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Quantifying Phenological Variations in Tropical Forests Using High Spatio-Temporal Resolution Satellite Remote Sensing

Forrest M. Hoffman[1], Jitendra (Jitu) Kumar[1], Morgan Steckler[1,2], Bharat Sharma[1,3], William W. Hargrove[4]

[1]Oak Ridge National Laboratory, [2]University of Tennessee Knoxville, [3]Northeastern University, [4]USDA Forest Service

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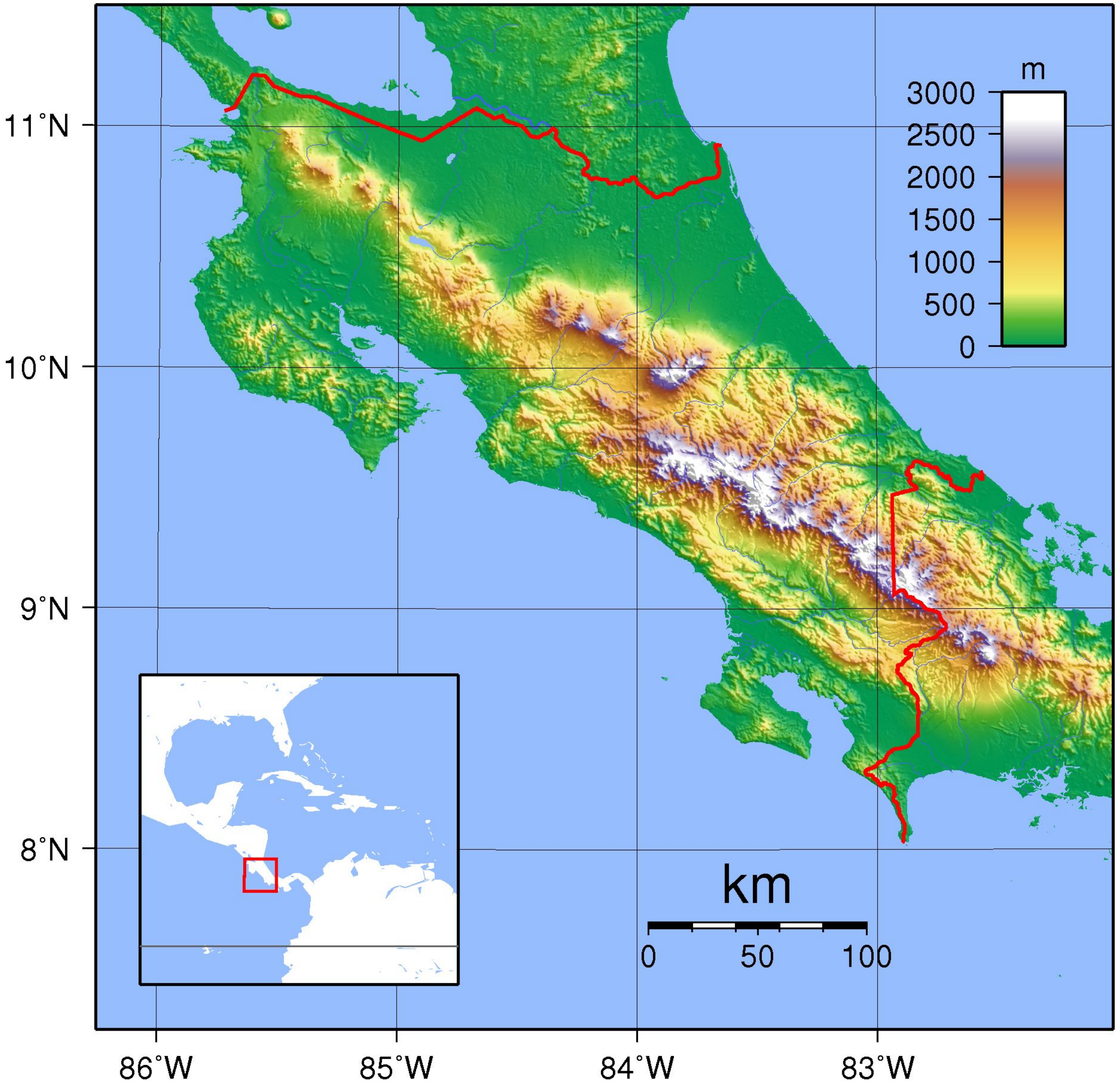
Objectives

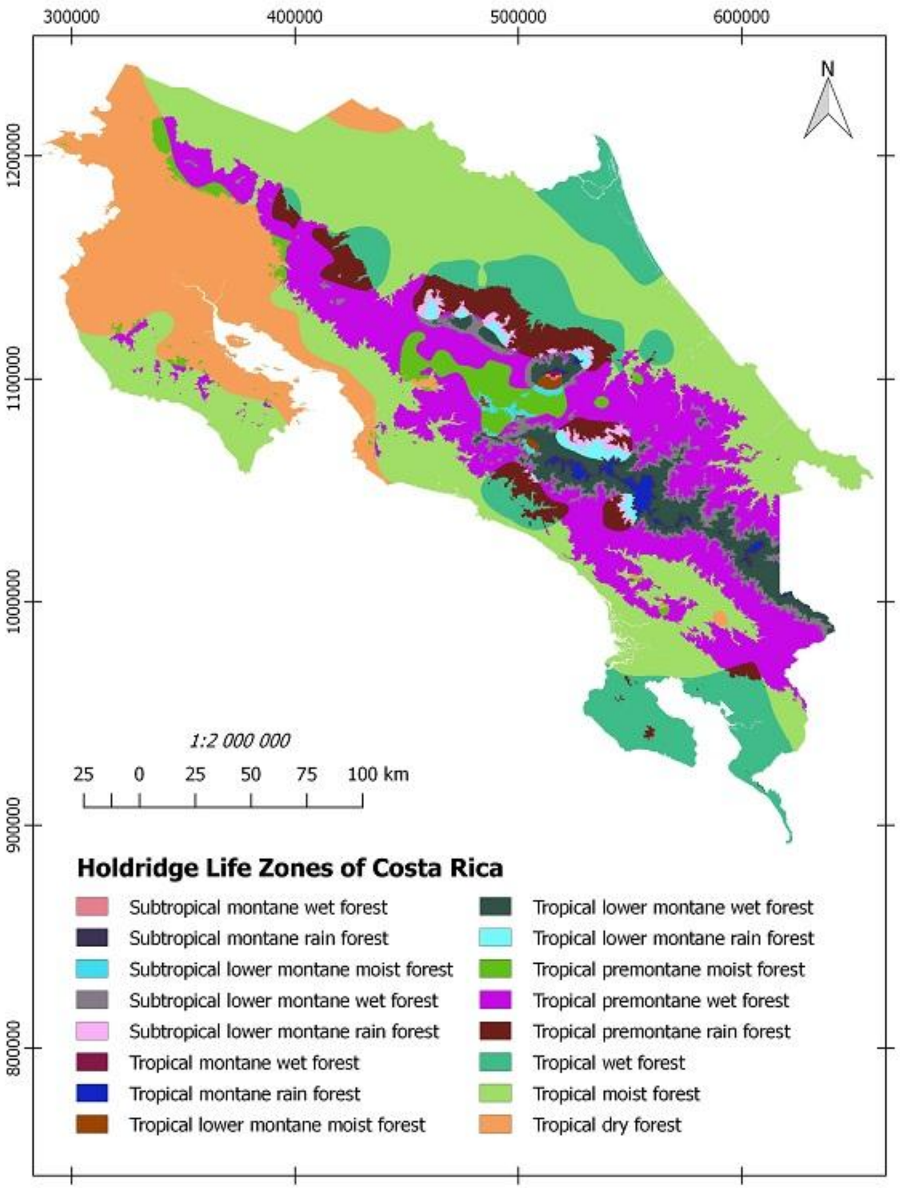
- What are the dominant patterns of vegetation phenology and their spatio-temporal variations across the diverse tropical region?
- How do phenological responses to inter- and intra-annual variability in meteorological conditions vary across heterogeneous vegetation types and regions of the tropics?
- Which climate conditions drive the anomalies/extremes in vegetation phenology?

Understanding mechanisms of phenological change?

- What drives the change (positive or negative) in vegetation phenology, beyond expected interannual variability?
- How do these drivers vary by land cover/vegetation types and regionally?
- We analyzed climate reanalysis time series from ERA5
  - Temperature, Precipitation, Soil Moisture, Radiation*
  - Spatial resolution: 0.25 degrees
  - Temporal resolution: 15 days (aggregated from daily)

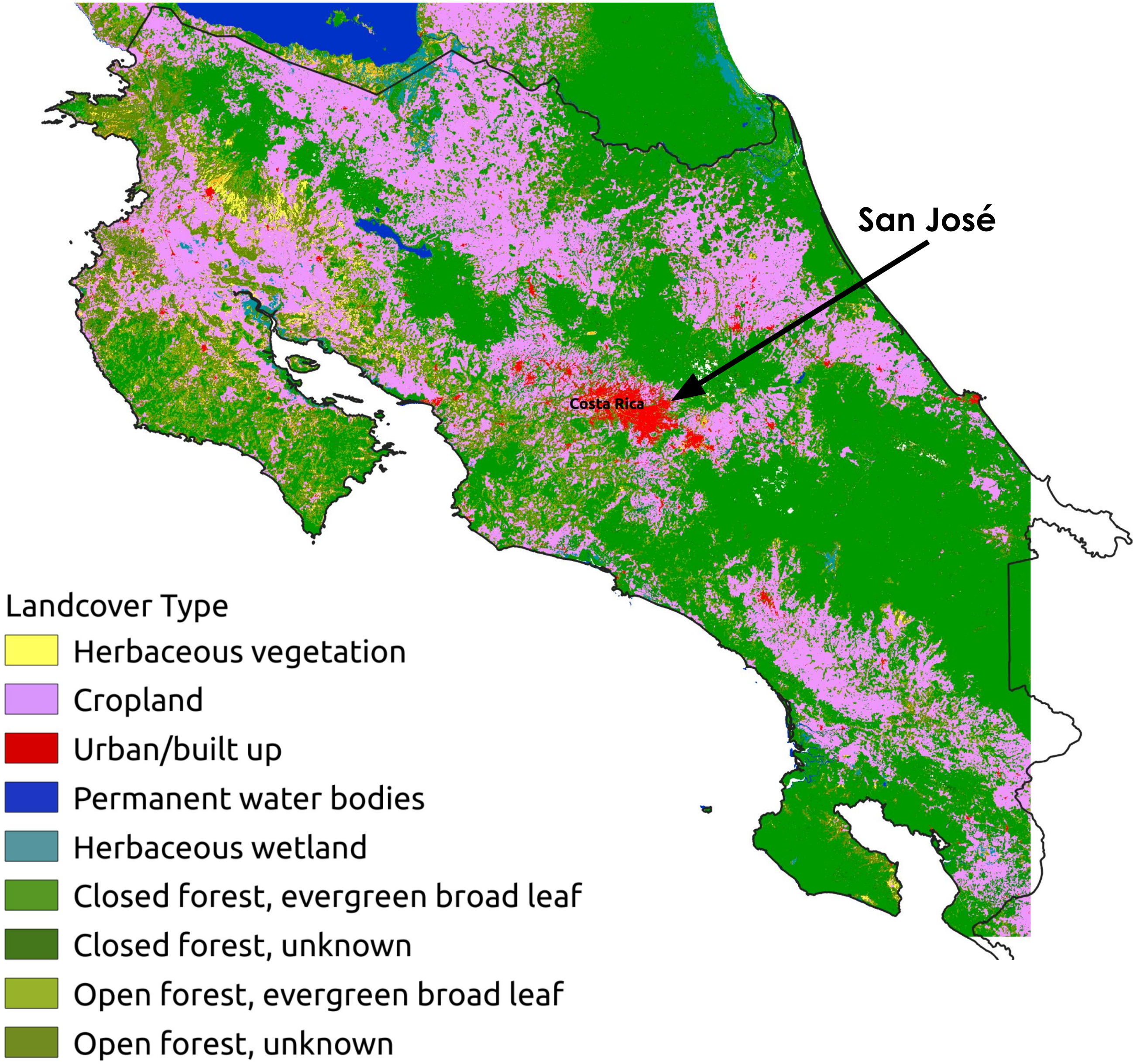
Study Region: Costa Rica





Land Cover/Vegetation in Costa Rica

Land Cover	% Area
Herbaceous vegetation	1.30
Cropland	**29.76**
Urban	1.15
Water bodies	2.59
Wetland	1.53
Evergreen Broadleaf (closed)	**44.64**
Closed forest	1.52
Evergreen Broadleaf (Open)	4.81
Open forest	**11.88**



Source: PROBA-V 100m, https://land.copernicus.eu/global/products/lc

Satellite remote sensing

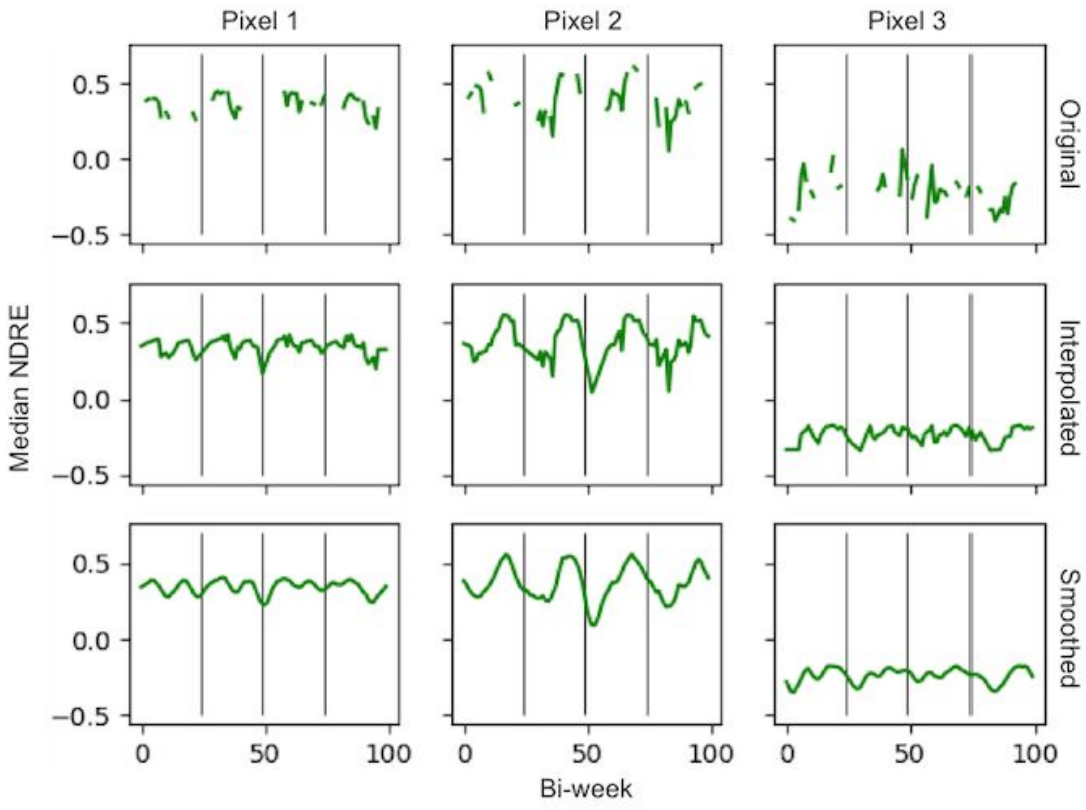
- Sentinel-2 time series for the period 2017–2020.
- Normalized Difference Red Edge Index (NDRE):

  NDRE = (NIR – RE) / (NIR + RE) | NDRE = (B8 – B5) / (B8 + B5)

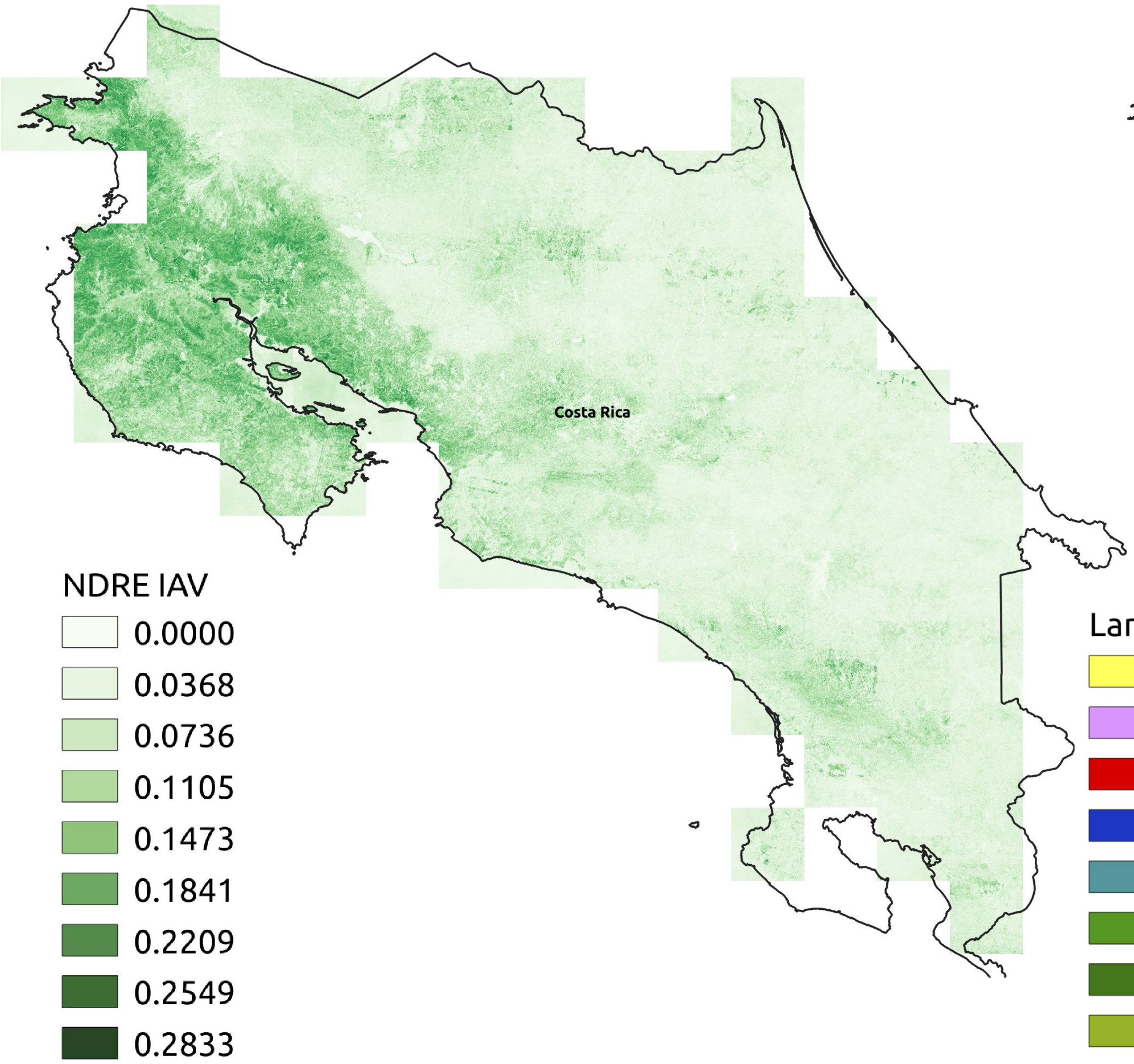
- Spatial resolution: 20m
- Temporal resolution: 15 days
- Data processing:
  - NDRE data processing, cloud/shadow removal performed within Google Earth Engine platform.
  - This is a slow and limiting step, and thus we are processing small regions at a time

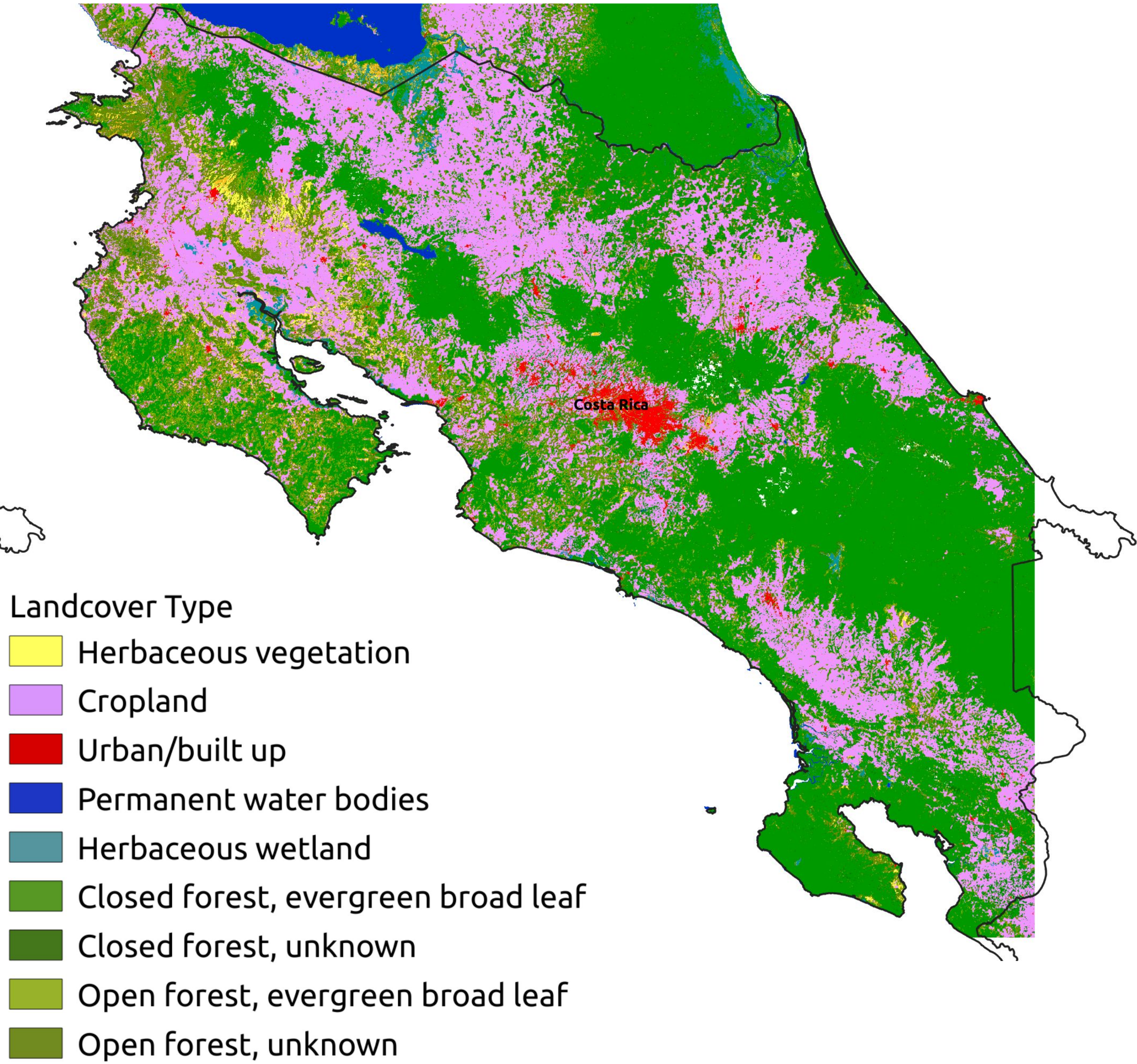
Noise filtering and gap filling

- NDRE data are noisy in space and time and require corrections.
- We developed and applied a workflow to identify and filter noisy data, a curve-fitting based gap filling, and a Savitzky-Golay filter for smoothing.



Interannual variability in phenology (CR)





Landcover product: PROBA-V 100m, https://land.copernicus.eu/global/products/lc

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Phenological classification for Costa Rica

	2017	2018	2019	2020
1	26.04	26.67	26.43	26.70
2	6.05	7.93	10.26	5.54
3	12.58	12.32	11.37	12.43
4	19.40	17.85	16.49	18.01
5	18.60	18.41	17.53	17.82
6	11.43	10.24	5.05	4.06
7	0.99	1.01	1.00	1.00
8				
9	4.36	4.17	4.11	4.85
10	0.55	1.40	7.77	9.58

Fractional area occupied by each cluster

Landcover product: PROBA-V 100m, https://land.copernicus.eu/global/products/lc

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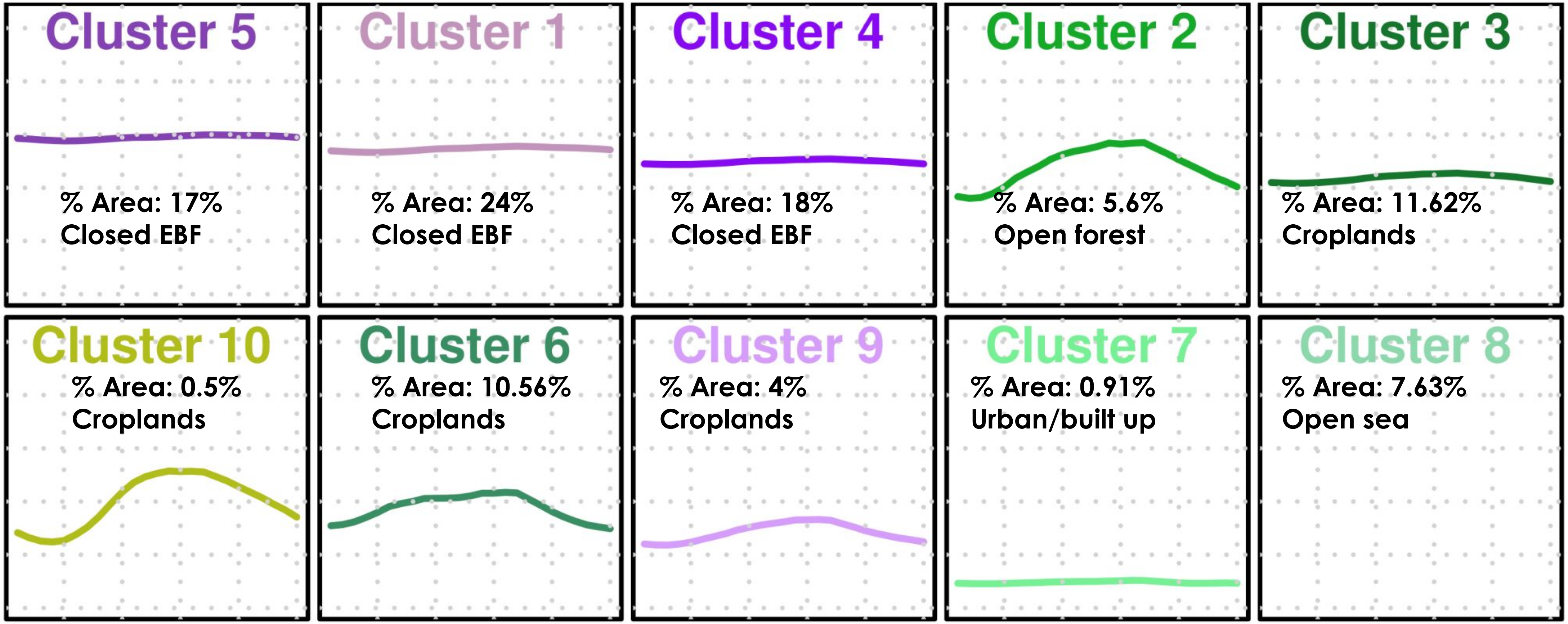
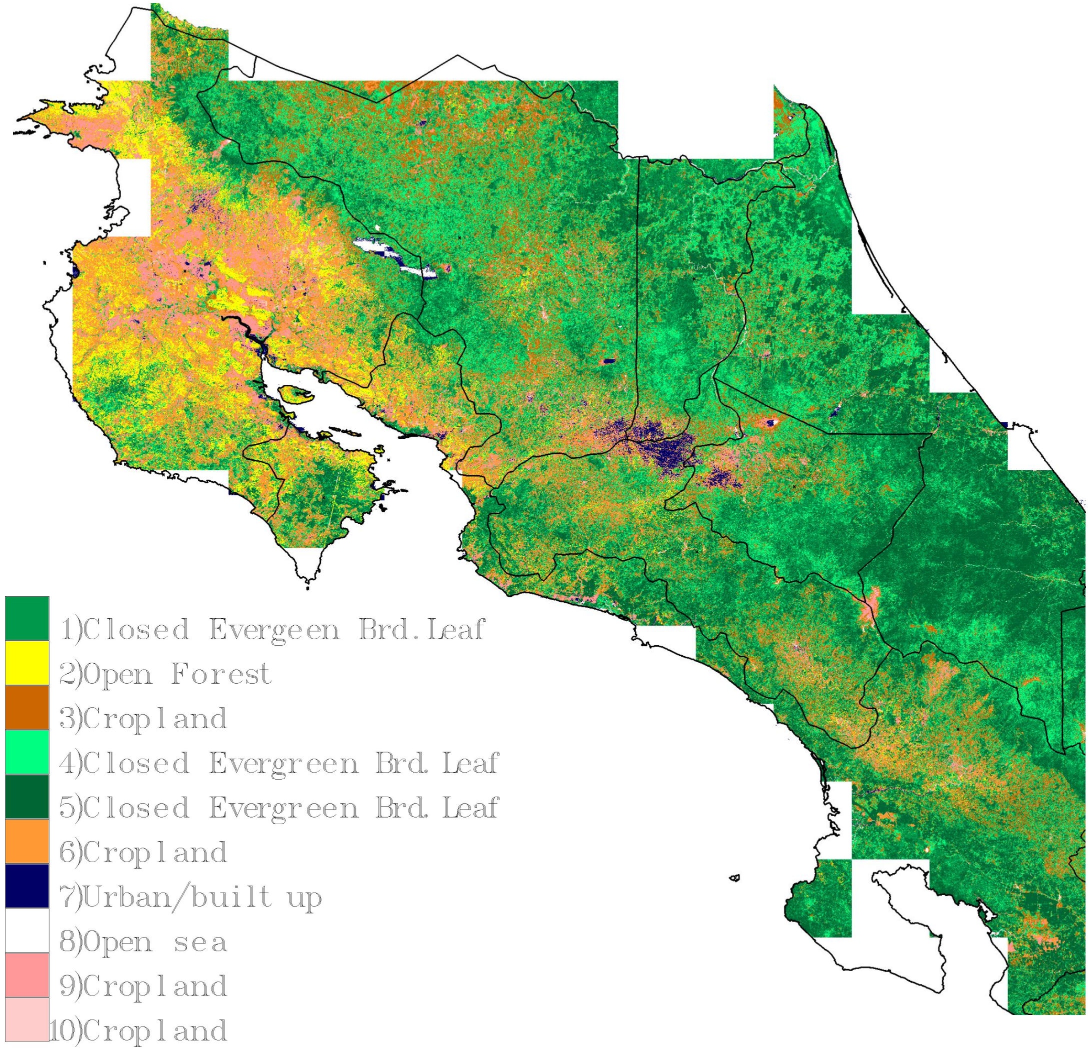


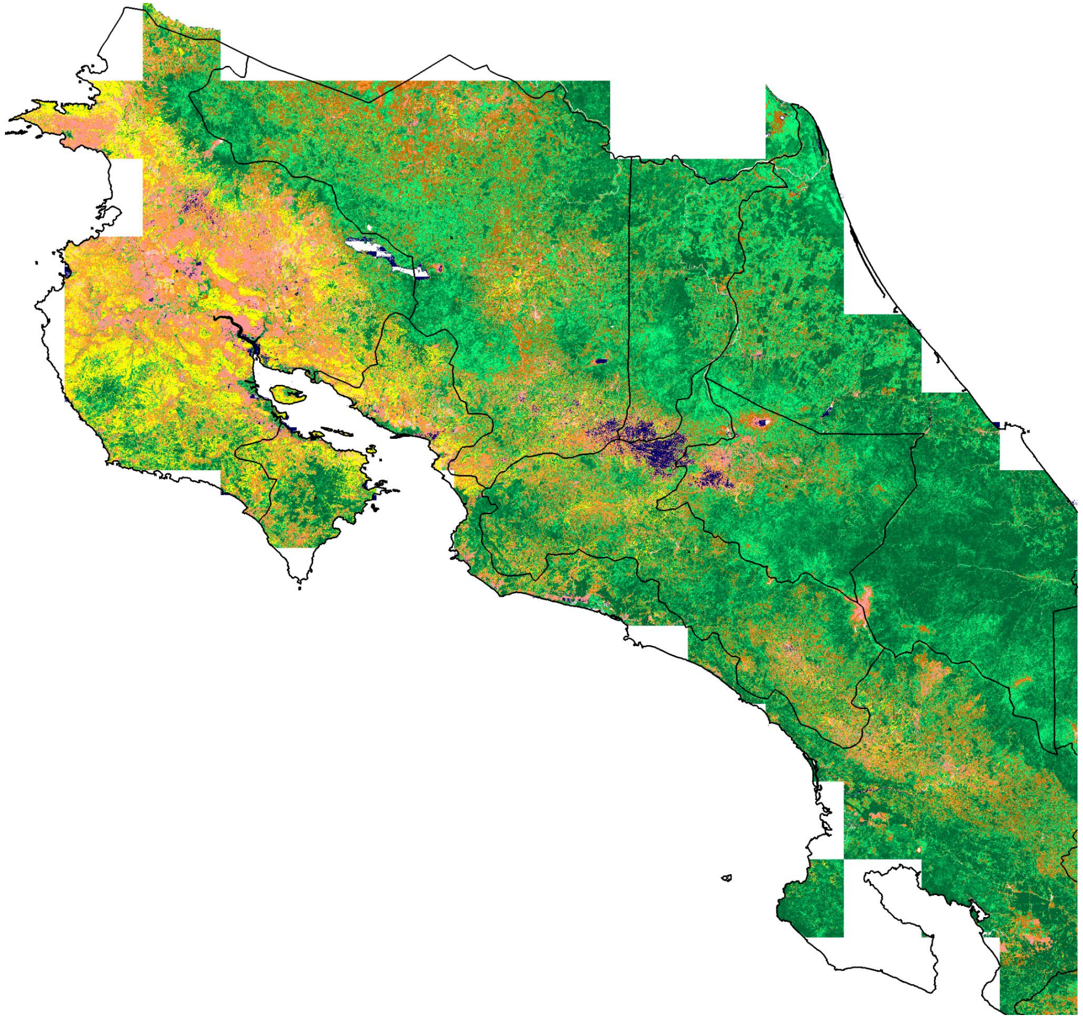
Landcover labels are for phenology-based clusters are derived using spatial overlays with PROBA-V landcover products using MapCurves algorithm.

Landcover product: PROBA-V 100m, https://land.copernicus.eu/global/products/lc

Phenological classification for Costa Rica

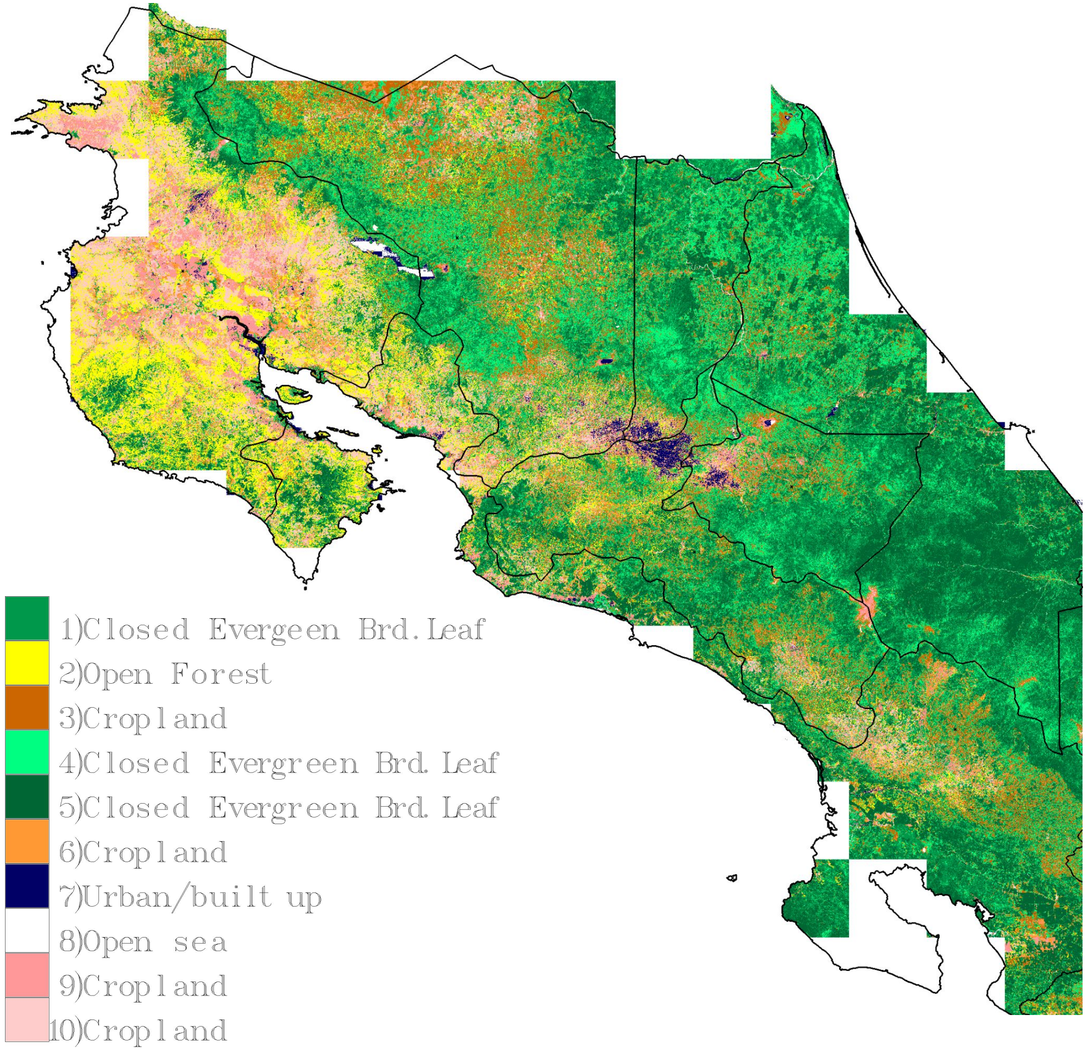


2017

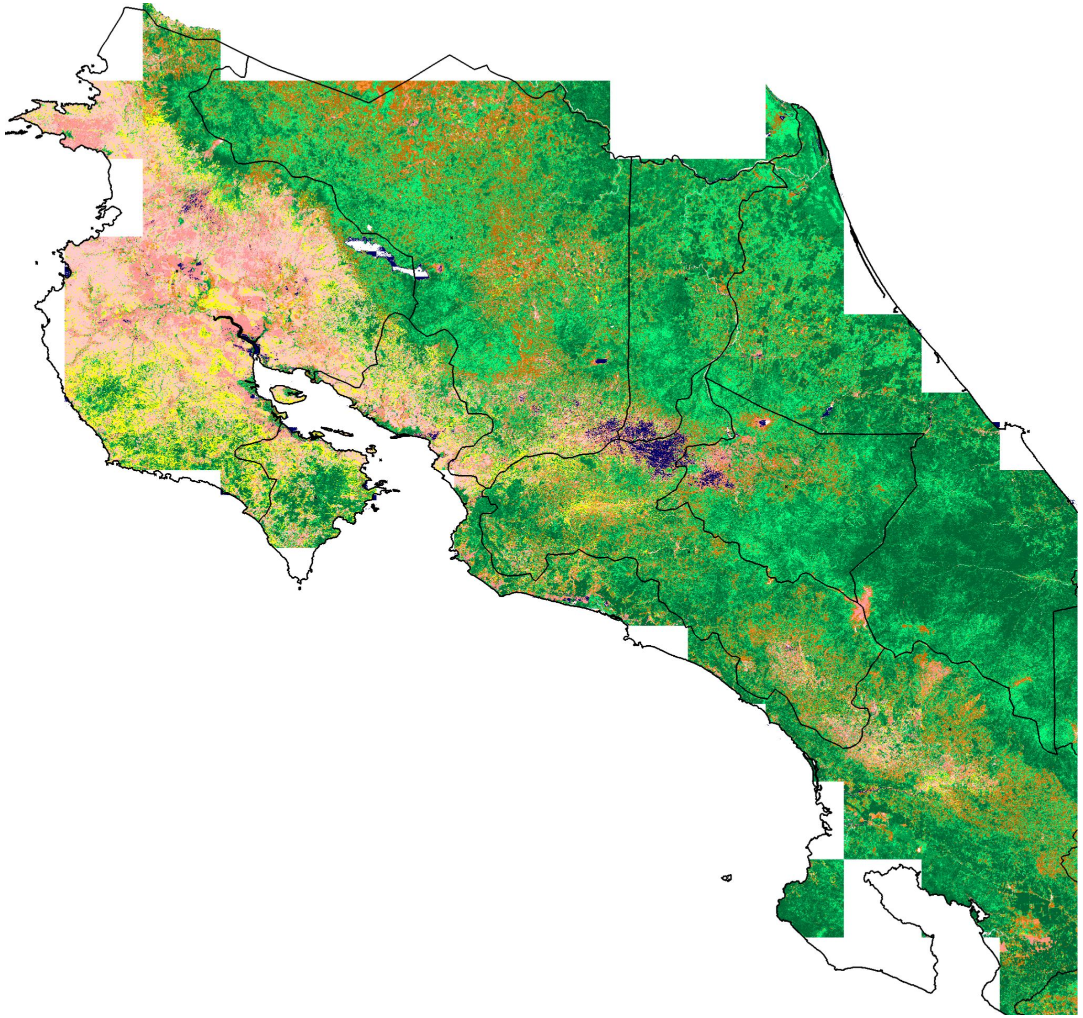


2018

Phenological classification for Costa Rica



2019



2020

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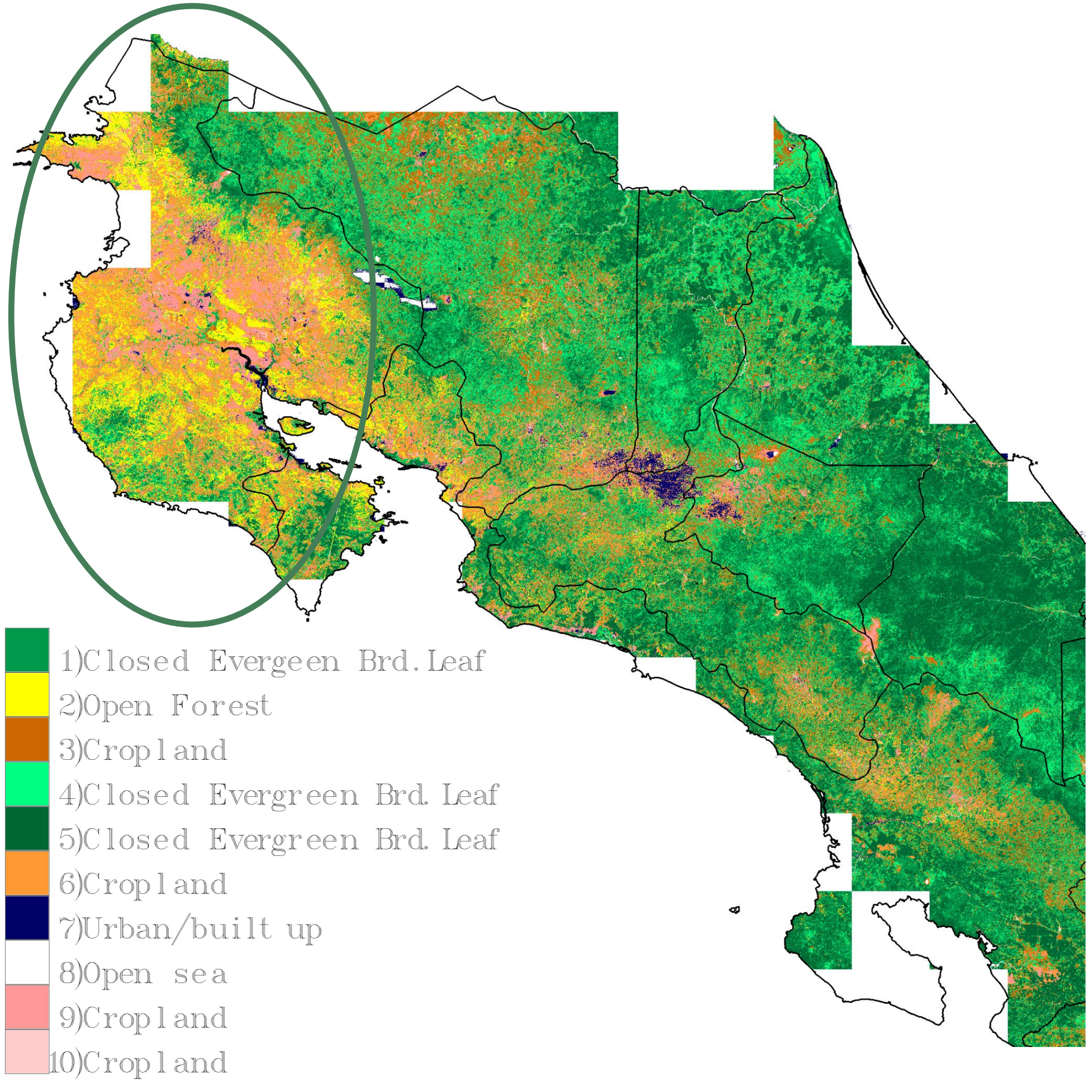
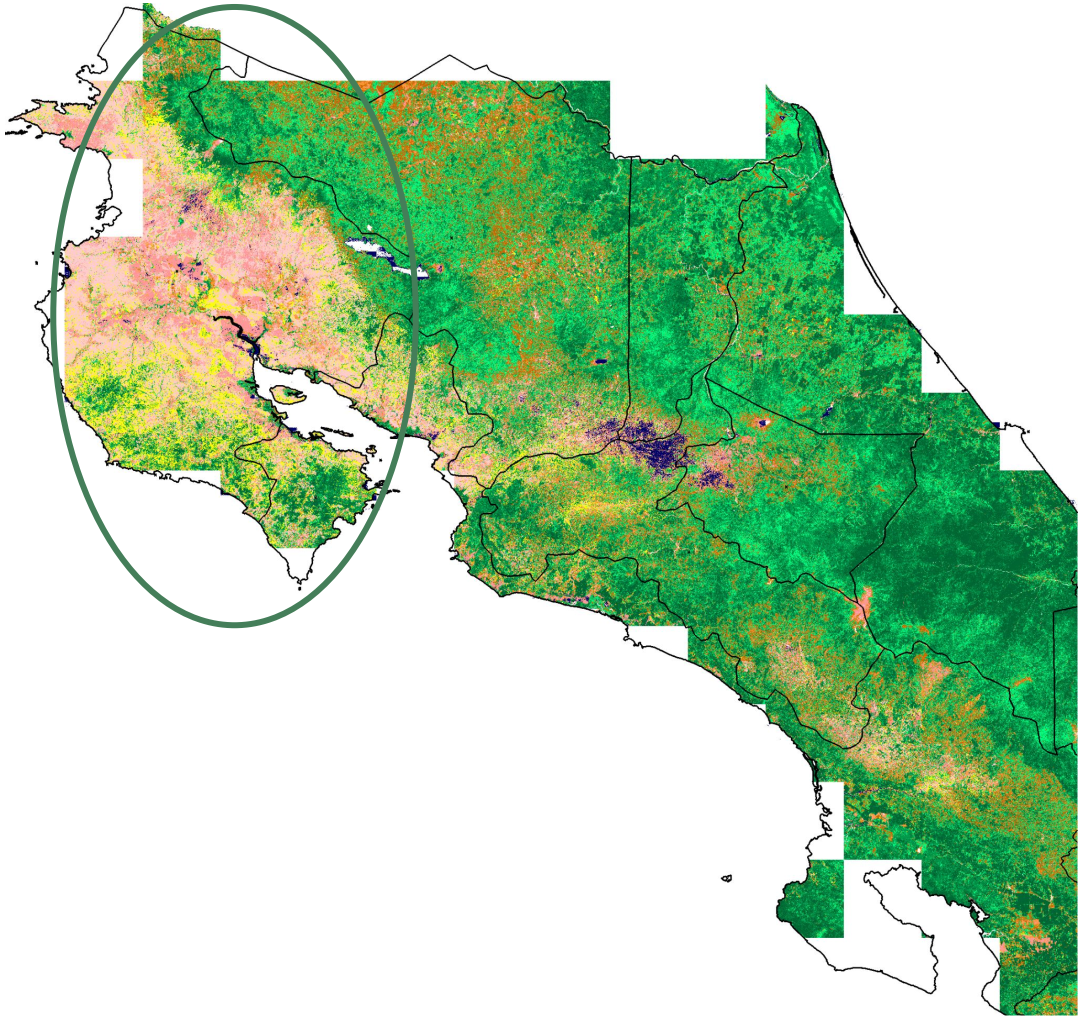
Phenological changes over 2017-2020

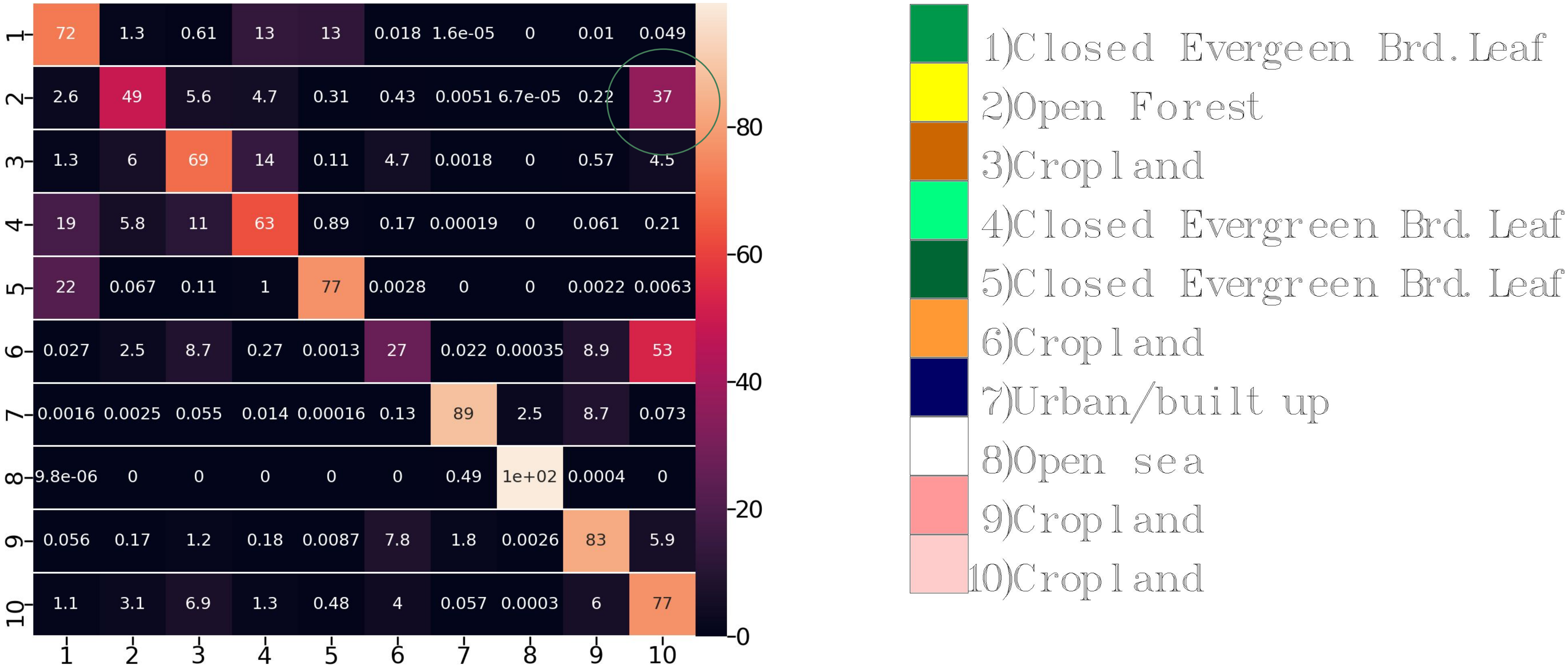


2017



2020

What transitions have occurred over 2017-2020



2017-2020

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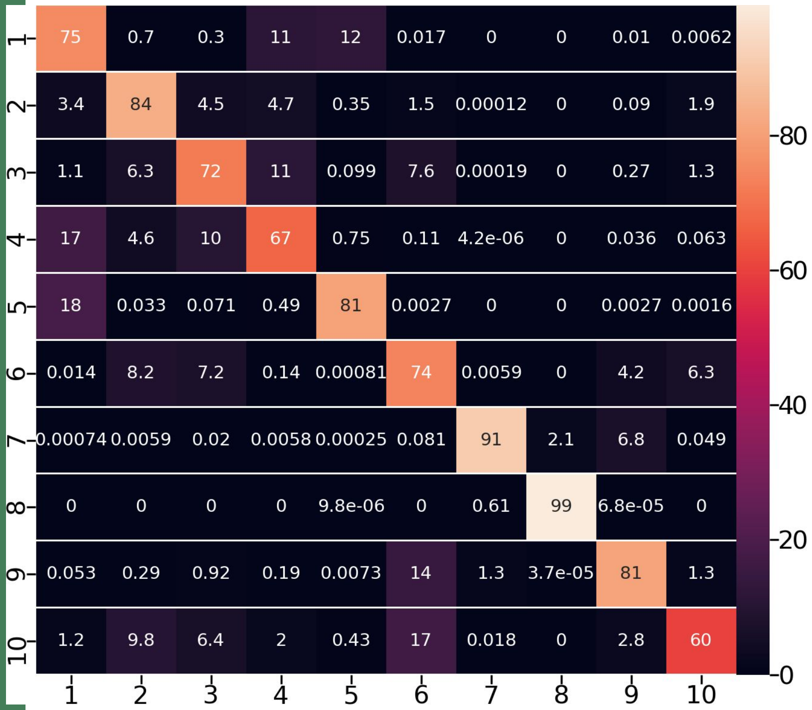
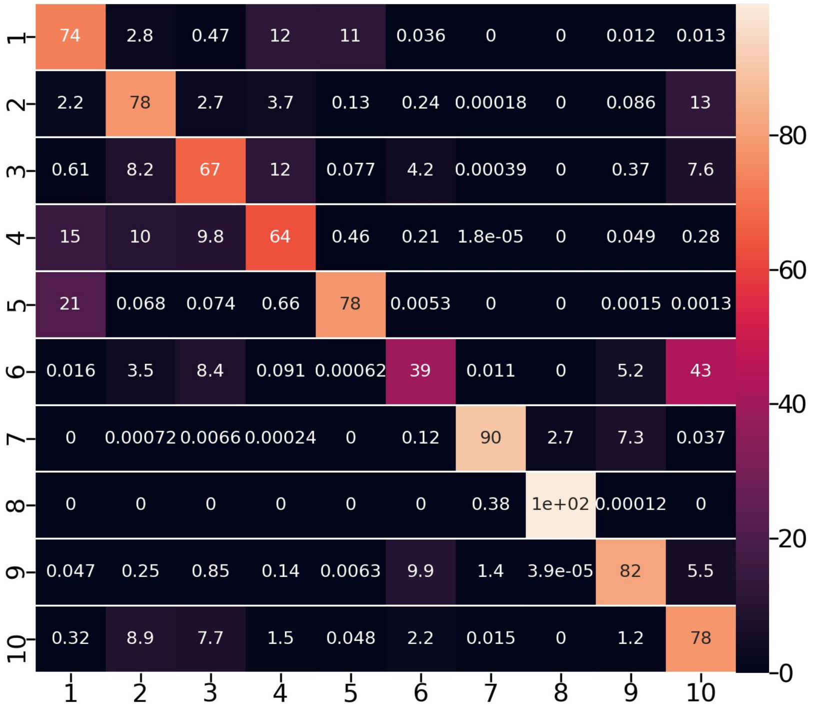
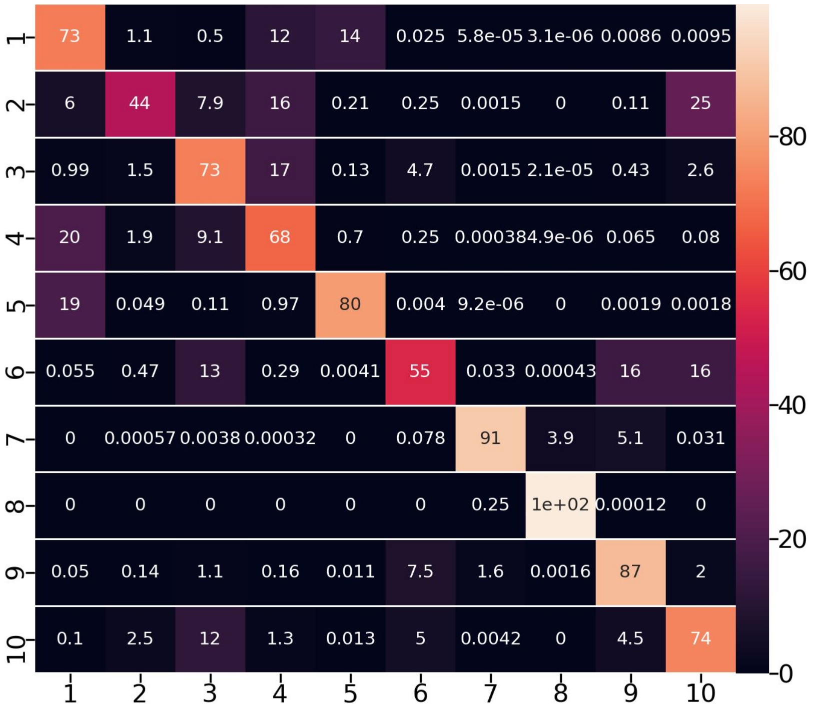
How stable or transient are the phenological states?



2017-2018



2018-2019



2019-2020

year to year transition matrix

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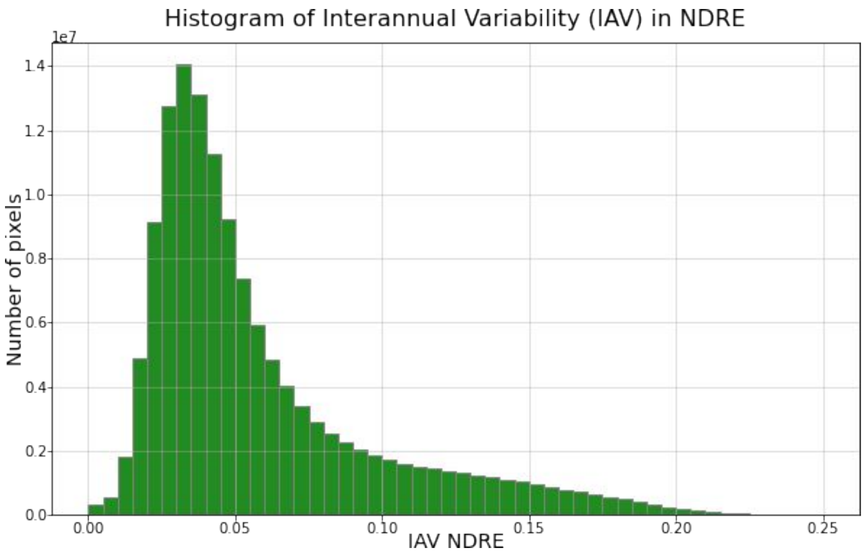
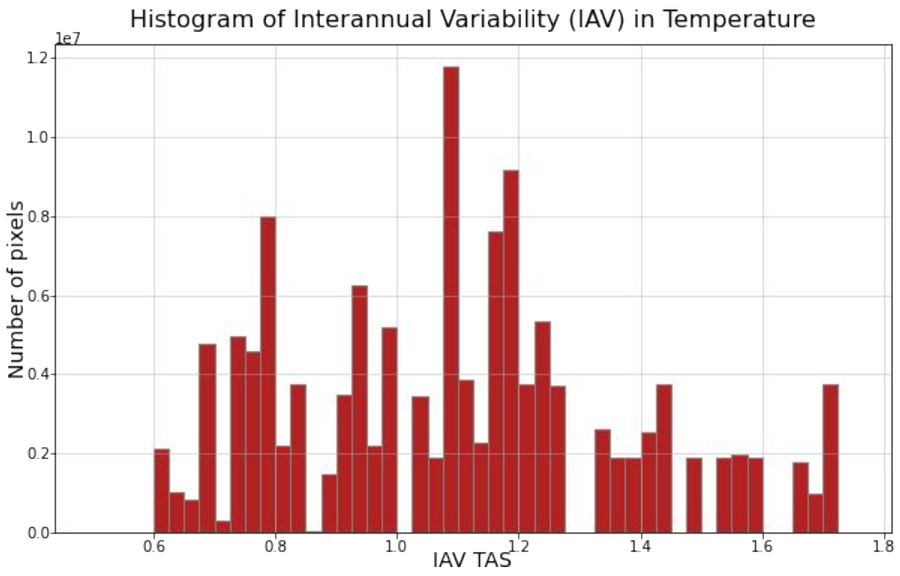
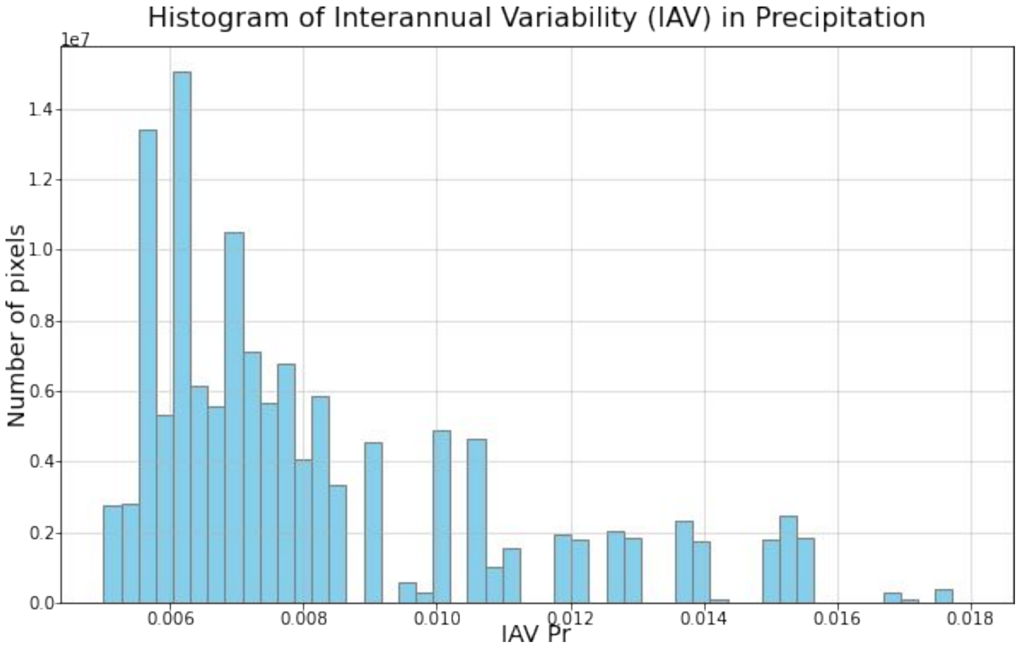
Interannual variability in phenology (CR)







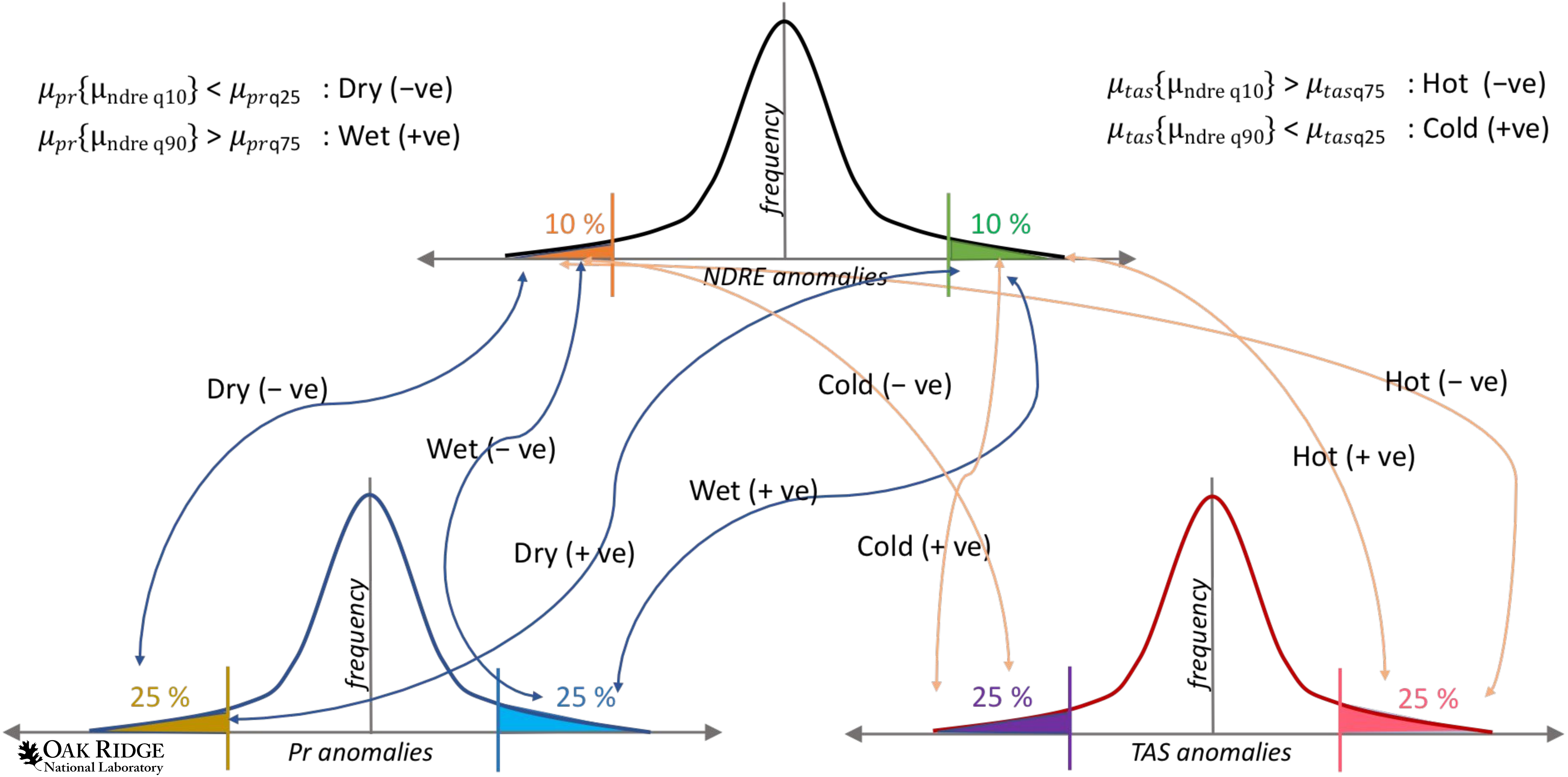
Methodology to detect extremes in phenology and attribution to climate drivers

$\mu_{pr}\{\mu_{ndre\ q10}\} < \mu_{prq25}$: Dry (–ve)

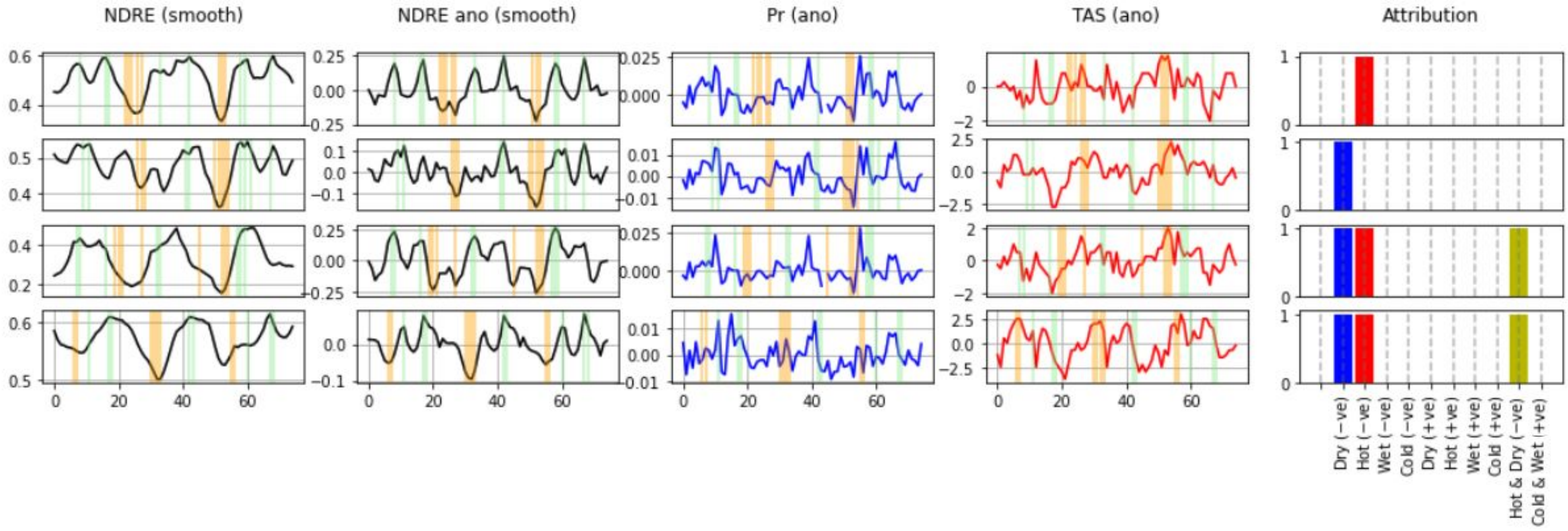
$\mu_{pr}\{\mu_{ndre\ q90}\} > \mu_{prq75}$: Wet (+ve)

$\mu_{tas}\{\mu_{ndre\ q10}\} > \mu_{tasq75}$: Hot (–ve)

$\mu_{tas}\{\mu_{ndre\ q90}\} < \mu_{tasq25}$: Cold (+ve)

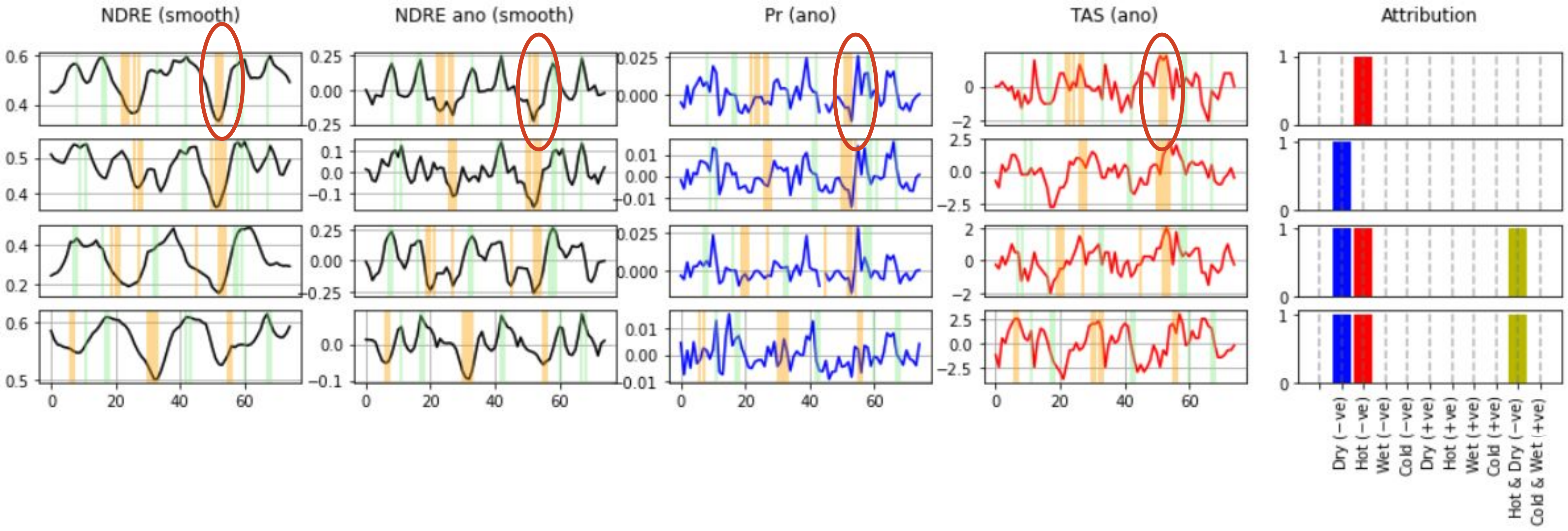


Anomalies in drivers vs NDRE (CR)



Are anomalies in phenology driven by anomalous conditions?

Anomalies in drivers vs NDRE (CR)



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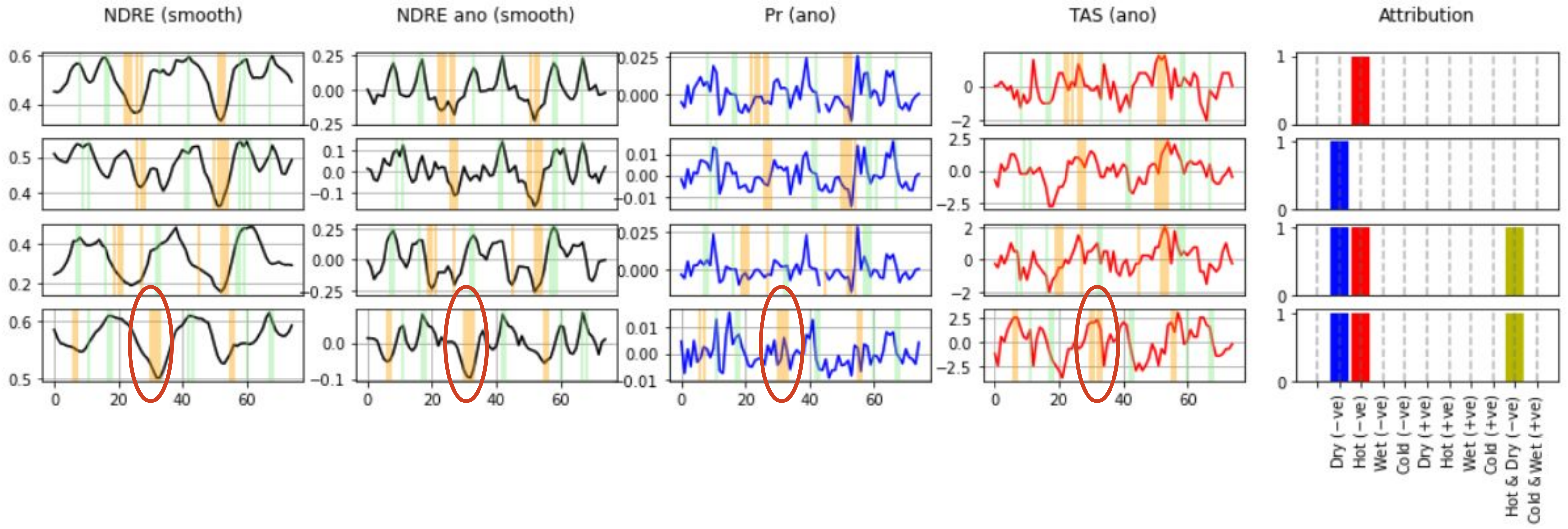
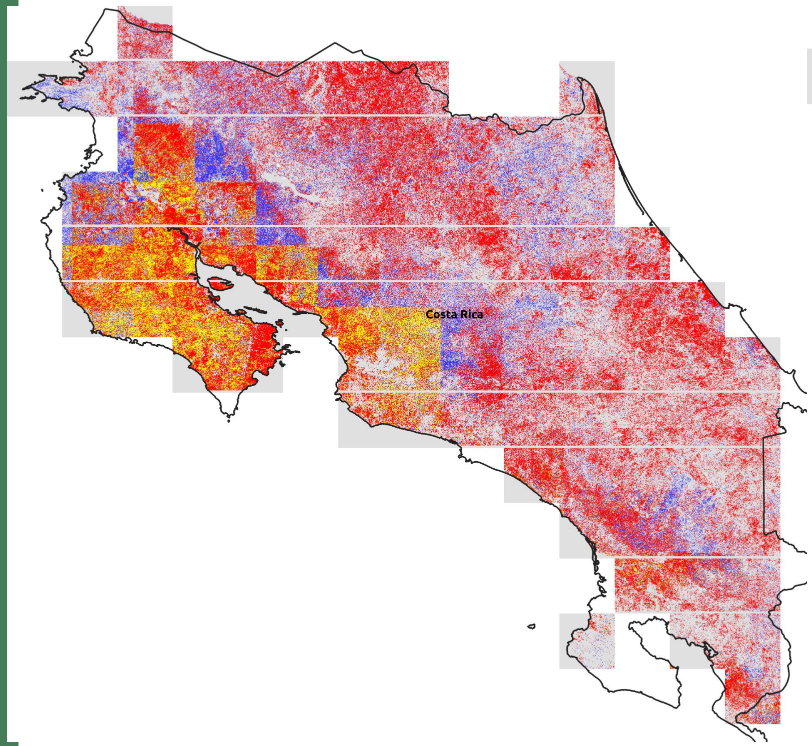
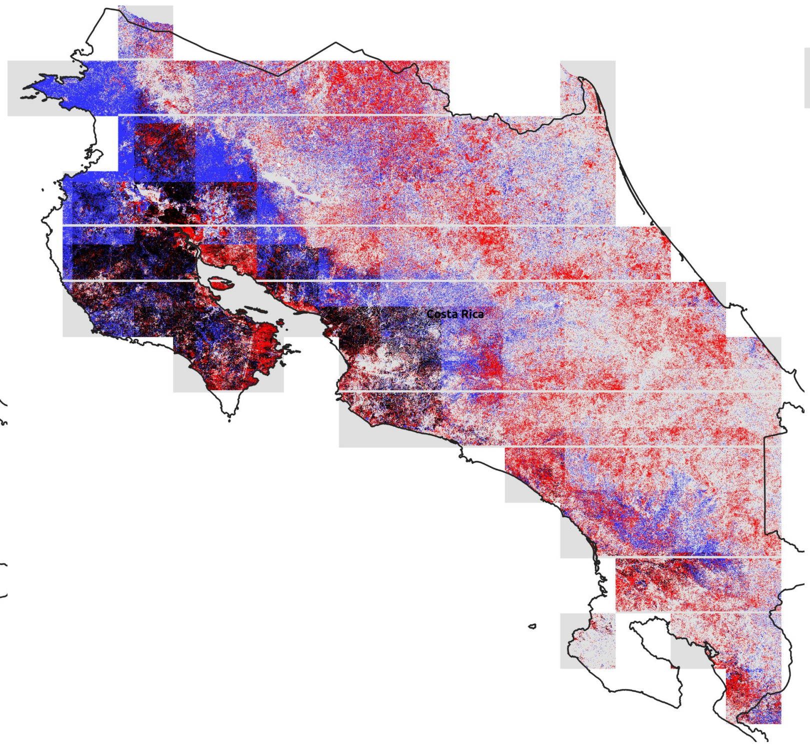


Are extreme anomalies in phenology driven by anomalous/extremes climate conditions?

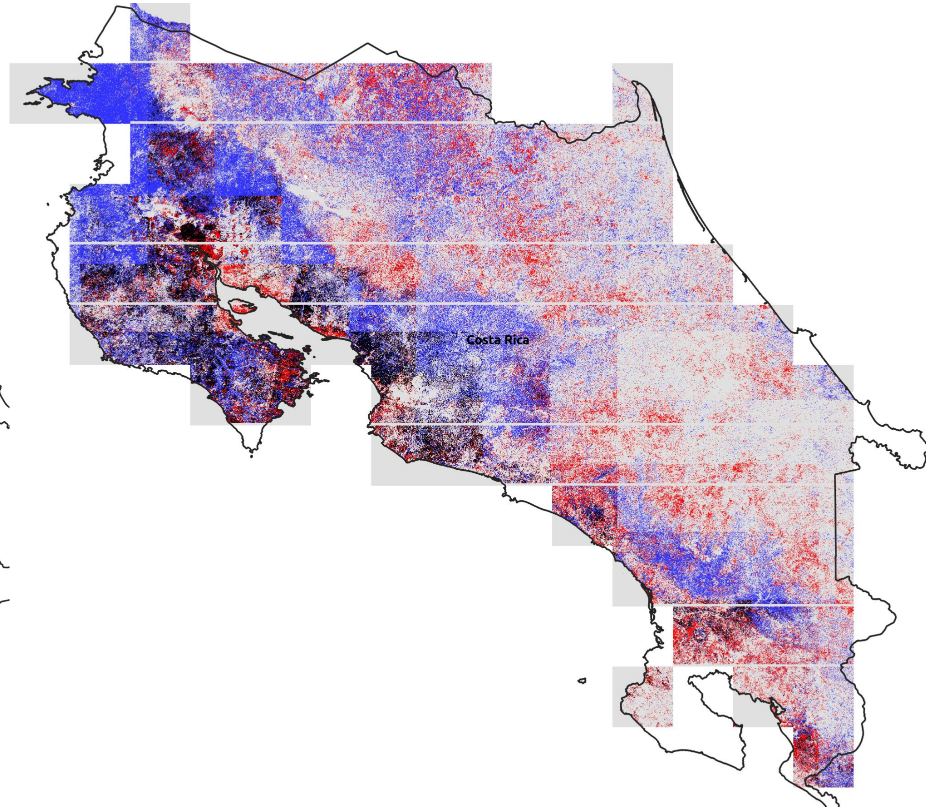
Spatial patterns of drivers



Time lag: 0 days



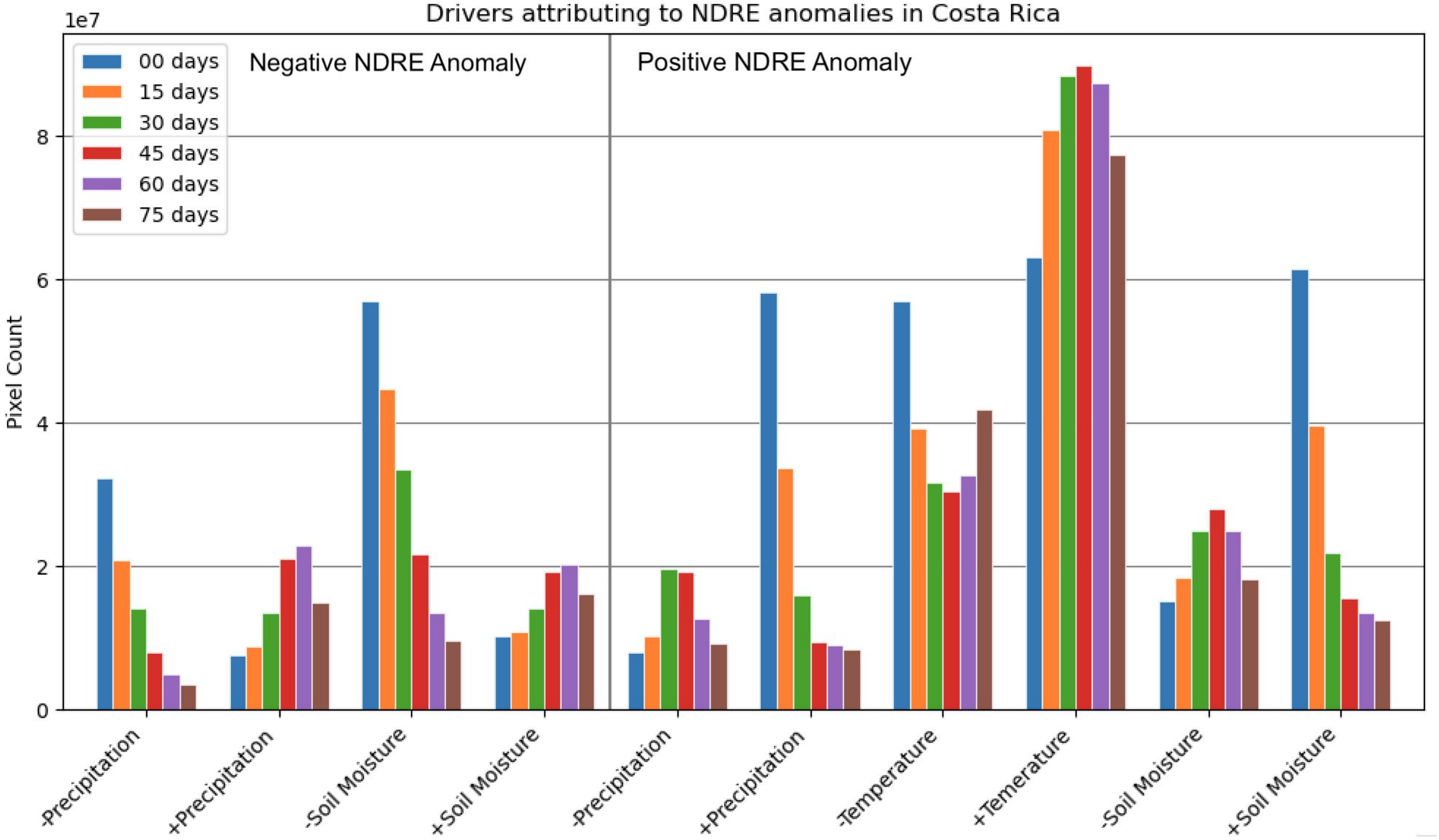
Time lag: 15 days



Time lag: 30 days

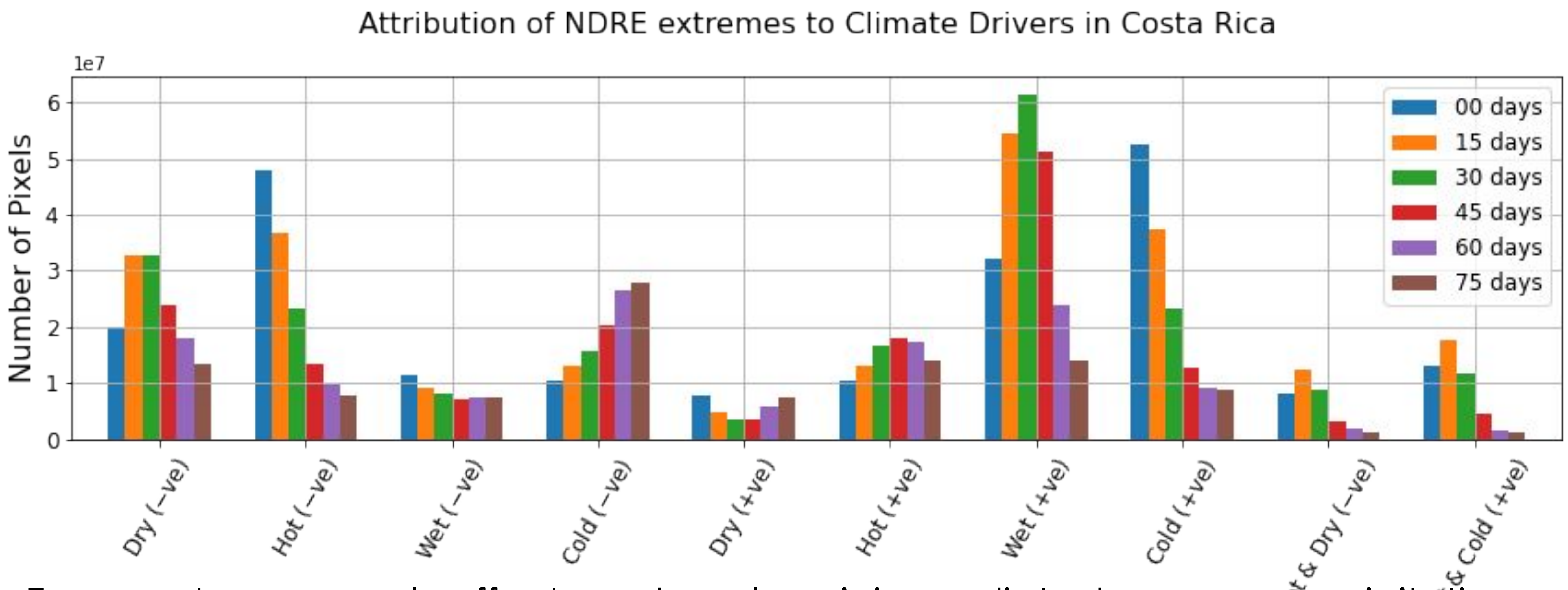
Environmental Driver
- dry
- hot
- dry and hot

Meteorological drivers of NDRE anomalies

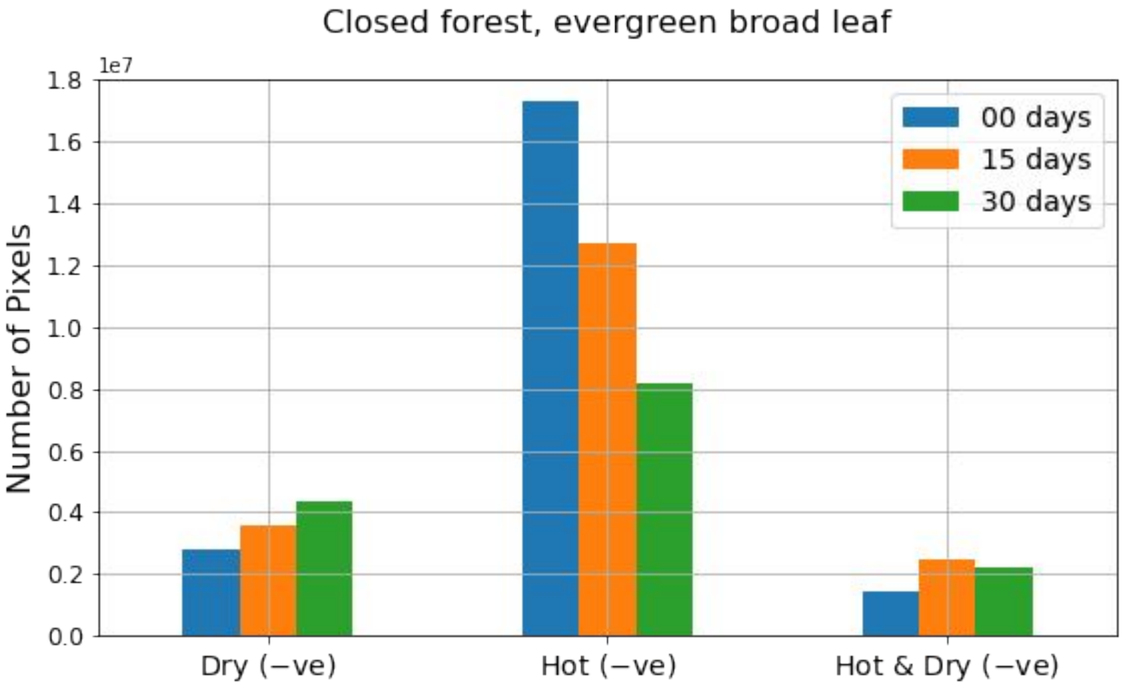


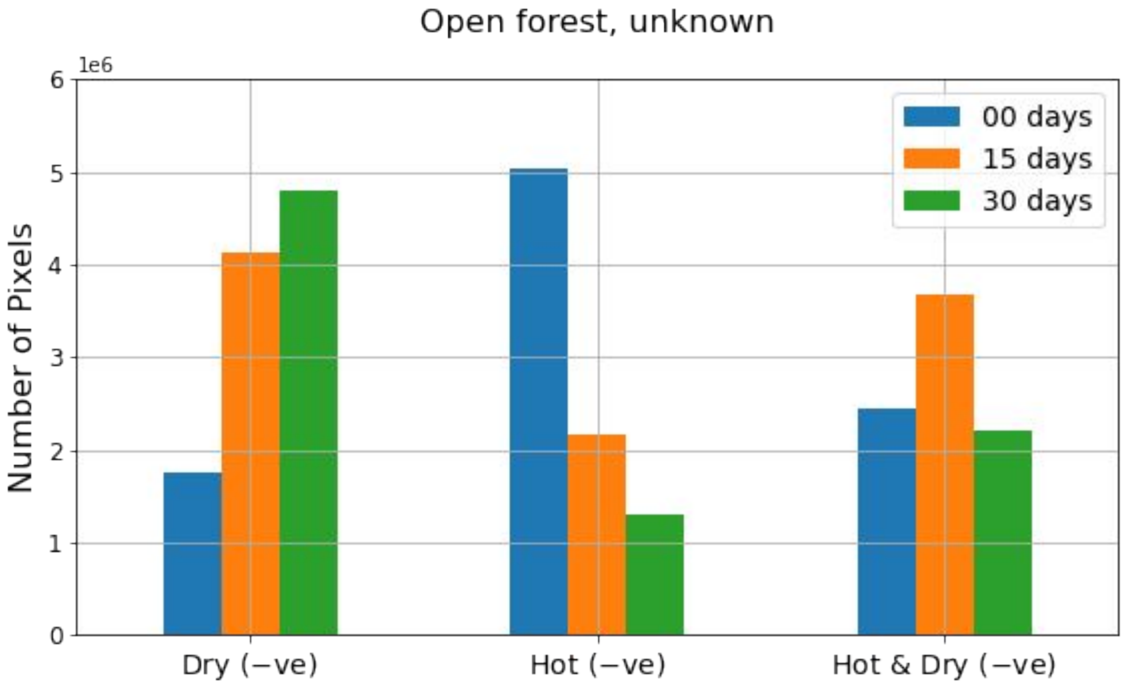
- Low precipitation & soil moisture conditions lead to immediate decrease ("browning") in NDRE
- Increased precipitation & soil moisture drives delayed decrease in NDRE
- Increased temperature has a lagged/delayed impact on NDRE increase ("greening")

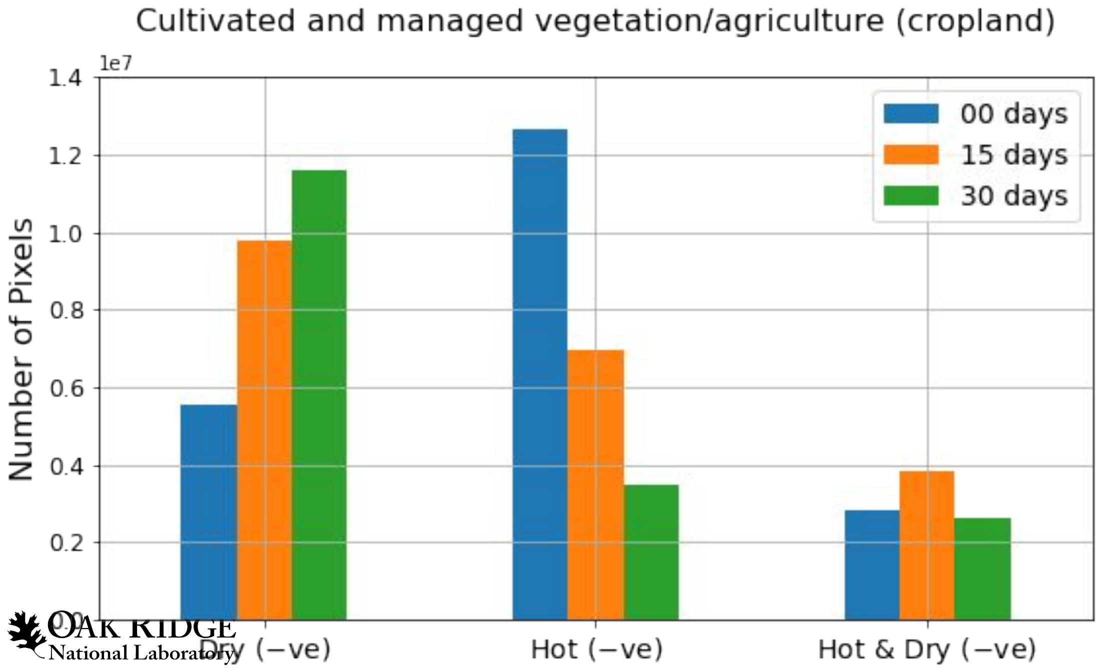
Role of individual and compound effects of meteorological drivers



Temperature anomaly effect on phenology is immediate; however, precipitation (via soil moisture) anomalies over a longer time period play an important role.







- Different vegetation/landcover types respond differently to anomalies in meteorological conditions
- Croplands (and other low height and shallow rooted vegetation are more susceptible to anomalies in moisture availability

Summary

- High spatio-temporal resolution remote sensing allows us to identify dominant phenological patterns across the tropics.
- We can identify regions with stable vs. transient phenological patterns (albeit with a short time series).
- We characterized the meteorological anomalies that drive anomalies in phenology.
- Drivers of extremes/anomalies show regional and land cover type-specific patterns.
- We are expanding the study to other parts of the tropics.