SIM: SMART IRRIGATION FROM SOIL MOISTURE FORECAST USING SATELLITE AND HYDRO –METEOROLOGICAL MODELLING

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KEY POINTS

- *Smart irrigation forecast*
- *Meteo-hydrological modelling*
- *Remote sensing land surface temperature*

1 INTRODUCTION

The conflicting use of water is becoming more and more evident, notably in regions that are traditionally rich in water. With the world's population projected to increase to 8.5 billion by 2030, the simultaneous growth in income will imply a substantial increase in demand for both water and food. The agricultural sector, which is the biggest and least efficient user of water is likely to face enormous challenges in order to sustain food production. Literature provides several studies on the optimization of irrigation water management starting from the FAO Paper 56 based on crop coefficient (*Allen et al., 1998*), to water balance modelling and satellite data algorithms for optimizing off-farm irrigation scheduling (*D'Urso and Menenti 1995, Belmonte, et al., 2005; Forrest et al., 2012*), to the more recent studies based on the coupling of meteorological forecasts and hydrological models *(Cabelguenne et al., 2009, Ceppi et al., 2014, Pelosi et al., 2016*). Different irrigation triggering techniques have been developed in literature based on the deficit between potential and actual evapotranspiration (*D'Urso and Menenti, 1995*) or on a soil moisture threshold (*Allen et al., 1998*). However, *Consoli et al., 2014*, among others researches, showed that even with a deficit irrigation (e.g. 50 % of the potential evapotranspiration) with no changes in crop yield. For real time applications, the integration of remote sensing data with distributed hydrological models will allow continuous in time estimates of soil moisture. At local scale, these can be calibrated and validated against soil moisture or evapotranspiration data from eddy covariance stations (*Cammalleri et al., 2012*), while for large irrigation districts, where ground measurements are not representative and available, some approaches based on multi parameters calibration approach have been developed using remote sensing data (*Crow et al., 2003; Corbari and Mancini 2014*).

The main objective of this paper is the development of a system for operative irrigation water management based on the coupling of remote sensing data, distributed water-energy hydrological model and meteorological forecasts. Discussion on the methodology approach is presented, showing the calibration technique based on satellite and ground data, and comparing for reanalysis periods the forecast system outputs with observed soil moisture and crop water needs proving the reliability of the forecasting system and its benefits. This approach is shown for the case study of the Capitanata Irrigation Consortium in Southern Italy.

This is part of the European SIM project (Smart Irrigation Modelling, www.sim.polimi.it) which has as main objective the parsimonious use of agricultural water through an operational web tool to reduce the use of water, fertilizer and energy keeping a constant crop yield, supporting different level of water users from irrigation consortia to single farmers. The project methodology is now tested in different experimental sites which are located in Italy, the Netherlands, China and Spain, which are characterized by different climatic conditions, water availability, crop types and irrigation schemes. This also thanks to Italian ANBI, Capitanata and Chiese irrigation consortia and Dutch Aa and Maas water board.

2 METHODS

The SIM system combines the state of the art of satellite monitoring of soil moisture and evaporative fluxes (*Herrero-Huerta et al. 2015; Jiménez-Muñoz et al. 2009*), quantitative meteorological forecasts (*Amengual et al. 2017*) and detailed distributed hydrological modelling (*Corbari and Mancini, 2014*) of soil water balance and crop water needs. The economic impact of the system is evaluated in terms of profitability and productivity based on the local cost of the water and crop production, but also considering the environmental benefit of a prudent use of the water (*Natali and Branca, 2017*).

The distributed hydrological model, Flash–flood Event–based Spatially–distributed rainfall–runoff Transformation- Energy Water Balance model (FEST-EWB) is used for continuous in time soil moisture accounting based on an energy-water balance scheme, thanks to a double link with satellite data as input parameters (e.g. LAI) and as variables for model states update (LST). The energy and water mass balance equations are solved for a pixel representative equilibrium temperature (RET) which can be directly compared with the LST satellite data (*Corbari et al., 2011*). This approach allows to control and to improve the understanding of surface fluxes exchanges model representation that are internal model variables (SM, ET) according to Dooge's definition (*Dooge, 1986*). The LST from remote sensing is also used for model internal calibration and validation as a complementary method to the traditional discharge measurements.

The SIM system is based on meteorological deterministic and ensemble forecasts at short and medium-range (1-10 days) coupled with hydrological simulations. Different meteorological models are used: deterministic MOLOCH and BOLAM models by the Italian ISAC-CNR at about 1.5 km and 11 km as spatial grid resolution, 1 hour as temporal resolution with 45 and 72 hours as lead time, the deterministic ECMWF and the 50 ensemble ECMWF models by the University of Balearic Islands at about 9 km and 18 km as spatial grid resolution, 6 hours as temporal resolution with 240 hours as lead time, the multi-model WRF by Epson Meteo Centre at about 5 km as spatial grid resolution, 1 hour as temporal resolution with 72 hours as lead time.

The decision criteria in order to plan whether or not to irrigate is based on the comparison between the present and forecasted soil moisture and a water stress threshold (θcrit) below of which the crop begins to suffer for lack of water. This stress threshold is a function of the different types of soils and crops, but also of the vegetation growth stage and of the climatology of the area of study. The implemented procedure relies on the methodology of *Allen et al.*, (*1998*) in the FAO-56 paper.

3 RESULTS

The results are shown for the Sud Fortore District of the Capitanata Irrigation consortium which covers an area of about 50'000 hectares which are mainly irrigated by the pressurized aqueduct distribution network and also by with private wells. The district is an intensive cultivation area, mainly devoted to wheat, tomatoes and fresh vegetables cultivation that to its a flat topography and its favorable climate with hot summer and warm winters.

3.1 Calibration and validation at local and basin scale

FEST-EWB is run for the period between 2014 and 2016 at the temporal resolution of 1 hour and at the spatial resolution of 30 m. The calibration of soil hydraulic and vegetation parameters is performed through the comparison between RET estimates and LST from LANDSAT data and the ground radiometer. With a trial and error approach, the model parameters are modified from the original values minimizing the difference pixel by pixel between observed LST and simulated RET. FEST-EWB with the original soil / vegetation parameters before calibration generally highly underestimates observed satellite values, with a mean absolute difference pixel by pixel of 5 °C; while after the calibration procedure it is equal to 2.5 °C (Figure.1). FEST-EWB model is then validated by comparing the simulated energy and water fluxes (LE, SM, H, Rn) with the observed ones at four eddy covariance stations in a field of asparagus, cabbage and two tomatoes field. As example, the agreement is good for the cabbage field (Figure1), with the coefficient of determination being 0.86, the angular coefficient 0.95, the RMSE 20.9 W m-2 for Rn, for LE by a coefficient of determination equal to 0.85 and a RMSE of 33.3 W m-2, while for H with R2 of 0.76 and RMSE of 32.7 W m-2. Soil moisture is correctly reproduced with a RMSE of 0.04

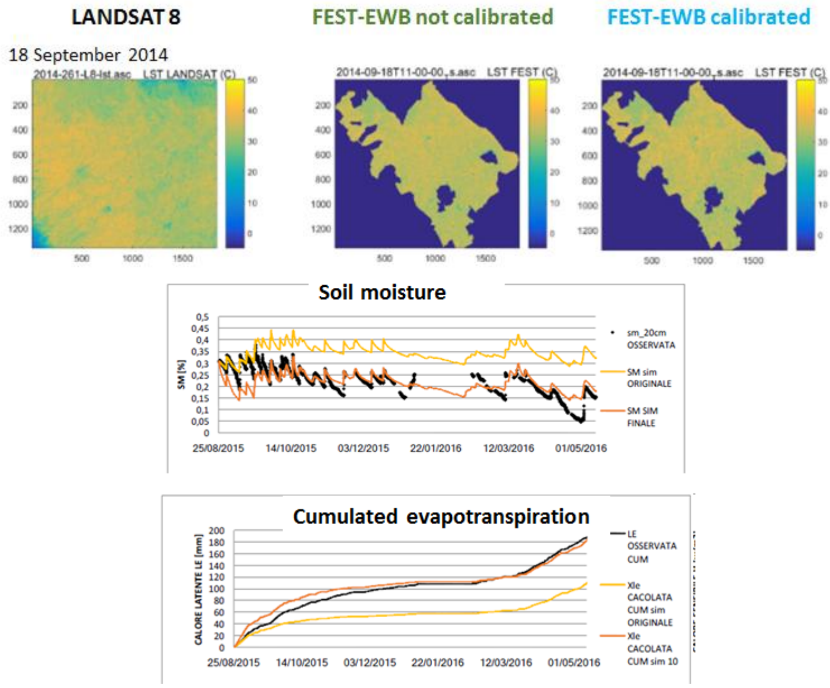

Figure.1 Comparison between calibrated and not calibrated RET and LST from LANDSAT for 18 September 2014, and for the cabbage field, the comparison between evapotranspiration and soil moisture from FEST-EWB before and after the calibration and ground measurements.

3.2 Real-time soil moisture forecast

Calibrated FEST-EWB model with satellite LST is then used, coupled with meteorological models forecast, as support to irrigation water need forecast testing the reliability of this forecasting system and its benefits for the 2016 growing season. Hydrological model simulations and forecasts are compared against ground observed measurements. The results show how the proposed Smart Irrigation Management system is able to have a high reliability of forecast for the following days ahead (Table.1).

As example, soil moisture forecasts are shown by the Bolam, Moloch, WRF (25°, 50°, 75° percentiles), ECWMF (deterministic), ECMWF (control run), ECMWF (25°, 50°, 75° percentiles) models at day +1 for July 2016 (Figure2).

Table 1 Mean Error for each hydro-meteorological variable of each weather model in comparison with observed data measured at field site from 15th May to 24th September 2016. The simulated results referred to the FEST-EWB simulations with observed data.

ME	Air Temperature [°C]	Air Humidity [-]	Solar Radiation [W/m2]	Wind Speed [m/s]	Daily Precipitation [mm]	Daily Evapotranspiration [mm]	Soil Moisture [-]	Soil Temperature [°C]
Simulated	-0.53	0.00	-33	-0.02	3.98	1.13	0.02	-3.8
Bolam+1	0.65	-0.04	6	0.70	-0.63	1.39	0.00	-2.9
Moloch+1	0.73	-0.02	2	0.19	-0.40	1.22	0.01	-2.8
WRF_25+1	0.80	-0.10	35	0.89	-1.11	1.64	-0.01	-2.7
WRF_50+1	1.33	-0.07	74	1.42	-0.76	1.88	0.00	-2.1
WRF_75+1	2.07	-0.05	97	1.88	0.48	2.18	0.01	-1.3
ECMWF+1	1.06	-0.06	-242	0.15	-0.17	1.24	0.01	-2.9
ECMWF_CR+1	1.01	-0.05	-225	-0.03	-0.20	1.20	0.01	-2.8
ECMWF_25+1	0.70	-0.06	-248	-0.28	-0.91	1.04	0.00	-3.1
ECMWF_50+1	0.97	-0.05	-224	-0.05	-0.38	1.19	0.01	-2.8
ECMWF_75+1	1.21	-0.03	-205	0.17	0.46	1.34	0.01	-2.6

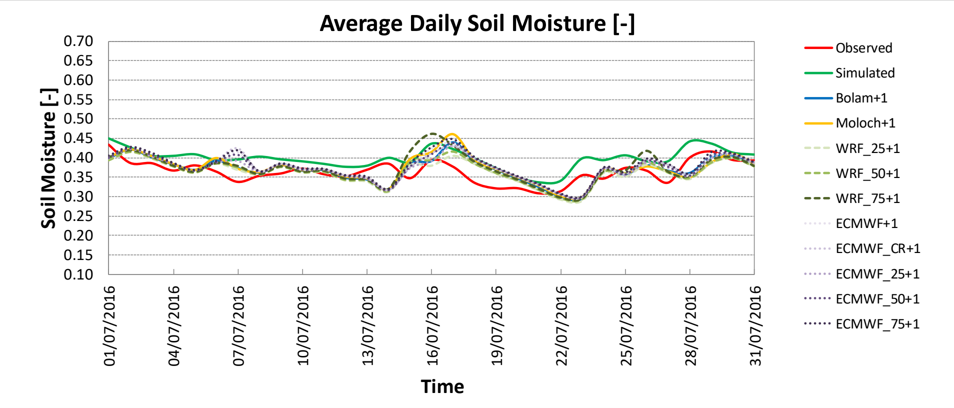

Figure.2 Soil moisture forecasts from the meteo-hydrological system

4 CONCLUSIONS

The paper shows the potentiality of satellite LST data to improve and control soil moisture variable at pixel scale in a distributed hydrological model. This is assessed writing the energy and water mass balance in the hydrological model explicating LST that in this way may be directly compared to satellite observation.

The potentiality of satellite soil moisture control is also provided in an application for operative forecasting system of irrigation water needs.

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