REMOTE SENSING DEVELOPMENTS AT NASA’S JET PROPULSION LABORATORY

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Global estimates of the land–atmosphere water flux based on monthly AVHRR and ISLSCP-II data, validated at 16 FLUXNET sites


Numerous models of evapotranspiration have been published that range in data-driven complexity, but global estimates require a model that does not depend on intensive field measurements. The Priestley–Taylor model is relatively simple, and has proven to be ...
\[ LE_{pot} = \alpha \frac{\Delta}{\Delta + \gamma} R_n \]
\[ LE_{pot,\text{canopy}} = (1 - f_{\text{wet}}) \alpha \frac{\Delta}{\Delta + \gamma} R_{nc} \]

\[ LE_{pot,\text{soil}} = (1 - f_{\text{wet}}) \alpha \frac{\Delta}{\Delta + \gamma} R_{ns} \]

\[ LE_{pot,\text{interception}} = f_{\text{wet}} \alpha \frac{\Delta}{\Delta + \gamma} R_{n} \]
\[ LE_c = (1 - f_{\text{wet}}) f_g f_T f_M \frac{\Delta}{\Delta + \gamma} R_{nc} \]

\[ LE_s = (f_{\text{wet}} + f_{\text{SM}} (1 - f_{\text{wet}})) \alpha \frac{\Delta}{\Delta + \gamma} (R_{ns} - G) \]
\[ LE = LE_s + LE_c + LE_i \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Data Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Radiation</td>
<td>MODIS</td>
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<tr>
<td>Air Temperature</td>
<td>MODIS</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>MODIS</td>
</tr>
<tr>
<td>Vegetation fraction</td>
<td>MODIS</td>
</tr>
</tbody>
</table>
\[ R_n = (1 - \text{albedo}) \times SW_{dn} + LW_{dn} - LW_{up} \]

- We combined **11 variables from 6 different MODIS products** daily over the MODIS era to estimate the components of \( R_n \).

<table>
<thead>
<tr>
<th>Component of ( R_n )</th>
<th>MODIS products and method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albedo</td>
<td>Albedo from <strong>MCD43</strong> (500 m, 8-day), land cover from <strong>MCD12</strong> (500 m, annual)</td>
</tr>
<tr>
<td>Incoming Shortwave (( SW_{dn} ))</td>
<td>Cloud optical thickness, cloud top altitude, and solar zenith angle from <strong>MOD06</strong> (5 km, daily); aerosol optical thickness at 550 nm from <strong>MOD04</strong> (10 km, daily); Input MODIS data to a radiative transfer model (Kobayashi et al., 2008)</td>
</tr>
<tr>
<td>Incoming Longwave (( LW_{dn} ))</td>
<td>Near surface air temperature and vapor pressure from <strong>MOD07</strong> (5 km, daily); estimate emissivity from vapor pressure and temperature</td>
</tr>
<tr>
<td>Outgoing Longwave (( LW_{up} ))</td>
<td>Land <strong>surface temperature</strong> and emissivity from <strong>MOD11</strong> (1 km, daily); estimate broadband emissivity</td>
</tr>
</tbody>
</table>
Figure 4. Mean global net energy flux ($R_n$) from MODIS.
- Validation at 126 sites across FLUXNET and SURFRAD.
JPL MODIS

Boreal (CA–Man)

Temperate–Continental (RU–Fyo)

Temperate (NL–Loo)

Mediterranean (US–SO3)

Semi–Arid (IL–Yat)

Tropical (AU–How)

Net Radiation (Wm$^{-2}$)

Day of Year
Figure 3. Comparison between daily (8 day time scale) MODIS and measured net radiation in six different climate types.

- Boreal
- Temperate–Continental
- Temperate
- Mediterranean
- Semi–Arid
- Tropical

Measured Net-radiation (Wm$^{-2}$) vs. MODIS Net-radiation (Wm$^{-2}$)
y = 1.07x

$r^2 = 0.90$
PT-JPL ET VALIDATION

Bondville (Temperate C3/C4 Crop)

Griffin (Temperate Evergreen Needleleaf Forest)

Niwot (Sub-Alpine Evergreen Needleleaf Forest)

NSA-OBS (Boreal Evergreen Needleleaf Forest)

Hainich (Temperate Deciduous Broadleaf Forest)

Hesse (Temperate Deciduous Broadleaf Forest)

Takayama (Cold-Temperate Deciduous Broadleaf Forest)

Tapajos (Tropical Evergreen Broadleaf Forest)

Howland (Cold-Temperate Evergreen Needleleaf Forest)

Mer Bleue (Boreal Wetland)

Tonzi (Mediterranean Savanna)

Tumbarumba (Temperate Evergreen Broadleaf Forest)

Mize (Subtropical Evergreen Needleleaf Forest)

Morgan Monroe (Temperate Deciduous Broadleaf Forest)

Virginia Park (Woody Savanna)

Walnut River (Temperate C3/C4 Grassland)
Vinukollu et al. 2011: Remote Sensing of Environment
INDEPENDENT EVALUATION (BEIJING)

Chen et al. 2014: Remote Sensing of Environment
Multi-site evaluation of terrestrial evaporation models using FLUXNET data

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2 Water Resources and River Centre, King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia
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Abstract

We evaluated the performance of four commonly applied land surface evaporation models using a high-quality dataset of selected FLUXNET towers. The models that were examined include an energy balance approach (Surface Energy Balance System; SEBS), a combination-type approach (single-source Penman-Monteith; PM), a complementary method (advection-entropy; AA) and a radiation-based approach (modified Priestley-Taylor; PT-JPL). Twenty FLUXNET towers were selected based upon satisfying stringent forcing data requirements and representing a wide range of biomes. The models were compared to measured ET using ET datasets from 26 FLUXNET towers, which cover a range of biomes, canopy types, and forcing conditions. The ensemble mean of models showed performance compared to PM, possibly due to the partitioning of total evaporation (canopy transpiration, soil evaporation, wet canopy evaporation) and lower uncertainties in the required forcing data. The SEBS model showed low performance over tall and heterogeneous canopies, which was a consequence of the effects of the roughness sub-layer parameterization employed in this scheme. However, SEBS performed well overall. Relative to PT-JPL and SEBS, the PM and AA showed low performance over the majority of sites, due to their sensitivity to the parameterization of evaporation. It should be noted that no single model was consistently best across all biomes. Indeed, this outcome highlights the need for further evaluation of each model’s structure and parameterizations to adequately simulate evaporation at different surface types and scales. It is expected that the results of this study can be used to inform decisions regarding model choice for water resources and agricultural management, as well as providing insight into model selection for global flux monitoring efforts.

1. Introduction

Reliable estimates of evaporation (E) are required for the accurate representation of mass and energy exchanges at the land surface. In hydrological and water resource studies, evaporation models are required to characterize the exchange of moisture between the surface and the overlying atmosphere. Not surprisingly, the choice of model can have considerable impact on water resource planning and decision support across a range of temporal and spatial scales. Improved understanding of the influence of model choice on flux estimation is required in order to better characterize the fidelity of these simulations, particularly in light of an increasing number of regional and global scale efforts to produce land surface heat flux data products (Jin et al., 2011; Mueller et al., 2011).

A number of models have been developed for the estimation of either the reference, potential or actual values of evaporation (see reviews of Kustas et al., 2008 and Wang and Dickinson, 2012). The reference evaporation is defined as the evaporation from a hypothetical, well-watered “reference” crop (Allen, 2000), while potential evaporation is the maximum evaporation for a given surface if moisture is not limiting (Penman, 1948; Inam and Hanan, 2001). Estimation of the reference and potential evaporation is
Work in progress:

- Global, 1 km, daily, MODIS-era (10+ years)
- PT-JPL, PM-MOD16, SEBS, PMBL
Actual evapotranspiration in drylands derived from in-situ and satellite data: Assessing biophysical constraints

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d Desertification and Geneecolgy Dept. Estación Experimental de Zonas Áridas (EEZA), Consejo Superior de Investigaciones Científicas, Crtra. de Sacramento s/n La Cañada de San Urbano, E-04120 Almería, Spain

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ABSTRACT

Improving regional estimates of actual evapotranspiration (ÆE) in water-limited regions located at climatic transition zones is critical. This study assesses an ÆE model (PT-JPL model) based on downscaling potential evapotranspiration according to multiple stresses at daily time-scale in two of these regions using MSG–SEVIRI (surface temperature and albedo) and MODIS products (NDVI, LAI and fPAR). An open woody savanna in the Sahel (Mali) and a Mediterranean grassland (Spain) were selected as test sites with Eddy Covariance data used for evaluation. The PT-JPL model was modified to run at a daily time step and the outputs from eight algorithms differing in the input variables and also in the formulation of the biophysical constraints (stresses) were compared with the ÆE from the Eddy Covariance. Model outputs were also compared with other modeling studies at similar global dryland ecosystems.

The novelty of this paper is the computation of a key model parameter, the soil moisture constraint, relying on the concept of apparent thermal inertia (fSM_ATI) computed with surface temperature and albedo observations. Our results showed that fSM_ATI from both in-situ and satellite data produced satisfactory results for ÆE in the Sahelian savanna, comparable to parameterizations using field-measured Soil Water Content (SWC) with r² greater than 0.80. In the Mediterranean grasslands however, with much lower daily ÆE values, model results were not as good as in the Sahel (r² = 0.57–0.31) but still better than reported values from more complex models applied at the site such as the Two Source Model (TSM) or the Pennman–Monteith Leuning model (PML).

PT-JPL–daily model with a soil moisture constraint based on apparent thermal inertia fSM_ATI offers great potential for regionalization as no field-calibrations are required and water vapor deficit estimates, required in the original
site-level ET uncertainty from LST uncertainty

<table>
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<tr>
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<th>$\Delta$</th>
<th>$\Delta^\circC$</th>
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<tbody>
<tr>
<td>$m$</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td>$r^2$</td>
<td>0.82</td>
<td></td>
</tr>
<tr>
<td>RMSE</td>
<td>37.7</td>
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</tbody>
</table>
site-level ET uncertainty sensitivity from LST uncertainty.
• **ET UNCERTAINTY**
  \[ ET_{\text{UNCERTAINTY}} = \text{abs}(ET^{LST_0-} - ET^{LST+}) + \text{abs}(ET^{LST_0-} - ET^{LST-}) \]
  \[ = \text{abs}(50 - 51 \text{ W m}^{-2}) + \text{abs}(50 - 58 \text{ W m}^{-2}) \]
  \[ = 9 \text{ W m}^{-2} \text{ (global mean)} \]

• **ET SENSITIVITY**
  \[ ET_{\text{SENSITIVITY}} = \frac{\text{abs}(ET^{LST+} - ET^{LST-})}{ET^{LST_0}} \]
  \[ = \frac{\text{abs}(51 - 58 \text{ W m}^{-2})}{50 \text{ W m}^{-2}} \]
  \[ = 14\% \text{ (global mean)} \]
AMAZON DROUGHT 2005

Indication of future?

Kamel Didan, University of Arizona Terrestrial Biophysics and Remote Sensing Lab

July-September 2005 Drought

Rainfall Anomaly

below average  average  above average
**Drought:** meteorological (or, climatological, atmospheric), agricultural, hydrologic, socio-economic; exceedance of threshold.

**Vegetation drought:** physical drying of soil such that the overlying vegetation experiences physiological water stress manifested in a reduction of productivity, loss of leaves/needles, and, ultimately, mortality.

**Soil Water Deficit (SWD):**
\[ \delta S = P - ET \]

IF \( P - ET > 0 \), THEN \( SWD_i = 0 \), ELSE \( SWD_i = P - ET + SWD_0 \)

**Maximum Cumulative Water Deficit (MCWD):**
\[ \text{max} \sum SWD \]

**Drought:**
\( CWD_i, MCWD_i > \overline{CWD}, \overline{MCWD} \)

Tropical Rainfall Measuring Mission (TRMM)
Drought: meteorological (or, climatological, atmospheric), agricultural, hydrologic, socio-economic; exceedance of threshold.

Vegetation drought: physical drying of soil such that the overlying vegetation experiences physiological water stress manifested in a reduction of productivity, loss of leaves/needles, and, ultimately, mortality.

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- \( \text{CWD}_i, \text{MCWD}_i > \overline{\text{CWD}}, \overline{\text{MCWD}} \)

EVAPOTRANSPIRATION

$y = 1.07x$

$r^2 = 0.90$
**Drought**: meteorological (or, climatological, atmospheric), agricultural, hydrologic, socio-economic; exceedance of threshold.

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\[ \delta S = P - ET \]

**Soil Water Deficit (SWD)**:
- IF \( P - ET > 0 \), THEN \( SWD_i = 0 \)
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**Maximum Cumulative Water Deficit (MCWD)**:
- \( \text{max} \sum SWD \)

**Drought**:
- \( CWD_i, MCWD_i > \overline{CWD}, \overline{MCWD} \)

Drought?

MORTALITY?
As drought increases, live trees decrease.
Nutrient Cycles

Brevia

The 2010 Amazon Drought

Simon L. Lewis,b,4* Paulo M. Brandao,b,4* Oliver L. Phillips,4 Geertrui M. F. van der Heijden,b* Daniel Nepstad,b

Several global circulation models (GCMs) project an increase in the frequency and severity of drought events affecting the Amazon region as a consequence of anthropogenic greenhouse gas emissions (1). The proximate cause is twofold, including Pacific sea surface temperatures (SSTs), which may intensify El Niño Southern Oscillation events and associated periodic Amazon droughts, and an increase in the frequency of biennially more droughts associated with high Atlantic SSTs and northwest displacement of the intertropical convergence zone (2, 3). Such droughts may lead to a loss of some Amazon forests, which would accelerate climate change (4). In 2005, a major Atlantic SST-associated drought occurred, identified as a 1-in-100-year event (5). Here, we report on a second drought in 2010, when Atlantic SSTs were again high.

We calculated standardized anomalies from a decade of satellite-derived dry-season rainfall data (Tropical Rainfall Measuring Mission, 0.25° resolution) across 3.3 million km² of Amazonia for 2010 and 2005 (6). We used identical reference periods to allow a direct comparison of both drought events (4). On the basis of this index, the 2010 drought was more spatially extensive than the 2005 drought (table S1), anomalies of 0.4 SD over 3.0 million km² and 1.9 million km² in 2005 and 2010, respectively (Fig. 1 and fig. S1). Because dry-season anomalies do not necessarily correlate with water stress for forest trees, we also calculated the maximum climatological water deficit (MCWD) for each year as the most negative cumulative value of water input minus estimated forest evapotranspiration (5). This measure of drought intensity correlates with Amazon forest tree mortality (6). In 2010, the difference in MCWD from the decadal mean that significantly increases tree mortality (~25 mE) spanned 3.3 million km², compared with 2.5 million km² in 2005. The 2010 drought had three identifiable epicenters in southwestern Amazonia, north-central Bolivia, and Peru’s Madre de Dios state. In 2005 only a single southwestern Amazonia epicenter was detectable (fig. S1). The relationship between the change in MCWD and changes in aboveground carbon storage derived from forest inventories across the Amazon basin suggests that the 2010 drought (5) provides a first approximation of the biomass carbon impact of the 2010 event. Summing the change in carbon storage predicted by the 2010 MCWD difference across Amazonia gives a total impact of 22 Pg C (95% confidence interval 11 and 34), compared with 1.6 Pg C for the 2005 event (6, 8, 2, 6). These values are relative to the pre drought carbon uptakes and represent the sum of the temporary cessation of biomass increases over the 2-year drought measurement interval (~0.8 Pg C) and (2) biomass lost via tree mortality, a committed carbon flux from decomposition over several years (~1.4 Pg C after the 2001 drought). In most years, these forests are a carbon sink, drought reverses this sink.

Consistent uncertainty remains, related to the soil characteristics within the epicenters of the 2010 drought, which could moderate or exacerbate climate drying, whether a second drought will kill more trees (i.e., those damaged by the initial drought) or fewer (i.e., if most drought susceptible trees are already dead), and whether drought slows soil respiration (temporarily offsetting the biomass carbon source). New field measurements will be required to refine our initial estimates.

Several mechanisms by which remaining intact tropical forest ecosystems of South America can shift from buffering the increase in atmospheric carbon dioxide to accelerating it. Indeed, two major droughts in a decade may critically outstrip the net gains of ~0.9 Pg C year⁻¹ in intact Amazon forest aboveground biomass in nondrought years. Thus, repeated droughts may have important decadal-scale impacts on the global carbon cycle.

Droughts occur with periods of the activity (5). Such interactions among climatic changes, human actions, and forest responses represent potential positive feedbacks that could lead to widespread Amazon forest degradation or loss (7). The significance of these processes will depend on the growth response of tropical trees to increased atmospheric carbon dioxide concentration, fire management, and deforestation trends (8). Nevertheless, any shift to drier conditions would decrease forest carbon uptake and adapted species, and drier forests store less carbon (9). If drought events continue, the net of intact Amazon forests buffering the increase in atmospheric carbon dioxide may have passed.

References and Notes
4. Mortality and methods are available as supporting material on Science Online.
9. We thank S. Baker and L. Neias for assistance and the Royal Society, NERC Foundation, and NSF for funding.

Supporting Online Material
www.sciencemag.org/cgi/content/full/331/6017/795/DC1
Materials and Methods
Fig. S1
Table S1
References
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