NASA DEVELOP National Program
2024 Spring Project Proposal

North Carolina – NCEI
Northern Brazil Agriculture

Measuring Crop Yields in Northern Brazil During El Niño Years to Evaluate Trends in Agricultural Production and Support Crop Forecasting

Project Overview

Project Synopsis: Brazil is the fourth-largest agricultural-producing country in the world. Reductions in crop yields due to climatic variability in Brazil affect food supply globally, and the El-Niño-Southern Oscillation (ENSO) causes interannual variation in the Brazilian climate. To assess the impact of ENSO on agricultural production in Brazil, this project will partner with the USDA Foreign Agriculture Service (FAS) International Production Assessment Division (IPAD) and World Agricultural Outlook Board to evaluate trends in crop yields in northern Brazil, where drier-than-normal conditions are typically present during El Niño years. Using data collected by Landsat Missions 5–9, the project team will generate maps depicting normalized difference vegetation index (NDVI) on croplands during El Niño years at a sub-state level to supplement crop yield data that are collected at the state level. Trends in agricultural production will be compared with precipitation and ENSO data to inform partners' efforts to produce crop production outlooks.

Study Location: BA, MT, PA, TO, Brazil
Study Period: 1984 – 2023

Advisor(s): Dr. Garrett Graham (North Carolina Institute for Climate Studies) garrett.graham@noaa.gov, Dr. Boyin Huang (NOAA National Centers for Environmental Information) boyin.huang@noaa.gov, Molly Woloszyn (NOAA National Integrated Drought Information System) molly.woloszyn@noaa.gov

Partner Overview

Partner Organizations:

Organization	Contact (Name, Position/Title)	Partner Type	Sector
USDA Foreign Agriculture Service, International Production Assessment Division	Dr. Sunita Yadav-Pauletti, Crop Analyst for Brazil	End User	Federal Government
USDA Office of the Chief Economist and World Agricultural Outlook Board	Mark Brusberg, Chief Meteorologist	Collaborator	Federal Government

End User Overview

End User's Current Decision-Making Process & Capacity to use Earth Observations: The USDA FAS coordinates the USDA's international activities to enhance export opportunities and global food security through trade policy, global market development, and the collection and analysis of statistics and market information. IPAD assesses global agricultural production outlook and conditions affecting food security internationally by estimating area, yield, and production of crops. IPAD collaborates with NASA to produce the Global Inventory Monitoring and Modeling Studies (GIMMS) Global Agriculture Monitoring (GLAM) system, which provides a global agricultural production outlook and monitors conditions affecting global

food security using MODIS & VIIRS NDVI imagery. With the return of El Niño in 2023, IPAD is interested in assessing the impact of El Niño–Southern Oscillation on crop production in Brazil to inform estimates of agricultural production in the country.

Earth Observations Overview

Earth Observations:

Platform & Sensor	Parameter(s)	Use
Landsat 5 TM	Vegetation	Normalized difference vegetation index (NDVI) will be calculated using at-surface reflectance data to measure crop yields at a 30m spatial resolution and 16-day spatial resolution.
Landsat 7 ETM+	Vegetation	Normalized difference vegetation index (NDVI) will be calculated using at-surface reflectance data to measure crop yields at a 30m spatial resolution and 16-day spatial resolution.
Landsat 8 OLI/TIRS	Vegetation	Normalized difference vegetation index (NDVI) will be calculated using at-surface reflectance data to measure crop yields at a 30m spatial resolution and 16-day spatial resolution.
Landsat 9 OLI-2/TIRS-2	Vegetation	Normalized difference vegetation index (NDVI) will be calculated using at-surface reflectance data to measure crop yields at a 30m spatial resolution and 16-day spatial resolution.

Ancillary Datasets:

- Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) Daily Precipitation – Evaluate precipitation trends across the study period
- Niño 3.4 – Determine onset and termination El Niño of conditions during the duration of the study period
- Companhia Nacional de Abastecimento (CONAB) Crop Yield Data – Annual, state-level, corn and soy crop yield data will be used to measure and map variations in crop yields across the study area
- MapBiomas Agricultural Lands – Locations of soy production will be used to mask non-agricultural lands from analysis

Software & Scripting:

- Climate Engine Research Application 2.1 – Acquisition, processing, and time series generation of Landsat 5–9 NDVI and CHIRPS precipitation data
- Esri ArcGIS Pro 3.0.1 – Generate NDVI deviation from average maps
- Google Earth Engine API – Acquire and process Landsat 1–4 NDVI data

Decision Support Tool & End Product Overview

End Products:

End Product	Partner Use	Datasets & Analyses
Crop Yield and NDVI Cropland Maps	Maps depicting NDVI and corn and soy yields on crop lands during El Niño conditions will be used by project partners to evaluate the impact of ENSO on crop	NDVI will be calculated using Landsat data during El Niño years from 1984–2023. NDVI and crop yields will be mapped across croplands in Brazil.

	production at state and sub-state levels between 1984–2023.	
Time Series Trend Comparison of Crop Yield and Environmental Conditions	Time series of corn and soy production, NDVI, and precipitation rates during ENSO phases will be used to assess trends in crop production during El Niño conditions.	Time series of ENSO conditions, crop yields, NDVI, and precipitation will be generated from 1984–2023 using *in situ* crop production levels, Landsat 5–9 imagery, the Niño 3.4 index, and CHIRPS data, respectively.
Crop Yield and El Niño Correlation Analysis	Crop yield data will be compared with ENSO conditions to evaluate the impact of El Niño on crop production in Brazil. These results will be used by partners to inform crop production outlooks during El Niño years.	Crop yields will be correlated with trends in ENSO conditions using crop production data and data from the Niño 3.4 index.

Project Timeline & Multi-term Objectives

Project Timeline: 1 Term: 2024 Spring

Similar Past DEVELOP Projects:

- 2015 Summer NC Pacific Water Resources (Internal DEVELOPedia link)
- 2016 Summer NC Pacific Water Resources II (Internal DEVELOPedia link)
- 2016 Fall JPL Costa Rica Agriculture II (Internal DEVELOPedia link)
- 2018 Summer NC – Central America Agriculture & Food Security (Internal DEVELOPedia link)
- 2019 Fall NC – Central America Dry Corridor Food Security & Agriculture (Internal DEVELOPedia link)
- 2022 Summer NC – Mato Grosso Agriculture (Internal DEVELOPedia link)

Notes & References:

***Notes*:** Mark Brusberg (World Agricultural Outlook Board) described that variation in soybean production attributed to ENSO has already been observed in the 2023–2024 El Niño years. Mark plans to describe these variations more during the first partner meeting. The 2022 Summer NC Mato Grosso Agriculture project attempted to create cropland masks for the state of Mato Grosso but encountered difficulties in creating those products. Please refer to the Mato Grosso Ag technical paper for more information about their methodology. Garrett, Mark, and Sunita, who were part of that project, may also be able to provide recommendations based on the Mato Grosso Ag team's work. Finally, here is a document with agendas and notes from all pre-project meetings.

References:

E. Becker. (2023). June 2023 ENSO update: El Niño is here. *Climate.gov*. https://www.climate.gov/news-features/blogs/enso/june-2023-enso-update-el-nino-here

Cirino, P. H., Féres, J. G., Braga, M. J., & E. Reis. (2015). Assessing the impacts of ENSO-related weather effects on the Brazilian agriculture. *Procedia Economics and Finance*, *24*, 146–155. https://doi.org/10.1016/S2212-5671(15)00635-8

Júnior, R. S. N., Fraisse, C. W., Karrei, M. A. Z., Cerbaro, V. A., & D. Perondi. (2015). Effects of the El Niño Southern Oscillation phenomenon and sowing dates on soybean yield and on the occurrence of

extreme weather events in southern Brazil. *Agricultural and Forest Meteorology*, *290*. https://doi.org/10.1016/j.agrformet.2020.108038

2024 Spring Project Work Plan

Project Summary

- **Primary Question 1**: Does crop production in northern Brazil at the state (Brazilian CONAB crop-yield data) and sub-state (NDVI) levels vary with ENSO (assessed using maps, time series, correlation analysis)?
    - **Tiered Question 2**: How did precipitation vary with ENSO (assessed using maps, time series, correlation analysis)?
    - **Tiered Question 3**: How do 1st and 2nd corn yields vary with ENSO (assessed using time series and correlation analysis)?

Methodology questions to consider:

- How will maps illustrate trends in crop production?
    - Ideas:
        - NDVI departure from x-year average
        - Peak NDVI
- Statistical analyses:
    - Which analyses (e.g. time-lag correlation) will be performed to analyze trends in crop production and NDVI?
    - How will crop productions be detrended over the study period to account for production increases due to technology development?

Notes to keep in mind:

- From Mark: Flag crop yields affected by Asian rust outbreak during the study period
- Garrett: Recommends exporting cropland mask from GIS into Python based on difficulties in Mato Grosso Ag project
    - The Mato Grosso Ag team worked on creating a cropland mask for Brazil but had difficulties finishing that mask, so consider beginning this portion of the project early on in case of difficulties/project time constraints
    - Sunita shared the ESA's World Cereal Crop Map, which has some information about corn lands in Brazil and may be helpful for masking non-crop lands (link to the map viewer)

Objectives and Priorities

1. **Acquire, export, and share datasets**: Partners' first priority is having data in the usable formats that they can use to run analyses:
    - Time series – use Excel (.csv file)
    - Maps – compatible with GIS system (e.g. geotiff)
2. **Statistical analyses** comparing trends in ENSO conditions, NDVI, crop yields, and precipitation
3. **Maps** depicting NDVI and crop yields during El Niño years

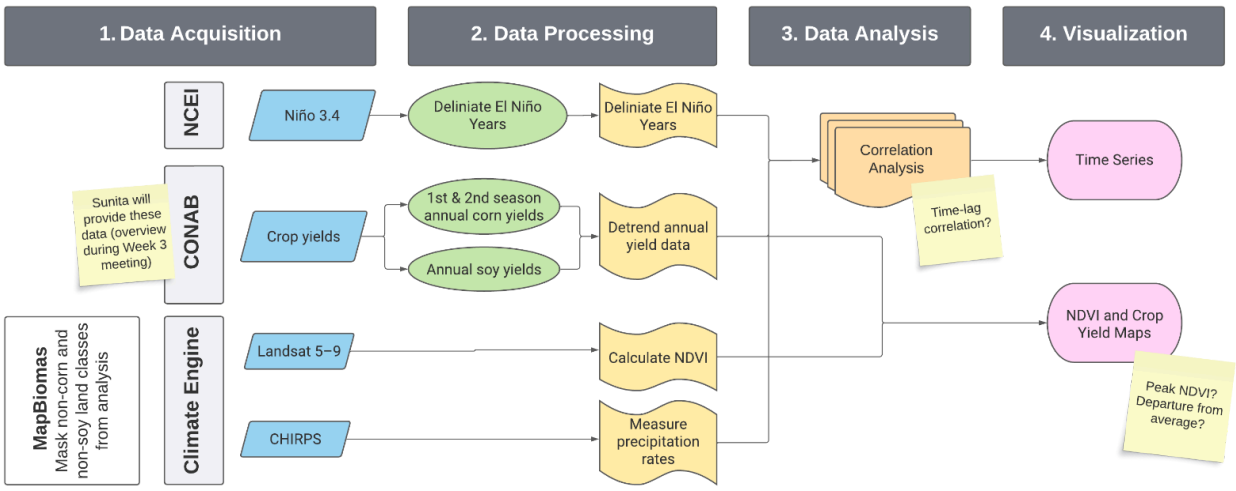

Figure 1. Editable flowchart for project methodology (requires a free account). Source: Lucidchart.

Project Partners

USDA FAS IPAD

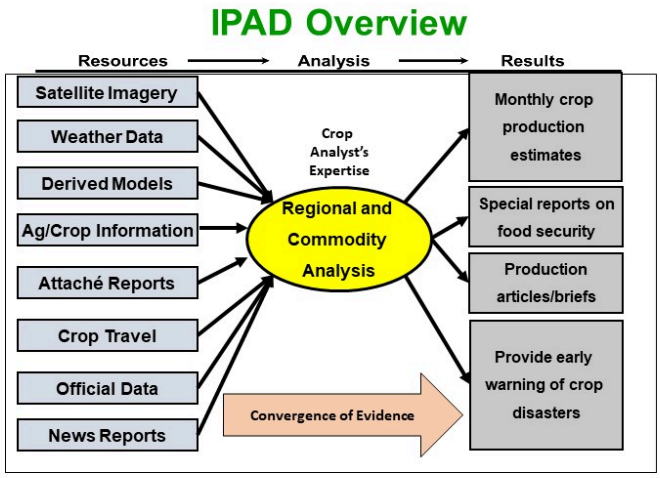

Figure 2. IPAD overview: The International Production Assessment Division (IPAD) of the USDA's Foreign Agricultural Service (FAS) is responsible for global crop condition assessments and estimates of area, yield and production for grains, oilseeds and cotton. Source: USDA FAS IPAD.

- IPAD Country Summary - Brazil
- IPAD Crop Explorer - Brazil
- IPAD Crop Explorer - Commodity Intelligence Reports - Brazil
- IPAD Crop Production Maps - Brazil

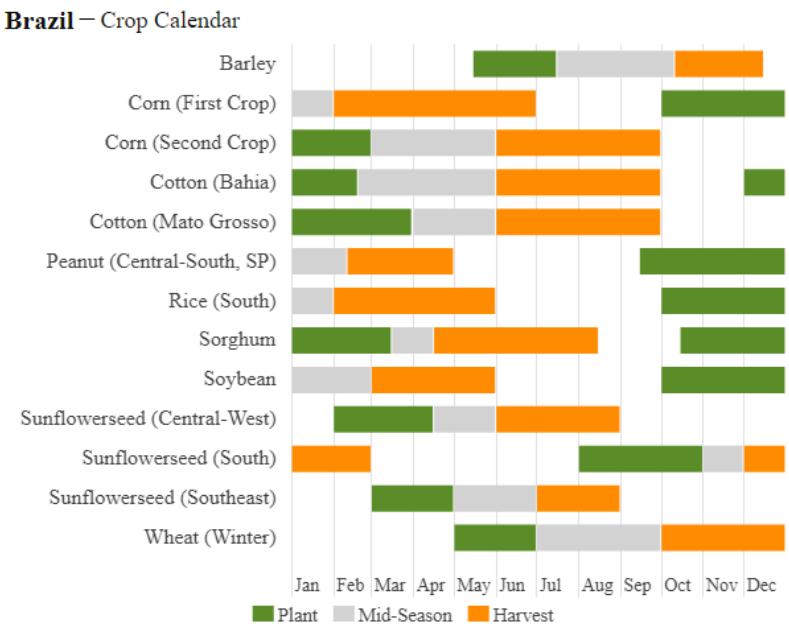

Figure 3. Annual crop calendars for Brazil. Source: USDA FAS IPAD.

Study area

Northern Brazil:

- Project partners are interested in studying northern Brazil (Figure 4) due to drier-than-normal conditions during El Niño years (Figure 5)
    - According to Mark Brusberg (project partner), corn and soy production has expanded northward into the northeast interior of Brazil in recent decades. Project partners are interested in understanding whether this expansion is placing farmers at risk of crop reduction due during El Niño years.

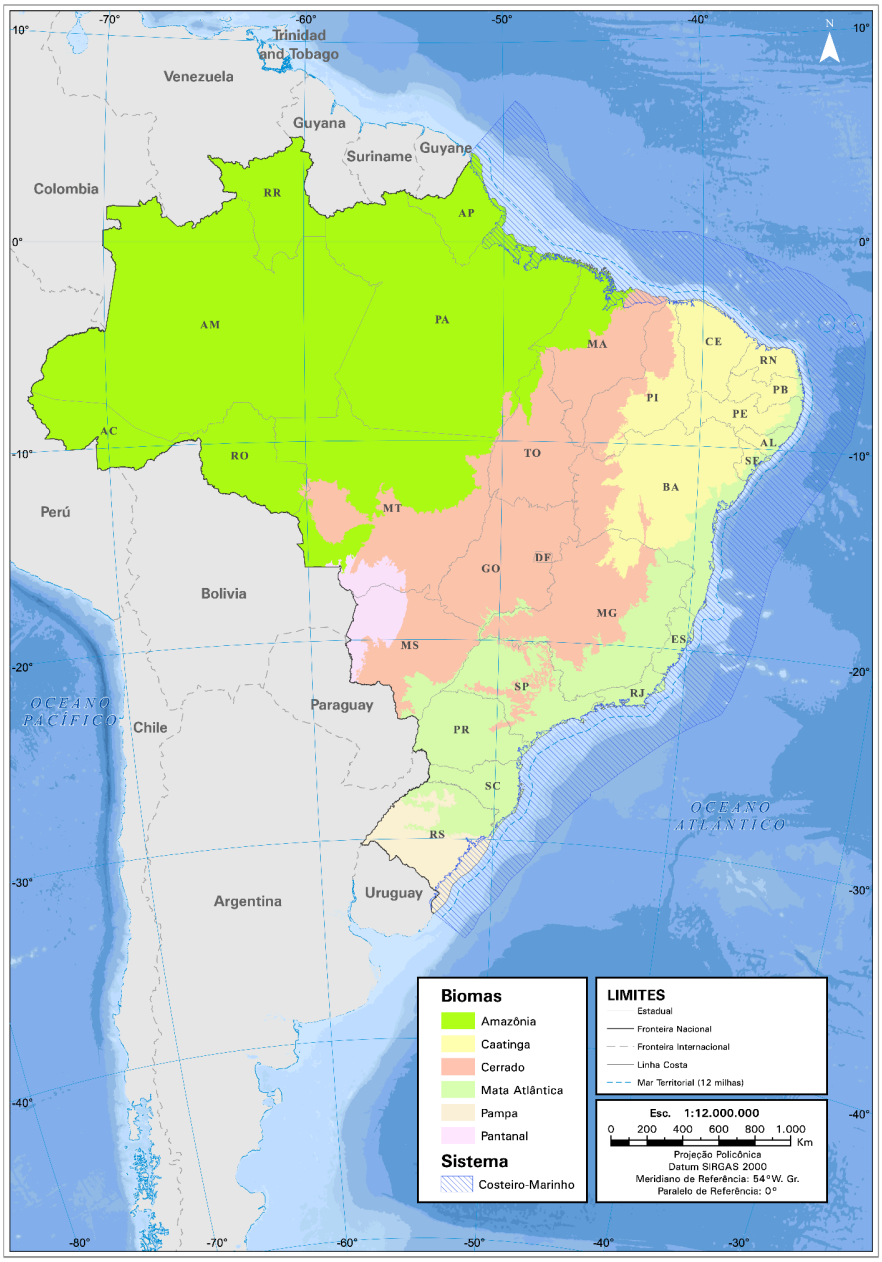

Figure 4. Biomes and coastal-marine system of Brazil. Acronyms for each state: Acre-AC; Alagoas-AL; Amapá-AP; Amazonas-AM; Bahia-BA; Ceará-CE; Distrito Federal-DF; Espírito Santo-ES; Goiás-GO; Maranhão-MA; Mato Grosso-MT; Mato Grosso do Sul-MS; Minas Gerais-MG; Pará-PA; Paraíba-PB; Paraná-PR; Pernambuco-PE; Piauí-PI; Roraima-RR; Rondônia-RO; Rio de Janeiro-RJ; Rio Grande do Norte-RN; Rio Grande do Sul-RS; Santa Catarina-SC; São Paulo-SP; Sergipe-SE; Tocantins-TO. Source: Instituto Brasileiro de Geografia e Estatística; IBGE (English: Brazilian Institute of Geography and Statistics).

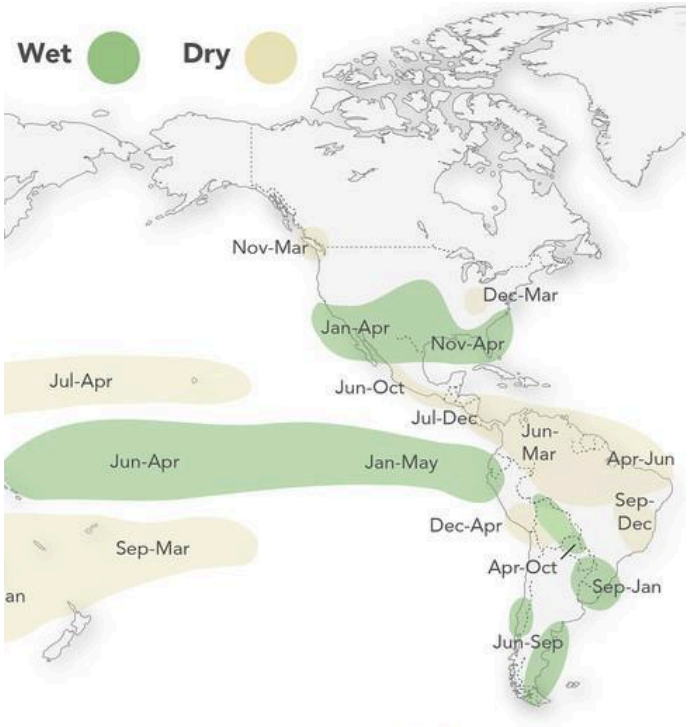

Figure 5. Typical global rainfall anomalies during El Niño years (1951–2016). Source: International Research Institute (IRI) for Climate and Society (Lenssen et al. 2020; Mason & Goddard, 2001).

Subject Matter Exploring

Please note that trainings are optional, and project work should be prioritized before taking trainings.

ARSET Trainings:

1. Fundamentals of Remote Sensing link (on-demand training)
2. Satellite Remote Sensing for Agricultural Applications (four 90-minute sessions) link
    1. Part 1: NASA ARSET: Overview of Agricultural Remote Sensing, Part 1/4
    2. Part 2: (Not relevant)
    3. Part 3: NASA ARSET: Earth Observations for Agricultural Monitoring, Part 3/4
    4. Part 4: (Not relevant)
3. Other ARSET trainings related to agriculture link

Earth observations

Landsat:

- The study period will start in 1984 based on the beginning of the Landsat 5 period of record (Figure 5).
    - Landsat NDVI data are available through Climate Engine, which requires a free profile to access:
        - Link (ClimateEngine Data Search) to information about Climate Engine datasets
        - YouTube Tutorials

- Support site (articles, tutorials, and troubleshooting guides)
- API

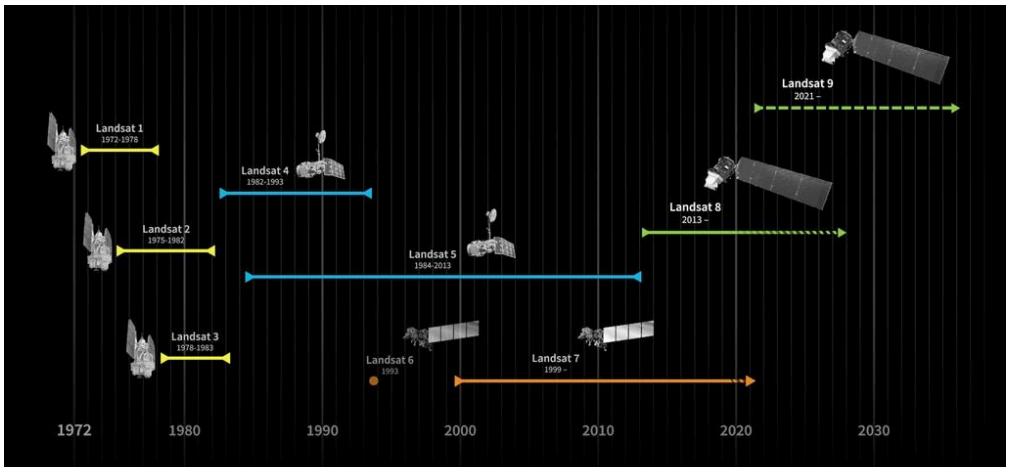

Figure 6. Timeline of Landsat missions. Source: NASA Scientific Visualization Studio.

Partner Data Use Note: The USDA FAS currently uses the Global Inventory Monitoring and Modeling Studies (GIMMS) Global Agricultural Monitoring (GLAM) interface to access MODIS & VIIRS NDVI imagery. More information about GIMMS GLAM can be found here.

Ancillary Datasets

NOAA Oceanic Niño Index:

- The science advisors have recommended using the Niño 3.4 ENSO index (Figures 7–8) to delineate ENSO phases in Brazil.
  - Background information about the Niño 3.4 Index may be found on the NOAA NCEI Equatorial Pacific Sea Surface Temperatures (SST) page
  - Here is a Climate.gov article describing some of the different ENSO indices

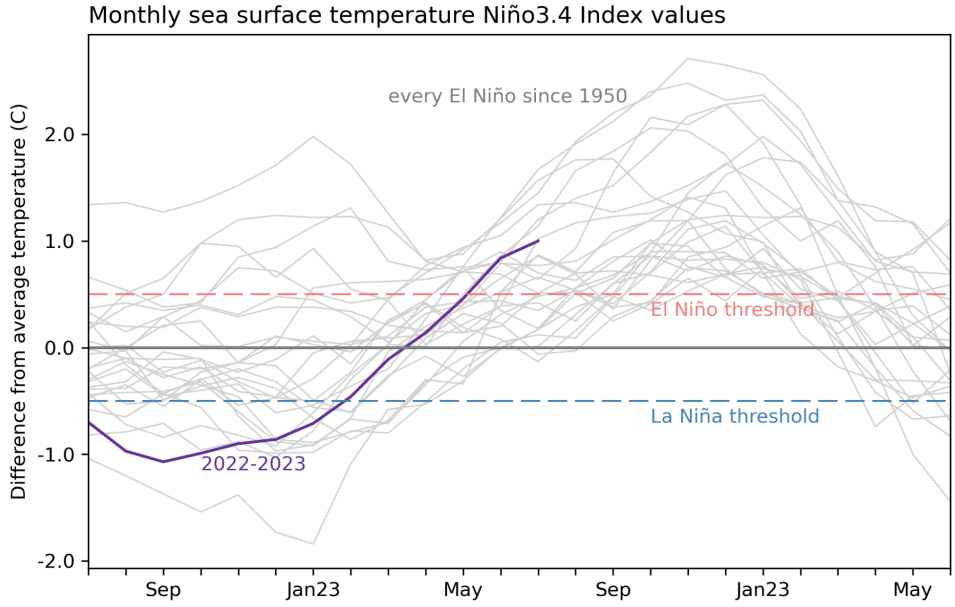

Figure 7. 2-year history of sea surface temperatures in the Niño-3.4 region of the tropical Pacific for all events evolving into El Niño since 1950 (gray lines) and the current event (purple line) as of August 2023. NOAA

Climate.gov image based on a graph by Emily Becker and monthly Niño-3.4 index data from CPC using ERSSTv5. Source: Climate.gov.

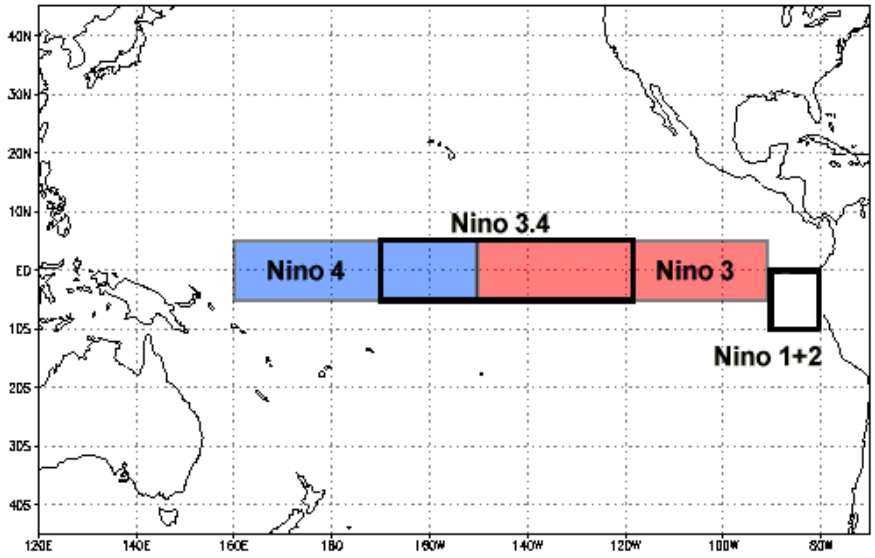

Figure 7. Niño Regions. Source: NOAA NCEI.

- NASA Earth observatory story (Figure 9)

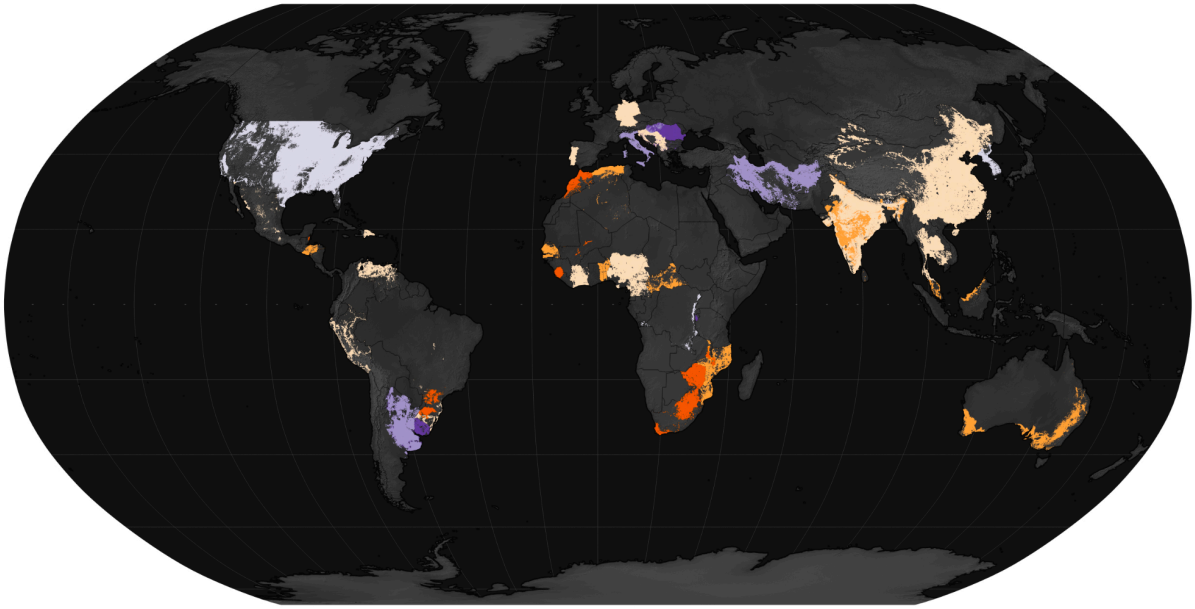

Figure 9. 2023–2024 forecasted El Niño impact on crop yields (red = negative, purple = positive) using Famine Early Warning Systems Network (FEWS NET) crop yield data, which are based on FAOSTAT country-level crop yields, and forecast soil moisture percentile data for southern Africa from FEWS NET Land Data Assimilation (FLDAS). Source: Michala Garrison and NASA Earth Observatory.

CHIRPS Daily Precipitation:

- CHIRPS daily precipitation data are available through Climate Engine, which requires a free profile to access:

- Link (ClimateEngine Data Search) to information about Climate Engine datasets
- YouTube Tutorials
- Support site (articles, tutorials, and troubleshooting guides)
- API

Cropland Mask:

- Sunita Yadav (project partner) suggested using the following datasets to mask non-agricultural lands from analysis:
  - ESA WorldCereal (link to map viewer)
  - MapBiomas Agricultural Lands:
    - Citation: Souza at. al. (2020). Reconstructing Three Decades of Land Use and Land Cover Changes in Brazilian Biomes with Landsat Archive and Earth Engine - Remote Sensing, Volume 12, Issue 17, 10.3390/rs12172735.
    - Note: MapBiomas Agricultural Lands does not list "corn" as a class category (Figure 10). Sunita mentioned that corn may be planted on soybean lands at different times during the year, so the soybean class may also include lands that produce corn.

Farming	Agriculture	Temporary Crop	Soybean	Areas cultivated with soybean.	AMc (s)	OCA	AC
			Sugar cane	Cultivated areas with sugar cane.	AMc (c)	OCA	AC
			Rice	Areas cultivated with rice, exclusively under irrigation, in the states of Rio Grande do Sul, Tocantins, Santa Catarina and Coast of Paraná. This map is the same one presented in the irrigation module in the "Irrigated Rice" class.	AMc	OCA	AC
			Cotton (beta)	Areas cultivated with cotton cultivation.	AMc (s)	OCA	AC
			Other Temporary Crops	Areas occupied with short or medium-term agricultural crops, generally with a vegetative cycle of less than one year, which after harvesting need to be planted again to produce.	AMc	OCA	AC
		Perennial Crop	Coffee	Areas cultivated with coffee plantation.	AMp (c)	OCP	PER
			Citrus	Areas cultivated with citrus cultivation.	AMp	OCP	PER
			Palm Oil (beta)	Areas cultivated with palm oil plantation.	AMp	OCP	PER
			Other Perennial Crops	Areas occupied with agricultural crops with a long vegetative cycle (more than one year), which allow successive harvests, without the need for new planting. In this version, the map covers mostly cashew areas on the northeast coast and oil palm in the northeast region of Pará, but without distinction between them.	AMp	OCP	PER

Figure 10. MapBiomas Collection 8 agriculture legend description. Source: MapBiomas Agricultural Lands.

Annual, State-Level Crop Yield Data:

- CONAB: Séries históricas das safras
  - Corn yields
    - 1st harvest:
      - All annual yields by state dating back to 1976/1977
    - 2nd harvest:
      - Annual yields for BA date back to 1979/1980
      - Annual yields for MT date back to 1991/1992[1]
      - Annual yields for PI date back to 2010/2011[1]
      - Annual yields for TO date back to 2003/2004[1]
  - Soy yields
    - Annual yields for BA date back to 1979/1980
    - Annual yields for MT date back to 1976/1977
    - Annual yields for PI date back to 1987/1989[1]
    - Annual yields for TO date back to 1987/1988[1]

[1] The collection periods for these datasets do not span the entire study period.