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A simple method to estimate evapotranspiration from a combination of vegetation index and temperature

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Abstract

Satellite remote sensing is a promising technique for estimating global or regional evapotranspiration (ET). A simple but relatively accurate method is essential when estimating ET using remote sensing data. Such a method is investigated by taking advantage of satellite measurements and the extensive ground-based measurements available at the eight enhanced surface facility sites located throughout the Southern Great Plains (SGP) area of the United States from January 2002 to May 2005. Data analysis shows that correlation coefficients between ET and surface net radiation are the highest, followed by temperatures (air temperature or land surface temperature, LST), and vegetation indices (enhanced vegetation index (EVI) or normalized difference vegetation index (NDVI)). A simple regression equation is proposed to estimate ET using surface net radiation, air or land surface temperatures and vegetation indices. ET can be estimated using daytime-averaged air temperature and EVI with a root mean square error (RMSE) of 29.2 W m^{-2}, and a correlation coefficient of 0.91 across the sites and the years. ET can also be estimated with comparable accuracy using NDVI and LST. More importantly, the daytime-averaged ET can also be estimated using only one measurement per day of temperatures (the daytime maximum air temperature or LST) with comparable accuracy. The regression equation can predict ET under a wide range of soil moisture content.

Data and Study region

Given that satellite can only provide limited information pertaining to ET, a major task in the remote sensing of ET is to identify key factors influencing the processes involved and its parameterization from satellite data. To this end, extensive measurements of surface fluxes, meteorological and soil variables, as well as coincident satellite data are required. This requirement is met thanks to the continuous observations made over the past decade at the Southern Great Plains site under the aegis of the Atmospheric Radiation Measurement (ARM) Program.

Eleven Energy Balance Bowen Ration and Solar and Infrared Radiation stations systems were deployed to measure the ET, radiation components and the related meteorological parameters (e.g. the air temperature), as well as the soil moisture. The MODIS land surface products related to ET, including LST, vegetation indices, and land cover type are used in this study. The two data sets cover a period ranging from January 2002 to May 2005. To keep the scale consistent, the LST used here is calculated from ground-based measurements of the upwelling longwave radiation.

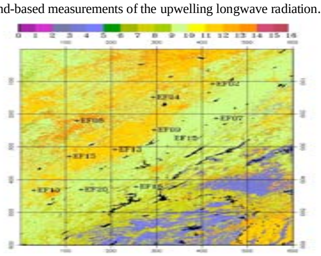


Figure 1. The land covers of the study region on the South Great Plain. The pixel resolution is about 1 km and the whole region is about 500×500 km². International Geosphere-Biosphere Programme (IGBP) land cover types were shown in the figure. The eight enhanced facility sites are shown.

Data analysis

Table 1. The correlation coefficients between daily evapotranspiration (ET) and the daytime-averaged air temperature ($R_{ET,Tad}$), the daytime maximum air temperature ($R_{ET,Tam}$), daytime-av ace temperature ($R_{ET,Tsm}$), the downwelling shortwave radiation ($R_{ET,Rsd}$), the net shortwave radiation ($R_{ET,Rsn}$), the surface net radiation ($R_{ET,Rn}$), the Enhanced Vegetation Index ($R_{ET,EVI}$), soil moisture ($R_{ET,SM}$). Data used here were collected during January 2002 to May 2005. The daily vegetation indices are directly obtained from MODIS 16-day vegetation indices products. are surface net radiation, temperatures and vegetation indices.

Site	$R_{et,Tad}$	$R_{ET,Tam}$	$R_{ET,Tsd}$	$R_{ET,Tsm}$	$R_{ET,Rsd}$	$R_{ET,Rsn}$	$R_{ET,Rn}$	$R_{ET,EVI}$	$R_{ET,NDVI}$	$R_{ET,SM}$
EF07	0.667	0.659	0.676	0.664	0.704	0.747	0.809	0.644	0.624	-0.194
EF08	0.625	0.604	0.622	0.614	0.676	0.710	0.762	0.515	0.409	-0.059
EF09	0.800	0.783	0.832	0.801	0.720	0.749	0.826	0.720	0.664	-0.381
EF12	0.781	0.761	0.769	0.7461	0.683	0.679	0.763	0.800	0.793	-0.5205
EF15	0.708	0.760	0.792	0.778	0.714	0.731	0.788	0.614	0.531	---------
EF18	0.745	0.749	0.779	0.782	0.789	0.813	0.864	0.669	0.666	-0.416
EF19	0.687	0.669	0.674	0.663	0.664	0.662	0.736	0.719	0.702	-0.386
EF20	0.682	0.670	0.688	0.682	0.702	0.711	0.773	0.712	0.667	-0.190
Total*	0.713	0.700	0.710	0.707	0.695	0.707	0.777	0.680	0.636	-0.101

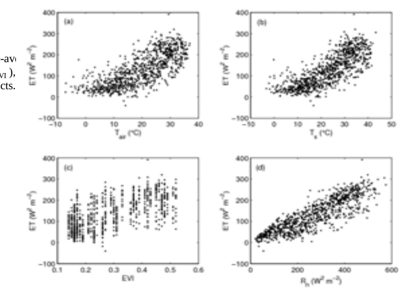
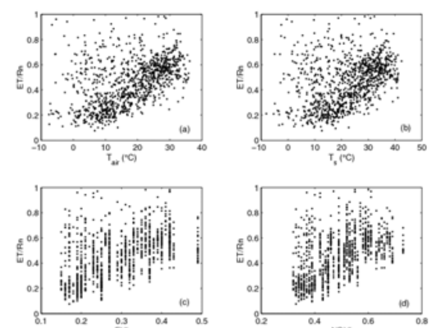


Figure 2 Scatterplots of the ET as a function of (a) the daytime-averaged air temperature (Tair), (b) daytime-averaged land surface temperature (Ts), (c) enhanced vegetation index (EVI) and (d) surface net radiation (Rn) collected during January 2002 to May 2005 at site EF18. Table 1 shows that surface net radiation has the highest correlation coefficients with ET, and this Figure shows that ET increases nearly linearly with surface net radiation. Therefore it is seam reasonable to select surface net radiation as the first factor to parameterize ET

Parameterization of ET



Surface net radiation is selected to normalize ET because their linearly relationship. Figure 3 shows the scatterplots of the normalized Etas a function of daytime-averaged air temperature, daytime-avereaged LST ,the EVI and NDVI.colloected at EF09. The normalized ET increases nearly linearly with temperatures and vegetation indices. Therefore, ET can be parameterized as:

$$ET = R_n \cdot (a_0 + a_1 \cdot VI + a_2 \cdot T) \qquad (1)$$

Where: VI can be EVI or NDVI, T can be daytime-averaged (or daytime maximum) air temperature (or LST). The data collected at all the sites throughout the years of 2002-2005 were used to obtain the three parameters a0, a1, and a2. Then equation (1) are used to predict the ET at the sites. Table 2 summarizes the statistical parameters of the predict and measured ET at each sites.

Site	EF07	EF08	EF09	EF12	EF15	EF18	EF19	EF20
Correlation coefficient	0.88	0.88	0.95	0.96	0.91	0.94	0.90	0.88
Bias (relative)	-16.08 (-12.4%)	4.50 (4.5%)	-0.66 (-0.5%)	1.05 (0.8%)	2.46 (2.3%)	-5.00 (-3.9%)	4.08 (3.4%)	-5.48 (-4.6%)
RMSE (relative)	33.08 (25.6%)	25.57 (25.3%)	23.98 (19.0%)	22.54 (17.8%)	29.80 (27.4%)	25.82 (20.1%)	34.18 (28.5%)	30.47 (25.6%)

Results

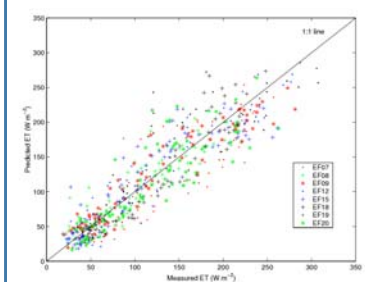


Figure 4. Scatterplots of the predicted ET (using Equation (1) with EVI and daytime-averaged air temperature) as a function of the measured ET for the 8 sites.

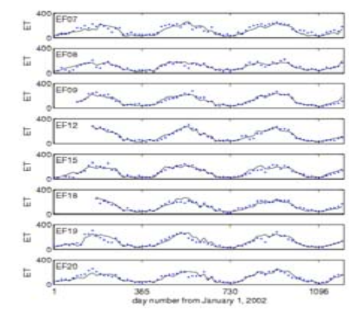


Figure 5. Time series of the measured (blue dot) and predicted ET (black line) using equation (1) with EVI and daytime-averaged air temperature at the 8 sites. Figure 5 shows that equation (1) can accurately predict the ET at all sites for all years.

Conclusion

A simple but relatively accurate method is essential to estimate ET using remote sensing data. The suitability of the method also depends on the practicability of the required input data. In the present study, this was done by taking advantage of satellite measurements and the extensive ground-based measurements available at 8 enhanced surface facility sites located throughout the SGP from January 2002 to May 2005. Data analysis shows that the dominant factors driving the seasonal variation of ET are surface net radiation, temperatures and vegetation indices. Correlation coefficients between surface net radiation and ET are the highest, followed by temperatures and vegetation indices. A simple regression equation is obtained to estimate ET using surface net radiation, air or land surface temperatures and vegetation indices. ET predicted from the equation using a combination of surface net radiation, daytime-averaged air temperature and enhanced vegetation index (EVI) has an average RMSE of 29.2 Wm-2, and the correlation coefficients between measured and predicted ET vary from 0.88 to 0.96 for all the sites. ET can also be estimated from NDVI and LST with comparable accuracy. More importantly, daytime-averaged ET can be estimated using only one measurement of temperatures (daytime maximum air temperature or LST) per day with comparable accuracy.