Remote Sensing in Sub-Saharan African Agriculture: A Geoportal Schema

Author's Statement

I originally wrote this research paper for 76-101: Interpretation and Argument with Dr. Alan Kohler. My section of 76-101 was "Smart Food: Tackling Global Food Security and Sustainability Problems," and for this final paper, we were invited to connect our fields of study to the fight against food insecurity by contributing meaningfully to the discourse around our chosen topic. As a Statistics and Machine Learning major, I've always been passionate about applied data science, and I quickly fell in love with remote sensing. Through remote sensing, machine learning is leveraged towards improving the resilience of a whole system. However, as exciting as technological innovation is, real change occurs when that technology is implemented—whether formally through policy or through increased institutional usage. One barrier to that is simply accessibility in both use and access. As someone with very limited experience with data processing at the time, I decided to investigate a few free RS geoportals to see how much information could be gleaned, and how easy it was to do so. I hope that this paper serves to highlight the capabilities of remote sensing for crop forecasting, and how accessible much of that data is. In the future, climate change will continue to strain our world's food systems, and I look forward to seeing how human collaboration and increased integration of technological advances will help ease that burden.

- Natalie

Abstract

To make data-driven agricultural policy decisions, there is a need for accurate data. One such data point that can inform decisions is that of forecasted food crop yield, and recent advances in satellite remote sensing (RS) technology has made it easier to gather this data on a larger scale. Given a wide variety of free, publicly available RS geoportals, this paper focuses on how the deliberate use of three specific geoportals (African Crop Production Model, GIEWS Earth Observation, GEOGLAM Crop Monitors) can lead to effective crop forecasting. This paper also presents a schema for determining which geoportal to use for a given data need. Using geoportals effectively can support a better integration of RS technology in Sub-Saharan African (SSA) agricultural policy making.

Key words: remote sensing, geoportals, Sub-Saharan Africa, agriculture, crop forecasting

Introduction

Sub-Saharan African (SSA) countries rely heavily on agriculture to maintain food security, and yet "Africa remains the world's only region that is a net importer of food products," despite having "sufficient resources…to be a breadbasket" (Begue, 2020, pg. 2). Given that "African farmers are mostly smallholders who grow food for consumption and income…a relatively low-intensity shock could significantly impact their food security status" (Ly, 2021, pg. 131). Thus, food security can very well depend on the ability of governments to respond effectively to the impacts of adverse growing conditions. To make policy decisions to best support agricultural infrastructure, there is a need for accurate and accessible growing data, which includes crop yield forecasting and prediction. In recent years, the emergence of remote sensing (RS) technology has created an opportunity for increased spatial resolution, temporal resolution, and scope of crop forecasting data. Harnessing RS for crop forecasting can allow SSA governments to improve agricultural policymaking around food security.

Synthetic Review

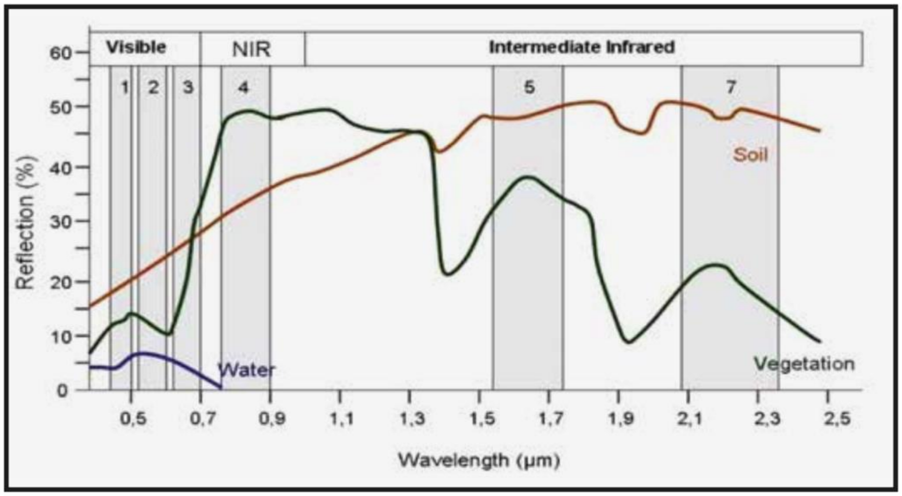
Background of Remote Sensing

Before the advent of satellite imaging to survey whole countries with relative ease, crop yield forecasting involved much more manpower. In Kenya, "agricultural extension officers" would be deployed to "observe and estimate the area planted and the yield [at farms], and to compute agricultural production…[and] the methods used by each…officer…are largely based on informal interviews with local farmers and communities" (Khamala, 2017, pg. 64). Aside from this being a more labor-intensive way to gather data, it's also generally more inaccurate, as "area does not translate to harvested acreage," and estimates around acreage planted fall prey to "systematic error" (Khamala, 2017, pg. 64). In contrast, even though it isn't perfect, RS is simply more efficient than the previous method and more accurate overall.

At its core, remote sensing is the process of using a device to take measurements of something without coming into direct contact with it. In the context of agriculture and crop forecasting, RS data most commonly comes from satellites like NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) and Landsat, and ESA's Sentinel-2 ("What is Synthetic Aperture Radar?"). These satellites capture surface images and/or produce spectral graphs of the visible and near-infrared radiation reflected back from and absorbed by crop fields. Based on the spectral graphs, experts can determine the type of crop, the pH level of the soil, the growth density of the crop, and various agricultural indices (“Remote Sensing in Agriculture”). An example of this can be seen below.

A graph of spectral signatures collected from the satellite LANDSAT 7, which can then be analyzed to indicate vegetation, soil, and water status

FIGURE 2. Spectral signatures of soil, vegetation and water, and spectral bands of LANDSAT 7.



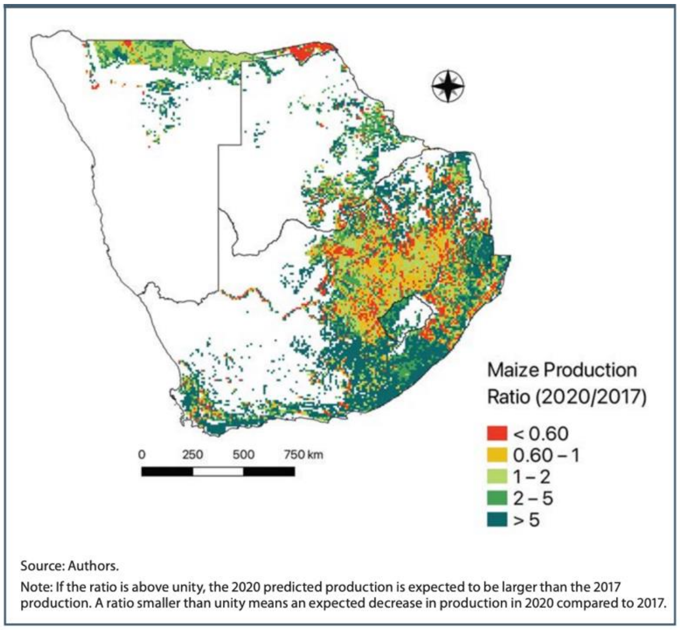
Source: Siegmund & Menz, 2005 (with modifications).

Source: *Food and Agriculture Organization of the United Nations*, 2021

One such agricultural index that can be gleaned from analysis from a spectral graph like this one is the Normalized Difference Vegetation Index (NDVI), which is a “proxy to indicate the density and health of vegetation” (Khamala, 2017, pg. 27) and can be broadly described as the “greenness of ground cover” (Country Indicators). When the NDVI is paired with agrometeorological variables (i.e. rainfall, daytime land surface temperature) that impact crop growth or indicate signs of potential drought or flooding, RS data for those variables can be input into crop growth simulation models that result in statistical yield estimates.

When RS data is put together and visualized, the result can look something like this:

Across Southern Africa, maize production for 2020 will mostly meet or exceed maize production from 2017.



Source: *International Food Policy Research Institute*, 2021

Given the massive scope of the maize production data represented in this map, one can argue that RS can allow statisticians and policymakers to view crop yield predictions like never before.

Uses of RS Data

Though having accurate crop yield forecasting is a useful datapoint for agriculture policy for SSA countries in general, we can turn to the Monitoring and Analysing Food and Agricultural Policies (MAFAP) program to see one such application of the data. The MAFAP program is a policy support initiative of the Food and Agriculture Organization of the United Nations that has been "[working] with [certain sub-Saharan] countries in Africa to strategically prioritize, reform, and implement policies on food and agriculture" for the last few decades ("Monitoring and Analysing"). Economic policies like price incentives and public spending can all help bolster a country's agrifood industry, and keeping watch on the growing season can help with this ("FAO steps up"). Additionally, knowing how much wheat will be produced nationally could inform where a government might set a price floor when dealing with external pressures, like war (Selassie).

Before continuing with how to improve integration of RS data into policymaking, it is worth addressing the current shortcomings of RS. This can be summarized into two main issues: data inaccuracies and challenges of integrating data into policymaking. As for the former, while RS data is currently accurate enough to be reasonably relied upon, the practice of ground truthing (i.e. the confirmation of RS data from farmers and officials) can mitigate inaccuracies in RS data that arise from low resolution and should be developed in tandem with RS improvements. It should also be noted that in order for a ground truthing system to be viable, it must be in place at the time of the RS data collection (Wu, 2022), otherwise the ground truthing will attempt to confirm data for crops that have grown significantly since the RS measurements were taken. The latter issue of integrating data into policy-making includes difficulties in funding RS projects, RS training for governments, and so on, but for the scope of this paper, we will be primarily focusing on how to effectively harness existing RS resources.

Research Study: RS Geoportals

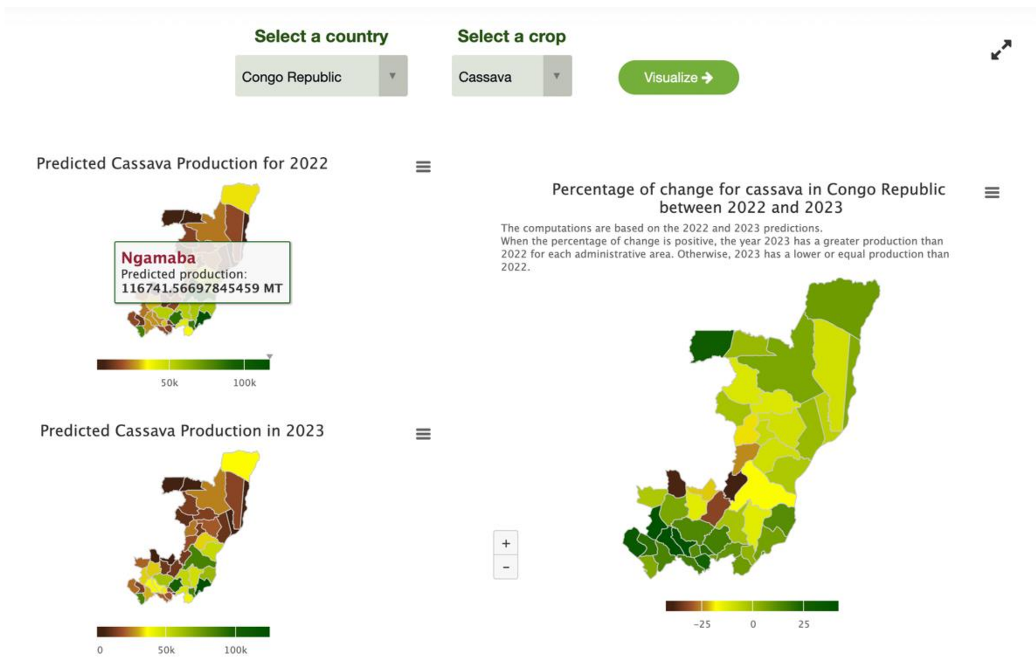
Collecting all of one's own RS data is generally an unnecessary endeavor, since various agencies around the world have already launched satellites to do so and made the data publicly available. While one could perhaps increase the spatial resolution of the data by deploying drones and other low-flying aircraft with sensors to survey a certain region, this would only really be applicable on a small scale. Thus, taking advantage of the many free online resources and geoportals to access available RS data should be a priority, since this is both cost-effective and digitally accessible (Khamala, 2017). To see how "usable" these geoportals are for crop forecasting, especially for someone with a limited RS background, I ran a study of the following geoportals to ascertain what the strengths and weaknesses were of each: the Africa Crop Production Model (AfCP), the Global Information and Early Warning System (GIEWS) Earth Observation Portal, and the GEOGLAM portal. For each of these geoportals, I spent a few hours exploring the site to get a feel for the user experience, and to ascertain the potential uses of each geoportal based on the data visualizations offered (such as the scale of the maps presented, ranging from continental to national), and the temporal and spatial resolution of the data used. Additionally, I checked to see if the geoportal directly presented a crop forecast, or if it instead offered the user data for the various agricultural indices that could go into crop forecasting, thus requiring further user analysis and a strong command of data science to use. Aside from analyzing user experience, my other goal of the study was to create a schema for the geoportals such that someone would be able to easily pinpoint which geoportal to use given a specific user type and data need.

African Crop Production Model (AfCP)

AfCP Summary

Run by the Africa Agriculture Watch, the AfCP model is a machine learning model that predicts food crop production with the Normalized Difference Vegetation Index (NDVI), Daytime Land Surface Temperature (LST), rainfall data, and evapotranspiration data, which describes how much water actually "reaches the leaves [of a crop] before evaporating into the atmosphere" (Africa Crop Production Model). Data is presented as a series of color-coded maps, and on the AfCP site, maps are presented either by district or by pixel. For the district-level forecasts, a user can select a country and select between 1-2 staple food crops for that country to see predicted production for. One can also hover over certain districts to get a statistic of predicted production in metric tons for that district.

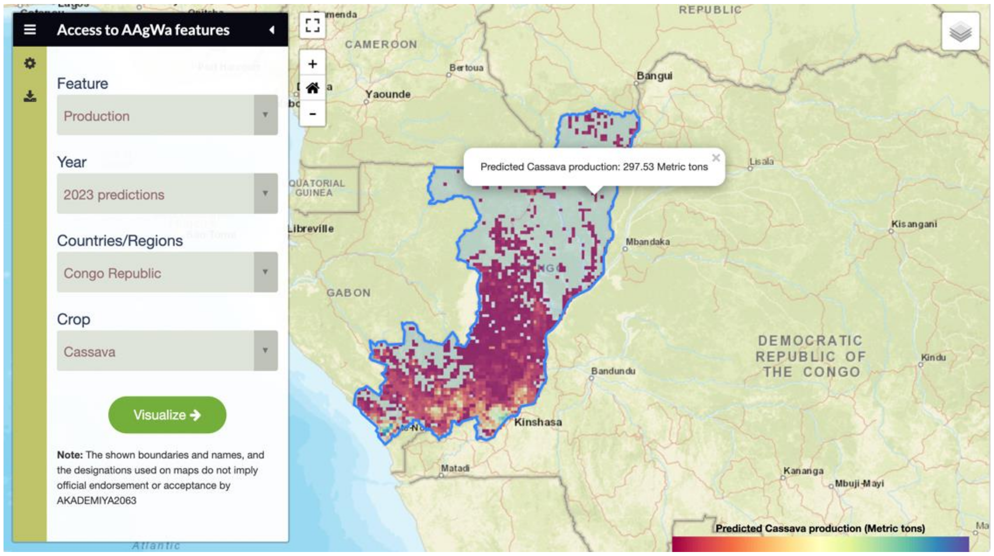
District-level maps of predicted cassava production for the Congo Republic



Source: *Africa Agriculture Watch*, 2023

For the maps presented by pixel, an overlay of predicted production is put over an interactive, scrollable map. The spatial resolution of each pixel is 10 kilometers, and once again, the user can click on any pixel to see the predicted production for that 10-kilometer square.

Country-level map of predicted cassava production for the Congo Republic



Source: *Africa Agriculture Watch*, 2023

<u>AfCP Evaluation</u>

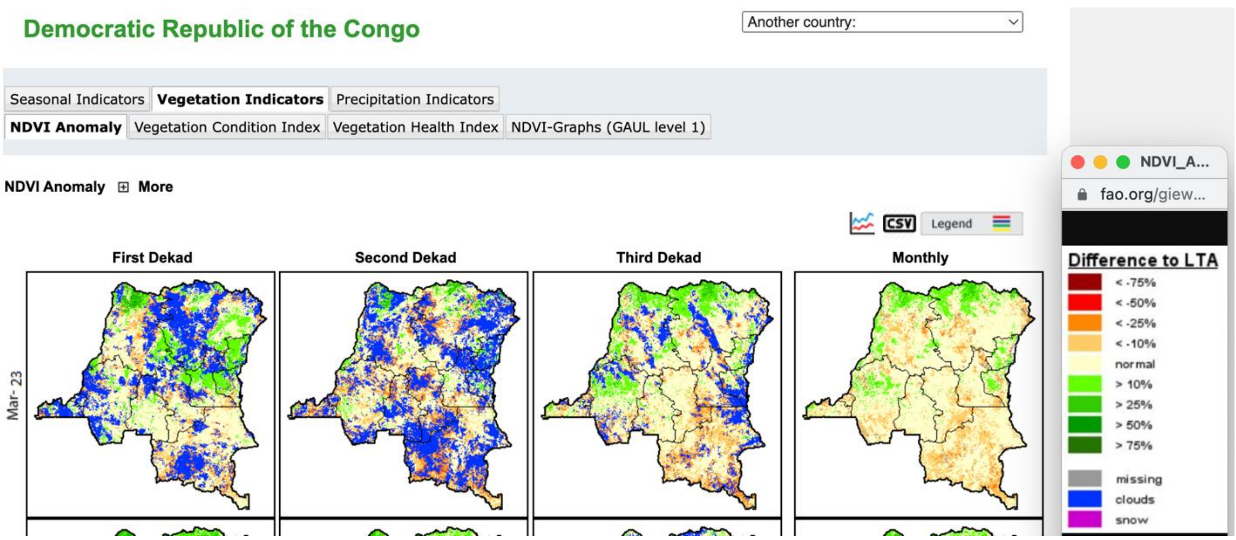
The AfCP site is extremely easy to use and feels clean, modern and fairly intuitive. One major benefit of using the AfCP site is that it differentiates between crop types and presents a precise prediction on crop yield. This does mean, however, that a statistician would be unable to use this geoportal to gather data about variables to make their own crop predictions. Additionally, there's only data on a very limited number of staple crops per country, so this site wouldn't be useful for any research or deliberation on crops not listed. Given the somewhat low spatial resolution, AfCP is also best for a beginner in RS that would like to get an overall view of how production is changing year-to-year, and a general idea of yield.

GIEWS Earth Observation

<u>GIEWS Summary</u>

The GIEWS Earth Observation site is run by the Food and Agriculture Organization of the United Nations and is best used by agricultural statisticians who want direct access to RS satellite data for key crop forecasting variables. The temporal resolution of the data is fairly high, with maps updated for every *dekad* [1], though the data isn't posted immediately after a *dekad* concludes. Some of the data is visualized in the form of maps, and the user can select a certain index that they want to see the map for, including the NDVI, the Vegetation Condition Index, and the Vegetation Health Index. All three of these variables can be used for crop yield estimates.

NDVI maps of the Democratic Republic of the Congo, by *dekad*

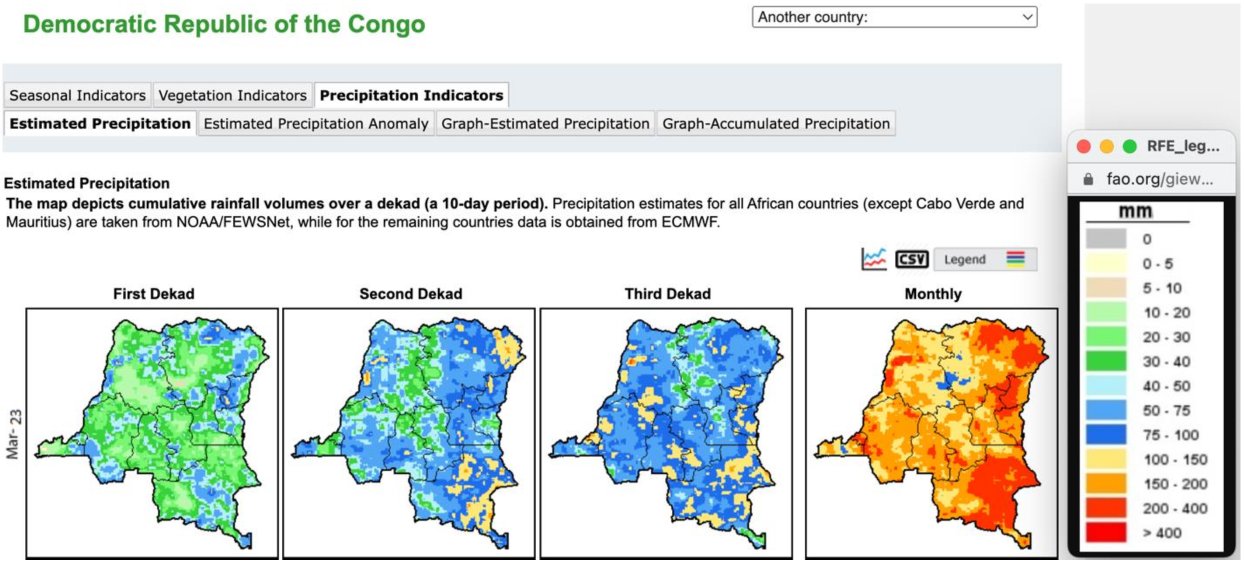


Source: *GIEWS Earth Observation*, 2023

Other maps can be accessed by selecting different indicators, including precipitation:

[1] A *dekad* is a ten-day rainfall period, and in climate data, every month is split into three *dekads*, such that "the first two *dekads* have 10 days, and the third is comprised of the remaining days of the month. Therefore, the length of the third *dekad* of each month is not consistent and varies from 8-11 days, depending on the length of the month" ("Dekadal Rainfall Estimates").

Estimated Precipitation maps of the Democratic Republic of the Congo, by *dekad*



Source: *GIEWS Earth Observation*, 2023

There's also an option to see the data visualized in the form of a graph, but these are a little harder to interpret than the color-coded maps. If the user downloads GIS software, the GIEWS portal can also provide the user with a link to a file with an interactive map, or with an entire dataset that the user can analyze further.

<u>GIEWS Evaluation</u>

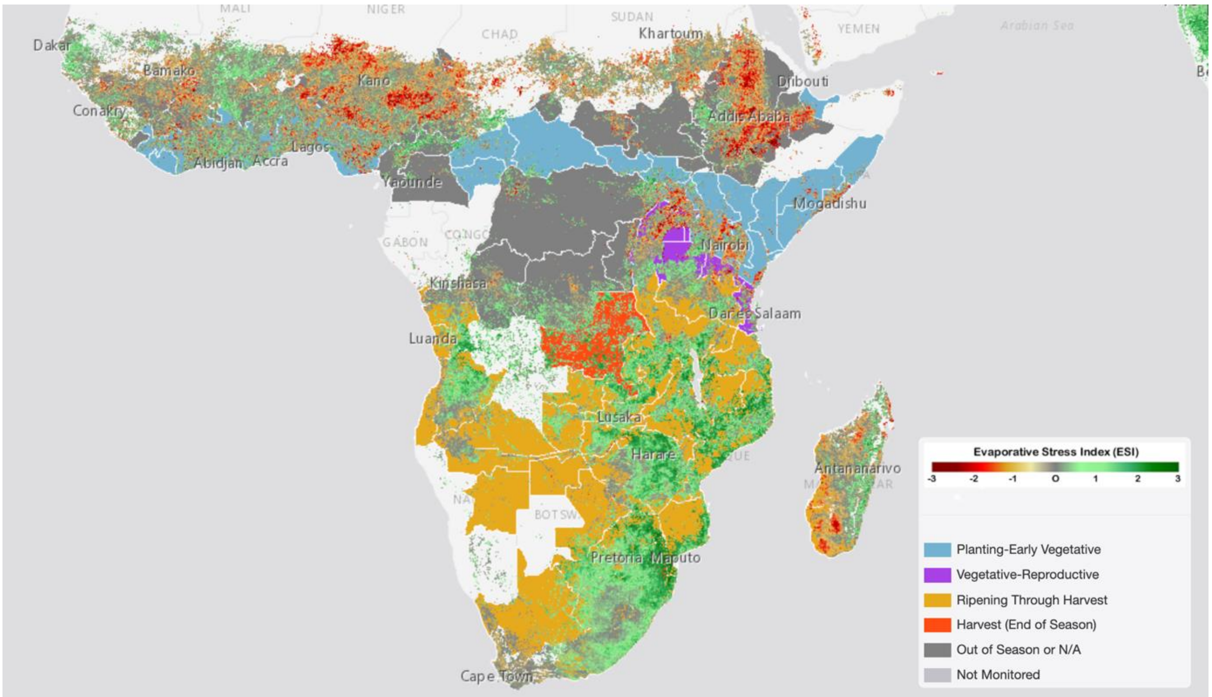
Ultimately, the GIEWS portal has a slight user challenge for a beginner, since it can be more difficult to understand what data is being shown. It also won't be immediately useful for crop yield forecasting, unless the user has an understanding of how the vegetation and precipitation indicators will influence crop yield. There is also no crop differentiation in the geoportal. However, unlike the AfCP model, this portal has more access to index data, and a much higher temporal resolution, with maps being updated every month or so, rather than having predictions come out every year.

GEOGLAM Crop Monitors

GEOGLAM Summary

The Group on Earth Observations Global Agricultural Monitoring Initiative (GEOGLAM) arose from a 2011 G20 summit, and it has since produced two Crop Monitors—the Crop Monitor for the G20 Agricultural Market Information System (AMIS), and the Crop Monitor for Early Warning (CM4EW). The former seeks to assess the "crop growing conditions, status, and agro-climatic factors" that will impact production of four major AMIS crops (wheat, maize, rice, and soybeans), and the latter is a warning system for unfavorable crop conditions, to signal failing crops "before humanitarian crises arise" ("About the Crop Monitors"). Both systems are valuable applications of RS to indicate and predict crop yield. The AMIS and EW condition plots, like the AfCP model, have maps for crops broken down by country district, and also include specific crop selection. The user can also overlay data from "satellite products" to see how different indices (i.e. NDVI, Evaporative Stress Index) impact the planting season of the crop type. Below, we can see an image of the Early Warning Crop Monitor showing a map of maize on April 1st of this year. The area highlighted is split into various country districts, and there's an overlay of the Evaporative Stress Index (ESI) on top.

Planting stages for Maize in Sub-Saharan Africa, with an overlay of the Evaporative Stress Index

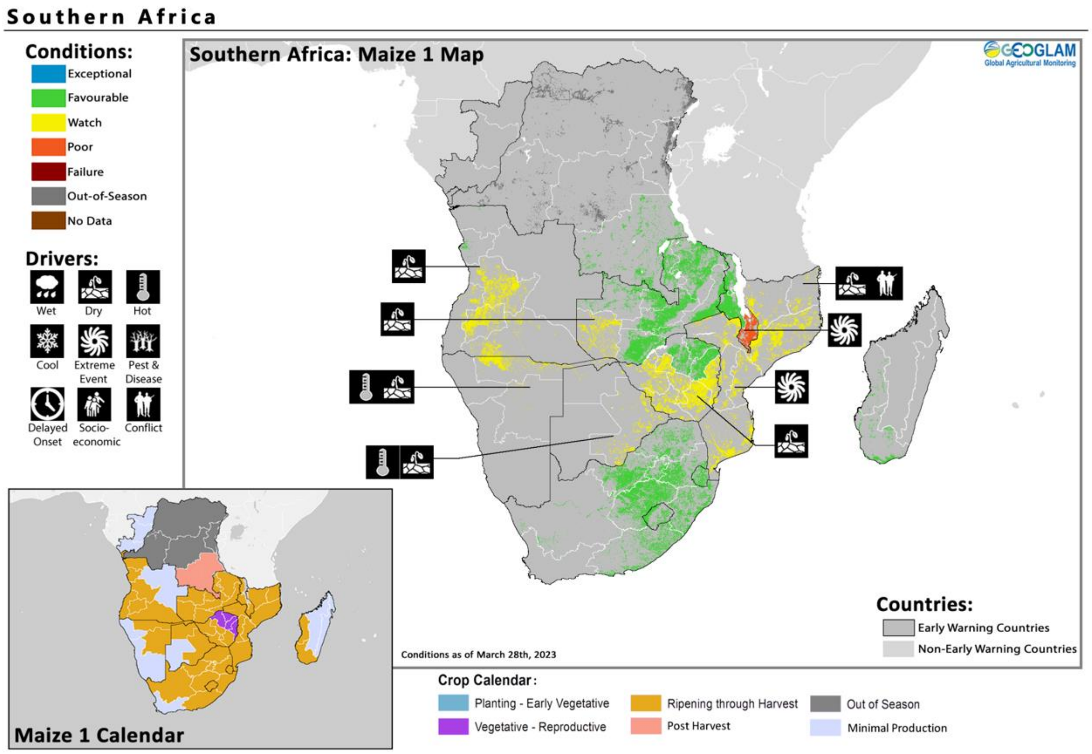


Source: *GEOGLAM,* 2023

<u>GEOGLAM Evaluation</u>

Though GEOGLAM's Crop Monitors do present data well, it was ultimately a little frustrating to figure out how to use it to its full potential. The site had some difficulties in loading the maps in a timely manner, and aside from the satellite data overlays, this had perhaps the lowest spatial resolution of any geoportal. It also does not offer much specific information on crop yield, unlike the AfCP model. Using the geoportal alone simply felt like an ineffective way to use RS data for crop prediction. It should be noted, however, that while it may be difficult to glean data from the geoportal, GEOGLAM does publish monthly reports that synthesize the data from its Crop Monitors. A graphic from its April 2023 report can be seen below:

Predicted Maize conditions for Southern Africa, linked to certain "drivers" that will impact crop growth



Crop condition map synthesizing Maize 1 conditions as of March 28th. Crop conditions over the main growing areas are based on a combination of inputs including remotely sensed data, ground observations, field reports, national, and regional experts. ***Crops that are in other than favourable conditions are labeled on the map with their driver.***

Source: *GEOGLAM Crop Monitor,* April 2023

Here, in these reports, GEOGLAM reports on the conditions of various staple crops and connects it to the drivers of those conditions. The reports even include a detailed a country-by-country breakdown of various planting seasons and recent meteorological events in Sub-Saharan Africa. For example, the April 2023 report writes that in the Democratic Republic of the Congo this month, "harvesting of main and second cereals is underway…[but] excessive rainfall in the South Kivu highlands…have caused landslides and localized crop loss, particularly around Minembwe" (Crop Monitor Early Warning Report). These valuable insights are extremely specific, centralized, and timely. As such, though the GEOGLAM geoportal is not an ideal way to gather RS agricultural data, the GEOGLAM reports are a valuable resource for anyone seeking a specific summary of how a country's staple crops are doing, and why.

Final Schema

Based on the analysis presented above, I ended up with this final schema for RS geoportal use.

A schema for determining what free geoportal to use for SSA remote sensing, based on a project's data needs

Sub-Saharan Africa Remote Sensing Geoportal Use Schema

Geoportal	Types of RS Data presented	Data format	Crop type differentiation?	Spatial resolution	Temporal resolution	Ideal use
African Crop Production Model (AfCP)	Crop yield and crop prediction (metric tons), percent change in both	Country maps	Yes, 1-2 staple crops per country	Country district	Yearly	Use geoportal to see crop yield/ prediction estimate maps
GIEWS Earth Observation	Seasonal, vegetation, and precipitation indicators, Agricultural Stress Index, Drought Intensity, Weighted Mean Vegetation Health Index, etc.	Regional and country maps	No	10 kilometers	Year, month, dekad	Use GIS software for its interactive maps, download datasets to use for statistical model inputs
GEOGLAM Crop Monitors	Crop condition, planting season stage, crop condition drivers (in report only)	Regional maps, monthly crop reports	Yes, AMIS crops only in geoportal (rice, wheat, maize, soybean)	Country region in geoportal, 10 kilometers in report	Bimonthly	Read the monthly Early Warning crop reports for a detailed summary of growing conditions and driving factors

Though these three geoportals could certainly be used in separate contexts, their strengths and weaknesses complement each other, and I'd recommend using all three to get a full understanding of an agricultural context. The AfCP is a good geoportal to start off with, since its intuitive interface and easy-to-access crop prediction maps allows for a broad overview of how crops have done for the past few years. In order to dive into predictive work for the coming agricultural season(s), one can then turn to the GIEWS Earth Observation geoportal to see data on different agricultural indices for the past dekads. The wide variety of variables presented (ranging from rainfall to the NDVI) means that this geoportal's data will suit most needs, as long as the user has an understanding of what variables indicate crop welfare. If user has a data science background, they can export the data and further analyze it themselves—as such, the GIEWS Earth Observation portal will likely be the most useful for statistical manipulation, if a certain project requires it. Additionally, the increased spatial resolution of the GIEWS maps allows users to "zoom in" further for regional data than in the AfCP. Finally, to gain a contextual understanding of the various factors impacting the growing season in Sub-Saharan Africa, one should read the monthly Early Warning reports from the GEOGLAM Crop Monitors. The reports are fairly easy to understand for any reader with a decent understanding of the agricultural industry and offer incredibly valuable insights into driving factors behind crop conditions. Though they each have limitations when used alone, in tandem, these three free geoportals provide a well-rounded knowledge base for crop forecasting and basic remote sensing projects.

Discussion and Future Steps

In future studies, the Famine Early Warning System (FEWS Net) and Vegetation/Proba-V data portals could be analyzed and included in the schema as data-rich alternatives for the GIEWS Earth Observation portal. Given that this study focused on free RS geoportals, it would also be worth exploring the world of paid RS geoportals to see any additional data they have to offer. It's very likely that the data offered by all geoportals will expand as RS technology continues to develop, and these geoportals will become ever more useful for both policymakers who want to get a general sense of food crop yield that year, and for statisticians who want to download the data and make their own predictions. To further support the integration of RS, "African governments must create special units in which emerging technologies can be harnessed" and incentivize private-sector initiatives to do so (Ly).

Additionally, systems for effective ground-truthing must be put in place to verify the accuracy of RS data. In a world where RS is fully integrated into agricultural decision-making, we can expect to see a more prompt and governmental response to famine and drought from early warning systems, more supportive economic policymaking for smallholder farmers in times of war and peace, and more data-informed decision-making run on less resources and with less cost. Even through free, publicly accessible geoportals, RS has been shown to be a powerful tool for informing decisions that maintain food security.

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