation Water Of Cloud (PWC):

Amount of the condensed water present in a moist air column is called PWC and is expressed in centimeter or millimeter. In fact, PWC is considered as vapor mass, water present in an air column with S cross section from the earth's surface up to the end of stratosphere or between the both arbitrary compressive levels (Rogers and Yau, 1996). Since precipitation of cloud water is directly related to moist air, it is necessary that moist air thermodynamic to be fully known. (By moist air we mean the air which includes dry air and water vapor.) To determine precipitation waterof cloud in atmosphere, a column of the air with a square cross section of 1cm each side is considered. In this column, total water mass will be up to Z height:

$$\text{PWC} = \left(\frac{1}{g}\int_{P_{ccl}}^{P_{EL}} r\,dp\right) \times 10^{-1} \quad (3)$$

RESULTS AND DISCUSSION

5.1. Showlter Index:

Figure 1 shows the best regression of SI, as independent variable on average precipitation of 6 stations which have the highest correlation coefficient is shown. In addition, in figure 2, the best regression, SI, as independent variable on Mehrabad station precipitation is shown with a relatively better correlation.

As can be seen in diagrams, the data in average precipitation of six stations and in Mehrabad station have an almost similar correlation. Therefore, considering the data distribution in average precipitation of 6 stations, only Mehrabad station can be used for analysis. Given the diagram, it can be seen that precipitations less than 5mm have positive S-values and the more negative the SI become, the more precipitation occurs.

Considering the table 1, it can be concluded that when SI ≥ 1^0C, probability of more than 15 mm rain will be zero, and probability of less than 5mm rain will be 75%. In addition, if SI < -20^0C, probability of less than 5mm rain is zero and probability of more 10mm rain is 83%. Given the drawn diagrams, it can be seen that SI within range of -20^0C has almost fixed amount of rain and this indicates that cloud's depth and thickness within this range of indices have reached their maximum amounts.

5.1.1. Physical Analysis of SI:

Convective activities and heat transfer increase as a result of increase in cloud's life and thickness from cumulus stage to mature stage and dispersion stage. Droplets ascending movement near cloud's base have a low speed and as cloud's thickness increases, ascending speed by increase of instability and positive buoyancy power resulting from release of droplets condensation hidden heat increases. According to SI definition, the more negative the SI is, i.e. temperature difference of package and environment at 500mb level is greater, the more instable this level become. Near top and edge of cloud due to intermingling of environment's dry and cold air with cloud, droplets evaporate and this intermingling leads to quick temperature decrease and consequently decrease in flotation power and ascending paces. While, the dry and cold air which intermingles with cloud causes droplets evaporation and creation of cold at equivalent level and cloud's temperature decreases and upward movements turns in to downward movements (Rogers and Yau, 1996) and the reason why rain increase course does not continue with SI decrease and rain becomes unchanged can be explained that in SI calculation it is supposed that the package without mixing with environment continues to move upward (Manzato, 2003).

Given the drawn diagrams (fig. 1 and 2) , it can be concluded that SI is not able to properly show precipitation amount, because this index is only related to temperature difference between air package and environment at 500mb level. In fact, it depends on the flotation power at 500mb level and does not depend on cloud's thickness and life throughout the cloud column. In addition, it is possible that there is a strong inversion of temperature between 500 and 850mb level (Showlter, 1953). Based on these arguments, SI cannot be considered a good representative for explanation of atmosphere's general instability. In case cloud has grown at 500mb homogeneously in upward and downward directions, SI can be used for estimation of convective instabilities, so as if SI is positive, precipitation probability will be low and atmosphere will have little instability, and if SI is less than zero, instability and precipitation should be expected in the region and as SI becomes more negative, extreme instability and heavy rainfall should be expected in the region.

Table1: Precipitation probability with showlter index.

15 > Rain	15 < Rain ≤ 10	10 < Rain ≤ 5	Rain < 5mm	SI

0	8%	16%	75%	SI < 2
0	14%	28%	57%	0 ≤ SI < 2
7%	47%	29%	17%	-2 ≤ SI < 0
50%	33%	16%	0	SI ≤ -2

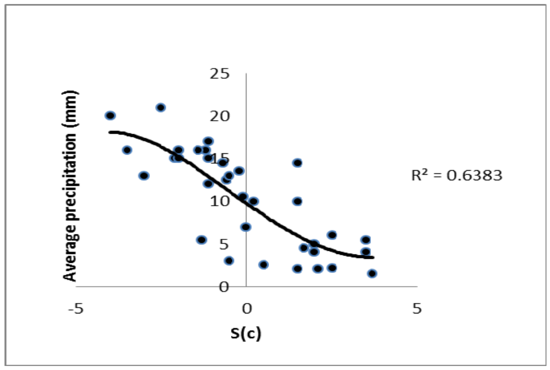

Fig. 1: Regression of average precipitation on 6 stations with SI.

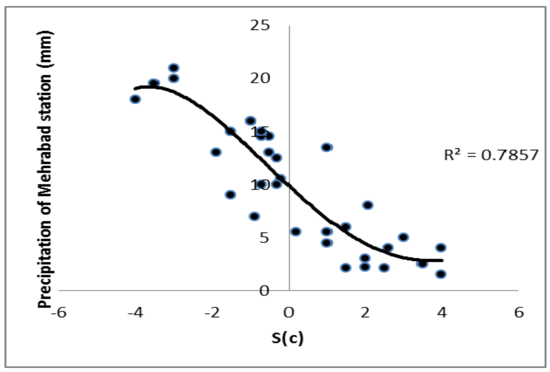

Fig. 2: Regression of precipitation on Mehrabad station with SI.

5.2. Convective Available Potential Energy (CAPE):

Given the calculated amounts in the mentioned days, the diagram related to regression of CAPE as independent variable on mean rain as dependent variable as well as on Mehrabad station's precipitation amount are shown in the following figures.

Figure 3 and 4 show that within range of 200-900 J/kg CAPE grows very much, while if amount of CAPE exceeds 1000 J/kg, the rain will be more than 15mm limit. Thus, in order to have a rain within a range above 15mm, amount of CAPE should be more than 1000 J/kg.

Table 2 show that it can be stated that if amount of CAPE is greater than 1000 J/kg, with 100% probability precipitation will be more than 10mm. In addition, if amount of CAPE is less than 400 J/kg, the probability of more than 10mm precipitation is almost zero and with 88% probability precipitation will be below 5mm.

5.2.1. Physical Analysis of CAPE:

CAPE index depends on two factors of buoyancy and height (cloud's thickness). According to Rogers and Yau (1996), it should be noted that convective movements and heat transfer increase as cloud's lifetime and thickness increase, i.e. the more the cloud's thickness becomes, the greater ascending speed with increased instability resulting from release of hidden heat of droplets condensation will be and as a result, CAPE based on the relation $\left(CAPE = \int_{Z_{LFC}}^{Z_{EL}} B dz\right)$ will increase.

As is seen in the diagrams, with increase of CAPE, amount of precipitation increases too. This precipitation increase continues up to 1000 J/kg and from 1000 J/kg and above, with increase of CAPE, precipitation finds a constant value. This difference can be explained that up to 1000 J/kg, cloud is at mature stage and with increase of cloud's life and thickness and consequently with increase in amount of CAPE, the rain increases too, while 1000 J/kg and above falls at dispersion stage so that with increase in cloud's life and thickness, intermingling becomes greater and ascending speeds gradually turn into descending speeds which lessens precipitation from cloud. Since CAPE index has direct relationship with cloud's thickness, it can have a good correlation with ascending speed and instability degree in cloud's whole depth.

This index compared to S and K indices yields better results, because buoyancy power $\left(B = \frac{T_p - T_e}{T_c}\right)$ which is temperature difference between air package and environment relative to environment's temperature measured in cloud's whole thickness. While in calculation of SI, it is sufficed with temperature difference air package and environment at 500mb level. This index for presentation of convective instabilities can definitely yield a better result, because CAPE value depends on the work which buoyancy power should do in order the package to move upward from LFC or LCC level to cloud's top (EL) (Moncrieff and Green, 1972). Given this definition, amount of CAPE is the surface below the curve from LFC to El. This index entails some errors as well. For example, amount of CAPE index for two distinct days may be equal, while on one day we may have weak buoyancy power and much thickness (i.e. surface area between air package and environment is narrow) and on another day buoyancy power may be strong and thickness insignificant (i.e. difference between air package and environment is narrow) while these two days have quite different rain conditions. It means that a thicker cloud has greater amount of PWC and precipitation. In general, given the respective diagram and table 2, it can be concluded that this index has a relatively good correlation with amount of rain but for determination of rain quantity, one cannot use only this index. However, it can be found that if CAPE value is less than 400 J/kg, few instabilities and light rain will occur in area of Tehran and in addition, in CAPE value is above 1000 J/kg, a downpour can be forecast in area of Tehran which sometimes leads to torrent in city of Tehran.

Table 2: Precipitation probability with CAPE index.

15 > Rain	15 < Rain ≤ 10	10 < Rain ≤ 5	Rain < 5mm	CAPE index
0	0	12%	88%	400 > CAPE
0	30%	42%	28%	400 < CAPE < 700
40%	30%	30%	0	700 < CAPE < 1000
84%	16%	0	0	CAPE > 1000

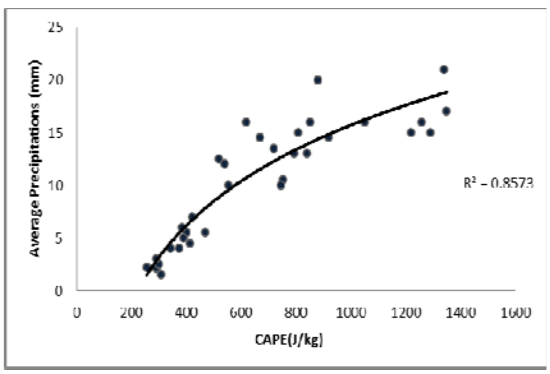

Fig. 3: Regression of average precipitation on 6 stations with CAPE index.

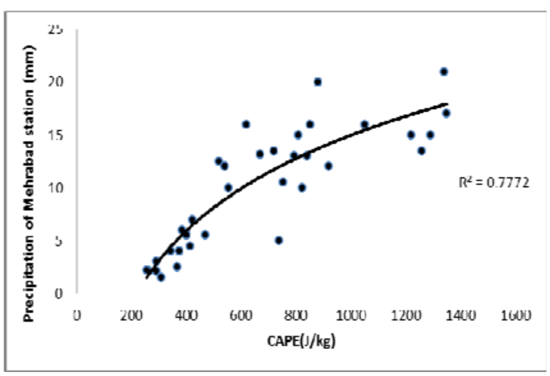

Fig. 4: Regression of precipitation on Mehrabad station with CAPE index.

5.4. Precipitation Water of Cloud (PWC):

The best regression of as independent variable on average precipitation in 6 stations with PWC as dependent variable as well as in Mehrabad station drawn in figures 5 and 6 have been shown. figures 5 and 6 show that it can be seen that there is a good correlation between the registered precipitation in the stations and PWC and generally the PWC is nearly one to two times of the registered rain in the stations, because based on exit-less processes it is supposed that cloud completely turns into dense rain. Calculations are done based on exit-less processes and the effects related to exit processes as well as intermingling effect on edges and near cloud's top have not been taken into consideration (Rogers and Yau, 1996).

From the table 3, it can be concluded that if PWC is higher than 26mm, probability of less than 10mm rain is almost zero, and probability of more than 15mm rain is above 75%. In addition, if PWC is less than 10 mm, probability of having above 10mm rain is definitely zero. Thus, it can be inferred that if PWC value is greater than 26mm, probability of having a heavy rain is very high and from the drawn diagrams it can be seen that PWC index from 26mm and above, has nearly constant amount of rain.

Table 3: Precipitation probability with PWC index.

15 > Rain	15 < Rain ≤ 10	10 < Rain ≤ 5	Rain < 5mm	PWC index
75%	25%	0	0	PWC > 26
43%	57%	0	0	18 < PWC ≤ 26
0	12%	50%	38%	10 < PWC ≤ 18
0	0	15%	85%	PWC ≤ 10

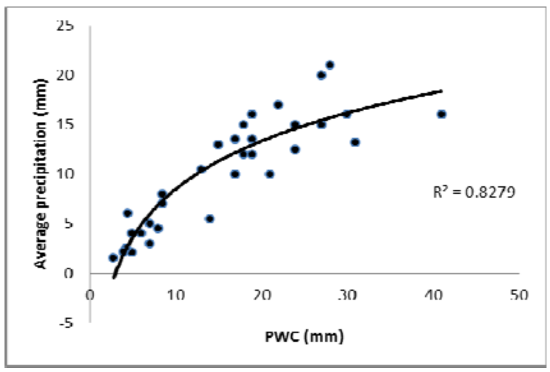

Fig. 5: Regression of average precipitation on 6 stations with PWC.

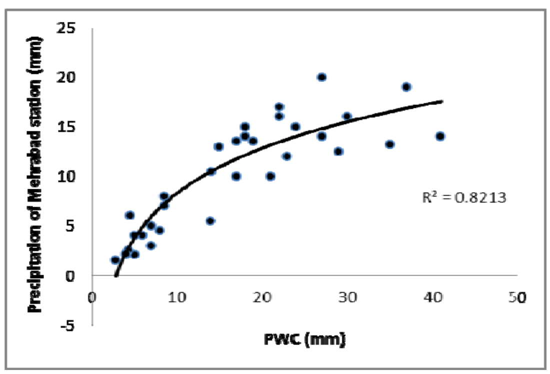

Fig. 6: Regression of precipitation on Mehrabad station with PWC.

5.4.1. Physical Analysis of PWC:

As can be inferred from figures 5 and 6 , in rains less than 20mm, rain increase with precipitation water of cloud increase has a rapid growth, but from 26mm and higher, with increase of precipitation water of cloud, rain with less intensity occurs. These changes in precipitation can be explained that at lower than 26mm rain, usually heavy rains occur and this is because cloud is at mature stage. At this stage in which cloud has reached a full thickness and ascending speeds reaches its maximum amount and heavy rainfall is observed. From 26 mm and above, dispersion stage starts in which with increase of cloud's life and thickness, intermingling of cold and dry air to inside cloud increases, while evaporation together with cooling and change of ascending speeds in to descending speeds in sum, result in reduction of rainfall increase rate.

Physical reason for this quality is that convective movements and heat transfer increase with increase in cloud's life and thickness and near cloud's base, droplets ascending movements have a low speed but as clouds thickness increases ascending speed with increase of instability resulting from release of droplets condensation hidden heat will become greater and therefore, precipitation water of cloud, heat transfer and CAPE increase. In fact, ascending movements and droplets' growth at ¾ from cloud's base reaches their maximum amount (mature stage). After this stage, near cloud's top, due to intermingling of dry and cold air around cloud, droplets evaporate and PWC decreases and ascending movements turn into descending movements and give rise to collapse and dispersion of cloud (Rogers & Yau, 1996).

Therefore, in case of precipitation from a cloud the depth and thickness of which is not sufficient or its PWC is less than 5mm, rain droplets in these clouds have not enough grown and in the way toward earth evaporate. Given the above results, it can be said that whenever PWC is more than 26mm, probability of more than 15mm rain is very great.

5-5. Study of Instability Indices in Warm and Cold Seasons:

In warm season, since cloud's potential for precipitation of moisture and being saturated is greater, cloud's thickness is greater as well. The greater the cloud's thickness is, the more the PWC becomes. In warm season, shower rains are from deep convective clouds which can be with a lot of precipitation water of cloud, but in cold season, shower rainfalls often are originated from convective clouds with lesser thickness (Manzato, 2003). For this reason, the indices are separately examined fro warm and seasons of year. In this study, from April to September is considered warm season and from October to March is considered as cold season.

In warm months of the year, for SI better correlation relative to cold months has been obtained and limit amount for flood probability in warm months of the year has been obtained less than -3^0C and in cold months of the year it has been obtained less than -2^0C(Fig. 7 and 8).

From definition of SI in section 4.3.1 through the relation 4.3.1 it has been found that this index too is used at a constant level of 500mb which indicates temperature difference of environment and package at 500mb level. As can be concluded from the diagrams, as SI becomes more negative, amount of rainfall becomes greater, i.e. as this value becomes more negative, storms will be stronger and clouds thicker. Thus, this index can be a relatively good index for representation of thunderstorms.

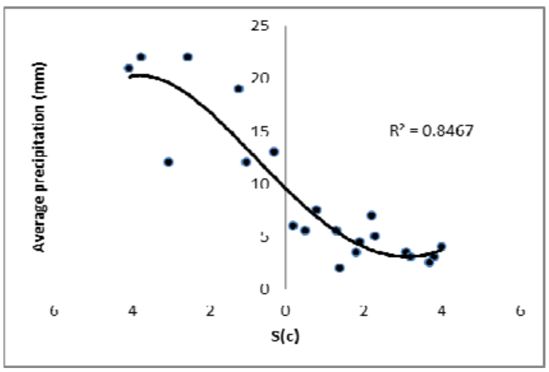

Fig.7: Regression of average precipitation of 6 stations with SI in warm seasons.

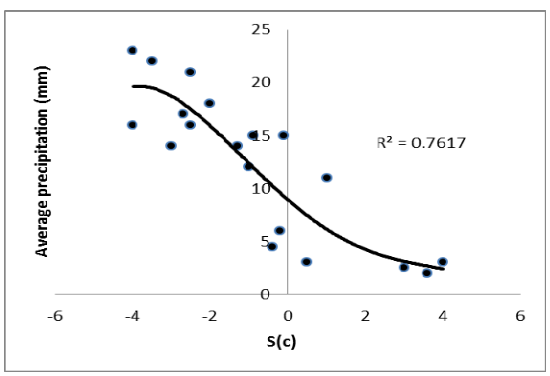

Fig. 8: Regression of average precipitation of 6 stations with SI in cold seasons.

Since CAPE index is obtained from buoyancy power measurement from cloud's base to cloud's top, can forecast thunderstorms better than SI, but because in the summer, the issue of evaporation and intermingling is more the case, CAPE can respond better in the winter rather than in the summer for Tehran.

Figure 9 and 10 show that it is seen that the diagrams related to warm and cold seasons are almost similar to each other. This is while, for a certain amount of CAPE, amount of rain in cold seasons is greater than that in warm seasons/ in cold seasons, increasing growth of rainfall with increase in CAPE value within range of 400 J/kg to 1000 J/kg is observed, while in warm seasons, this threshold of increasing growth is less than 400 J/kg.

In warm seasons, due to higher moist capacity for being saturated, greater amount of water evaporation is condensed. Hence, cloud's life and thickness increase and as a result CAPE value which depends on Buoyancy power and cloud's thickness grows. In this case, CAPE value increases, while amount of rainfall relative to cold seasons is lesser. In fact, in warm seasons, the year of rain intensity increases in short time but due to greater amount of evaporation at cloud's base as well as quicker intermingling, cloud disperses more rapidly. As a result, we should expect that in warm seasons of the year, CAPE value to be greater but amount of rainfall to be smaller. Therefore, according to figures 9 and 10, flood creation threshold in warm months of the year can be considered 1100 J/kg and for cold months 1000 J/kg.

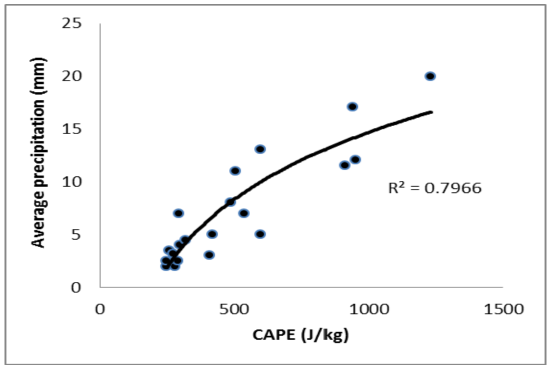

Fig. 9: Regression of average precipitation of 6 stations with CAPE in warm seasons.

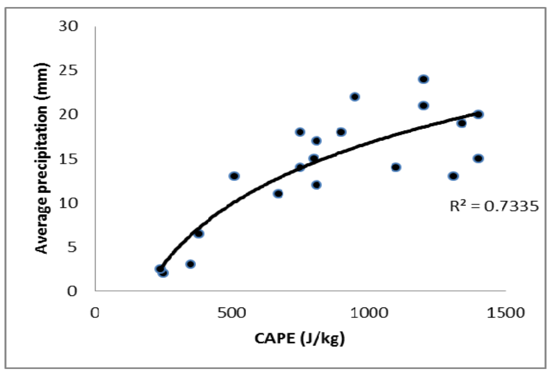

Fig. 10: Regression of average precipitation of 6 stations with CAPE in cold seasons.

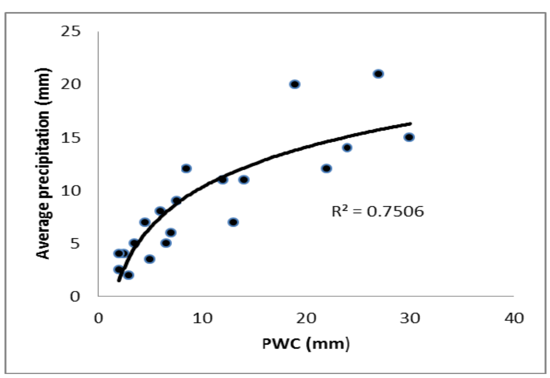

Fig. 11: Regression of average precipitation of 6 stations with PWC in warm seasons.

PWC index show the whole water content from cloud's base to its top is obtained, thunderstorm forecasting yields with this index yields better result than with SI (Fig. 11 and 12).

In the summer, due to increase in cloud's depth and thickness, PWC increases, while the issue of evaporation and intermingling in the summer is greater than in the winter, amount of rain in the summer is less but has greater intensity.

Given the above diagrams which are related to cold and warm seasons, we observe that these two diagrams correspond well to each other indicating that PWC has a good relationship with amount of precipitation.

In addition, it is seen that mean rain of events in cold seasons of the year is more than warm seasons and this causes greater amount of PWC in cold seasons relative to warm seasons to be obtained. Therefore, given figures 11 and 12, maximum rain threshold in warm seasons of the year can be considered about 26mm.

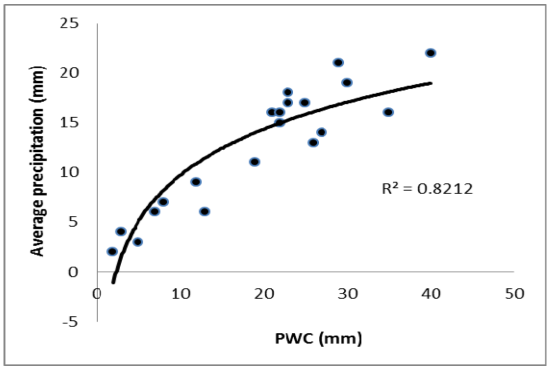

Fig. 12: Regression of average precipitation of 6 stations with PWC in cold seasons.

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