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D-C4.3.3 Evaluation of future diurnal variability and projected changes in extremes of precipitation and temperature and their impacts on crop production over regional case studies (e.g. Agroscenari case studies)

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Introduction

Surface temperature variability has been extensively studied for many years highlighting both temporal and spatial main features at global, regional and local scale. It has been also related to the natural and anthropogenic climate change. In particular, changes related to the difference between maximum and minimum daily temperature, also known as diurnal temperature range (DTR), received a special attention since it has many implications for land ecosystems. There are different physical mechanisms which force, and thus change, the DTR at local scale: cloudiness, surface energy fluxes especially related to nocturnal radiation, soil moisture and land use changes, large scale circulation. Many other additional factors affect diurnal temperature range, including land use/land cover changes (Gallo et al., 1996), irrigation (Karl et al., 1988), station moves, desertification, and other climatic effects (Karl et al., 1993; Qu et al., 2014). Braganza et al (2004) showed that DTR is independent of mean temperature for internal climate variability and therefore should contain additional information for the attribution of global climate change.

Often DTR changes, and in particular its reduction over time, has been identified as a fingerprint of anthropogenic forcing of climate change at global scale since it is related to the night time radiative effect of greenhouse gas increase (Easterling et al., 1997, Braganza et al., 2004). Recently several studies highlighted the complex features and temporal behaviours of DTR showing also a global scale weak raising by the end of the '80s (Rhode et al., 2013).

At regional scale DTR behavior is much more heterogeneous on the Earth (see for example Qu et al., 2014) with both regions of increasing values and region with decreasing values over time with strong relations with large scale atmospheric pattern variability (Wu, 2010). Lindvall and Svensson (2015) analyzed the DTR variability among CMIP5 global models for the recent past and future projections identifying major patterns and behavior in the projected future climate; in particular in the Mediterranean area DTR increased probably due to a reduction of long wave radiation and a dryer climate both link to a reduction of cloudiness (Lindvall and Svensson, 2015). Such findings was also highlighted by specific studies based on observed data (Bartolini et al., 2012) where the strong increase of summer maximum temperature may be stronger than any other signals.

The regional donwscaling technique applied in this study and the full physical treatment of atmospheric dynamics guaranteed guaranteed by the RAMS model, provides a framework of analysis which does not have any prescribed or a priori limitations on the distribution probability density function of analyzed data variables. Limits are only coming from the regional model ability of representing fine scale atmospheric processes driven by large scale variability provided by global models in the framework of anthropogenic future climate change. Other approaches, such as statistical downscaling techniques, which have prescribed rules sorted from observed time series and a limited treatment of extreme events, could be strongly biased and thus could reduce the strength of fingerprints of climate change due to extreme events and their relative impacts at local scale.

The direct and indirect (e.g. through increased VPD) impact of DTR on crop production is documented by several authors (e.g. Asseng et al, 2011; Lobell, 2007) which demonstrated non-linear effects of temperature on crop yield and the need for further studies. The impact of average temperature rise on crop production and water use may result from the confounding effect of concomitant factors (e.g. extreme max, DTR variation, cloudiness) that cannot be separated in a field experiment. By simulation modelling, it is possible to separate the impact of temperature from other factors and show the net effect of DTR under PC and FC.

Changes in water vapor, soil moisture and precipitation, not considered in this report, are also likely to have lesser but important impacts on simulated trends in Tmax and Tmin.

The main hypothesis of this sub-task 4.3.3. was that future climatic projections include a DTR shift and that these may have some influence on crop yield and water requirements under Mediterranean conditions. We applied this idea to the RAMS scenarios developed for the Oristanese (Italy) regional case study, in the Mediterranean region. As a first step, we limited our comparison to the least constrained cropping system in terms of water and nitrogen stress (the double cropping silagemaize + Italian ryegrass under irrigation), in order to reduce as far as possible other confounding effects.
We also tested the ability of WXGEN weather generator to accurately reproduce the shift of DTR associated to climate change as generated by the RAMS scenarios when used to extend the decadal weather dataset to a century.

Climate scenarios and DTR

The potential climatic forcing acting on the study area, and the changes due to CO_2 in the A1B scenario, were evaluated with a downscaling strategy to produce calibrated time series of rainfall and temperature over the study region. This strategy builds a modeling chain describing with a high level of reliability the main atmospheric variability that acts on the area, from large scale to local scale; and considering the change in the concentration of greenhouse gases. It applies a coupled model of general circulation to estimate large scale atmospheric and ocean response to future A1B emission scenario as described in Scoccimarro et al. (2010). In this regard, we selected two periods of 11 years: 2000–2010 representing current climate conditions (PC), and 2020–2030 as conditions of near future (FC). These global simulations belong to a specific set developed by the Euro-Mediterranean Center on Climate Change (www.cmcc.it) in the EU project Circe (http://www.circeproject.eu). The general circulation model drives the Regional Atmospheric Modelling System (RAMS) applied on the study area to increase the physical description of acting mechanism at local scale, and to better represent local variability (Pielke et al., 1992). The proposed RAMS model configuration follows settings as other studies on numerical weather forecast (Meneguzzo et al., 2004).
Due to limitations in the geo-morphological representation of numerical models (mountain chains or land cover), significant systematic errors may affect direct outputs of modeling chain atmospheric fields reducing the potential usage for agricultural applications. Such systematic errors were reduced by applying a post-processing procedure based on observed data. To this end the RAMS was also forced with reanalysis dataset: the Reanalysis-2 for the atmospheric component (Kanamitsu et al., 2002), and the reconstructed sea surface temperature from Hadley Centre (Rayner et al., 2003), with the same configuration for current and future scenarios. The direct RAMS model outputs, only forced by reanalysis datasets were compared to surface observed data of the study area for the period 2000-2010. Bias corrections were then computed using a linear regression at daily scale for temperature values, and a quantile-quantile correction for rainfall to reduce typical modeling bias as described in Pasqui et al. (2013). Those corrections were then applied to the outputs of RAMS simulations to calibrate current and future climate scenarios, assuming that the geo-morphological source of errors will act independently, since stationary by nature.

The daily min and max temperature data of each month of the two decades were compared on a monthly basis to check for relevant differences associated to the two climatic scenarios.
In order to understand the pure effects of DTR under PC and FC we ranked the diurnal DTR of the decade on a monthly basis following a quintile-quintile mapping procedure, and attributed the same rank of daily DTR's of FC to PC diurnal averages and then, as a cross comparison, the same rank of the daily DTR's of PC to FC diurnal averages. The other

climatic features of the PC and FC were not modified. In such way, we could compare four combinations of daily temperature data:

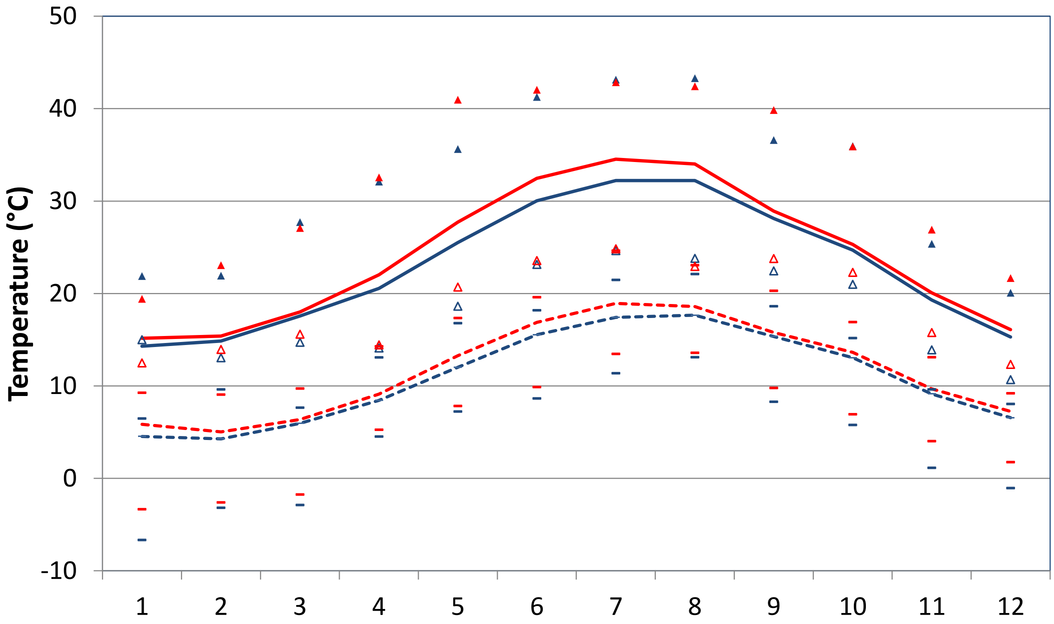
- PC: PC as obtained by calibrated RAMS for PC
- PC_DTRFC: PC as obtained by calibrated RAMS for PC biased using the DTR'S of FC of the same rank of PC
- FC: FC as obtained by calibrated RAMS for FC
- FC_DTRPC: FC as obtained by calibrated RAMS for FC biased using the DTR'S of PC of the same rank of FC

The daily weather of the four decades were used as input to EPIC simulation model to test the effects on crop yield, crop evapotranspiration, number of days with water and nitrogen stress in the silage maize - Italian ryegrass irrigated cropping systems in the Oristanese case study area (Dono et al, submitted to Agric Sys). The details of the crop model calibration for this simulation are beyond the scope of this report and will not be reported in this deliverable for the sake of brevity. Crop management was set to business as usual in the area but irrigation was set as automatic with a minimum interval between two irrigations of 4 days. The winter crop (Italian ryegrass) was also irrigated when soil water content dropped below 50% total available water. Nitrogen fertilization was set as automatic. All simulations were performed under a CO_2 concentration of 380 ppm. A pre-run was performed before the decadal simulations to stabilize soil organic C pools. The decadal means obtained with EPIC for yield and evapotranspiration under PC vs PC_DTRFC and FC vs FC_DTRPC were compared through a paired-t test.
The two decades (PC and FC) of daily weather data as generated by the RAMS scenarios were also submitted to the WXGEN weather generator to check for possible bias in reproducing the shift in DTR's.

Results

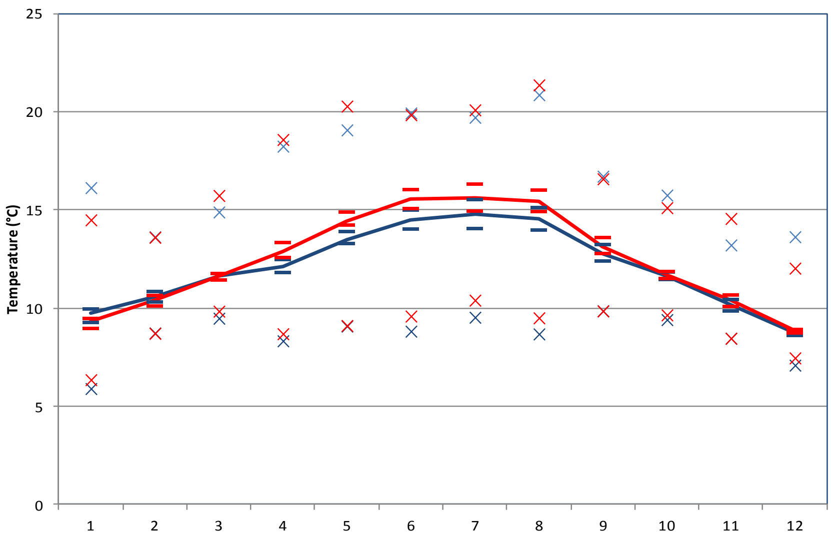
The shift in average max and min temperature of FC vs PC for Oristano forecasted by the RAMS climate scenarios was highest in the warmest months, reaching a maximum of average max temperature of +2.4°C in June and a maximum of average minimum temperature of +1.51 in July. The shift in DTR of FC and PC forecasted by the RAMS climate scenarios was significant only from April to August, while it was not significant in the rest of the year (Figure 1).

Figure 1 - Average max (solid lines) and min (dotted lines) temperature under PC (blue) and FC (red) as forecasted by the RAMS scenarios. Absolute daily min and max of PC (blue) and FC (red) are represented by triangle and line symbols respectively for absolute max and min temperatures.



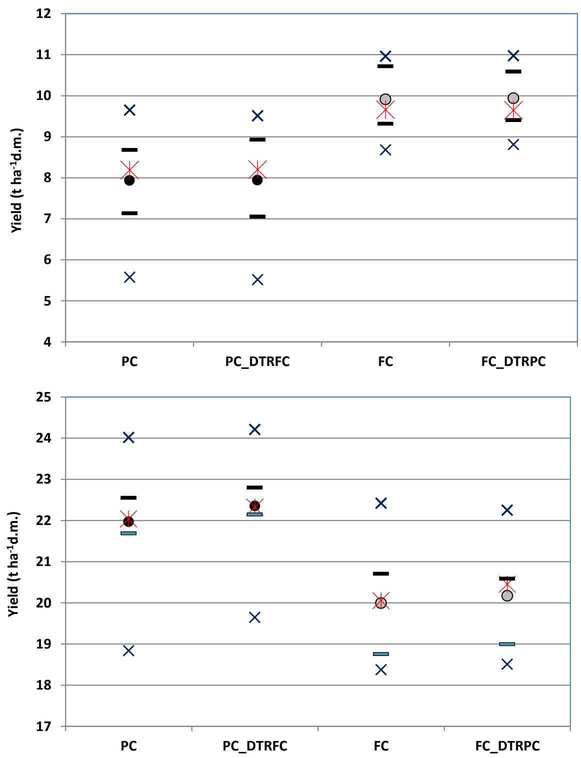
The yearly average DTR was +0.38°C in FC vs PC. Average DTR of FC was significantly lower than that of PC in January (-0.44°C), and higher in all other months except March, October and December, when differences were not significant (Figure 2). The differences between monthly average DTR were highest from April to August and reached a max in June (+1.1°C). The monthly average increase in DTR of FC vs PC reached its maximum in June (+1.1°C) and the minimum in January (-0.44).

Figure 2 - Monthly averages of the daily DTR under PC (2000-10, blue line) and FC (2020-30, red line) as forecast by the RAMS scenarios for Oristano (Italy). Horizontal line symbols show observed absolute daily min e max DTR. Horizontal line symbols show 1st and 3rd quartile, X indicates extremes DTR in the decade.



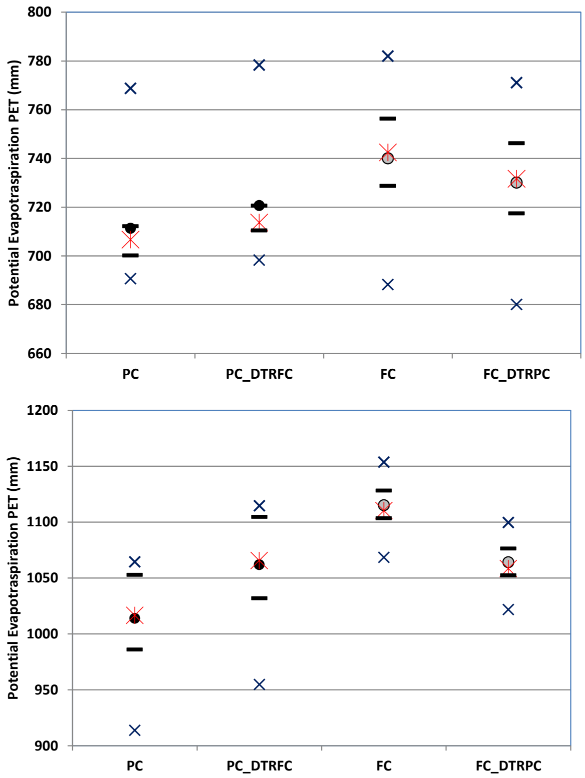
The response of crop yield to the overall shift in climate conditions was highly significant with higher production of Italian ryegrass and lower production of maize under FC vs. PC (Figure 3). The output of the simulations did not reveal significant effects on crop yield and yield distribution as a consequence of the pure shift of the DTR in both directions (FC DTR applied to PC averages and PC DTR applied to FC averages).

Figure 3 - Results of the EPIC model simulations of Italian ryegrass (left) and maize (right) forage yield (t ha^{-1} dry matter) under different temperature regimes: PC= present climate (2000-10); FC = future climate (2020-30), PC_DTRFC = PC with DTR of FC; PC_DTRPC = FC with DTR of PC.



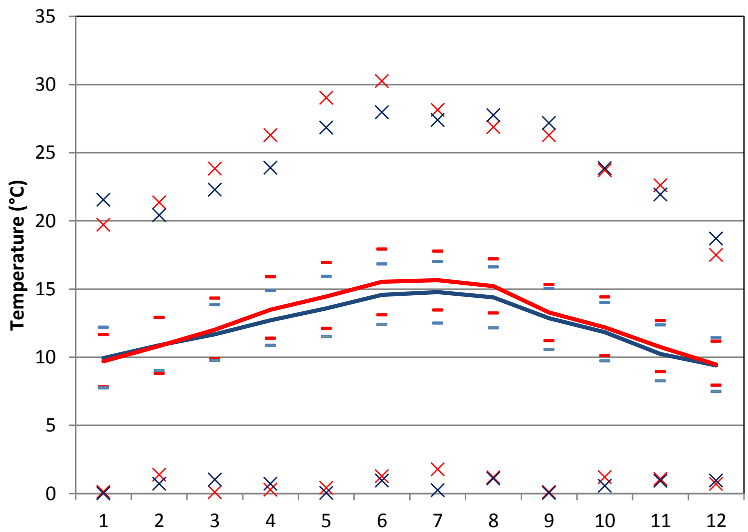
The net impact of the shift in DTR on crop evapotranspiration was highly significant both for PC and FC. The pure DTR shift associated to FC, when applied to PC significantly increased crop evapotranspiration by 9 mm in ryegrass and 48 mm in maize. When the PC DTR was applied to FC averages, this led to an average drop in crop evapotranspiration by 10 mm in ryegrass and 51 mm in maize (Figure 4). The net increase in evapotranspiration associated to FC DTR was 33% (ryegrass) and 47% (maize) of the total increase in evapotranspiration observed under FC vs PC.

Figure 4 - Results of the EPIC model simulations of Italian ryegrass (left) and maize (right) crop evapotranspiration (mm from seeding to harvest) under different temperature regimes: PC= present climate (2000-10); FC = future climate (2020-30), PC_DTRFC = PC with DTR of FC; PC_DTRPC = FC with DTR of PC.



The generation of a century of daily weather data with WXGEN starting from the four scenarios under comparison indicate that the weather generator was sufficiently accurate in reproducing the DTR patterns of the two climates in terms of means, while the variability observed in the generated data was substantially higher than that of the original decadal datasets (Figure 5). For the extreme data (abs max and min DTR), this result was attributed to the longer time series and the correspondent higher probability of extreme occurrencies. However the trend of amplifying the DTR variability by WXGEN is revealed also by the wider interval between the 1st and 3rd quartile.

Figure 5 - Monthly averages of the daily DTR under PC (blue line) and FC (red line) as generated by WXGEN (100 years) from the decadal data obtained by the RAMS scenarios for Oristano (Italy). Horizontal line symbols show 1st and 3rd quartile, X indicates extremes DTR in the century.



Discussion and conclusive remarks

The increased DTR predicted by the RAMS for FC is consistent to what found by other authors using several climatic models, i.e. DTR tends to increase with increased average T (e.g. Lobell, 2007). The monthly DTR pattern predicted for the FC indicates that spring and summer months are the most sensitive to DTR increase.
The increase ryegrass yield simulated by EPIC under FC was interpreted as the positive effects on increased temperature on the winter-spring grass growth rates. The decreased production of maize was attributed to a shortening of the crop cycle, which reduced the intercepted radiation.
The simulations run to assess the pure effect of DTR shift indicated almost no effects on crop yield but significant effects on crop evapotranspiration, whose increase observed under FC was largely associated to DTR, particularly in maize.
The stochastic generation of daily weather with WXGEN indicates a sufficient accuracy for average DTR patterns and the central part of the daily DTR distribution, while the range of absolute values increased substantially, in relation to the increased probability of extremes in one century vs one decade.

In conclusion, the observed relevant net impact of DTR on crop evapotranspiration indicates that much of the shift in crop water requirements under Mediterranean conditions is associated to a shift DTR other than just average temperature rise. For future work it is also worth assessing a more detailed description of physical local and remote mechanisms responsible of these conditions in the Mediterraean basin along with the sensitivity of different climatic models to DTR shifts an different crop models to the crop response to DTR shifts in terms of yield, as DTR is associated to many plant physiological process, from seed germination to fruit and seed set.

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