Assessing the Impact of Drought in Guanacaste, Costa Rica and Evaluating Potential Contributions of ECOSTRESS Evapotranspiration Data to Improve Drought Estimation

May 15, 2017

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## ECOSTRESS Science Data Products

<table>
<thead>
<tr>
<th></th>
<th>L2</th>
<th>L3</th>
<th>L4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Surface Temperature</td>
<td>- Evapotranspiration (ET)</td>
<td>- Water Use Efficiency</td>
</tr>
<tr>
<td></td>
<td>- Surface Emissivity</td>
<td></td>
<td>- Evaporative Stress Index (ESI)</td>
</tr>
</tbody>
</table>

Simulated ECOSTRESS (MODIS and NCEP)

ECOSTRESS

ECOSTRESS

NASA JPL

70 m/pixel

1 km/pixel
Main Ideas

• ECOSTRESS data complements existing measures of drought impacts

• Drought-induced plant stress varies depending on year, season and land use (not just precipitation)

• ECOSTRESS ET data can support farmers and land managers to more effectively steward their resources
Research Questions

1. How severe was the drought in Guanacaste from 2013 to 2015 relative to historical precipitation records?

2. What was the spatial distribution and magnitude of annual and seasonal anomalies in NDVI, ET, PET and ESI during the drought period?

3. How does plant stress, as measured by ESI, differ across land cover type, year, and season?
Hypothesis

1. Precipitation-based drought measurement
   - SPI
   - Annual 2015 rainfall is >2 standard deviations below historic mean
   - Seasonality doesn’t matter
   (Van Loon et al., 2014)

2. Vegetation-based drought measurement
   - NDVI
   - Seasonality does matter

3. ECOSTRESS drought measurement
   - ET, PET & ESI
   - Seasonality does matter
   (Vicente-Serrano et al., 2010)
**Methods**

1. **SPI**
   - IMN
   - GPCC
   - IMN
   - GPCC
   - 1951 – 2015 Precipitation
   - SPI Analysis
   - Seasonality?

2. **NDVI**
   - Landsat 7 16-day composite
   - 2000 – 2015 mean NDVI
   - Baseline and anomalies
   - Seasonality?

3. **ET, PET, ESI**
   - MODIS
   - NCEP
   - PT-JPL 2002 – 2015 ET, PET, ESI
   - Baseline and anomalies
   - Seasonality?
   - Landsat 8, Kauth-Thomas (1976)
   - RF Land Cover Classification
   - ANOVA
   - Digitized Training Data
Seasonal SPI Analysis

6 Month Wet Season SPI from 2000 to 2015
Guanacaste, Costa Rica

Slope = -0.16

6 Month Dry Season SPI from 2000 to 2015
Guanacaste, Costa Rica

Slope = -0.08
Seasonal NDVI Anomalies
Results – Annual PET Analysis

Simulated 1km ECOSTRESS PET
Guanacaste, Costa Rica
Mean Seasonal PET

- 2015 Dry Season
- 2014 Dry Season
- 2013 Dry Season
- 2015 Wet Season
- 2014 Wet Season
- 2013 Wet Season

Map showing seasonal PET for different years with color-coded intensity levels.
Seasonal PET Anomalies

2015 Dry Season

2014 Dry Season

2013 Dry Season

2015 Wet Season

2014 Wet Season

2013 Wet Season
ET Analysis

Simulated 1km ECOSTRESS ET
Guanacaste, Costa Rica
Seasonal ET Anomalies

2015 Dry Season

2014 Dry Season

2013 Dry Season

2015 Wet Season

2014 Wet Season

2013 Wet Season
Annual ESI

Lower plant stress

Higher plant stress

2015 Dry Season ESI
2014 Dry Season ESI
2013 Dry Season ESI

2015 Wet Season ESI
2014 Wet Season ESI
2013 Wet Season ESI
Random Forests Classification Map

Run (3)  Run (2)  Run (1)

Legend
- Cloud
- Water
- Urban
- Agriculture
- Forest
- Grassland

0  5  10  15  20 Miles
ANOVA Analysis

2013 2014 2015 Baseline

2016 Wet Dry

2017 Agriculture Forest Grassland
ANOVA Analysis

Assumptions

1. Randomly Sampled and Independent – **No** (Pixels have spatial autocorrelation)

2. Normality of data and residuals – **No** (Shapiro Wilks $W = 0.65733$, P-value <0.0001)

3. Homoscedasticity – **No** (Bartlett test for Year, Season, LC, ESI have P-value <0.0001)

Solution?

Bootstrap random samples of 1000 observations per LC category:

**Type 1** (balanced) fully-crossed, fixed effects model (Adèr et al., 2008)
ANOVA Analysis

Research Question

How does ESI differ across land cover type (agriculture, forest and grassland), year (2015, 2014, 2013 and baseline 2002-2012) and season (wet and dry)?

Null Hypothesis

There are no differences in ESI across the levels of land cover type, year and season.

ANOVA Design

Type 1 (balanced data) fully-crossed, fixed effects model:
meanESI ~ Year * Season * Land Cover
## ANOVA Type 1 (Balanced) Results

<table>
<thead>
<tr>
<th>Effect</th>
<th>Sum Sq</th>
<th>DF</th>
<th>F</th>
<th>P-Value</th>
<th>Effect Size (Partial η²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>1.374</td>
<td>3</td>
<td>401.653</td>
<td>&lt;0.0001</td>
<td>0.288</td>
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<tr>
<td>Season</td>
<td>0.053</td>
<td>1</td>
<td>46.405</td>
<td>&lt;0.0001</td>
<td>0.015</td>
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<tr>
<td>LC</td>
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<td>60.834</td>
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<td>0.039</td>
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<td>Year*Season</td>
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<td>Year*LC</td>
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<td>0.858</td>
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<td>Season*LC</td>
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<td>0.010</td>
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<td>Year<em>Season</em>LC</td>
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<td>6</td>
<td>1.111</td>
<td>0.353</td>
<td>0.002</td>
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<tr>
<td>Residuals</td>
<td>3.393</td>
<td>2976</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Future ECOSTRESS Applications

Analyze how water use and plant stress differed among varying land stewardship scenarios:

- EARTH University crop fields
- Partner producers
- Guanacaste National Park
- Estación Experimental Forestal Horizontes

Estación Experimental Forestal Horizontes, 1999

2001

2004
Main Ideas

• **ECOSTRESS data complements existing measures of drought impacts**
  - Precipitation-based drought indices cannot capture other moisture inputs to the land surface system (Allen et al. 2007, Anderson et al. 2007)

• **Drought-induced plant stress varies depending on year, season and land use (not just precipitation)**
  - Especially in Year and the interaction term of Year and Season

• **ECOSTRESS ET data can support farmers and land managers to more effectively steward their resources**
  - Intra-field ET variability across the diurnal cycle can inform farmers where and when to irrigate
  - Measuring the effects of various land stewardship scenarios on plant stress can inform drought resilient land management practices
Thank you for your attention!

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Annual SPI Analysis

Drought severity categories established by McKee et al. (1993)
**Methods – Priestley – Taylor model**

Priestley-Taylor (1972) model:

\[
PET = \alpha \frac{\Delta}{\Delta} + \gamma \quad Rn
\]

\[
\Delta = 0.200 (0.00738 T + 0.8072)^7
\]

\[
\gamma = \alpha \frac{C_p p}{0.622 \lambda}
\]

- **PET** = daily potential evapotranspiration (mm)
- **T** = daily mean air temperature (°C)
- **α** = correction factor = 1.26
- **Δ** = slope of saturation vapor pressure vs. temperature curve (kPa ° C⁻¹)
- **γ** = psychrometric constant modified by the ratio of canopy resistance to atmospheric resistance (∼ 0.066 kPa ° C⁻¹)
- **Cp** = specific heat of moist air (1.013 kJ Kg⁻¹ ° C⁻¹)
- **p** = atmospheric pressure (kPa)
- **Rn** = net radiation (MJ m² d⁻¹)
# Methods – PT-JPL model


<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Equation</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>ET</td>
<td>Evapotranspiration</td>
<td>$ET_s + ET_c + ET_i$</td>
<td>Priestley and Taylor (1972)</td>
</tr>
<tr>
<td>ET_s</td>
<td>Canopy transpiration</td>
<td>$(1 - f_{wt})f_g f_T f_M \alpha \Delta / \Delta + \gamma R_{nc}$</td>
<td>Priestley and Taylor (1972)</td>
</tr>
<tr>
<td>ET_c</td>
<td>Soil evaporation</td>
<td>$(f_{wt} + f_{SM}(1 - f_{wt}))f_g f_T f_M \alpha \Delta / \Delta + \gamma (R_{ns} - G)$</td>
<td>Priestley and Taylor (1972)</td>
</tr>
<tr>
<td>ET_i</td>
<td>Interception evaporation</td>
<td>$f_{wt} \alpha \Delta / \Delta + \gamma R_{nc}$</td>
<td>Priestley and Taylor (1972)</td>
</tr>
</tbody>
</table>

- $f_{wt}$: Relative surface wetness
- $f_g$: Green canopy fraction
- $f_T$: Plant temperature constraint
- $f_M$: Plant moisture constraint
- $f_{SM}$: Soil moisture constraint
- $f_{APAR}$: Fraction of PAR absorbed by green vegetation cover
- $f_{IPAR}$: Fraction of PAR intercepted by total vegetation cover
- $f_c$: Fractional total vegetation cover
- $T_{opt}$: Optimum plant growth temperature

### Equations

- $R_n = \text{net radiation}$
- $R_{nc} = \text{net radiation to the canopy} (R_n - R_{ns})$
- $R_{ns} = \text{net radiation to the soil} (R_n \exp(-kR_nLAI))$
- $\text{LAI} = \text{total (green + non-green) leaf area index} (-\ln(1 - f_c)/k_{PAR})$
- $G = \text{ground heat flux}$
- $T_{max} = \text{maximum air temperature}$
- $RH = \text{relative humidity}$
- $VPD = \text{saturation vapor pressure deficit}$
- $\Delta = \text{saturation-to-vapor pressure curve slope}$
- $\gamma = \text{the psychrometric constant} (\sim 0.066 \text{ kPa °C}^{-1})$
- $\alpha = 1.26, \beta = 1.0 \text{ kPa}, k_{R_n} = 0.6, k_{PAR} = 0.5,$
- $m1 = 1.2*1.136, b1 = 1.2* - 0.04,$
- $m2 = 1.0, b2 = - 0.05, \lambda = T_{opt}$

- $f_{APAR} = SAVI + b_1$
- $f_{IPAR} = NDVI + b_2$
2013
Mean = 0.575, Std. Dev. = 0.109

2014
Mean = 0.568, Std. Dev. = 0.105

2015
Mean = 0.552, Std. Dev. = 0.103
Simulated 1km ECOSTRESS PET
Guanacaste, Costa Rica

2013
Mean = 470 w/m², Std. Dev. = 29

2014
Mean = 457 w/m², Std. Dev. = 27

2015
Mean w/m² = 456, Std. Dev. = 23
Simulated 1km ECOSTRESS ET
Guanacaste, Costa Rica

2013
Mean = 428 w/m², Std. Dev. = 26

2014
Mean = 414 w/m², Std. Dev. = 22

2015
Mean = 416 w/m², Std. Dev. = 20
## ANOVA Type 3 (Unbalanced) Results

<table>
<thead>
<tr>
<th></th>
<th>Sum Sq</th>
<th>DF</th>
<th>F</th>
<th>P-Value</th>
</tr>
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<tbody>
<tr>
<td>(Intercept)</td>
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<td>&lt;0.0001</td>
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<td>Year</td>
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<td>6019.5</td>
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<tr>
<td>Season</td>
<td>0.95</td>
<td>1</td>
<td>869.76</td>
<td>&lt;0.0001</td>
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<tr>
<td>LC</td>
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<td>68.042</td>
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<tr>
<td>Year*Season</td>
<td>10.99</td>
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<td>3358.2</td>
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<tr>
<td>Year*LC</td>
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<td>22.042</td>
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<tr>
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<tr>
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<td>6.235</td>
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<td>Residuals</td>
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