Journal of Remote Sensing
A SCIENCE PARTNER JOURNAL

REVIEW

Earth Map: A Novel Tool for Fast Performance of Advanced Land Monitoring and Climate Assessment

Carmen Morales*, Alfonso Sanchez-Paus Díaz, Daniel Dionisio, Laura Guarnieri, Giulio Marchi, Danae Maniatis, and Danilo Mollicone

Food and Agriculture Organization of the United Nations, 00153 Rome, Italy.

*Author correspondence to: carmen.morales@fao.org

Citation: Morales C, Díaz AS, Dionisio D, Guarnieri L, Marchi G, Maniatis D, Mollicone D. Earth Map: A Novel Tool for Fast Performance of Advanced Land Monitoring and Climate Assessment. *J. Remote Sens.* 2023;3:Article 0003. https://doi.org/10.34133/remotesensing.0003

Submitted 2 May 2022
Accepted 19 October 2022
Published 12 January 2023

Earth Map (https://earthmap.org/) is an innovative and free application developed by the Food and Agriculture Organization of the United Nations that was designed in the framework of the Food and Agriculture Organization of the United Nations–Google partnership and facilitates the visualization, processing, and analysis of land and climate data. Earth Map makes petabytes of multitemporal, multiscale, multiparametric, and quasi-real-time satellite imagery and geospatial datasets available to any user thanks to the power of Google Earth Engine (https://earthengine.google.com/) and a point-and-click graphical user interface. These are further complemented with more planetary-scale analytical capabilities so that global and local changes and trends on Earth's surface can be easily detected, quantified, and visualized. It does not require users to master coding techniques, thereby avoiding bottlenecks in terms of technical capacities of nonexpert users. It ultimately paves the way for countries, research institutes, farmers, and members of the general public to access critical knowledge to develop science-based policy interventions, leverage investments, and sustain livelihoods. We provide a full overview of Earth Map's software architecture, design, features, and datasets. To illustrate the possible applications of the tool, different examples are presented including a few case studies that show how quick historical analysis of environmental and climate parameters can be performed and research questions answered. The examples demonstrate that Earth Map is a comprehensive and user-friendly tool for land monitoring and climate assessment and that it has the potential to be used to assess land use, land use change, climate change impacts, and natural disasters.

Introduction

Many scientific publications suggest that we are immersed in the middle of a new Earth Observation (EO) big data era [1,2] that is playing an important role in academia and decision-making. EO data have enabled us to make great advances in land monitoring and climate assessment thereby playing a critical role for the understanding of the world's most pressing environmental problems and the impacts of the climate change emergency [3]. For development organizations such as the International Fund for Agricultural Development, the World Bank, or the Food and Agriculture Organization of the United Nations (FAO), it is key to understand how and where climate change risks may arise in the Agriculture, Forestry, and Other Land Use (AFOLU) systems and pursue effective climate change adaptation interventions. Earth Map is part of a recent published catalog of innovative geospatial tools presented in the United Nations Framework Convention on Climate Change annual Conference of the Parties 26 in Glasgow that serve to support the mapping, assessment, and targeting of climate-related investments [4]. Recent years have been fundamental in terms of the amount of EO and climatic data freely available for society and researchers. Improvements in accessibility have been driven by technological advances (such as cloud-based storage and processing power) and open data policies adopted by governments and space agencies [3,5]. Cloud computing technologies and free satellite data are revolutionizing the way in which countries, organizations, academia, and even individuals approach the management of natural resources, including monitoring of climate parameters, deforestation, and desertification. FAO has created a simple and user-friendly Google Earth Engine (GEE) interface accessible to everyone with internet access that does not require users to master any coding techniques. Earth Map builds on the work done by GEE democratizing access to information contained within large remote-sensing datasets to noncoding users that otherwise would not have access to its vast datasets and powerful computation capacity.

Paradigm shift in EO through cloud-based technology

Satellite-based forest monitoring with Landsat 5 and 7 observations has been a common practice in Brazil since the 1990s through a data collection system called "Programa de Monitoramento da

Floresta Amazônica Brasileira por Satélite". In the first years, data were kept under the management of the government, and finally in 2002 [6], the full Programa de Monitoramento da Floresta Amazônica Brasileira por Satélite data became open access, making Brazil the first country in the world moving toward transparency and accountability of forest monitoring. This milestone made it possible for the scientific community, nongovernmental organizations, and the public to understand environmental problems and played a key role in slowing deforestation. Acclaimed as "one of the world's most dramatic environmental success stories", forest clearing in the Brazilian Amazon rainforest decreased nearly 80% per year by 2012 [6]. In 2005, Google released Google Earth, a virtual globe software, enabling users to freely visualize high and very high-spatial resolution satellite imagery. This tool, downloaded by billions of users, changed the way people approach geography today [7]. In 2008, the United States Geological Survey (USGS) adopted an open data policy with the Landsat imagery archive [8,9]. Four years after making the archive freely available, the number of image downloaded each month rose, exponentially increasing the use of satellite imagery for land monitoring [10]. Copernicus, the European Union's Earth Observation Programme, the largest space data provider in the world, currently delivers 16 terabytes of satellite images per day [11], and other providers of satellite images soon followed the example of USGS and adopted the open data policy. Around 2010, Google started to develop GEE, a planetary-scale platform that allows users to run geospatial analysis on Google's infrastructure with unprecedented and unparalleled capabilities.

GEE consists of a multipetabyte data catalog of satellite imagery and geospatial datasets that offers planetary-scale analysis capabilities, making it available for researchers and developers with coding skills to identify changes and trends on Earth's surface [5]. It provides users with the possibility to develop their personalized sites and analytical tools through an Application Programming Interface (API) and a web-based development environment called GEE Code Editor and to publish web-based interfaces using GEE apps. GEE provides both JavaScript and Python APIs. While prior experience with Geographic Information Systems (GIS), remote sensing and scripting are not strictly required, and the user's guide is oriented toward newcomers [5]; the learning curve can be steep, and the complexity of the GEE ecosystem is a barrier for many users to start using it. There was, therefore, a need for a simple and user-friendly interface to GEE so Earth Map was designed and developed with this aim. Earth Map now provides researchers, policy makers, and other users with no coding skills with the possibility to perform complex land monitoring, climate assessment, and other GIS and EO-based assessments. The different interfaces of the GEE Code Editor and Earth Map can be seen in Fig. 1.

Increased demand for climate and environmental data at policy level

In addition to the need for a simple and user-friendly GEE interface tool that allows overlaying different thematic layers (maps) and generating statistics on the fly, demand has raised for increased availability and improved accessibility of climate and environmental data for the Global Environment Facility (GEF) and the Green Climate Fund (GCF) project design and baseline assessments. GEF and GCF are both key financial mechanisms born to support the 3 Rio Conventions of the 1992 Rio Earth Summit: the Convention on Biological Diversity, the United Nations Framework Convention on Climate Change, and the United Nations Convention to Combat Desertification. The GEF was established on the eve of the 1992 Rio Earth Summit to help tackle our planet's most pressing environmental problems [12]. The GCF was established 18 years later, under the Cancún Agreements in 2010, and it is the world's largest climate fund [13]. Since the historic Paris Agreement, in 2015, resource mobilization from both funds has increased exponentially and so has the need to design, monitor, and evaluate different projects around the world. In Article 2.1c of the Paris Agreement, parties commit to "making finance flows consistent with a pathway toward low greenhouse gas emissions and climate-resilient development" [14]. Earth Map was created to ease the work of project designers in different contexts, allowing everyone to promptly explore their areas of intervention through a facilitated approach to the big data dimension.

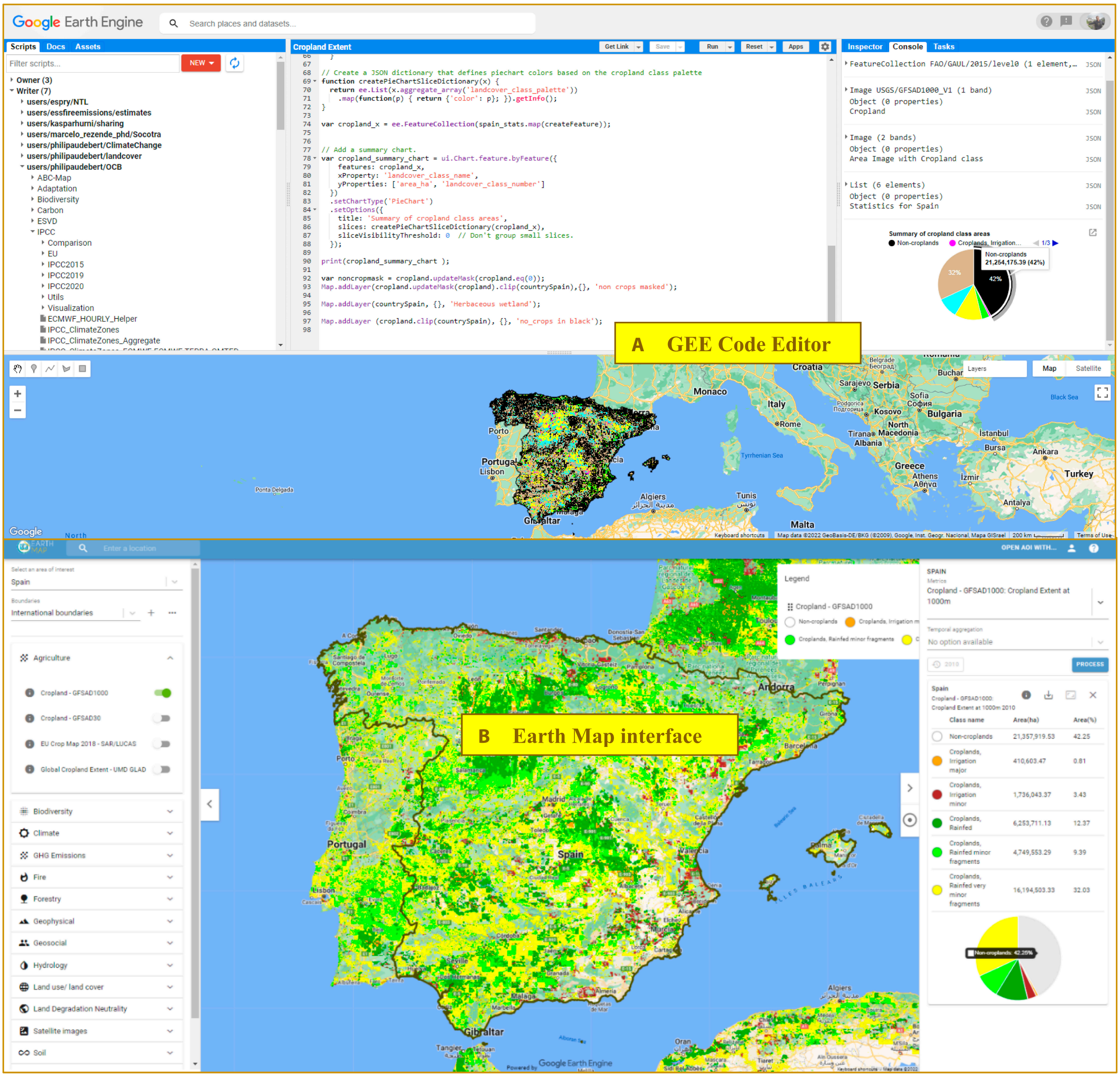
Still in 2015, the 2030 Agenda for Sustainable Development was adopted by all United Nations Member States. At its heart, the 17 Sustainable Development Goals (SDGs) stand, defined in a list of 169 SDG targets, and 73 of them are directly related to the environment [15]. Progress toward the 169 SDG targets was agreed to be tracked by 232 unique indicators, such as the Indicator 15.4.2—Mountain Green Cover Index—or the Indicator 15.1.1—forest area as a percentage of total land. Both indicators can be easily monitored and measured because of the global datasets available in Earth Map (Fig. 2). The United Nations has committed to the full implementation of the SDGs by 2030, just like the United Nations Decade on Ecosystem Restoration 2021–2030 that was conceived to restore degraded and destroyed ecosystems, contributing to efforts to combat climate change and safeguard biodiversity, food security, and water supply. In fact, restoration initiatives can help achieve the SDGs. Earth Map was designed to support the task of monitoring restoration projects around the globe during this important decade that scientists have identified as the last chance to prevent catastrophic climate change [16].

The 3 Rio Conventions, the SDGs, and the United Nations Decade on Ecosystem restoration are intrinsically connected; stakeholders should therefore have a holistic vision during its implementation for the effective achievement of these established United Nations goals until 2030. Earth Map can be used to rapidly build capacity for land monitoring and climate assessment and to substantially support the achievement of the abovementioned goals during the next decade.

State of the art of existing free land, biodiversity, and climate assessment applications

As well as Earth Map, numerous free and user-friendly applications for monitoring natural resources and the environment have been developed by building upon platforms for big EO like GEE and its freely accessible archive of data, satellite imagery, and cloud computing. Examples of some software comparable to Earth Map include: (a) MapX; (b) Earth Blox; (c) Global Forest Watch; (d) Resource Watch; (e) Climate Engine; (f) United Nations Biodiversity Lab; and (g) Global Agricultural and Disaster Assessment System (GADAS).

An overview of the design and features of the different applications is provided in Table 1. Since the availability of big EO platforms, different nongovernmental organizations and academic institutions (e.g., FAO, United Nations Environment



```
  }

// Create a JSON dictionary that defines piechart colors based on the cropland class palette
function createPieChartSliceDictionary(x) {
  return ee.List(x.aggregate_array('landcover_class_palette'))
    .map(function(p) { return {'color': p}; }).getInfo();
}

var cropland_x = ee.FeatureCollection(spain_stats.map(createFeature));


// Add a summary chart.
var cropland_summary_chart = ui.Chart.feature.byFeature({
    features: cropland_x,
    xProperty: 'landcover_class_name',
    yProperties: ['area_ha', 'landcover_class_number']
  })
  .setChartType('PieChart')
  .setOptions({
    title: 'Summary of cropland class areas',
    slices: createPieChartSliceDictionary(cropland_x),
    sliceVisibilityThreshold: 0  // Don't group small slices.
  });

print(cropland_summary_chart );

var noncropmask = cropland.updateMask(cropland.eq(0));
Map.addLayer(cropland.updateMask(cropland).clip(countrySpain),{}, 'non crops masked');

Map.addLayer(countrySpain, {}, 'Herbaceous wetland');

Map.addLayer (cropland.clip(countrySpain), {}, 'no_crops in black');
```

```
FeatureCollection FAO/GAUL/2015/level0 (1 element,…   JSON

Image USGS/GFSAD1000_V1 (1 band)                       JSON
Object (0 properties)
Cropland                                               JSON

Image (2 bands)                                        JSON
Object (0 properties)
Area Image with Cropland class                         JSON

List (6 elements)                                      JSON
Object (0 properties)
Statistics for Spain                                   JSON
```

SPAIN
Metrics
Cropland - GFSAD1000: Cropland Extent at 1000m
Temporal aggregation
No option available
2010

Spain
Cropland - GFSAD1000: Cropland Extent at 1000m 2010

Class name	Area(ha)	Area(%)
○ Non-croplands	21,357,919.53	42.25
● Croplands, Irrigation major	410,603.47	0.81
● Croplands, Irrigation minor	1,736,043.37	3.43
● Croplands, Rainfed	6,253,711.13	12.37
● Croplands, Rainfed minor fragments	4,749,553.29	9.39
● Croplands, Rainfed very minor fragments	16,194,503.33	32.03

Fig. 1. Calculation of Cropland Extent—GFSAD1000—in Spain with (A) the GEE Code Editor and (B) with Earth Map. With the GEE Code Editor, the expert would need to write at least 90 lines of JavaScript code, while anyone can perform the same calculation with a few clicks and in a matter of seconds thanks to Earth Map, although with less customization.

Programme, World Resources Institute, and Desert Research Institute) have developed free, browser-based tools with the intention to democratize the use of geographic information. Earth Map, MapX, Earth Blox, and Resource Watch were designed to visualize and analyze multithematic layers from climate change to poverty, water risk, air pollution to human migration, and more. In contrast, Climate Engine, Global Forest Watch, United Nations Biodiversity Labs, and GADAS were developed to perform specific types of analysis, such as climate, forest, and biodiversity monitoring. The Global Forest Watch, for example, was one of the first to create a fully interactive online platform in 2014 with forest data for the whole world. Some of the tools presented in Table 1 concentrate on imagery analysis, giving the user the possibility to display near-real-time satellite images (Global Forest Watch, GADAS, and Earth Blox), while others have put their focus on vector information, enabling functions such as overlap area estimation (MapX). All these software packages offer the possibility to visualize and combine different layers as well as to export the represented imagery in a series of formats. As for the sharing options, possibilities range from simple and fast applications, such as a shareable link with saved features in the URL, to map composers or not only even more sophisticated but also more complex story map editors. All the software presented in Table 1 are browser-based, allowing the

Table 1. Overview of relevant existing free land, biodiversity, and climate assessment software (as of May 2022)

		Earth Map	Map X	Earth Blox	Global Forest Watch	Resource Watch	Climate Engine	Un Biodiversity Lab	GADAS
Design	Multithematic	x	x	x		x			
	Free	x	x		x	x	x	x	x
	Browser-based	x	x	x	x	x	x	x	x
	Google Maps Interface	x		x			x		x
	Drop-down menu	x	x	x	x		x	x	x
Features and functionalities	Visualization and overlay of layers	x	x	x	x	x	x	x	x
	Rapid generation of statistics	x	x	x	x	x	x	x	x
	Pixel inspector	x							
	Conversion matrices	x							
	Selection of thresholds	x		x					x
	Export options imagery and statistics	x	x	x	x		x	x	x
	Import options (vector and/or raster data)	x	x	x	x		x	x	
	Display of semi-real-time satellite images	x		x		x	x		x
	Comparison of satellite images from different sensors and time	x		x					x
	Shareable link option	x	x	x	x	x			x
	Map composer		x	x	x				x

use to everyone with internet access. There is therefore no need to register to use the tools, and no coding skills, GIS, or remote sensing knowledge is required for most of the features. Registration in the platforms will, in many cases, unlock new but more complex features (e.g., spatial overlap analysis function in MapX and radar for detecting deforestation in Global Forest Watch). Earth Blox like Earth Map is driven by GEE's processing power. Earth Blox differs from Earth Map in the sense that it provides the user with a higher level of customization to produce assessments such as risk modeling for insurances or verification of carbon credits through rapid geospatial insights and highly accurate risk assessment methodologies. Nevertheless, Earth Blox is not a free application and is aimed at commercial users rather than non-for-profit like Earth Map and the other tools.

In comparison with the other tools presented in Table 1, Earth Map is novel because:

- It covers a wide range of user types (countries, research institutes, farmers, climate and environmental activists, and members of the general public) and, most importantly, can be used by anyone because of its simple drop-down menu design and Google Maps interface.
- The pixel inspector has the power to inspect different locations at the local level, allowing the user to diagnose the pixels that make up the colors in your scene. It can serve as a capacity building and research tool for remote sensing.
- Apart from statistics that can be aggregated at different time frames and different time periods, a threshold option for temperature (°C) and rainfall (mm) has been added to the platform for the identification of extreme events and trends under climatic extreme conditions.
- For some of the datasets (e.g., land cover/land use), conversion matrices can be performed, which can be useful for the calculation of the Green House Gas (GHG) inventories in the AFOLU sector.
- Earth Map is linked to the GEE app Imagery Compare, making it easy for the user to display semi-real-time high-resolution satellite images or carry out on-the-fly comparison of satellite images from different sensors and time frames.

In terms of user experience, the development of these tools has revolutionized the way users can access geographic information without the need to install any software on one's computer. Innovative development projects are heading toward this direction as more and more web-based and open-source platforms for land, biodiversity, and climate assessment are being designed and released.

Table 2. Datasets in Earth Map (as of May 2022)

Thematic section	Parameter	Data provider/data source	Nominal resolution	Temporal coverage	Spatial coverage
Africa Open DEAL	Land use, forest subdivisions, grassland subdivisions, cropland subdivisions, woody cover, tree cover inside and outside forest, tree count inside and outside forest	Africa Open DEAL—FAO	1,000 m	2000–2019	Africa
Agriculture	Cropland extent	USGS GFSAD30	30 m	1990–2017	Global
	Cropland extent	USGS GFSAD1000	1,000 m	2007–2012	Global
	EU Crop Map	JRC, Sentinel 1	10 m	2018	Europe
	Argentina crop map	INTA, Landsat 8		Winter 2019, summer 2020, winter 2020, summer 2021	Argentina
Biodiversity	Vulnerability, extinction risk, endemicity	WWF ecoregions, WB Habitat Maps	1,000 m	2019	Global
	biomes, ecoregions	RESOLVE	500 m	2017	Global
Climate	Temperature and precipitation (average, change, anomalies)	ECMWF ERA5	28,000 m	1979–2021	Global
	Precipitation (average, change, anomalies)	CHIRPS	5,000 m	1981–2021	Quasi-global (50 °S–50 °N)
	Aridity index (yearly), Aridity index (10 year median), changes in aridity 2001–2020	ECMWF ERA-Land and MODIS	500 m	2000–2020	Global
	Frost days per year, Heat stress days per year, extreme rain days per year	ECMWF ERA-Land	11,000 m	2000–2020	Global
	FAO Global Ecological Zones	FAO	10,000 m	2010	Global
	IPCC Climatic Zones	JRC	10,000 m	2021	Global
GHG emissions	Emissions—drained organic soil	FAO	1,000 m	1992–2018	Global
	Emissions—fires in drained organic soils	FAO	1,000 m	1992–2018	Global
	Emissions—biomass fires MODIS LC	FAO	500 m	2001–2020	Global
	Emissions—biomass fires CCI	FAO	500 m	2001–2020	Global
Fires	Burned area—yearly fires by land use	MODIS/CCI	500 m	2000–2022	Global
	Burned area—last year of observed fire, burned area—fire frequency	MODIS	500 m	2000–2022	Global
Forest	Global forest change	UMD Glad derived from Landsat	30 m	2000–2020	Global
	Global Forest Canopy Height	UMD Glad derived from Landsat	30 m	2019	Global
	Intact Forest Landscapes	UMD Glad derived from Landsat	30 m	2000–2020	Global
	Restoration potential, total tree carrying potential, risk of gain, and loss in tree cover	Worldclim 2, SRTM, Soilgrid, Hansen GlobCover 2009	1,000 m	2019	Global
	Forest Landscape Integrity Index	Grantham et al. [40] derived from Land Cover CCI, USGS GFSAD30, JRC, Landsat 5, 7, and 8, Protected Areas, Open Street Map	300 m	2019	Global

(Continued)

Thematic section	Parameter	Data provider/data source	Nominal resolution	Temporal coverage	Spatial coverage
Geophysical	Elevation, slope, aspect	SRTM	90 m	2000	80% of the globe
	Landform	SRTM CHILI, SRTM mTPI	30 m	2006–2011	80% of the globe
	Kapos Mountain classification	SRTM	250 m	2000	Global
Geosocial	Population, settlement, built-up	JRC, Global Human Settlement Layer	1,000 m	1975, 1990, 2000, 2015	Global
	Population	NASA, Gridded Population of World Version 4.11 (GPWv4)	1,000 m	2000, 2005, 2010, 2015, and 2020	Global
	Population	WorldPop Project Population Data	100 m	2010, 2015, 2020	Global
	Night lights	Night lights—VIIRS Daily Mosaic	450 m	2014–2020	Global
	Accessibility cities	Open Street Map and Google roads datasets, SRTM, Land Cover etc.	1,000 m	2015	Quasi-global (60°S–85°N)
Hydrology	River network	WWF HydroSHEDS	90 m	2000	Global
	Curve number	FAO—derived from 2019 CCI Land Cover 300 m/SoilGrids Clay content 250m/SRTM Slope 30m	250 m	2019	Global
	Curve number—average antecedent conditions	GCN250, new global gridded curve numbers for hydrologic modeling and design/ESA CCI-LC	250 m	2015	Global
	Curve number—dry antecedent conditions		250 m		Global
	Curve number—Wet antecedent conditions		250 m		Global
	Hydrologic soil groups	FAO—derived from ISRIC—Soil-Grids: clay content in grams per kilogram at 6 standard depths (0, 5, 15, 30, 60, and 100 cm)	250 m	2020	Global
	Hydrologic soil groups	HYSOGs250m—Global gridded hydrologic soil groups for curve-number-based runoff modeling	250 m	2018	Global
	Runoff (average)	FAO—derived from 2019 CCI Land Cover 300 m/SoilGrids Clay content 250m/SRTM Slope 30m	90 m	1981–2021	Global
	Total available water	FAO—derived from OpenLandMap Soil Texture Class (USDA System)	250 m	2021	Global
Land Maps	Land cover	GlobCover 2009	300 m	2009	Global
	Land cover	ESRI 2020	10 m	2020	Global
	Land cover	ESA 2020	10 m	2020	Global
	Land cover	Land Cover CCI	300 m	1992–2020	Global
	Land cover	Land Cover CGLS	100 m	2015–2019	Global
	Land cover	Land Cover IGBP—MODIS	500 m	2001–2019	Global
	Land cover	Land Cover Combined—MODIS/ESA	500 m	2001–2019	Global
	Land cover	CORINE	50–10 m	1990, 2000, 2006, 2012, and 2018	Europe
	Land cover	Land Cover Africa 2016—CCI	20 m	2016	Africa
	Land cover	Land Cover Meso-América 2018—CCI	10 m	2018	Meso-América
	Land cover	Land Cover Honduras 2018—CCI	10 m	2018	Honduras
	Land use	IPCC/Land Use CCI	100 m	1992–2018	Global
	Land use	IPCC/Land Use CGLS	300 m	2015–2019	Global

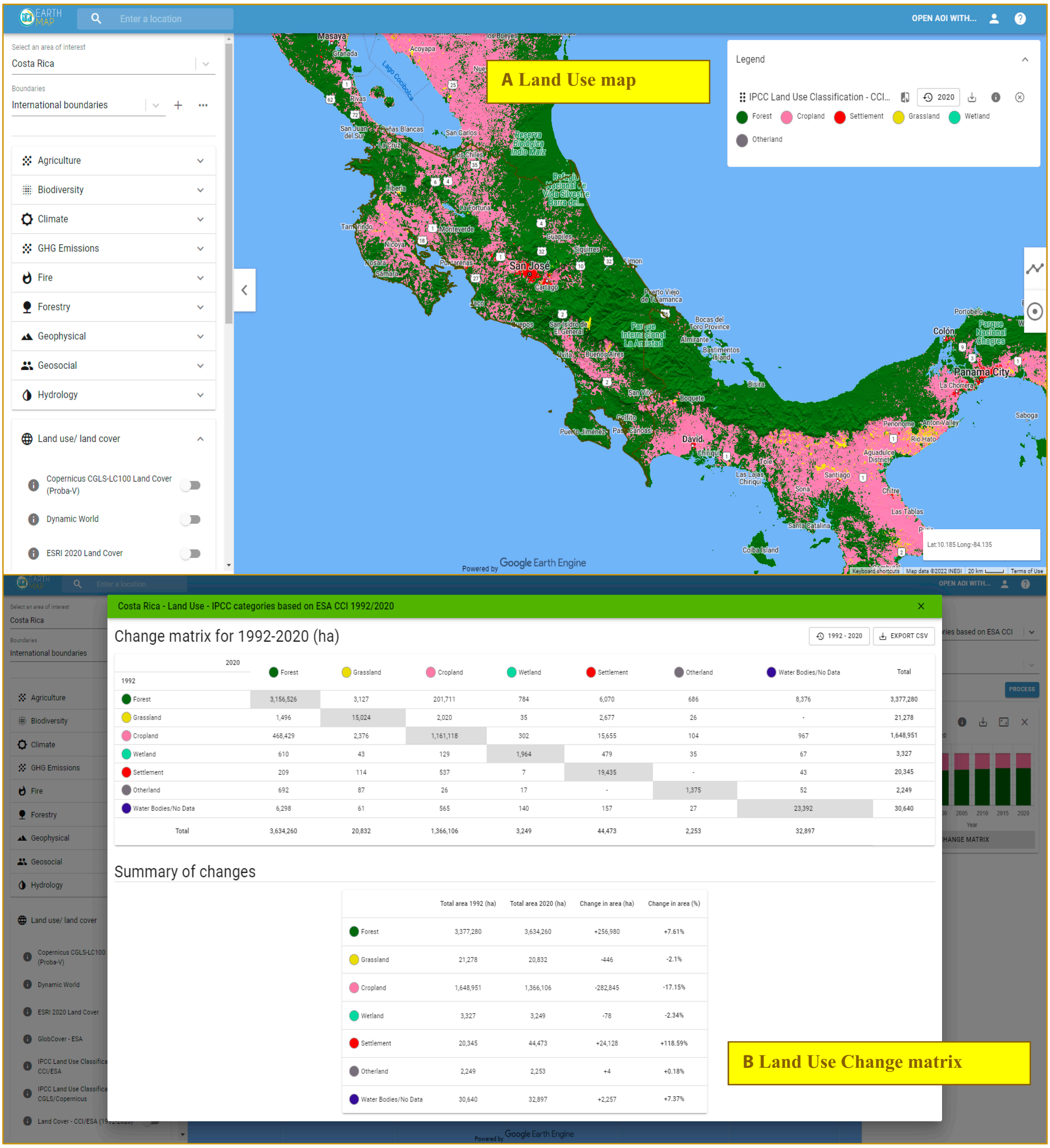
(Continued)

Thematic section	Parameter	Data provider/data source	Nominal resolution	Temporal coverage	Spatial coverage
Land degradation	Land productivity dynamics (LPD)	MODIS	250 m	2001–2018	Global
Satellite images	False-color mosaic nir-red-green	Sentinel 2—ESA	10 m	2019	Global
	False-color mosaic nir-swir1-red	Sentinel 2—ESA	20 m	2019	Global
	Sentinel 2 false-color mosaic	Sentinel 2—ESA	20 m	2015–2017, 2018, 2019, 2020, and changes 2017–2020	Global
	Greenest pixel	Landsat 5, 7, and 8	30 m	1984–2018	Global
	SAR mosaic	Sentinel 1	10 m	2017–2020	Global
	SAR mosaic	PALSAR	25 m	2007–2010 and 2015–2017	Global
	True- and false-color monthly mosaic	Planet Labs	5 m	2015–2020	Global Tropic regions
Soil	Global soil organic carbon	FAO	1,000 m	—	Global
	Histosols—Organic soils	FAO	1,000 m	—	Global
	OpenLandMap soil texture—multiple depths	EnvirometriX Ltd	250 m	—	Global
Vegetation	NDVI (average, change, anomalies)	MODIS	500/250 m	2000–2021	Global
	Potential evapotranspiration (average, change, anomalies)	MODIS	500 m	2000–2021	Global
Water	Water deficit (average, change, anomalies)	MODIS	500 m	2000–2021	Global
	Global surface water (surface water occurrence, surface water occurrence change intensity, surface water transition)	JRC—derived from Landsat 5, 7, and 8	30 m	1984–2019	Global
	WaPOR evaporation, transpiration, Reference evapotranspiration, actual evapotranspiration and interception, gross biomass water productivity, net primary production (average, change, anomalies)	FAO WaPOR—derived from Sentinel 2	250 m	2009–2021	Africa

Materials and Methods

Platform overview

Earth Map is a web-based application constituted by a map where geospatial layers can be easily displayed and statistics generated on the fly thanks to its graphical user interface. Earth Map's data are currently divided into more than 15 thematic groups that cover agriculture, biodiversity, climate, greenhouse gas emissions, fire, forestry, geophysical, geosocial, hydrology, land use/land cover, land degradation neutrality, satellite images, soil, vegetation, and water. The continent- or region-specific thematic sections or layers only appear once the user has selected a specific area of interest (AOI). For instance, Africa Open DEAL or the FAO Water Productivity through Open-access of Remotely sensed derived data (WaPOR; https://wapor.apps.fao.org/home/WAPOR_2/1) datasets (for more details, see Table 1) can only be displayed if the user selects Africa or any African-specific AOI [17]. The tool allows the user to visualize the layers (maps) with their corresponding legend, rendering a Google Maps high-resolution background map. More importantly, the user can perform deeper analysis by generating zonal statistics on the AOIs that complete the visual information of the maps. The user can easily access the data description and the data source for each of the more than 100 layers available. Some of these layers such as the European Space Agency's (ESA) Climate Change Initiative (CCI) land cover map or the Global Forest Change Tree Cover Loss map provide a time series permitting to highlight the dynamics of the parameters under analysis. Earth Map thereby gives users both a temporal (accessing data time series) and a spatial (visualizing maps) perspective to their



Select an area of interest: Costa Rica

Boundaries: International boundaries

Costa Rica - Land Use - IPCC categories based on ESA CCI 1992/2020

Change matrix for 1992-2020 (ha)

1992 \ 2020	● Forest	● Grassland	● Cropland	● Wetland	● Settlement	● Otherland	● Water Bodies/No Data	Total
● Forest	3,156,526	3,127	201,711	784	6,070	686	8,376	3,377,280
● Grassland	1,496	15,024	2,020	35	2,677	26	-	21,278
● Cropland	468,429	2,376	1,161,118	302	15,655	104	967	1,648,951
● Wetland	610	43	129	1,964	479	35	67	3,327
● Settlement	209	114	537	7	19,435	-	43	20,345
● Otherland	692	87	26	17	-	1,375	52	2,249
● Water Bodies/No Data	6,298	61	565	140	157	27	23,392	30,640
Total	3,634,260	20,832	1,366,106	3,249	44,473	2,253	32,897	

Summary of changes

	Total area 1992 (ha)	Total area 2020 (ha)	Change in area (ha)	Change in area (%)
● Forest	3,377,280	3,634,260	+256,980	+7.61%
● Grassland	21,278	20,832	-446	-2.1%
● Cropland	1,648,951	1,366,106	-282,845	-17.15%
● Wetland	3,327	3,249	-78	-2.34%
● Settlement	20,345	44,473	+24,128	+118.59%
● Otherland	2,249	2,253	+4	+0.18%
● Water Bodies/No Data	30,640	32,897	+2,257	+7.37%

Fig. 2. (A) Land use change map and (B) matrix for Costa Rica calculated with Earth Map and the CCI dataset from the ESA. The land use change matrix shows land use changes for all IPCC land use categories between 1992 and 2020 with a 7.61% gain in Forest Land.

areas of interest. GEE gives Earth Map the capacity to run statistics on the fly on several metrics like temperature, precipitation, burned areas, tree-covered area, aridity index, and among others. These statistics can be executed on any device in a matter of seconds, regardless of the device's computational power. Statistics can be aggregated at different time frames (yearly, monthly averages, and monthly time series) and different time periods. As statistical analysis is performed on the fly, information can be obtained at global, regional, or custom level.

Earth Map also includes a GEE app, Imagery Compare (https://earthmap.org/compare.html), which allows rapid access to multiple EO sources [Sentinel 1 and 2, Landsat 7-8-9, Moderate Resolution Imaging Spectroradiometer (MODIS), and others] to monitor areas in semi-real time. This is especially useful to monitor extreme events or climatic disasters. The Imagery

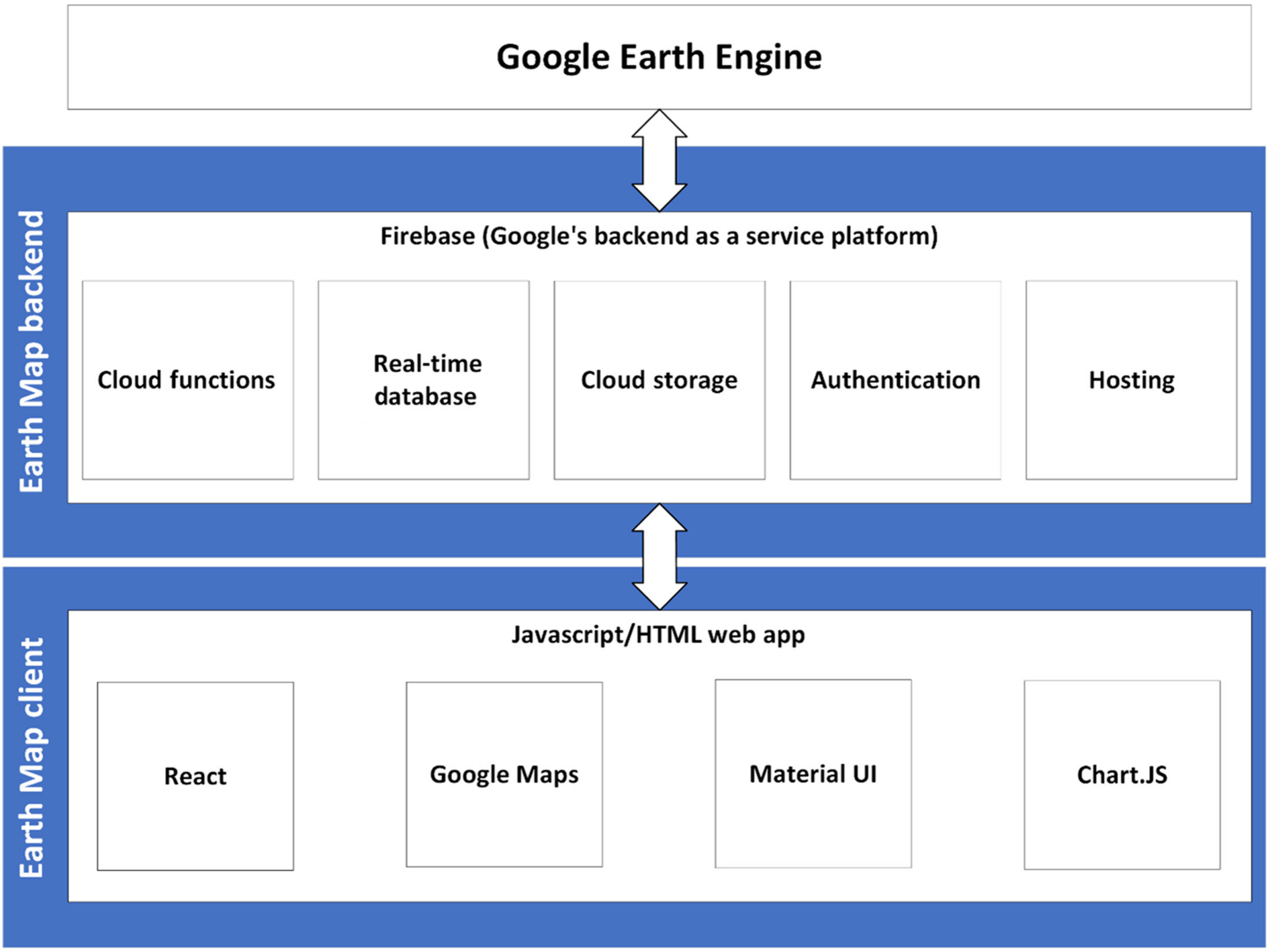


Fig. 3. Earth Map's software architecture. Earth Map is divided into a Firebase-based backend that interacts with GEE and a web-based client.

Compare provides the user with more than 20 examples all around the world that show the land before and after important events (mainly natural disasters like fires or floodings) and more than 10 data sources coming from different satellite images (optical and radar images).

Software architecture

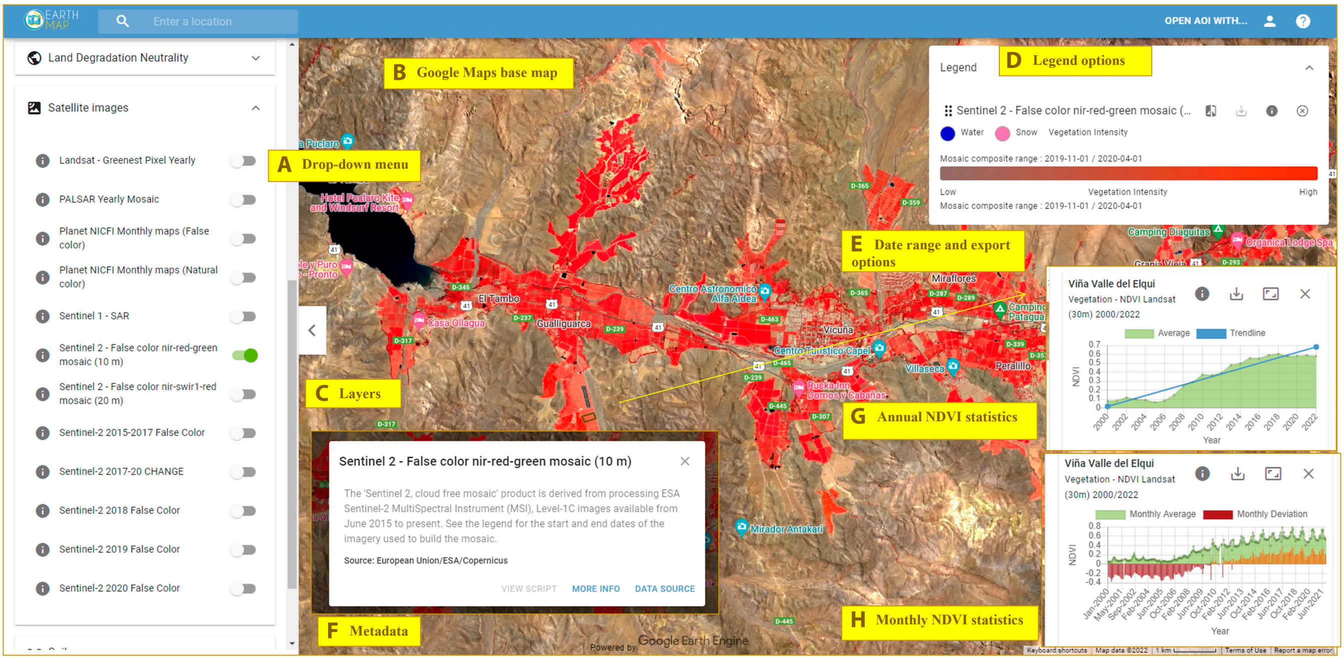
Earth Map is a web-based application, freely accessible and with a graphical user interface, and while it makes use of the GEE API, it is not a GEE app. No coding capacity is required for accessing geospatial data and conducting data analysis. Earth Map is accessible at earthmap.org. A Help Center (https://help.earthmap.org/) with user guides, metadata, and video tutorials is available for the user to easily understand the different features and application modalities of the tool.

Earth Map is divided into a Firebase-based backend and a web-based client as can be seen in Fig. 3.

The Earth Map backend is based on Firebase, a Google "backend as a service" platform, which handles hosting, user authentication, and data storage and provides a serverless framework called Firebase Cloud Functions. Firebase Cloud Functions are called by the Earth Map client based on user interaction. These functions communicate with the GEE through the GEE JavaScript API, returning the necessary data to show the maps or statistical results on the Earth Map client. The Earth Map client is a JavaScript web-based application based on React and Material UI and hosted by Firebase Hosting. This is the part of Earth Map responsible for displaying the geospatial data (layers and statistics) to the user. It makes use of Google Maps API as its main interface component.

The client is divided into 3 sections:

1. AOI/Layers: In this section, the user can select an AOI (project, region, continent, etc.) to start the analysis. Once the AOI and its respective layers are selected, Earth Map pulls information from the Firebase database to load the AOIs and the layers on the map. The boundaries that are then loaded, in the form a GeoJSON, come from Firebase storage.
2. Map: This is a Google Maps-based component that handles the visualization of the boundaries of the AOIs and the layers loaded by the user. It also provides basic base maps (satellite or map) and labels (administrative units, roads, waterbodies, etc.). When the user selects a layer, a call is made to a Google Cloud Function with the ID of the layer that returns a URL used by Google Maps to load the tiles from GEE. The Earth Map backend code is responsible for performing the necessary processing for setting the visualization of the layers.



Sentinel 2 - False color nir-red-green mosaic (10 m)

The 'Sentinel 2, cloud free mosaic' product is derived from processing ESA Sentinel-2 MultiSpectral Instrument (MSI), Level-1C images available from June 2015 to present. See the legend for the start and end dates of the imagery used to build the mosaic.

Source: European Union/ESA/Copernicus

Fig. 4. Earth Map user interface and functionalities. (A) Drop-down menu to select the AOI, (B) Google Maps base map in background, (C) visualization of layers, (D) legend options, (E) date range and export options, (F) access to metadata, execution of NDVI statistics at the (G) annual basis, and (H) monthly time series for a given AOI. The results show NDVI values at the annual and monthly basis within the selected AOI between 2000 and 2020.

3. Statistics: Once an AOI is selected, the user can obtain data by clicking on it and running zonal statistics from a list of available scripts. If there are layers loaded on the map, then the user can also use the pixel inspector to obtain the values of the pixels at the exact location. The Earth Map client makes a call to a Firebase function with the selected polygon or location and the ID of the selected script that return a JSON data structure with the zonal statistics. The Earth Map client uses Chart.JS for data visualization.

To access Earth Map, the user can either choose to login anonymously or to login with an email address or Google account to create a user profile. With the user profile, it is possible to upload and save AOIs (as GeoJSON, KML, or Shapefiles) for easier access for returning users.

Earth Map also provides its own API that allows other applications to use the Earth Map backend capabilities for interaction with GEE (Earth Map API description; https://earthmap.org/EarthMap-API-TESTING.html).

Earth Map is not currently an open-source tool. However, Earth Map uses 2 different code bases. One that is deployed to the Firebase functions end point used by the Earth Map User Interface (which is not publicly accessible) and a second one where a copy of the code is kept in a GEE code repository (openforisinitiative/EarthMap). This code repository is open and can be accessed through this link: https://code.earthengine.google.com/?accept_repo=users/openforisinitiative/EarthMap

For ease of use, the statistics that can be generated in Earth Map are available here: https://code.earthengine.google.com/?scriptPath=users%2Fopenforisinitiative%2FEarthMap%3AResults%2FPortal%2FCharts

The maps generated by Earth Map are summarized here: https://code.earthengine.google.com/?scriptPath=users%2Fopenforisinitiative%2FEarthMap%3AResults%2FPortal%2FImages

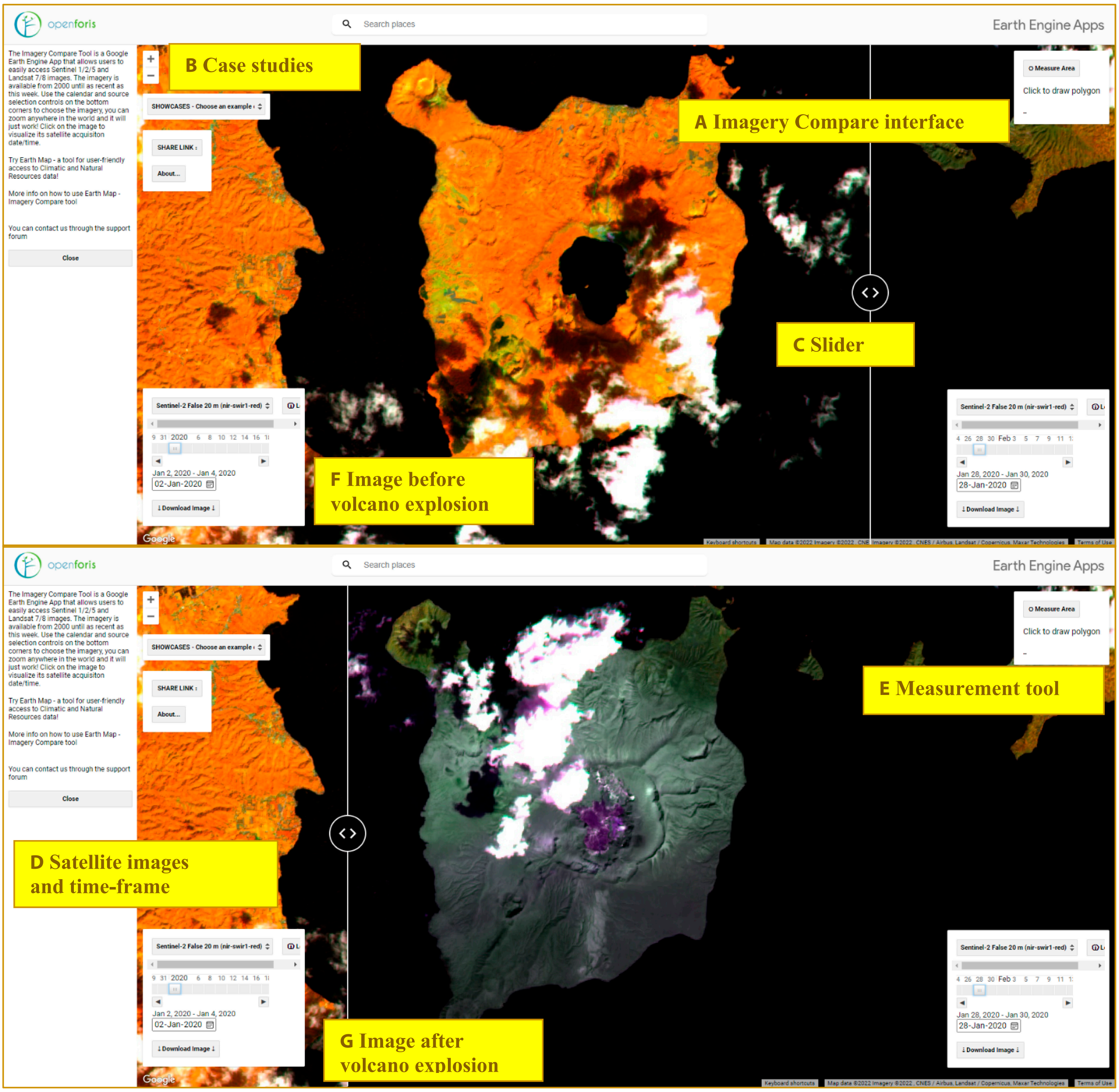
The structure of the code in Earth Map is complex and makes use of many scripts so an in-depth description of the full code is out of the scope of this paper.

Software functionalities and user interface

Following a period of internal review and numerous applications in projects and activities, Earth Map was officially launched in September 2020 [18]. Since then, more than 50 Earth Map trainings and events have been undertaken reaching different user groups, such as FAO country offices, government partners, FAO headquarters teams but also schools, universities, non-governmental organizations, and research centers across the world. These trainings included feedback sessions that provided useful insights on how to improve the user experience and how to prioritize future features.

The key Earth Map features and functionalities are presented below (as of the time of writing):

- Selection of commonly used AOIs: Users can quickly choose an AOI through a drop-down menu. Administrative boundaries (such as FAO Global Administrative Unit Layers), protected areas (such as World Database on Protected Areas), various levels of watersheds (HydroSHEDS), or areas such as the Great Green Wall can be selected to visualize layers or perform statistics within the given AOI (Fig. 4).
- Google Maps in background: Earth Map has an easy and user-friendly interface mainly because the base map is the commonly used Google Maps with imagery and vector map options. The labels with the name of the geographic features can be activated for an optimal exploration experience. The Google Maps location search field is also present making it easier to find AOIs (Fig. 4).



The Imagery Compare Tool is a Google Earth Engine App that allows users to easily access Sentinel 1/2/5 and Landsat 7/8 images. The imagery is available from 2000 until as recent as this week. Use the calendar and source selection controls on the bottom corners to choose the imagery, you can zoom anywhere in the world and it will just work! Click on the image to visualize its satellite acquisiton date/time.

Try Earth Map - a tool for user-friendly access to Climatic and Natural Resources data!

More info on how to use Earth Map - Imagery Compare tool

You can contact us through the support forum

The Imagery Compare Tool is a Google Earth Engine App that allows users to easily access Sentinel 1/2/5 and Landsat 7/8 images. The imagery is available from 2000 until as recent as this week. Use the calendar and source selection controls on the bottom corners to choose the imagery, you can zoom anywhere in the world and it will just work! Click on the image to visualize its satellite acquisiton date/time.

Try Earth Map - a tool for user-friendly access to Climatic and Natural Resources data!

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Fig. 5. Imagery Compare user interface and functionalities. (A) Imagery Compare representation with (B) case studies section, (C) slider, (D) satellite images and time-frame selection option, and (E) measurement tool. Sentinel 2 false 20-m (nir-swir1-red) false-color mosaic and on-the-fly comparison in different time frames [(F) before and (G) after volcano eruption].

- Visualization and overlay of raster layers: As an online geospatial platform, Earth Map makes it easy to search for overlay and rearrange layers activating them within the thematic sections. The map's legend will automatically pop up when the layer is activated (Fig. 4).
- Legend options, access metadata, opacity, and date range selection: Viewing legends, finding metadata, and the ability to apply opacity levels to contrast information in overlayed layers are standard features. The metadata can be always accessed by clicking the information button on the left side of the layer names. For any multitemporal layer, Earth Map allows the user to select the time through a button in the legend, e.g., Landsat yearly mosaics since 1984 (Fig. 4).
- Pixel inspector: While activating and visualizing a raster layer, the user may need to inspect different locations at the local level. The pixel inspector can diagnose the pixels that make up the colors in layers. After clicking on a given pixel, the coordinates and pixel values for all the activated layers will appear on the right panel.
- Execution of zonal statistics aggregated at different time frames and conversion matrices: Statistics can be aggregated at different time frames (yearly, monthly averages and monthly time series) and for different time

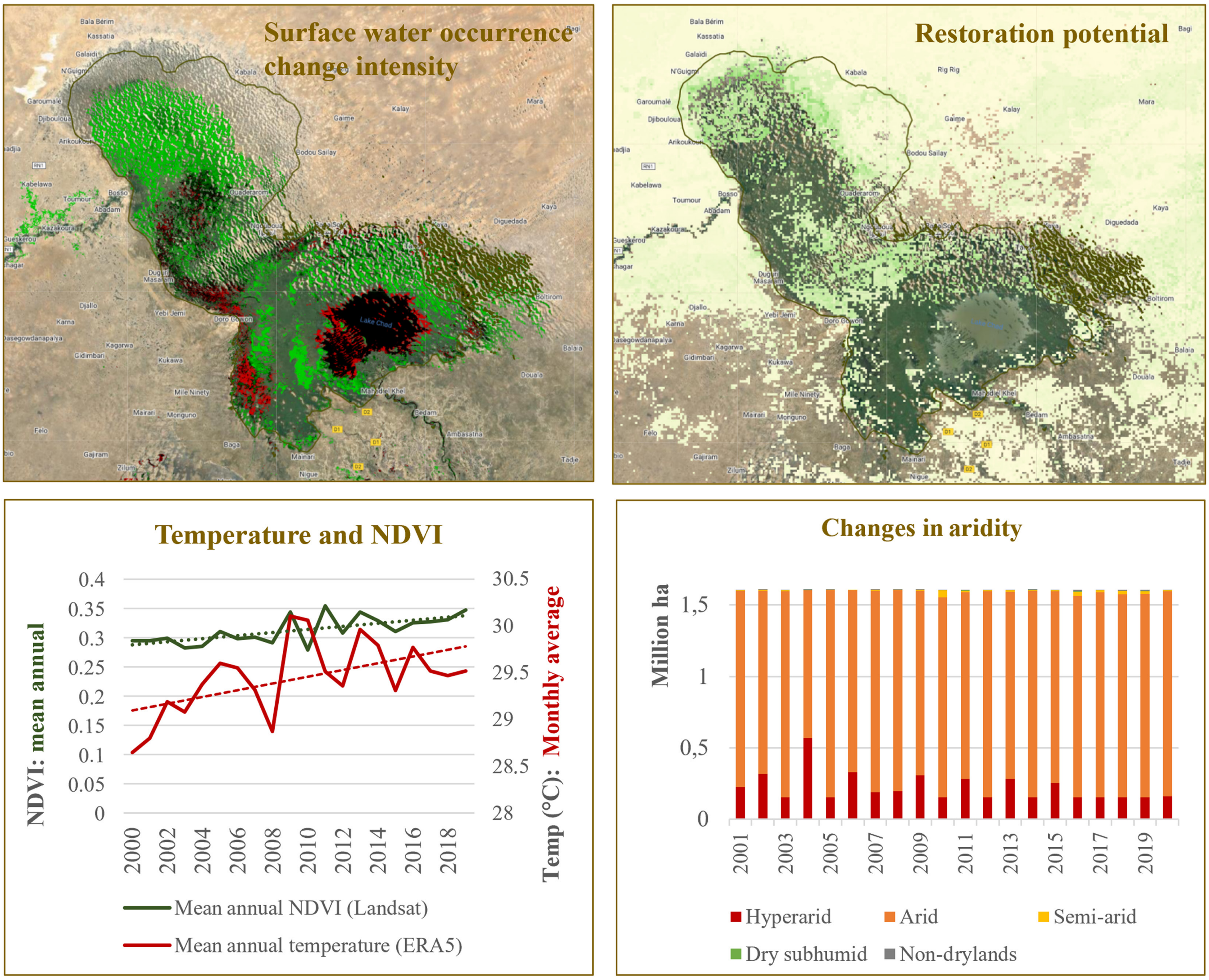

Fig. 6. Lake Chad case study. Surface Water Occurrence Change (JRC), potential of tree restoration [28], changes in temperature (ERA5), NDVI parameters (Landsat 30 m) and in aridity (ERA5-Land and MODIS) in the Lake Chad.

periods, by clicking the area before proceeding with the “Process” option (Fig. 4). For some of the datasets (land cover/land use maps or aridity index), conversion matrices can be performed to better understand the dynamics of the changes (Fig. 2). Spatially explicit land-use conversion matrices are the basis for the calculation of the GHG inventories in the AFOLU sector as specified in the Intergovernmental Panel of Climate Change (IPCC) guidelines on the consistent representation of lands [19].

- Selection of thresholds for visualization of layers and execution of zonal statistics: Recently, a threshold option for temperature (°C) and rainfall (mm) has been added to the platform for the identification of Heat Stress Days, Frost Days, and Extreme Rain Days. The user may select the threshold for the identification of extreme events and natural disasters.
- Vector upload or drawing of a new boundary, save you own AOI: Users can upload their AOI in shape file (zipped), GeoJSON, or KML formats, or they can choose to draw a new boundary on the map. AOI can be saved and managed in a user’s personal section that will be created if the user signs in with a personal account.
- Image and graphs export options: Images can always be downloaded for a given boundary. The scale of the image will be adjusted to keep its size under 32 megabytes as per GEE API limitations. The layer legend and the download option appear when a layer is selected for an AOI. Charts in the statistics area can be exported as images or as CSV files for integration on reports (Fig. 4).
- Sharing through URL links: Earth Map makes it easy to share the displayed information (AOI, active layers and statistics) by copying the URL of the page regardless of the type of user (signed-in or anonymous).
- Display and comparison of semi-real time satellite images: Through an “Open AOI with…” button, Earth Map is linked to the GEE app Imagery Compare that allows to display multitemporal and semi-real-time high-resolution satellite images (Sentinel, Landsat, and MODIS) or carry

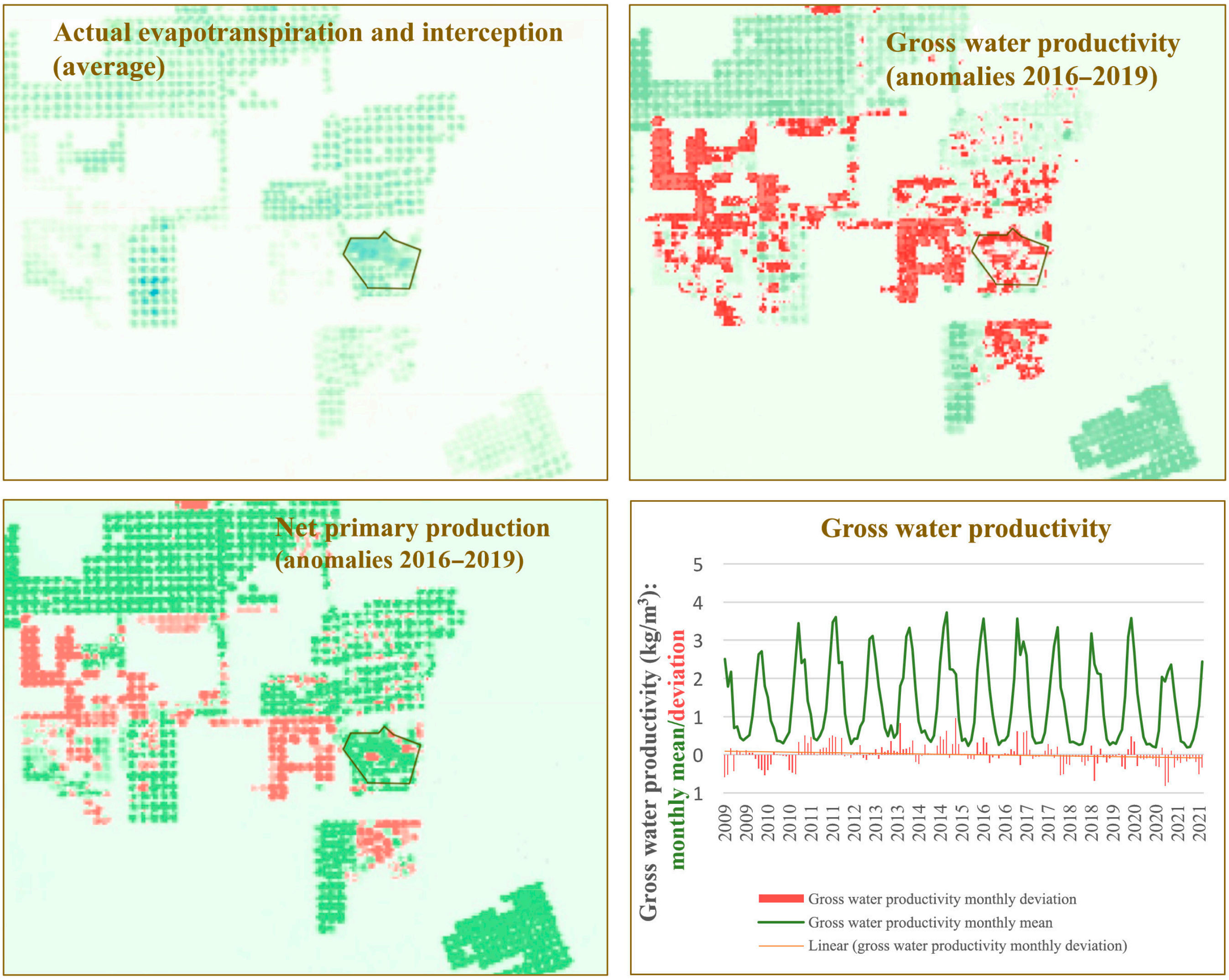

Fig. 7. Egypt irrigation scheme case study. Changes in actual evapotranspiration and interception, net primary production anomalies, and gross biomass water productivity anomalies (WaPOR) in the southwestern part of Egypt.

out on-the-fly comparison of satellite images from different sensors and time frames thanks to its split panels and slider (Fig. 5).

- Connections with other FAO tools: As of now, Earth Map is linked with the Imagery Compare app (see short explanation above) and the FAO Hand-in-Hand Geospatial Platform. In the future, the team plans to integrate Earth Map with more applications to improve the user experience. This will allow the user to work with features and datasets that might not be available in Earth Map but on other platforms.
- Mobile-friendly version: The aim is to make land and climate assessment accessible to farmers, climate and environmental activists, and members of the general public, providing everyone with the opportunity to improve their understanding of local circumstances. An Earth Map mobile-friendly version can be handy for fieldwork, facilitating the above-mentioned stakeholders' semi-real-time investigations in the field.

Dataset review

Most of the data in Earth Map are generated by sensor technologies based on satellites or aircraft that detect and classify objects on Earth. The Earth-observing remote sensing imagery includes not only Landsat or Sentinel 2 false-color mosaics, Sentinel 1, and the Phased Array L-band Synthetic Aperture Radar (PALSAR) Synthetic Aperture Radar images but also the recently launched Very-High Resolution Planet Labs imagery. MODIS-derived parameters such as the Normalized Difference Vegetation Index (NDVI), the Potential Evapotranspiration, or Burned Areas calculations and Landsat-derived datasets such as the Hansen Global Forest Change and the Joint Research Centre (JRC) Water Occurrence layers are within the reach of any Earth Map user. Climate information for the last 40 years is available as well. The platform also includes a wide range of land cover and land use maps [ESA CCI, Copernicus Global Land Service (CGLS), CORINE Land Cover, etc.] and many other environmental, geophysical, and socioeconomic datasets (Table 1). Earth Map includes continent-specific (Africa Open

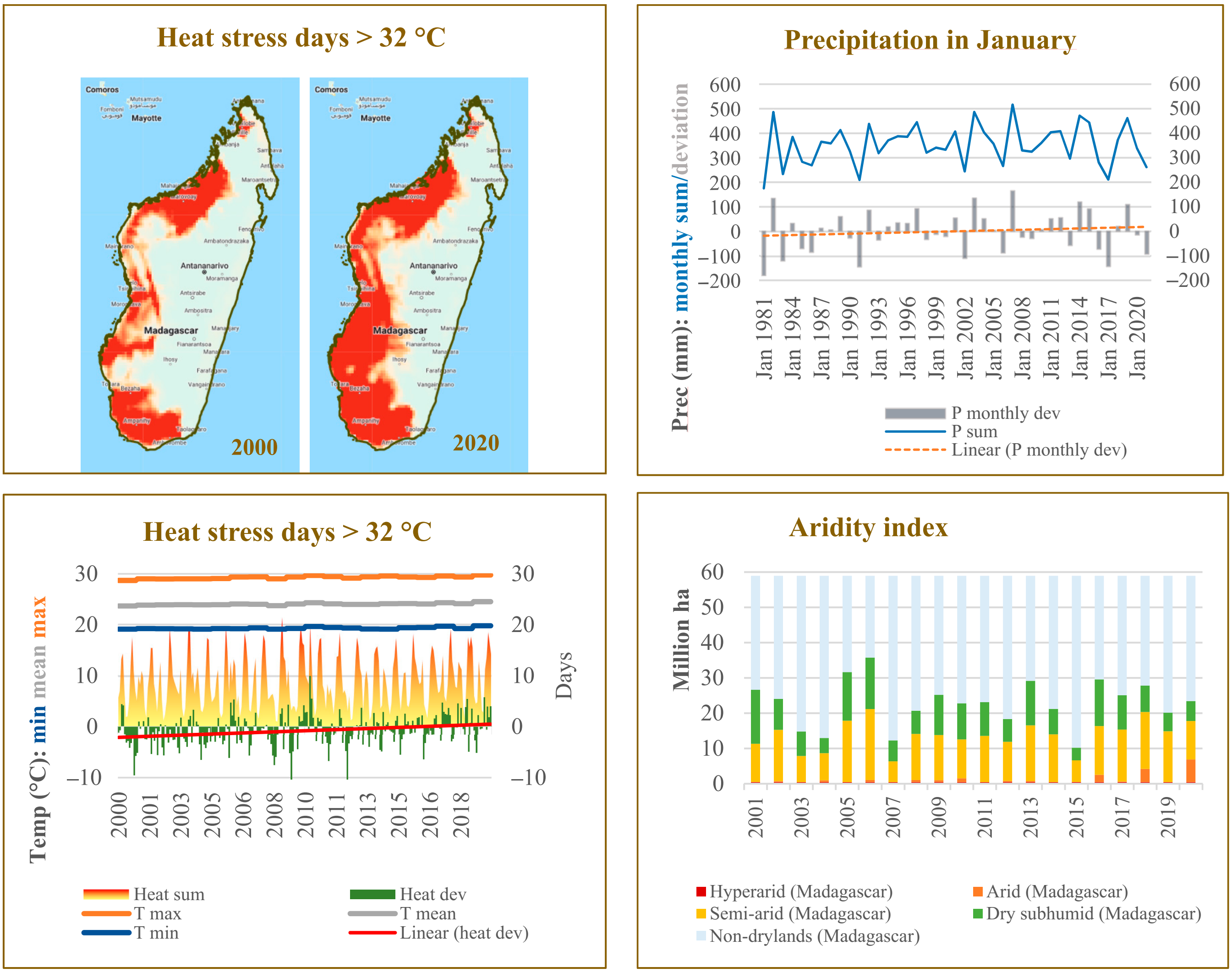

Fig. 8. Madagascar case study. Changes in heat stress days at >32 °C (derived from ERA5-Land datasets), deviations in precipitation in January the wettest month (CHIRPS), and aridity (ERA5 Land/MODIS) in Madagascar.

Deal developed by FAO) or country-specific (cropland maps developed by the National Institute for Agricultural Technology in Argentina) datasets in the platform that are not subjected to GEE. The repository is continuously updated with new datasets whose selection is demand-driven and can be requested by users (top-right question mark > Help Center/Tutorials > Contact us).

Quality control of satellite data and assumptions

Most of the datasets that can be found in Earth Map are coming from peer-reviewed literature, which allows the user to assess the methods of data generation and data quality. The user can easily find the datasets source thanks to the information button placed on the left side of the layer names and the Earth Map Help Center (https://help.earthmap.org/), which documents all the datasets with its metadata directing the user to the Earth Engine Data Catalog and corresponding data provider website or peer-reviewed literature.

The remote sensing imagery in Earth Map includes Landsat, Sentinel, PALSAR, and Planet Labs imagery. These products can be visualized through yearly mosaics (or monthly for Planet Labs), and some derived maps and statistics can be produced. These include the NDVI, one of the most widely used vegetation indicators due to its simplicity of usage and flexibility [20,21]. Earth Map applies cloud-masking algorithms (using image metadata and pixel-level quality bands) to the Landsat 8-, Sentinel 2-, and MODIS-derived NDVI maps to improve the robustness of their results. For further understanding of the processing applied by Earth Map, the GEE code repository can be accessed (see the Software architecture section).

Some of the datasets presented in Earth Map, such as the Global Forest Change application or the Surface Water Occurrence Change, are derived products and the results from time series analysis of Landsat images [22,23]. As described in the documentation, these datasets are a relative indicator of spatiotemporal trends in forest loss and water occurrence dynamics globally. The methods and models used to create them are considering several assumptions that are not adequate for all applications [24,25]. It is out of the scope of Earth Map to provide in-depth discussions of the accuracies and appropriateness of each product, as these come directly from the data

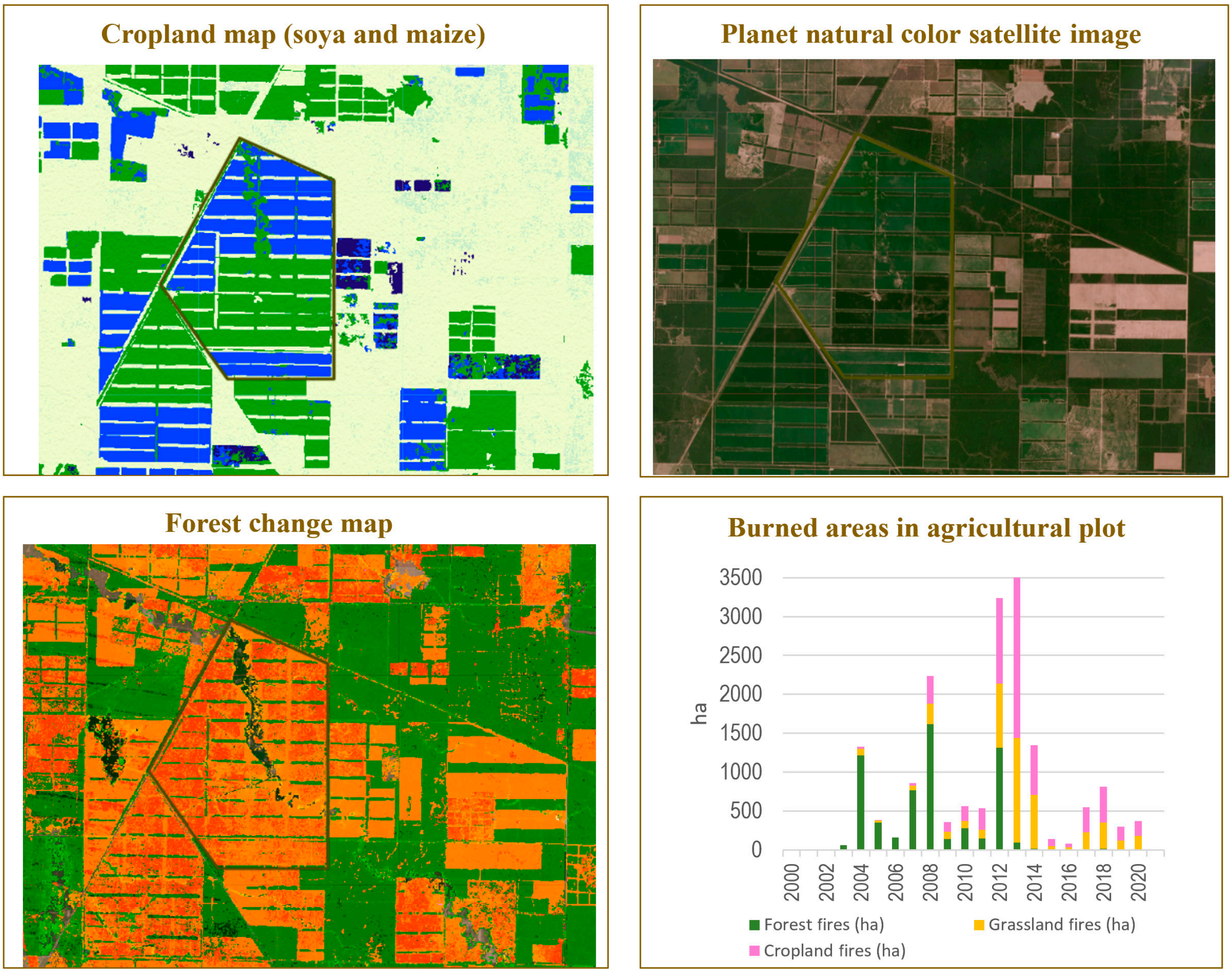

Fig. 9. Argentina case study. Summer cropland map (INTA, 2021), planet natural color satellite image (Planet, 2021), forest loss map (Hansen), and burned areas per land use (MODIS/ESA-CCI) in the selected agricultural plot in Argentina.

producers. Users, although not requiring GEE coding experience, should still acquire some understanding of which products are correct for their analysis.

Case Studies

This section highlights examples in which advanced custom-made assessments with global datasets in consultation with technical experts can guide decision makers, civil society, and local populations in the development of evidence-based policies and investment decisions for sustainable development. With these case studies, we want to emphasize the novelty of Earth Map and its research capabilities to solve complex issues in the context of forest restoration for resilient livelihoods and stable peacebuilding, water scarcity for agriculture in hyperarid regions, climate and humanitarian crisis. or agricultural expansion and biodiversity loss.

Ecosystem restoration in Lake Chad region, Africa

FAO experts developed a short assessment on climate and environmental related parameters in the Lake Chad region, whose results were published in the Georgetown Journal of International Affairs in August 2020 [26]. Considering that Lake Chad has stopped shrinking and has stabilized in the last 2 decades [27], it could be observed with Earth Map that surface water occurrence has been increasing in extensive areas especially in the northern part of the Lake Chad region between 1984 and 2020. Additionally, temperature and NDVI values have been on the rise as well, and hyperarid drylands have been decreasing within the last 20 years. We can observe that the mean average annual temperature in Lake Chad has increased from 28.5 °C in 1979 to 29.6 °C in 2019 and has an overall linear upward trend. Furthermore, NDVI values show that the vegetation in Lake Chad is on an upward trend. As can be seen in high-resolution satellite images, many villages across Lake Chad were abandoned or destroyed because of the conflict, but vegetation in the same areas recovered within just a few years. With data on the global tree restoration potential available in Earth Map, it was noted that there is an important tree restoration potential around the Lake (Fig. 6). In particular, 112,588 ha have the potential to be restored [28]. The results of this easy but precise Earth Map assessment served as an entry point to prove that nature is claiming its course in conflict areas and restoration activities, such as the Great Green Wall in Lake Chad, are an opportunity to lay the foundations for resilient livelihoods and stable peacebuilding acting as an immunization for humanitarian crisis. [26].

Water scarcity for agriculture in Southwest Egypt, Africa

This example was presented in the "Disrupting" Hydroinformatics Webinar organized by the World Bank in February 2022 and is now part of the content embedded in the World Bank Group Open Learning Campus. It analyzes the water dynamics within an irrigation scheme located in southwest Egypt, a hyperarid region in the Sahara Desert. The topic is important considering that agriculture is a key water user and careful monitoring of water productivity in agriculture is essential for the sustainable development of water scarce regions [29]. The center-pivot irrigation schemes are dependent on the fossil water from the Nubian Sandstone Aquifer System mined to support irrigated farming projects. Three FAO WaPOR layers—the actual evapotranspiration and interception, the net primary production anomalies, and the gross biomass water productivity anomalies—show the critical situation in terms of availability of groundwater for irrigation in this area. The actual evaporation and interception, which is the sum of the soil evaporation, canopy transpiration, and evaporation from rainfall intercepted by leaves in the selected irrigated plot, is higher than in the surrounding croplands. The sum of all 3 parameters, the actual evapotranspiration and interception, can be used to quantify the agricultural water consumption. Additionally, the statistics show an overall increase in crop biomass (net primary production) against a downward trend in gross biomass water productivity (negative anomalies between 2016 and 2019 and negative deviations since 2016), which expresses the quantity of biomass production in relation to the total volume of water consumed providing insights on the impact of vegetation development on the consumption of water [29]. The data demonstrate poor water resource management and should be a wake-up call for agriculture and water managers to work more closely together in the region and avoid negative consequences of water stress conditions (Fig. 7).

Climate and humanitarian crisis in Madagascar, Africa

As mentioned in the recently published IPCC Assessment Report 6 "Climate Change 2022: Impacts, Adaptation, and Vulnerability", Madagascar is one of the countries in Africa where aridity, drought, heavy precipitation, and pluvial flood will be increasing with high confidence [30]. In this short assessment, heat stress days (days with maximum temperature above 32 °C, derived from ERA5-Land datasets), deviations in precipitation in January, the wettest month, and changes in aridity were processed for the island of Madagascar. The results highlight an expansion of the area with heat stress days at >32 °C in the western part of the island and an increasing trend of these days since 2000. The same increasing trend can be found for precipitation deviations in January, the wettest month of the year highlighting the high exposure of the island to floods. Heavy precipitation in Madagascar is often caused by tropical cyclones usually causing damage and destruction of infrastructure and crops. Additionally, the arid dryland category experienced a 33% increase between 2000 and 2020 (Fig. 8). It is well known that drylands are characterized by a scarcity of water affecting both natural and managed ecosystems. The combination of all these climate hazards has created a climate emergency in southern Madagascar. The livelihoods of local communities depend heavily on the natural resources, which justifies the increasing land degradation and aridity in the region and the urgent need to restore the land. Immersed in a nutritional crisis, southern Madagascar is experiencing the worst drought in the last 30 years that should be translated into investments to improve the resilience of one of the most vulnerable countries in the world [31].

Biodiversity loss in Gran Chaco Argentina, South America

The expansion of soybean cultivation in the Argentinean Chaco since the late 1980s is causing the loss of native forest—the Gran Chaco—the second largest forest ecosystem in South America, after the Amazon. The 4 provinces, namely, Santiago del Estero, Salta, Chaco, and Formosa have accounted for 80% of deforestation in the last 30 years. The estimate is that half of the deforestation is due to soya cultivation and half to intensive livestock farming (and a small percentage to sunflower and maize) [32]. Here, we show one summer cropland map for the year 2021 developed by the National Institute for Agricultural Technology (INTA) in Argentina with an agricultural plot with soya and maize plantation [33]. In the "true-color" mosaics from Planet Labs that represent spatially accurate data with minimized haze, illumination, and topographic effects, the same patterns can be found, and the expansion of the plantations is clearly visible. The Global Forest Change map [22] with forest loss between 2000 and 2020 in orange and the burned area graph with forest area burned between 2003 and 2012 clearly show and demonstrate the forest decline (Fig. 9) that could have affected the habitat of the jaguar (Panthera onca) between 1985 and 2013. Zero deforestation policies and broad-scale conservation planning are demanded by environmental organizations such as Greenpeace, to safeguard the Gran Chaco and to preserve its biodiversity and the livelihoods of the local population in the region [32].

Results and Discussion

The most important innovation of Earth Map is that it enables anyone to conduct robust land and climate assessment of any area of the world without the need of being trained because of its simple drop-down menu design and Google Maps-like interface, making it possible to undertake on-the-fly comparison of satellite images from different sensors and periods and statistical aggregations at different time frames executed on any device, regardless of the device's computational power.

As presented above, Earth Map is not only a powerful tool but also has some limitations. First, users need Internet access and cannot perform all kinds of analysis but only the ones predetermined by the availability of datasets and features in Earth Map. In some cases, the user will need to perform his or her own analysis with GEE or other geospatial software. Furthermore, the products at very high resolution, like the NDVI from Sentinel, can be slow to generate, and analysis of very large areas may fail. As for any geospatial product analysis, the scale of the products and extension of the area to be analyzed are a limiting factor, although thanks to GEE's processing power, these are minimized. Most of the datasets found in Earth Map are published in peer reviewed literature. The user should easily find the datasets source and all the relevant documentation to be aware of the data's limitations and application options as presented on the dataset producer's documentation. Nevertheless, there is a risk of the data being inappropriately interpreted leading the user to wrong conclusions. For example, users may not be aware of data uncertainties, or they may choose inappropriate datasets for a given assessment. This is a challenge faced in any geospatial analysis, and it needs to be raised when deriving insights. For example, land cover change analysis using global products should be subject to a proper quantification of their accuracy to provide a reference for users studying different regions [34,35]. For fire detection and assessment, Earth Map offers the area-burned maps and statistics coming from MODIS MCD64A11 Burned Area Product Monthly 500 m that fail to map small ($\lesssim$100 ha) fires and often omit small fires in croplands (~10× underestimate) [36]. Other uncertainties such as temperature biases in ERA5-Land that overestimates soil temperature in high latitudes in America but underestimates it in mid-low latitudes are well known [37]. In addition, the ERA5 lake surface water temperature biases in some greater Lakes regions in the world are important to consider [38].

While it is true that data can be misused, the repercussions of not having access to any data can be far more impactful. To mitigate this issue, we provide a Help Center pointing the user to data description and video tutorials and have trained more than 2,000 users from over 65 countries since the launch of the tool. Earth Map can be used as a stepping stone to build capacity for land monitoring and climate assessment and for countries, organizations, or individuals to move into more advanced custom-made analysis.

We envision Earth Map as a tool that should create the initial knowledge from a wide range of topics and bring together experts from different sectors and decision makers for informed technical discussion in a way that is understandable by policymakers. Using its full capacity, Earth Map is a powerful tool to undertake research on the world's most pressing environmental problems and the impacts of the climate change emergency and develop science-based policy interventions, leverage investments, and sustain livelihoods.

Conclusion

The next 10 years will be decisive to avoid catastrophic climate change effects and mass extinctions. More than 3 quarters of Earth's land surface is impacted by human activity. It is therefore more important than ever that countries, organizations, communities, and individuals are conscious of current, past, and future land characteristics and dynamics [16,39].

Accurate, simple, and free tools for land and climate monitoring are crucial for a sustainable and robust approach to project design, implementation, and evaluation as well as for the GHG inventories and national and international reporting just to name the most relevant applications. The development of web-based tools with access to EO big data has revolutionized the way users can access geographic information without the need to install any software or download large files. In the last 2 decades, we have witnessed an exponential increase in the availability of free datasets and software for EO yet often accompanied by a learning curve that prevents a truly wide adoption. At the same time, the rise of cloud computing has enabled access and processing of datasets on a scale never possible before.

Novel, cloud-based tools like Earth Map provide a wide range of users, including nonremote sensing experts, the possibility to take advantage of big data to access critical knowledge and apply it through land monitoring and climate assessment. Earth Map allows to transform big data into actionable information by everyone, thus democratizing the application of remotely sensed data. It enables a broader array of actors to take an active role in monitoring lands currently impacted by human activities.

Acknowledgments

Earth Map has been developed with the support of the Government of Germany through the International Climate Initiative from the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection and focused financial support from other projects at FAO. We are grateful for the technical support received from the Google Earth Outreach team. The Earth Map Help Center (https://help.earthmap.org/) documents all the datasets with its metadata directing the user to the Earth Engine Data Catalog and corresponding data provider website or peer-reviewed literature. The data that support the findings of this study are available from the corresponding author upon request. **Author contributions:** C.M. conceived the study and wrote the manuscript together with A.S.-P.D. and D.D., which was reviewed by the rest of the authors. All authors have read and agreed to the published version of the manuscript. A.S.-P.D. and D.D. have produced the software code, while all the authors have contributed to the conceptualization of Earth Map. **Competing interests:** The authors declare that they have no competing interests. The views expressed in this publication are those of the author(s) and do not necessarily reflect the views or policies of FAO.

Data Availability

Datasets can be found in https://help.earthmap.org/

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