Optimization of Anchor Pixel Selection in Surface Energy Balance Algorithm for Land (SEBAL) Using Genetic Algorithm for Enhanced SWAT Model Calibration with Evapotranspiration Data

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Table of Contents

- Introduction
- Literature Review
- Research Gaps
- Methodology
- Results
- References

Introduction: Why Streamflow Calibration Alone Falls Short in SWAT Modeling?

Problem Statement

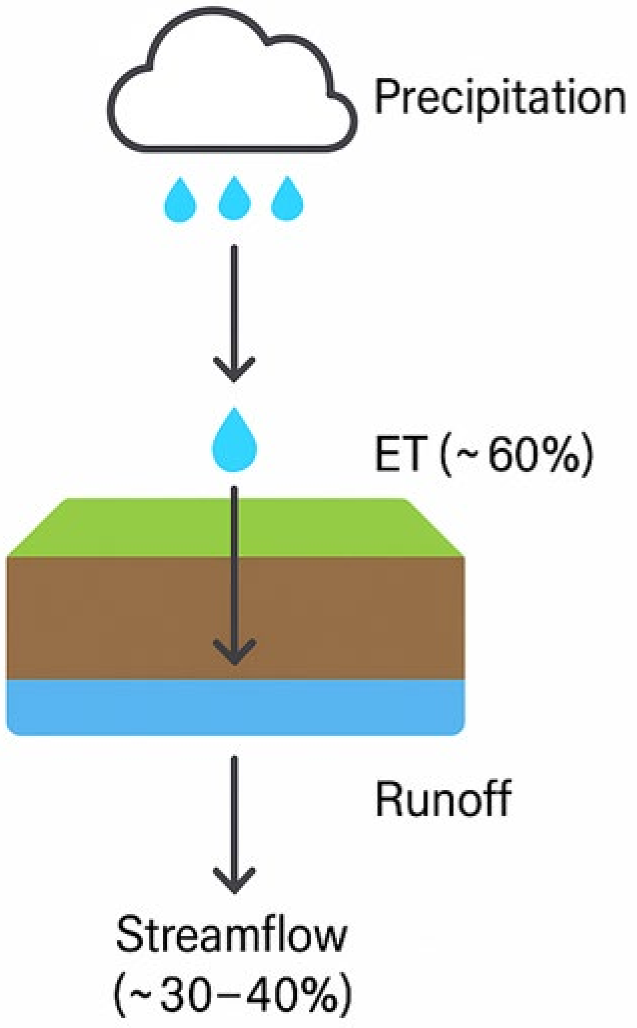
•SWAT calibration often focuses only on streamflow.
•However, streamflow represents <40% of the terrestrial water balance.
•Evapotranspiration (ET) accounts for ~60% or more, especially in agriculture.

Consequences of ignoring ET

🔄 Compensating errors: Hidden issues in ET, soil moisture, percolation.
🌱 Unrealistic ET estimates: Distorts crop water use accuracy.
📉 Poor internal validation: Misrepresentation of water balance components.

Why Include ET in Calibration?

•More realistic partitioning of water
•Improves model accuracy for crop and water planning.
•Better for climate-smart agriculture strategies



Literature Review – Evapotranspiration estimation

In-situ measurement

- Bowen ratio
- Lysimeter

- Eddy Flux

Remote Sensing based Estimates

- Energy balance based methods
- Water balance method
- PT/PM based methods

Empirical based Estimates

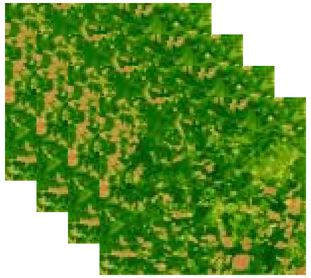
- Thornthwaite method
- Hargreaves method
- Penman-Monteith
- Priestley Taylor

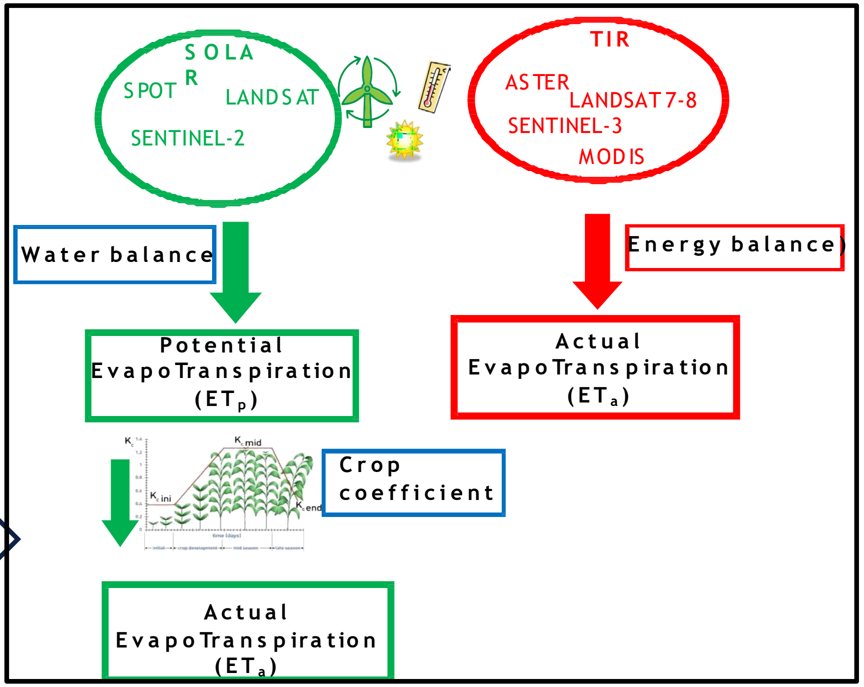
Source: Zhang et al. 2016

Literature Review – Evapotranspiration estimation

(Lakhiar et al., 2025)
ET estimation using in situ measurements

- Traditional methods of ET measurement like **lysimeter and Bowen ratio** provide only localized ET.
- Continuous ET estimation is inherently difficult to obtain on a larger basin or sub basin scale.





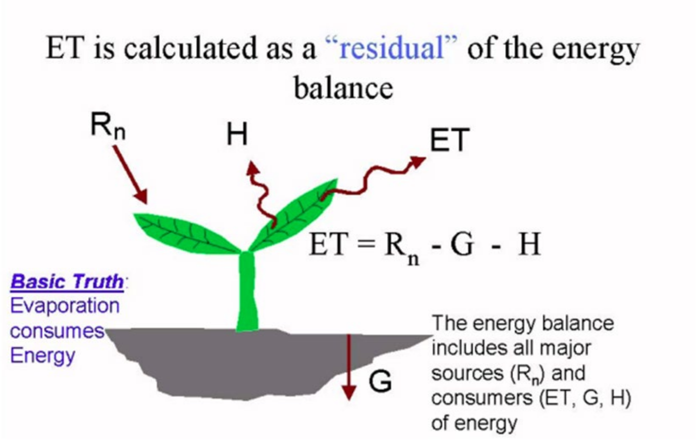
(Amani et al., 2023)
Remote sensing based ET estimates

- Remote sensing-based ET estimation gives accurate data for a larger scale.
- Remote sensing estimates ET using **VNIR** bands, such as in the **Penman-Monteith method**, relying on vegetation reflectance, **and thermal bands**, applied in **energy balance equations** for ET estimation based on surface temperature

(Aryalekshmi et al., (2021)
IPA using Remote sensing based ET estimates

- **Energy balance methods** are favored for estimating Actual ET as they utilize an energy balance approach, in contrast to methods relying on reference ET and tabulated crop coefficients, providing a more direct assessment of ET.

Energy balance model



Net radiation: $R_n = R_{s\downarrow} - \alpha R_{s\downarrow} + R_{L\downarrow} - R_{L\uparrow} - (1-\varepsilon_o)R_{L\downarrow}$

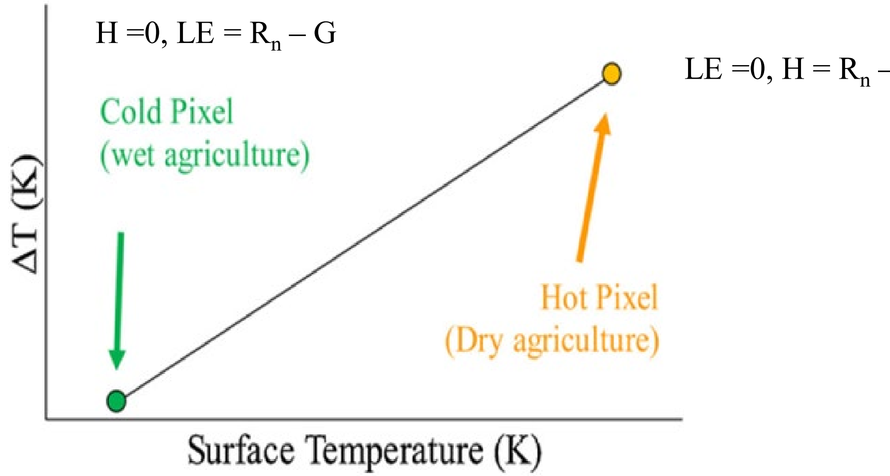
Soil Heat Flux: $G = R_n \left(\frac{T_s}{\alpha}\right) \times (0.0038\,\alpha + 0.0074\alpha^2) \times (1 - 0.98\,NDVI^4)$

Sensible Heat Flux: $H = \rho\, C_p \frac{dT}{r_{ah}}$

Anchor pixel selection in SEBAL

$$dT = aT_s + b$$

- The SEBAL process utilizes two "anchor" pixels to fix boundary conditions for the energy balance
- The "cold" pixel is selected as a wet, well-irrigated crop surface having full ground cover by vegetation
- The surface temperature and near-surface air temperature are assumed to be similar at the cold anchor pixel
- The "hot" pixel is selected as a dry, bare agricultural field where ET is assumed to be zero



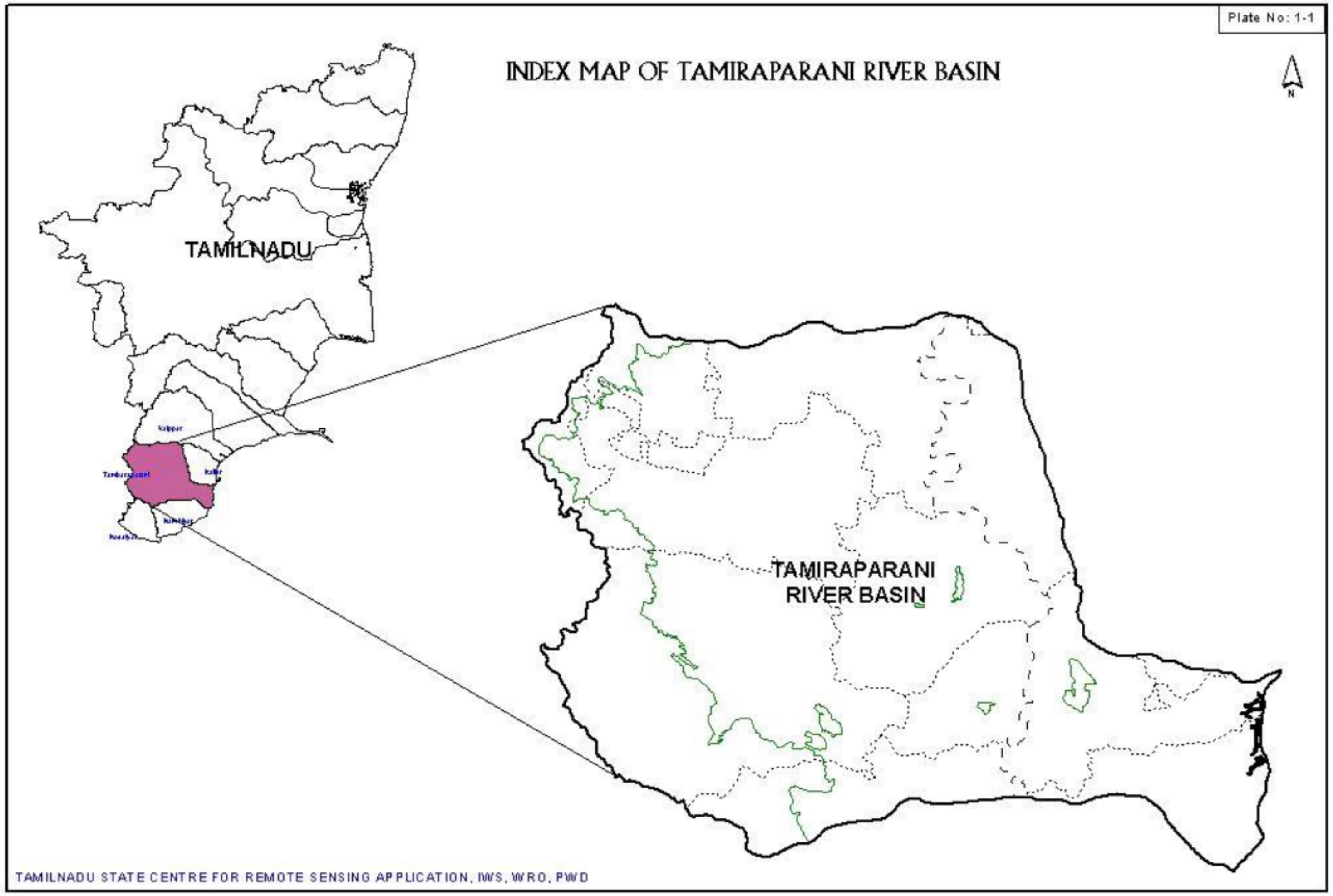
Literature Review – Energy balance models

Reference	Methodology	Review
Allen et al., (2015)	Performed sensitivity analysis of SEBAL and METRIC with respect to the input parameters	• The selection of anchor pixels is subjective and totally depends upon the modeler. This selection can induce a lot of uncertainty in the model especially when applied to a vast heterogenous terrain
Long et al., (2011)	Performed sensitivity analysis of SEBAL model with respect to **spatial scale** by implementing SEBAL model on three	• SEBAL suffer from domain dependence if the selected extreme pixels show disparate characteristic

Inference:

- ➢ A significant source of uncertainty in the Energy Balance model arises from the Anchor pixels, which impact the model's application on heterogeneous terrain.
- ➢ Demarcating the boundary of a study site within which there exists a “sufficiently large hydrologic contrast” really poses a big challenge for the appropriate use of SEBAL

Study area



Index Map of Study area :Tamiraparani River basin (National Water Mission,2017)

- The Tamiraparani River Basin is one of Tamil Nadu's 17 river basins, comprising 7 sub-basins
- The area experiences two primary crop growing seasons: Kar (June to September during the south-west monsoon) and Pishanam (November to February during the north-east monsoon).
- Crop patterns vary across Taluks, with paddy being the dominant crop at 43% of the total cultivated area, followed by pulses.
- Other crops include banana, sugarcane, maize, groundnut, and coconut

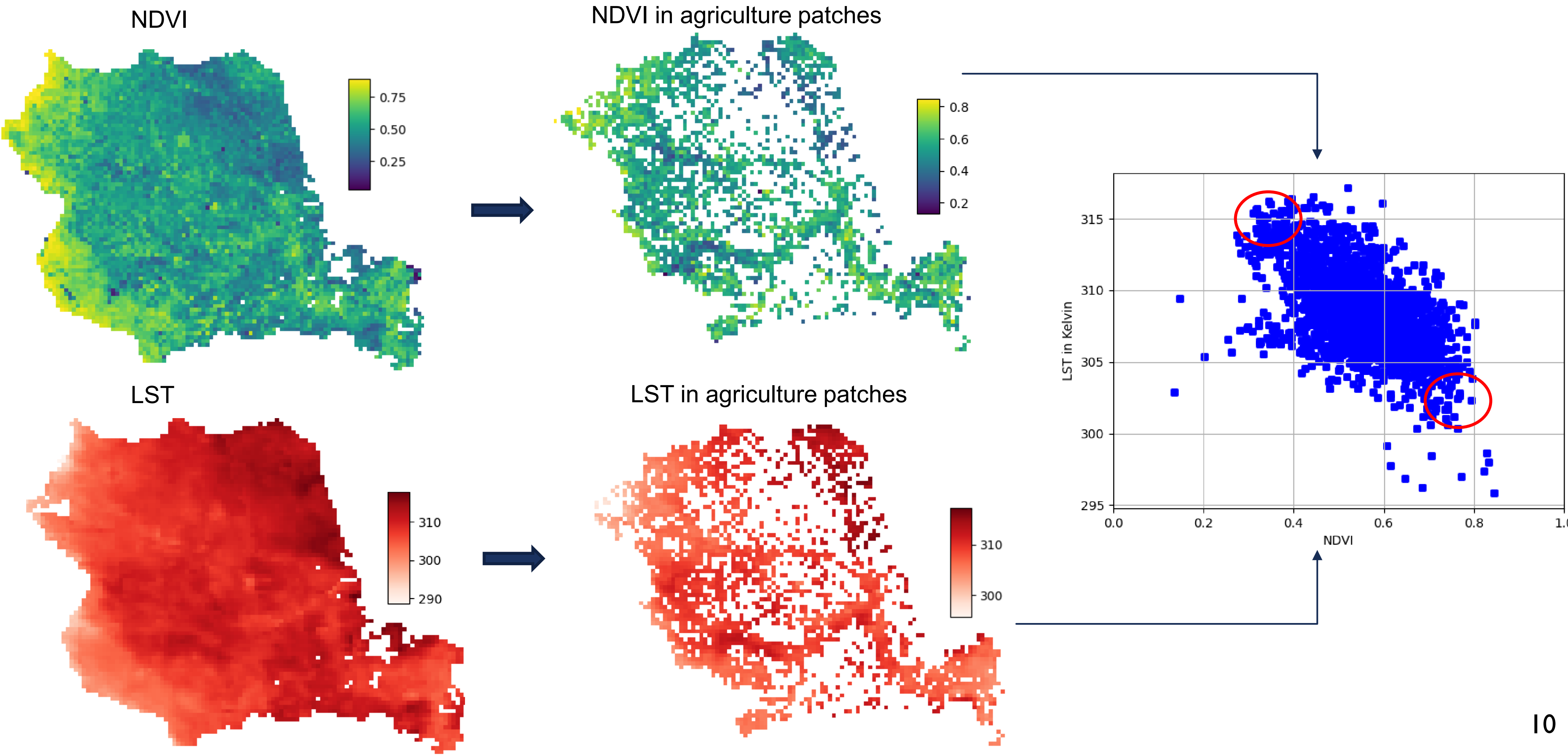
Remote sensing Datasets

Datasets:

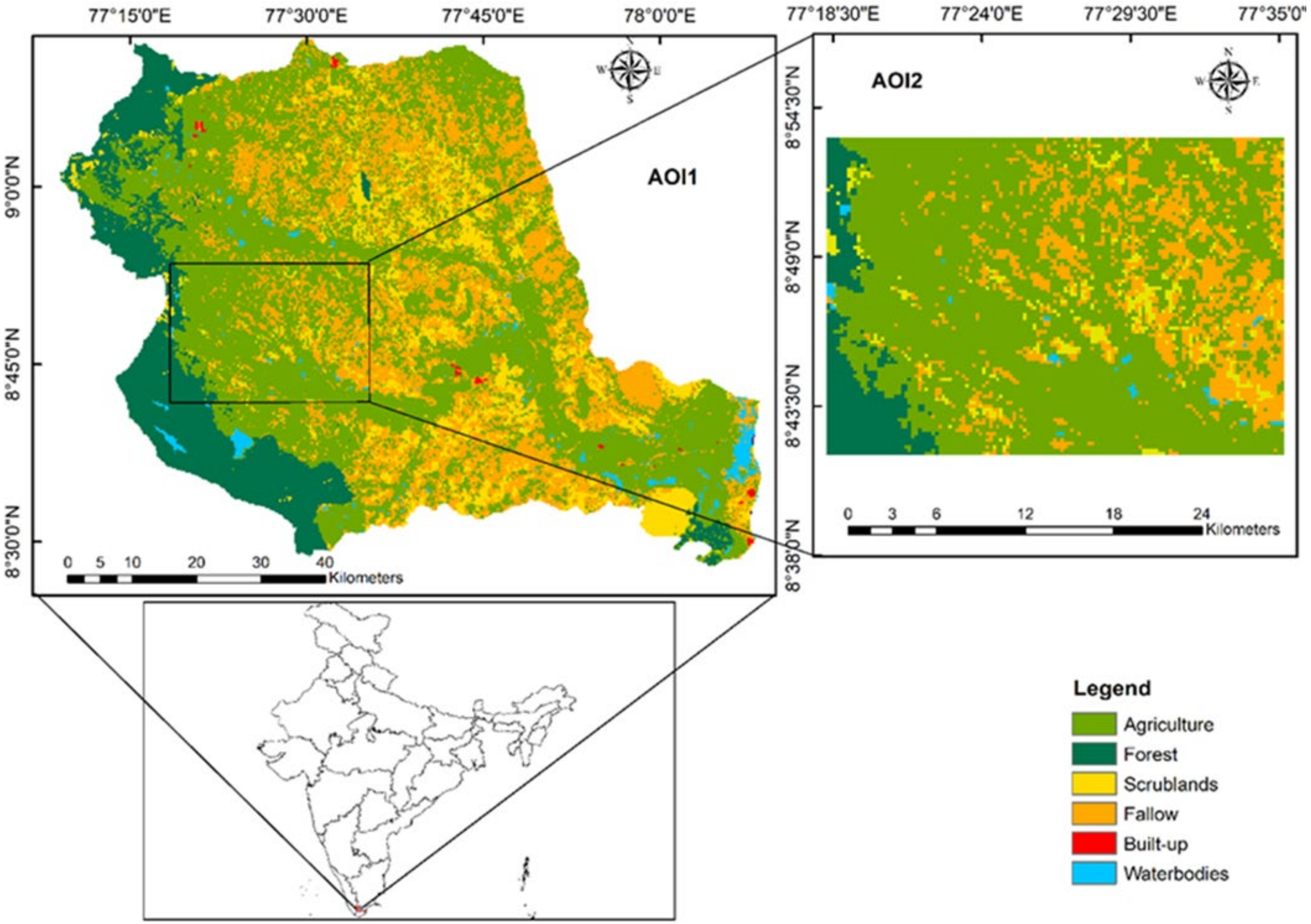
- MODIS - Surface reflectance bands 1 to 4 (MOD09A1), Emissivity 31and 32(MOD11A2), Leaf area index (MCD15A2H), solar zenith (MOD09A1), **Land surface Temperature (LST)** (MOD11A2) and Normalized Difference Vegetation Index (NDVI) (MOD13Q1 and MYD13A1).
- NRSC LULC map.
- DEM from SRTM
- Wind velocity from the Indian reanalysis data portal
- All the datasets will be resampled to 1000m

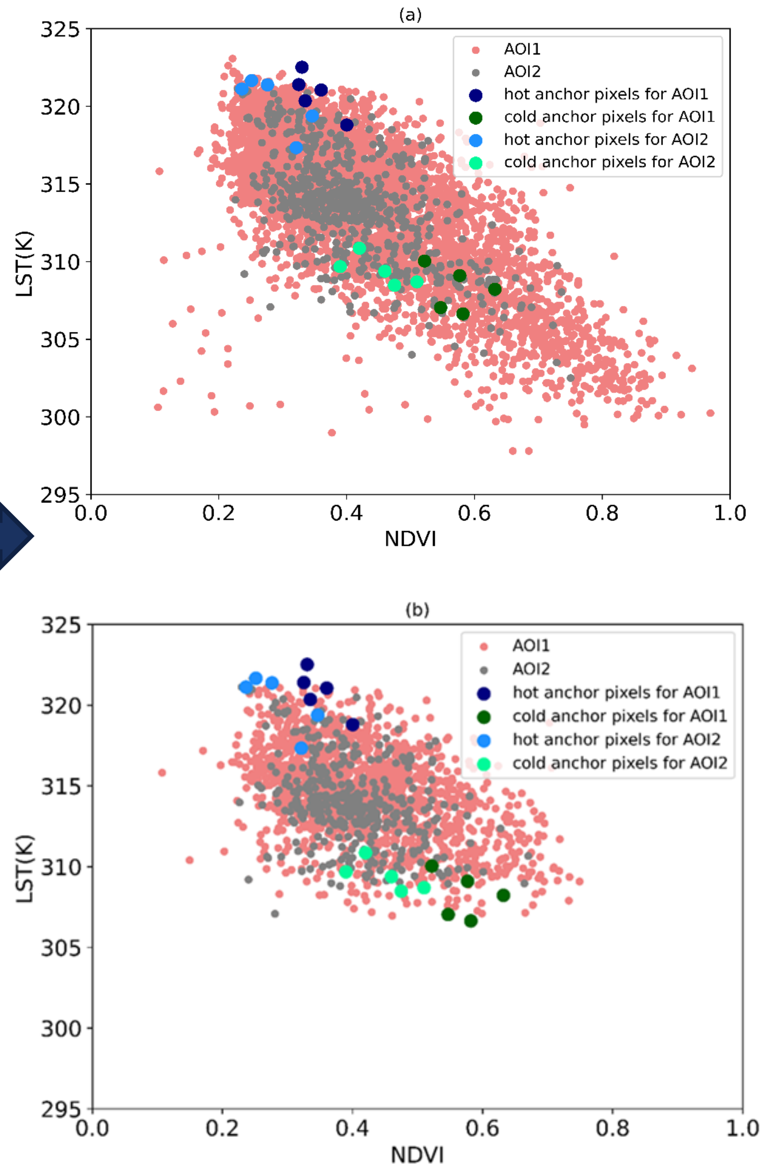
Time period used for current analysis: May 2015- June 2016

Anchor pixel selection in SEBAL– Based on linear relationship between LST and NDVI



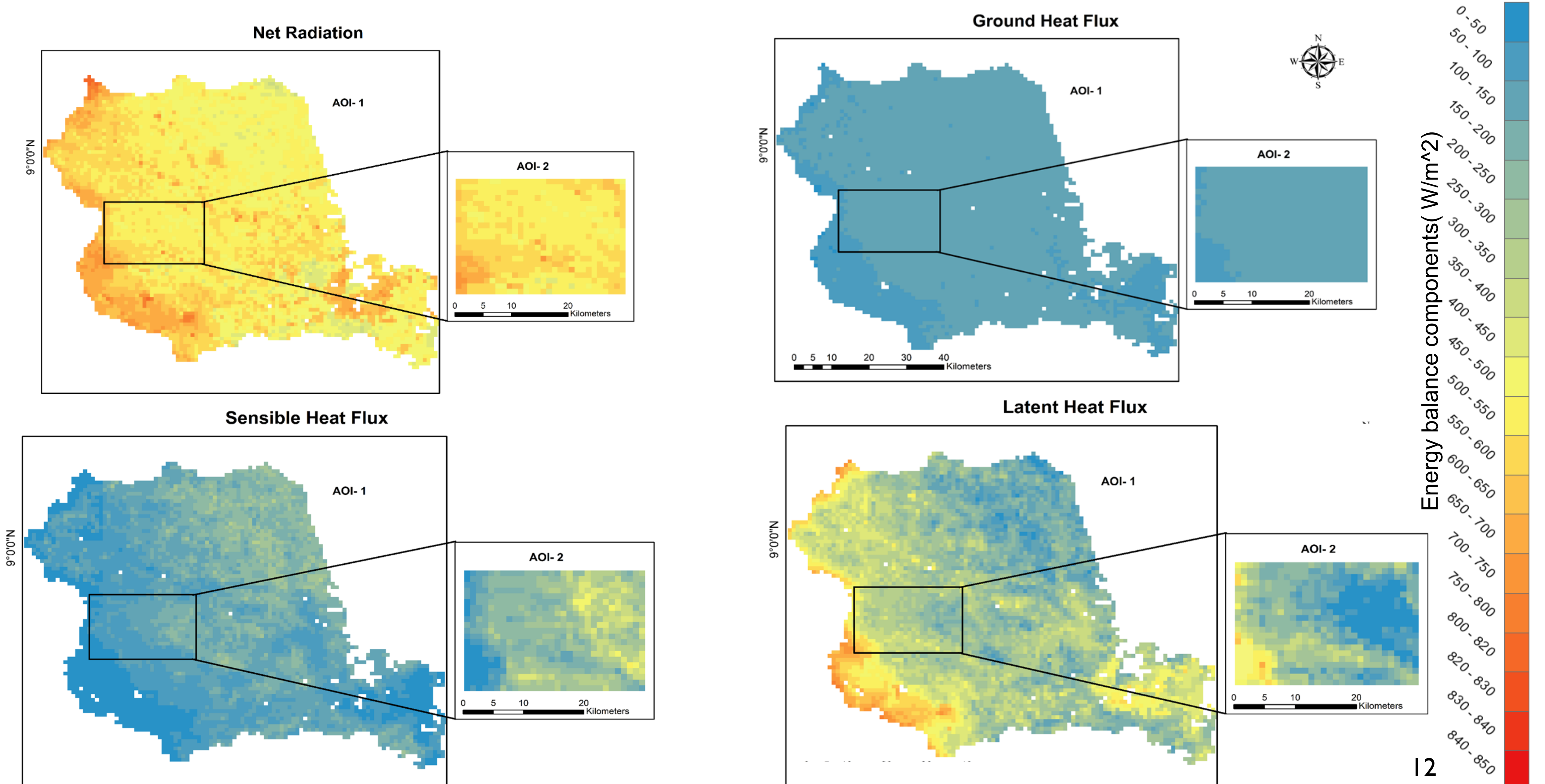
Sensitivity due to spatial scale – change in anchor pixel location



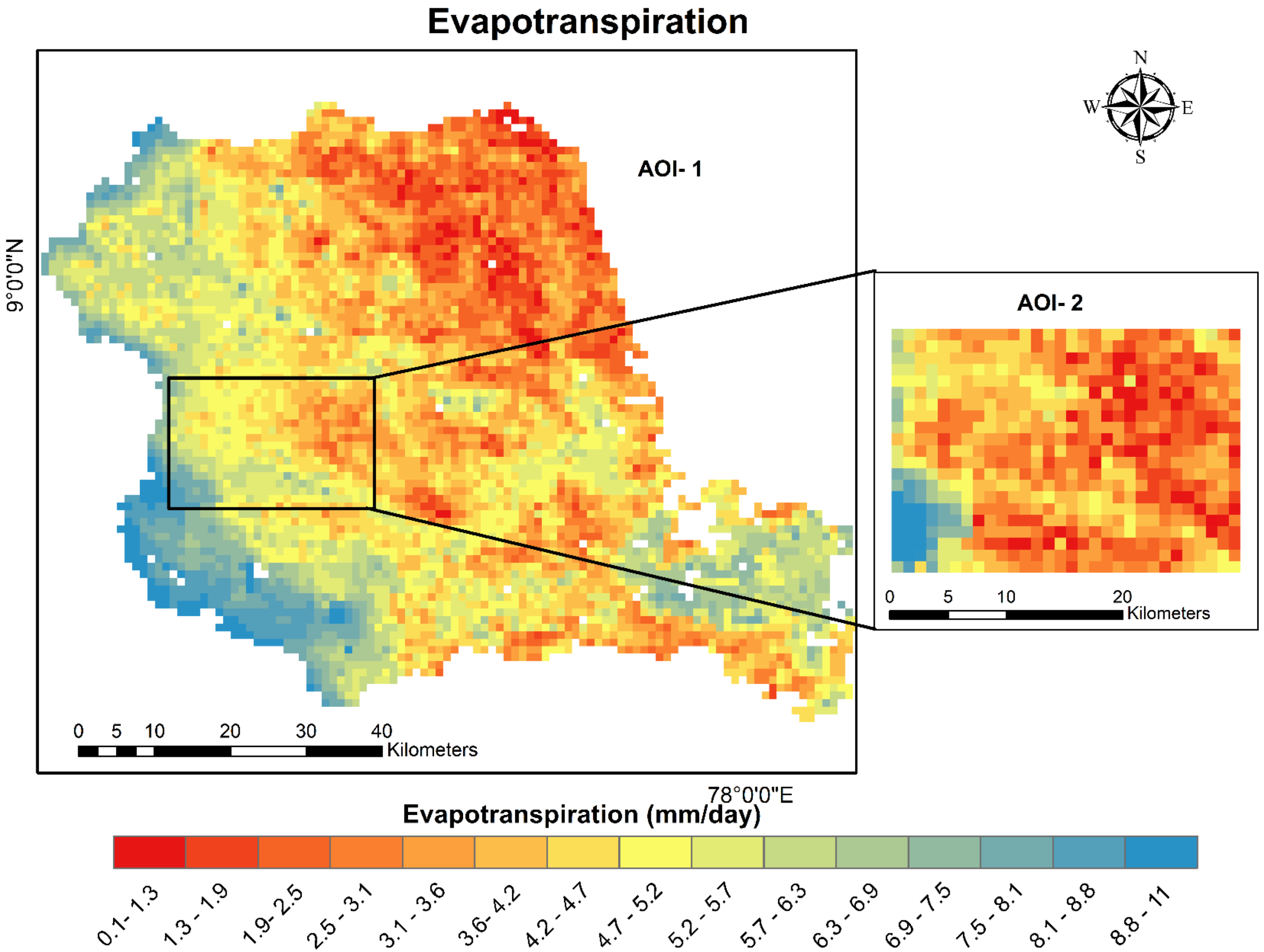


NDVI-LST scatter plot for image acquired 17th May 2015 (a) Entire Image and (b) only masked-out agricultural area

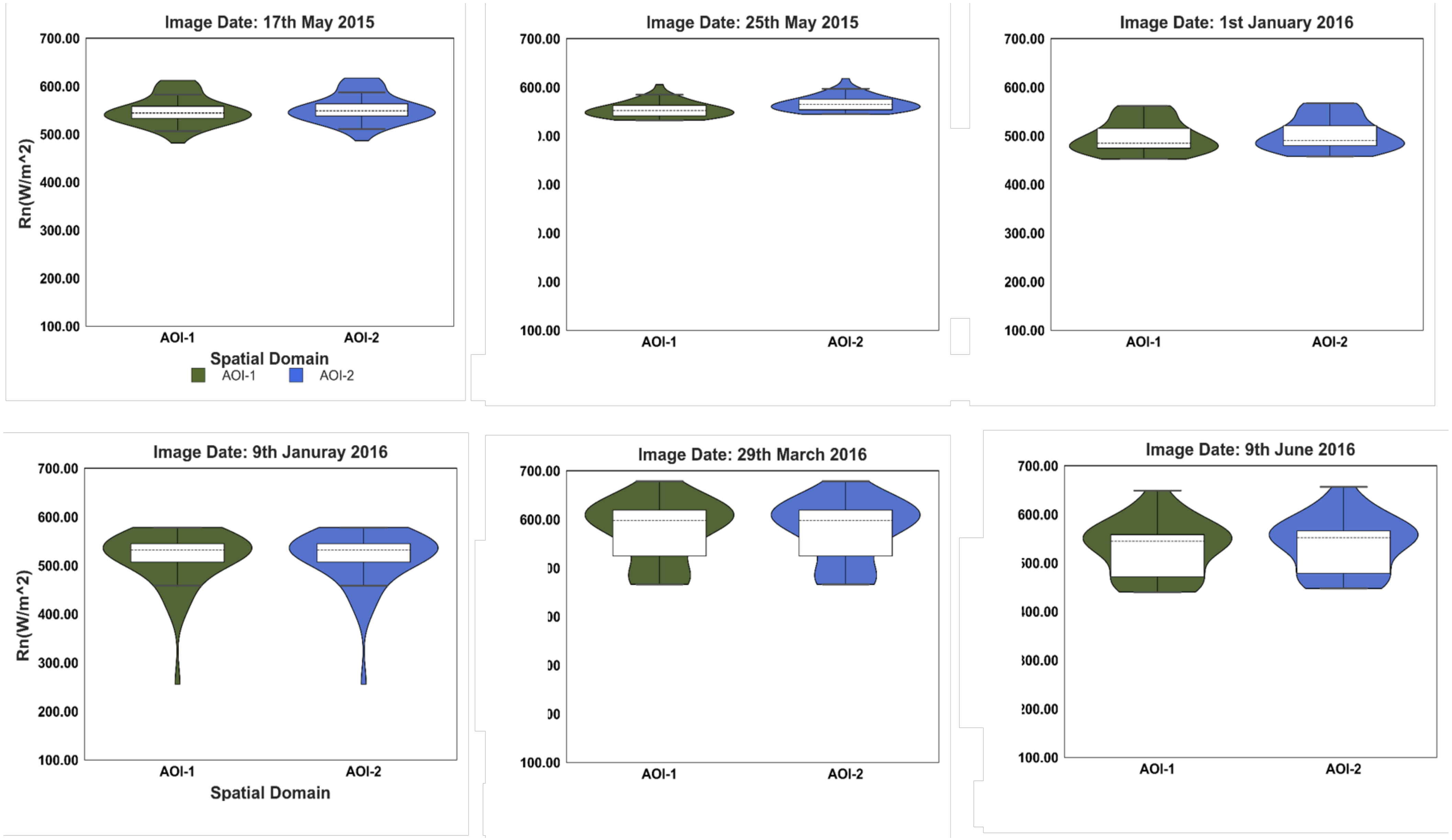
Energy Balance Components estimated for the image captured on May 17th 2015



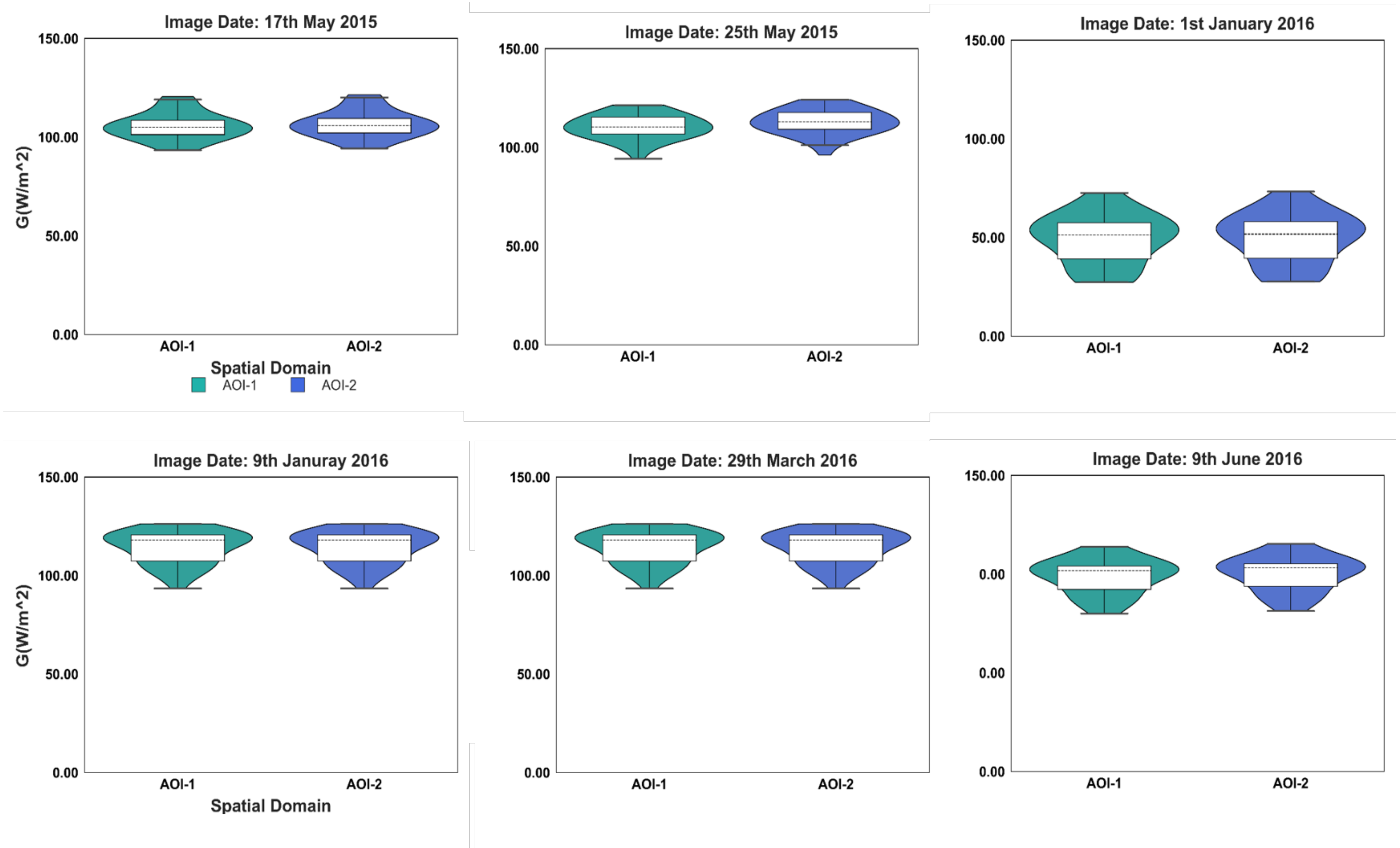
Evapotranspiration modelled by SEBAL on the image acquired on May 17th 2015



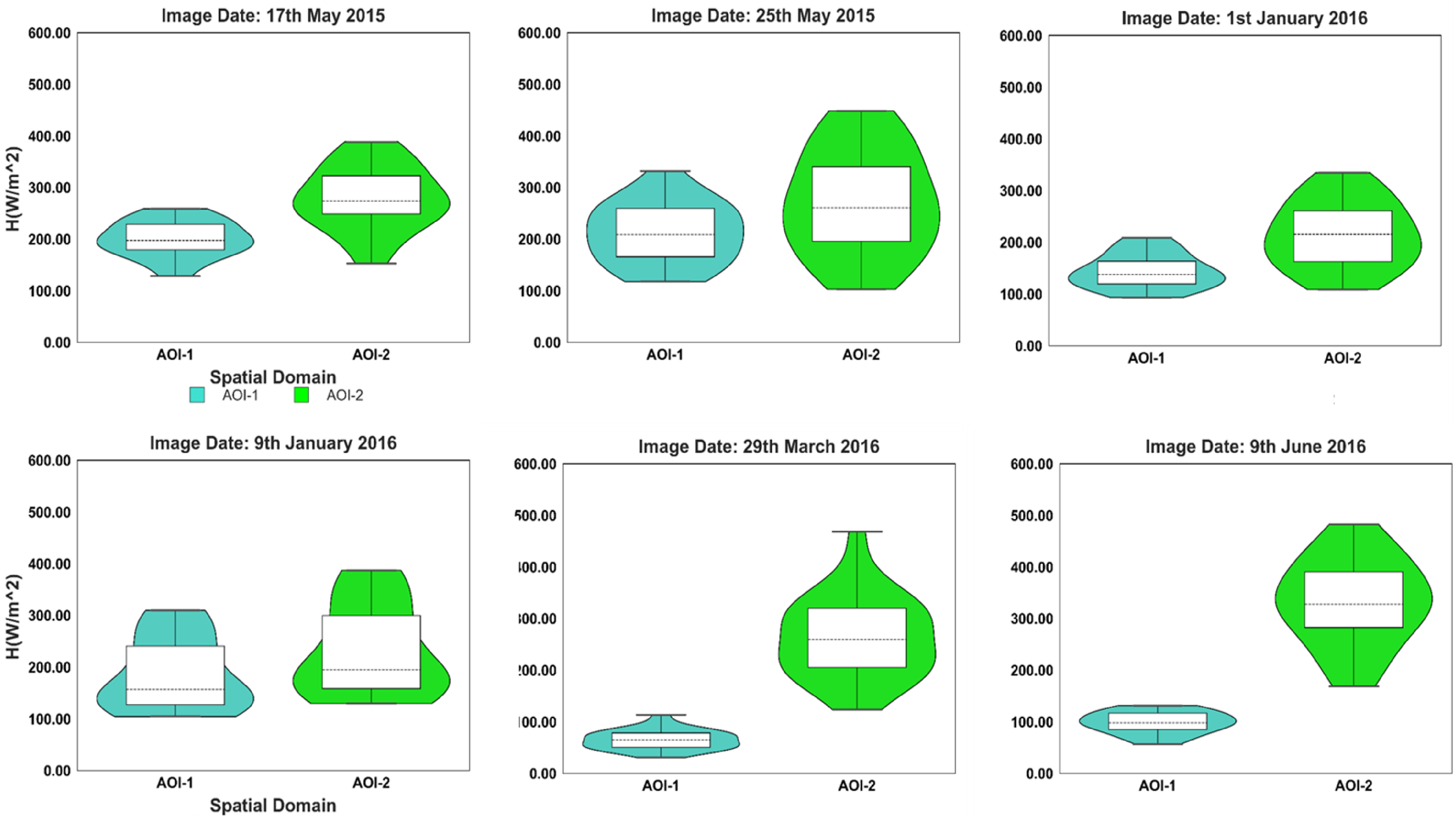
Distribution of Rn estimates over two spatial domains



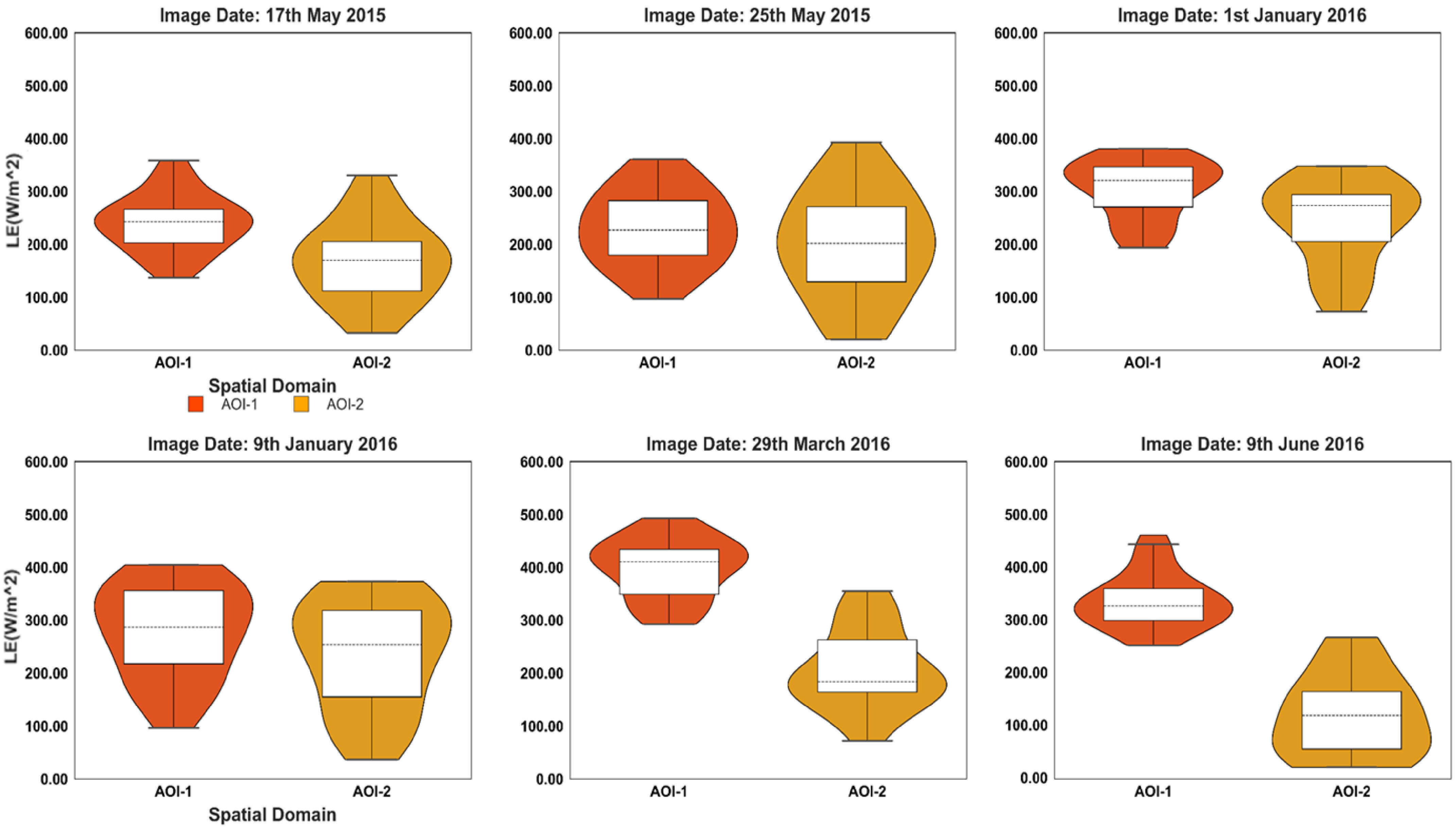
Distribution of G estimates over two spatial domains



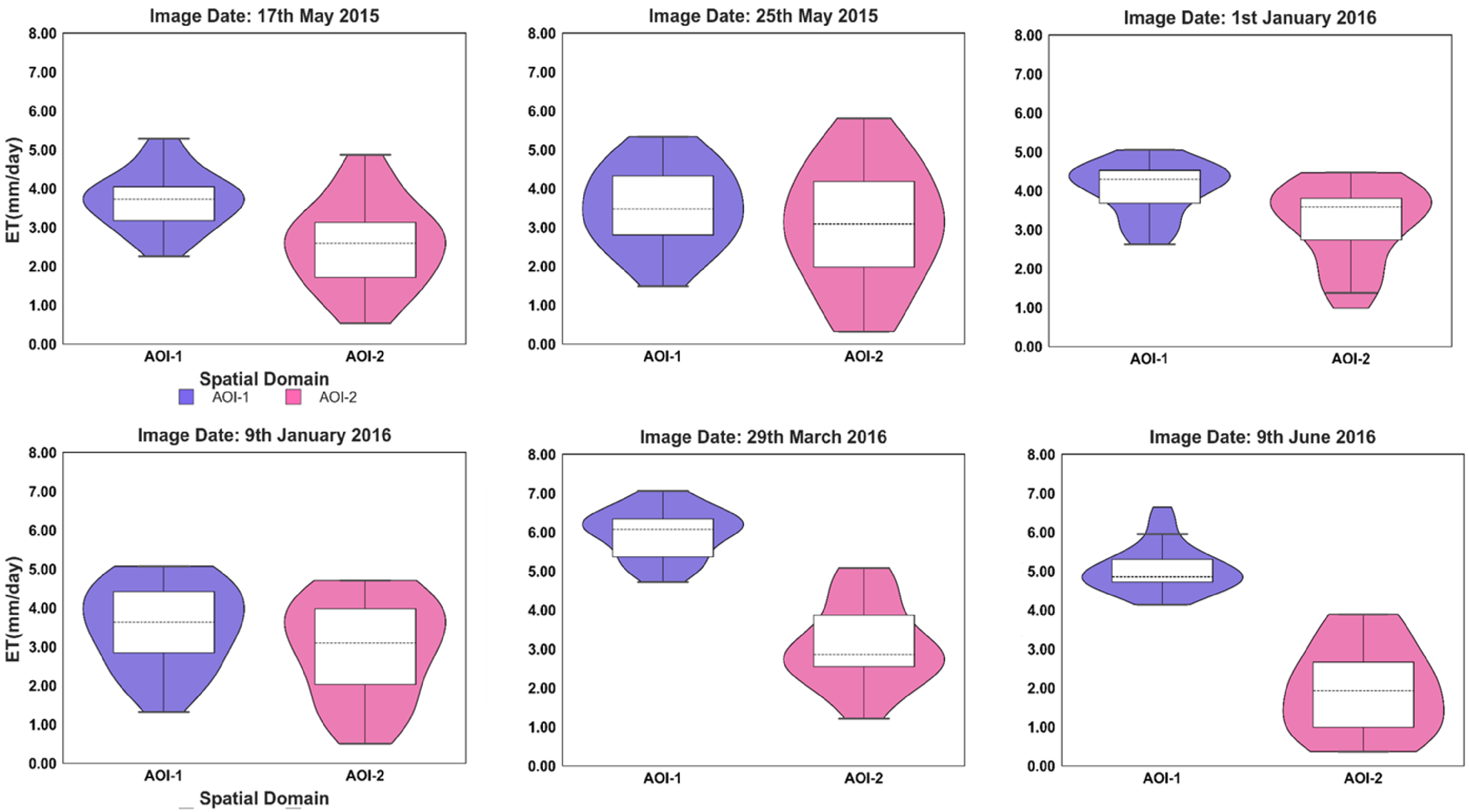
Distribution of H estimates over two spatial domains



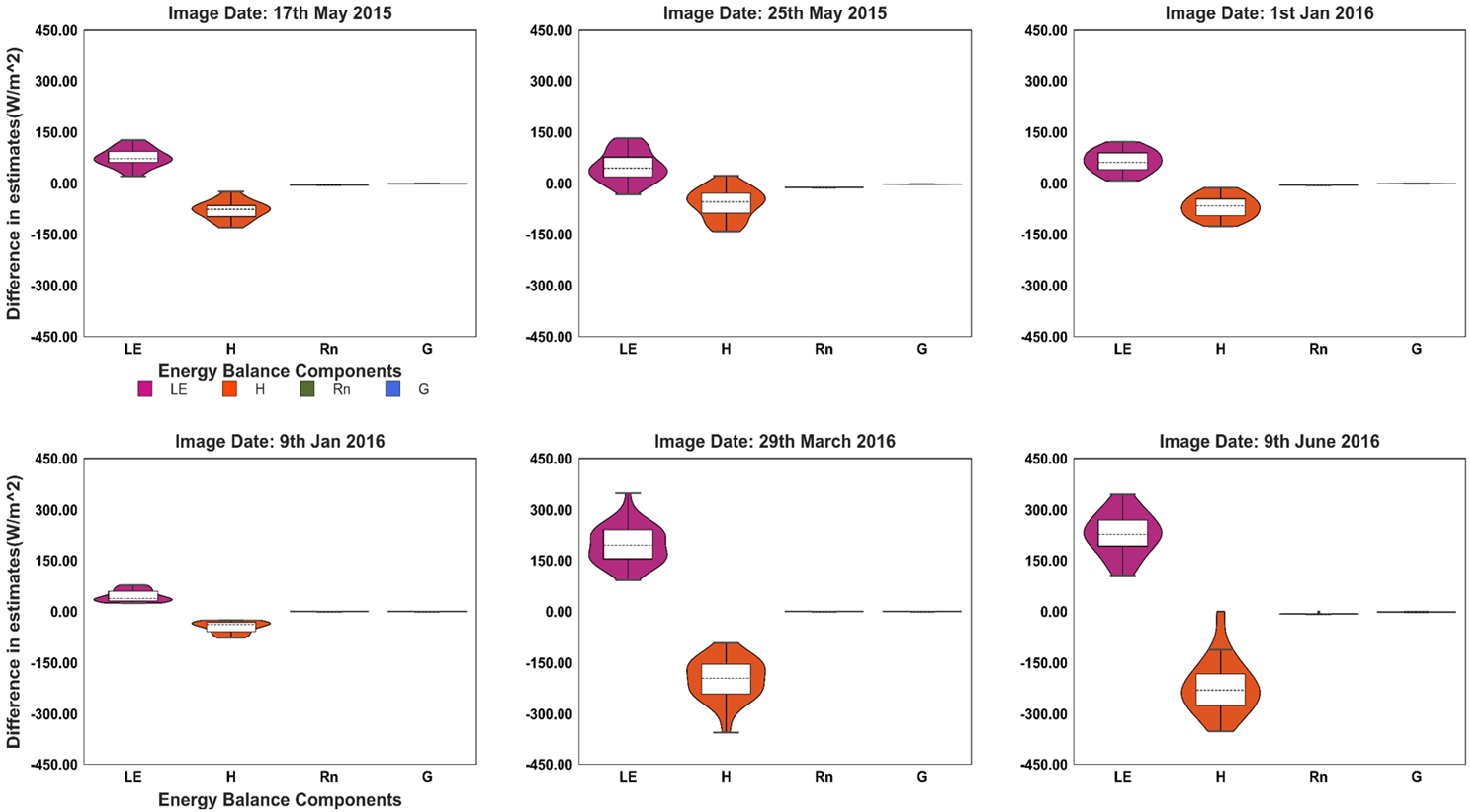
Distribution of LE estimates over two spatial domains



Distribution of ET estimates over two spatial domains



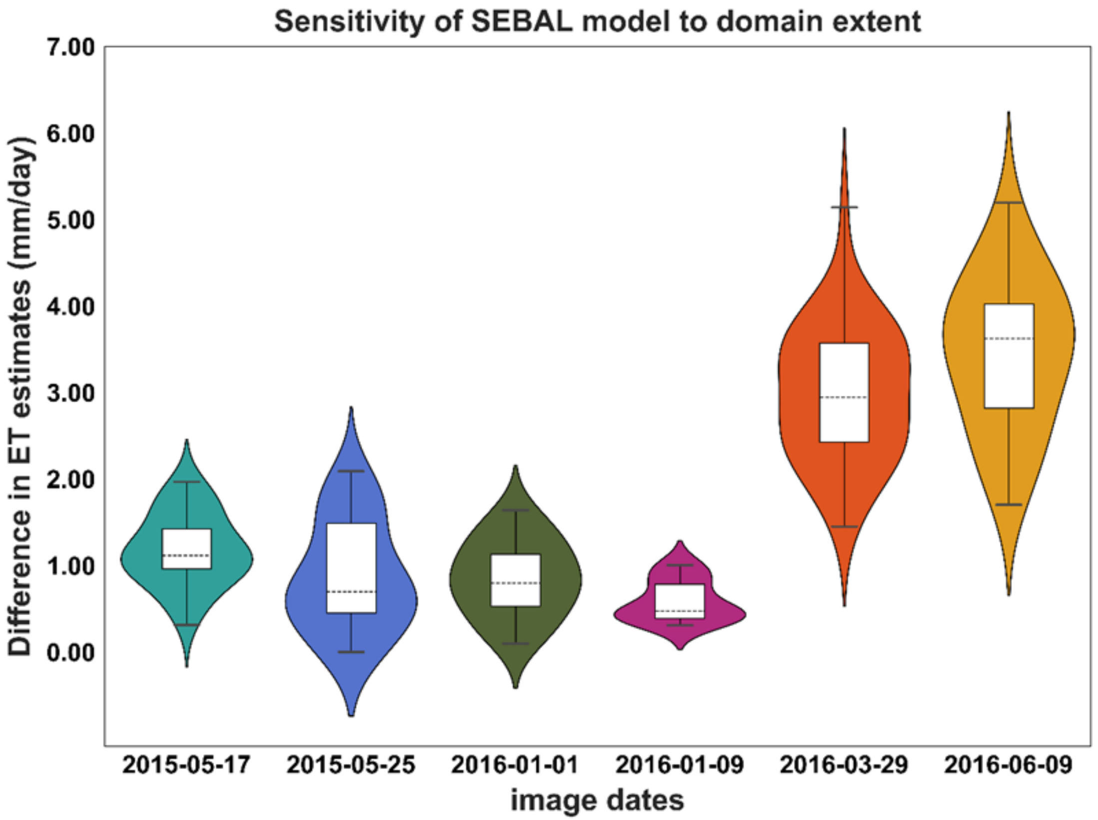
Pixel wise difference in Energy balance components while applying SEBAL model on two spatial domains



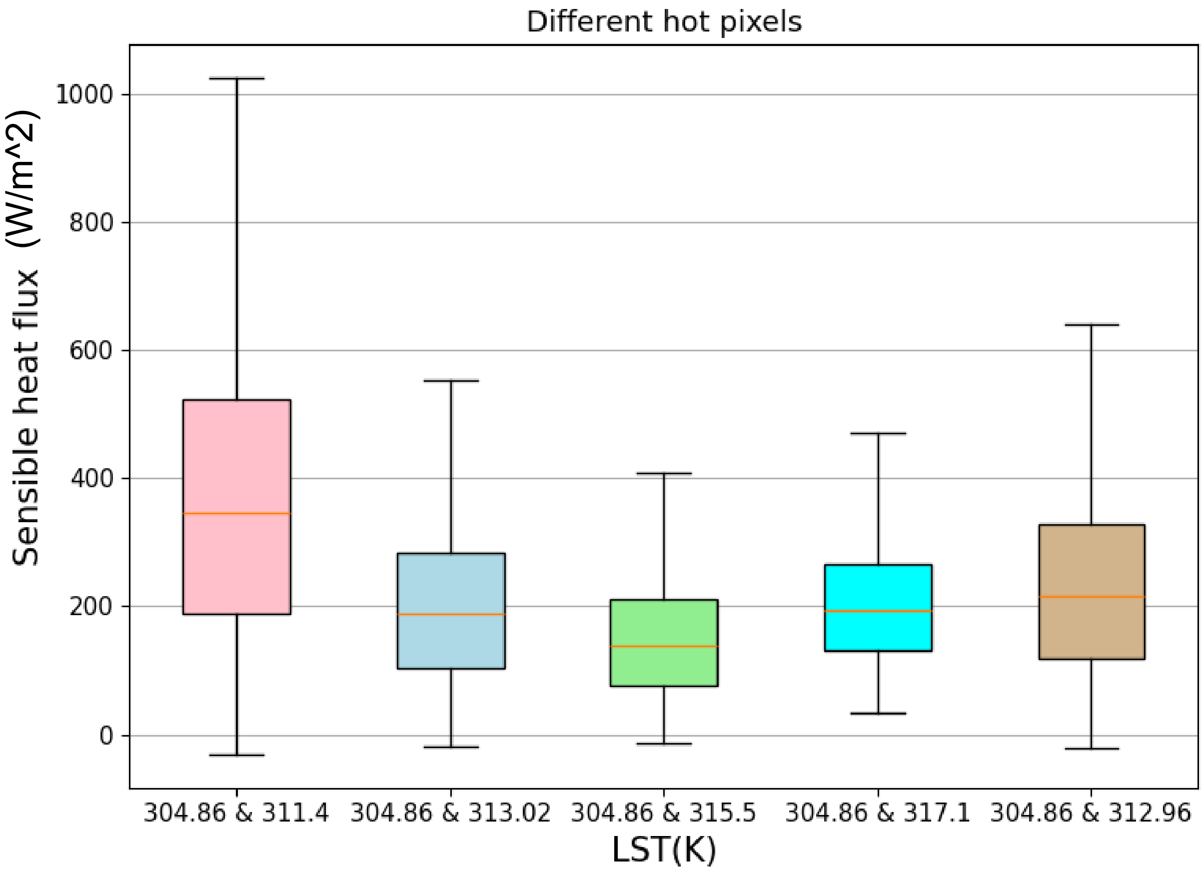
Pixel wise difference in ET estimates while applying SEBAL model on two spatial domains

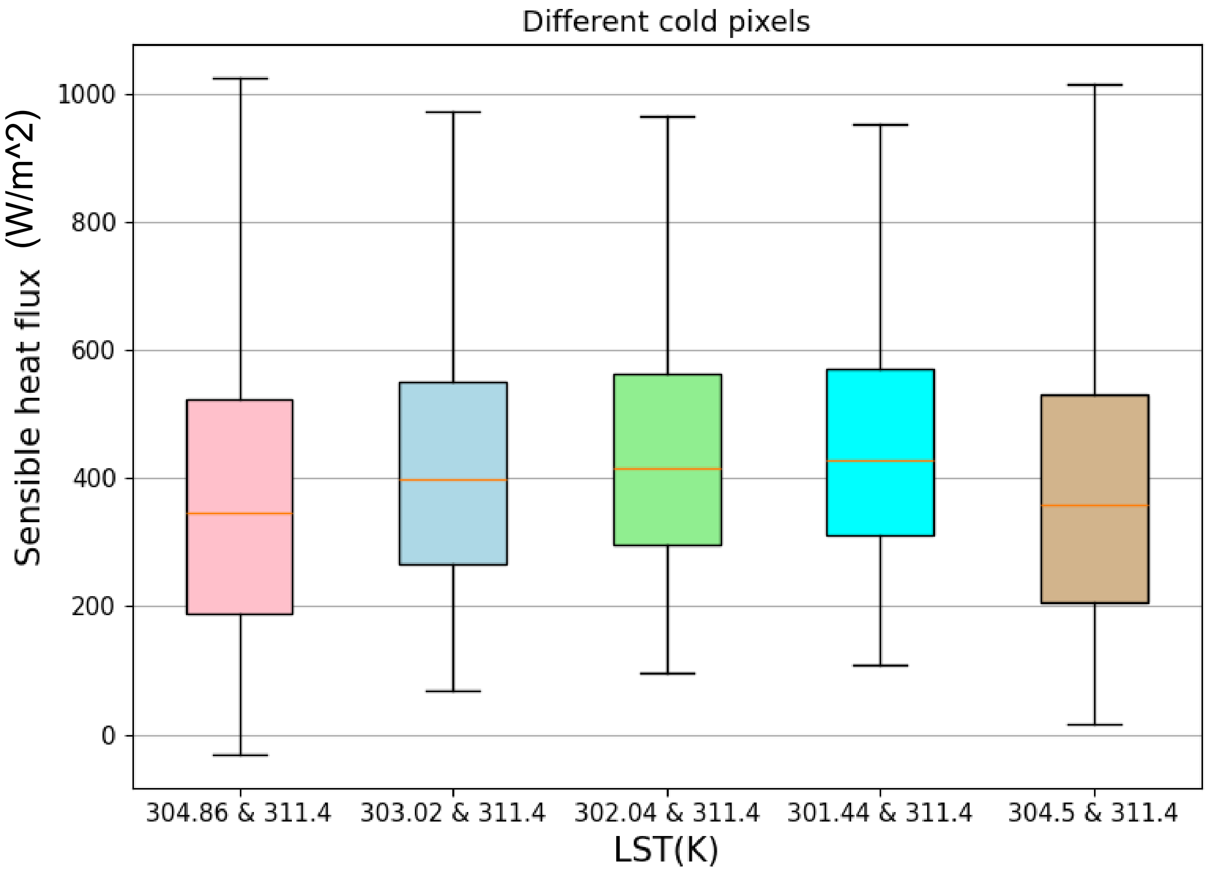
Anchor Pixel Characteristics

Image date	AOI	T_{hot} (in K)	T_{cold} (in K)	$NDVI_{hot}$	$NDVI_{cold}$
17-May-2015	1	315.7	303.46	0.31	0.58
	2	313.14	304.46	0.38	0.55
25-May-2015	1	317.68	303.58	0.36	0.67
	2	315.66	306.14	0.29	0.63
1-January-2016	1	303.86	297.14	0.60	0.83
	2	303.78	298.36	0.59	0.85
9-January-2016	1	304.98	295.88	0.34	0.75
	2	304.3	295.88	0.65	0.75
29-March 2016	1	324.62	303.86	0.25	0.71
	2	313.48	303.86	0.33	0.71
9-June-2016	1	317.28	299.16	0.28	0.64
	2	309.88	300.76	0.11	0.58



Sensitivity analysis of SEBAL due to Anchor pixels





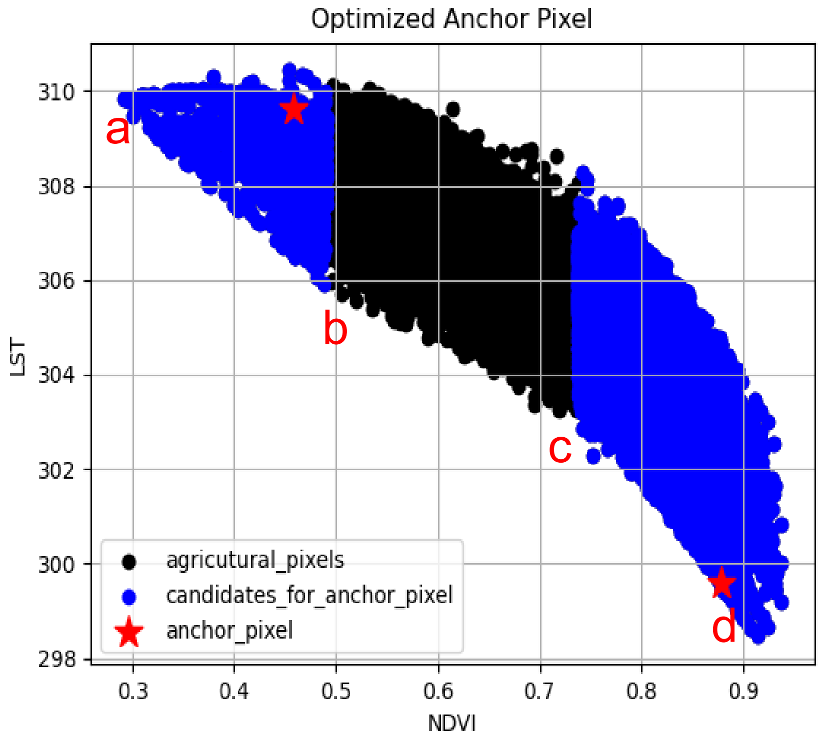
Optimization of SEBAL model using genetic Algorithm

- Setting the boundaries for selecting the anchor pixels based on NDVI

- Finding the maximum and minimum NDVI in the study area :

  Candidate hot anchor pixels = (minimum NDVI, minimum NDVI + 0.20)

  Candidate cold anchor pixels = (maximum NDVI - 0.20, maximum NDVI)



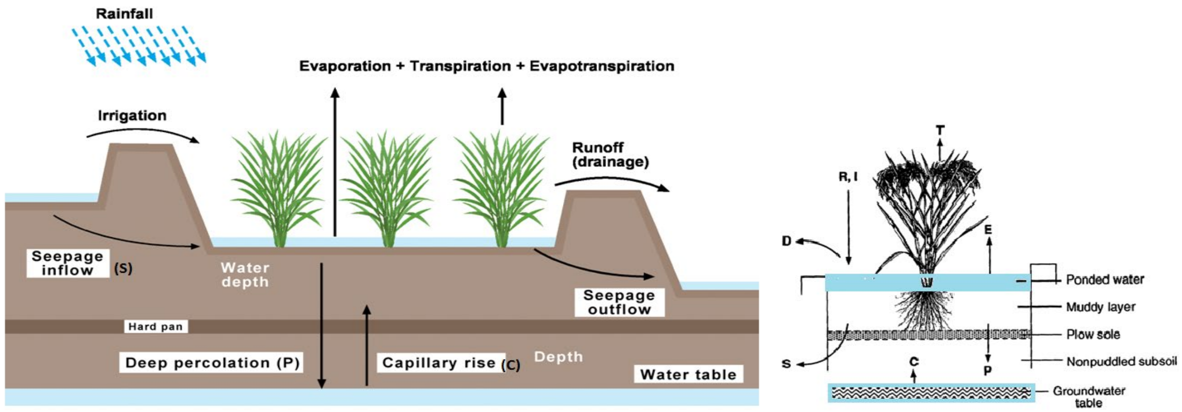
Hot Anchor Pixel: $LST_{opt} = LST_b + x1 * (LST_a - LST_b)$

Cold Anchor Pixel: $LST_{opt} = LST_d + x2 * (LST_c - LST_d)$

Find The Optimized Anchor Pixel By Using The Genetic Algorithm

- Variables = *x1* and *x2*
- Objective Function: $\sum_{i=1}^{n}\{ET_{EB} - ET_{observed}\}$

Estimation of ET using the water balance approach in paddy fields



$$\boxed{ET = I + C + R - dW - S - P - D}$$

Schematic diagrams representing the water balance in the paddy field. (Source: IRRI & Bouman et al., 2001)

- Equation (1) for calculating ET requires measuring or estimating various water balance components, including precipitation (P), irrigation (I), runoff, (R) capillary rise (C), percolation (P), seepage (S) and change in soil water storage (dW).

- Precipitation and irrigation are straightforward to measure, estimating percolation and soil water storage changes often necessitates specialized instruments like neutron probes and time-domain reflectometers

- The requirement for these instruments and the intricate process of estimating ET can limit the practicality of field-based ET measurements.

- In this context, this study focuses on utilizing available field data in a field level water balance model to estimate other water balance components and subsequently derive ET estimates.

References

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- Results
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2

1. (2007). Satellite-based energy balance for mapping evapotranspiration with internalized calibration (metric)4,Journal of 3(4):380–394.

2. Amani, S., & Shafizadeh-Moghadam, H. (2023). A review of machine learning models and influential factors for estimating evapotranspiration using remote sensing and ground-based data. Agricultural Water Management, 284, 108324. https://doi.org/10.1016/j.agwat.2023.10832

3. Allen, R.G., Kilic, A., Trezza, R., Hendrickx, J., Bastiaanssen, W., & Kjaersgaard, J. (2011). Satellite-based ET estimation in agriculture using SEBAL and METRIC. Hydrological Processes, 25, 4011–4027.

4. Allen, R.G., Tasumi, M., Morse, A., Trezza, R., Wright, J.L., Bastiaanssen, W., Kramber, W., Lorite, I., & Robison, C.W. (2007). Satellite-based energy balance for mapping evapotranspiration with internalized calibration (METRIC)—Applications. Journal of Irrigation and Drainage Engineering, 133(4), 395–406.

5. Allen, R.G., Tasumi, M., & Trezza, R. (2007). Satellite-based energy balance for mapping evapotranspiration with internalized calibration (METRIC). Journal of Irrigation and Drainage Engineering, 133(4), 380–394.

6. Aryalekshmi, B.N., Biradar, R.C., Chandrasekar, K., & Ahamed, J.M. (2021). Analysis of various surface energy balance models for evapotranspiration estimation using satellite data. The Egyptian Journal of Remote Sensing and Space Sciences, 24(3), 1119–1126.

7. Lakhiar, I.A., Yan, H., Zhang, C., Zhang, J., Wang, G., Deng, S., Syed, T.N., Wang, B., & Zhou, R. (2025). A review of evapotranspiration estimation methods for climate-smart agriculture tools under a changing climate: vulnerabilities, consequences, and implications. Journal of Water and Climate Change, 16(2), 249–288. https://doi.org/10.2166/wcc.2024.048

8. Long, D., Singh, V.P., & Li, Z.L. (2011). How sensitive is SEBAL to changes in input variables, domain size and satellite sensor? Journal of Geophysical Research: Atmospheres, 116(D21), D21107. https://doi.org/10.1029/2011JD016542

9. Zhang, K., Kimball, J.S., & Running, S.W. (2016). A review of remote sensing based actual evapotranspiration estimation. WIREs Water, 3, 834–853. https://doi.org/10.1002/wat2.1168

Thank you