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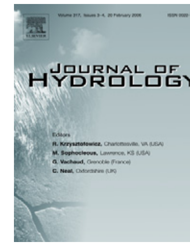

Monitoring daily evapotranspiration at a regional scale from Landsat-TM and ETM+ data: Application to the Basilicata region

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Summary The increasing interest of hydrological, climatic and meteorological models in the different components of the surface energy balance has encouraged the development of operational methods for estimating surface energy fluxes at a regional scale. In this paper, a sequence of three high-resolution satellite-based surface energy fluxes images are analyzed over an extensive area with a large variety of land uses. Two images from Landsat 7-ETM+ (1999, 2002) and one from Landsat 5-TM (2004) are collected covering the whole Basilicata region (Southern Italy). A Simplified version of a Two-Source Energy Balance (STSEB) model is used to retrieve the surface sensible heat flux. A balance between the long-wave and short-wave radiation is applied to extract the net radiation flux. The evapotranspiration (*LE*) is obtained as a residual term of the energy balance equation. The different croplands are characterized from the CORINE Land Cover maps, and the required meteorological variables are obtained by interpolating the data of a network of agro-meteorological stations distributed within the region. Atmospheric profiles from radiosoundings are used in the radiative transfer model MODTRAN 4.0 to correct the satellite data. Maps of the different fluxes are produced. Daily *LE* results are compared with some ground measurements, and an analysis is made taking the land use classification as a basis. An accuracy close to 1 mm day^{-1} is obtained. This value is in agreement with the typical uncertainties reported in the literature.

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Introduction

The physical characterization of the hydrological processes plays a very important role in the framework of the activities for the management of the hydrological resources. Particularly, the soil–vegetation–atmosphere energy exchanges are the basis of an appropriate hydrological balance, and thus, of an appropriate planning of the hydrological resources.

The fusion of physical models for estimating the hydrological balance, and particularly the evapotranspiration (*LE*), with technological advances for the characterization of hydrological, hydro-geological, and atmospheric issues, is of great utility. Although there are several surface-based methods that can accurately measure surface heat fluxes at point locations, it is not feasible to use a network of these systems to create spatially distributed flux maps because of the high variability of real landscapes. As stated by Scott et al. (2000), micrometeorological approaches can only realistically provide measurements representative of a particular type of vegetation cover when there is a reasonably extensive, uniform area of that vegetation immediately upwind of the instruments. The use of remote sensing techniques supplies the frequent lack of ground-measured variables and parameters required to apply the local models at a regional scale. Modelling evapotranspiration is very sensitive to the surface features and conditions. For this reason, a regional model must account for the surface variability. In this context, satellite remote sensing has become a basic tool since it allows us the regular monitoring of extensive areas. Different surface variables and parameters can be extracted from the combination of the multi-spectral information contained in a satellite image. The surface can be characterized with a detail depending on the spatial resolution of the sensor used.

Inoue and Moran (1997) proposed a simple method to estimate daily values of actual canopy transpiration. The method utilizes instantaneous differences of canopy and air temperature around mid-day as a major input. Results were found to be well correlated to those measured by steam-flow heat balance method in soybean canopies. Anderson et al. (1997) presented an operational two-source (soil + vegetation) model for evaluating the surface energy balance given measurements of the time rate of change in radiometric surface temperature during morning hours. Using this model, the need for ancillary measurements of near-surface air temperature is eliminated. The performance of this model was evaluated in comparison with data collected during the first International Satellite Land Surface Climatology Project field experiment, in Kansas, and the Monsoon'90 experiment, conducted in southern Arizona. Comparisons yielded uncertainties comparable to measurement errors typical of standard micrometeorological methods for flux estimation. Chehbouni et al. (2001) used dual angle observations of radiative surface temperature in conjunction with a two-layer model to derive sensible heat flux over the Semi Arid Land Surface Atmosphere program (SALSA) in Mexico. The average error was about 23%. Moran et al. (1994) introduced a water deficit index for evaluating evapotranspiration rates of both full cover and partially vegetated sites. This index can be computed using remotely sensed measurements of surface temperature and reflectance with limited on-site meteorological data. Comparison with simulations of a two-source energy balance model showed accurate estimates of field evapotranspiration rates. French et al. (2005) used data from ASTER collected over an experimental site in central Iowa, in the framework of the Soil moisture Atmosphere Coupling Experiment (SMACEX), to retrieve surface energy fluxes. Two different approaches, designed to account for the spatial variability, were considered: the Two-Source Energy Balance model (TSEB) and the Surface Energy Balance Algorithm for Land model (SEBAL). Comparison of the results with eddy-covariance measurements showed better agreement using the TSEB model with average deviations lower than 20 W m^{-2}. These results were also supported by Li et al. (2005). These authors compared local model output using two different versions of the TSEB (series and parallel) with tower-based flux observations. Root mean square differences ranged from 20–50 W m^{-2}. In this case, land surface temperatures were derived from high-resolution Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) scenes and aircraft imagery. Su et al. (2005) used also SMACEX data to evaluate the Surface Energy Balance System (SEBS) model using both high-quality local scale data and high-resolution remote sensing data from the Landsat ETM+.

Several authors such as Moran et al. (1997), Kustas et al. (2004) or McCabe and Wood (2006) have studied the effect of the satellite spatial resolution on the surface energy fluxes retrieval. Moran et al. (1997) compared remotely sensed variables and energy balance components calculated in two ways: first, calculated at the pixel resolution and averaged to the coarser resolution; and second, calculated directly at the coarse resolution by aggregating the fine-resolution data to the coarse scale. These authors concluded that knowledge of the surface heterogeneity is essential for minimizing error in aggregation of surface fluxes. Kustas et al. (2004) examined the effect of sensor resolution on model output using Landsat data collected during SMACEX. The pixel resolution of the remote sensing inputs were varied from 60 m to 120 m, 240m, and 960 m. Comparison of the results with tower and aircraft-based flux measurements indicated that when the input resolution is lower than the length scale defining agricultural field boundaries across the landscape, variation in fluxes between different crop fields is not feasible. These results were also supported by McCabe and Wood (2006). These authors used data from Landsat ETM+, ASTER, and MODIS to independently estimate evapotranspiration during SMACEX. They observed a high degree of consistency between the retrievals from Landsat ETM+ and ASTER, as well as the utility of MODIS for regional scale evapotranspiration estimation.

Despite the wide variety of remote sensing-based works and proposed models on evapotranspiration retrieval, there is not a generalized agreement about the most appropriate model depending on the application area. In this paper, we present a methodology focused on the daily evapotranspiration retrieval (LE_d) from high-resolution satellite data. The bases of this method are the energy balance equation and a Simplified Two-Source Energy Balance (STSEB) model proposed by Sánchez et al. (2007a) for estimating instantaneous surface fluxes. This model was validated over a