An assessment of Climate change impact on wheat evapotranspiration using the CERES-Wheat model

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Abstract: Global warming and Climate change are anticipated to cause changes on evapotranspiration. Higher temperatures are expected to lead to increasing evapotranspiration. in studies relating to water availability for crops, evapotranspiration play key role. In order to explicit the impact of climate change on Crop evapotranspiration under standard conditions (ETc) using CERES-Wheat model and Penman-Monteith formula for baseline period (1981 to 2010) and future period (2015-2044) in Ahwaz City, ETc and were calculated. Using thirteen AOGCMs outputs and Cumulative probability distribution function (CDF), climate change scenarios for 2015-2044 under 5 probability levels 0.10, 0.25, 0.50, 0.75 and 0.90 generated. ETc was calculated for climate change scenarios and compared with ETc of baseline period using analysis of variance and kolmogorov-Smirnov test. Result showed that cumulative ETc and mean daily ETc in all of climate change scenarios in comparison with baseline period have increased about 100mm and 0.7mm day-1, respectively.

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Introduction

In recent years great emphasis has been given to the potential impact that human induced increases in atmospheric carbon dioxide (CO2) will have on the global climate during the next years (IPCC, 2001; IPCC, 2007). Climate change is anticipated to cause negative and adverse impacts on water systems throughout the world. Higher temperatures are expected to lead to a host of problems. These include melting snowpack, altering both the intensity and frequency of precipitation, increasing demands for urban water, hydropower, and irrigation, increasing evapotranspiration and else. (O'Hara, 2007). Evapotranspiration is a key hydrological variable to reflect the effect of climate change (Liu and Yang, 2010). Also, in studies relating to water availability for crops, evapotranspiration play important role. There are several factors affecting evapotranspiration. The first of these is air temperature. As temperatures increase, evapotranspiration also goes up. Evapotranspiration varies regionally and seasonally; during a drought it varies according to weather and wind conditions. Because of these variabilities, water managers who are responsible for planning of water resources need to have a thorough understanding of the evapotranspiration process (Hanson, 1991). crop evapotranspiration (ETc), reflects complex interactions between climate, crop, soil and hydrological processes (Donohue et al., 2010; Liu and Yang, 2010). Some study conducted to indicate climate change impact on ET e.g, Harmsen et al. (2009) estimate reference evapotranspiration (ETo), under climate change conditions for three locations by the Penman–Monteith method. Temperature data were statistically downscaled and evaluated using the DOE/NCAR PCM global circulation model projections for the B1 (low), A2 (mid-high) and A1fi (high) emission scenarios. Results from the analysis indicate that ETo will increase during the next 100 Years (2000-2100). Liu and Yang (2010) estimated the impact of climate change on actual evapotranspiration. The results presented that negative trends for ETa were detected and significant decreasing trends (at 95% confidence level). Chaouche et al. (2010) analyzed of evapotranspiration in a French Mediterranean region in the context of climate change and observed an increase in annual mean temperature and annual potential evapotranspiration throughout western part of the French Mediterranean area. Calanca et al. (2006) studied the effect of climate change on the summertime evapotranspiration regime of three Alpine river basins. The results hydrological simulations revealed a reduction in the evapotranspiration efficiency that depends on altitude. Actual evapotranspiration was found to increase at high altitudes, but to decrease in low elevation areas. Such a differentiation does not appear in the GCM scenario, which predicts an overall increase in evapotranspiration over the Alps. Also other studies have been conducted to address the climate change impact on evapotranspiration in different of regions globally, (e.g. McVicar et al., 2007; Chattopadhyay and Hulme 1997; Jun et al., 2012; Goyal 2004; Kang et al., 2006; Reddy 1995).

In this paper we studied the impact of climate change on the Crop evapotranspiration under standard conditions (ETc) of Ahwaz region, Iran using CERES-Wheat model. The objective of this work is to examine the effect of climate change on the ETc regarding to uncertainty of Atmosphere-Ocean General Circulation Models (AOGCM) and Greenhouse Gases Emission (GHG) scenarios. This study is the first of its kind in Ahwaz region and provides potentially important information for water resource planners.

Materials and Methods

Description of the study area

The study area is Ahvaz region located in the south west of Iran where the climate is hot and humid. Ahvaz city is the capital of the province Khuzestan and it is built on the banks of the Karun River, the largest river in the Iran. Average elevation and annual precipitation in this region is 20 m above sea level and 250 mm respectively. Ahvaz has a desert climate with long, extremely hot summers and mild, short winters. Summertime temperatures routinely exceed 50 degrees Celsius with many sandstorms and duststorms common during the summer period while in winters the minimum temperature could fall around zero degrees Celsius.

Evapotranspiration model

There are several models for the estimation of reference evapotranspiration (ET_o). The selection of a particular method for the determination of ET_o depends upon the type of meteorological data available for the given region and the accuracy desired in the computation of water needs (Goyal, 2004) . FAO Penman–Monteith (FAO PM) method is considered as a standard and the most precise method to estimate ETo. It is expressed as (Allen et al., 1998):

$$ET_O = \frac{0.408 \cdot \Delta(R_n - G) + \gamma \cdot (900/(T+273)) \cdot u_2 \cdot (e_s - e_a)}{\Delta + \gamma \cdot (1 + 0.34 \cdot u_2)} \quad (1)$$

Where

ETo reference evapotranspiration (mm day^{-1}), R_n net radiation at the crop surface (MJ m^{-2} day^{-1}), G soil heat flux density (MJ m^{-2} day^{-1}), T mean daily air temperature at 2 m height (°C), u_2 wind speed at 2 m height (m s^{-1}), es saturation vapour pressure (kPa), ea actual vapour pressure (kPa), es-ea saturation vapour pressure deficit (kPa), Δ slope vapour pressure curve (kPa $°C^{-1}$) and γ psychrometric constant (kPa $°C^{-1}$).

Eq. (1) applies specifically to a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m^{-1} and an albedo of 0.23 (Allen et al., 1998).

Crop evapotranspiration under standard conditions (ETc)

The crop evapotranspiration under standard conditions, denoted as ETc, is the evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions. (Allen et al., 1998)

Crop ET (ETc) is then simply estimated by multiplying ETo by an empirical crop coefficient (Kc) which is provided by CROPWAT for different growth stages:

$$ETc = Kc\ ETo \quad (2)$$

Data source

Two sets of data, i.e. historical weather data (measured station data) and AOGCMs (Atmosphere – ocean General Circulation Models) outputs are used in this study to calculation of ETo on the Ahwaz region of Iran for the period 1980–2010 and 2015–2044, respectively. All the historic data used in the present study were collected from the Ahwaz City's weather station located at latitude 31̊ 20́ N, longitude48̊ 40́ E and altitude 22.5 m. Daily minimum, maximum and mean temperature, average wind speed, sunshine hours and other meteorological data of recent 31 years (1980-2010) which are needed for ETo calculation collected from the Ahwaz City's weather station.

Climate change scenarios generation

GCMs compute future climates under anthropogenic forcing (i.e., present and projected future emissions of greenhouse gases (Zhao et al., 2011). Their use in studies of climate change impact assessment is widespread (Guo et al., 2011; Chattopadhyay and Hulme 1997, 1997). In peresent study thirteen GCMs (Table 1.) and one greenhouse gases emission (GHG) scenarios (A2) are selected for generation of climate change scenarios (temperature scenarios). A2 represents a very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines (Nakicenovic et al., 2000). The GCMs were run both for a control period (1971-2000) and for future time period (2015-2044).

Downscaling and Uncertainty climate change scenarios

Since the GCMs provide output at a low level spatial resolution downscaling to local conditions was essential. There are also many techniques available for downscaling GCM outputs. From the various existing downscaling method, we used the LARS-WG model. But should be noted that When projections of climate change variables or climate change impacts, there are many sources of uncertainty which must be considered (covey et al., 2003; Visser et al., 2000). Two major sources of uncertainty are related AOGCMs and GHG scenarios (Ready and Fowler, 2008). While most papers considered uncertainty, the analyses often involved little more than comparing coefficients of variation. But Cumulative probability distributions are more informative and deserve wider use (Thornton and Hoogenboom, 1994; Thornton and Wilkens, 1998; White et al., 2001). In present paper, we used cumulative probability distributions for study of uncertainty of AOGCMs and GHG scenarios in ETc calculation. For this purpose, ΔT parameters at monthly scale are calculated for each GCM model by following equation (Table 2):

$$\Delta T = \overline{T}GCM_{Fut,i} - \overline{T}GCM_{Base,i} \quad (3)$$

Where ΔT is long term (thirty years) temperature differences between control and future period, respectively $\overline{T}GCM_{Fut,i}$ average future GCM temperature (2015-2044) for each month, $\overline{T}GCM_{Base,i}$, average control period GCM temperature (1971-2000) for each month, i is index of month. Then, using calculated ΔTs for each month Beta distribution was fitted. Cumulative probability distribution function (CDF) was deducted from Beta distribution. ΔT for each month was derived for probability levels (0.10, 0.25, 0.50, 0.75and 0.90) from CDF.

Table 1. Atmosphere-Ocean General Circulation Models used in this study

model	center
BCM2.1	Bjerknes Centre for Climate
CGCM3-T63	Canadian Centre for Climate Modelling and Analysis (CCCma)
CNRMCM3	Centre National de Recherches Meteorologiques
CSIROMK3.5	Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO)
ECHAM5OM	Max Planck Institute für Meteorologie
ECHO-G	Meteorological Institute, University of Bonn Meteorological Research Institute of KMA Model and Data Groupe at MPI-M
GFDLCM2.1	Geophysical Fluid Dynamics Laboratory (GFDL), USA
GISSE-R	GISS
HADCM3	UK Met. Office
IPSLCM4	Institut Pierre Simon Laplace
MIROC3.2 medres	National Institute for Environmental Studies
MRICGCM2.3.2a	Meteorological Research Institute, Japan Meteorological Agency, Japan
NCAR-CCSM3	National Center for Atmospheric Research (NCAR), USA

Table. 2. ΔTs at monthly scale for all climate change scenarios

probability levels	month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.10	0.67	0.55	0.86	1.07	1.05	1.27	1.21	1.21	1.11	1.14	0.86	0.64
0.25	0.83	0.78	1.04	1.29	1.29	1.46	1.34	1.37	1.32	1.30	1.02	0.82
0.50	1.04	1.08	1.29	1.61	1.59	1.71	1.52	1.57	1.60	1.52	1.23	1.06
0.75	1.25	1.35	1.53	1.96	1.89	1.96	1.70	1.77	1.87	1.75	1.44	1.28
0.90	1.41	1.55	1.72	2.25	2.10	2.15	1.84	1.91	2.08	1.92	1.60	1.43

Using the measured T_{max} and T_{min} for the 30-year baseline period (1981-2000), calculated ΔTs probability levels (0.10, 0.25, 0.50, 0.75 and 0.90) and LARS-WG, daily T_{max} and T_{min} time series under 5 probability levels (0.10, 0.25, 0.50, 0.75 and 0.90) generated for future period (2015-2044). LARS-WG is a stochastic WG based on the series approach (Racsko et al., 1991), with a detailed description given in Semenov (2007).

Model calculation of crop ET

CERES (Crop Environment REsource Synthesis)-Wheat under the Decision Support System for Agrotechnology Transfer (DSSAT) is a process-based, management-oriented model that can simulate the growth and development of wheat as affected by varying levels of water and nitrogen (Ritchie et al., 1998). The model has been successfully applied in many regions of the world (Popova and Kercheva, 2005; Zhao et al., 2011; Guo et al., 2010; Panda et al.,2003; Timsina et al.,2008; Arora et al.,1998).

CERES-Wheat can calculates ETc from the FAO version of the Penman equation (Doorenbos and Pruitt, 1984), which requires the inputs of Tmax, Tmin, wind speed and relative humidity and Solar Radiation (Hoogenboom et al., 2003).

Results and discussion

Model calibration and evaluation

The CERES-Wheat model was calibrated and validated by comparing simulated phenological stages and crop yields to field experiments that were conducted in 2010-2011 and 2002-2003 at the experimental farm of the Khuzestan Agriculture And Natural Resources Research Center (KANRC), located at Ahwaz in south western Iran(31.20°N and 48.8° E). Wheat is usually a 130–50 days cereal crop in this region. Sowing date was set to about 20 November, at a density of 400 No/m^2, at a depth of 3 cm. Three fertilizer levels were applied at each growth season (55 kg/ha at each stage). Crop parameters were measured during different stages of growth. The crop data included planting date, date of emergence, flowering date, maturity date, harvest date, planting depth, data on grain yield, above ground dry matter (ADM) yield and leaf area index (LAI) were recorded during each crop experiment. The genetic parameters of the CERES-Wheat model were calibrated in order to minimize the difference between the observed and corresponding simulated data. we derived the 7 genetic coefficients of the wheat variety CHAMRAN. The final values of cultivar parameters were 0 for P1V (Vernalization coefficient), 106 for P1D (Photoperiod coefficient), 550 for P5 (Relative grain filling duration), 110 for PHINT (phyllochron interval), 15 for G1 (kernel number), 41 for G2 (kernel mass), and 0.9 for G3 (Non-stressed dry stem weight). After obtaining the genetic parameters, the CERES-Wheat model was validated by comparing simulations with observed data. The results showed good agreement between these simulated and observed parameters.

Calculation of ETc

Daily ETc during wheat growing seasons calculated with the Penman–Monteith equation (Allen et al.,1998) using CERES-Wheat and daily weather data for baseline period (1981-2010) and future period (2015-2044) scenarios. Future period scenarios were generated under 5 probability levels 0.10, 0.25, 0.50, 0.75 and 0.90. Under each scenario for each day of growing season, 30 ETcs calculated and Cumulative probability distribution function (CDF) determined and ETc deducted under probability 0.75 (Figure 1).

Table 3 and Figure 1 indicate that Cumulative ETc and mean daily ETc in all of climate change scenarios in comparison with baseline period have increased about 100mm and 0.7mm day-1, respectively. Calculated ETc for climate change scenarios and baseline period compared with each other by analysis of variance. Results showed significant difference (99%) between mean of ETc of baseline period in comparison with climate change scenarios, whereas mean of calculated ETc from climate change scenarios hadn't significant difference. Cumulative distribution ETc for climate change scenarios and baseline period compared using kolmogorov-Smirnov test. This test tries to determine if two datasets differ significantly. The test identify significant difference between Cumulative distribution of ETc of baseline period in comparison with climate change scenarios whereas didn't identify significant difference between climate change scenarios. Also table 2 shows a decreasing in Length of Growing Period due to temperature increase. Longest and shortest Growing Period occurred in baseline period (148 days) and 0.90 probability level (144 days), respectively, which had lowest and highest mean temperature.

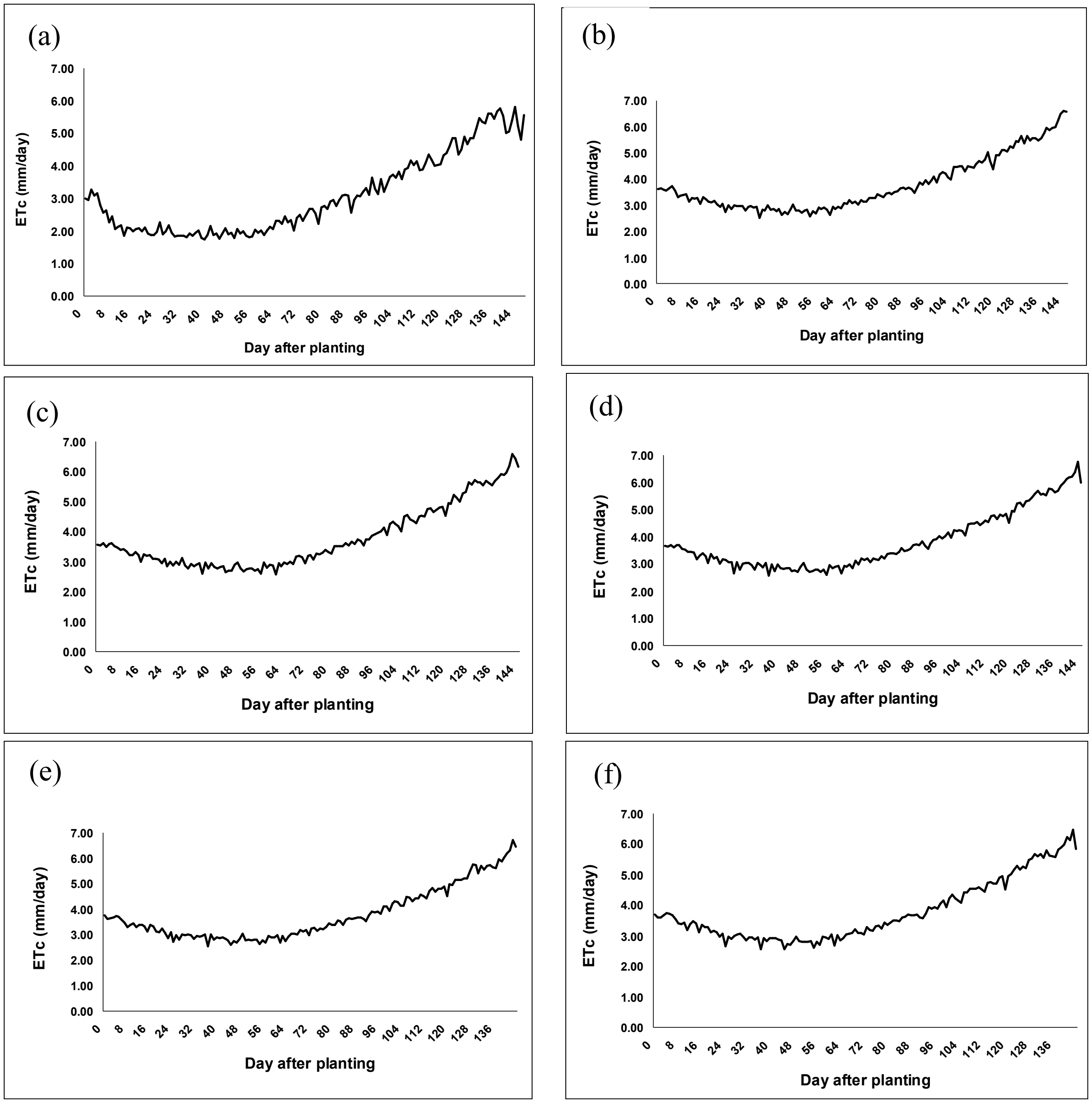

Figure 1. ETc changes during wheat growing seasons (a), baseline period (b), 0.10 probability level scenario (c), 0.25 probability level scenario (d), 0.50 probability level scenario (e), 0.75 probability level scenario (f), 0.90 probability level scenario.

Table 3. Daily-mean and sum of evapotranspiration in wheat growing season and length of growing period for baseline period and climate change scenarios

parameter	scenarios					
	baseline	0.10 probability	0.25 probability	0.50 probability	0.75 probability	0.90 probability
sum of ETc (mm)	454	554	549	552	550	546
Daily-mean of ETc (mm/day)	3.07	3.77	3.76	3.81	3.79	3.79
LGP1 (day)	148	147	146	145	145	144

1- LGP is Length of Growing Period,

Conclusion

In studies relating to water availability for crops, evapotranspiration play important role. There are several factors affecting evapotranspiration. The first of these is air temperature. Climate change is anticipated to impact on evapotranspiration. Evapotranspiration is a key hydrological variable to reflect the effect of climate change. In this paper climate change impact on the Crop evapotranspiration under standard conditions (ETc) of Ahwaz region was studied using CERES-Wheat model. It was found that Cumulative ETc and mean daily ETc in all of climate change scenarios in comparison with baseline period have increased about 100mm and 0.7mm day-1, respectively. As the temperature increases due to climate change, length of Growing Period decreases.

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6/13/2014