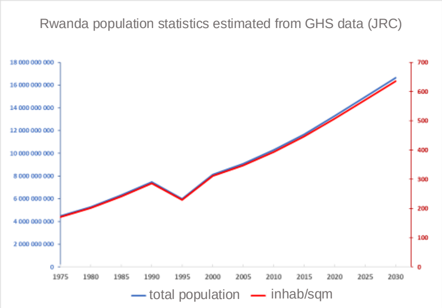
Rwanda, known as the "Land of a Thousand Hills," is a landlocked and densely populated country in East Africa, with fertile land in the hills and a population of about 13 million (2020). The attached figure on the right shows the estimated population change based on the *Global Human Settlement* data of the JRC between 1975 and 2030 (see animation).

Rwanda is bordered by the Democratic Republic of Congo (DRC) to the west, Tanzania to the east, Uganda to the north and Burundi to the south. Rwanda consists of 5 provinces: North, East, South, West and Kigali City (Fig.1a). The whole of Rwanda is hilly and over 1,000 meters above sea level, with the lowest point along the Rusizi River at 950 meters above sea level (Fig.1b).



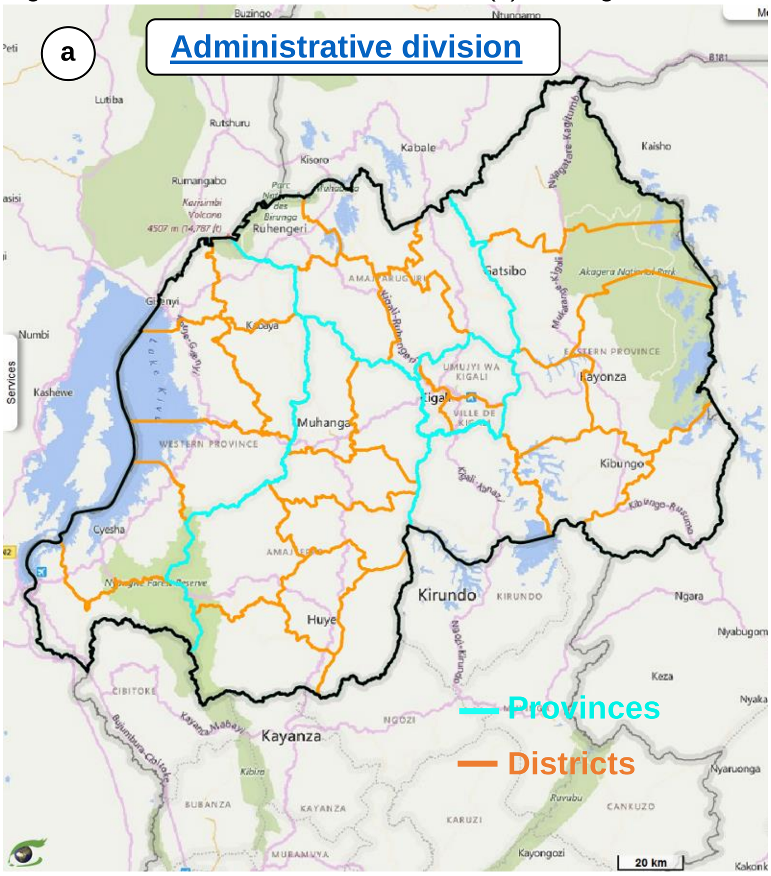
Rwanda seen from space

Sentinel-1, Sentinel-2, DEM

2D_layer_stack

From a conservation point of view, Rwanda encompasses 4 national parks: Parc National des Volcans, Akagera National Park, Nyungwe National Park and Gishwati Mukura National Park. Fig.2a and Fig.2b show Sentinel-1 radar and Sentinel-2 optical views of Rwanda and its national parks respectively.

Fig.1: Provinces and districts of Rwanda (a) and digital terrain model (b).



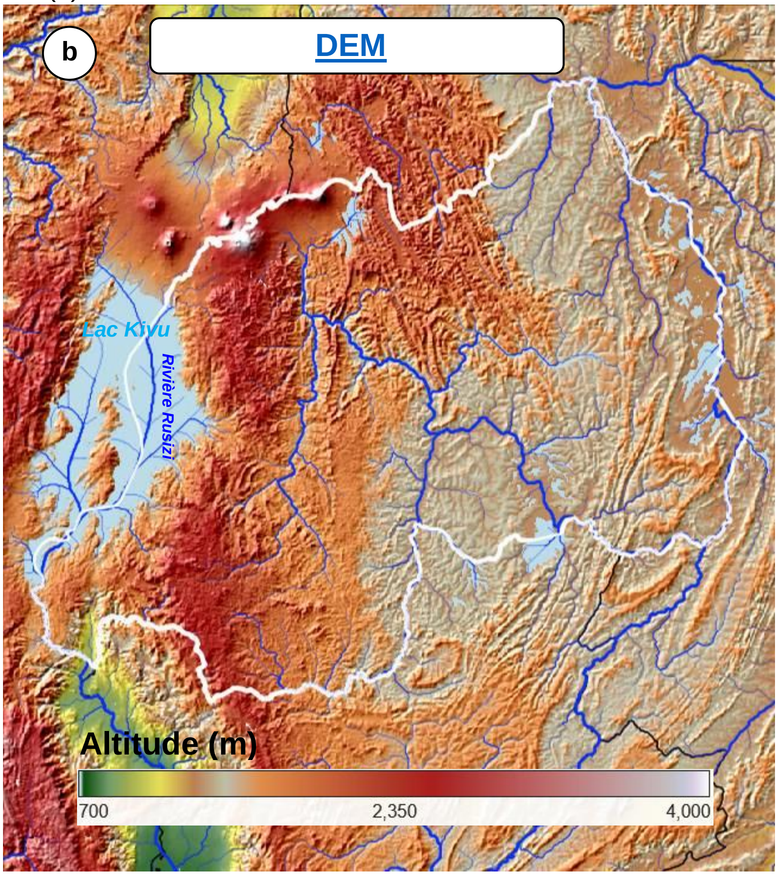
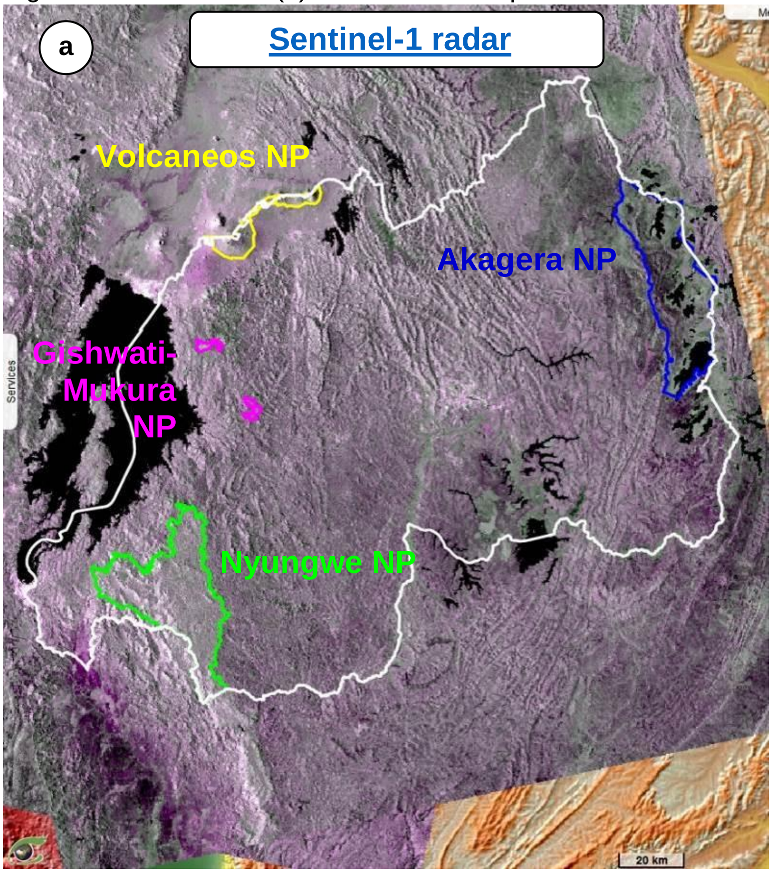
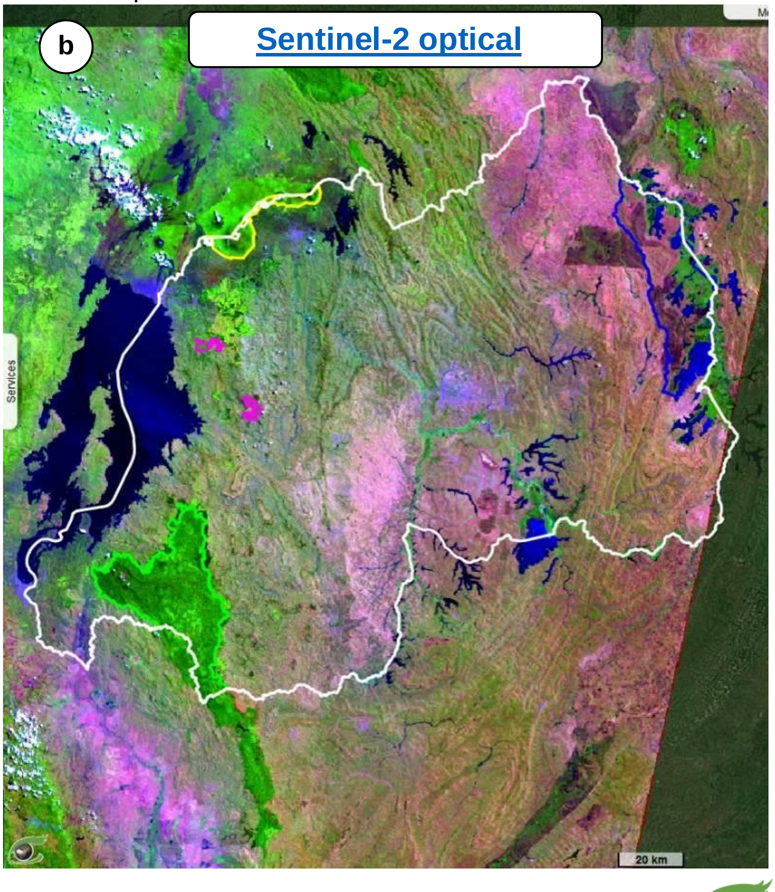


Fig.2: Sentinel-1 radar (a) and Sentinel-2 optical views with the four national parks of Rwanda.





powered by VisioTerra

Agriculture plays a major role in Rwanda's economy and labor market. The agricultural sector accounted for one-third of the country's GDP in 2009-2013 and employed more than 80 percent of the Rwandan population (World Bank, 2015).

Rwanda's agricultural sector is characterized by six agro-ecological zones (Fig.3a), dominated by smallholders ([Source](#)), and benefits from two dry and two rainy seasons (Fig.3b). However, with an imposing climate change context and a growing population, agriculture is facing many challenges.

In this context, VisioTerra provides tools / solutions for monitoring, early warning and seasonal agricultural assessment using Earth Observation data. These geoservices provide administrators and farmers with the ability to monitor and assess their plots through indicators of vegetation, surface moisture, precipitation, temperature...

This document shows an example of monitoring / analysis of a plot located in Bugesera district (yellow polygon in Fig.5a) belonging to the agro-ecological region "Eastern Plateau & Eastern Savanna" ([FAO](#)).

Fig.4a shows the crop calendar of the dominant crops in this agro-ecological region.

Monitoring of agriculture Seasons and crop calendar

Fig.3: Agro-ecological zones (a) and average monthly rainfall over the last 4 years (ERA5) over Rwanda.

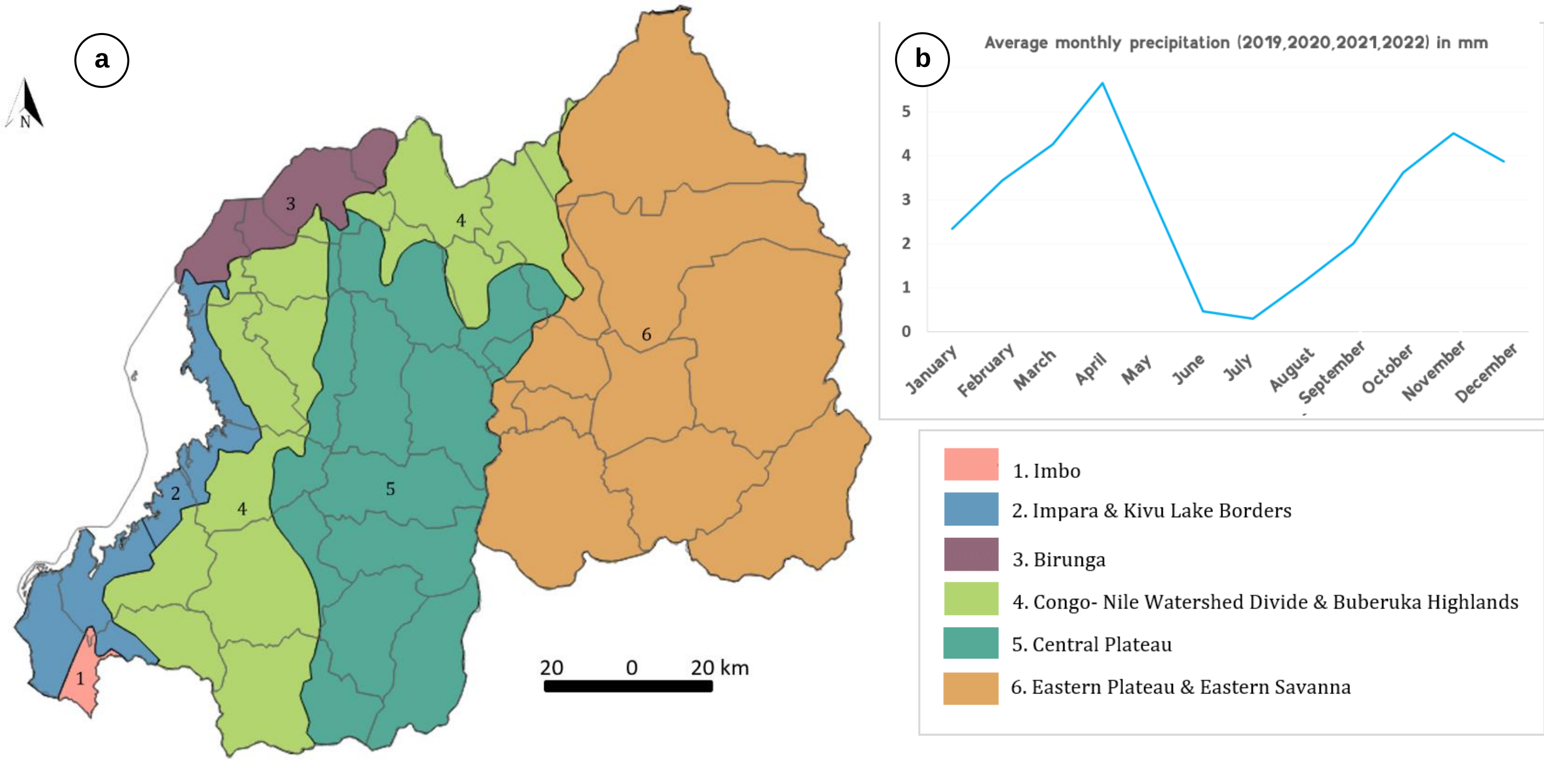
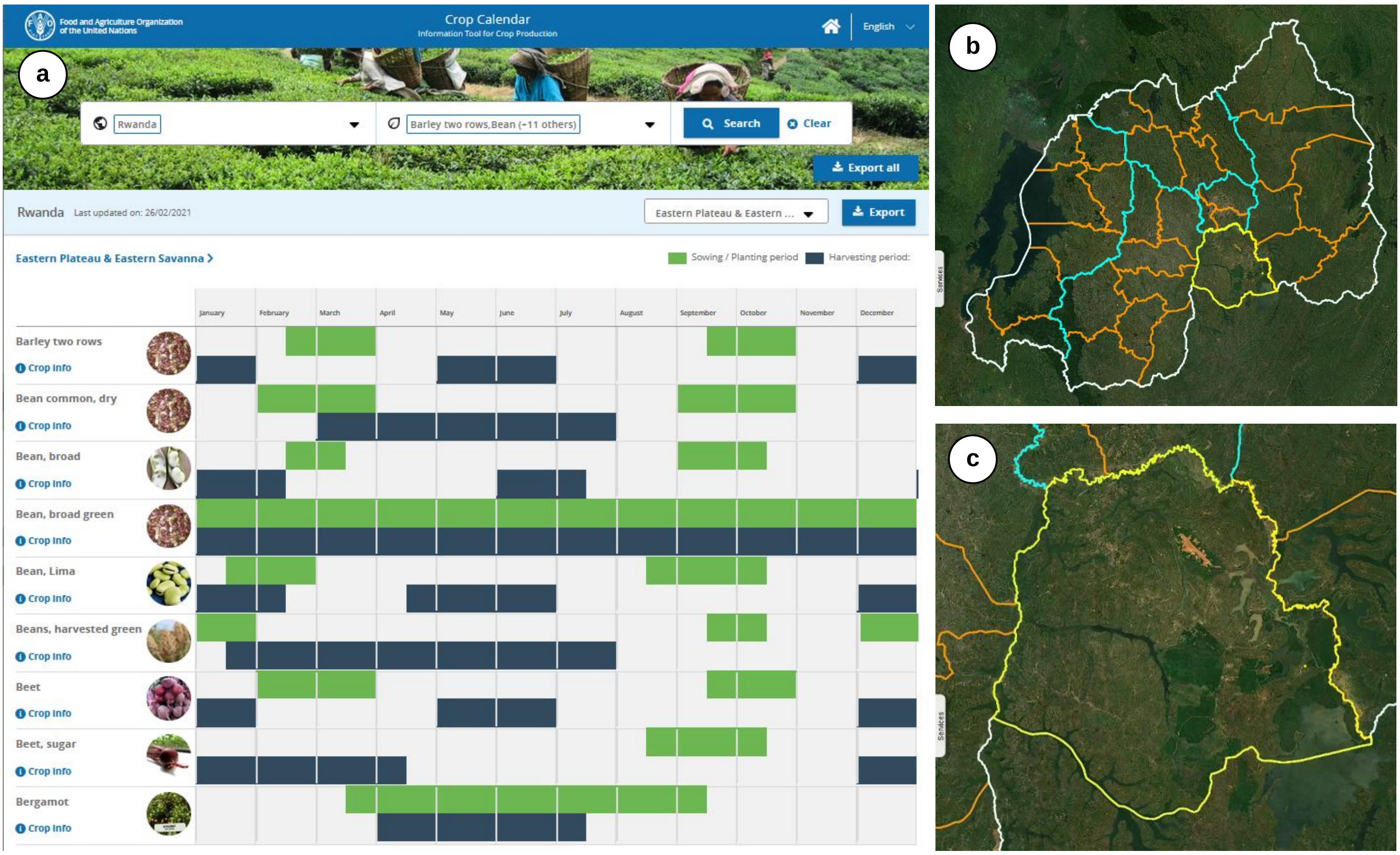


Fig.4: [Cropping calendar](#) of the "Eastern Plateau & Eastern Savanna" region (a) which contains the Bugesera district.



This example shows a plot that we assume to be of beans (to be confirmed). Fig.5a shows a very high-resolution image (Bing Map) and Fig.5b shows a Sentinel-2 image (observed on 19.03.2019) both cantered on the plot. Fig.6a and Fig.6b show the vegetation indicator (NDVI) and the soil moisture indicator (NDWI-SM) respectively.
The **NDVI** (Normalised Difference Vegetation Index) is among the most commonly used indicators to monitor the percentage of vegetation cover in an area.
The **NDWI-SM** (Normalised Difference Water Index - Soil Moisture) was developed by Gao (1996) and measures the liquid water contained in the vegetation cover.

$$NDVI = \frac{NIR - R}{NIR + R} \quad , \quad NDWI - SM = \frac{NIR - SWIR}{NIR + SWIR}$$

Where **NIR** is one of the two near infrared bands (band 8) of the MSI sensor of the Sentinel-2 satellite, **SWIR** is the first mid-infrared band (band 11) of Sentinel-2 and **R** is the red band (band 4) of Sentinel-2.

Agriculture Monitoring
Vegetation and moisture indicators

Fig.5: Plot in Bugesera district seen by Bing (a) and Sentinel-2 (19.03.2019).

left_view right_view

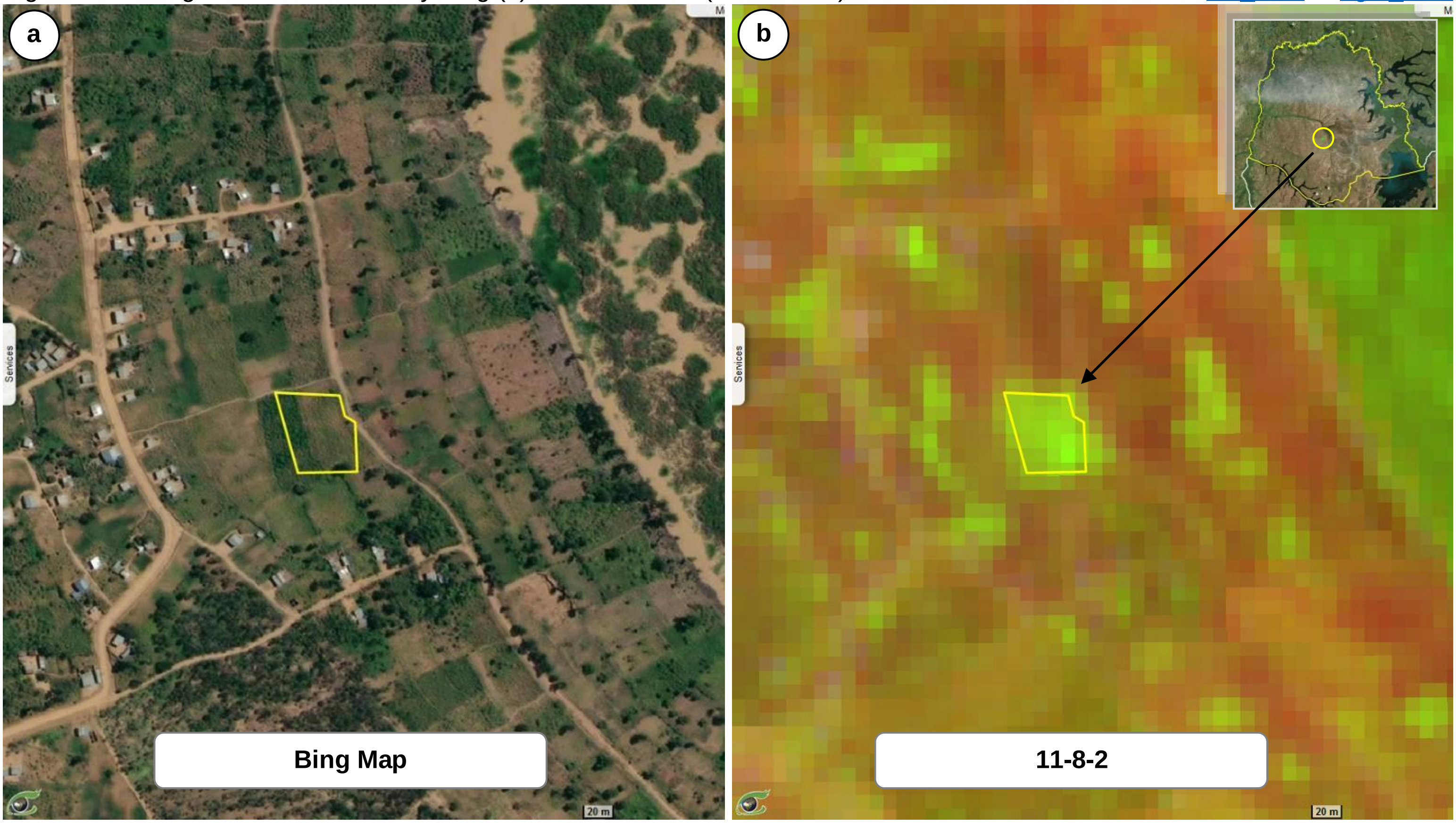


Fig.6: Vegetation (a) and soil moisture (b) indices.

left_view right_view

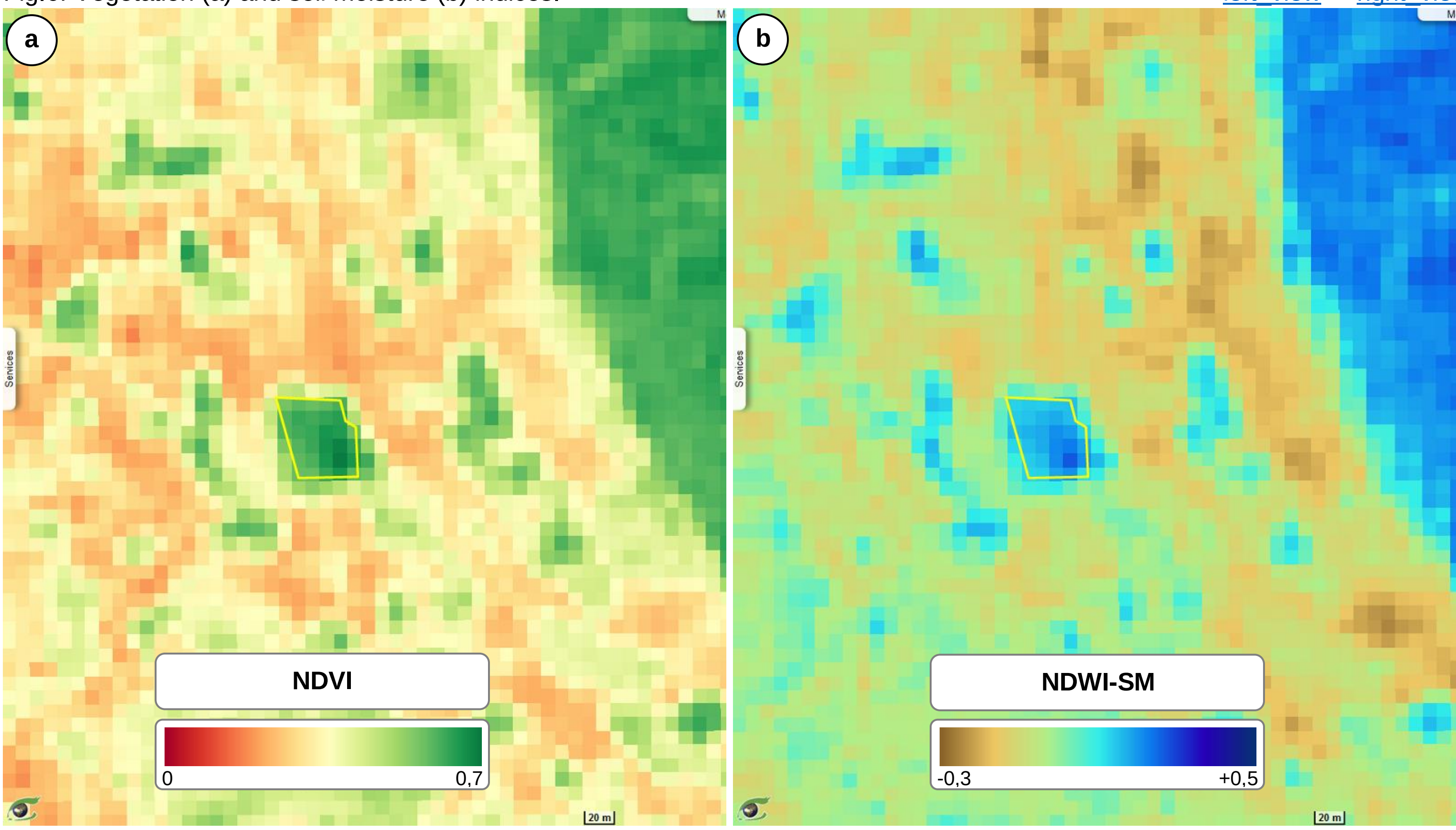


Fig.7 shows the calculated rainfall on this plot between 2019 and 2022. This figure shows two dry seasons and two rainy seasons (February and June and September to January).
The vegetation indicator also shows two growing seasons (Fig. 9). The first season is between February and May and the second between September and December.
Precipitation, soil moisture (Fig.8), and the vegetation indicator all show good agreement from 2019 to 2022. This suggests that this plot is rainfed. The vegetation indicator corresponds to the phenological cycle of beans (to be verified) as suggested by the cropping calendar (Fig.4a). This crop is characterized by a sowing period beginning in February, a growing period between March and April and a harvesting period between May and July for the first rainy season (season A). For the second rainy season (season B), the sowing period starts in September with a growing period between November and mid-December and a harvest period between mid-December and January.
The low NDVI during the year 2022 suggests a lower yield compared to other years.

Monitoring of agriculture
Time series analysis

Fig. 7: Time series between 2019 and 2022 of monthly rainfall on the plot in seasonal view.

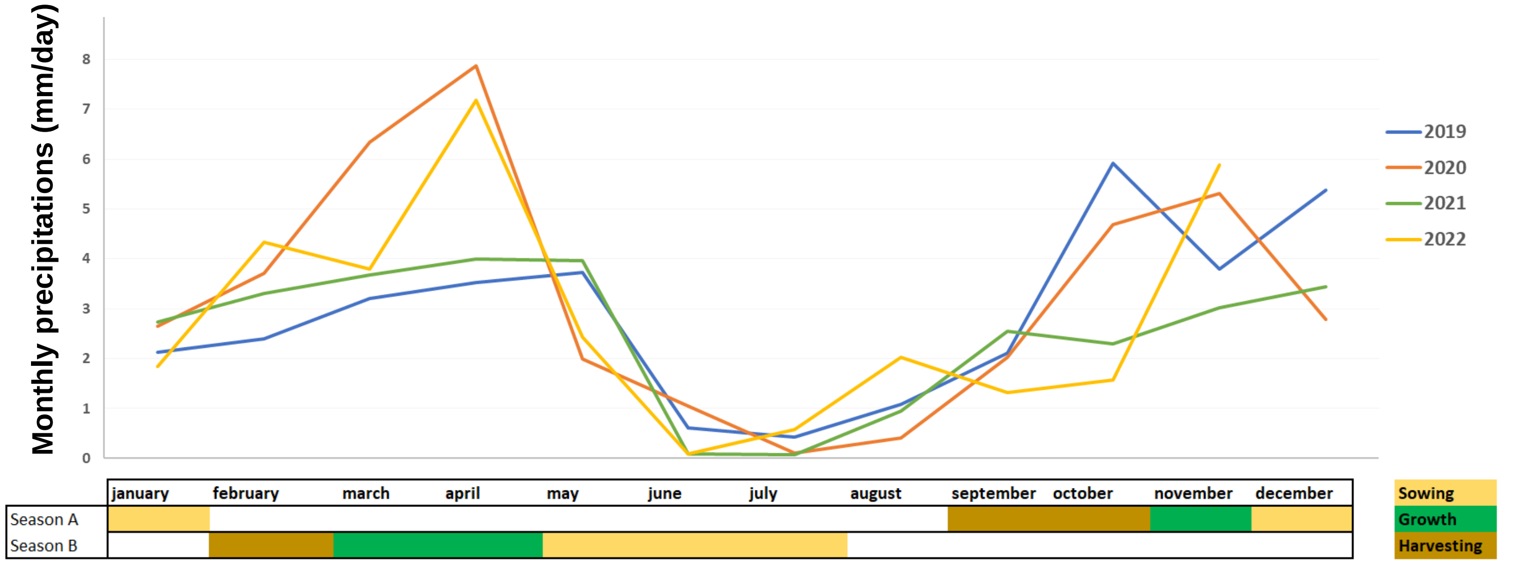


Fig.8: Time series between 2019 and 2022 of the soil moisture index (NDWI-SM) in seasonal view.

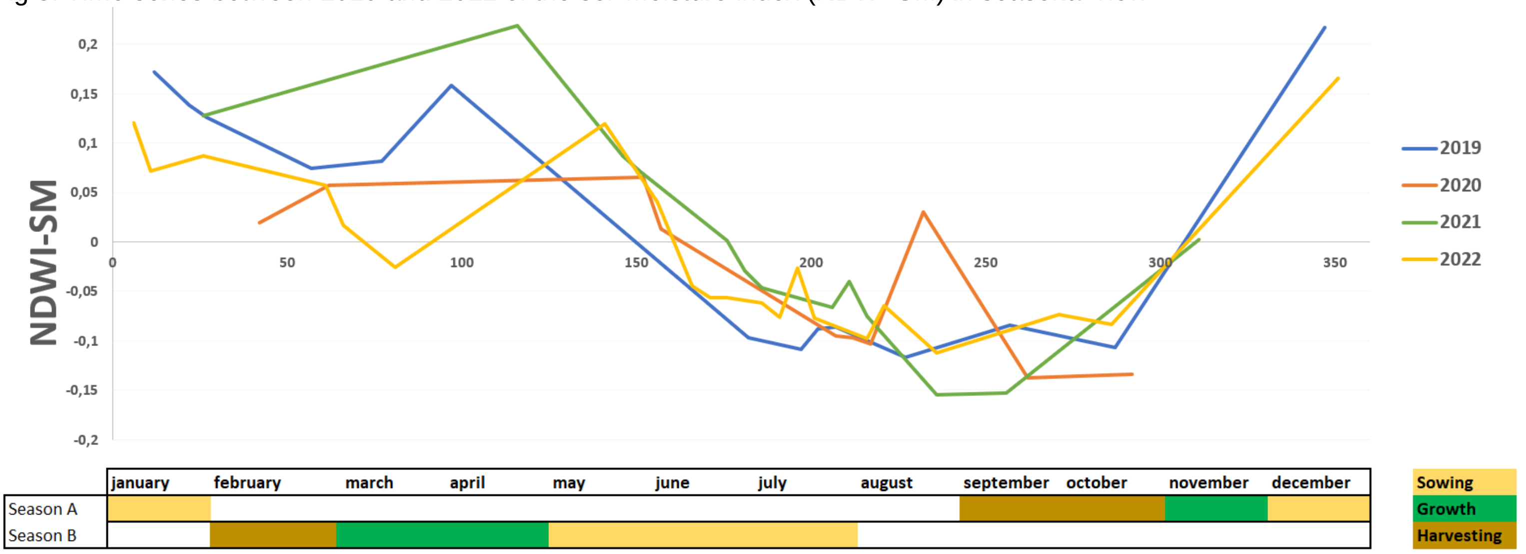
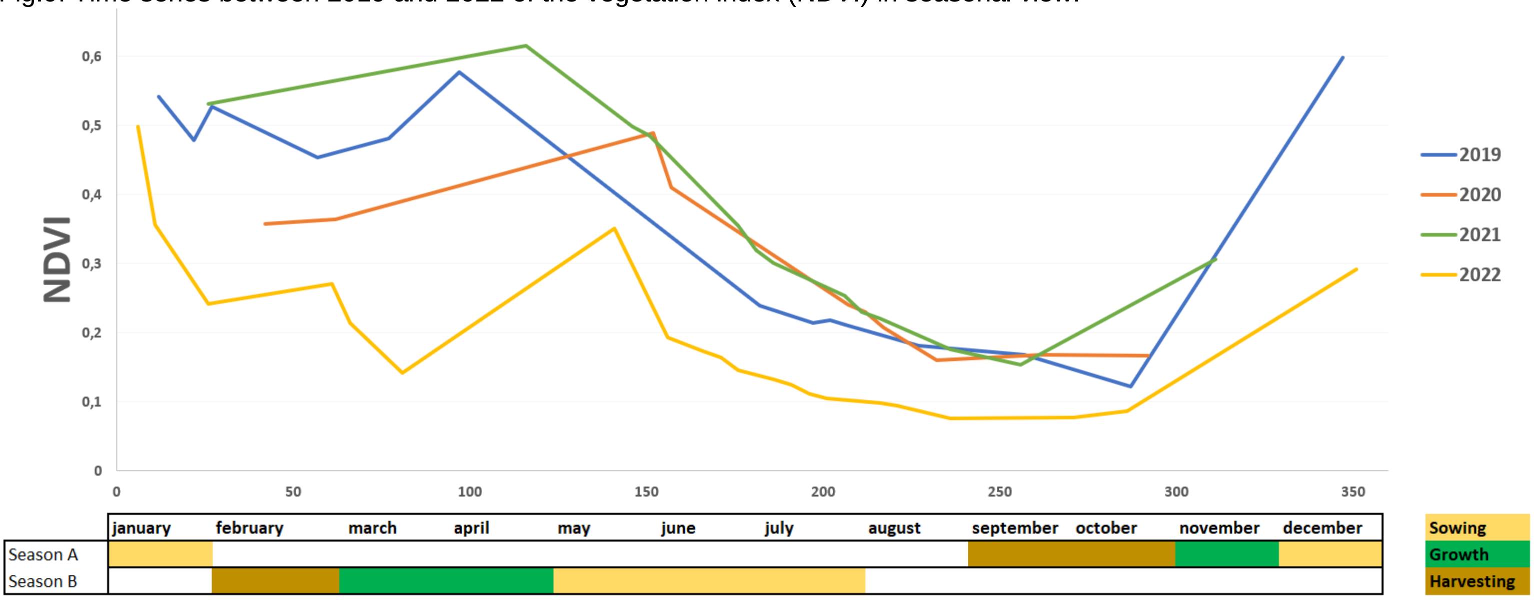


Fig.9: Time series between 2019 and 2022 of the vegetation index (NDVI) in seasonal view.



Risk of river flooding

South of Kigali

Rwanda is a country prone to a wide range of natural hazards, including riverine floods, which each year burden the most vulnerable communities and have adverse consequences in terms of economic losses and human lives. VisioTerra has implemented flood indicators calculated from Sentinel-1 radar data using Machine Learning methods based on a large number of learning plots. This methodology consists of two steps:

1. Separate the "Water" class from the other land cover classes (bare soil, low vegetation, high vegetation, savannah, built-up area...) detectable from Sentinel-1 radar data.
2. Detect the "Flood" change class, which corresponds to areas that are not usually covered by water but have been invaded by water at some point due to precipitation. Flood recurrence measures the probability of flooding.

The final product is a **flood hazard map**. The figures below show an example of river flooding that occurred south of Kigali on 11/21/2022. Sentinel-1 radar images are acquired every 12 days (for a single satellite) or every 6 days (for the constellation of two Sentinel-1 satellites). Since the radar signal passes through the clouds, the regularity of these observations is guaranteed. For each new image (Fig.11), the difference between the pixels classified as "water" and those of the previous image (Fig.10) is calculated. This difference produces an additional occurrence of the "flood" class (Fig.12).

Flooding in this area is due to Kigali's geographical location and topographical features (Fig. 13), combined with the lack of drainage infrastructure and solutions to increase infiltration and slow down runoff, exposing the city to frequent flooding and landslides (World Bank).

Fig.10: Sentinel-1 image acquired before river flooding on November 21, 2022 10km south of Kigali. 2D view

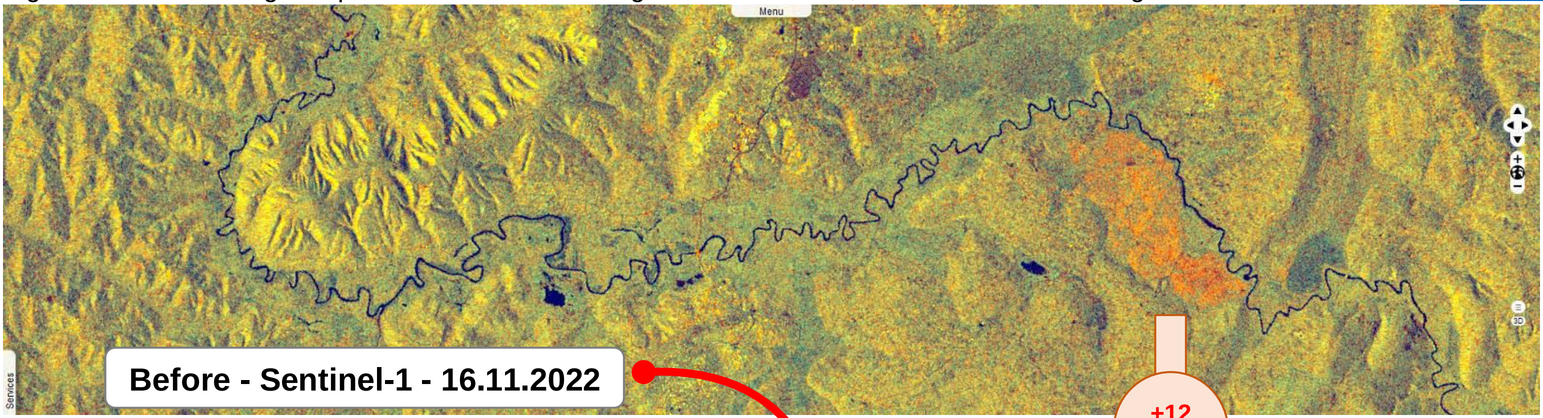


Fig.11: Sentinel-1 image acquired after the river floods. 2D view animation

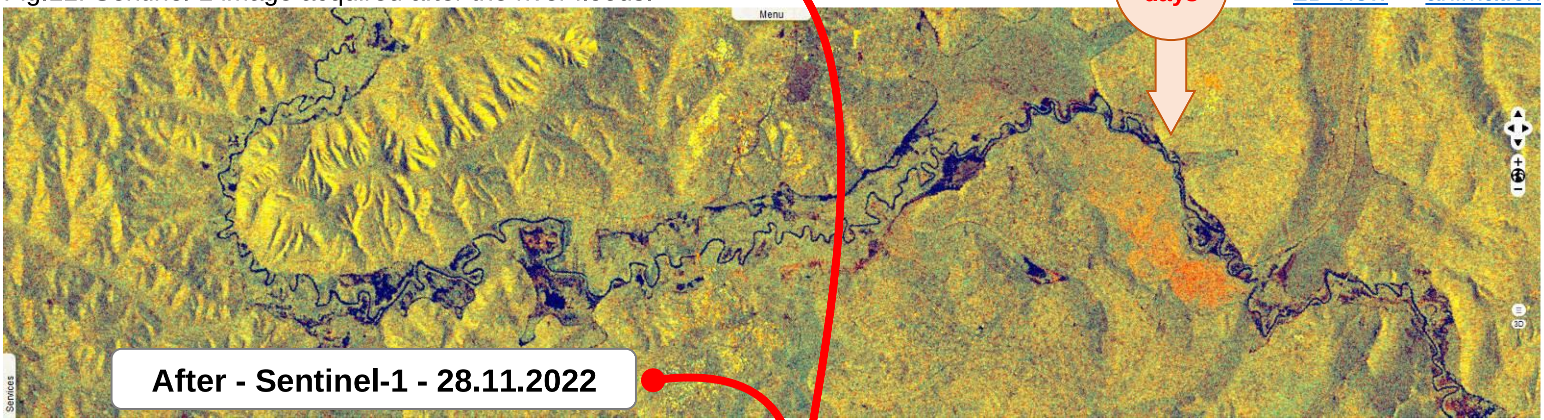


Fig.12: Flooded areas (red) superimposed on an OSM background 2D view

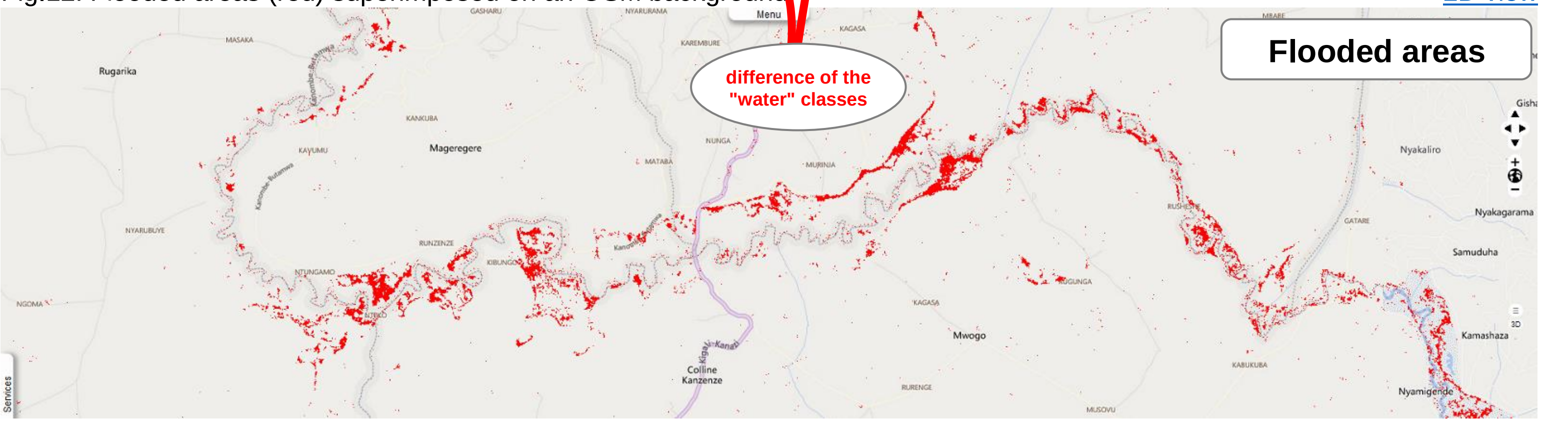
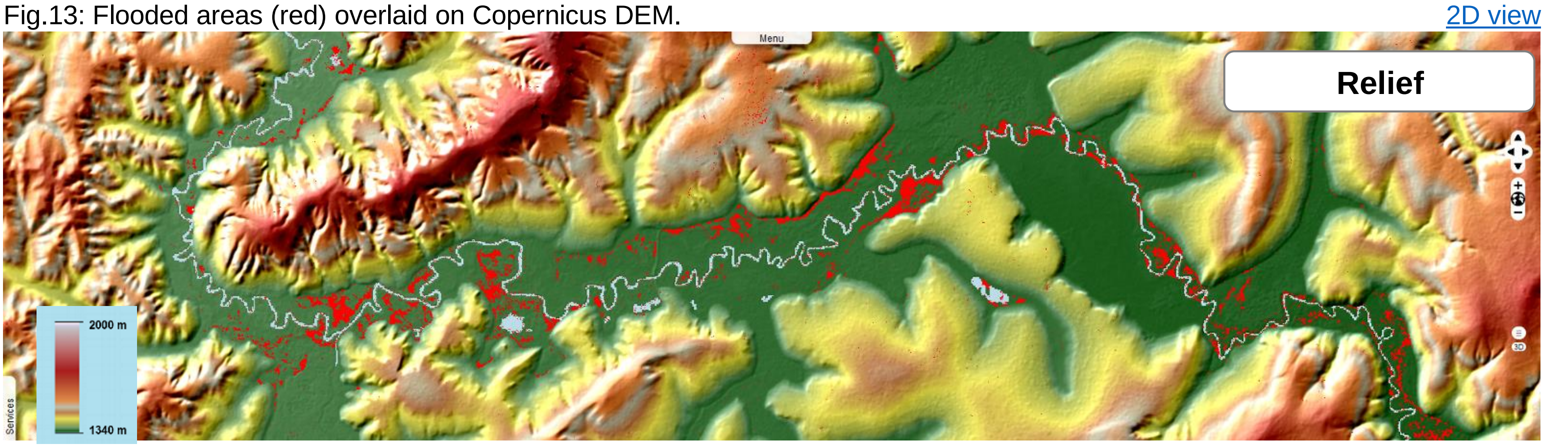


Fig.13: Flooded areas (red) overlaid on Copernicus DEM. 2D view



In addition to monitoring agriculture and natural hazards such as river flooding, VisioTerra also provides geoservices for the detection, monitoring, and interactive visualization of burned area and active fire indicators.

Fig.14a shows a Sentinel-2 image that exploits the spectral band richness of its multispectral MSI instrument. Here, bands 11, 8 and 2 correspond to the shortwave-infrared, near infrared and blue. These three bands 11, 8, 2 have been assigned to the red, green and blue planes respectively.

The Sentinel-2 tile (Fig.14a) was acquired in the dry season on July 6, 2022. Burned areas occurring southwest of Akagera National Park are automatically detected and rendered in red (Fig.14b).

Fig.15 shows another example of automatically detected burned areas north of Akagera National Park.

The burned area indicator is calculated from Sentinel-2 optical data using an algorithm derived from a classification analysis using machine learning methods.

Burned areas

Akagera National Park

Fig.14: Sentinel-2B image acquired on 21-01-2019 (a) and the automatically detected burned areas (b). animation

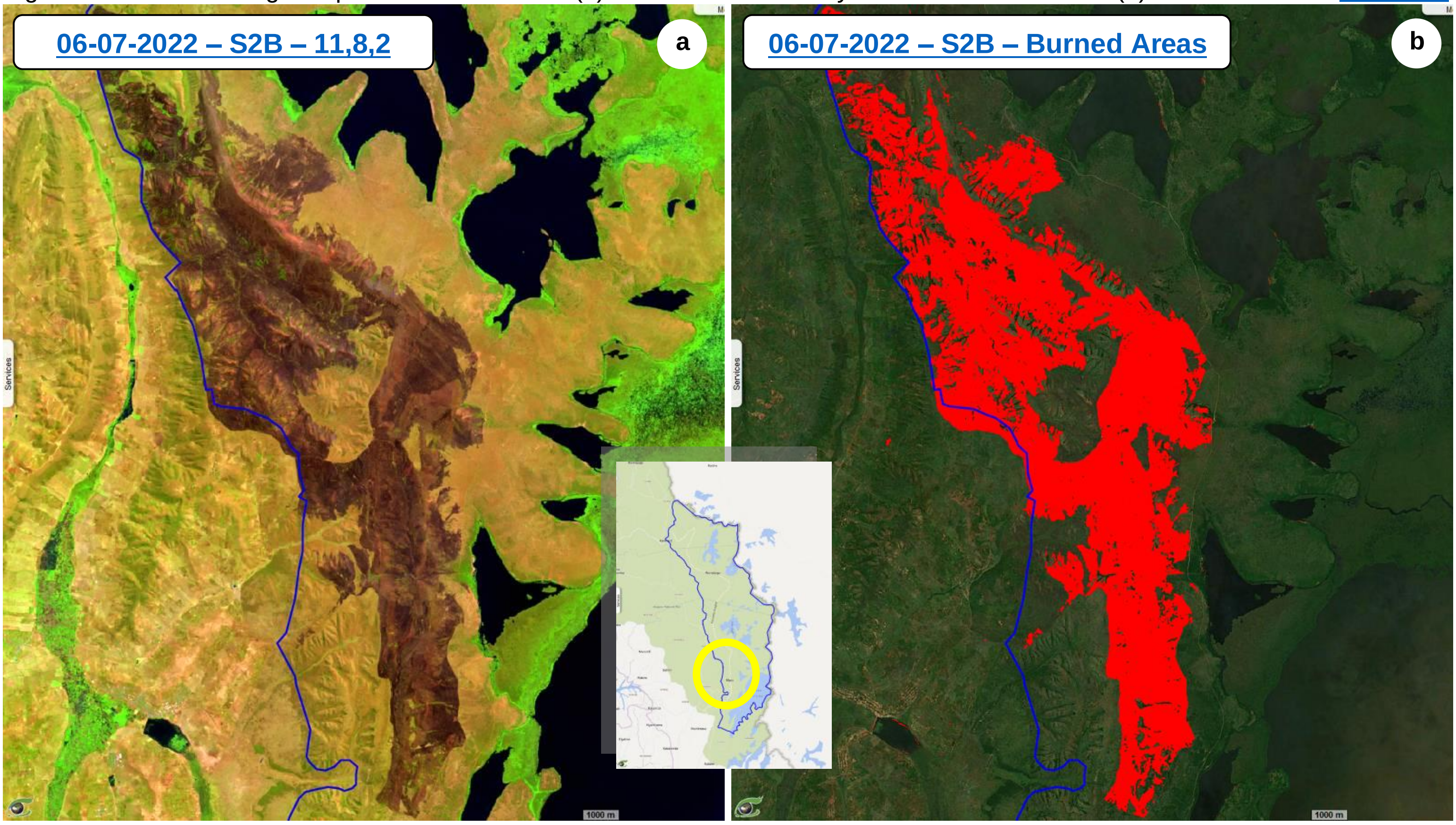


Fig.15: Zoomed view of fig.23.a (a) and automatically detected burnt areas (b). animation

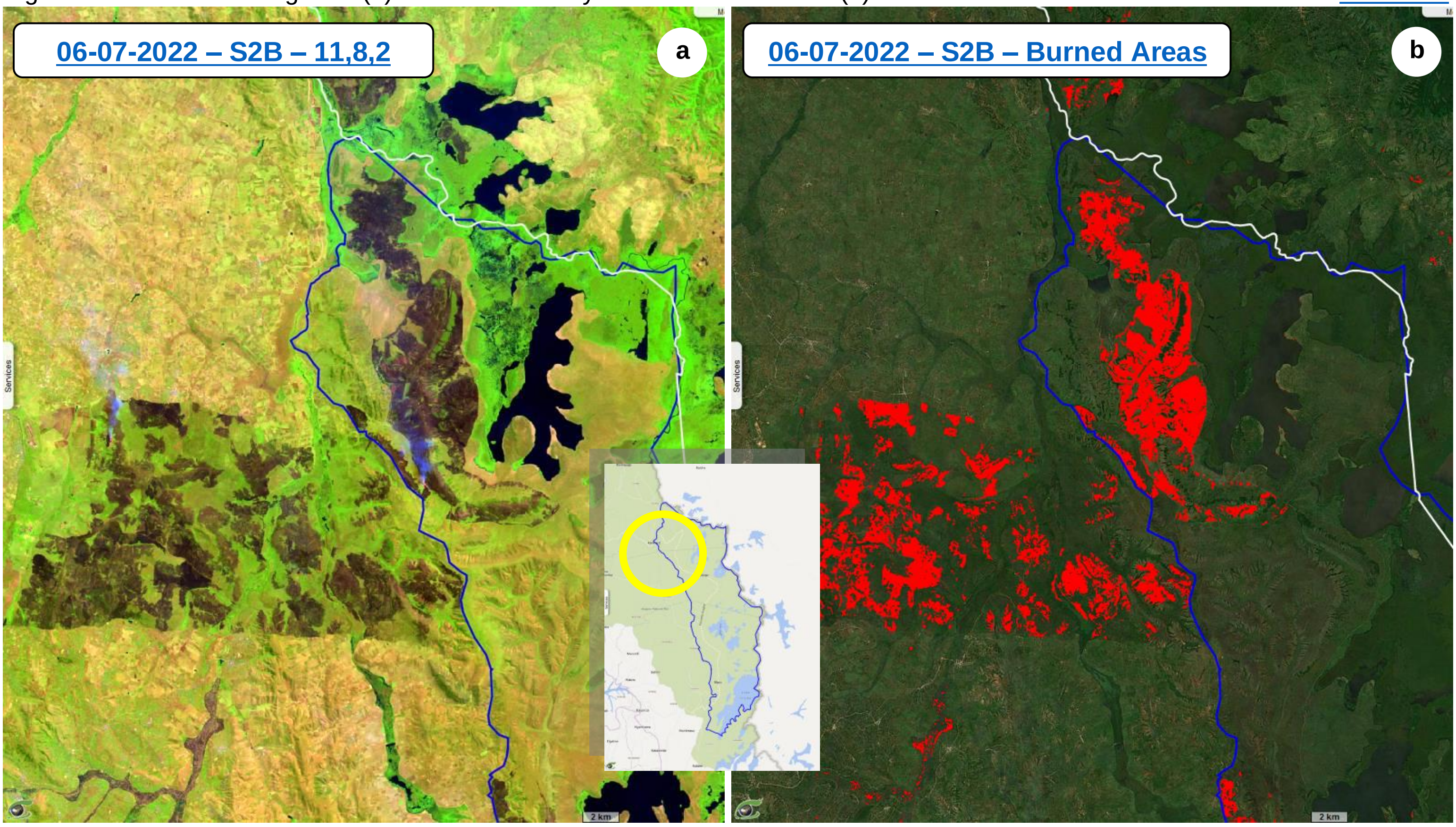


Fig.16 shows a Sentinel-2 image acquired on July 6, 2022 in colour composition 11,8,2 (Fig.16a) and in colour composition 12,11,2 (Fig.16b). Both coloured compositions show active fire fronts. Fig.16c shows the result of active fires detected automatically for the same date, rendered in red.

The active fire indicator is computed from Sentinel-2 optical data using the "Burned Area Index for Sentinel-2" (BAIS2)

$$BAIS2 = \left(1 - \sqrt{\frac{B06 * B07 * B8A}{B4}}\right) * \left(\frac{B12 - B8A}{\sqrt{B12 + B8A}} + 1\right)$$

Active fires

Akagera National

Fig.16: Sentinel-2B image acquired on 06-07-2022 (a, b) and automatically detected active fires (c). animation

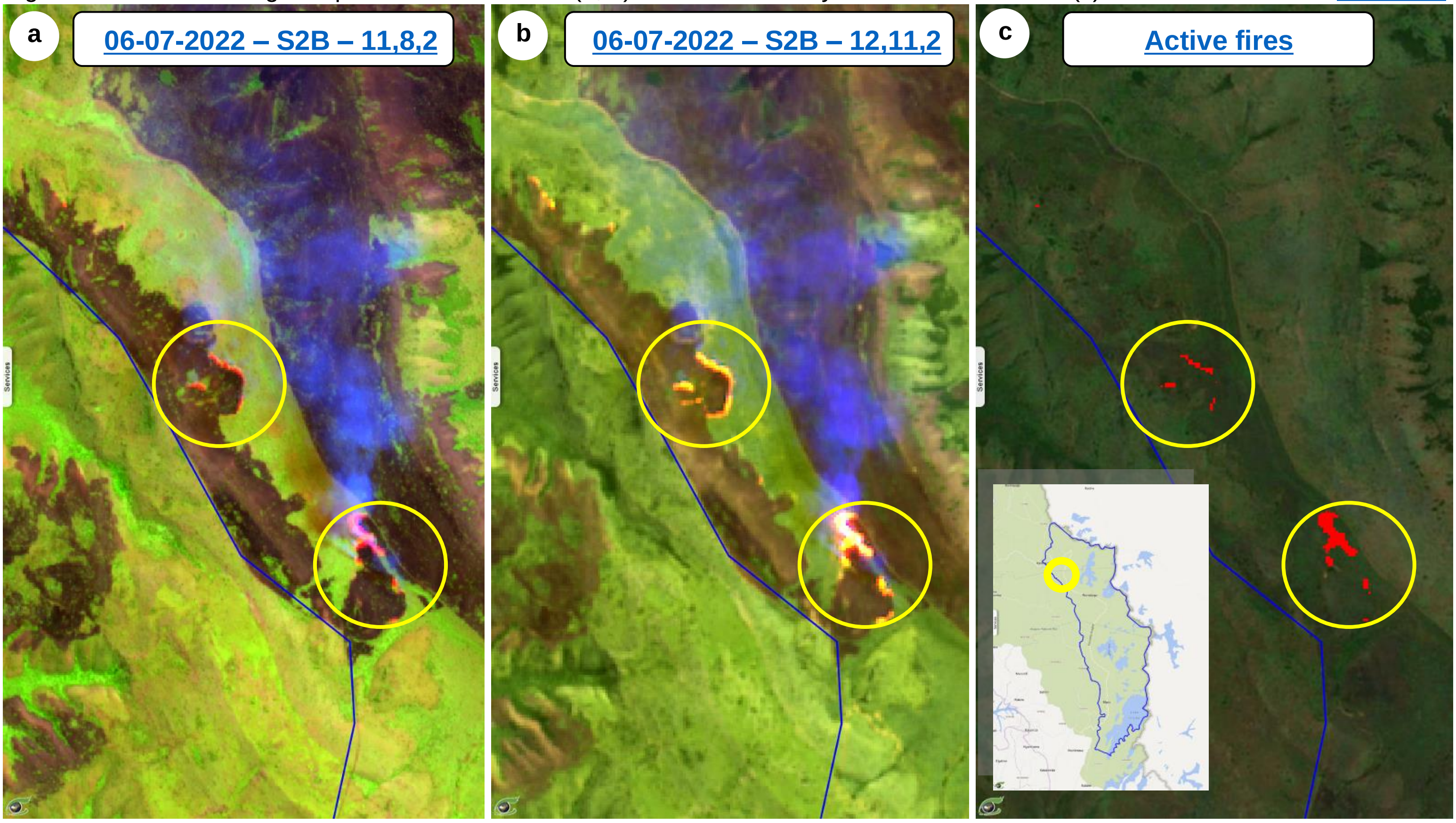
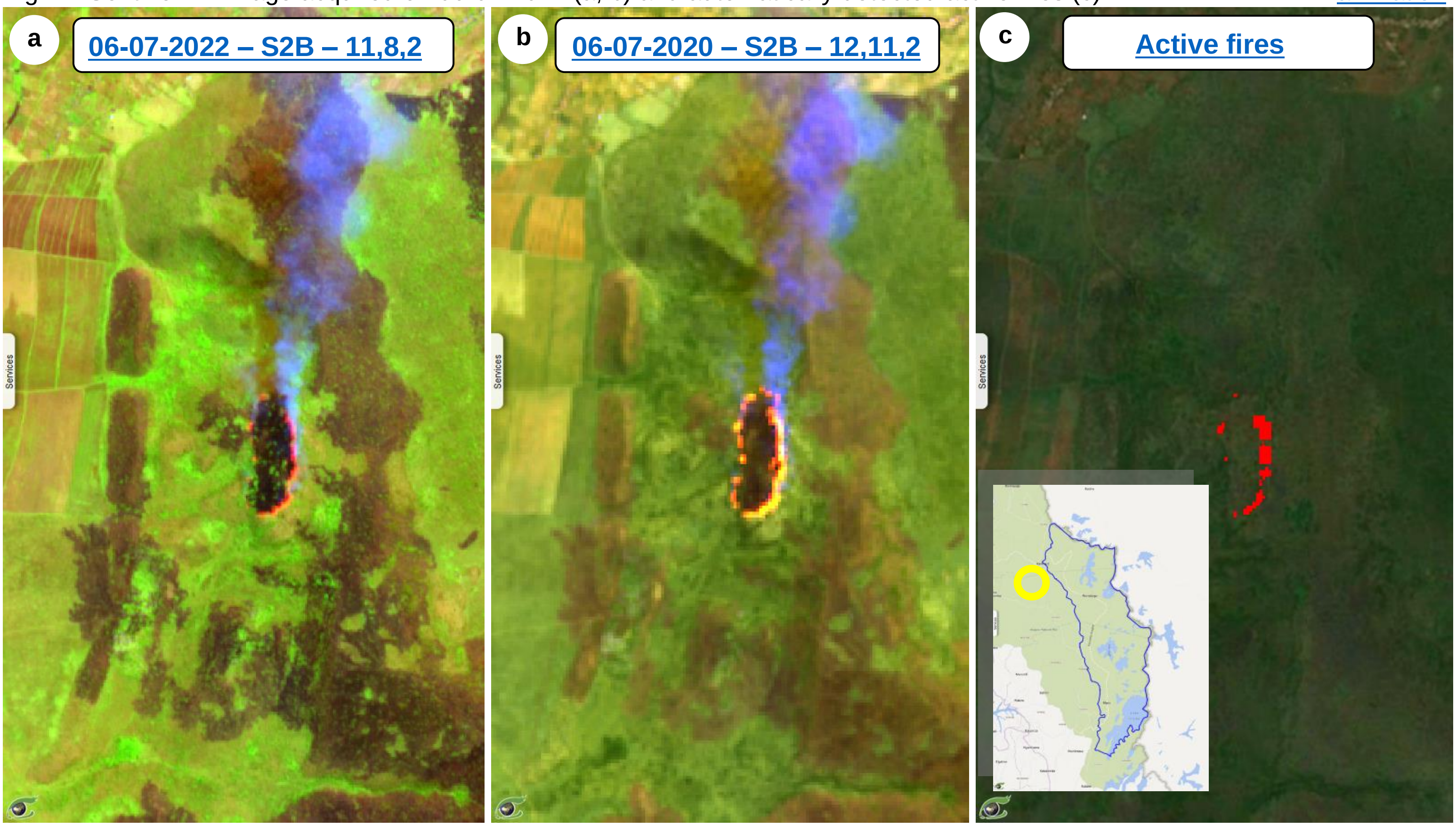


Fig.17: Sentinel-2B image acquired on 06-07-2022 (a, b) and automatically detected active fires (c). animation



The ICESat-2 (Ice, Cloud, and Elevation Satellite) satellite carries an instrument called ATLAS (Advanced Topographic Laser Altimeter System), a laser altimeter that allows to measure with high accuracy the different surface variations.

The GEDI (Global Ecosystems Dynamics Investigation Lidar) also uses laser technology to produce elevation profiles of the Earth.

Fig.18 and 19 show for example 2 altimetry profiles, one from GEDI (24/08/2021, with green contours) and one from ICESat (07/03/2022, with red contours). The two acquisitions are spaced 7 months apart and no significant changes in lake level are noted.

VisioTerra will develop in 2023 a "virtual water level station" tool using data from several altimetry satellites as well as LiDAR data from satellites and the international space station.

Spatial Altimetry
Lake Kivu water level

Altimetry profiles from GEDI and ICESat-2

Fig.18: Two altimetric profiles acquired on 24/08/2021 and 07/03/2022 on Lake Kivu and S1 scenes from December 2021.3D_view

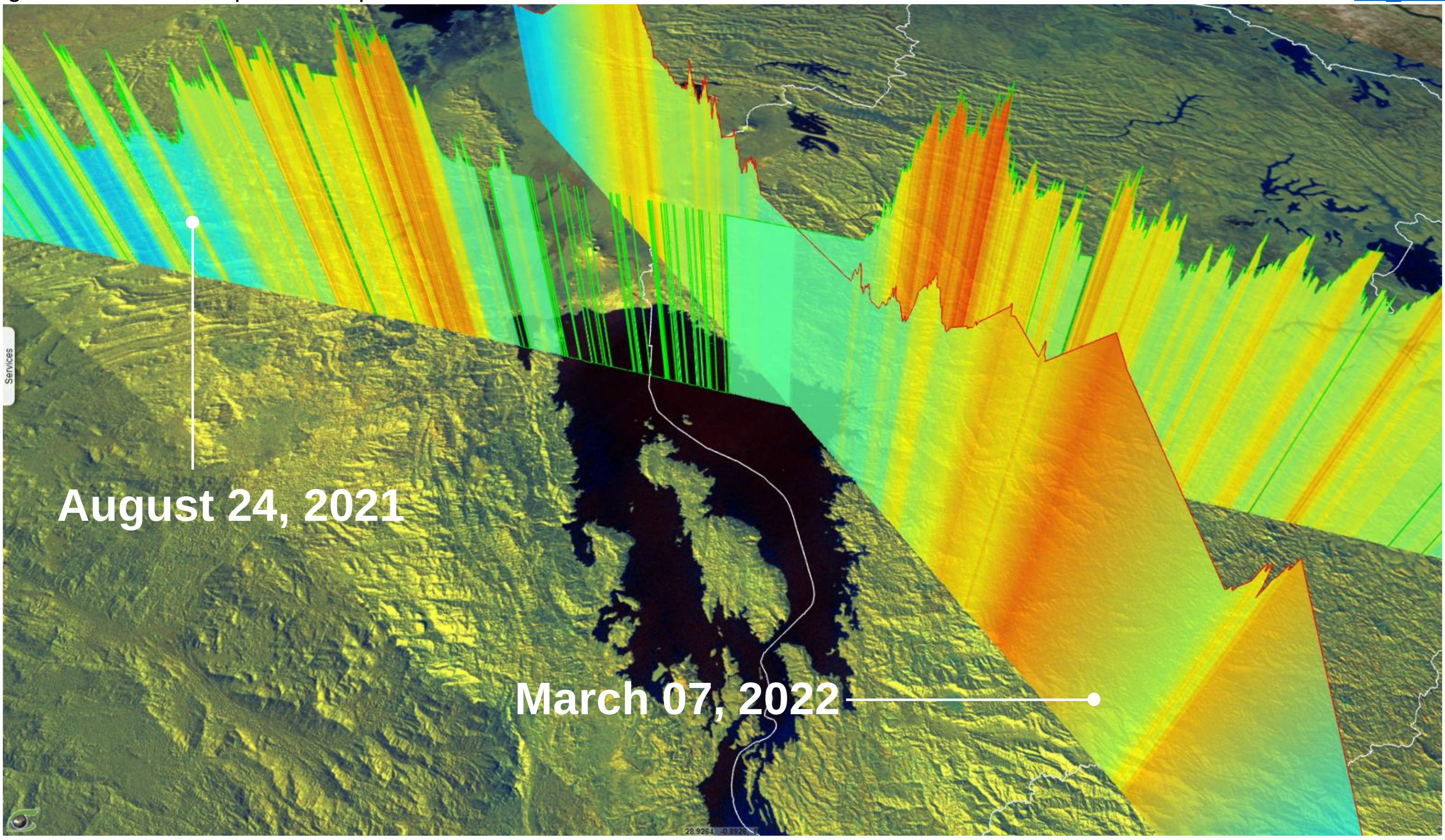


Fig.19: Two altimetric profiles acquired on 24/08/2021 and 07/03/2022 on Lake Kivu and S1 scenes from December 2021.3D view