ISOLINES OF EVAPOTRANSPIRATION FOR THE A1B SCENARIO OF CLIMATE CHANGE

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RESUMEN

Utilizando los resultados de anomalías de temperaturas procesados de 16 modelos climáticos analizados por expertos del IMTA se estimaron las isolíneas de Eto para nueve estados de la República Mexicana, para el escenario A1B del cuarto informe del IPCC. Aunque los escenarios RCP2.6, RCP4.5, RCP6 y RCP8.5 del quinto informe del IPCC ya existen, este trabajo solo dispuso de datos del anomalías de temperatura del escenario A1B (que está muy cerca de las condiciones del RCP6). Se utilizó el método Hargreaves-Samani (calibrado con el método Pen-man-Monteith ASCE) para estimar isolíneas de Eto para Baja California Sur, Baja California, Chihuahua, Sinaloa, Sonora, Tamaulipas, Nuevo León, Coahuila y Durango. Los principales resultados son: las variaciones ETo entre el escenario contemporáneo (escenario cero) y el escenario 2030 son significativos, según los datos de 160 estaciones meteorológicas; para las variaciones de temperatura entre 0.1 ° C y 0.45 ° C, la fluctuación ETo correspondiente va del 2% en el escenario actual al 7% en el escenario 2030.

Palabras clave: Evapotranspiración del cultivo de referencia, Hargreaves-Samani, Cambio Climático.

ABSTRACT

Using the results processed for IMTA from 16 climate models that participated in IPCC for the fourth evaluation report were estimated the reference evapotranspiration (ETo) isolines for two temporary scenarios: zero (current scenario) and 2030 (future scenario) for nine states from Mexico for the A1B scenario of fourth report of IPCC. Although the scenarios RCP2.6, RCP4.5, RCP6 and RCP8.5 of the fifth IPCC report already exist, this work had only data from the A1B. In this work was used the Hargreaves-Samani method (calibrated against the Penman-Monteith ASCE method) in order to estimated isolines Eto for Baja California, Baja California Sur, Chihuahua, Sinaloa, Sonora, Ta-maulipas, Nuevo León, Coahuila and Durango. The principal results are: the ETo variations between the contemporary scenario and the 2030 are quite significant, according to the data of 160 meteorological stations; for temperature variations between 0.1C° to 0.45C° the corresponding ETo fluctuation goes from 2% in the current scenario to 7% in the 2030 scenario.

Keywords: Reference evapotranspiration, Hagreaves-Samani, Climatic change.

INTRODUCCIÓN

The major agricultural districts are at the north of the country and they consume 80 of every 100 liters of water used in Mexico, from which 50% of water resource is wasted. Therefore, considering the potential risk and vulnerability of the area, it is important to estimate the effects of climatic change in reference evapotranspiration (ETo) in the principal irrigation districts of the country to calculate the possible growth on water demand, for it would mean to make use of a greater water volume from the dams in a region where this resource is limited.

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However, it is not easy to quantify climate change effects on agriculture for several scientific rea-sons; the most important of them are three: first, the estimation of the quantitative effects of global warming over future climate involves the use of numeric models on global scale that do not contain all variables influencing the phenomenon (e.g. ocean's CO_2 absorption). It also uses inconsistent data, for example the rate of greenhouse gases emission depends on the anthropogenic effect, especially in the consumption and emission of fossil fuels, choice of technology, economy evolution and demographic growth of each country. In second place the results of global models that estimate future climate (increase or decrease of temperature or precipitation) generate data that cannot be directly applied to specific regions, so it's necessary to regionalize it in a process that, if not executed, directly affects the accuracy of the calculations. In third place, empiric (temperature and radiation models) and semi-empiric (Penman–Monteith models) evapotranspiration models were not designed to estimate the reference evapotranspiration (ETo) under climatic change conditions. In its current state, this set of equations is limited to model climate change and its effects on ETo, and can be used to perform sensitivity analysis at most. Due to the complexity of global warming effects on temperature estimations, IPCC established different scenarios of climate change that take on account expected variability of conditions instead of a single calculation of greenhouse gas emission, and its relationship with the raise of global temperature. Each exponential shows answers based on different actions to mitigate climate change impact, for example: in the fourth report of IPCC (IPCC, 2000) the higher tendency (upper exponential) is constructed under a vision of total failure in the efforts to diminish the effects of global climate change. The two center exponentials are associated with the hypothesis of the proper function of carbon market, i.e., the state and private actions are effective to diminish the greenhouse gas emission which allows a moderately lesser impact of climate change. Finally, the lower exponential of the graph assumes that all involved countries sign the Kyoto Protocol to mitigate climate change impact. In this work, in spite of the fifth report of IPCC was published (IPCC, 2014) is presented the evapotranspiration simulation using data of average anomalies in temperature obtained from IPCC for the A1B scenario that is located between RCP6,0 and RCP4,5 (but is very close to the conditions of the RCP6).

ETo ESTIMATIONS MADE WITH HARGREAVES-SAMANI METHOD AND REGIONAL DATA

In order to estimate isolines of reference evapotranspiration for nine states of Mexican Republic, the following methodology was used:

a. A method for calculating ETo on the northern region of Mexico was selected. This method was to meet certain requirements, including: the usage of few variables to estimate ETo, for the lack of meteorological data prevented the use of the Penman-Monteith (PM) equation; accuracy in the ETo estimate results, or close to parallel the precision of the PM equation and to serve as reference for different researchers as a precise method for ETo assessment.
b. The site to calibrate the method was selected. Irrigation district 041 in Valle del Yaqui, state of Sonora was chosen, due to Sonora being one of the most important states in the northern region of the country and having a network of automated meteorological stations for the calibration of the selected method.
c. The method was calibrated to estimate ETo. The daily and monthly results were compared against the estimated results obtained from the witness method (Penman-Monteith ASCE).
d. The northern states of Mexico which include major irrigation districts were selected. Nine states from the north were designated, as well as 160 meteorological stations that hold records with more than 30 years worth of data.
e. Climate change scenarios were selected. Once the method for evapotranspiration estimation was calibrated, two types of scenarios were picked, the A1B and the A2. The results obtained with the A1B scenario are presented in this work.
f. Data of average anomalies in temperature obtained from IPCC models on A1B scenarios was used. The results processed from 16 climate models that participated in IPCC for the fourth evaluation report were analyzed by the hydro-meteorology IMTA (Instituto Mexicano

de Tecnología del Agua by acronym in Spanish) team using the downscaling technique. The data was later used in the research.

g. The ETo data in the "zero scenario" (current conditions), and the average temperature anomalies calculated for year 2030 were compared. The ETo was evaluated with the current scenario anomalies (present temperature conditions) and the estimated stipulation for year 2030; after that, a comparison was made between both sets.

Therefore, for a precise ETo calculus under climate change scenarios (sensibility analysis) it would be convenient to use the Penman-Monteith ASCE equation for all the northern part of the country, as the one stated below (Jensen et al, 1990):

$$\tau Et_o = \left(\frac{\Delta}{\Delta+\gamma^*}\right)(Rn - G) + \left(\frac{\gamma}{\Delta+\gamma^*}\right)\frac{k_1(0.622)\rho\tau}{P_a}\frac{1}{r_a}(e^o - e_z) \quad (1)$$

Where:

ETo= Evapotranspiration of referenced crop (mmd^{-1})
Rn= Net solar radiation on the surface of the crop (MJ m^{-2} d^{-1})
G= Sensitive heat flux from soil (MJ m^{-2} d^{-1})
Δ = Vapor pressure curve inclination (kPa)
γ = Psychometric constant (kPa ^{o}C^{-1})
γ^*= Modified psychometric constant (kPa ^{o}C-1)
ρ= Density of the fluid at a constant pressure (kg m^{-3})
τ= Latent vaporization heat (MJ^{-1} ^{o}C^{-1})
P_a= Atmospheric pressure (kPa)
e_z^0= Saturated vapor pressure of air at z height (kPa)
e_z= Vapor pressure of air at z height (kPa)
r_c= superficial resistance to vapor transfer (sm^{-1}), or simply surface resistance.
r_a = Aerodynamic resistance to sensible heat and va por transfer (sm^{-1}), or aerodynamic resistance.

However this equation needs variables and data that are not available in all studied places. For this reason an analysis was made on over a dozen of empiric methods that would allow calculating with precision the ETo. Thus the Hargreaves-Samani (HS) method was selected to estimates these variables. The HS method originates from various adjustments were made to the initial equation introduced on 1975 (Hargreaves et al, 1982; Hargreaves et al 1985). This HS equation estimates the evapotranspiration of a harvest using grass as reference. The HS equation is (Jensen et al, 1990):

$$ET_o = 0.0023R_a(TD)^{1/2}(t_m+17.8) \quad (2)$$

Where:

TD = Difference between maximum and minimum temperature (^{o}C)
R_a= Extraterrestrial radiation[1] (mmd^{-1}), (R_a Variable is obtained from tables or with a equation)
RS= Solar radiation (mm d^{-1})

This method is recommended by several investigators for its precision (Jensen et al, 1990; Choisnel et al, 1992); Hargreaves, 1994; Allen, 1995; Amatya et al, 1995). It can even, if required, be used to estimate ETo for periods of five days and on daily scale (Snyder, 2000; Snyder, 2002). It is a simple method that only needs extraterrestrial radiation and minimum and maximum temperature data to calculate ETo. For its calibration the daily and monthly information collected from 10 stations in irrigation district 041, Valle del Yaqui was used. Stations have daily measurements of radiation, relative humidity, wind speed, temperature and precipitation; some with over ten years of data.

RESULTS

In figures 1 and 2 are shown the results of the comparison between the HS and the Penman-Monteith ASCE methods for the CIANO station, located in block 910, lot 3, in the following coordinates of Ya-

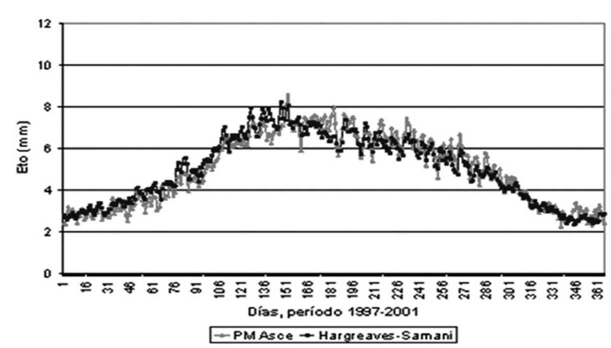

Fig. 1 Penman-Monteith (PM) ASCE vs. Hargreaves-Samani comparison on a daily scale.

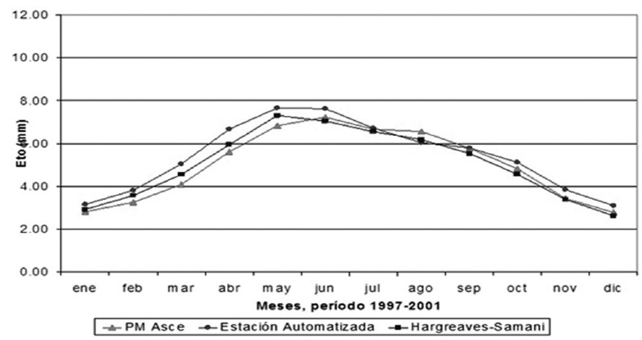

Fig. 2 Penman-Monteith (PM) ASCE vs. Hargreaves-Samani comparison on a monthly scale

qui Valley: 27º 22′ 14 North latitudes, 109º 55′ 4 West longitudes.

In both cases the linear regression coefficient is higher than 0.92, with a standard deviation from the model of 1.63mm, a quadratic error of 0.44 in the first case and 0.6 in the second case, as well as 0.93 model efficiency for the daily scale and 0.97 for the monthly scale. Once the precision of the method was proven, the selection of the IPCC climate change scenarios proceeded. The results presented in this work were obtained under the A1B scenario considerations. The A1 family is characterized by a rapid economic growth, a global population that will reach its peak in 2025 and a society that adopts and uses efficient technologies. This family divides into two: A1F1 (intense use of petroleum fuels) and A1B (balanced use of different energy sources).

When the scenario was selected, an analysis of the obtained information on the global IPCC models followed. Large scale climate models are not able to adequately simulate climate variations at regional level (regional climate behavior is a stochastic process, conditioned by global climate), therefore it is necessary to use downscaling techniques to complete the process. Downscaling techniques allow the derivation of information from global models to regional ones through the statistic inference of the relationship between both scales. Consequently, investigators from the sub-coordination of hydrometeorology of IMTA2 studied the results of 16 climate models addressed in the Fourth Evaluation Report (2007), from where the monthly average anomalies registered during the 1960-1989 period for the A1B scenario were obtained from the models using statistic downscaling techniques. With the estimated temperature anomalies for year 2030 (in A1B scenarios), simulations were performed to calculate ETo in the principal irrigation districts of the following states: Baja California, Baja California Sur, Chihuahua, Sinaloa, Sonora, Tamaulipas, Nuevo León, Coahuila and Durango. Figure 3 shows the ETo isolines for July in the current scenario while figure 4 illustrates ETo isolines for the 2030 scenario.

When both figures are compared, an increment

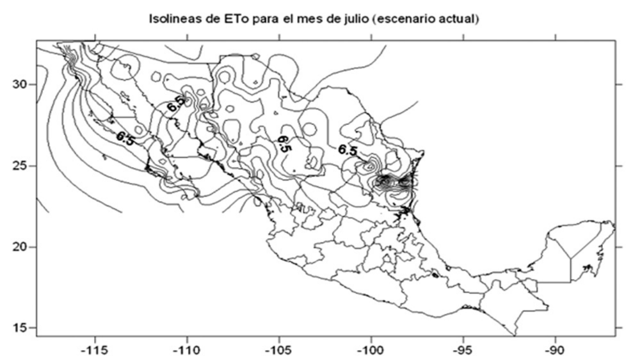

Fig. 3 ETo isolines in July for the current scenario.

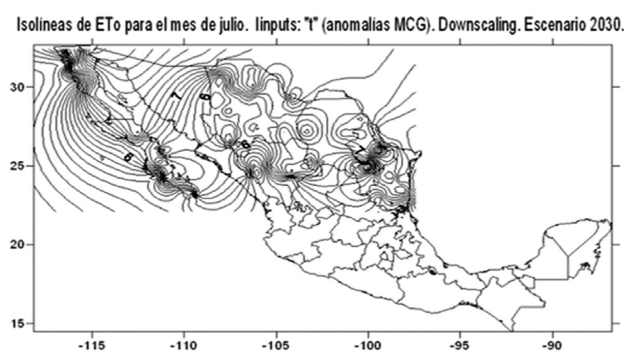

Fig. 4 ETo isolines in July for the 2030 scenario.

by 7% in the ETo is clear between the actual scenario and the 2030 scenario, as well as a major density of isolines in 2030 that indicates greater temperature gradients.

CONCLUSION

In this study a new methodology to estimate the ETo before climate change scenarios is introduced, which includes the selection of the Hargreaves-Samani method (HS), calibrated and compared against the Penman-Monteith ASCE method in various irrigation districts in the northern part of the country, obtaining ETo estimations with a 93% precision. This procedure was applied to nine states in north Mexico: Baja California, Baja California Sur, Chihuahua, Sinaloa, Sonora, Tamaulipas, Nuevo León, Coahuila and Durango. The principal results are enunciated as follows: the ETo variations between the contemporary scenario and the 2030 scenario are quite significant, ac-cording to the data of 160 meteorological stations; for temperature variations between 0.1C° to 0.45C° the corre-sponding ETo fluctuation goes from 2% in the current scenario to 7% in the 2030 scenario. It is prudent to point out that this results are only indicative because of the limitations the evapotranspiration methods have to do ETo estimations under climate change scenarios and the complexity of the theme, however, it is also important to highlight that the results allow to form an idea of the potential effect of mean temperature increase in irrigation zones. Because of the importance of the topic and the need to calculate more accurately the effects of climatic variability in irrigation and seasonal areas, the investigation must continue as well as the developing of new calculation methods that include not only the climate change effect, the needs and availability of water for crops but also the consequence of this changes on crop performance. It's important to develop and adapt methodologies that allow the estimating of crop functionality by using biological simulations, also ones that consider the potential effect of carbon dioxide and water availability. It is also important to obtain the anomaly values of "t" in a lower scale (downscaling), e.g. on a watershed scale or an irrigation district scale to obtain more accurate ETo estimations under climate change scenarios.

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