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VALIDATION OF A DISTRIBUTED HYDROLOGICAL ENERGY WATER BALANCE MODEL USING REMOTE SENSING LAND SURFACE TEMPERATURE AND GROUND DISCHARGE MEASUREMENTS

Introduction

Reliability of distributed hydrological models is an important task in hydrology to understand their ability to estimate energy and water fluxes at agricultural district scale as well as at basin scale for water resources management in agricultural and flood forecast. In this context this extended abstract has as main objective the internal validation of a distributed energy water balance model, Flash–flood Event–based Spatially–distributed rainfall–runoff Transformation - Energy Water Balance model (FEST-EWB) using land surface temperature (LST) retrieved from operational remote sensing data as a complementary method to the traditional calibration with discharge measurements at river control cross sections. Calibration and validation of distributed models at basin scale generally refer to external variables, which are integrated catchment model outputs and usually depend on the comparison between simulated and observed discharges at the available rivers cross sections, which are usually very few (Beven, Binley 1992; Refsgaard 1997; Brath *et al.* 2004). However distributed models allow an internal validation due to their intrinsic structure (Dooge 1986; Fawcett *et al.* 1995), so that internal processes and variables of the model can be controlled in each cell of the domain (e.g. water content (SM), land surface temperature and evapotranspiration fluxes (ET)). In this way there is the opportunity to increase fluxes control points so that mass balance accuracy can be improved. Satellite data of land surface temperature, for their intrinsic spatial nature, can be used for the internal validation of distributed hydrological model if these

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latter are based on energy-water balance equations, thanks to LST relationship with SM and latent and sensible heat fluxes. Satellite images are an important instrument for the use in conjunction with distributed model, even if some uncertainties have to be addressed, such as the definition of satellite LST over heterogeneous area considering their spatial resolution, scan angle of view of the sensor and emissivity (Kustas *et al.* 2004; Jacob *et al.* 2004; Soria, Sobrino 2007; Sobrino *et al.* 1994).

In the last years the research community widely used LST images from different sensors as input variable of energy water balance models for evapotranspiration estimate (Bastiaanssen *et al.* 1998, Su 2002, Norman *et al.* 1995, Roerink *et al.* 2000, Famiglietti, Wood 1994). Nevertheless low efforts have been made to understand if the LST detected from satellites can be a representative proxy of the water balance process at surface, so that can be used to calibrate and validate hydrological models.

1. Hydrological model

FEST-EWB is a distributed hydrological energy water balance model that computes all the main processes of the hydrological cycle in each cell of the domain. A detailed description of the different updates of FEST-EWB hydrological model can be found starting from Mancini (1990), to Rabuffetti *et al.* (2008), Corbari *et al.* (2009), Corbari *et al.* (2010), Ravazzani *et al.* (2011) and Corbari *et al.* (2011). The model solves the system between energy and mass balance at the ground surface:

$$\begin{cases} \dfrac{d\,SM}{dt} = \dfrac{P - R - PE - ET}{dz} & (1) \\ R_n - G - H - LE = \dfrac{dS}{dt} & (2) \end{cases}$$

where: SM (-) is the soil water content, P (mm) is the precipitation rate, R (mm) is the runoff flux, PE (mm) is the drainage flux, ET (mm) is the evapotranspiration, Dz (mm) is the soil depth, R_n (Wm^{-2}) is the net radiation, G (Wm^{-2}) is the soil heat flux, H (Wm^{-2}) is the sensible heat flux, LE (Wm^{-2}) is the latent heat flux, *dS/dt* encloses the energy storage terms, such as the photosynthesis flux and the crop and air enthalpy changes. These equations are solved explicitly respect to LST so that the computed temperature can be seen as the representative equilibrium temperature of the pixel (RET). In fact it includes the heterogeneity of pixel surface, the multi source emissivity of land surface temperature and the link with the aerodynamic resistance in the turbulent fluxes estimate. So following the proposed approach, LST can be seen as a proxy of soil moisture and then a key variable in the fluxes estimates.

2. Test site

The test area is the upper Po river basin closed at the confluence between Po and Ticino rivers at the cross section of Ponte della Becca, in Northern Italy, with a total area of about 38000 km2. Meteorological Data of rainfall, air temperature, incident short wave solar radiation, relative air humidity and horizontal wind velocity are available from 1 January 2000 to 31 December 2003 at hourly or sub-hourly time step from data are collected by the monitoring system of Arpa Piemonte, Lombardia and Valle d'Aosta and of Switzerland.

3. Results

3.1. *Validation against remote sensing LST*

FEST-EWB model is then validated by comparing simulated RET and observed LST from MODIS satellite. 130 daytime and night-time MODIS11 LST products are compared with FEST-EWB land surface temperature over 4 years of simulation from 2000 to 2003. In particular only images with cloud cover below 20 % over the entire area were selected. In figure 1. as examples, sixteen maps of LST from MODIS and RET are reported for 2003 and a good ability of the model in reproducing satellite data is observed for summer as well as winter periods. This similarity is also confirmed from the frequency distribution analyses which have been performed for the entire database. In figure 2. histograms are reported, as example, for the three selected dates of 25 January at 13:00, 16 March at 13:00 and 7 June at 15:00 for the year 2003. A similar distribution of pixels number is found between RET and MODIS LST in each class. Moreover autocorrelation functions (AC) of LST from MODIS and RET have been computed for the same dates in order to understand the capability of FEST-EWB model to correctly reproduce the surface heterogeneity of the Upper Po river basin (fig. 2.) and a similar behavior of LST from MODIS and RET from FEST-EWB is shown with a similar degree of correlation decreasing with the distance. Soil moisture maps and its AC from FEST-EWB are also considered (fig. 2) showing a good agreement with modeled and observed LST.

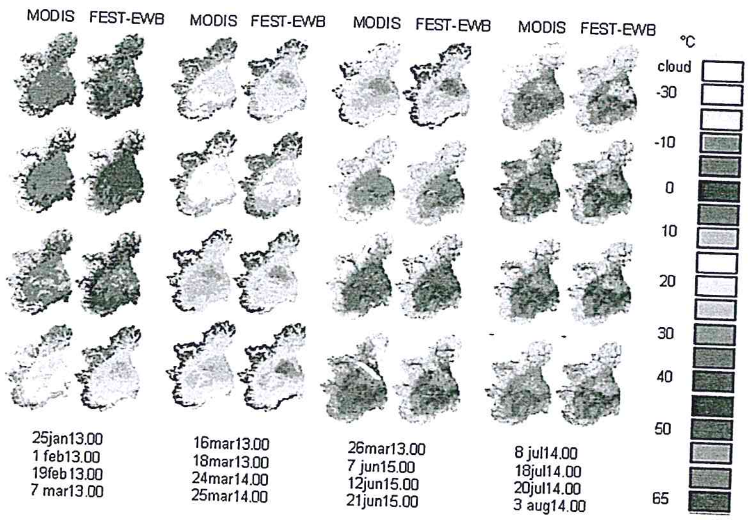

Fig.1 – Comparison between RET from FEST-EWB and LST from MODIS for the selected images in the year 2003.

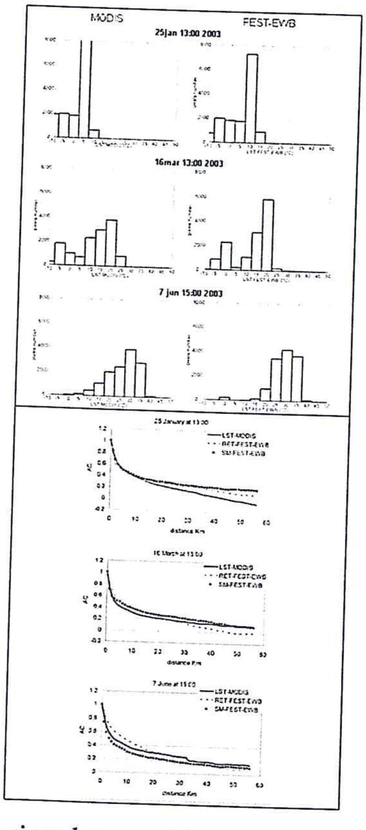

Fig. 2 – Examples of comparison between histograms and autocorrelation functions of RET from FEST-EWB and of LST from MODIS for 25 January at 13:00, 16 March at 13:00 and 7 June at 15:00 for the year 2003.

Modeled RETs over the four years of simulation are on average 2.9 °C higher than satellite ones with a standard deviation of 5.8 °C and with a good Nash-Sutcliffe index equal to 0.8 over the entire upper Po river basin. These results indicate that the model is in a reasonable agreement with observed land surface temperature.

3.2. *Validation against ground discharge measurements*

The model was subjected to a rigorous process of calibration and validation against observed discharges for the entire basin and different sub-basins. The available data sets for hydrological simulations were divided into two not overlapping periods. The year 2000 was used as the calibration period. The remaining period was used for the verification of the model performance without any further adjustment of the parameters. Calibration of the infiltration related parameters was made by comparing simulated and observed discharge at the river Toce outlet. The calibration of the accumulation parameters and of the snow melt parameters is described in Corbari *et al.* 2009. As example, simulated volume for Candoglia station in the Toce river basin is compared with observed measurements and in table 1, the Nash- Sutcliffe index and the relative volume error is reported for the different years. The simulation period from 1 January to 31 July 2000 is considered a start-up period, due to the fact the snow initial condition is zero.

TABLE 1 – *Simulated and observed volume error (%) and the Nash- Sutcliffe index at Candoglia.*

	η	**Volume error %**
4 years	0.76	-6 %
2000 from August	0.84	-10 %
2001	0.65	10 %
2002	0.65	-3 %
2003	0.81	-15 %

CONCLUSIONS

In this abstract the internal validation of FEST-EWB model is presented showing the feasibility of using land surface temperature retrieved from remote sensing data at different spatial and temporal resolutions as a control of mass balance accuracy into a distributed hydrological model in each pixel of the domain, due to the effect of LST on energy and mass fluxes estimates. The comparison between RET from FEST-EWB and remote sensing data of LST at different spatial scale has been shown and the results presented in this work indicate that the modeled RET is in a reasonable agreement with measured land surface temperature from remote sensing so that LST can be seen as a proxy of soil water content.

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