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Estudo comparativo das alterações climáticas e da sua influência sobre as necessidades de rega no clima Mediterrâneo

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Resumo

É geralmente aceite que o aumento das emissões de gases com efeito de estufa, e a utilização extensiva de combustíveis fósseis está a provocar uma alteração climática ao nível mundial. O crescimento das culturas é muito afectado pelo clima e as suas alterações podem afectar seriamente a segurança alimentar a nível global. Por outro lado, as reservas de água para a rega estão a diminuir e é importante avaliar os efeitos das alterações climáticas sobre o consumo de água pelas plantas. Estudos anteriores indicam que na Ibéria as temperaturas médias do ar aumentaram ao ritmo de 0,3-0,7 ºC década^{-1} em Espanha e 0,4 ºC década^{-1} no Sul de Portugal.

O presente estudo utiliza séries de dados de 20 anos da Califórnia, região que também tem um clima Mediterrâneo, para estudar as implicações das alterações climáticas sobre as necessidades de rega. Os dados referem-se a 20 estações climáticas distribuídas pelo Estado da Califórnia. Os resultados indicam que as temperaturas aumentaram ao ritmo de 0,15 ºC década^{-1} nos últimos 20 anos, o que está de acordo com a tendência de aumento da temperatura do ar verificada em estudos realizados em Portugal e Espanha. Adicionalmente, a radiação solar aumentou em 8 W m^{-2} durante os vinte anos do estudo, o que representa um aumento de 4% na energia total recebida através da radiação. Este aumento importante no *input* de energia solar, associado ao aumento da temperatura resultou num aumento de 0,11 mm dia^{-1} década^{-1} na evapotranspiração calculada pelo método de CIMIS Penman e de 0,12 mm dia^{-1} década^{-1} na evapotranspiração quando calculado pela equação de Penman Monteith. Estes valores representam um aumento de, respectivamente, 6,6 e 7,2% no período 1991-2011.

Palavras chave: Alterações Climáticas, Clima Mediterrâneo, Evapotranspiração, Califórnia

Comparative study of climate change and its influence on irrigation requirements in the Mediterranean climate

Abstract

It is generally accepted that the increase in the emissions of greenhouse gases and the extensive use of fossil fuel is leading to a global climate change. Crop production is very much affected by climate and any changes can greatly affect the world´s food security. Additionally, the reserves of water for irrigation are decreasing and it is important to study how climate change can affect water consumption by crops. Previous studies have shown that in Iberia the average air temperature has increased at the rate of 0.3 - 0.7 ºC decade^{-1} in Spain and up to 0.4 ºC decade^{-1} in southern Portugal

This study uses 20 year data series from California, which also has a Mediterranean climate to study the implications of climate change on crops irrigation requirements. The meteorological data used in this study is from 20 stations distributed throughout the State. The results indicate the temperatures have increased at the rate of 0.15ºC decade^{-1} over the past twenty year study period, which is in line with the air temperature increase trend identified in previous studies carried out in Portugal and Spain. Additionally, solar radiation increased by 8 W m^{-2} during the twenty years of the study period, which represents an increase of 4% in the total energy received through radiation. This increase in the solar energy input as well as the increase in temperatures resulted in an increase of 0.11 mm day^{-1} decade^{-1} in evapotranspiration when using the CIMIS Penman ETo equation and 0.12

mm day^{-1} decade $^{-1}$ when using the Penman Monteith ETo equation. These values represent an increase of 6.6 and 7.2%, respectively in the 1991-2011 period.

Keywords: Climate Change, Mediterranean Climate, Evapotranspiration, California

Introduction and justification

It is estimated that agriculture is responsible for 85% of the total human water use (Haie et al. 2008). Presently the existing water resources have reached their limits in some areas of Iberia, such as the Guadalquivir river basin, where the water authority has reduced the amount of water assigned to each irrigation district (Rodríguez Dias et al. 2007).

Global climate change is expected to have a significant impact on the availability and use of water resources and thus on the future of irrigated agriculture. According to the 4th report of the evaluation of the inter-government panel for climate change (IPCC), between 1906 and 2005 the average air temperature increased 0.74ºC, while most of the change was at the northern hemisphere. During the same period, the average air temperature in Europe increased 1ºC. Since the industrial revolution and until 2004, the concentration of CO_2 in the atmosphere has increased 35% due to human activity (Santos et al., 2006). The annual emission of CO_2 increased 70% between 1970 and 2004 (IPCC; 2007). Additionally the increase in global temperatures has caused other climate changes, such as a change in the rainfall patterns, resulting in significant cycles of draught and floods.

Various researchers have used climate models to simulate the impact of different scenarios on the agricultural use of water (Guereña, 2001; Döll e Siebert, 2001). For example the GIM model (Doll, 2002) foresees an increase of 3-5% in net radiation until 2020. This work also indicates an increase of up to 15% in irrigation water requirements in south east Asia until 2070.

Marsal e Utset (2007) simulated various scenarios for Lérida (Spain) and foresee an increase of 4ºC until the end of the Century. Rodríguez Dias et al. 2007 modeled the impacts of climate change on irrigation water demand in Southern Spain and observed a increase of between 15 and 20% in seasonal irrigation requirements by the 2050s, depending on the location.

The general purpose of this work is to compare the recent changes in climate in two regions with Mediterranean climate and evaluate to what extent this change has translated into increased water requirements for irrigation, in the form of reference evapotranspiration (ETo). The study will focus on California, and compare the climate change data with previous studies carried out in tow other Mediterranean regions: Southern Spain and Portugal.

Material and Methodology

The United Nations Food and Agriculture Organization (FAO) adopted the Penman-Monteith method as a global standard to estimate ETo from four meteorological data (temperature, wind speed, radiation and relative humidity), with details presented in the Irrigation and Drainage Paper no. 56 (Allen et al. 1998), referred to hereafter as PM:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \qquad (1)$$

where:

R_n – net radiation at crop surface [MJ m^{-2} day^{-1}],
G – soil heat flux density [MJ m^{-2} day^{-1}],
T – air temperature at 2 m height [ºC],
u_2 – wind speed at 2 m height [m s^{-1}],
e_s – saturation vapor pressure [kPa],
e_a – actual vapor pressure [kPa],
e_s-e_a – saturation vapor pressure deficit [kPa],
Δ – slope vapor pressure curve [kPa ºC^{-1}],
γ – psychrometric constant [kPa ºC^{-1}],

The PM model uses an hypothetical green grass reference surface that is actively growing and is adequately watered with an assumed height of 0.12 m having a surface resistance of 70 s m^{-1} and an albedo of 0.23 which would closely resemble evapotranspiration from an extensive surface of green grass cover of uniform height, completely shading the ground and not short of water (Allen et al., 1998). This methodology is generally considered to be the most reliable in a wide range of climates and locations because it is based on physical principles and considers the main climatic factors which affect evapotranspiration.

The CIMIS Equation uses a version of the Penman combination equation, as modified by Pruitt and Doorenbos (1977) which calculates hourly ETo. It also employs a wind function developed at the University of California, Davis. For California, 20 years of daily data from 20 CIMIS stations were collected and used in this study. The twenty stations were selected to be as diverse as possible, covering different geographic areas, as well as different elevations (Table 1). The data were then averaged to obtain the annual values.

Table 1: *The twenty CIMIS stations used in this study*.

Station number	Station name	Elevation (m)	Latitude (deg)	Longitude (deg)
2	Five Points	86.87	36.34	-120.11
6	Davis	18.29	38.54	-121.78
8	Gerber	76.20	40.05	-122.16
13	Camino	847.34	38.75	-120.73
19	Castroville	2.74	36.77	-121.77
35	Bishop	1271.02	37.36	-118.4
41	Calipatria/Mulberry	33.53	33.04	-115.42
43	McArthur	1008.89	41.07	-121.45
54	Blackwells Corner	214.88	35.65	-119.96
57	Buntingville	1220.72	40.29	120.43
62	Temecula	432.82	33.49	-117.22
64	Santa Ynez	149.35	34.58	-120.08
71	Modesto	10.67	37.65	-121.19
77	Oakville	57.91	38.43	-122.41
78	Pomona	222.50	34.06	-117.81
88	Cuyama	697.99	34.93	-119.61
91	Tulelake	1229.87	41.96	-121.47
99	Santa Monica	103.63	34.04	-118.48
105	Westlands	58.22	36.63	-120.38
106	Sanel Valley	160.02	38.98	-123.09

Results and Discussion

The results indicate a small change in average temperature, which increased 0.15 ºC decade^{-1} over the twenty year study period (Figure 1). Additionally a slight increase in the maximum temperature (0.28 ºC decade^{-1}) and a slight decrease in the minimum temperature (0.03 ºC decade^{-1}) can be observed. The changes in air temperature are not significant, since the coefficient of determination is low.

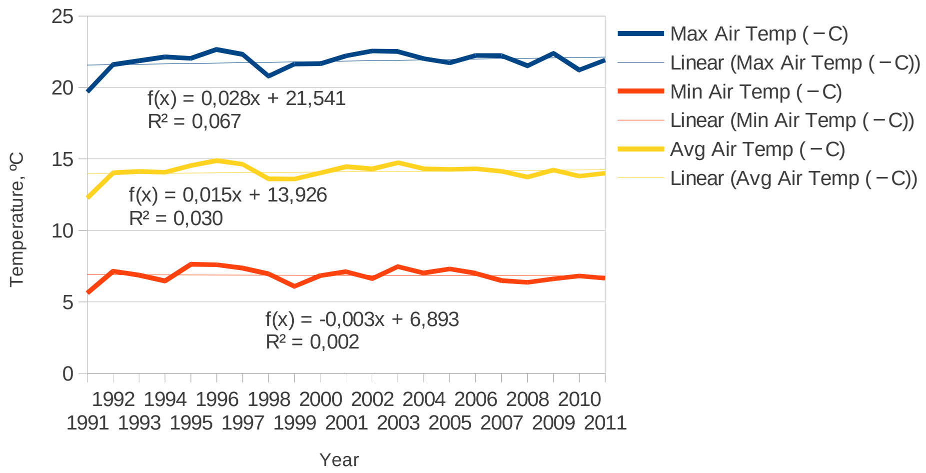

Figure 1. Evolution of minimum, average and maximum temperature over the study period.

The Analysis of the other climate variables required for the ETo calculation with the Penman equationindicate that the solar radiation increased by 8 W m^{-2} during the twenty years of the study period (Figure 2). This represents an increase of 4% in the total energy received through radiation. Additionally this was accompanied by an increase of 0.1 m s^{-1} in the wind speed and an increase of 0.7 percentage points in the relative humidity. It can be observed for the four main parameters affecting evapotranspiration, that while the increase in temperature, radiation and wind speed contribute to an increase in evapotranspiration, the slight increase in relative humidity has the inverse effect.

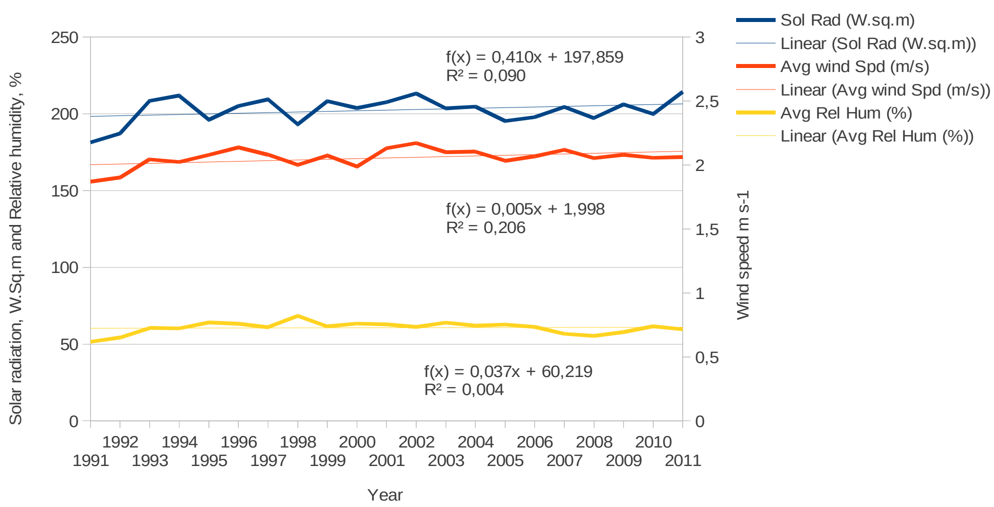

Figure 2 Evolution of the solar radiation, relative humidity and wind speed during the study period.

The evolution of the annual evapotranspiration values is presented in Figure 3. The results indicate that the average ETo increased in the 20 California stations between 1991 and 2011 at an average rate of 0.11 mm day^{-1} decade^{-1} when using the CIMIS Penman ETo equation and 0.12 mm day^{-1} decade $^{-1}$ when using the PM ETo equation. These values represent an increase of 6.6 and 7.2%, respectively, in the 1991-2011 period.

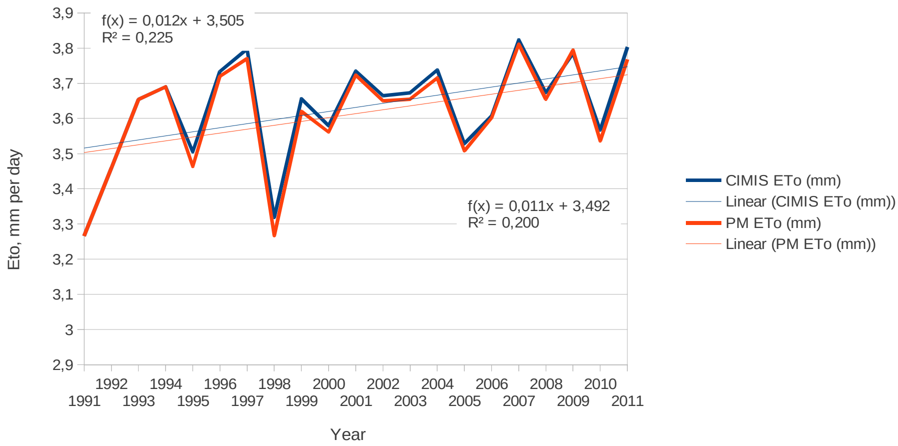

Figure 3. Evolution of the CIMIS ETo and Penman-Monteith ETo during the study period.

These results are in agreement with what has been observed in southern Iberia. For example the work of Moratiel et al. (2010) shows that in the 38 meteorological stations they studied, between 1973 and 2002, the average temperature increased between 0.3 and 0.7 ºC decade^{-1}. Additionally they observed that the relative humidity fluctuated between 0.1 and -3.7% decade^{-1}. In a previous work on the evolution of climate in southern Portugal covering the 1965-2009 period (Shahidian et al. 2012) a gradual increase in the average temperatures was observed, with some areas showing an increase of up to 0.4 ºC decade^{-1}. These authors also observed an increase of 0.1mm day^{-1} in the daily average ETo values during the 1965-2009 period, which translated into an increase of 35mm year^{-1}.

The data from California indicate that besides the increase in average temperatures, there is an important increase in the average daily radiation, which can be assumed as one of the causes for the increase in the daily temperatures. There is still little information on what is the compound result of the various changes in the climate parameters. A recent study (Famiglietti and Min-Hui Lo, 2003) shows that the large amount of evapotranspiration from the California Central Valley irrigations boost humidity, and eventually using a climate model, they concluded that in some areas, the water evaporated from the fields can return in the form of rainfall, reaching a maximum of 350 mm year^{-1}. It can thus be assumed that the increase in evapotranspiration observed might be responsible for the increase in relative humidity, and that eventually some of this evapotranspiration might be returned in the form of precipitation.

Conclusions

Twenty years of climate data from California CIMIS stations indicate that the temperatures have increased at the rate of 0.15 ºC decade^{-1} over the twenty year study period, although the time series are

not long enough to statistically validate the results. These temperature increase trend is in line with previous studies carried out in Portugal and Spain, where temperature has increased at the rate of 0.3 - 0.7 ºC decade^{-1} in Spain and up to 0.4 ºC decade^{-1} in southern Portugal.
Additionally the data indicate an important increase in the solar radiation received at the stations. The solar radiation increased by 8 W m^{-2} during the twenty years of the study period, which represents an increase of 4% in the total energy received through radiation. This increase in the solar energy input as well as the increase in temperatures resulted in an increase of 0.11 mm day^{-1} decade^{-1} in evapotranspiration when using the CIMIS Penman ETo equation and 0.12 mm day^{-1} decade $^{-1}$ when using the PM ETo equation. These values represent an increase of 6.6 and 7.2%, respectively, in the 1991-2011 period.

If these tendencies continue over the next decades, it might be important to seriously reconsider the prevailing lifestyle of the developed world, and reduce the use of fossil fuels.

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