ETLook: a novel continental evapotranspiration algorithm

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Abstract ETLook is a newly developed algorithm to compute the evapotranspiration of large areas using an array of remote sensing data: moderate resolution visible and near infrared data from the MODIS sensor and low resolution estimates of soil moisture from the AMSRE sensor. The Penman-Monteith equation is solved separately for vegetation and soil, enabling the division of evapotranspiration into transpiration and evaporation. The ETLook algorithm has been applied in Australia, China and the Indus basin.

Key words evapotranspiration; remote sensing; microwave; river basin

INTRODUCTION

Numerous algorithms based on actual evapotranspiration (ET_{act}) mapping using visible, near infrared and thermal data exist. ET mapping of river basins and continents at a moderate resolution (1 km) is important to detect the spatial heterogeneity of ET and it's response to weather events (rainfall or drought). Surface energy balance techniques like RSEB (Kalma and Jupp, 1990), SEBI (Menenti and Choudhury, 1993), SEBAL (Bastiaanssen et al., 1998), SEBS (Su, 2002), and METRIC (Allen et al., 2007) estimate ET_{act} as a latent heat flux (residual term in surface energy balance). The major drawback of these techniques is the need for thermal infrared data to assess surface temperature. Thermal infrared data cannot provide reliable estimates on surface temperature under cloudy or hazy conditions, rendering the algorithms less useful in temperate climates. The visible and near infrared data are used to provide information on vegetation conditions and surface albedo for absorbed solar energy. These parameters are less critical to cloudy conditions, as their variation is not as large and irregular as the surface temperature. Verhoef (1996) showed that missing data of NDVI and surface albedo can be estimated using observations from other data.

ETLook is specifically developed to map ET_{act} for large areas on a daily to weekly basis for longer time periods with a resolution of 1 km. Typical outputs consist of yearly ET_{act} with an interval of one week associated with biomass growth with an interval of two weeks for large watersheds. Sufficient detail within the watersheds can be used to monitor local differences in water management.

ETLook is a newly developed algorithm to compute ET_{act} of large areas using soil moisture estimates from the passive microwave sensor AMSRE. The advantage of using passive microwave sensor data is that its signal is not affected by clouds. A drawback of the passive microwave sensor data is the low resolution of the data. Downscaling in ETLook is achieved by linking the soil moisture estimates from the AMSRE sensor to a global soil map with known hydrological properties per soil type. The result is a topsoil estimate on the relative moisture content for smaller discrete areas.

ETLook uses moderate resolution visible and near infrared data from the MODIS sensor for determining surface albedo and vegetation cover. Routine meteorological measurements (wind speed, air temperature and relative humidity) at a number of stations within the area are used to infer the current meteorological conditions. Because the main driving force of the algorithm is soil moisture derived from passive microwave sensors, the algorithm is applicable under all weather

conditions. Therefore the algorithm can be used operationally, making it useful for real time hydrological modelling and operational land surface models.

THEORY

The Penman-Monteith equation is solved separately for vegetation and soil in order to split the evapotranspiration into transpiration (T) and evaporation (E):

$$T = \frac{\Delta(Q^*_{canopy}) + \rho c_p \frac{\Delta_e}{r_{a,canopy}}}{\Delta + \gamma(1 + \frac{r_{canopy}}{r_{a,canopy}})} \qquad E = \frac{\Delta(Q^*_{soil} - G) + \rho c_p \frac{\Delta_e}{r_{a,soil}}}{\Delta + \gamma(1 + \frac{r_{soil}}{r_{a,soil}})}$$

where Δ is the slope of the saturation vapour pressure curve [mbar K^{-1}], Δ_e vapour pressure deficit [mbar], ρ is the air density [kg m^{-3}], c_p is the specific heat of dry air [J kg^{-1} K^{-1}], γ is the psychrometric constant [mbar K^{-1}], G is the soil heat flux [Wm^{-2}], Q^*_{canopy} and Q^*_{soil} [Wm^{-2}] are the net radiation for canopy and soil respectively, r_{canopy} and r_{soil} [sm^{-1}] are the canopy and soil resistance respectively, $r_{a,canopy}$ and $r_{a,soil}$ [sm^{-1}] are the aerodynamic canopy and soil resistance respectively.

The soil resistance r_{soil} is a function of the soil moisture content in the topsoil and is therefore a strong reflection of the microwave measurements. The canopy resistance r_{canopy} is a function of the leaf are index and four dimensionless stress functions. Three of the stress functions are related to meteorological conditions: temperature stress, vapour pressure stress and radiation stress. The fourth stress factor is related to the soil moisture content in the subsoil.

The aerodynamic canopy and soil resistance, $r_{a,canopy}$ and $r_{a,soil}$ are a function of wind speed and surface roughness. An iteration procedure is needed to correct for unstable conditions. The Monin-Obukhov theory (1954) is used to parameterize the effects of shear stress and buoyancy.

APPLICATIONS AND VALIDATION

The algorithm has been tested for different climatological conditions and locations. It has been tested for continental Australia for three years (2002-04 and 2005-06), China (2009) and the Indus Basin (2007). Some first results are presented hereafter.

Australia

ETLook has been run for three years (2002-04 and 2005-06) for the whole of Australia. The E and T were calculated on a weekly basis. Figure 1 shows the results for a cropland pixel south of Griffith, NSW Australia, for the period of July 2004 - June 2005. The growing season is from August 2004 to November 2004 and in the remainder of the period no crops are grown. In the beginning of this period transpiration is dominant while in the remainder of the period ET is equally partitioned between E and T. After intensive rainfall events an increase in E is observed. A dry-down period in spring 2005 can also be detected by a monotonic decrease in E.

Figure 2 shows the agreement between the mean yearly ET measured by ETLook for the year 2005 and the mean yearly ET reported by the National Water Commission of Australia (Australian Water Resources 2005 - A baseline assessment of water resources for the National Water Initiative, level 2, National Water Commission (www.water.gov.au) for the same period for a large number of priority water balance areas in Australia. There is generally a good agreement between both data sources. The average error, taking into account the various sizes of area of each waterboard, is 26 mm/year.
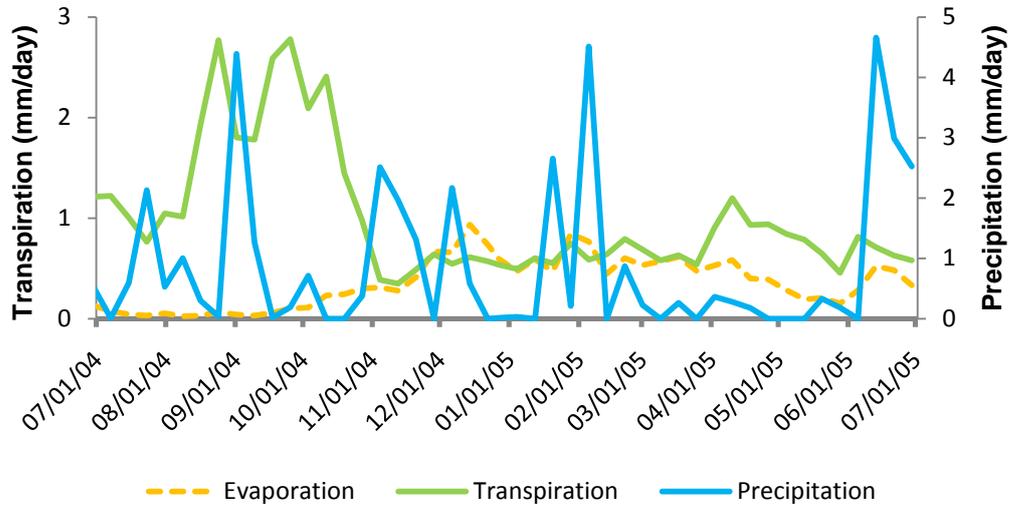
Fig. 1 Time series of ETLook evaporation, transpiration and measured precipitation for a cropland near Griffith NSW, Australia.
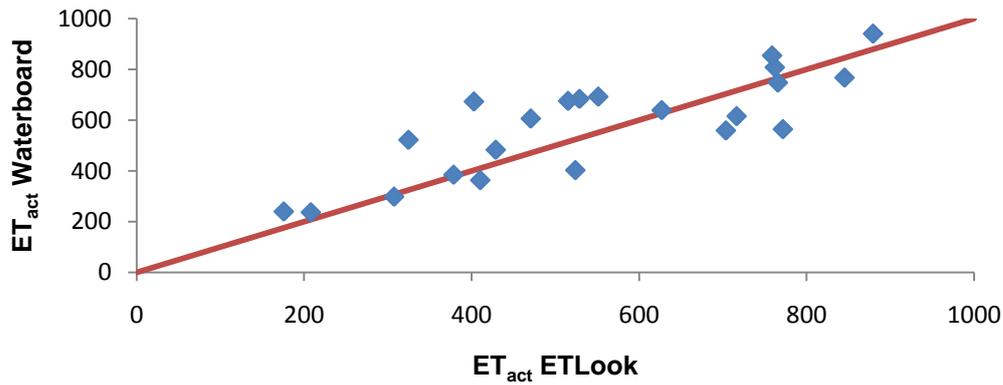

Fig. 2. Comparison of mean actual evapotranspiration as reported by Australian Water Resources Study 2005 and ETLook for 22 priority water balance areas
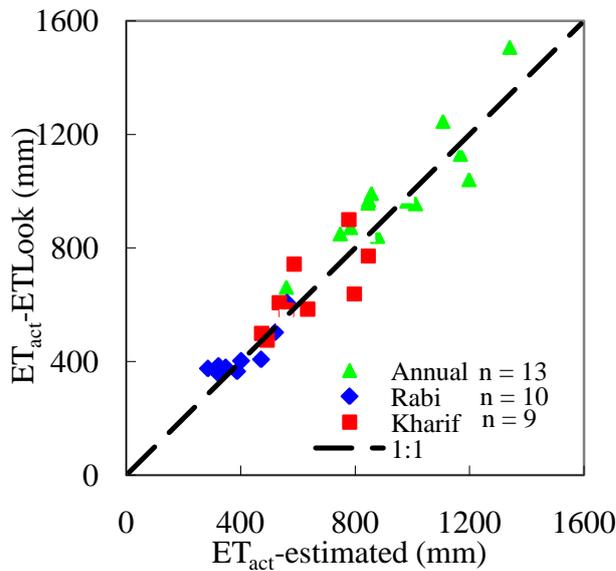

Fig. 3. Comparison of evapotranspiration estimated by previous studies and ETLook for different seasons measured at different locations in the Indus Basin.

Indus Basin

The Indus basin is located between 25° to 37° N and 66° to 82° E. The basin exhibits complex hydrological processes due to variability in topography, rainfall, and land use. The elevation ranges from 0–8000 m. The mean annual rainfall varies from approximately 200 to 1500 mm.Figure 4 shows the comparison of actual ET estimated by ETLook and actual ET compiled from different data sources for the annual ET and for the two main growing seasons in the Indus basin: Rabi and Kharif. Also here there is good agreement between both data sources in spite of climatic differences between the considered years. The correlation coefficient (R^2) for annual, rabi and kharif season is 0.76, 0.60 and 0.47, respectively with the regression line fitted through the origin.

China

ETLook was used to estimate 20-day actual ET in 2009. The uncalibrated results were compared to Eddy correlation measurements of actual evapotranspiration at Haibei Flux Research site.
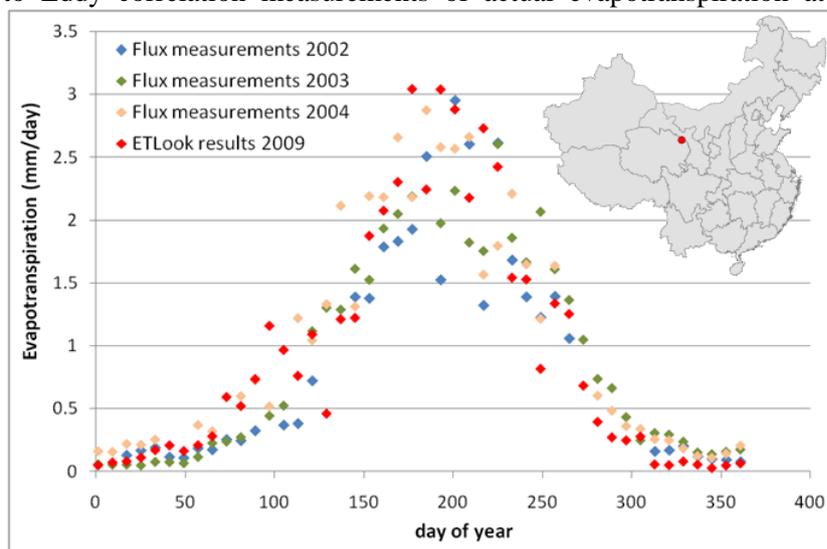

Fig. 4. Comparison of 10-day actual evapotranspiration estimated by an Eddy correlation station in Haibei (data courtesy of Fluxnet) and uncalibrated ETLook for different years.

The magnitude of the evapotranspiration during the year 2009 as predicted by ETLook corresponds well with the measurement for previous years.

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