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ESTIMATING ET USING SCINTILLOMETERS AND SATELLITES IN AN IRRIGATED VINEYARD IN THE COSTA DE HERMOSILLO, SONORA, MEXICO

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Abstract Visible data from geostationary satellites may be combined with vegetation index data and Land Surface Temperature data from MODIS are combined to provide estimates of incoming solar radiation and actual evapotranspiration at 1 km resolution over large areas. The methodology is evaluated using data from a optical scintillometer at an irrigated vineyard site in northwest Mexico.

Key words evapotranspiration, geostationary satellite, large aperture scintillometer

METHODOLOGY

Estimation of evapotranspiration (ET) is of great importance in hydrological studies and for determining crop water requirements in irrigated agriculture. The *reference ET* (ET_{ref}) refers to crops with complete ground cover that are well supplied with water. Several formulations are available. One of the simplest is the one developed by Makkink (1957) (see also de Bruin, 1987) in which reference ET is mainly determined by incoming solar radiation (R_s)

$$L_v\, ET_{ref} = C_M \left[\frac{s}{s+\gamma}\right] R_s$$

where L_v is the latent heat of vaporization (J kg^{-1}), s is the slope of the saturated vapour pressure (Pa K^{-1}) at air temperature (T_a), γ is the psychometric constant (Pa K^{-1}) and C_M (usually 0.65) is an empirical constant. The Makkink formulation has been used in many previous studies at sites where local measurements of R_s are available. The use of earth observation satellite data enables us to apply the methodology over large areas where measurements of R_s may be sparse or absent. In previous studies, simple estimates for clear sky solar radiation were combined with estimates of cloud cover during daylight hours obtained using visible image data from geostationary satellites (Stewart et al., 1998; Garatuza-Payan et al., 2001). The methodology has been has been improved over the years and was tested recently using METEOSAT data for sites in Africa (Schuttenmeyer et al., 2007) and the basic steps are presented here. Currently, visible data for the GOES satellites have a spatial resolution of 1km and are usually available every 15 minutes. A cloud index CI is defined for each pixel using the visible count values (c)

$$CI = \frac{c - c_{min}}{c_{max} - c_{min}}$$

where c_{min} refers to clear sky conditions and c_{max} refers to completely overcast conditions. It is important to take into account that:

a) c vary diurnally with solar elevation and must be normalized to eliminate this effect
b) c_{min} varies in time and space as land cover changes and must be updated regularly
c) c_{max} (after normalization) can be regarded as constant for all images

So R_s can be obtained from CI and clear sky solar radiation $R_{s,clear}$ (Perez, 2002)

$$R_s = [0.02 + 0.98(1 - CI)]R_{s,clear}$$

where the clear sky solar radiation is obtained combining the calculated exo-atmospheric solar radiation for the location and date with parameters that depend on atmospheric turbidity and the elevation of the site. This procedure can be used to calculate reference ET for anywhere in the world and requires only visible geostationary satellite data and air temperature. In order to obtain *actual* ET we need to determine the fractional vegetation cover f_c, which can be estimated using satellite vegetation indices. At the moment, the most convenient choice is the 16 day composite product with 500m resolution (MOD13A) of the Enhanced Vegetation Index (EVI) from the MODIS sensor on the TIERRA satellite, where

$$f_c = \frac{EVI - EVI_{min}}{EVI_{max} - EVI_{min}} \quad \text{and} \quad ET = f_c \, ET_{ref}$$

EVI_{min} corresponds to bare soil and EVI_{max} corresponds to full vegetation cover and their values are estimated to be 0.08 and 0.65 respectively (Schuttenmeyer et al., 2007). The above should give satisfactory results for crops and short vegetation but may not work for forests, where ET may exceed the reference ET as defined above.

The method was applied for a 72 hectare field vineyard in the Costa de Hermosillo irrigation district on the coastal plain west of Hermosillo, Sonora en northwest Mexico. There is an automatic weather station at the site, providing air pressure, temperature and humidity, wind speed and direction, solar radiation. A Scintec BLS-450 Boundary Layer Scintillometer was operated at the site between July 2009 and August 2010. The scintillometer consists of a Transmitter and Receiver for infrared radiation (880 nm) over distances up to 5 km. The Signal Processing Unit at the receiver produces information about atmospheric turbulence, including 10 minute averages for the structure parameter for the refractive index of air (C_n^2) which can be related to the sensible heat flux (H) using similarity theory and local measurements of wind speed and air temperature (de Bruin et al., 2003). Estimates for actual ET are then obtained using the surface energy balance

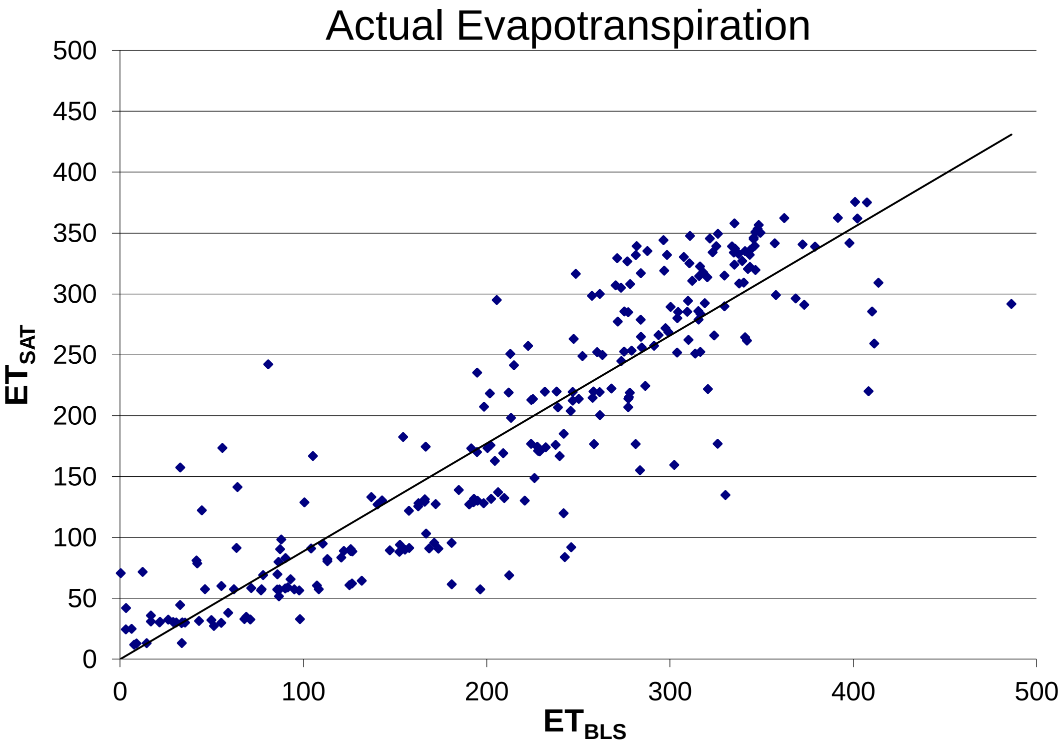
$$ET = \frac{R_n - G - H}{L_v}$$

where R_n is the net radiation at the surface and G is the ground heat flux. In this study, net radiation measured using an NRLite net radiometer (Kipp&Zonen, Netherlands) was used. G was obtained as a fraction of net radiation $G = A * R_n$ where the factor A was obtained as a function of surface temperature (Santanello and Friedl, 2003) using the MODIS Land Surface Temperature data (8 day composites from the AQUA satellite MYD11A2). The advantage in using scintillometers for validating satellite estimates for ET is that their spatial scales are similar (1 km in this example) but the disadvantage is that the measurement is indirect and so other components of energy balance are also required. This may slightly reduce the reliability of the ET estimates obtained in this way, particularly in light of the well known difficulties with energy balance closure at micrometeorological measurement sites.

A comparison between the ET estimated from the Boundary Layer Scintillometer (BLS) measurements (plus the estimates for net radiation and sol heat flux) and the ET estimated from the satellite data shows that the satellite estimate on average is 11% larger than the ground measurements

$$ET_{SAT} = 0.89\ ET_{BLS}$$

with considerable scatter ($R^2 = 0.81$) as can be seen in the following figure.



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