TOWARDS MONITORING DROUGHT CONDITIONS IN SICILY USING AN ENERGY BALANCE APPROACH

Stefan Niemeyer, Jürgen V. Vogt
Space Applications Institute
Joint Research Centre of the European Commission,
TP 441, I-21020 Ispra (VA), Italy
phone: +39-332-78.5481
drop: +39-332-78.9469
e-mail: stefan.niemeyer@jrc.it, juergen.vogt@jrc.it

Abstract

The moisture status of the surface cover in Sicily is monitored by the evaporative fraction, EF. An energy balance modelling is performed in order to describe the energy partitioning at the land surface. Estimates of actual evapotranspiration derived from EF agree well with standard methods and highlight the advantage of using remote sensing data through a significantly improved spatial resolution.

1 - INTRODUCTION

Within the last decades several drought situations of different intensity and extent have occurred within the Mediterranean Basin. An example is the drought in Italy from 1988 to 1990 (Rossi et al. 1995). The case of the region of Sicily serves as an example in the study presented in this paper.

The ruling physical principles of drought events can be described by the components of the water and energy balance. With respect to the energy balance, the partitioning of available energy into sensible and latent heat is an indicator of the moisture status of the land surface. Among the various flux ratios used to characterise the energy balance, the evaporative fraction has received special interest, e.g. (Brutsaert and Seguita 1992), (Zhang and Lemeur 1995), (Crago 1996). This ratio represents the part of the available energy actually used for evaporating water. It has further been discussed whether the evaporative fraction can be used for the transformation of instantaneous fluxes into daily rates of mass flow by assuming a constant ratio of the latent and sensible heat fluxes during daytime (Crago and Brutsaert 1996).

In the present study the evaporative fraction (EF) is considered to be indicative of the moisture status of the various surface cover classes to be found in Sicily. It has been calculated as an instantaneous value and on a daily basis from meteorological data, remote sensing data, and data on landcover types. Under the assumption that the early afternoon instantaneous EF is representative for the daily energy partitioning, estimates of daily rates of evapotranspiration have further been derived.

The different data sources combined in this study account for the various processes that determine water availability and evapotranspiration. While the remote sensing data provide spatially resolved measurements of a few physical parameters, the point data from surface meteorological measurements have a high accuracy, but...
spatially not resolved. The data on landcover give integrated, qualitative information of the surface cover, but remain static in time.

Considering the aim of an operational use of the developed methodology and a possible transfer to other regions throughout the Mediterranean, the use of operationally available data is emphasised in this study. The different data types used comprise daily meteorological data from about 100 meteorological stations in Sicily, daily remote sensing data from the AVHRR aboard the NOAA satellites, and land cover data from the European CORINE land cover database (CORINE 1993). The latter provides information on the various surface cover types, which is used to estimate related physical surface parameters.

2 - METHOD

On a daily basis the surface energy budget has been estimated for the entire region of Sicily. In a first step the available energy \( \left( R_{\text{net}} - G \right) \) and the sensible heat flux \( H \) are derived independently. The latent heat flux \( \lambda ET \) is then obtained in a second step as the residual of the energy budget equation (in \( \text{W/m}^2 \)):

\[
\lambda ET = \left( R_{\text{net}} - G \right) - H
\]

The components of the net radiation \( R_{\text{net}} \) have been derived as follows (in \( \text{W/m}^2 \)):

\[
R_{\text{net}} = R_G \left( 1 - \alpha_s \right) + L \downarrow - L \uparrow
\]

Global radiation \( R_G \) is taken from existing estimates for an operational agrometeorological model (Supit 1994) and the surface albedo \( \alpha_s \) is derived from the short-wave reflectances as measured by the AVHRR sensor. The long-wave components \( L \downarrow \) and \( L \uparrow \) are estimated from the air temperature and humidity and from the long-wave emittance as measured by the AVHRR.

The instantaneous soil heat flux \( G \) is approximated by a fraction of the net radiation, as a function of the Normalized Difference Vegetation Index (Choudhury et al. 1987).

The sensible heat flux \( H \) has been estimated from the difference between radiometric surface temperature and surface-measured air temperature, and the formulation of a bulk aerodynamic resistance (in \( \text{W/m}^2 \)):

\[
H_i = c_p \rho_{\text{air}} \frac{1}{r_a} \left( T_s - T_a \right)_i
\]

The difference between the known radiometric surface temperature and the unknown aerodynamic surface temperature, which actually should be applied, is taken into account within the formulation of the aerodynamic resistance \( r_a \). This is achieved through the definition of different roughness lengths for heat \( (z_{0h}) \) and for momentum \( (z_{om}) \) (in s/m):
$r_a = \frac{\ln \left( \frac{z_m - d}{z_{0m}} \right) * \ln \left( \frac{z_h - d}{z_{0h}} \right)}{k^2 * u(z_m)}$ (4)

d being the displacement height, \( k \) the von Karman constant, \( z \) the observation height and \( u \) the wind speed at height \( z_m \). Finally, the evaporative fraction (\( EF \)) is expressed as:

\[
EF = \frac{\lambda ET_i}{(R_{net} - G)_i}
\] (5)

\( EF \) indicates how much of the available energy is used for evapotranspiration, that is, for transpiration of the vegetation and evaporation of the soil. As long as moisture is available, energy will be used for its evaporation. With no moisture left, all available energy will be directed into the sensible heat flux and \( EF \) will approach zero.

Under the assumption that the instantaneous evaporative fraction is representative of the daily energy partitioning, the daily rate of actual evapotranspiration (\( ETa_d \)) can be estimated from the daily available energy (\( R_{net} G_d \) in mm/d):

\[
ETa_d = EF * (R_{net} - G)_d
\] (6)

where \( G_d \) has been taken as \( \approx 0 \) in a first approximation.

In order to compare the results to a standard method of estimating regional evapotranspiration rates from meteorological data, daily \( ETa \) has further been computed according to the approach of Priestley and Taylor (Priestley and Taylor 1972) (in mm/d):

\[
ET_a = \alpha * \frac{\Delta}{\Delta + \gamma} * (R_{net} - G)
\] (7)

with \( \Delta \) being the slope of the saturation vapour pressure, \( \gamma \) the psychrometric constant and \( \alpha \) the Priestley-Taylor coefficient.

3 - RESULTS

Images of the evaporative fraction in Sicily for selected days in 1991 are presented in fig.1. Green colours indicate areas with ample water supply, where evapotranspiration is limited only by the available energy. Yellow and especially red colours indicate a lack of moisture at the surface cover, which seriously restricts evapotranspiration.

Since clouds obviously limit the use of optical remote sensing data, the days presented were chosen according to minimum cloud cover. A clear and realistic evolution of \( EF \) can be seen over the year. The image of 27th March shows a fairly uniform distribution of high \( EF \) values, which indicates that evapotranspiration throughout Sicily is unlimited by the water supply. However, by the end of May large areas exhibit yellow and
orange colours with $EF$ values as low as 0.1. These values represent regions where evapotranspiration is strongly limited by the available water.

During the summer (June until August) only the mountainous regions in the north and northeast of Sicily remain with a sufficient water supply for evapotranspiration, while the extent of areas with little or almost no evapotranspiration reaches its maximum, covering up to 90% of Sicily.

Opposite to 1991, which for Sicily was an average year regarding precipitation and its distribution, the year of 1989 can be considered as a drought year. This event is clearly seen in fig. 2. In contrast to the situation in 1991 as seen in fig. 1, evapotranspiration is restricted by a limited water supply in large areas of Sicily in early spring 1989. While low values of the evaporative fraction during summer describe a normal situation in Sicily, the early decrease in 1989 indicates a large moisture deficit with severe consequences for agriculture and natural vegetation. Water stress becomes less severe only in November 1989 as shown by $EF$ values ranging from 0.6 to 0.9.
Fig. 2: Examples of the evaporative fraction on selected days in 1989 for Sicily.

Rates of daily evapotranspiration as estimated for 1990 by the described method are shown in fig. 3. Even if exact absolute values cannot be expected at this stage of the study, the regional and temporal pattern is presented realistically. In general, two types of minimum evapotranspiration are visible: one due to limited energy supply in early spring and autumn, the other due to a lack of moisture in summer. The latter only occurs in regions where water supply is severely restricted (western and central-southern Sicily), whereas the former is evenly distributed over Sicily, since it depends mainly on the uniformly incoming global radiation as the forcing function in the energy budget. Opposite to that, the mountainous region in the north-east (Nebrodi Mts.) and the Mt. Etna show maximum evapotranspiration in summer when energy supply peaks and water availability is not severely limited.
Fig. 3: Estimates of the daily rate of actual evapotranspiration on selected days in 1990 for Sicily. Data have been smoothed by a 5×5 pixel moving window filter.

For comparison, the daily rate of actual evapotranspiration has been computed according to the method of Priestley-Taylor. The results of this computation are shown in figure 4. A comparison of figures 3 and 4 shows that the order of magnitude of the ETa estimates is roughly the same. However, it is evident that the input of remote sensing data in the model decisively improves the spatial resolution. The remote sensing method, in addition, accounts much better for the influence of the surface, since parameters like canopy height or fractional vegetation cover have been included.

4 - CONCLUSION AND OUTLOOK

The results of this study show a realistic evolution of the evaporative fraction in Sicily during the summer season. Sufficiently detailed spatial resolution is obtained, even if
the original resolution of the AVHRR sensor of \(1.1 \times 1.1\) km has been smoothed by a moving-window filter.

The approach allows for the combination of heterogeneous data with different spatial features, such as point, raster and vector data, different temporal resolution, and different data qualities like measured data and thematic data. Their integrated analysis within a Geographic Information System results in the derivation of a physically meaningful parameter to describe the daily development of the moisture status of the land surface on the regional scale.

In a next step, the validation of the results by local measurements of actual evapotranspiration rates and the application to other climatic regions in order to test the transferability of the approach will be performed.

**Fig. 4:** Estimates of daily rates of actual evapotranspiration on selected days in 1990 for Sicily (according to Priestley-Taylor).
5 - REFERENCES


