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# Modelling of water balance and crop growth based on Earth Observation and re-analysis data

By


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# Abstract

Agriculture is not only one of the most ancient economic assets known to man: it also has enormous importance as the most valuable human activity which ensures global food security. Optimal vegetative growth, and therefore crop production, is heavily dependent on the hydro-climatic variables necessary to fulfill the evapotranspirative requirement of plants. According to FAO, more than 1.2 billion people live in regions where water scarcity is a serious threat to agriculture. Therefore, assessment of agricultural water requirements is essential in order to develop effective water-related policies in a globalized world with unprecedented population growth and unevenly distributed water resources. Irrigated areas have almost doubled in the last 50 years and account for 20% of global croplands; they currently consume 70% of freshwater withdrawn for human purposes. Furthermore, rainfed agriculture provides 60% of total food production and is highly dependent on meteorological factors. The assessment of climate-driven changes of crop water requirements and water stress periods is very important in order to highlight future weaknesses of food security. The impact of climate change on food production has become an extremely important issue and is dealt with an increasing number of studies; a cross-sectoral approach must therefore be adopted to effectively address its effect on agriculture, adopting appropriate adaptation strategies across local, regional and global scales.

In recent years, the spread of Earth Observation (EO) data has radically changed the range of technologies currently available to manage agriculture. The possibility to retrieve near real-time information of crop health status and localized criticalities has improved the quality of intensive farming, especially in terms of resource use. Satellites are widely used for the acquisition of large-scale data and modern sensors can reach very high spatial, temporal and spectral resolutions. Nowadays, reanalysis climate datasets offer new possibilities for hydrological modelling, working at relatively high spatio-temporal resolutions.

This thesis aims to exploit the potential of the EO-based data to strengthen the scientific knowledge of how climate variability impacts the water requirements of global agriculture, by (i) developing a model to assess the comprehensive daily crop irrigation requirement (i.e. the ideal input of water needed to avoid water stress); (ii) to assess the climate-driven crop water requirements from 1970 to 2019, highlighting significant trends of irrigation requirements and water stress periods on rainfed croplands; (iii) to combine several satellite measurements to retrieve high-resolution information on actual sowing periods and crop growth, to limit some of the main uncertainties related to crop modelling. In order to achieve this, a hydrological soil-water balance model was developed to model the climate-driven evapotranspirative requirements using the daily hydro-climatic data from ERA5, the reanalysis dataset provided by the European Centre for Medium-Range Weather Forecasts. The model was tested for year 2000 at the global scale, comparing the modeled irrigation requirements to the national volumes of water withdrawn for irrigation. The analysis was then extended over a 50-year period, highlighting critical issues peculiar to rainfed and irrigated scenarios. In order to improve the quality of crop growth modelling, a synergistic use of optical and radar data from the Sentinel constellation was tested to retrieve information

on maize sowing periods and growing phases. The analysis was performed over a densely cultivated pilot area in South Piedmont (Italy).

Results show a good agreement between the estimated irrigation requirements for year 2000 (962 $km^3$ globally) and national withdrawals for irrigation. A focus on three areas of the world (California, Northern Italy and India) highlights the wealth of information provided by the model in different climatic conditions. Increases of irrigation requirement rates were found on more than 60% of irrigated lands, especially in South Europe, North-East China, West US, Brazil and Australia, where the mean rate increased more than 100 mm/year from 1970s to 2010s. The analysis of rainfed crops highlights statistically significant trends of water stress duration for more than 38% of rainfed croplands, while only 6% were affected by negative trends and shorter stress duration. The satellite-based analysis described in the third part of the thesis highlights the potential of combined optical and radar data to retrieve information of maize growing phases. The actual sowing periods were retrieved for 1154 test fields and results show that most of the maize were sown in late April or in the second half of May in 2019.

This thesis contributes to advancing our knowledge on the impact of climate spatio-temporal variability on agricultural water requirements. The EO-based data is proven to be a valuable instrument (i) for large-scale hydrological modelling, (ii) to describe the global variability of climate-driven impacts on crop water requirements and (iii) to retrieve high-resolution information to improve the accuracy of crop growth monitoring, in order to perform future analyses of actual irrigation practices.