The HARMONIZE Project and the EODCtHRS Architecture: An Earth Observation Data Cube tuned for Health Response Systems

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Abstract. *The HARMONIZE project, coordinated by the Barcelona Supercomputing Center, aims to create a digital infrastructure for health data integration and climate analysis in Latin America & the Caribbean. It includes a data platform, a climate module, and software toolkits to explore the data. This paper presents EODCtHRS, an instance of the Brazil Data Cube Platform, named HARMONIZE Instance, which accommodates data collected by drones in health oriented field missions, local and regional health data, and data from in-situ weather stations and climate models. The article presents the architecture of EODCtHRS, its current stage of development and planned versions.*

1. Introduction

The lack of scientific knowledge about the connection between extreme weather events, environmental degradation, and socioeconomic inequalities and their impacts on epidemics of infectious diseases increases the risk of spreading these diseases. This is particularly important in local communities susceptible to the effects of climate change in the Latin America and the Caribbean (LAC) region. One component of the risk of pandemics of infectious diseases is the lack of alertness by agencies and the government. Even though early warning systems for infectious diseases and extreme climatic events exist, the capacity to integrate them is still lacking [Barcellos et al. 2016].

The HARMONIZE project, Harmonizing Multi-scale Spatiotemporal Data for Health in Climate Change Hotspots in Latin America and the Caribbean, is coordinated by the Global Health Resilience group of the Earth Sciences Department at the Barcelona Supercomputing Center (BSC). Its goal is to create digital toolkits that stakeholders in climate change hotspots can use to combine data about the environment, climate, and health in a cost-effective and reproducible way. To do this, the project brings together groups of different stakeholders, including software engineers, epidemiologists, and data scientists from Latin America and Europe, to build digital infrastructure and tools for key partners who are in charge of monitoring and sending out alerts about diseases that may be affected by climate change, such as arboviruses, which are viruses spread by arthropods like flies, mosquitoes, and ticks. The infrastructure will provide an enriched, harmonized set of data from different sources, such as climate reanalyses and forecasts, Socioeconomic data, Demographic data, Health and Disease Surveillance data, Earth Observation (EO) data, and high-resolution images from Remotely Piloted Aircraft[1] (RPA).

The HARMONIZE project is funded by the Wellcome Trust, partners include the Oswaldo Cruz Foundation and the National Institute for Space Research (INPE) in Brazil; the Universidad Peruana Cayetano Heredia in Peru; the Universidad de los Andes in Colombia; the Oficina Nacional de Meteorología in the Dominican Republic; and the Inter-American Institute for Global Change Research in Uruguay.

The Earth Observation Data Cube tuned for Health Response Systems (EODCtHRS) is a component of the HARMONIZE project, supported by the digital infrastructure of the Brazil Data Cube (BDC) developed at INPE [Ferreira et al. 2020]. This project has a software-based platform used for the integration and interoperability of the datasets in the HARMONIZE framework.

In this context, we present an overview of the EODCtHRS component. The development was divided into four working streams, referring to modules with different data RPA, Health, Climate and Data Science Environments. A web entry point is also been developed to provide access to data visualization and analysis, including the front-end and back-end solutions, named HARMONIZE Instance. Its development is based on the software ecosystem related to the BDC Platform. This paper is organized as follows: Section 2 presents the Data Cubes concepts and BDC initiative. Section 3 describes each working stream of the EODCtHRS component and some preliminary results. Section 4 presents the HARMONIZE Instance. Final considerations are presented in Section 5.

2. Earth Observation Data Cubes

The Earth Observation (EO) data cubes refer to a data management technology used to abstract data storage needed for an EO data organization. There is no specific definition for them, but many examples of approaches exist [Sudmanns et al. 2023]. For example, in the context of the BDC project, an EO data cube is a set of image time series associated with spatially aligned pixels having two spatial dimensions and one temporal dimension associated with a set of values [Ferreira et al. 2020]. Recent initiatives to create EO data cubes from remote sensing images for specific regions include the Swiss Data Cube, Sen2Cube.at semantic EO data cube for Austria, Digital Earth Africa, Virginia Data Cube, Digital Earth Pacific, Mexican Geospatial Data Cube, Open Data Cube, Australian Geoscience Data Cube, Euro Data Cube and Brazil Data Cube [Sudmanns et al. 2023].

[1]Remotely Piloted Aircraft (RPA), aka “drone”, is an unmanned aircraft piloted from a remote station by a qualified professional [International Civil Aviation Organization – ICAO 2016]

2.1. Brazil Data Cube

Earth observation data acquisition and processing is a very big challenge for a country with a continental-scale area such as Brazil. Currently, there is an abundance of data from different satellites and sensors with distinct spatial, temporal, and spectral resolutions available. The BDC project emerges in this context to facilitate the extraction of information for the visualization and processing of large time series of Earth observation data. By providing analysis-ready data organized as spatio-temporal data cubes, it removes from researchers the exhaustive task of preparing these large amounts of data. It also provides the infrastructure to generate and maintain the data cubes [Marujo et al. 2022].

The project develops a set of software packages to process and analyze data using artificial intelligence, machine learning, and time series analysis of images, as well as a web platform to allow its access and visualization. To ensure accessibility and collaborative engagement, the BDC adopted an open-source approach for the two categories of software packages: services and applications. Services are responsible for accessing and processing the datasets and their metadata. Applications are software products for the end user, including systems with Graphical User Interface (GUI) and application Programming Interfaces (API) for the R and Python programming languages [Ferreira et al. 2020].

2.2. SpatioTemporal Asset Catalog (STAC)

The datasets produced in the BDC project can be discovered and accessed using the SpatioTemporal Asset Catalog (STAC). The STAC is a set of specifications created by several organizations collaborating to improve the interoperable search for satellite imagery. A SpatioTemporal Asset is any data file that represents information about the Earth at a certain place and time, generally in Cloud Optimized GeoTIFF (COG) format. This format has an internal organization to enable efficient data access in distributed and high-performance cloud environments [Zaglia et al. 2019]. The main goal of STAC is to standardize the way Asset metadata is structured and queried. The specification was initially developed to handle scenes of satellite imagery, but it can be extended to include other diverse types of data, such as aircraft and drone sensor data, videos, point clouds, digital elevation models, vector data, etc [STAC Community 2022].

2.3. Brazil Data Cube Explorer

Brazil Data Cube Explorer (BDC Explorer)[2] is a web platform that presents improved capabilities for discovering, visualizing, and downloading collections and data cubes of remote sensing images. Also for accessing, visualizing, and analyzing time series extracted from data cubes and Land Use and Land Cover (LULC) trajectories from classified maps.

3. Earth Observation Data Cube tuned for Health Response System

The EODCtHRS component core features are the integration and interoperability between climate, socioeconomic, demographic, health, disease surveillance, high spatial resolution RPA images and the digital infrastructure of the BDC project. We developed a conceptual design called HARMONIZE Instance to handle these features based on the back-end and front-end solutions to allow the generation and management of collections of images and

[2]BDC Explorer platform available at `https://brazildatacube.dpi.inpe.br/portal/explore`.

mosaics from RPAs, multidimensional data cubes from medium spatial resolution images from satellites such as CBERS, LANDSAT, and SENTINEL, health and climate data. The HARMONIZE Instance will be a technological ecosystem for use in health decision systems, focused on monitoring and early warning for vector-borne diseases in the context of environmental degradation and climate change in two areas: the semi-arid region in the Northeast of Brazil and in the Lower Tocantins areas in the Amazon (Figure 1).

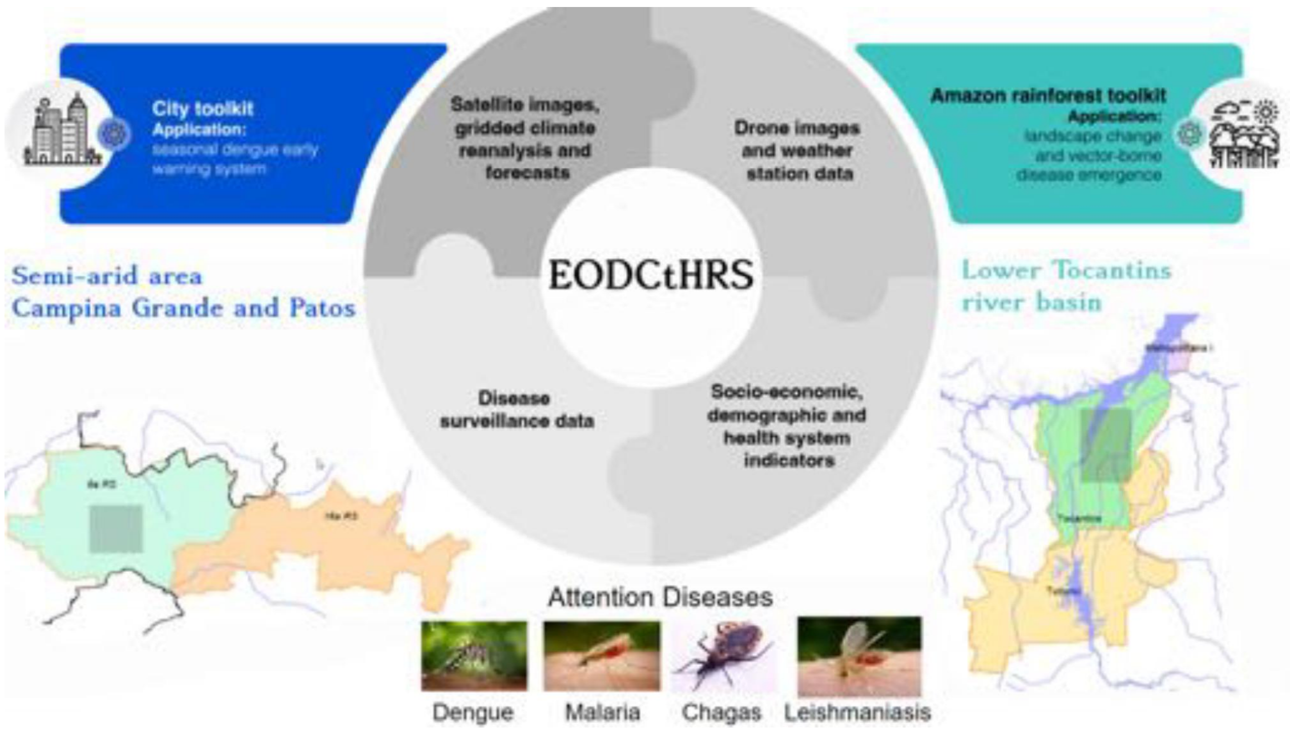

Figure 1. The EODCtHRS component scope.

RPA images, health and climate data come from different databases with different formats and processing requirements. To deal with this we proposed a procedure based on steps starting with the identification of multisource datasets until the publishing of these data on STAC catalogs to enable search, visualization and analyses based on front-end platforms (Figure 2). The first step defines which sources will be used to create the catalogs. Next in the Processing step, projection, spatial and temporal composition are performed to export new datasets into a standard format (COG) adopted for the EODCtHRS component. After that, the procedure utilizes GeoServer [3] and the BDC-STAC service to publish raster and vector data together with their corresponding metadata. All this information can be accessed using packages that implement STAC API specifications, such as `PySTAC` and `rstac`. In the scope of the EODCtHRS component, we use this API for Data Visualization and Analysis through the HARMONIZE Explorer and HARMONIZE Data Science Environment, which compose the HARMONIZE Instance (Conceptual Design). Please refer to Section 4 for further information about these elements of conceptual design.

The subsequent subsections provide detailed descriptions of the four working streams, the modules within them, the proposed integration architecture, and the dissemination of data from each individual module.

[3]"GeoServer is a Java-based server that allows users to view and edit geospatial data. Using open standards set forth by the Open Geospatial Consortium (OGC), GeoServer allows for great flexibility in map creation and data sharing." Available at `https://geoserver.org/about`.

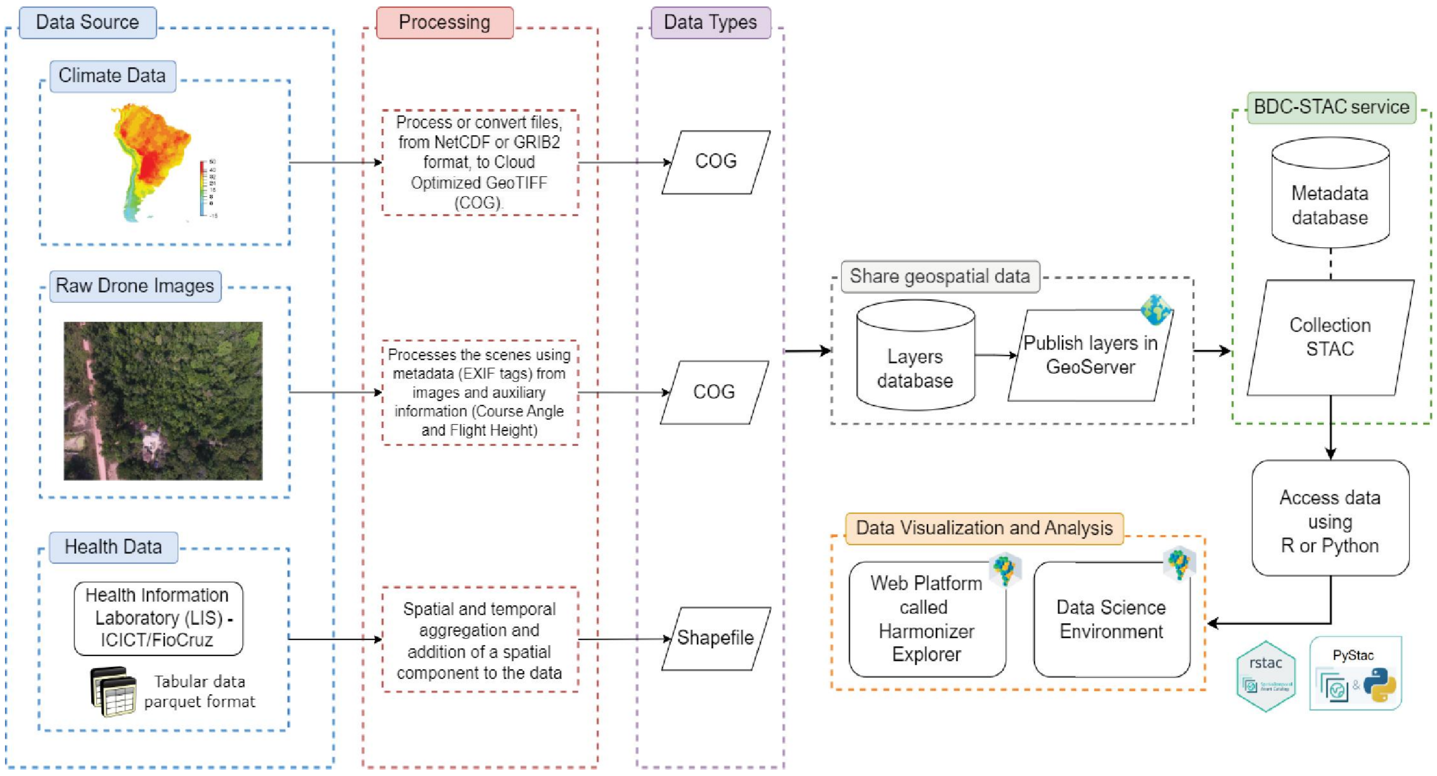

Figure 2. The integration architecture and dissemination of RPA images and health and climate data.

3.1. Module 1 - Remotely Piloted Aircraft (RPA)

The main goal of RPA image integration in the context of EODCtHRS is to provide a data infrastructure that meets the demands of the health surveillance, especially in areas considered hotspots of climate change. In this context, this data can be used to downscale and improve LULC maps in target areas of the project whose importance is determined by the endemic occurrence of some diseases (malaria, dengue, Chagas disease, leishmaniasis), which can be exacerbated by environmental changes caused by anthropologic actions. This way, we started exploring the integration of the images generated by fieldwork campaigns in some locations of Pará State (Figure 3), North Region of Brazil [Souza et al. 2021], resulting in collections available in STAC catalogs that can be accessed using STAC clients.

In order to make RPA images available through an STAC catalog, the first step is to guarantee their correct geolocation. This represents a challenge because this type of fieldwork campaign can produce thousands of images making it practically impossible to collect control points for cartographic projection[4], especially in areas of difficult access such as the fieldwork realized in Pará state, predominantly marked by areas of vegetation and water bodies.

In the context of our proposal, we handle this using embedded metadata from images (center coordinates, height, width, camera focal length) and auxiliary information provided by the flight mission plan (flight height and course angle) and finally the characteristic of equipment (sensor pixel dimension). All these parameters combined enable us to estimate the corner coordinates of the image and through an affine operation, we can

[4]Ground Control Points (GCPs) are points on the surface of the Earth with known localization used to georeference remote sensing images. Usually through a Geographical Information System (GIS) software. However, it depends on the good precision of the GPS collector and easy access to the area mapped [Ribeiro 2018].

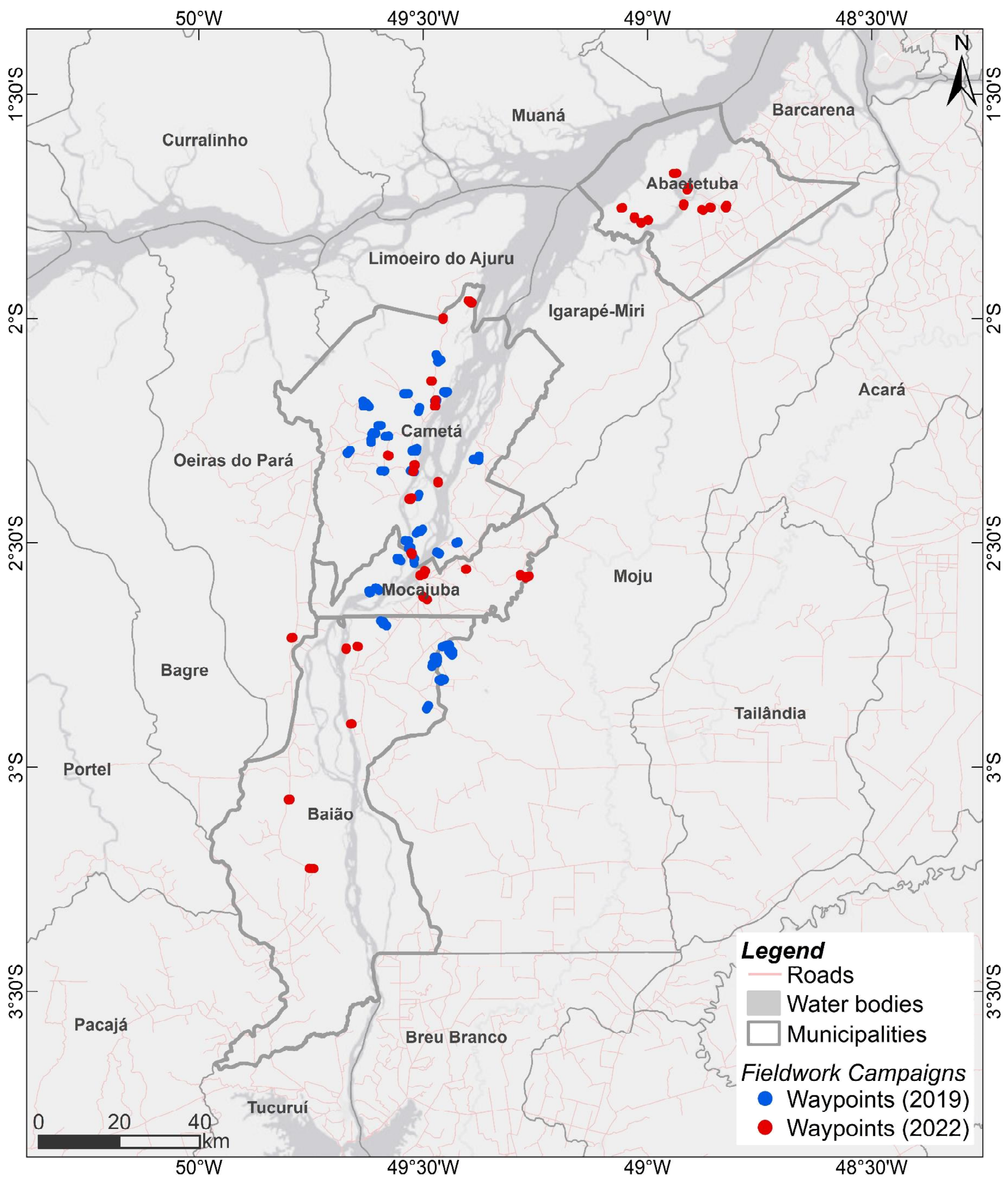

Figure 3. Fieldwork Campaigns Northeast of Pará State 2019 and 2022

apply a rotation based on the course angle positioning the image with a good accuracy over the Earth's surface (Figure 4). The final result of this process is a COG file, standard for data made available through a STAC catalog.

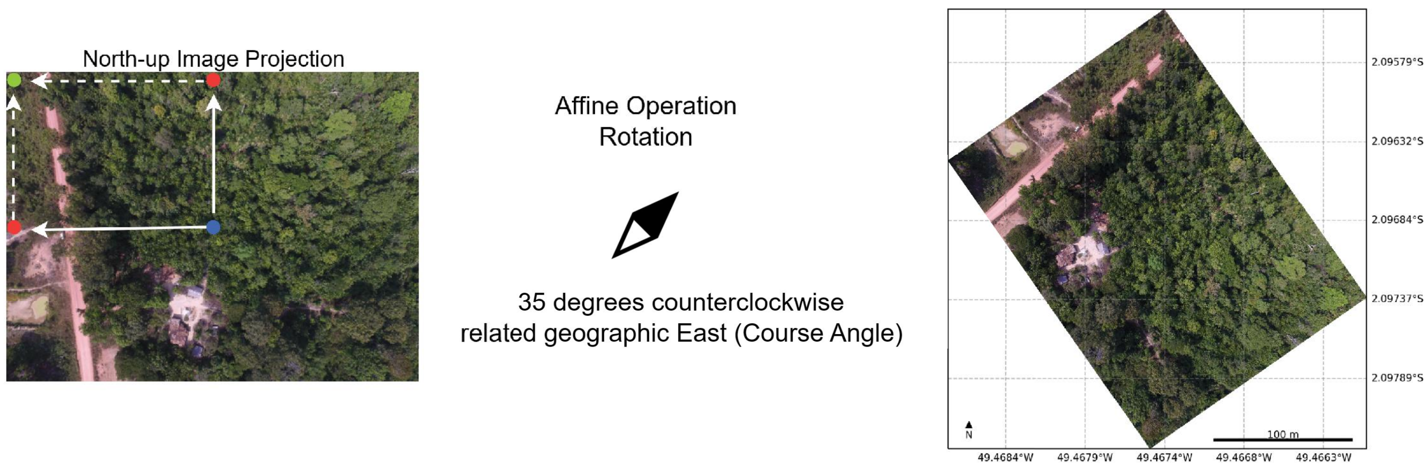

Figure 4. Approach used to spatial projection of RPA images.

3.2. Module 2 - Health data

This module integrates health data for EODCtHRS. In the context of the project, the health working stream considers different stakeholders mainly the Health Information Laboratory (LIS) - Institute for Scientific and Technological Communication and Information (ICICT)/Fiocruz and the InfoDengue initiative. They produce health indicators taking into consideration the impacts of environmental and climate change on the health of the Brazilian population.

Experimental studies were carried out with the indicators produced by LIS. During these experiments, the Fiocruz and INPE teams defined the data format and the indicator visualization workflow. For the preliminary tests, two indicators were used, dengue confirmed cases and dengue mortality rate (per 100,000 inhabitants). The first indicator is the number of positive dengue cases, identified by the International Classification of Diseases (ICD-10) [World Health Organization 2023] code A90. The second one is related to a rate that points out severe manifestations of dengue requiring hospitalization, identified by ICD-10 codes A90 and A91.

Both of the aforementioned indicators were calculated using an R package developed by the LIS team, called `bilis` [Saldanha et al. 2023]. Both indicators contain attributes called *agg* and *agg_time*, which identify the temporal and spatial granularity of the data. The temporal aggregation levels were defined by health data specialists as epidemiological week, month and year, and the spatial aggregation as municipality, health region and state. Based on these attributes, the data was separated taking into account the combinations between the spatial and temporal aggregations defined.

The data sets were spatially aggregated according to the order of spatial aggregation from smallest to largest (municipal, health region and state) provided by the LIS team, converted and saved as shapefiles. This data processing is shown in Figure 5. After the processing stage, the data and its metadata are published by GeoServer and the BDC-STAC service, respectively, and the layers can be viewed in the HARMONIZE Explorer.

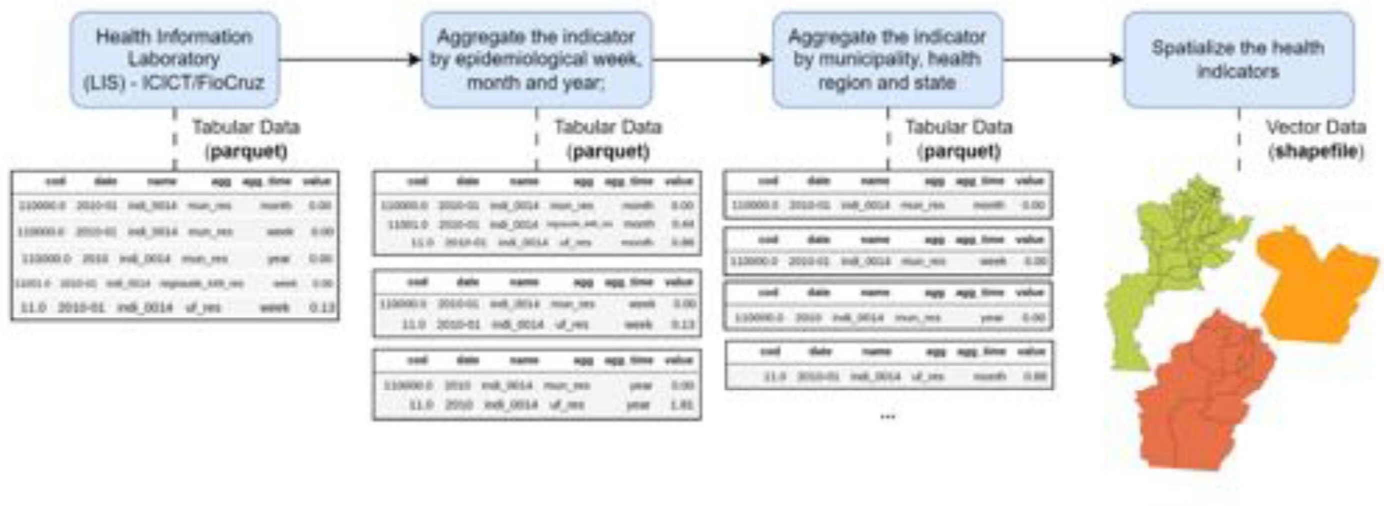

Figure 5. Processing flow of health data provided by LIS.

3.3. Module 3 - Climate data

This module integrates climatological data for EODCtHRS, enabling direct query execution via access interfaces, and eliminating the need for data transfer. Experimental studies were developed using the BDC-STAC service [Ferreira et al. 2020] and the access was tested using the `R` package called `rstac` [Simoes et al. 2021] with the aim to learn and configure the BDC services. In order to make initial tests using BDC's technologies, BDC-STAC service and Explorer, we use products made available by the Center for Weather Forecasting and Climate Studies (CPTEC/INPE): SAMeT[5], which provides daily values of maximum and minimum temperatures.

Currently, in collaboration with the Fiocruz Team, studies are being conducted to generate four climate indicators. The monitoring of these indicators can provide useful information to prevent and answer the possible appearance of health problems, or outbreaks of diseases, such as dengue. These studies were concentrated in the Lower Tocantins region, Pará, Brazil, one of the hotspots of the HARMONIZE project. As preliminary results, we generate a set of raster in GeoTIFF formats with the following indicators:

- maximum and minimum temperature indicators from the Land Surface Temperature (LST) product generated from Sea and Land Surface Temperature Radiometer (SLSTR) on board the Sentinel-3 satellite. The LST product generated with a 1 km spatial resolution [Polehampton et al. 2022];
- precipitation indicator from the Climate Anomaly Monitoring System (CAMS) which is a precipitation estimation technique which produces real-time monthly analyses of global precipitation [Janowiak and Xie 1999];
- anomaly for maximum temperature indicator, which considers the number of consecutive days in which the maximum temperature exceeds the maximum temperature of the climatological normal of the place, with references 1991-2020 period, from the National Institute of Meteorology (INMET)[INMET 2023].

We use the epidemiological week (epi week), dividing the year into standardized weeks (starting on Sunday and ending on Saturday), to aggregate temperature and anomaly indicators, this enables consistent year-to-year data comparison.

The maximum and minimum temperature indicators were downloaded for November and December 2022 (44 to 52 epi week). For this, we write a Python script using Sentinelsat API[6] for downloading the Sentinel-3 LST Product. Followed by other procedures, in R, such as: extracting the LST_in.nc files which consist of LST values in Kelvin for each 1x1 km grid, and geodetic_in.nc which contain the latitude and longitude of each of those 1x1 km grids, both in NetCDF format; application of a mask to remove all clouds, using flags_in.nc, and outliers values, followed by conversion from Kelvin to Celsius; and extraction of Maximum and Minimum temperatures from the set of grids.

For the precipitation indicator, the following steps were executed: binary data download for November 2022; resampling data from 2.5 degree latitude and longitude to 1 x 1 km spatial resolution; and reprojection to the WGS84 spatial reference system. The maximum temperature anomaly indicator was calculated from each epi week of images LST (44 to 52), and November values of the Climatological Normal Maximum Temperature for the period 1991-2020 (INMET), for all municipalities in the Lower Tocantins region. To this, we applied the Inverse Distance Weighted (IDW) interpolation from three meteorological stations located in the region, with the max temperature of the climatological normal, to estimate unknown values for the entire study area. After, we compute

[5]SAMeT. Available at `http://ftp.cptec.inpe.br/modelos/tempo/SAMeT/DAILY`
[6]Sentinelsat API - `https://sentinelsat.readthedocs.io/en/stable/`

the number of days with maximum temperature greater than the climatological normal to generate the anomaly indicator. The data processing to generate climate indicators is shown in Figure 6.

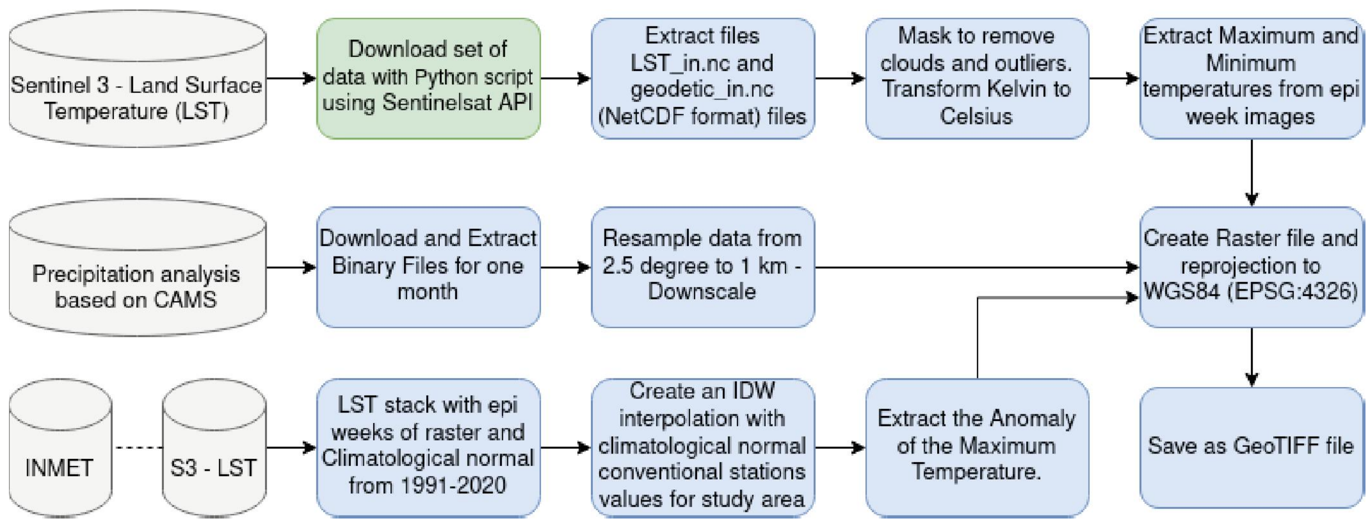

Figure 6. Flowchart for generation of the climate indicators. The green and blue rectangles indicate interfaces written in Python and R, respectively.

3.4. Module 4 - Data Science Environment

The objective of the BDC/EODCtHRS data science environment is to provide users with a set of geospatial data analysis tools integrated with BDC data. This environment will be based on the software ecosystem developed by the BDC project and each user will have access to use RStudio and QGIS software and to create Jupyter Notebooks using `R` and `Python` programming languages with several pre-installed geospatial libraries.

In this environment, users will not need to download Earth observation data to their local machine, as the processing will be performed entirely on the BDC computing infrastructure. Among some of the topics of the study are access management and user data storage management, with the aim of ensuring data persistence, reliability and security (Figure 7).

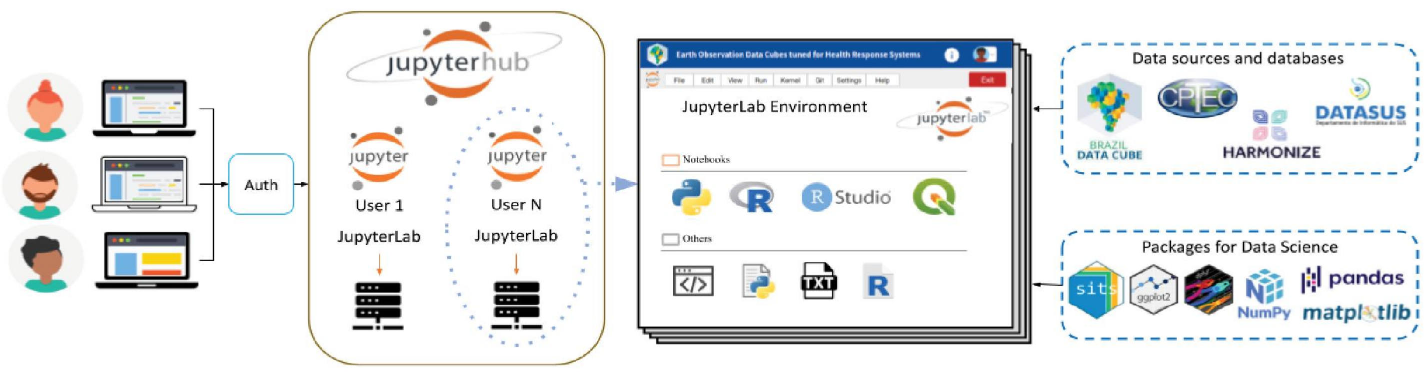

Figure 7. Data science environment prototype.

4. HARMONIZE Instance

Figure 8 shows an overview of our technical-scientific proposal (HARMONIZE Instance Concept) for data visualization and analysis, it is composed of a web portal and a Data Science platform that provide the user with mechanisms for manipulating Earth observation data, RPA images, health and climate data. This flow begins when the user defines a site through a spatial and temporal extension and a collection of data. From this, a query is made via STAC API in the data repository to verify the products available for the search made, returning to the user all the data or images found. To harmonize data from different data sources and maintain interoperability between all parts of the system, the idea is to use the STAC to index RPA imagery, health and climate data. As well as a Data Science environment, multi-user data science, with all the necessary packages for processing health and geospatial data.

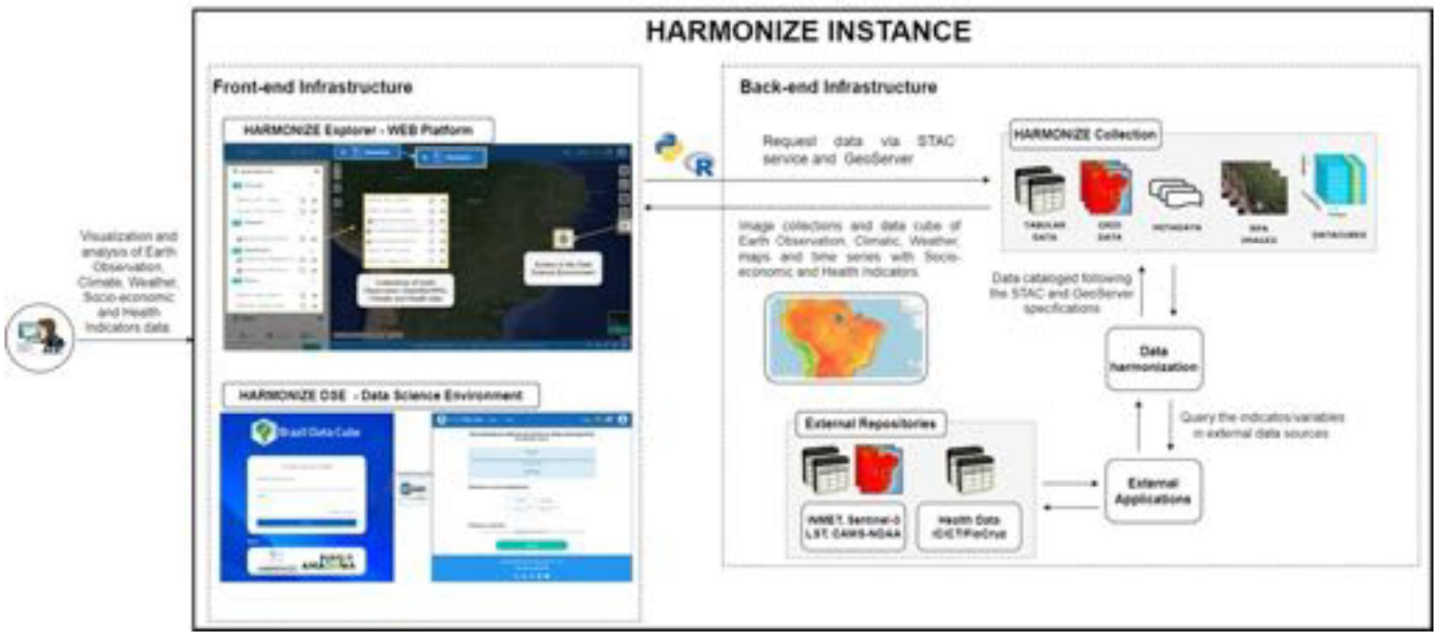

Figure 8. The design concept of a technical-scientific proposal for the HARMONIZE Instance.

HARMONIZE Explorer is a web platform for viewing and analysis of EO, health, meteorological and climate data based on BDC Explorer. The platform will be able to combine EO data cubes with specific collections tailored for EODCtHRS components (RPA images, health and climate data), as well as enable access to Data Science Environment for complex analyses using several libraries in R and Python with direct access to all Analysis-Ready Data (ARD) collections. Figure 9 presents an overview of the prototyped HARMONIZE Explorer interface, followed by the visualization of RPA image, health and climate data as examples of data stored using GeoServer.

5. Final Considerations

In this paper, we present an overview of a software environment called HARMONIZE Instance as a component of the HARMONIZE project hosted at INPE. This environment is composed of four modules with different data, such as RPA, health, climate and data science environment. Currently, data integration and interoperability are being prototyped using the digital infrastructure of the Brazil Data Cube (BDC) for visualization and analysis. The development of the HARMONIZE Instance has demonstrated the utility of geoservices and technologies, with standard infrastructure and protocols, as an effective way to harmonize different data formats from diverse data sources.

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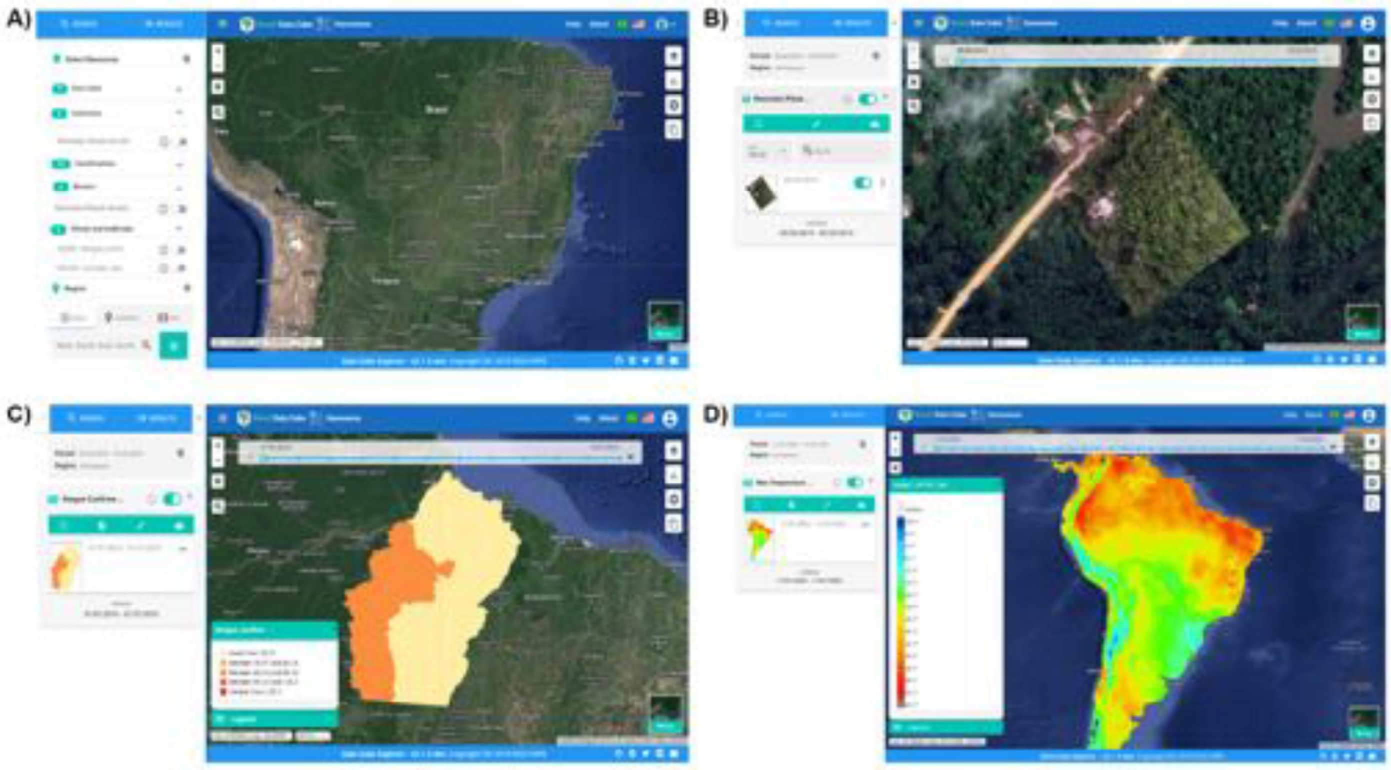

Figure 9. The interface for the HARMONIZE Explorer: a) home page; b) RPA images; c) Health data; d) Climate data

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