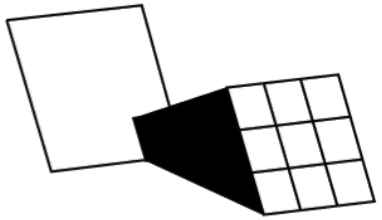
Assessing the Impact of Drought in Guanacaste, Costa Rica and Evaluating Potential Contributions of ECOSTRESS Evapotranspiration Data to Improve Drought Estimation

May 15, 2017

Savannah Cooley

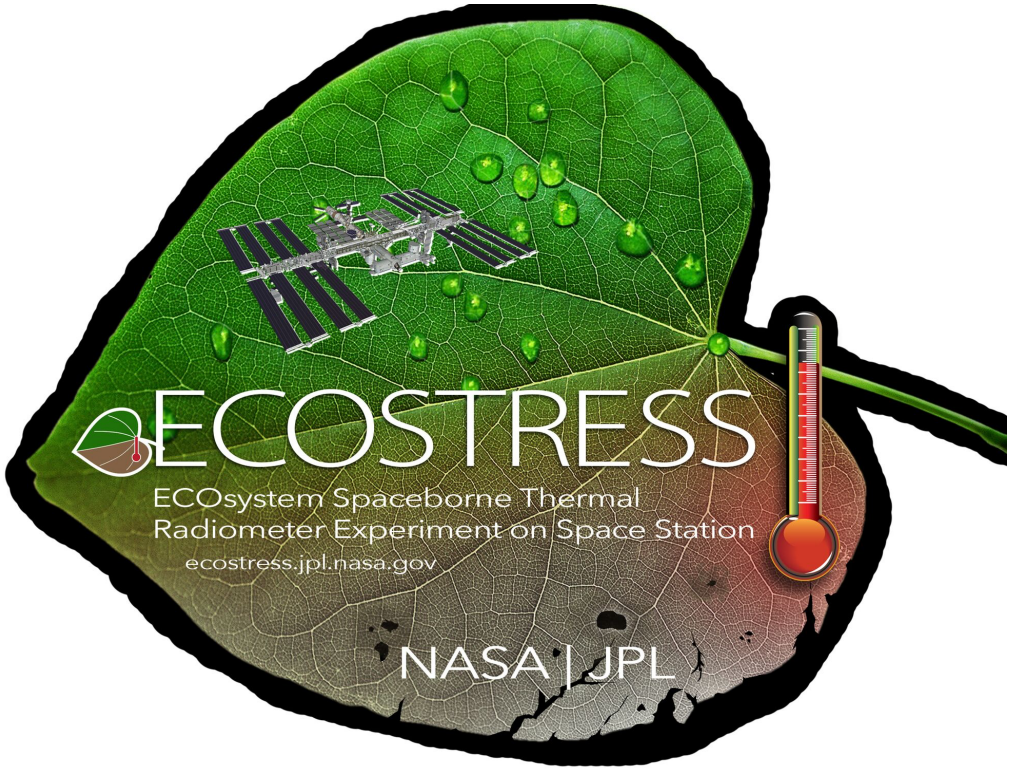
ECOSTRESS

Simulated ECOSTRESS
(MODIS and NCEP)
1km/pixel



ECOSTRESS
70 m/pixel

ECOSTRESS Science Data Products	
L2	- Surface Temperature - Surface Emissivity
L3	**- Evapotranspiration (ET)**
L4	- Water Use Efficiency **- Evaporative Stress Index (ESI)**



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

- ↓ NDVI
- Seasonality does matter

3. ECOSTRESS drought measurement

ET, PET & ESI

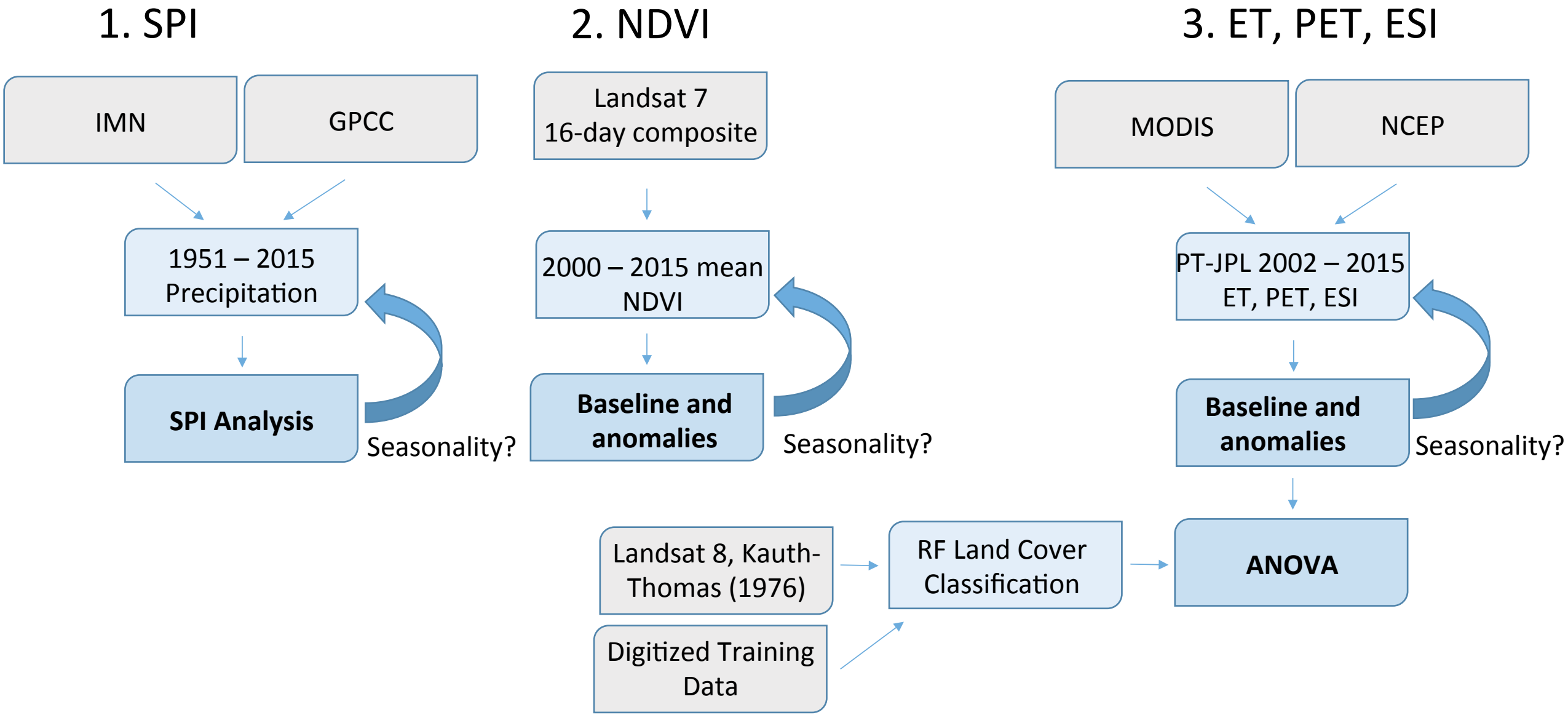
- ↓ET, ↑ PET, ↓ ESI

(Fisher et al. 2008, Shah 2003)

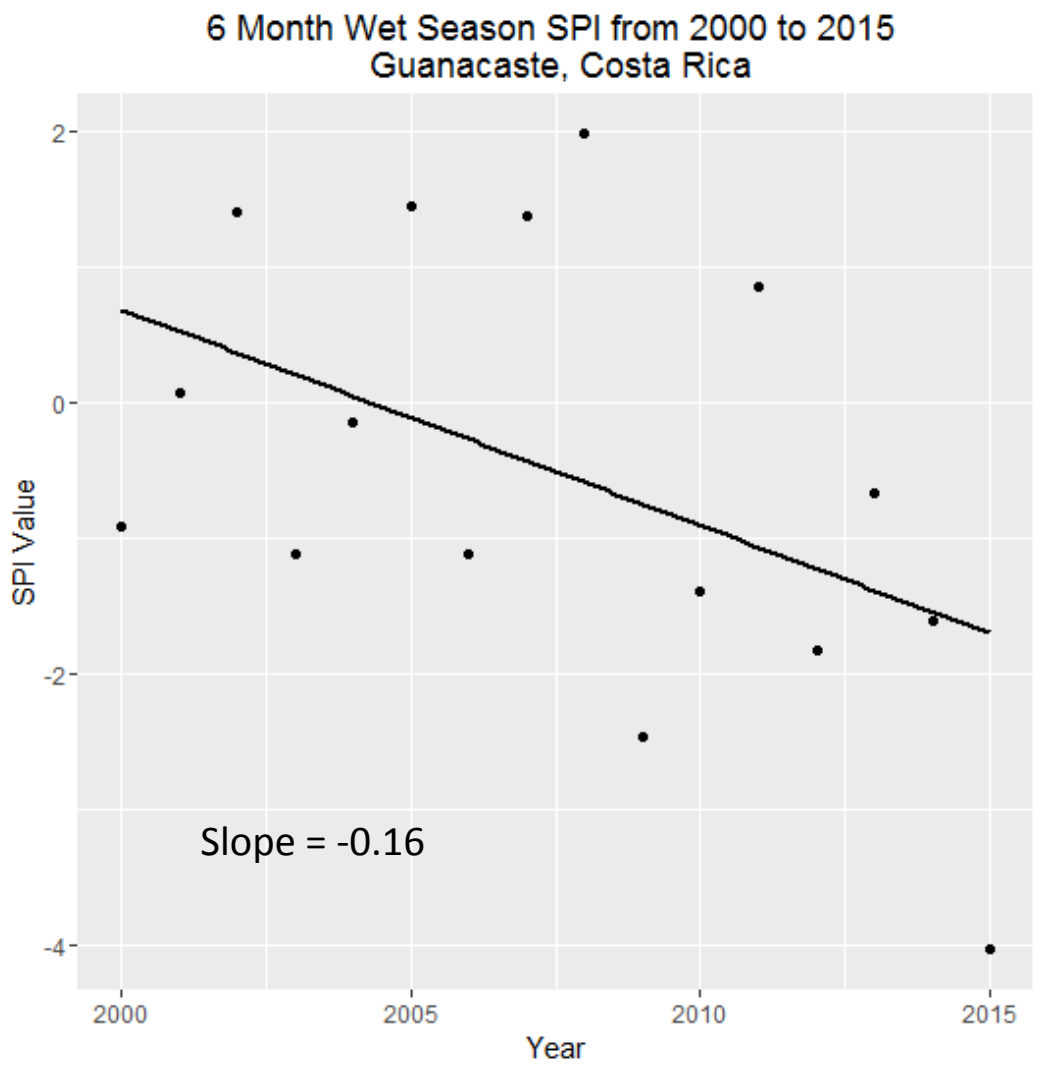
- Seasonality does matter

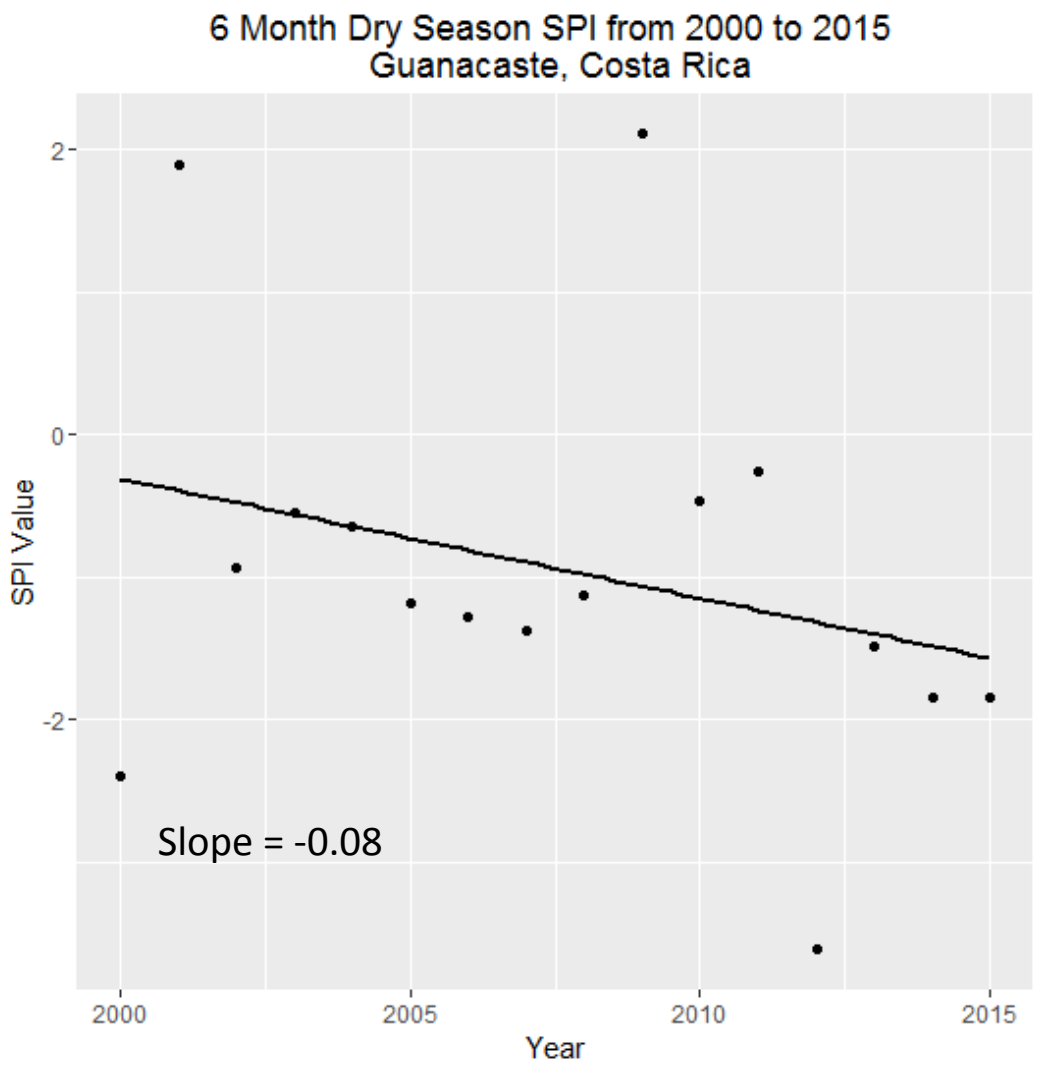
(Vicente-Serrano et al., 2010)

Methods

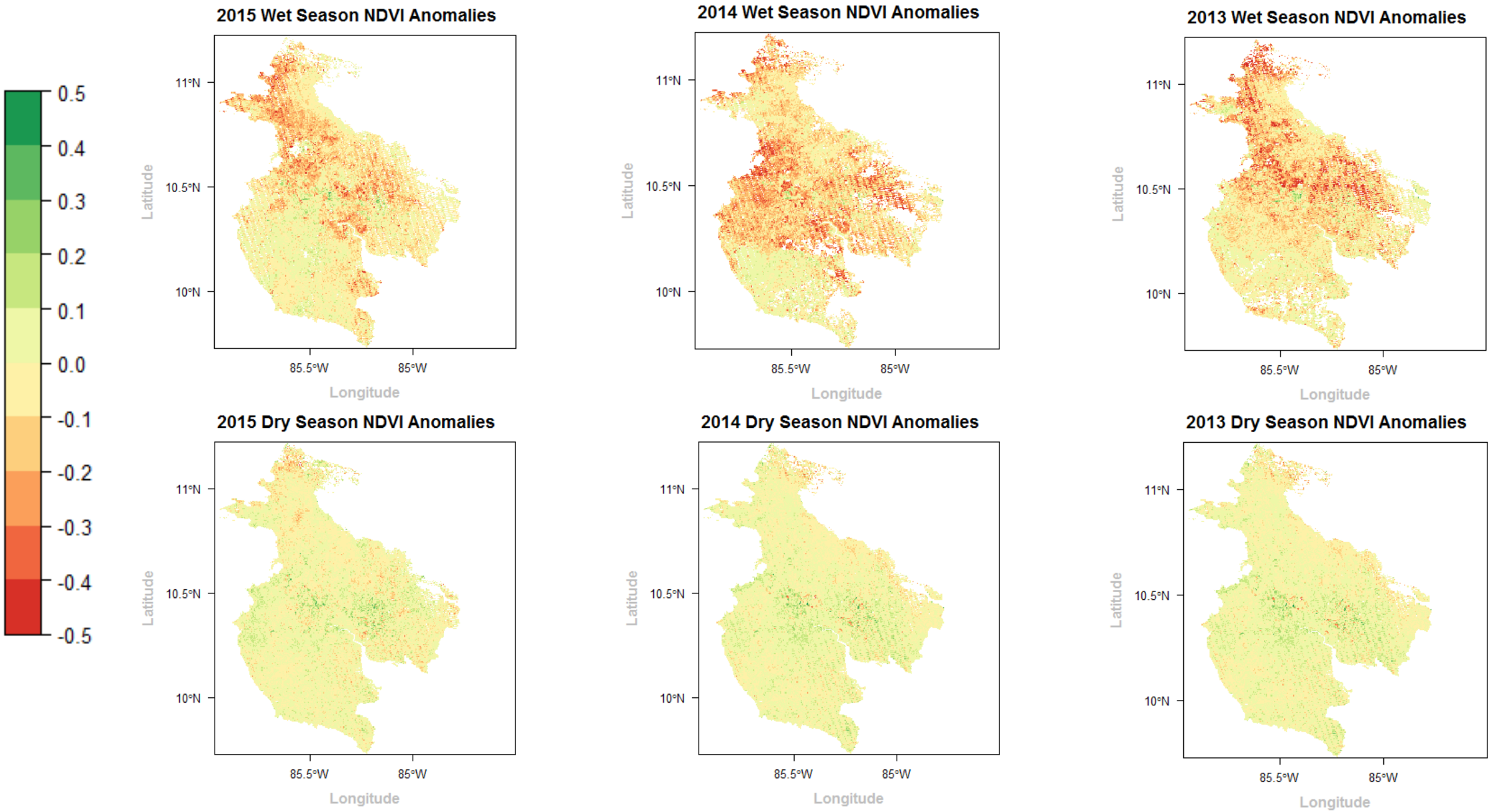

1. SPI
IMN
GPCC
1951 – 2015 Precipitation
SPI Analysis
Seasonality?
2. NDVI
Landsat 7 16-day composite
2000 – 2015 mean NDVI
Baseline and anomalies
Seasonality?
3. ET, PET, ESI
MODIS
NCEP
PT-JPL 2002 – 2015 ET, PET, ESI
Baseline and anomalies
Seasonality?
Landsat 8, Kauth-Thomas (1976)
Digitized Training Data
RF Land Cover Classification
ANOVA

Seasonal SPI Analysis

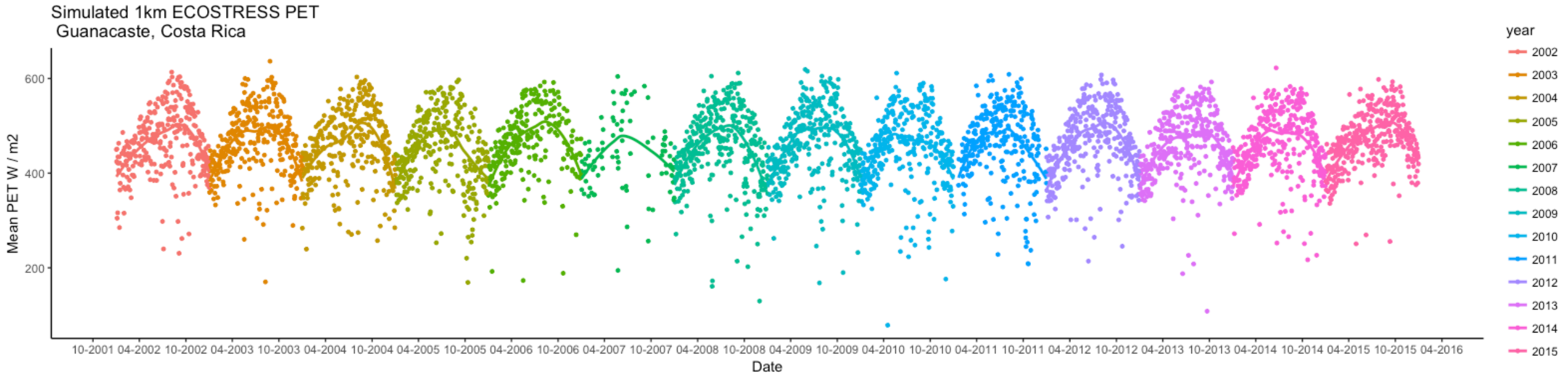




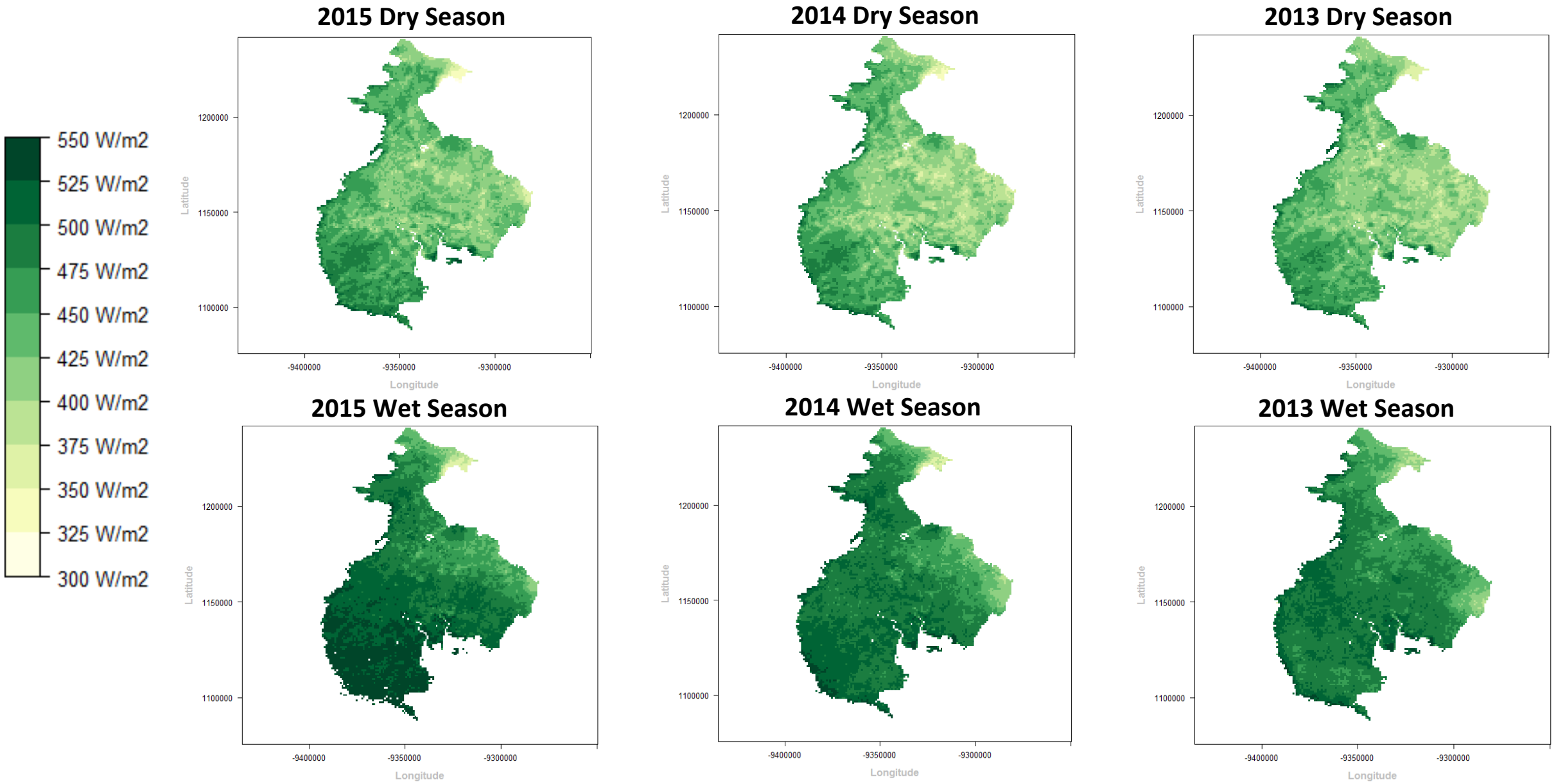
Seasonal NDVI Anomalies



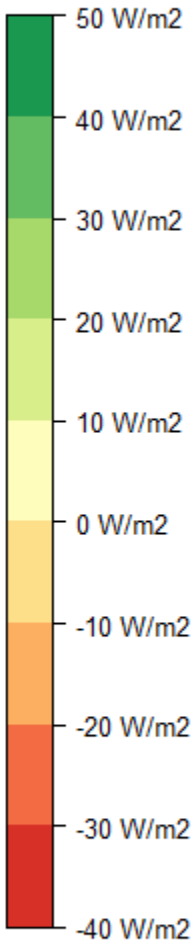
Results – Annual PET Analysis



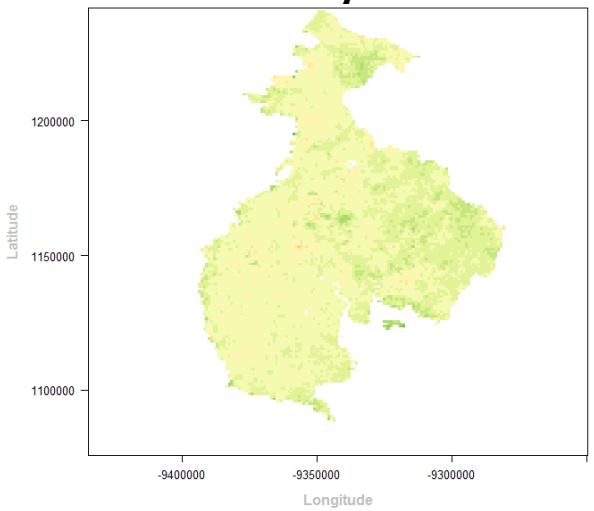
Mean Seasonal PET



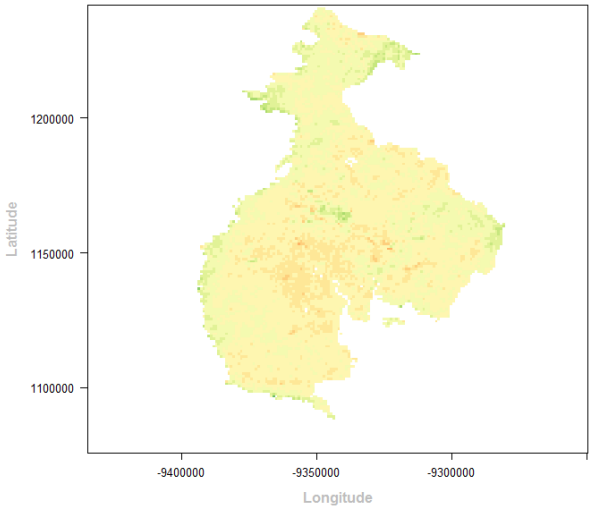
Seasonal PET Anomalies



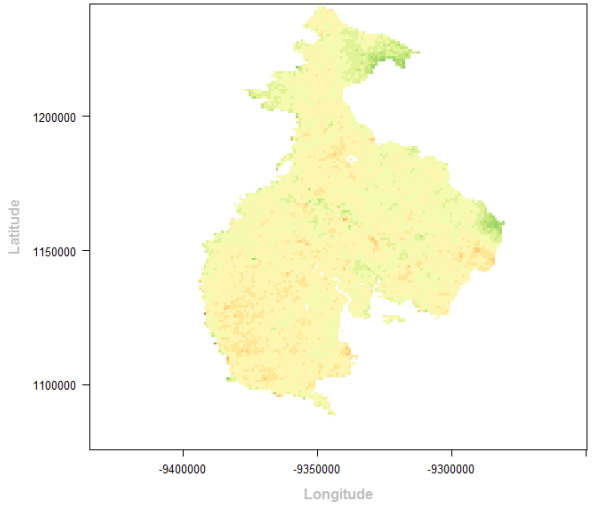
2015 Dry Season



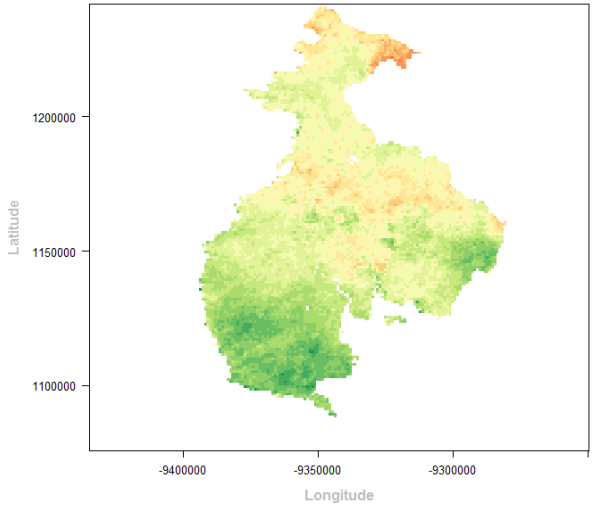
2014 Dry Season



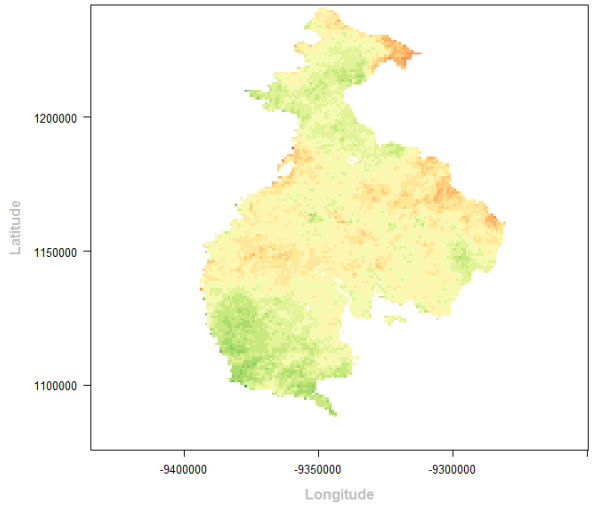
2013 Dry Season



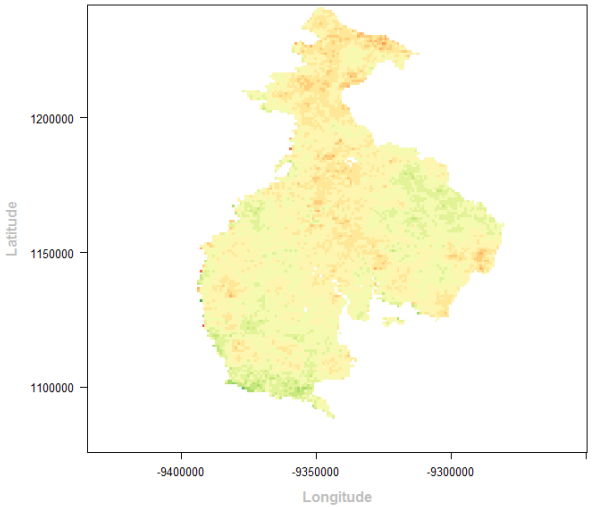
2015 Wet Season



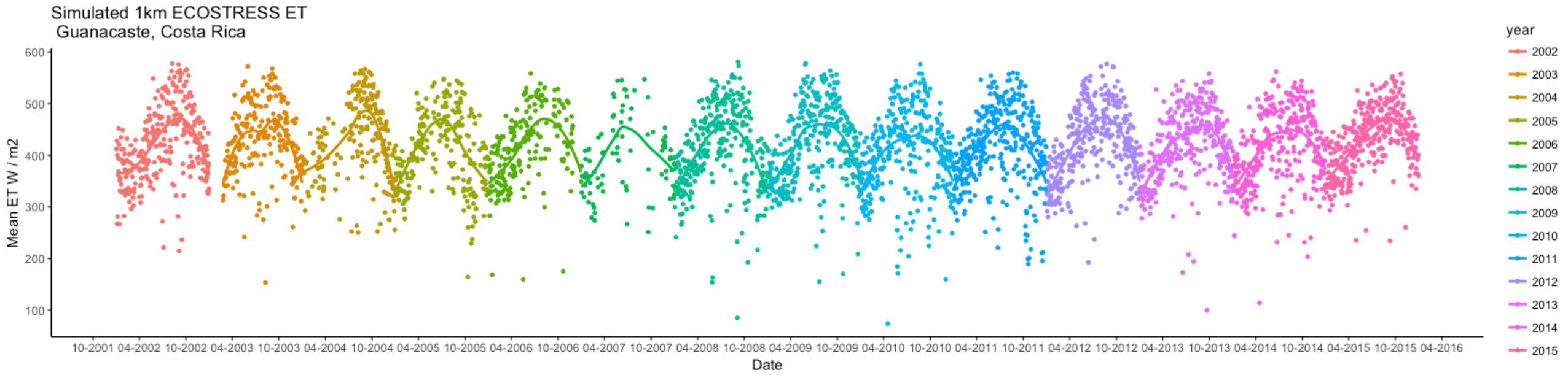
2014 Wet Season



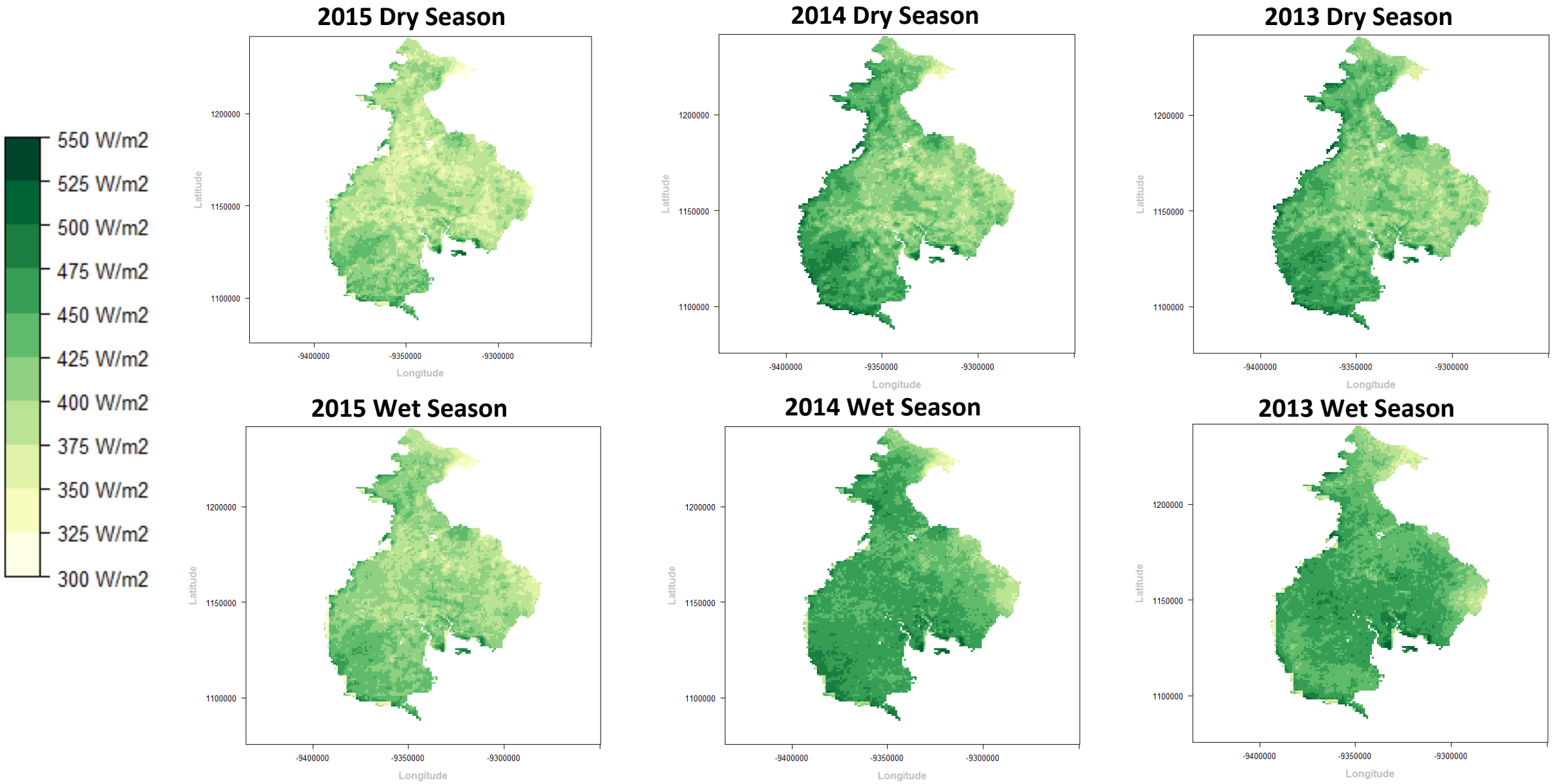
2013 Wet Season



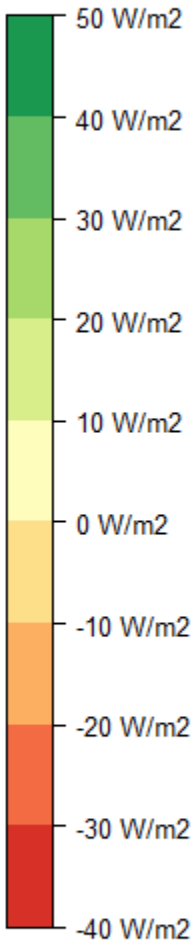
ET Analysis


Simulated 1km ECOSTRESS ET
Guanacaste, Costa Rica
Mean ET W / m2
600
500
400
300
200
100
10-2001 04-2002 10-2002 04-2003 10-2003 04-2004 10-2004 04-2005 10-2005 04-2006 10-2006 04-2007 10-2007 04-2008 10-2008 04-2009 10-2009 04-2010 10-2010 04-2011 10-2011 04-2012 10-2012 04-2013 10-2013 04-2014 10-2014 04-2015 10-2015 04-2016
Date
year
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015

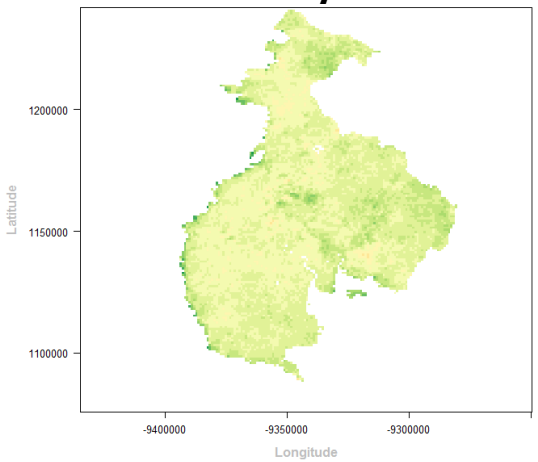
Mean Seasonal ET



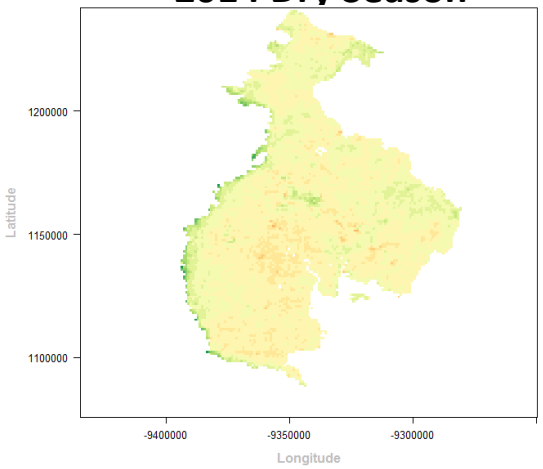
Seasonal ET Anomalies



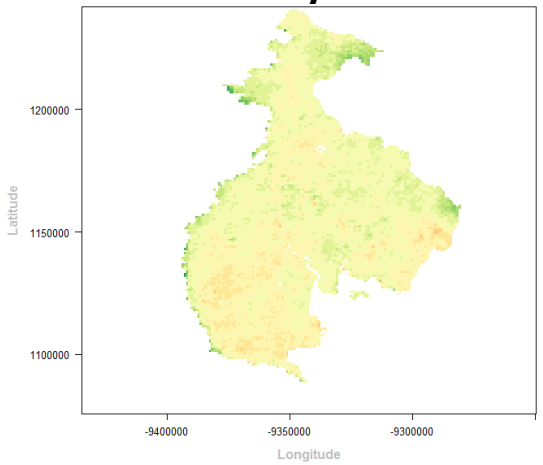
2015 Dry Season



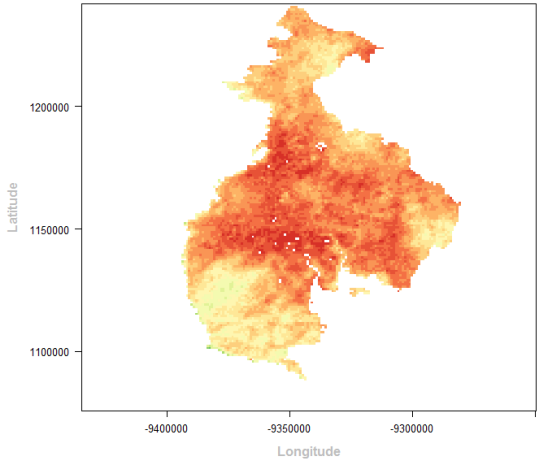
2014 Dry Season



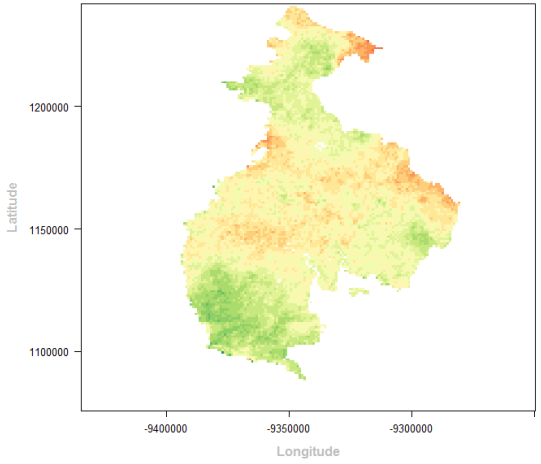
2013 Dry Season



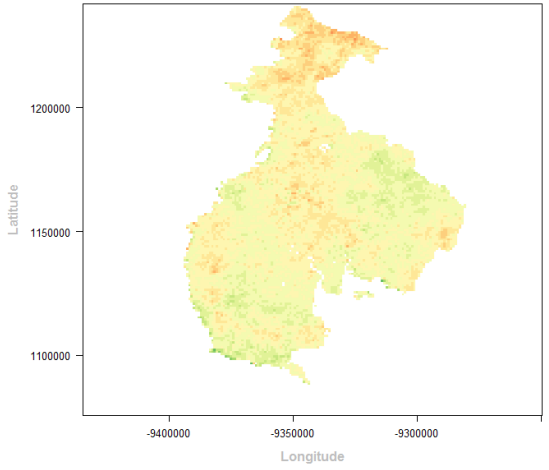
2015 Wet Season



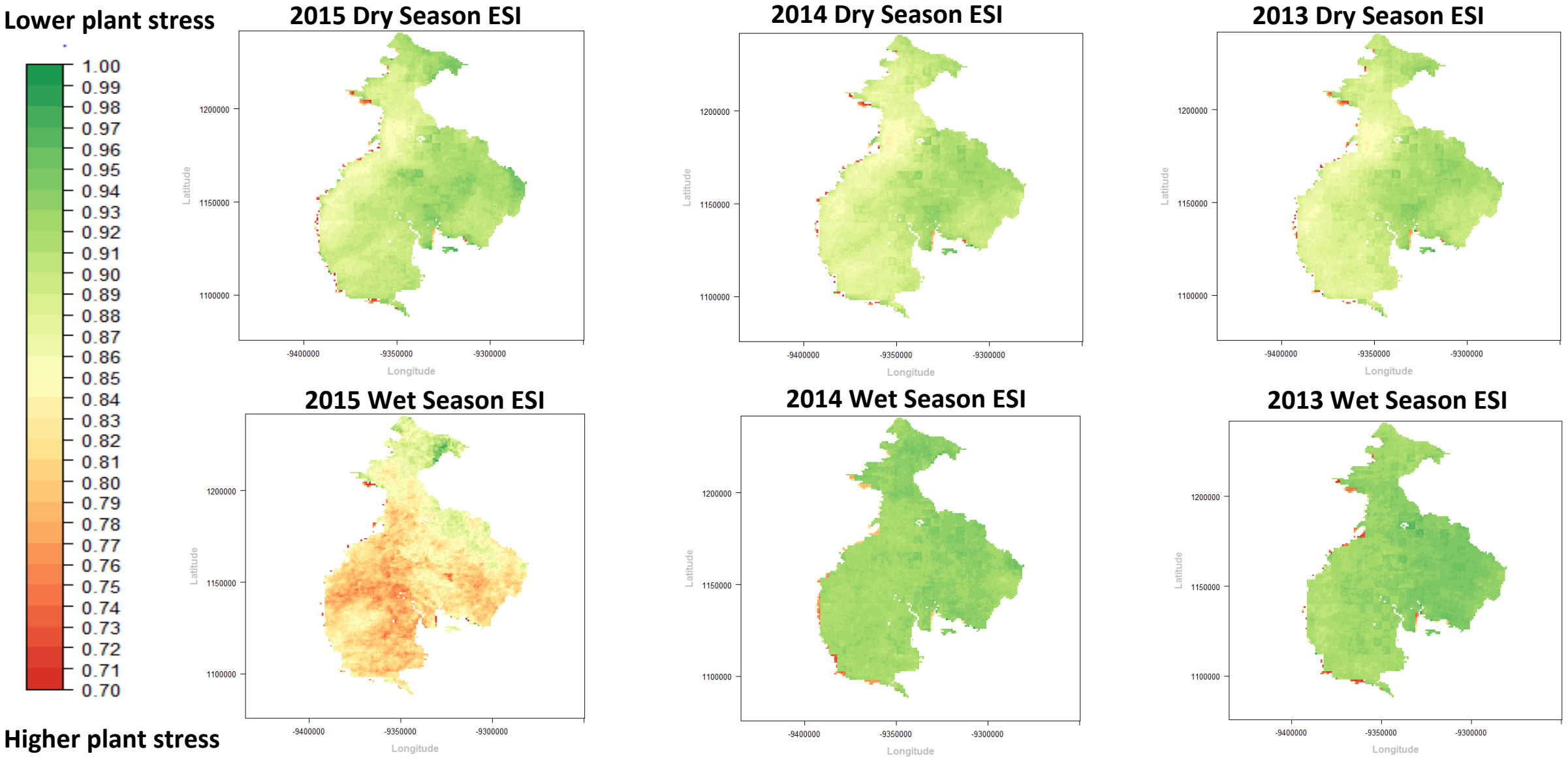
2014 Wet Season



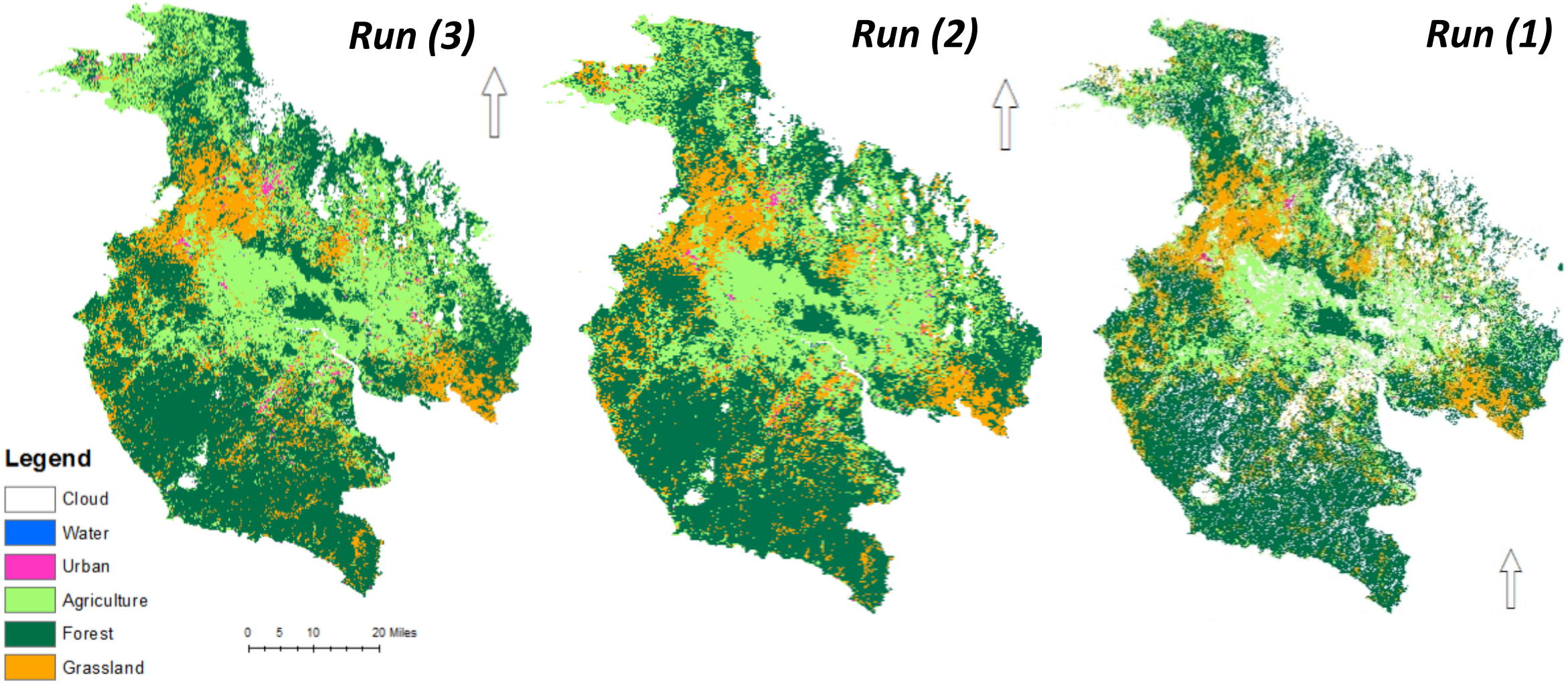
2013 Wet Season



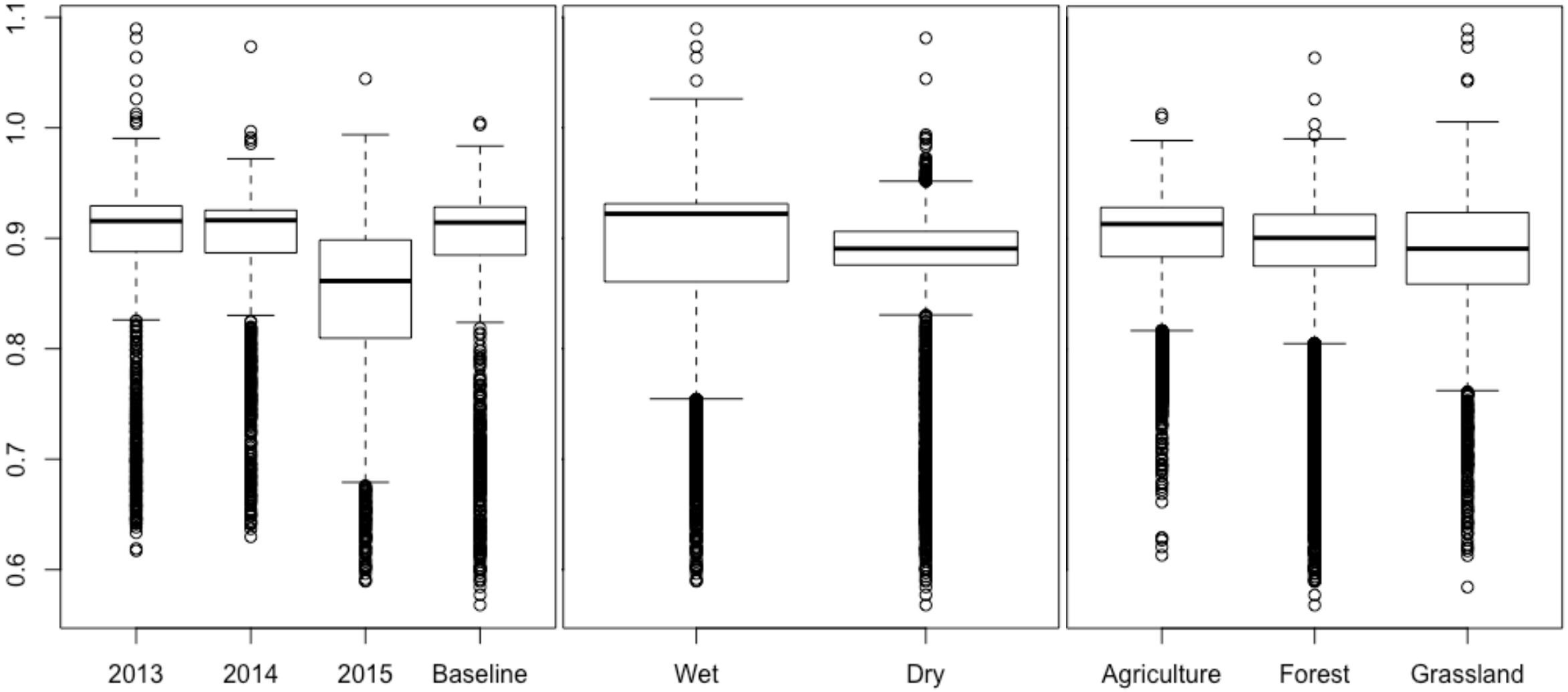
Annual ESI


Lower plant stress
1.00
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
0.90
0.89
0.88
0.87
0.86
0.85
0.84
0.83
0.82
0.81
0.80
0.79
0.78
0.77
0.76
0.75
0.74
0.73
0.72
0.71
0.70
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
Latitude
1200000
1150000
1100000
Longitude
-9400000
-9350000
-9300000

Random Forests Classification Map



ANOVA Analysis



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

	Sum Sq	**DF**	**F**	**P-Value**	**Effect Size** (Partial η2)
Year	1.374	3	401.653	<0.0001	0.288
Season	0.053	1	46.405	<0.0001	0.015
LC	0.139	2	60.834	<0.0001	0.039
Year*Season	2.131	3	623.046	<0.0001	0.386
Year*LC	0.003	6	0.432	0.858	0.001
Season*LC	0.036	2	15.928	<0.0001	0.010
Year*Season*LC	0.008	6	1.111	0.353	0.002
Residuals	3.393	2976			

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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References

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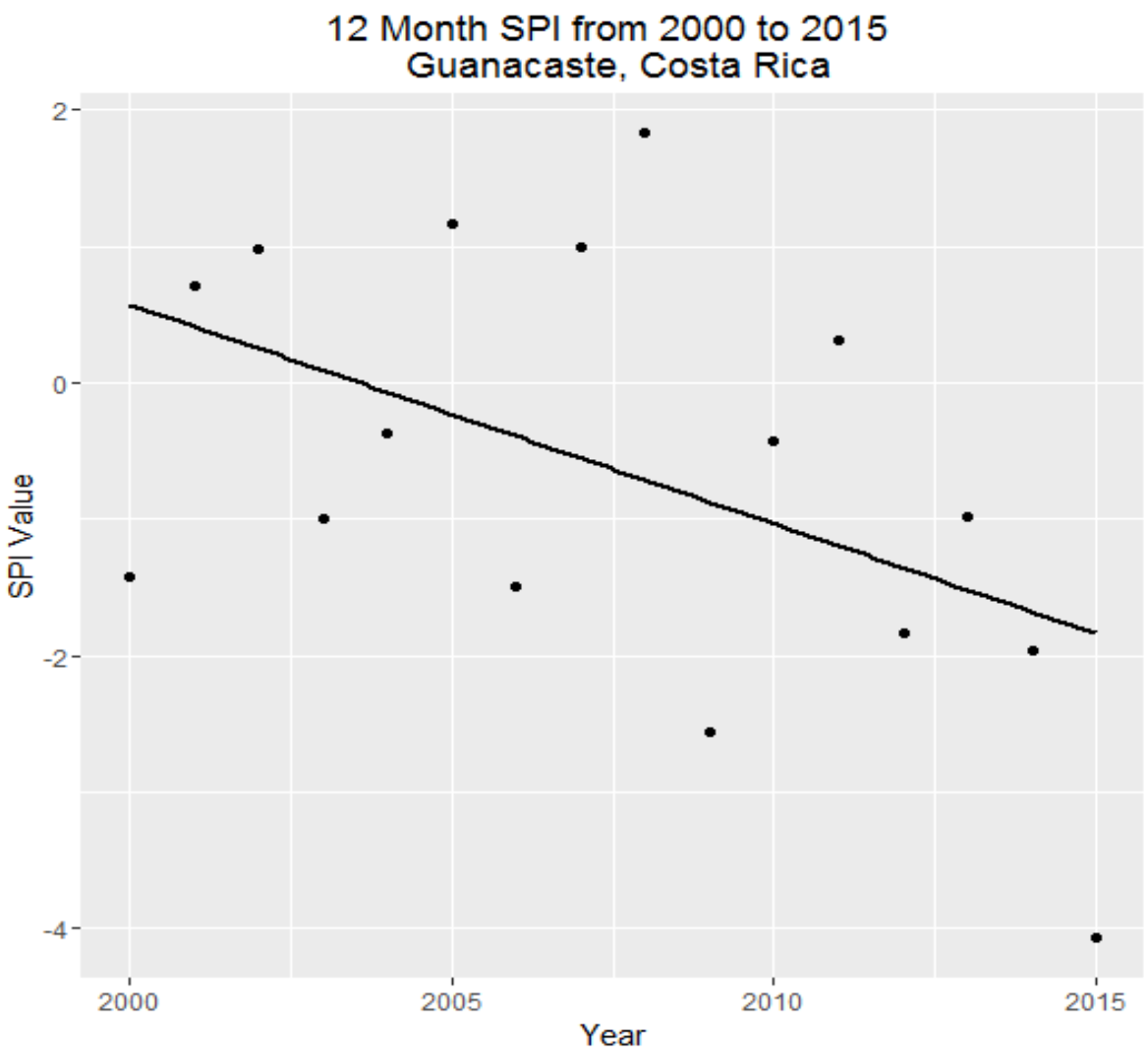
Annual SPI Analysis



SPI Values	Drought Category	Cumulative Probability	Time in Category
0 to -0.99	mild drought	0.158	24%
-1.00 to -1.49	moderate drought	0.067	9.2%
1.50 to -1.99	severe drought	0.023	4.4%
≤ -2.00	extreme drought	<0.023	2.3%

Drought severity categories established by McKee et al. (1993)

Methods – Priestley – Taylor model

Priestley-Taylor (1972) model:

$$PET = \alpha \, \Delta/\Delta+\gamma \;\; Rn$$

$$\Delta = 0.200\,(0.00738\,T + 0.8072)^7$$

$$\gamma = \alpha \, Cp \; p/0.622\lambda$$

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 m^2 d^{-1})

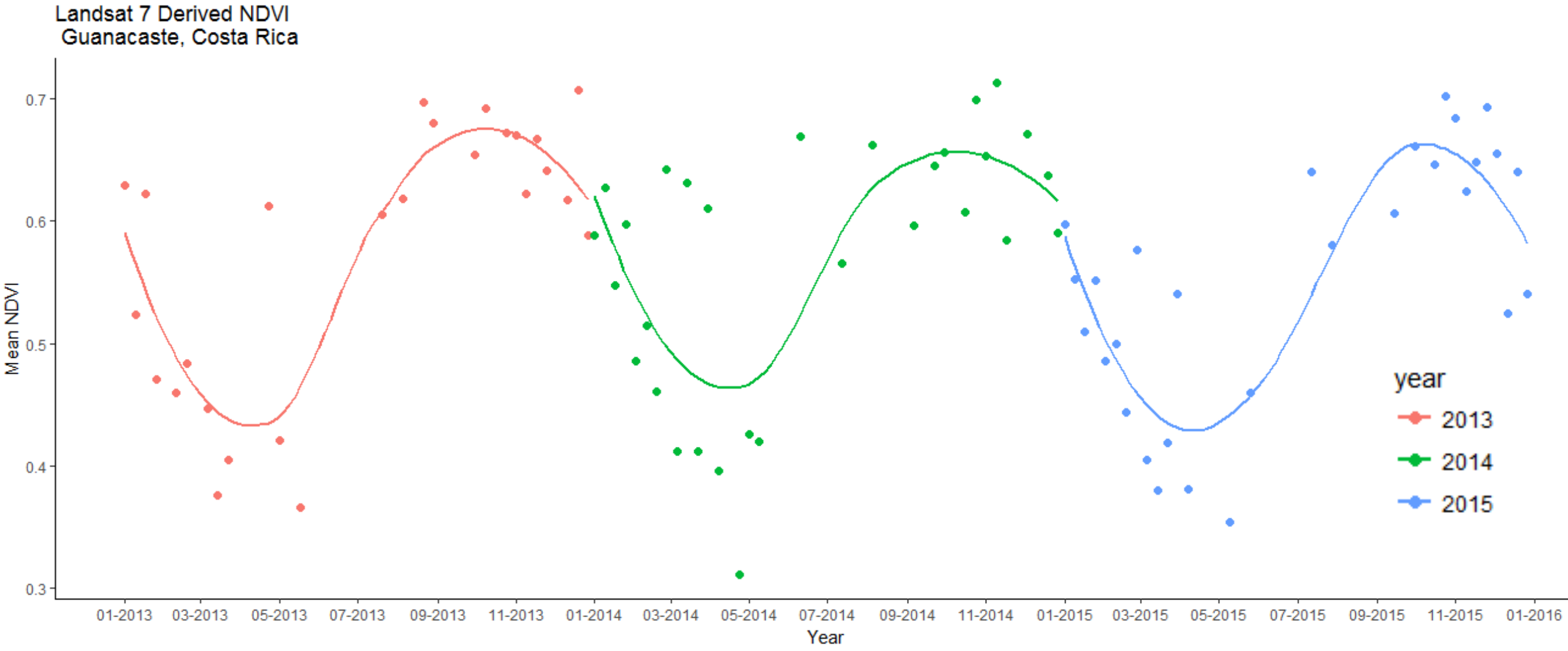
Methods – PT-JPL model

Priestley Taylor Jet Propulsion Laboratory (PT-JPL) model parameters, descriptions, equations and references from Fisher et al (2008).

R_n = net radiation
R_{nc} = net radiation to the canopy ($R_n - R_{ns}$)
R_{ns} = net radiation to the soil ($R_n \exp(-kR_n LAI)$)
LAI = total (green + non-green) leaf area index ($-\ln(1 - f_c)/ k_{PAR}$)
G = ground heat flux
T_{max} = maximum air temperature
RH = relative humidity
VPD = saturation vapor pressure deficit
Δ = saturation-to-vapor pressure curve **slope**
γ = the psychrometric constant (~ 0.066 kPa °C^{-1})

α = 1.26, β = 1.0 kPa, kR_n = 0.6, k_{PAR} = 0.5,
m1 = 1.2*1.136, b1 = 1.2*– 0.04,
m2 = 1.0, b2 = – 0.05, λ = Topt

Parameter	Description	Equation	Reference
ET	Evapotranspiration	$ET_s + ET_c + ET_i$	
ET_c	Canopy transpiration	$(1 - f_{wet}) f_g f_T f_M \alpha \Delta/\Delta+\gamma R_{nc}$	Priestley and Taylor (1972)
ET_s	Soil evaporation	$(f_{wet} + f_{SM}(1 - f_{wet})) f_g f_T f_M \alpha \Delta/\Delta+\gamma (R_{ns} - G)$	Priestley and Taylor (1972)
ET_i	Interception evaporation	$f_{wet} \alpha \Delta/\Delta+\gamma R_{nc}$	Priestley and Taylor (1972)
f_{wet}	Relative surface wetness	RH^4	Fisher et al (2008)
f_g	Green canopy fraction	fAPAR/fIPAR	
f_T	Plant temperature constraint	$\exp(-(Tmax-Topt/\lambda)\uparrow 2)$	June et al (2004)
f_M	Plant moisture constraint	fAPAR/fAPARmax	Fisher et al (2008)
f_{SM}	Soil moisture constraint	$RH^{VPD/\beta}$	Fisher et al (2008)
f_{APAR}	Fraction of PAR absorbed by green vegetation cover	$m_1 SAVI + b_1$	Gao et al (2000)
f_{IPAR}	Fraction of PAR intercepted by total vegetation cover	$m_2 NDVI + b_2$	Fisher et al (2008)
f_c	Fractional total vegetation cover	f_{IPAR}	Campbell and Norman (1998)
T_{opt}	Optimum plant growth temperature	T_{max} at max{PAR f_{APAR} T_{max} / VPD}	Fisher et al (2008)



2013

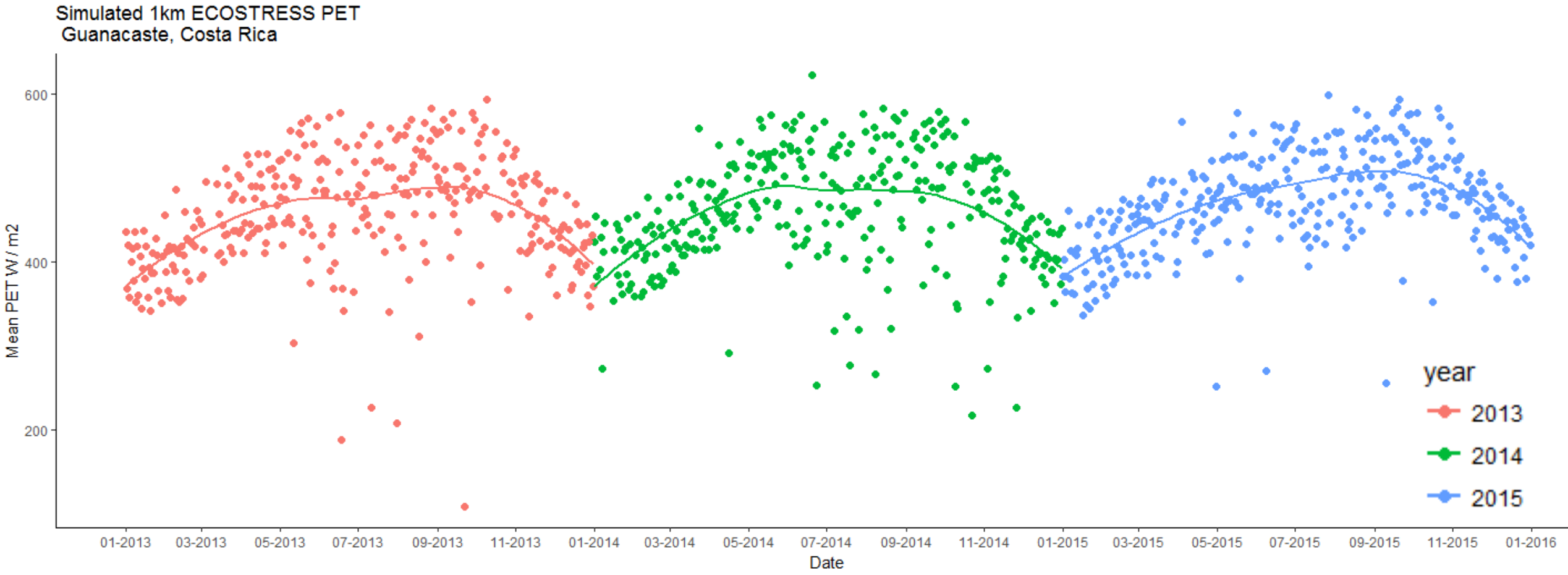
Mean = 0.575, Std. Dev. = 0.109

2014

Mean = 0.568, Std. Dev. = 0.105

2015

Mean = 0.552, Std. Dev. = 0.103



2013

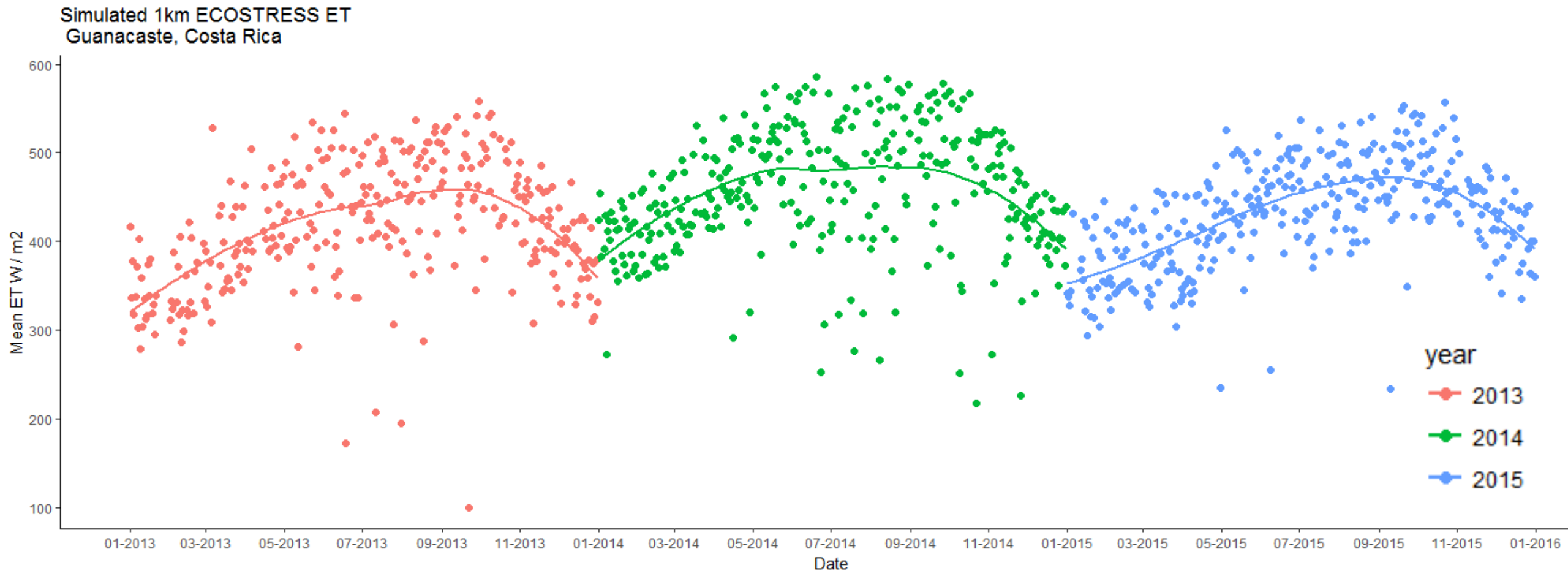
Mean = 470 w/m2, Std. Dev. = 29

2014

Mean = 457 w/m2, Std. Dev. = 27

2015

Mean w/m2 = 456, Std. Dev. = 23



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

	Sum Sq	DF	F	P-Value
(Intercept)	1585.96	1	1454400	<0.0001
Year	19.69	3	6019.5	<0.0001
Season	0.95	1	869.76	<0.0001
LC	0.15	2	68.042	<0.0001
Year*Season	10.99	3	3358.2	<0.0001
Year*LC	0.14	6	22.042	<0.0001
Season:*LC	0.03	2	15.919	<0.0001
Year*Season*LC	0.04	6	6.235	<0.0001
Residuals	48.42	44227		