Estimation of evapotranspiration using satellite TOA radiances

Jian Peng

Max Planck Institute for Meteorology
Hamburg, Germany
Satellite top of atmosphere radiances
Surface temperature/vegetation index feature space

\[
ET = EF (R_n - G) \\
EF = \phi_{\text{max}} \frac{T_{\text{max}} - T_S}{T_{\text{max}} - T_{\text{min}}} \frac{\Delta}{\Delta + \gamma} \\
NDTI = \frac{T_{\text{max}} - T_S}{T_{\text{max}} - T_{\text{min}}}
\]

Petropoulos et al. (2009)
Research questions

1. Is it possible to estimate NDTI using TOA radiances?
2. How representative is instantaneous EF for daytime EF?
3. How accurate is the daytime EF estimated from TOA radiances?
4. Is it possible to estimate daytime ET from TOA radiances?
1. Is it possible to estimate NDTI using TOA radiances?*

Using TOA Radiance directly instead of surface temperature products

\[ \frac{T_{\text{max}} - T_s}{T_{\text{max}} - T_{\text{min}}} \quad \text{Valor and Caselles (1996)} \]

Planck’s law
Radiance transfer equation
If surface emissivity, atmospheric temperature and water vapor are constant over the study area, then:

\[
\frac{T_{\text{max}} - T_s}{T_{\text{max}} - T_{\text{min}}} = \frac{L_{\text{max}} - (1 - t_{i}^{\text{max}})[1 + (1 - \varepsilon_{i}^{\text{max}})t_{i}^{\text{max}}]B_{i}(T_{a}^{\text{max}})}{L_{\text{max}} - (1 - t_{i}^{\text{max}})[1 + (1 - \varepsilon_{i}^{\text{max}})t_{i}^{\text{max}}]B_{i}(T_{a}^{\text{max}})}
\]

\[
\frac{L_{\text{min}} - (1 - t_{i}^{\text{min}})[1 + (1 - \varepsilon_{i}^{\text{min}})t_{i}^{\text{min}}]B_{i}(T_{a}^{\text{min}})}{L_{\text{min}} - (1 - t_{i}^{\text{min}})[1 + (1 - \varepsilon_{i}^{\text{min}})t_{i}^{\text{min}}]B_{i}(T_{a}^{\text{min}})}
\]
Sensitivity analysis

Spatial variation
- Emissivity < 0.05
- Atmospheric temperature < 4 K
- Water vapor < 10%
- NDTI uncertainty < 10%
MODIS data and study area

Terra polar orbiting satellite

MODIS
(Moderate Resolution Imaging Spectroradiometer)

<table>
<thead>
<tr>
<th>MODIS data</th>
<th>Category</th>
<th>Parameters used</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOD02</td>
<td>Level 1</td>
<td>TOA radiance</td>
</tr>
<tr>
<td>MOD09</td>
<td>Level 2</td>
<td>Surface reflectance</td>
</tr>
<tr>
<td>MOD11</td>
<td>Level 2</td>
<td>Surface temperature</td>
</tr>
</tbody>
</table>

Study area: Poyang Lake basin, southeast of China
Surface temperature/vegetation index feature space

\[
\frac{L_{\text{max}} - L_s}{L_{\text{max}} - L_{\text{min}}} \quad \frac{T_{\text{max}} - T_s}{T_{\text{max}} - T_{\text{min}}}
\]

Petropoulos et al. (2009)
Comparison of the NDTI_Ts and NDTI_TOA

Spatial variation
- Emissivity < 0.01
- Atmospheric temperature < 1 K
- Water vapor < 10%

5.9 (DOY208), 3.9 (DOY279)
Water Vapor (g cm⁻²)
2. How representative is instantaneous EF for daytime EF?*

The assumption of constant EF during daytime

Instantaneous NDTI from TOA radiances

\[ EF = \phi_{\text{max}} \frac{L_{\text{max}} - L_s}{L_{\text{max}} - L_{\text{min}}} \frac{\Delta}{\Delta + \gamma} \]

Instantaneous EF

Daytime EF

Slide: 13 / 31
FLUXNET measurements

FLUXNET A global network of eddy covariance towers, providing measurements of water and energy fluxes

Flux tower

Eddy covariance instrument

http://hpwren.ucsd.edu/news/20080516/
The FLUXNET sites used in this study

72 sites across a wide range of ecosystems and climates are used in this analysis
Diurnal variations of surface fluxes and EF

Instantaneous EF:

$$EF(t) = \frac{LE(t)}{LE(t) + H(t)}$$

Daytime EF:

$$EF_{\text{daytime}} = \frac{\int_{t_1}^{t_2} LE(t) \, dt}{\int_{t_1}^{t_2} [H(t) + LE(t)] \, dt}$$
Comparison between instantaneous and daytime average EF

Clear sky conditions

Partly cloudy sky conditions
The EF constant assumption is strictly true only for clear sky conditions.

The effects of cloudiness need to be considered, when the EF constant assumption is applied under cloudy conditions.
Influence of biome types on EF
costant assumption
3. How accurate is the daytime EF estimated from TOA radiances?*

Using FLUXNET measurements to validate daytime EF from MODIS TOA radiances

Daytime EF from FLUXNET

\[ EF_{\text{daytime}} = \frac{\int_{t_1}^{t_2} LE(t) \, dt}{\int_{t_1}^{t_2} [H(t) + LE(t)] \, dt} \]

Validate

Daytime EF from MODIS TOA radiances

\[ EF = \phi_{\text{max}} \frac{L_{\text{max}} - L_s}{L_{\text{max}} - L_{\text{min}}} \frac{\Delta}{\Delta + \gamma} \]
Comparison between estimated and measured daytime EF

Croplands

$R^2 = 0.638$
BIAS = -0.027
RMSD = 0.160

‘+’ marker
Influenced by precipitation

‘x’ marker
Outside growing season

USNe2
USNe3
USBkg

Slide: 22 / 31
Accuracy assessment of the estimated daytime EF in the literature

- Nishida et al. (2003)
- Venturini et al. (2004)
- Wang et al. (2006)
- Stisen et al. (2008)
- Jiang et al. (2009)
- Tang et al. (2011)

Present study

- BIAS
- $R^2$
- RMSD
4. Is it possible to estimate daytime ET from TOA radiances?*

Estimation of daytime ET

Daytime EF from TOA radiances

\[ ET = EF(R_n - G) \]

Daytime ET from TOA radiances

Tang et al. (2006)
Wang et al. (2009)
Estimation of daytime ET

\[ ET_{\text{daytime}} = EF_{\text{daytime}} \cdot R_n^{\text{daytime}} \]

Sinusoidal model with MODIS overpass from Bisht et al. (2005)
Assessment strategy

1. MODIS TOA radiances → Daytime $R_n$, EF and ET
2. In situ measurements → Validation/Comparison
3. MODIS products → Daytime $R_n$, EF and ET

Legend:
1 = cropland, 2 = forest, 3 = grassland, 4 = urban areas, 5 = water, 6 = bare soil
Comparisons between estimates and observations

- Estimated $R_n$ vs. Observed $R_n$
- Estimated ET vs. Observed ET
- Estimated EF vs. Observed EF

- $R_n$ from MODIS TOA radiances
- $R_n$ from MODIS products
- ET from MODIS TOA radiances
- ET from MODIS products
- EF from MODIS TOA radiances
- EF from MODIS products

- $R^2$ and Relative Error analysis

- $R_n$ (TOA), $R_n$ (Products), EF (TOA), EF (Products), ET (TOA), ET (Products)
Seasonal variation of estimated daytime ET
Conclusions

1. The NDTI can be estimated using TOA radiances with an accuracy of 90% under certain conditions.

2. The EF constant assumption works well under clear sky conditions over a wide range of ecosystems and climates.

3. The accuracy of the EF estimated from TOA radiances is comparable with those satellite products based estimates.

4. The direct use of TOA radiances to estimate daytime ET is feasible and applicable.
1. Estimate ET under full sky conditions through integrating data from different satellite systems, such as passive microwave and geostationary sensors.

2. Validate the ET estimated from TOA radiances over basin scale by constructing water balance equation from ground-based measurements.

3. Inter compare ET estimates from different satellite based methods and land surface models.

Thank you very much!