Monitoring Global Land Surface Drought Based on a Hybrid Evapotranspiration Model

Yunjun Yaoa, Shunlin Liang, Qiming Qin, Kaicun Wang, Shaohua Zhao

International Journal of Applied Earth Observation and Geoinformation

Objectives

I. Introduce a linear combination of the most important parameters (air temperature, net radiation, etc.) controlling the actual ET to simplify the evaporative fraction (EF), and to then develop a new hybrid ET model. Also, to validate the hybrid ET model using Atmosphere Radiation Measurement (ARM), FLUXNET and data from Chinese experiments

II. Use the evaporative drought index (EDI) to infer global land surface dryness conditions from 1984 to 2002 using the hybrid ET model with GEWEX, AVHRR-GIMMS-NDVI, and NCEP-2 products. The EDI patterns are compared with Palmer Drought Severity Index (PDSI) products to determine the validity of the method's drought assessment on a global scale.

Data

- Global monthly surface SW ↑↓ and LW ↑↓, derived from the Global Energy and Water Cycle Experiment (GEWEX), 1 deg resolution
- Monthly NDVI – obtained from NOAA/AVHRR observations
- Monthly mean air temperature and T_{max} and T_{min} – obtained from NCEP-2 reanalysis data

Data - Validation

- NDVI (modis) – 16 day composites interpolated to daily values
- Flux tower data – 12 ARM towers, 7 Fluxnet towers, 3 towers in China
- Palmer's drought index (1984 – 2000), 2.5 deg resolution

ET model

- Assume – landscape is a mixture of bare soil and vegetation elements
- Proportion of vegetation – obtained from vegetation fraction
- Total ET in a pixel = combination of ET from soil and ET from vegetation

$$ET = (1 - f_{veg})ET_{soil} + f_{veg}ET_{veg}$$

$$f_{veg} = \frac{NDVI - NDVI_{\min}}{NDVI_{\max} - NDVI_{\min}},$$

$NDVI_{min} = 0.05$
$NDVI_{max} = 0.95$

ET model

- Introduce evaporation fraction:

$$EF = \frac{ET}{Q} = \frac{ET}{R_n - G} = \frac{ET}{(1 - G_0)R_n}$$

- Can use EF to describe both ET_{soil} and ET_{veg}

$$ET_{soil} = Q_{soil}EF_{soil} = a_0 Q * EF_{soil} = a_0(1 - G_0)R_n EF_{soil}$$

$$ET_{veg} = Q_{veg}EF_{veg} = a_1 Q * EF_{veg} = a_1(1 - G_0)R_n EF_{veg}$$

ET model

- Evaporation fraction for soil, by Nishida et al., 2003:

$$EF_{soil} = \frac{Q_{soil0}}{Q_{soil}} \frac{T_{soil,\max} - T_{soil}}{T_{soil,\max} - T_a} = \frac{Q_{soil0}}{Q_{soil}} \left(1 + \frac{T_a - T_{soil}}{T_{soil,\max} - T_a} \right)$$

- Assume that Q_{soil0}/Q_{soil} and (T_a −T_{soil})are all invariant constants. To calculate EF_{soil} approximately using air temperature, can replace ($T_{soil,max}$ −T_a)with the diurnal air temperature range (T_{max} −T_{min}) to simplify the EF_{soil} by adding the empirical coefficients.

$$EF_{soil} = b_0 + \frac{b_1}{T_{\max} - T_{\min}}$$

Tmax, Tmin = daily maximum and minimum air temperatures
b0, b1 = empirical coefficients

ET model

- Evaporation fraction for vegetation by Nishida et al., 2003:

$$EF_{veg} = \frac{\alpha\Delta}{\Delta + \gamma(1 + r_c/2r_a)}$$

*

$$\frac{1}{r_c} = \frac{f_1(T_a)f_2(VPD)f_3(PAR)f_4(\Psi)f_5(CO_2)}{r_{c\_min}} + \frac{1}{r_{cuticle}}$$

α = 1.26
Δ = de_{sat}/dT
VPD = vappr pressure deficit
Phi = soil water potential
r_a = aerodynamic resistance
r_c = canopy resistance

- Simplifications: develop a linear combination of WS, PAR, T_{air}, VPD, atmospheric CO_2 concentration and root soil moisture to approximately simulate (*).
  - WS, VPD and CO_2 not available from satellite – omitted
  - Rn replaces PAR due to their approximately linear relationship
  - $1/(T_{max} – T_{min})$ selected to denote soil moisture near the soil

ET model

- $EF_{veg} = b_2 + b_3 + b_4R_n + b_5/(T_{max} – T_{min})$

- Combination of all previous equations yields:

$$ET = \left(1 - \frac{NDVI - 0.05}{0.95 - 0.05}\right) a_0(1 - G_0)R_n \left(b_0 + \frac{b_1}{T_{max} - T_{min}}\right)$$

**

$$+ \frac{NDVI - 0.05}{0.95 - 0.05} a_1(1 - G_0)R_n \left(b_2 + b_3T_a + b_4R_n + \frac{b_5}{T_{max} - T_{min}}\right)$$

- Further simplification by integrating a series of empirical coefficients in order to propose a hybrid regression equation based on (**):

$$ET = R_n^2(c_1NDVI - c_2) + R_n\left(c_3 + c_4T_a + \frac{c_5}{T_{max} - T_{min}}\right) + R_n\left(c_6 + c_7T_a + \frac{c_8}{T_{max} - T_{min}}\right) NDVI$$

Estimation of potential evapotranspiration (PET)

- PET represents the ideal evaporation rate for capturing the response to forcing variables if soil moisture is unlimited.
- Adopted the Hargreaves method to estimate PET - this method is simple for practical use because it requires only two easily accessible parameters: temperature and solar energy

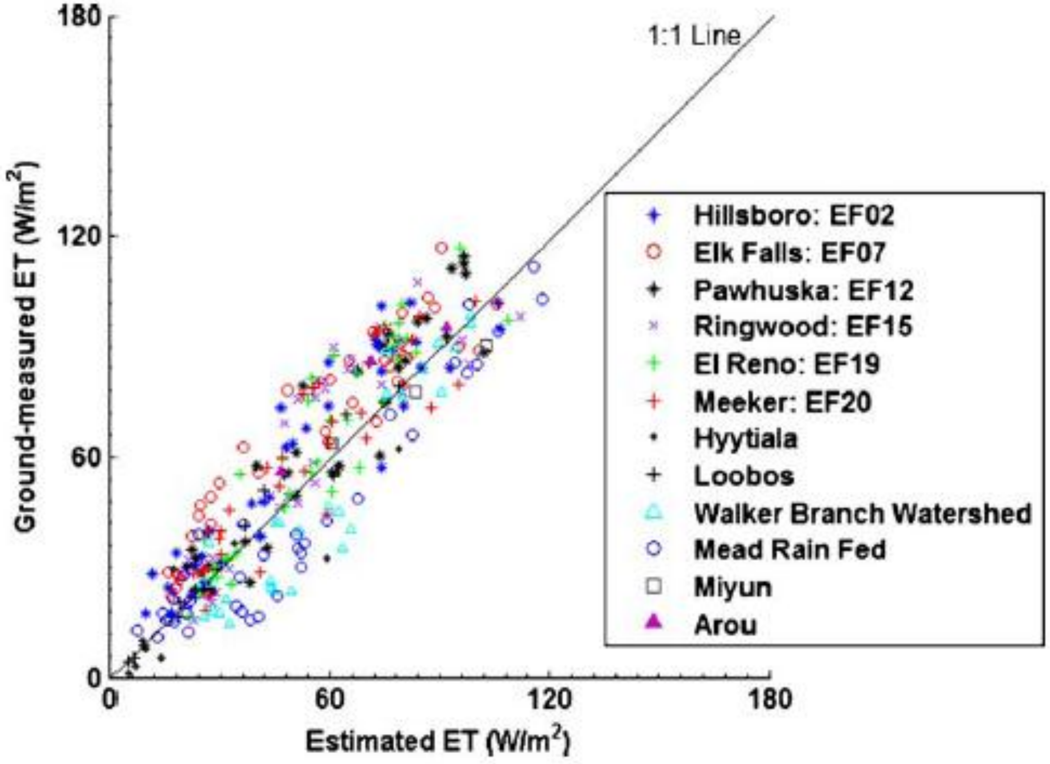
$$PET = 0.0023 R_a (T_{mean} + 17.8)\sqrt{T_{\max} - T_{\min}}$$

Ra = solar radiation at TOA

Model Validation

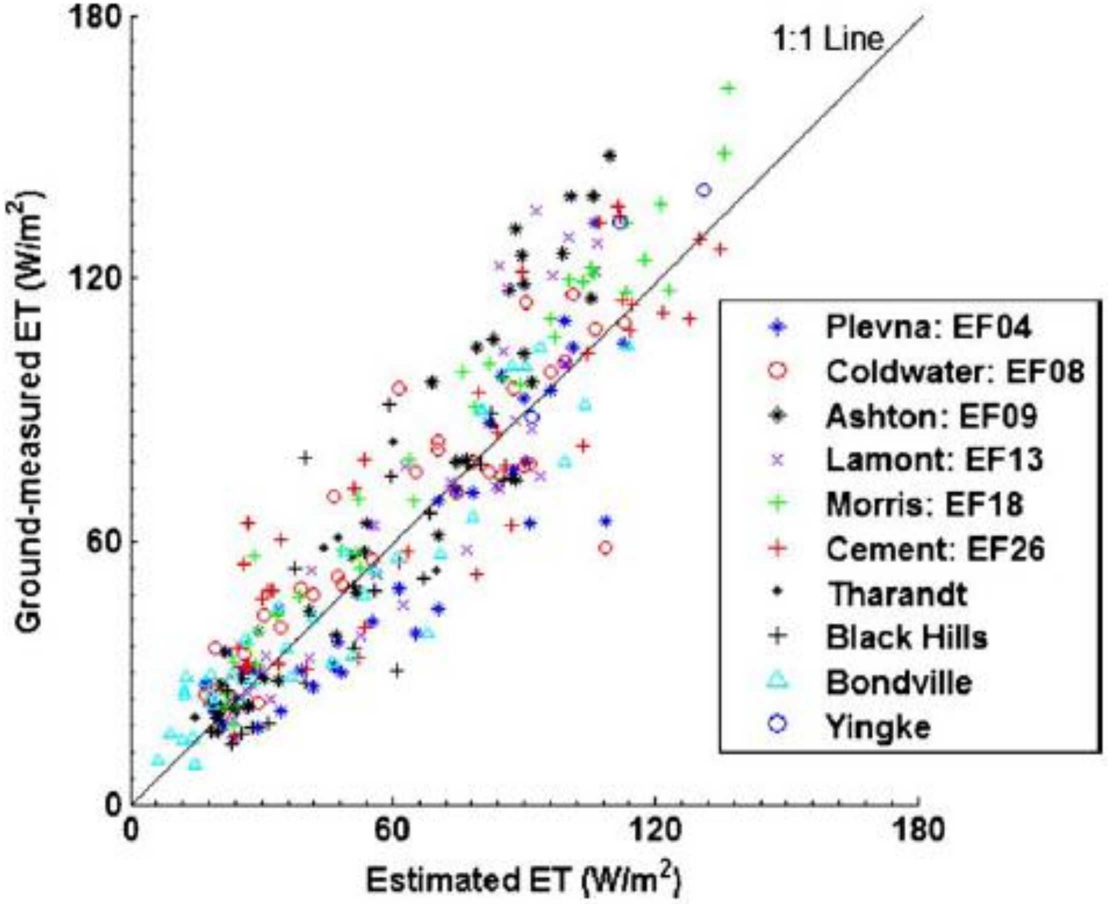
- Randomly divided the 22 flux towers into 2 groups – used group 1 to estimate the coefficients, used group 2 to validate the results

Results



Scatter plots of the predicted monthly ET and ground-measured ET for the first group of flux towers using the second group data to calibrate the eight parameters

Results



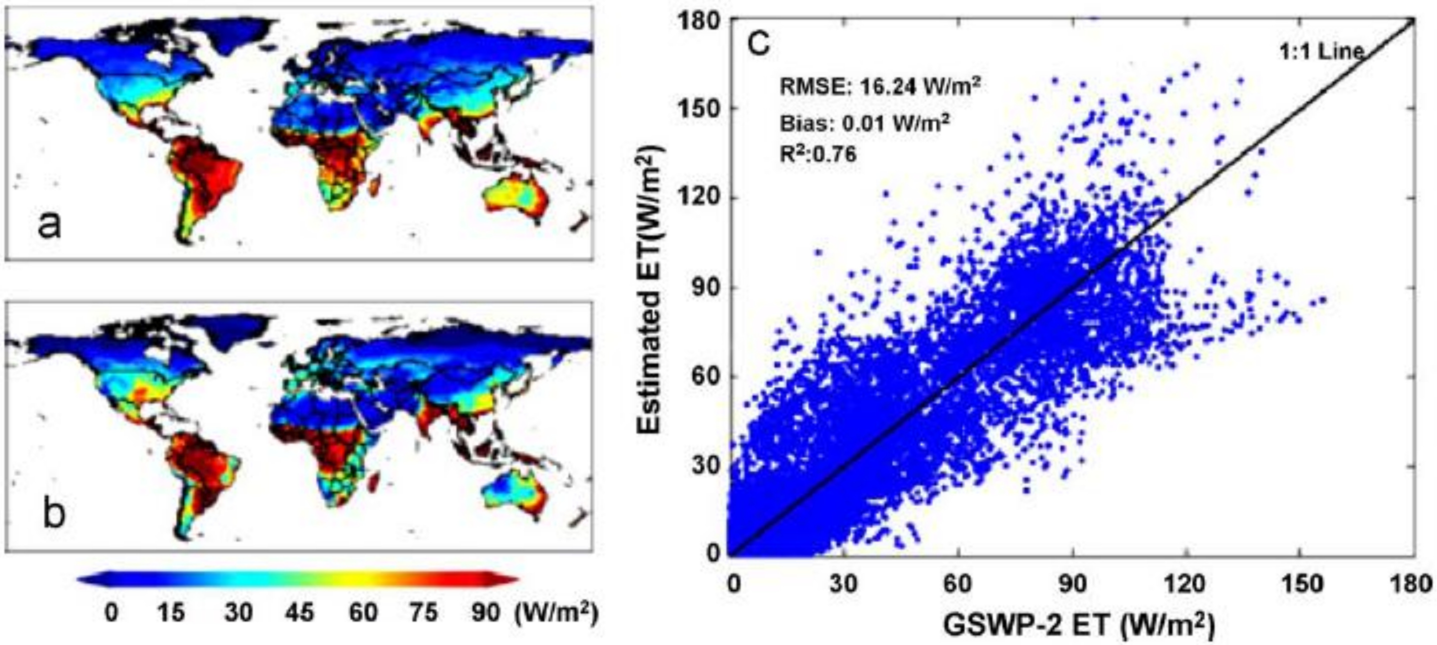
Scatter plots of the predicted monthly ET and ground-measured ET for the second group of flux towers using the first group data to calibrate the eight parameters in Eq

Global Implementation

$$
\begin{aligned}
ET = {} & R_n^2(0.00084NDVI - 0.000978) \\
& + R_n\left(0.3044 + 0.0029T_a + \frac{0.284}{T_{\max} - T_{\min}}\right) \\
& + R_n\left(0.1273 + 0.01T_a + \frac{0.065}{T_{\max} - T_{\min}}\right)NDVI
\end{aligned}
$$

"Sufficiently representative" except for desert and glacier regions.

Global implementation - 1986



An example of the comparison of monthly ET using GEWEX, AVHRR-GIMMS-NDVI and NCEP-2 datasets of October 1986, and the corresponding latent heat flux from the GSWP-2 datasets. (a) The spatial distribution of the estimated monthly ET obtained using Eq. (21) for October 1986; (b) spatial distribution of the corresponding GSWP-2 ET; and (c) scatter plots of the estimated monthly ET for October 1986 and the corresponding GSWP-2 ET.

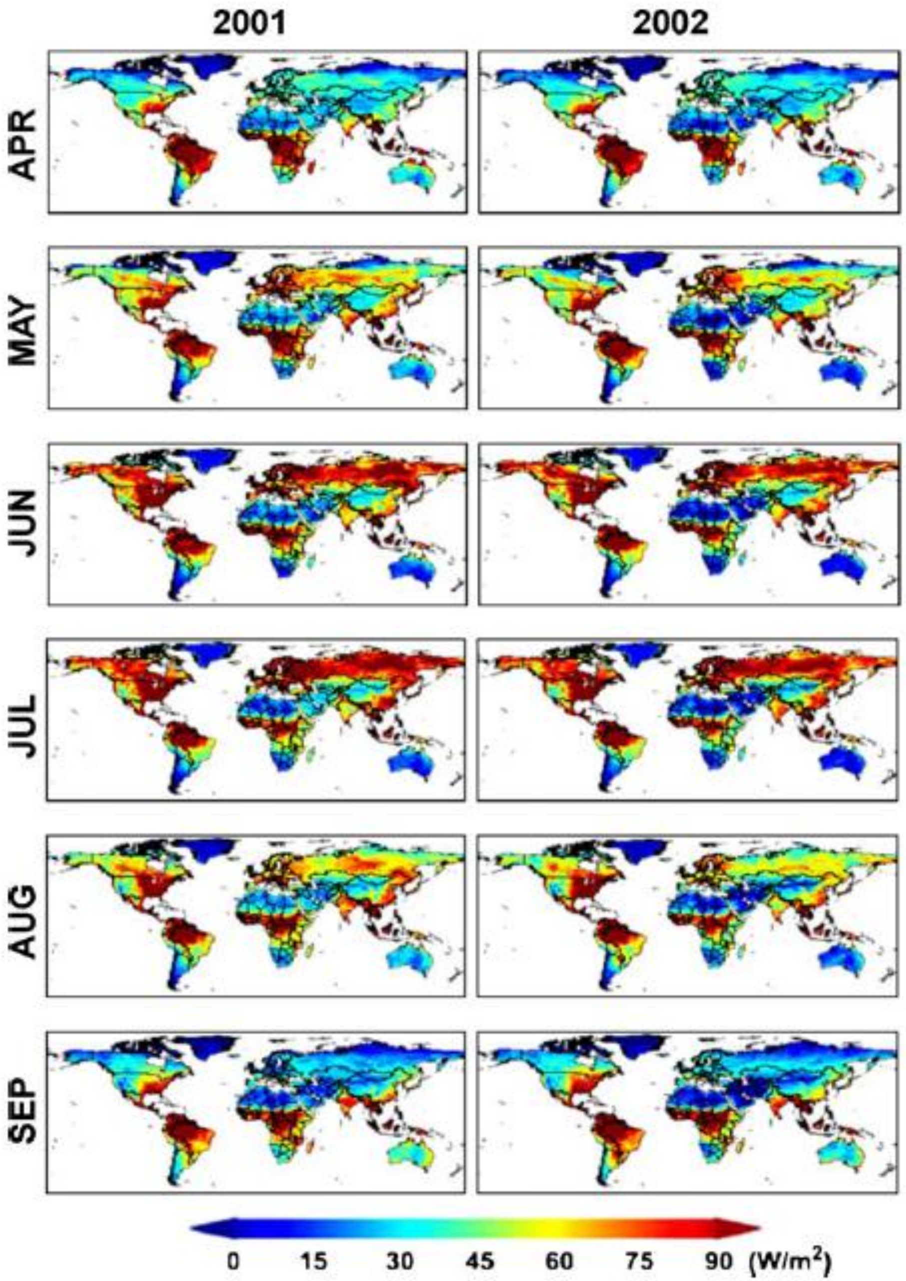


Fig. 6. Estimated global monthly ET for April–September of 2001–2002.

EDI vs. PDSI

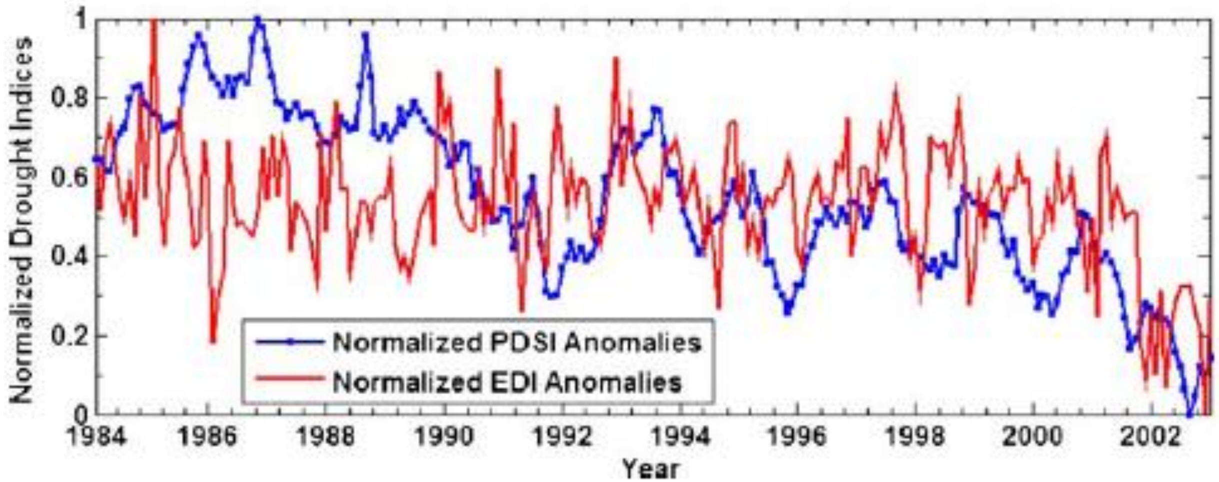


Fig. 7. Temporal variation of monthly normalized EDI and PDSI anomalies from January 1984 to December 2002.