Crop water stress detection from remote sensing using the SSEBI-2 algorithm: A case study in Morocco

Claire Jacobs[1], Gerbert J. Roerink[1] & Ali Hammani[2]

[1] ALTERRA, Wageningen, The Netherlands
[2] Institut Agronomique et Vétérinaire Hassan II, Rabat, Morocco

Corresponding author:
ir. Claire Jacobs
ALTERRA
PO Box 47, 6700 AA Wageningen
The Netherlands
Phone + 31 317 486579
Fax + 31 317 419000
Email claire.jacobs@wur.nl

Keywords: water stress, irrigation, evapotranspiration, monitoring, remote sensing, SSEBI-2

ABSTRACT

Accurate estimations of Actual Evapotranspiration (ETa) are a prerequisite for optimal irrigation scheduling. Quantification of ETa at critical growth stages can be used to avoid water stress in crops. For large irrigated areas, remote sensing techniques are important tools for ETa assessments. This paper describes the application of a simplified remote sensing algorithm (SSEBI-2) to derive daily estimates of actual evapotranspiration for the Tadla irrigation perimeter in Morocco.

1 INTRODUCTION

Accurate estimations of actual evapotranspiration (ET_a) give insight in water consumption, crop water stress, and production levels of crops. For planning and management of water resources, water managers and specifically irrigation engineers need to have temporal and spatial values of ET_a for various land uses.

The use of remote sensing is a powerful tool to estimate ET_a for large areas. A simplified method is provided by the SSEBI algorithm, developed to estimate surface fluxes from remote sensing images. SSEBI provides accurate ET_a values, and has the advantage that limited field data is required (Roerink *et al*., 2000). Previously, SSEBI was applied to separate remote sensing images, representing individual days within a growing season. A method for temporal integration of the images into a time series of daily ET_a maps was lacking. The current paper describes a new, easy to use procedure that applies such a temporal integration: the SSEBI-2 algorithm. SSEBI-2 derives daily actual and potential ET maps from remote sensing. The approach allows a quick temporal and spatial assessment of seasonal water consumption for large river basins or irrigation systems, with a minimum amount of input data required.

The SSEBI-2 algorithm is applied to the Tadla irrigation perimeter, one of the most productive irrigation areas in Morocco. Low resolution MODIS images of 2006 have been used in combination with meteorological data to derive actual and potential ET on a daily basis.

2 THE CASE STUDY AREA

The Tadla irrigated perimeter is located on the left and right banks of the Oum Er Rbia river, some 170 km south of Rabat, Morocco (figure 1). The main activity in the Tadla plain is agriculture, which uses more than 90% of the available water resources of the Oum Er Rbia catchment. Tadla irrigates more than 100,000 hectares and is one of the most important agricultural areas in Morocco regarding its contribution to the Gross National Product.

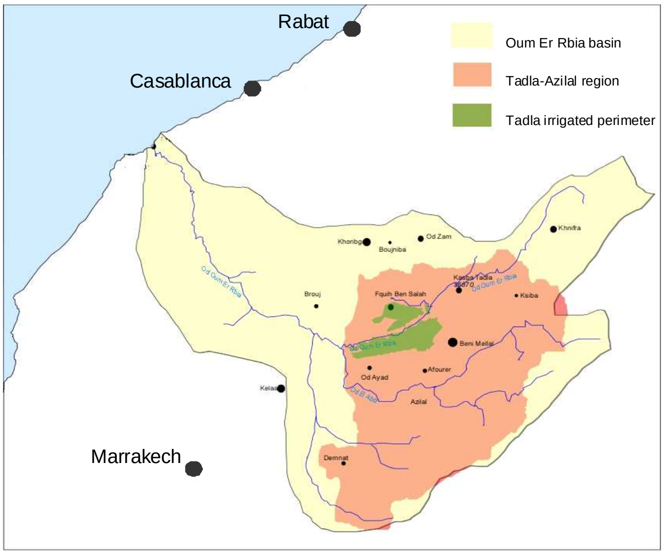

Fig. 1 Tadla irrigation perimeter, Morocco

The perimeter is composed of two sub perimeters which are hydraulically distinct. The Beni Amir sub-perimeter irrigates 30500 hectares on the right bank of the Oum Er Rbia river. The Beni Moussa sub perimeter irrigates 69500 hectares and is located on the left bank of the Oued Oum Er Rbia, and is divided into two management areas, Beni Moussa West and Beni Moussa East (figure 2).

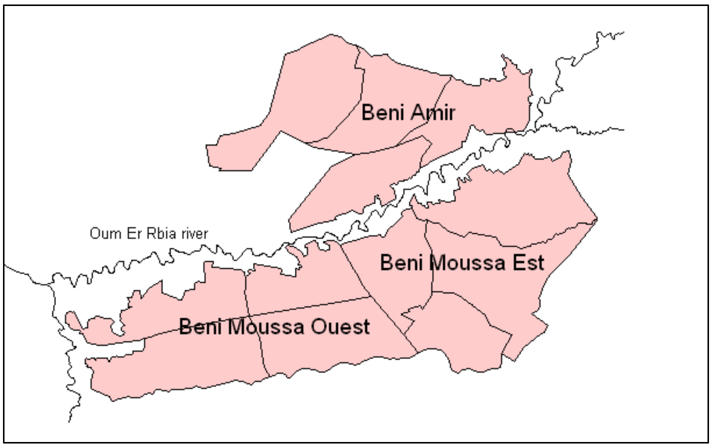

Fig. 2 Layout Tadla irrigation perimeter, with irrigation unit boundaries

The area has an arid to semi-arid climate, receiving about 300 mm of rain annually, most of which is received during the winter rainy season from November to March. The temperatures vary widely, being more temperate during the winter, but with peaks in summer reaching at times 45-50 degrees Celsius.

The main irrigated crops in the area are fodder crops (alfalfa, maize), wheat, olives, citrus, various vegetables and some spices. Livestock production (milk, meat) also plays an important role in Tadla.

The Tadla area is suffering from water stress, and the main problems in relation to agricultural water management are:

- High losses of irrigation water due to inefficient irrigation techniques. In the Tadla region, "robta" irrigation (furrow flooding) is used by farmers on 97% of the irrigated area. This technique results in a lower efficiency (50%) instead of the 70% efficiency envisaged for the original design (Essafi and Vidal, 2000). The government is currently encouraging the adoption of more efficient irrigation methods (e.g. drip irrigation and modernised basin irrigation) through subsidies in order to reduce water losses, and thus improve on-field irrigation efficiency.

- Groundwater over-exploitation. Farmers supplement their irrigation supplies with groundwater using private wells, leading to water table depletion in the area. Since the eighties, the dry climatic conditions of the last ten years combined with an increase of the amount of private wells used for irrigation have resulted in a fall of the water table level, reaching now in some places more than 20 meters depth.

3 MATERIAL AND METHOD

MODIS images

A total number of 22 cloudfree MODIS images of 2006 have been obtained from the LP DAAC (Land Processes Distributed Active Archive Centre) EOS Data Gateway. The Terra MODIS daily surface temperature and surface reflectance products have been used for the study, with resolutions of 1x1 km and 500x500 m respectively.

The SSEBI-2 algorithm

The Simplified Surface Energy Balance Index (SSEBI) algorithm (Roerink et al., 2000) has been developed to solve the surface energy balance with remote sensing techniques on a pixel-by-pixel basis. It is given by:

$$Rn = G0 + H + \lambda E \qquad (1)$$

where:

Rn	= net radiation	[W m-2]
G0	= soil heat flux	[W m-2]
H	= sensible heat flux	[W m-2]
λE	= latent heat flux	[W m-2]

SSEBI requires scanned spectral radiances under cloudfree conditions in the visible, near-infrared and thermal infrared range to determine its constitutive parameters: surface reflectance, surface temperature and vegetation index. With this input and some additional meteorological data, the energy budget at the surface can be determined.

First the net radiation term is calculated as the rest term of all incoming and outgoing shortwave and longwave radiation. Secondly the soil heat flux is derived with an empirical relationship of the vegetation and surface characteristics. The sensible and latent heat flux are not calculated as separate parameters, but as the evaporative fraction, Λ, which is determined as:

$$\Lambda = \lambda E / (Rn - G0) \qquad (2)$$

It has been observed that surface temperature and reflectance of areas with constant atmospheric forcing are correlated and that the relationships can be applied to determine the effective land surface properties (Bastiaanssen, 1995; Roerink et al., 2000). By assuming constant global radiation and air temperature, a formal explanation can be given to the observed surface reflectance and temperature.

The SSEBI model is based on the principle that two boundary conditions can be distinguished in the reflectance-temperature relationship; one for completely wet surface conditions and the other for completely dry surface conditions (figure 3). For completely wet surface conditions all available energy (Rn-G0) goes to the evapotranspiration process (λE) and nothing goes to the heating process of the surface (H). Therefore a constant temperature is expected with increasing reflectance. For completely dry areas all available energy goes to the heating process of the surface and nothing goes to the evapotranspiration process. A decreasing surface temperature with increasing reflectance values is expected, as increasing reflectance values result in decreasing solar radiation values and less energy becomes available for the heating process.

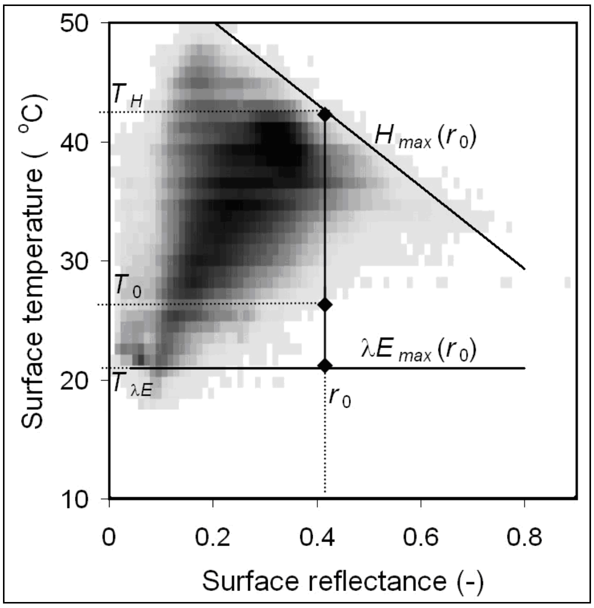

Fig. 3 Schematic representation of the relationship between surface reflectance and temperature together with the basic principles of SSEBI.

In the case where the two reflectance-to-temperature relationships for zero evapotranspiration and potential evapotranspiration can be determined, SSEBI then calculates the evaporative fraction as follows: For each pixel the surface reflectance, r0, and surface temperature, T0, are determined; where temperature is related to soil moisture and thus the fluxes. The evaporative fraction is calculated as a temperature ratio:

$$\Lambda = \frac{T_{dry} - T_0}{T_{dry} - T_{wet}} \quad \left(= \frac{\lambda E}{R_n - G_0} \textit{ in energy balance terms} \right) \qquad (3)$$

The S (of Simplified) in the SSEBI model stands for the case where the extreme temperatures Twet and Tdry can be determined from the image itself. This is only possible when the atmospheric conditions are constant over the image and sufficient wet and dry pixels are present throughout the reflectance spectrum. Note that a different wind speed will change the values of the extreme temperatures Twet and Tdry, but as long as the wet and dry pixels are present the SSEBI method will work.

So far, SSEBI is applied to separate remote sensing images, representing individual days within a season. A method for temporal integration of the images into a constant time series of daily ET maps was lacking. SSEBI-2 is a new, easy to use procedure that applies such a temporal integration. SSEBI-2 first uses remote sensing images to derive maps of the surface albedo, surface temperature, evaporative fraction and emissivity. The next step is a daily interpolation of these remote sensing maps, from which the daily evapotranspiration (ETa) is calculated. As the evaporative fraction behaves constant during the day, ETa is calculated as:

$$ET_a = \Lambda \, R_n \qquad (4)$$

where the daily net radiation (R_n) is calculated from remote sensing (albedo, temperature) and standard meteorological measurements (solar radiation).

This approach allows a quick temporal and spatial assessment of seasonal water consumption for large river basins or irrigation systems, with a minimum amount of input data required.

The SSEBI method was validated in earlier studies given accuracies within 10% (Roerink et al, 2000). The new SSEBI-2 algorithm is validated -so far- using flux tower measurements in the Netherlands (figure 4).

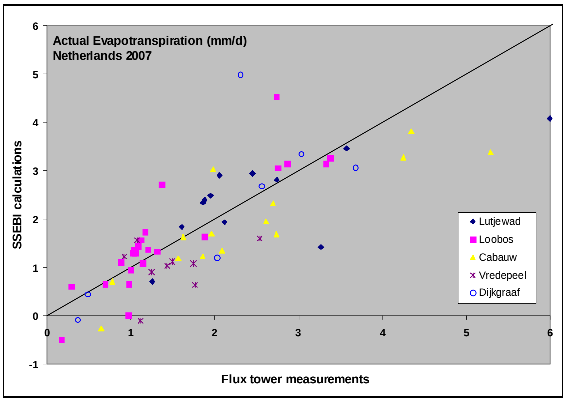

Fig. 4 SSEBI-2 validation based on a comparison to flux measurements

4 RESULTS

ETa and ETp maps

SSEBI-2 was applied for the 2006 hydrological year, based on 22 MODIS images. The resulting ETa and ETp maps for Tadla are shown as yearly totals in figure 5.

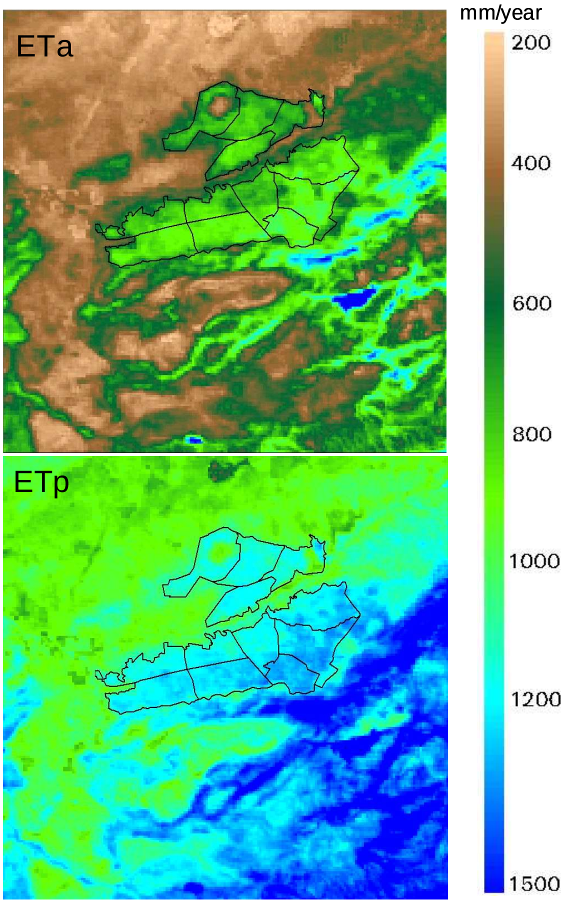

Figure 5 Spatial presentation of yearly ETa and ETp from SSEBI-2, Tadla 2006.

Spatial ETa-ETp comparison

The ratio of ETa over ETp can be used as an indicator to detect water short areas. It is generally recommended that this ratio does not drop below 0.70 throughout the year (Bos et al, 2005). Comparing the sub perimeters, it can be seen that the Beni Amir area is somewhat drier than the other sub perimeters.

Table 1 Yearly ratio of ETa over ETp for the Tadla irrigation units

	Irrigation unit (CGR) no	ETa/Etp ratio ratio
Beni Amir	1	0.59
	2	0.65
	3	0.60
	4	0.66
	average	0.62
Beni Moussa Est	5	0.72
	6	0.66
	7	0.69
	8	0.69
	average	0.69
Beni Moussa Ouest	9	0.66
	10	0.66
	11	0.70
	12	0.69
	average	0.68

Temporal ETa-ETp comparison

Figure 6 shows a temporal comparison of monthly ETa and ETp values for Beni Amir and Beni Moussa Est. The comparison reveals the occurrence of crop water stress in the Tadla perimeter during the summer months June, July and August. The Beni Amir sub perimeter shows more severe crop stress in summer than the Beni Moussa Est sub perimeter. This information can be used to improve irrigation strategies or to propose alternative cropping calendars.

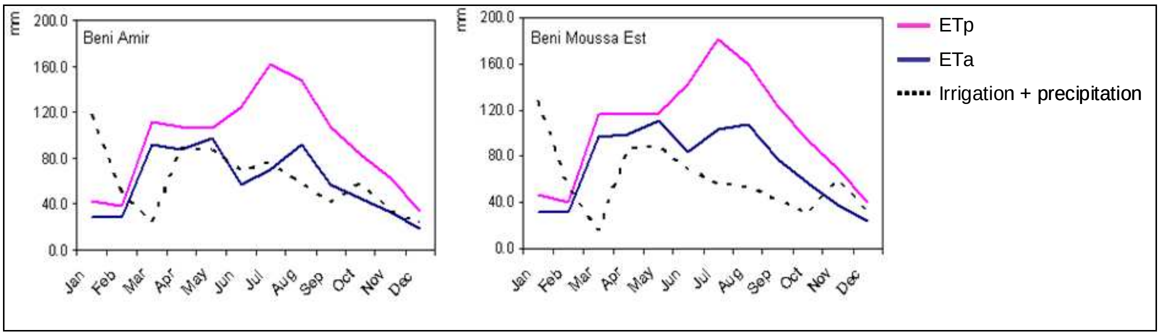

Figure 6 Comparison of ETa and ETp to available water (irrigation and precipitation)

Comparing water consumption to water availability, it is clear that more water is evapotranspired than is available from canal irrigation and precipitation. This makes it evident that another source of water is used or irrigation, namely groundwater. Especially in Beni Moussa Est the use of groundwater appears to be substantial. During the months of July and August almost twice the amount of water available from irrigation and precipitation was consumed.

Validation of ETa and ETp derived from SSEBI-2

The Potential Evapotranspiration (ETp) values derived from SSEBI-2 were compared to the ETp values resulting from the agro-hydrolocal model CRIWAR, showing good correlations (Kselik et al, 2008). At the moment a study is being carried out to further validate the Actual Evapotranspiration values for the Tadla area derived from SSEBI-2 with local surface flux measurements.

5 CONCLUSIONS

Promising results have been obtained so far, which demonstrate the usefulness of SSEBI-2 to derive constant time series of evapotranspiration for irrigation assessments, in a way that is understandable and reproducible by non remote sensing experts.

A comparison of actual and potential ET reveals the occurrence of crop water stress at specific moments in the irrigation season of 2006 in Tadla. This information can be used to adapt irrigation strategies or propose alternative cropping calendars. In addition, when the water consumption is compared to the water that is available from canal irrigation and precipitation, it is clear that another source of water is important for the area, being groundwater. Especially in the Beni Moussa Est sub perimeter the use of groundwater as an alternative source for irrigation is proven to be substantial.

The use of MODIS appears highly suitable for the calculation of ET time series, due to its (i) high temporal resolution, (ii) standard atmospheric correction and (iii) standard geometrical correction. An additional advantage is the easy access of MODIS images (free of charge through internet) which provides the opportunity for routine processing of images. This is promising for operational crop monitoring applications that require processing at a near-real-time basis.

6 ACKNOWLEDGEMENTS

The research described in this paper is conducted in the framework of the AquaStress project (2005-2009), an EU funded integrated project (http://www.aquastress.net/). The authors would also like to thank the director of the Irrigation Department ORMVAT and his staff, especially Mr. Aziz Bellouti, Mrs. Fatima Z. Cherkaoui and M. Saaf, for the data provided and the personal assistance.

REFERENCES

AQUASTRESS, 2007. Modeling water saving options in agriculture. Aquastress project deliverable D3.4-3. Available from http://environ.chemeng.ntua.gr/aquastress.

Bastiaanssen, W.G.M., 1995. Regionalization of surface flux densities and moisture indicators in composite terrain. A remote sensing approach under clear skies in Mediterranean climates. Agricultural University of Wageningen. PhD Thesis. 273 pp.

Bos, M.G., M.A. Burton and D.J. Molden, 2005. Irrigation and Drainage Performance Assessment: Practical Guidelines. CABI Publishing UK, 158 pp.

Essafi, Boubker and Alain Vidal, 2000. Morocco success story: Improvement of on-farm irrigation by laser levelling and basin irrigation in Tadla. GRID Issue 16, August 2000. Available from ftp://ftp.fao.org/agl/iptrid/grid16_e.pdf.

Kselik, R. A. L., M. G. Bos, A. Hammani, A. Bellouti, 2008. Assessment of sustainable agriculture in the irrigated perimeter of Tadla, Morocco using the CRIWAR strategy module. Paper scheduled for oral presentation at the 13th IWRA World Water Congress, Montpellier, France, 1-4 September 2008.

Roerink, G.J., Z. Su and M. Menenti, 2000. S-SEBI: A simple remote sensing algorithm to estimate the surface energy balance, Phys. Chem. Earth, Vol. 25, No. 2, pp 147-157.