Natural Environment Change
Vol. 3, No. 1, Winter & Spring 2017, pp. 1-9
DOI: 10.22059/jnec.2017.225831.63
Print ISSN: 2476-4159 Online ISSN: 2476-4167
Web Page: https://jnec.ut.ac.ir/
Email: jnec@ut.ac.ir

A synoptic-climatology approach to increase the skill of numerical weather predictions over Iran

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Received: January 23, 2017 Accepted: May 06, 2017

Abstract
Simplifications used in regional climate models decrease the accuracy of the regional climate models. To overcome this deficiency, usually a statistical technique of MOS is used to improve the skill of gridded outputs of the Numerical Weather Prediction (NWP) models. In this paper, an experimental synoptic-climatology based method has been used to calibrate, and decrease amount of errors in GFS numerical weather prediction model. Usually, physiographic characteristics, climatic behavior and synoptic climatology of the region are not included in MOS techniques. In this regard, an experimental model for Precipitation potential using Synoptic-climatology and Physiographic characteristics (PSP) of the region has been developed for statistical downscaling of the NWP outputs over the study region. A Climatic and Physiographic Index for surface weather stations is defined to represent their climatic and physiographic characteristics in MOS technique. CPI covers monthly mean precipitation, temperature, monthly number of wet and dry days, and latitude and height of station. CPI index which is defined in this paper can be used as climate classification index. In this study daily gridded outputs from Global Forecast System (GFS) has been used for calibration and running the PSP experimental model. Inputs of the model are gridded meteorological parameters in 500 hpa and surface layer from GFS model. Data from more than 85 daily weather systems have been used to find synoptic climatology characteristics, and coefficients needed as input for PSP equations in the period of 2002-2007. Coefficients are computed by using regression equation between observed and computed precipitation over each station with 85.

Keywords
climatic and physiographic index, Iran, numerical weather prediction, precipitation forecast, synoptic climatology.

1. Introduction
Accuracy of Numerical Weather Predictions (NWP) is highly important in decreasing human and economic damages because of the increasing in extreme weather and climate events. There are two main approaches of dynamical and statistical methods in weather and climate modeling. In statistical methods, a statistical relation models predict the weather and climate by appropriate equations from daily to yearly time scales. Dynamical models solve the basic equation of weather and climate by applying differencing methods to the basic equations. Dynamical models can be divided into two main types: regional climate models, and global

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circulation models. Regional models need to have boundary condition data from a global climate models. Gridded outputs of dynamical models must be regionalized to increase skill of weather forecast.

One of the valuable methods for regionalizing gridded NWP data to station-scale is the Model Output Statistics (MOS). Application of the MOS technique to the outputs of numerical gridded data can decrease errors of the NWP forecasts. But, initially, MOS does not include climatic and physiographic characteristics of the study region. Rainfall intensity over eastern coastline of USA has been calculated by Marks et al. (1998) by using MOS technique and meteorological parameters from radar observations. Vislocky et al. (1989) compared the results of perfect prog (PP), and modeled output statistics over four weather stations during six months in Pennsylvania. They found that MOS forecasts can be increased from 6 to 37% when using the PP technique. Yokuver (1975) and Krueizing (1983) demonstrated an analogue-based model to the surface and 500 hpa meteorological parameters for 30 days. They compared simulated data with the results of numerical weather prediction outputs. They found that analogue-based model have valuable results compared with the NWP. A Log (PT^2) non-linear model was developed by Cline et al. (1991) using linear stepwise regression between types of precipitation and thickness between 850-1000, 700-850, and 700-1000 hpa pressure level in synoptic patterns. Tapp et al. (1985) have increased the skill of prediction up to 50% by applying regression equations. They used precipitation climatology of some major cites of Australia in subtropical region and 24-hour prognostic maps in the regression model. A composite stepwise of 6 to 72 hours regression model also developed by brunt Brunet et al. (1988) for Canada climate. Accuracy of precipitation forecast has been increased by using this method.

There are many researches that worked about precipitation features in Iran. Some of them concentrate on synoptic features of precipitation and some of them studied classified patterns with statistical approach. There are a few researches about spatial modeling of precipitation on Iran that the studied used latitude, longitude and elevation data to present a spatial statistical model (Asakereh & Seyfipoor, 2014; Sari Saraf et al., 2010; Asakereh, 2006).

Regarding to the above mentioned statistical and synoptic models developed around the world, we attempt to introduce a similar model over Iran plateau. In this research an experimental model of Precipitation potential using Synoptic-climatology and Physiographic characteristics (PSP) of the region are used together with MOS technique to increase skill of numerical weather prediction model forecasts over Iran.

2. Study area

Iran has different topography and climate, including arid region in the central part, mountainous area over northern and western regions, costal area of Caspian Sea and Persian Gulf, and forest land over northern barrier of Alborz. Study region covers whole of Iran plateau and parts of Middle East and central Asia. The model has been focused over the Middle East grids of GFS data, but calibrations have been done only over Iran. Complex topography and climate of Iran and Middle East have important effects over synoptic systems. There are two major mountain ranges in Iran plateau, including (Fig. 1):

- Alborz ranges that have west to east direction. Its length is about 1000 km in northern part of Iran in 36 ^{o}N latitude.
- Zagros ranges that have west to south direction. Its length is about 1350 km in western part of Iran.

3. Materials and Methods

3.1. Data used

In this research, two kinds of data are used, including: observation data from 151 surface weather stations over Iran and predicted gridded 500 hpa height and mean sea level pressure with 2.5×2.5 resolution from Global Forecast System (GFS). Finally, an 11×13 grid point matrix is prepared both in surface and 500 hpa level for 1200 GMT. To compute climatic behavior of the region, observation data covers at least 30 years period, ending 2003 (Fig. 2).

Fig.1. Representation of two mountain ranges of Alborz and Zagros in Iran plateau

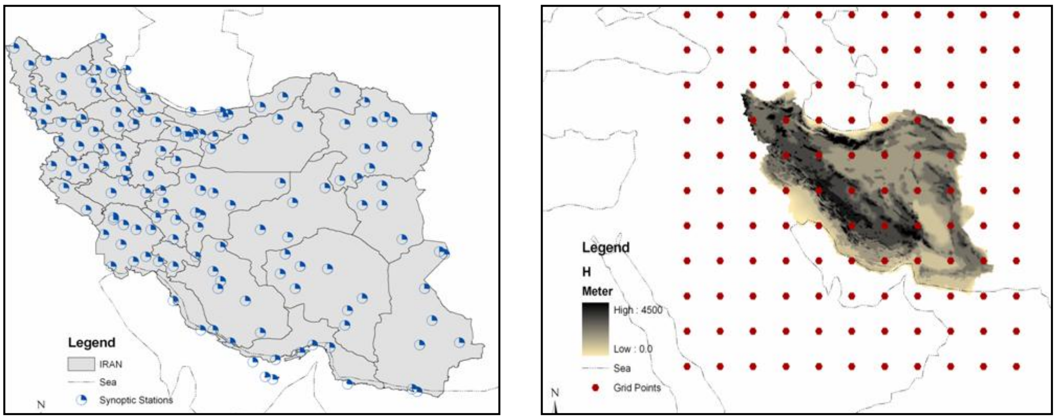

Fig. 2. Two kinds of data of climatology and grided model output data that are used in this research. a) Observed data from 151 surface weather stations (left) and b) Grided data from GFS model (right).

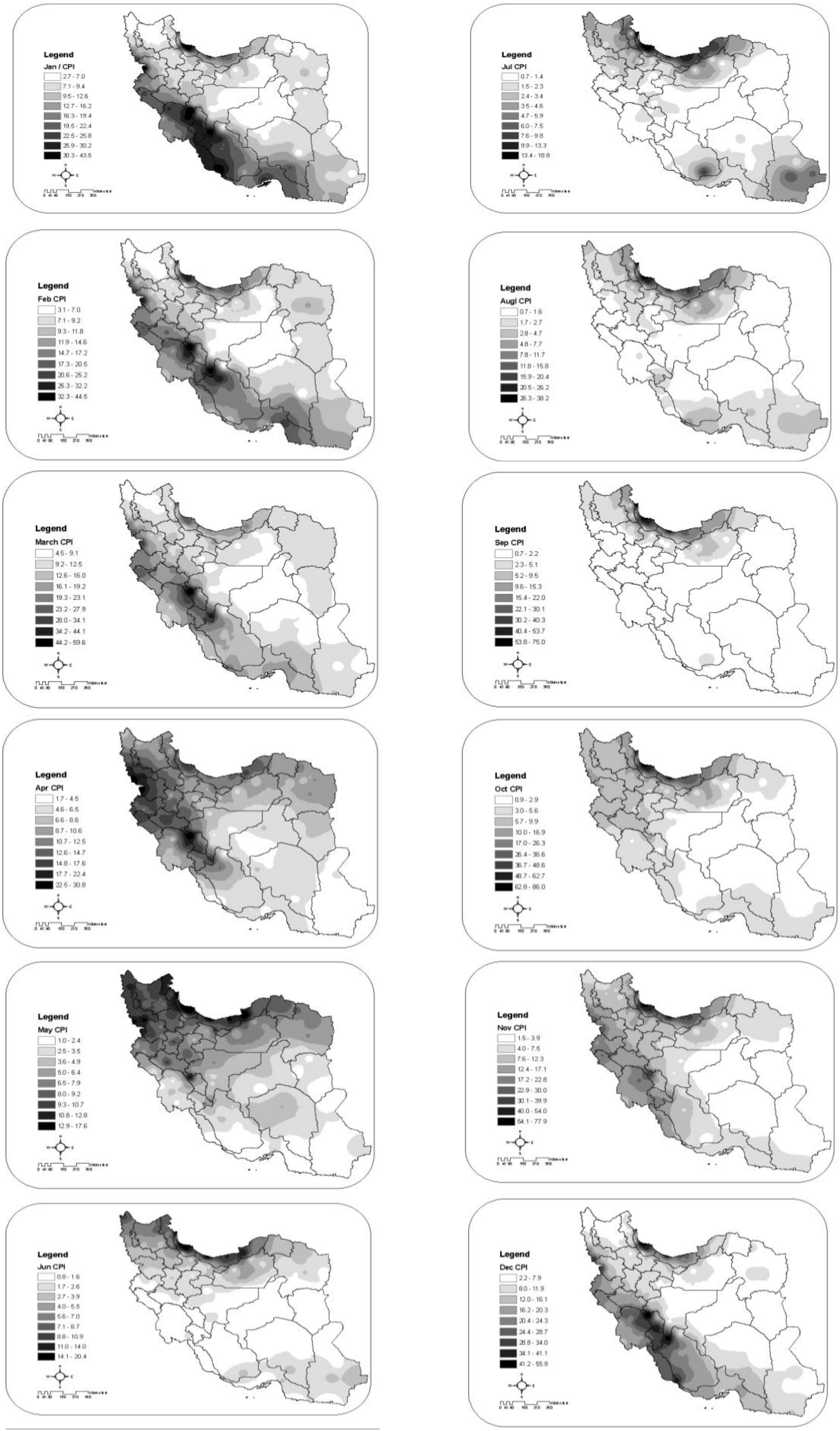

Fig. 3. Monthly CPI spatial distribution computation over Iran

3.2. Methods

3.2.1. Defining climatic and physiographic index (CPI)

Climatic and physiographic behaviors of the surface are not well resolved in Numerical Weather Prediction models. For solving this deficiency, we firstly defined a Climatic and Physiographic Index of CPI.

CPI regrinds climatic and geographic characteristics of surface weather stations including mean monthly precipitation, temperature, wet and dry days, maximum daily precipitation and altitude to all grid points similar to NWP model. An example of monthly CPI index is shown in Figure 4. From this figure, it is concluded that southwest of Iran has high amount of CPI index and this area has maximum potential of precipitation when weather system affecting Iran plateau in winter months. CPI, which is an essential factor for improving skill of numerical weather prediction over each surface weather station can be computed using Equation (1).

$$CPI = TOP * 0.1\sqrt{(1+P_m)^2 * \frac{(1+\cos\varphi)\cdot(T_m+100)}{\log(H+100)\cdot(1+N)}} \qquad (1)$$

CPI monthly maps are depicted in Figure 4 using CPI equation. The amount of CPI over the Caspian Sea is high during the summer months because of summer rainfalls.

If the CPI became a large value in Equation (2), then the potential of rainfall for that station had increased.

3.2.2. Precipitation potential using synoptic-climatology and physiographic characteristics (PSP)

Station scale precipitation can be computed by considering both CPI and some dynamical parameters of the numerical model. PSP can estimate precipitation potential of surface weather station by using physio-climatically behavior of the station as well as dynamical parameters of the numerical model in the grid point that surface weather station lies in that grid. Figure 4 shows a schematic diagram of the process computing PSP. Three inputs of topography data and climatic behavior of the station are analyzed together with synoptic-dynamic parameters of the weather system, and then the value of PSP computes using Equation (1). In order to integrate more weather system properties, many experiment equation were generated that applied over the weather chart.

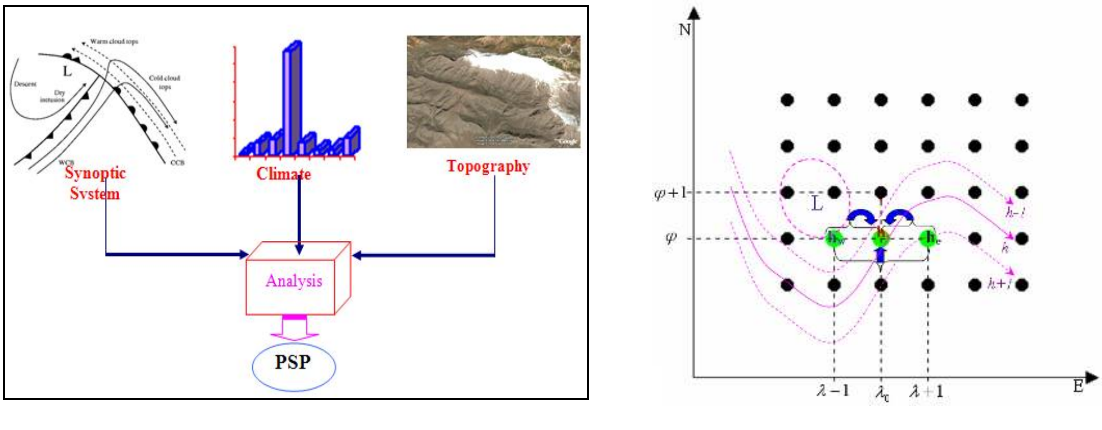

Fig. 4. Schematic diagrams of the process needed for computing PSP in computational grid points matrix

4. Results and Discussion

Two case studies of 2-20 February 2007 (winter) and 25-31 March 2009 (spring) have been analyzed using PSP technique in this paper. In the case of 2–20 February 2007, a Mediterranean low pressure system was gradually forming from 2 February 2007 over west of Mediterranean Sea. Western part of Iran was affected by the system from 3 February when low pressure was moving toward east of the Sea. Precipitation started from 3 February 2007 over west and southwest of Iran. Figure 5 shows the observed precipitation of the 3 February 2007. By some fluctuations, precipitation was continued to 14 February 2007. In the period of 8 to 10 February 2007, there was a cutoff low over the Zagros mountain chain. Mean sea level pressure and 500 mb geopotential charts are shown in Figure 5.

All of gridded meteorological and dynamical parameters such as vorticity, divergence, advection, and geopotential height are calculated using gridded data that have already been received from GFS numerical weather prediction model. PSP distributions with and without CPI index have been shown in Figures 6.

Another active system that has been studied in this research is the system that affected Iran plateau during Iranian New Year, starting from 23 March (25-31 March 2009). This was the first weather system that affected Iran after one month dry days in winter. After above mentioned system, there were clusters of weather systems affecting Iran with heavy rainfalls, especially over the southwest regions. Figure 7 shows mean sea level pattern and 500 mb geopotential height of the system under study. In 500 mb, a cutoff low is in the boundary of Iraq, Jordan and Syria and a low pressure is located in Saudi Arabian peninsula.

This system caused many flash flooded rainfalls in Iran, especially in the southwestern provinces such as Fars, and other provinces located near southern part of Zagros mountain chain. Total amount of precipitation is shown in Figure 8.

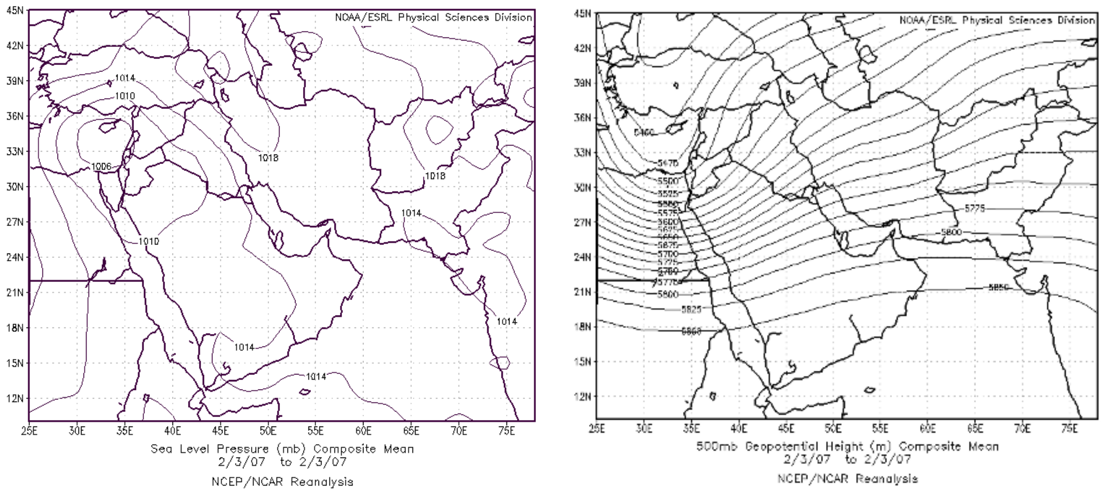

Fig. 5. Mean sea level pressure (left) and 500 mb (right) charts of 3 February 2007

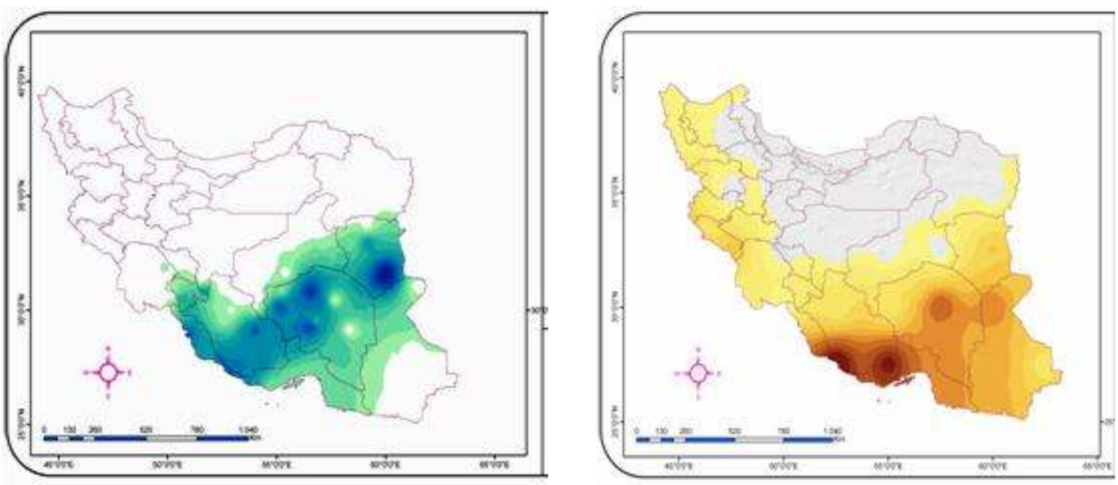

Fig. 6. Observed (left) and simulated (right) precipitation over Iran on 3 February 2007

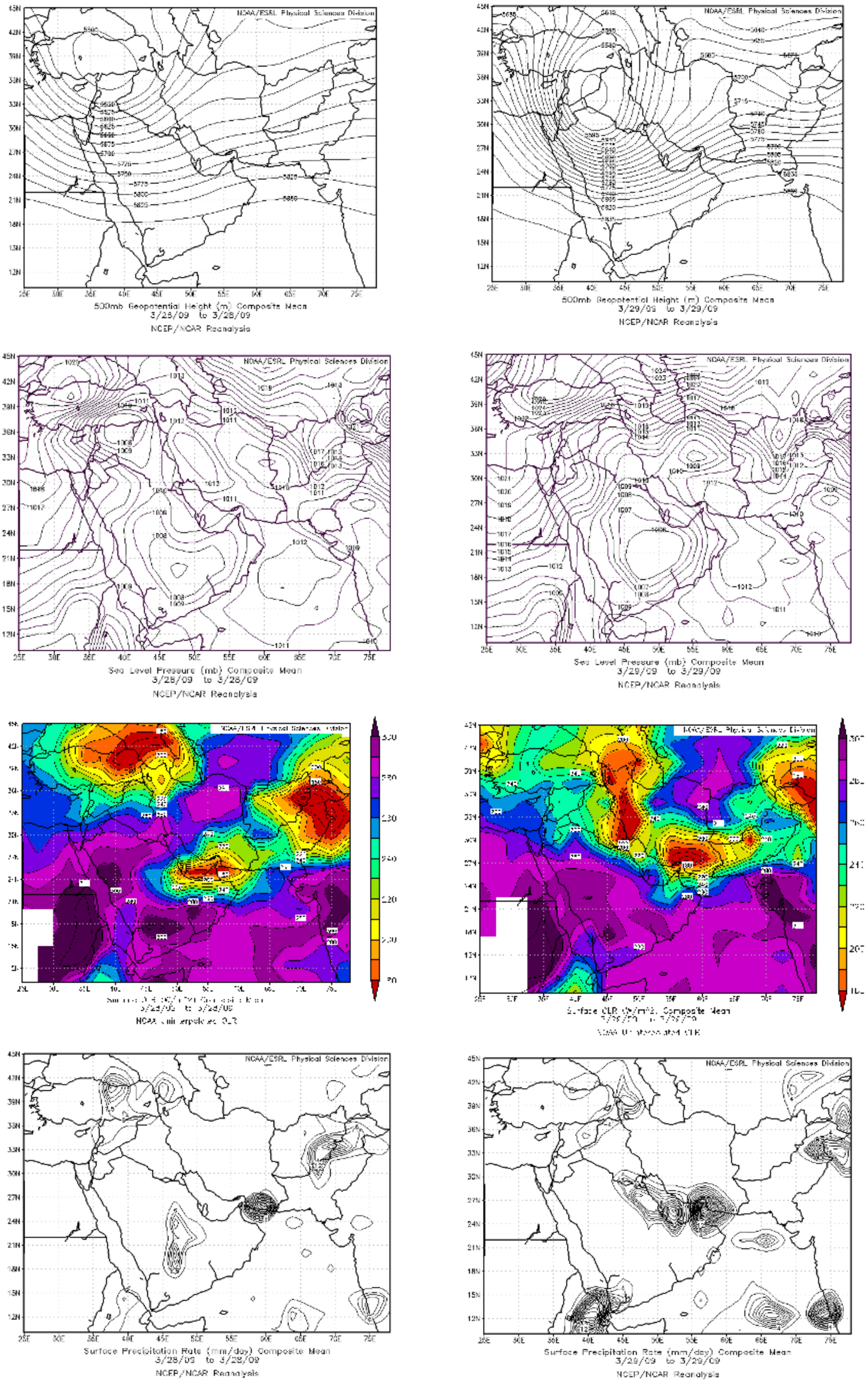

Fig. 7. Synoptic features of 29 March 2009. Left: surface weather chart, and right: 500mb geopotential height

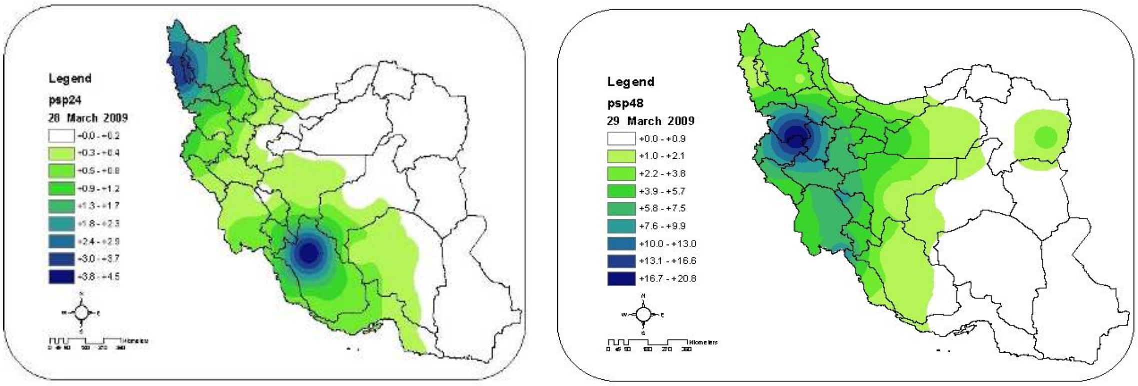

Fig. 8. PSP distribution over Iran on 28-29 March 2009. Left: without applying CPI index and right:: with applying CPI index

Relationship between PSP data and CPI were computed using regression methods. Table 2 shows the correlation between observed precipitation with PSP and CPI. Figure 11 implies that PSP can improve climatic-physiographic behavior of the region and mean correlation index of PSP is higher than CPI, especially in real time precipitation the correlation is 92% in PSP and 72% in CPI index.

Based on Table 1, few relationship were computed between PSP and CPI in the case study that occur during February 2007.

Table 1. Correlation between cPSP and observed precipitation

r	P_{00}	P_{24}	P_{48}	P_{72}	P_{96}	P_{120}	P_{144}
PSP_{00}	0.92						
PSP_{24}		0.93					
PSP_{48}			0.74*				
PSP_{72}				0.81			
PSP_{96}					0.91		
PSP_{120}						0.85	
PSP_{144}							0.89
CPI	0.78	0.89	0.89	0.85	0.89	0.87	0.66*

We found that NWP precipitation can be modified by using Equation (2) in winter time precipitation:

$$P = 0.5(0.9 * PSP + 1.03 * CPI - 29.73) \qquad (2)$$

Maximum and minimum relationships between precipitation and PSP have been found to be in 24 and 48 hours forecast with 0.93 and 0.74. Also, minimum relationships have computed between CPI of Feb and observed precipitation in 144 hours forecast by 0.66.

5. Conclusion

A precipitation potential of weather systems using synoptic climatology and physiographic characteristics of the region is defined to increase the skill of numerical weather prediction models.

In this research when a low pressure is nearing to Iran, the amount of *PSP* increases rapidly and when a high pressure develops, the *PSP* decreases rapidly. There was a maximum PSP in 03/27/2006 over west of Iran accompanying by an active frontal cyclone around studied areas. In 9 February 2007, the amount of PSP was among 39 to 42 in the east of Iran with observed precipitation of 34 to 40 mm. In the second case the precipitation was among 0 to 3.2 mm while PSP was among 0 to 1.2.

Also we found that:

- The PSP maximum values are coincide on place of maximum wind especially close to jet streams.
- Generally maximum instability shift to north, northwest or east is relative to maximum of PSP that may due to vorticity, humidity, and warm advections.
- The *PSP* model properly shows the speed, direction, trajectory, and displacement of the synoptic systems.
- Maximum PSP is coincided to maximum instability.
- The places of before point (PSP) more occur over west of country compared to east.
- For the regions with high amount of CPI, usually the model has wet precipitation bias and vice versa.
- PSP cannot capable to well predict the amount of precipitation when the wavelength is very small comparing to $2.5^{\circ}\times2.5^{\circ}$ grids of the model.

Acknowledgments
Authors will be very thankful from forecasting center of Iran meteorological organization and local meteorology offices of Kermanshah, and Sabzevar regional meteorological Office, and Climate Research Institute (CRI), and special thanks to Mr. Hamid Pezeshki, who helped us in programming the model using Visual Basic language.

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