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TECHNICAL REPORT

# Satellite-based Tracking of Agricultural Adaptation Progress

**Louis Reymondin**
Alliance Bioversity International-CIAT

**Aaron Golden** and **Charles Spillane**
University of Galway, Ireland

**Summary** Lack of systematic tools and approaches for measuring climate change adaptation limits the measurement of progress toward the adaptation goals of the Paris Agreement. To this end, we piloted a new approach, the Biomass Climate Adaptation Index (Biomass CAI), for measuring agricultural adaptation progress in Ethiopia across multiple scales using satellite remote sensing data. The Biomass CAI can monitor agri-biomass productivity associated with adaptation interventions remotely and facilitate more tailored precision adaptation. The Biomass CAI focuses on decision-support for end-users to ensure that the most effective climate change adaptation investments and interventions can be made in agricultural and food systems.

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# Satellite-based Tracking of Agricultural Adaptation Progress in Ethiopia

Louis Reymondin, Aaron Golden, and Charles Spillane

## Introduction

Systematic tools and approaches for measuring climate change adaptation are lacking, limiting the measurement of progress toward the adaptation goals of the Paris Agreement. Ideally, we argue that an adaptation measurement or tracking system should be systematically coherent (i.e., measuring adaptation itself), comparable (i.e., allowing comparisons across geographies and systems), and comprehensive (i.e., supported by readily available data).

To this end, we are developing a new approach, Biomass Climate Adaptation Index (Biomass CAI), for agricultural systems, where climate adaptation progress across multiple scales can be measured by publicly available satellite remote sensing data. The Biomass CAI can be used at the global, national, landscape, and farm levels to remotely monitor agri-biomass productivity associated with adaptation interventions and to facilitate more tailored, precision adaptation. The Biomass CAI aims to support policymakers' decisions to ensure the most effective climate change adaptation investments and interventions for the climate smart agrifood systems[1].

# Data and Methods

## Workflow in five steps

The Biomass CAI workflow can be split into a series of steps (Figure 1).

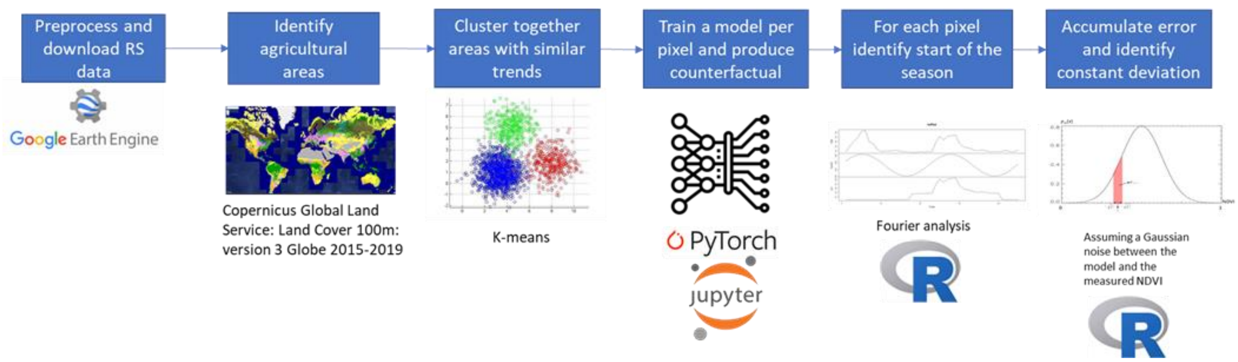


*Figure 1 Adaptation tracking workflow*

1. A map of cropland areas must be either identified from existing data sources or created based on remote sensing data.
2. An unsupervised clustering method is performed to group together agricultural lands that follow similar phenologies across the years.
3. Location-specific Vegetation Index (VI) time series will be modeled for cropland areas as a function of exogenous weather correlates such as precipitation and surface temperatures, geographic conditions (e.g., soils, topography, or coordinates), and past NDVI trends. These models should generate spatially and temporally continuous measures of predicted

[1] We note that this work is highly inspired and built upon SEIRS, a system developed by the Alliance of Bioversity and CIAT to track and evaluate the impact of development intervention in agricultural lands through earth observations and deep learning.

greenness, from which predicted vegetation peak and green-up integrals can be inferred.

4. A Fourier analysis is performed for each time series in order to identify a crop calendar, such as the start and end of the growing season, for each pixel. The number of crop iterations within a year is also defined based on this method.
5. Finally, the predicted measures of VI are probabilistically compared to observed VI measures. Observed and predicted measures of VI should be very highly correlated. However, the proposed activity will leverage the differences between predicted and observed measures of VI during weather shocks, such as droughts and floods, to estimate the change in climate resilience at specific sites.
   - If the difference between observed and predicted measures of VI is *positive*, then the area is performing better than what is expected, given the baseline. The area is, therefore, more resilient to climate shock and must be going through an adaptation process.
   - On the contrary, if the difference between observed and predicted measures of VI is *negative*, then the area is going through a degradation process and is highly impacted by climate change. Such areas should be put as high priorities for climate adaptation interventions.
   - Or, if areas show *no differences* between predicted and observed measures, the area follows the business-as-usual trend as observed during the baseline.

Given the prediction model is trained on site-specific data, estimates would naturally control for local variation in suitability or annual weather conditions[2].

## Enabling near-real-time monitoring

The core of the Biomass CAI prediction model was built upon large Convolutional Neural Networks (CNN) that are particularly suited for learning complex and often highly diverse patterns and relationships. CNN is particularly useful for impact assessments that operate at a given time, yet CNN in itself is unsuitable for processing time series data to make short-term predictions using near-real-time input data.

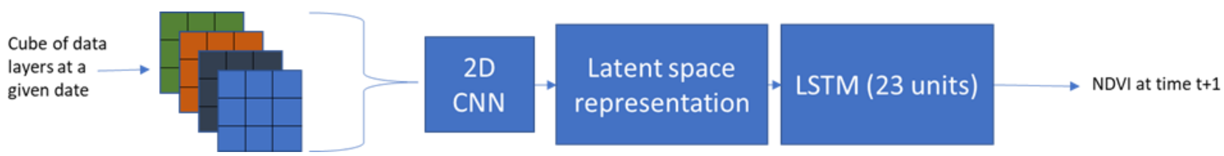


*Figure 2 A new model structure enabling near real-time monitoring of climate adaptation progress*

In order to enable near-real-time monitoring of climate adaptation progress, we thus added a Long Short Term Memory (LSTM) component coupled with a CNN (Figure 2). LSTM is well known for time series regression, while CNN provides insights into the spatial structure of the agricultural landscape. By coupling them within the workflow, the Biomass CAI workflow was able to utilize near-real-time data to monitor the adaptation process on a timely basis.

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[2] See the following journal article for more details on the methodology:
*Ferguson, Amy; Murray, Catherine; Tessema, Yared Mesfin; McKeown, Peter C.; Reymondin, Louis; Loboguerrero, Ana Maria; Talsma, Tiffany; Allen, Brenden; Jarvis, Andy; Golden, Aaron; Spillane, Charles. 2022. Can remote sensing enable a Biomass Climate Adaptation Index for agricultural systems? Frontiers in Climate 4:938975.* https://doi.org/10.3389/fclim.2022.938975

# Preliminary Results

The Biomass CAI workflow was tested in two study areas in Senegal and Ethiopia.

For the calibration of the system in both study areas, we used the MODIS MOD13Q1 NDVI data for the vegetation status, Global Precipitation Measurement (GPM) data for the rainfall, and the MODIS Land Surface Temperature (MOD11) for the temperature data. Finally, we added input on the elevation and slope derived from the Shuttle Radar Topography Mission (SRTM) DEM dataset. The land cover map used to identify agricultural lands for this study was provided by Copernicus Global Land Service: Land Cover 100m: version 3 Globe 2015-2019.

## River Valley in Senegal

The first site is located around the Senegal River Valley. This area was prioritized for investment by the Millennium Challenge Corporation, which financed large-scale irrigation development projects completed in 2015. As we previously explored the adaptation status of the area during the SEIRS project, we compared the result from the Biomass CAI system (utilizing near-real-time time-series data) with the previous SERIS system (using the annual historical data).

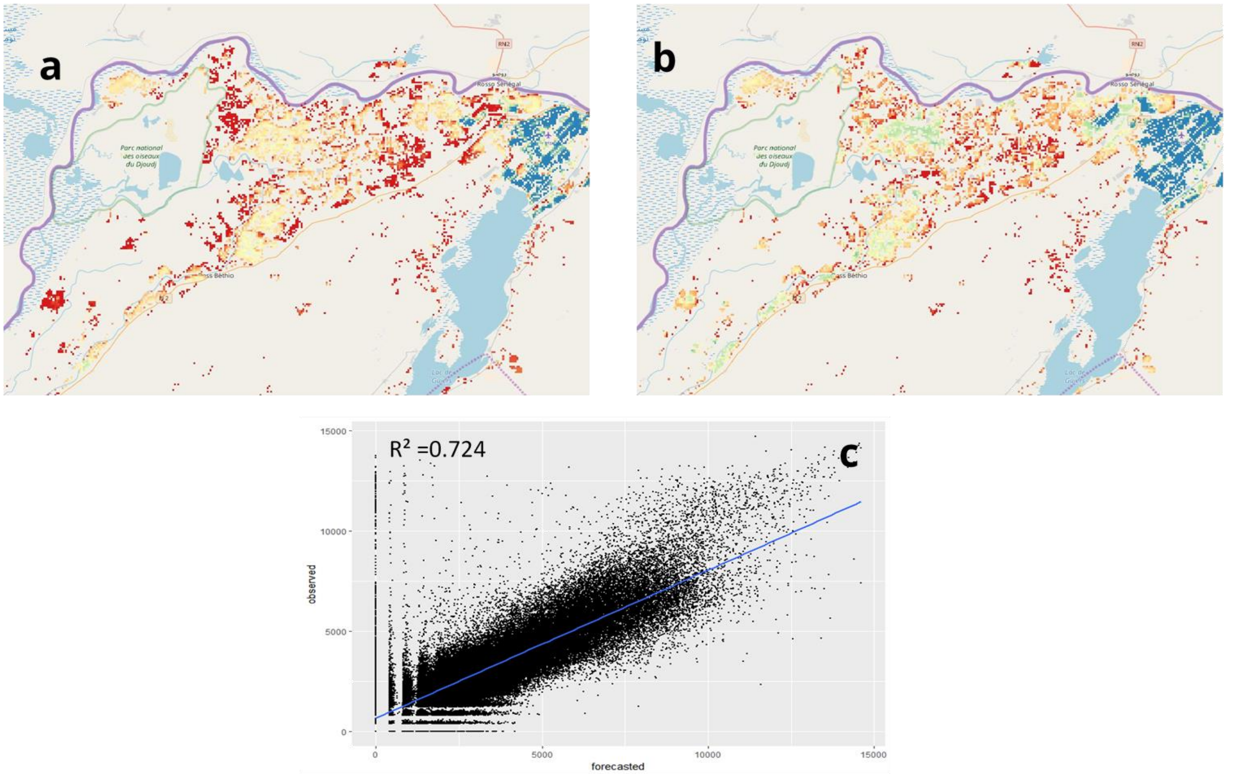


*Figure 3 Comparison of the actual (a) and modeled (b) vegetation status at a given date, as well as (c) the scatter of the data points around the fitted regression line.*

As shown in Figure 3, results in the River Valley site in Senegal showed that the current Biomass CAI model provided the model-estimated counterfactual data with a similar level of coefficient of determination compared to the previous SEIRS model (i.e., 0.72 for the current Biomass CAI model against 0.68 on average for the previous SEIRS model). The current system is, however, delivering the data analysis every 16 days – following the MODIS data frequency instead of the assessment made on an annual basis by SEIRS.

## Enderta Woreda in Ethiopia

In Ethiopia, the Biomass CAI system was implemented in the Enderta Woreda. It was selected as it is one of the successful sites of the UNDP/GEF Project, "Promoting autonomous adaptation at the community level in Ethiopia (2012 –

2016)." The UNDP-internal impact assessment of the project was positive enough to receive approval and funding for scaling up. Furthermore, the area registered one of the worst droughts in decades that hit north and central Ethiopia in 2015, reportedly affecting nearly 10 million people.

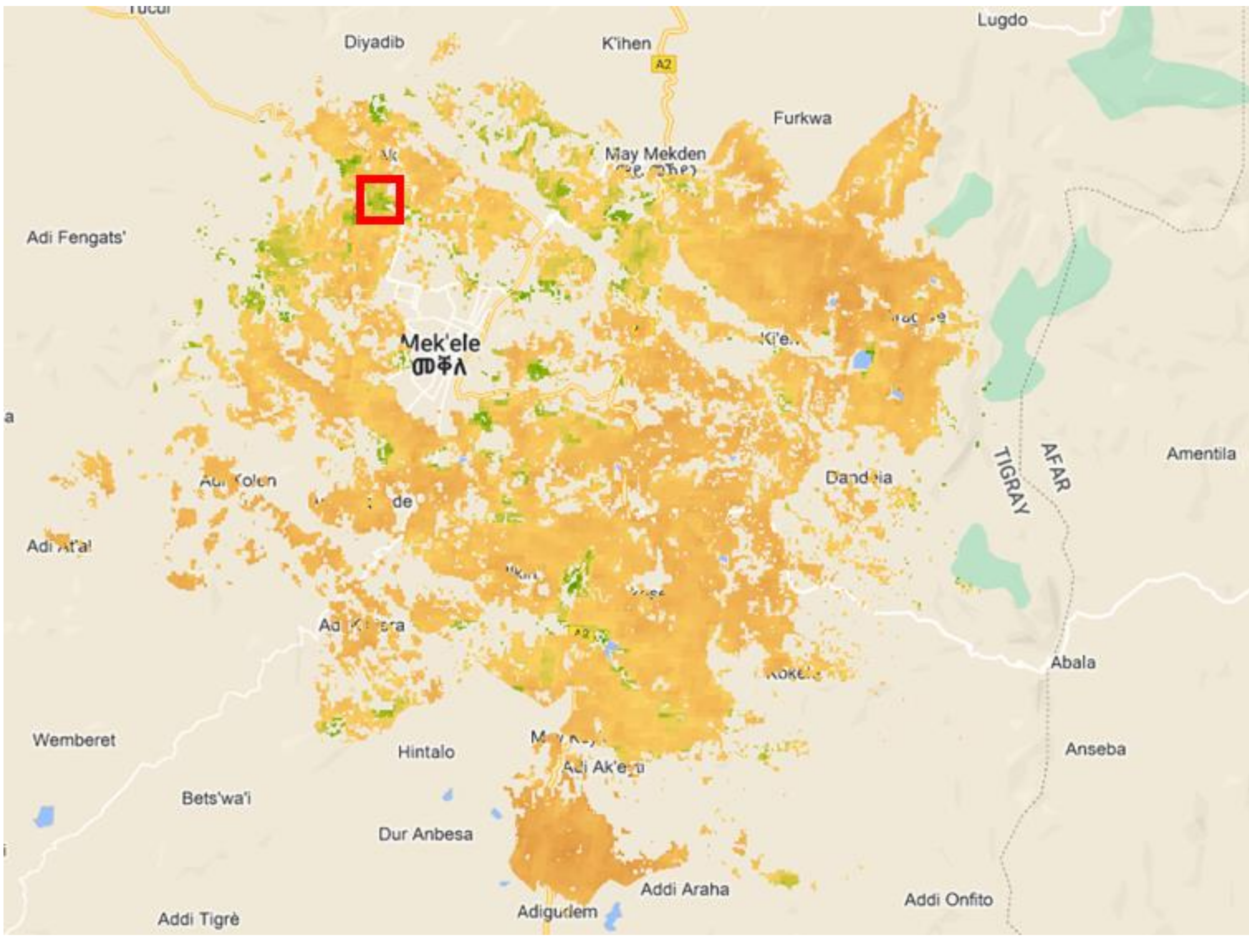


*Figure 4 Anomalies detection, highlighted in green, during the 2015 drought (here 10 June 2015)*

The Biomass CAI result showed that the areas within the UNDP/GEF project intervention district have significantly higher NDVI values than the model-estimated ones during the 2015 drought, highlighted in green in Figure 4, implying the area positively adapted to the climate shock (i.e., drought) compare to the other areas.

# Concluding Remarks

We successfully developed a new analytical workflow, Biomass CAI, to help track the agricultural climate adaptation progress in near-real-time utilizing open-access satellite remote sensing-derived vegetation and climate data and the LSTM machine learning algorithms. This new system improves the previous effort, SEIRS, which was limited to the annual data with no climate context. Preliminary results from two sites with large-scale adaptation investments showed promising patterns, agreeing with known adaptation to historical droughts. While encouraging, we recognize that it is crucial to assess the model performance more thoroughly across broader areas with diverse agroclimatic conditions.

Our specific next steps include the following.

- Automation of the workflow: Current workflow includes a series of scripts on different software frameworks. We will migrate the system into one single processing site for automated processing of near-real-time data at scale.
- Testing in diverse climate zones: Both study sites in Senegal and Ethiopia were in arid landscapes where precipitation explains the vegetation trends. We will explore the model performance across different climate zones.
- Testing on perennial agriculture: Current system is tailored for seasonal crop-based agriculture. We will explore approaches to monitor pastureland or tree crops with less varying vegetation trends.
- Linking with climate information systems: The development and testing of the Biomass CAI system relied on historical large-scale climate shocks (e.g., 2015-2016 El Niño). To fully operationalize the system, we will establish a direct linkage with climate information systems that can inform the location

and scale of such climate shocks and also incorporate the estimated adaptation monitoring from our system into a decision support process.