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Advanced Sentinel-1 Analysis Ready Data for Africa (ESA EO4SD: SAR-4-Africa)

D5 - Final Report

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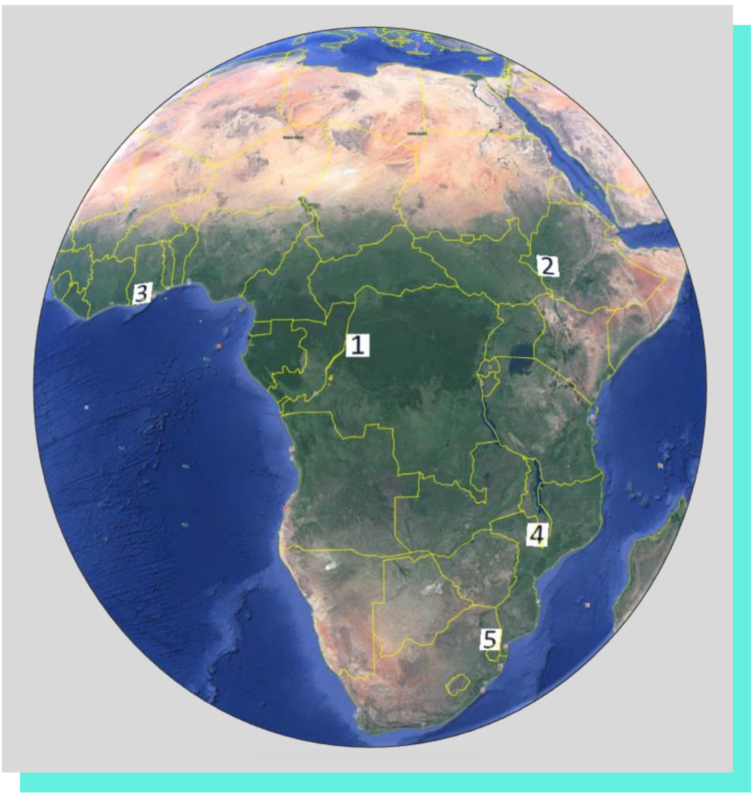

REPORT 3 – 2020

NORCE CLIMATE

Project title:	Advanced Sentinel-1 Analysis Ready Data for Africa
Project number:	101542
Institution:	NORCE – Norwegian Research Centre AS
Client/s:	ESA EO Science for Society EOEP-5 BLOCK 4, contract No. 4000125675/18/I-NB
Classification:	Public
Report no.:	3-2020
ISBN:	978-82-8408-079-6
Number of pages:	78
Publication month:	April 2020
Citation:	Haarpaintner, J., H. Hindberg, T.G. Yitayew, I. Arntzen, and R. Main. 2020. Advanced Sentinel-1 Analysis Ready Data for Africa (ESA EO4SD: SAR-4-Africa), D5 – Final Report, *ESA EO4SD project "SAR-4-Africa", NORCE Klima report nr. 3-2020, April 2020.*
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Sentinel-1 (S1) of the European Copernicus Program provide consistent global cloud-independent synthetic aperture radar (SAR) imagery. However, there is a strong reluctance to use SAR data because of its complexity. Combined with the vast amount of data, S1 is out of reach for many stakeholders that could benefit from its monitoring potential. This project aims to overcome these technical challenges and subjective reluctance by providing attractive, easy-to-use "Advanced Sentinel-1 Analysis Ready Data" (ASARD) imagery. The main objective is to incite especially African users to include S1 data in their operations and thereby support the UN Sustainable Development Goals.

Revisions

Rev.	Date	Author	Checked by	Approved by	Reason for revision
V 0.0	20.03.2020	J. Haarpaintner			Draft
V 1.0	16.04.2020	J. Haarpaintner	H.Hindberg		review

Tromsø, 16.04.2020

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Abstract

Sentinel-1 is the operational C-band synthetic aperture radar (SAR) satellite mission of the European Copernicus Program providing weather and sunlight independent radar imagery of the whole Earth on a consistent 12-day repeat cycle. However, there is a strong reluctance to use SAR data because of its complexity in regard to sensor-specific noise, topographic effects, (pre-)processing requirements, and unfamiliar appearance for interpretation. These technical and human capacity requirements as well as the vast amount of data makes it out of reach for most non-technical user groups that could benefit from its monitoring potential in general and especially in persistently cloud-covered areas as the tropics. This project aims to overcome these technical challenges and subjective reluctance by providing attractive, easy-to-use "Advanced Sentinel-1 Analysis Ready Data" (ASARD) image products with a focus on African users. Such imagery needs to be timely accessible, visually attractive and easier interpretable without losing essential information for the users monitoring needs and potential further numerical analysis. To a large extent, such information can be conserved by statistical analysis of dense time series and providing noise-reduced mosaics instead of single satellite images. By a demand-driven approach and user assessment involving five African countries (D.R. Congo, Ethiopia, Ghana, Malawi and South Africa), we standardize such ASARD products to a set of monthly and yearly averaged Sentinel-1 mosaic [RGB = [VV,VH,NDI] and yearly statistical analysis images representing, mean, median, variance, minimum, maximum, number of acquisitions and an accumulated SAR shadow/overlay mask for each SAR polarization. The aim of providing such easy-to-use imagery is to boost the use of Sentinel-1 data for operations to a wider user community, including the non-technical community and policy makers, in order to support the United Nations Sustainable Development Goals. The user's ASARD service and product assessments showed high general satisfaction; products generally exceeded the quality of their in-house processed S1 data, are easy to understand and use and satisfy general operational requirements. The users concluded that it would be highly beneficially if such ASARD data would be available operationally on a national and global scale. Finally, the ASARD processing line was successfully tested to run in a cloud environment on CreoDIAS, one of Copernicus' Data and Information Access Services. Ghana data was also ingested directly in the African Regional Data Cube (ARDC).

1. Introduction

1.1. Scope of this delivery

This delivery is the final project report of the ESA EO Science for Society EOEP-5 BLOCK 4 project "Advanced Sentinel-1 Analysis Ready Data for Africa (SAR-4-Africa)". It describes the whole project including a description of the data, user and test areas, the processing methodology, the Advanced Sentinel-1 Analysis Ready Data (ASARD) products delivered to the users, some examples of applications, a short description of the test processing in the cloud on CreoDIAS and the users service and products assessment.

1.2. Project Objective

The objective of this project is to develop and provide user-driven advanced high-level Sentinel-1 Analysis Ready Data with the goal to overcome the subjective threshold and reluctance of the wider community to use SAR because of its specific characteristics, like speckle noise, topographic and ground humidity effect and general unfamiliar appearance and at the same time reduce the overall data quantity. We want to incite especially African users to include Sentinel-1 data in their operations and analysis.

1.3. Project Summary

Sentinel-1 is the operational C-band synthetic aperture radar (SAR) satellite mission of the European Copernicus Program providing weather and sunlight independent radar imagery of the whole Earth on a consistent 12-day repeat cycle. However, there is a strong reluctance to use SAR data because of its complexity in regard to sensor-specific noise, topographic effects, (pre-)processing requirements, and unfamiliar appearance for interpretation. These technical and human capacity requirements as well as the vast amount of data makes it out of reach for most non-technical user groups that could benefit from its monitoring potential in general and especially in persistently cloud-covered areas as the tropics. This project aims to overcome these technical challenges and subjective reluctance by providing attractive, easy-to-use "Advanced Sentinel-1 Analysis Ready Data" (ASARD) image products with a focus on African users. Such imagery needs to be timely accessible, visually attractive and easier interpretable without losing essential information for the users monitoring needs and potential further numerical analysis. To a large extent, such information can be conserved by statistical analysis of dense time series and providing noise-reduced mosaics instead of single satellite images. By a demand-driven approach and user assessment involving five African countries (D.R. Congo, Ethiopia, Ghana, Malawi and South Africa), we standardize such ASARD products to a set of monthly and yearly averaged Sentinel-1 mosaic [RGB = [VV,VH,NDI] and yearly statistical analysis images representing, mean, median, variance, minimum, maximum, number of acquisitions and an accumulated SAR shadow/overlay mask for each SAR polarization. The aim of providing such easy-to-use imagery is to boost the use of Sentinel-1 data for operations to a wider user community, including the non-technical community and policy makers, in order to support the United

Nations Sustainable Development Goals. The user's ASARD service and product assessments showed high general satisfaction; products generally exceeded the quality of their in-house processed S1 data, are easy to understand and use and satisfy general operational requirements. The users concluded that it would be highly beneficially if such ASARD data would be available operationally on a national and global scale. Finally, the ASARD processing line was successfully tested to run in the cloud environment on CreoDIAS, one of Copernicus' Data and Information Access Services. Ghana data was also ingested directly in the African Regional Data Cube (ARDC).

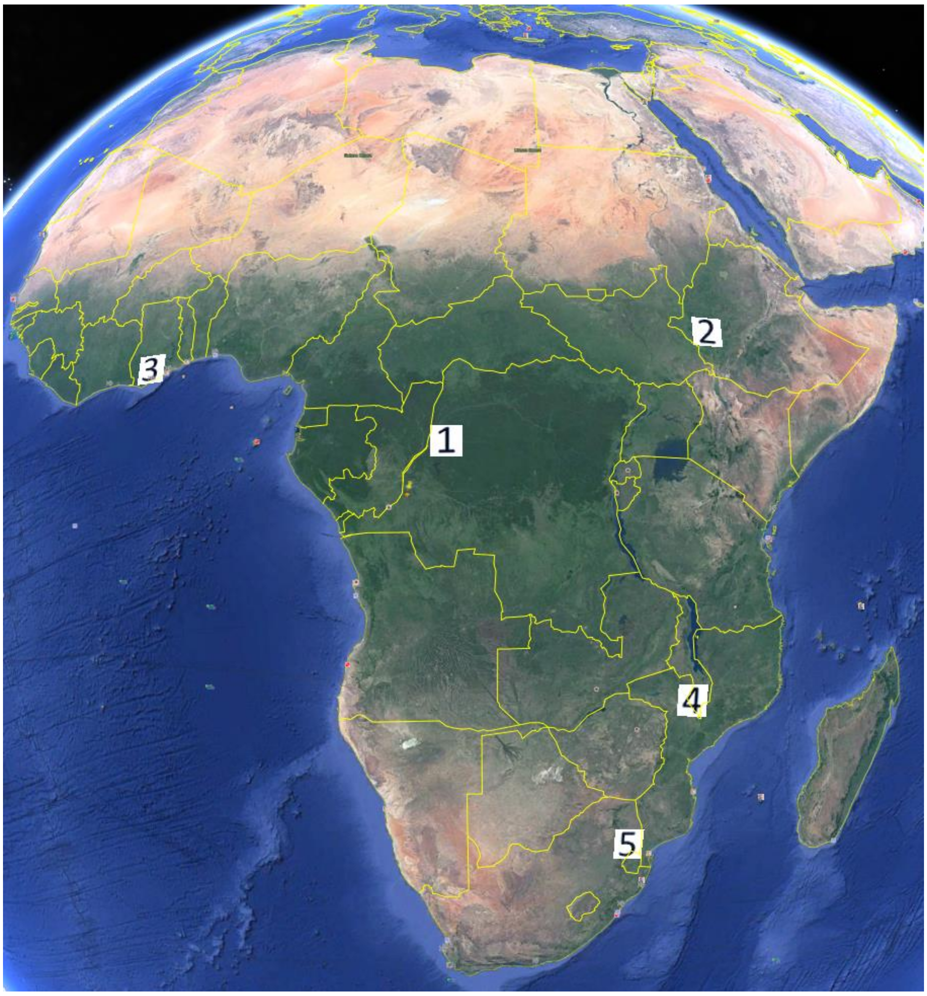


Figure 1. Location of the demonstration sites in five African countries: (1) Democratic Republic of Congo (DRC), (2) Ethiopia, (3) Ghana, (4) Malawi and (5) South Africa (SA); as specified by the Service Level Agreements.

1.4. Background

Historically for land application, synthetic aperture radar (SAR) satellite imagery has often been seen only as a compliment to optical remote sensing in cloud covered areas. There are several reasons for this: 1) the threshold of interpretation and understanding of SAR imagery is often perceived as very high to an untrained user, 2) the human capacity and technical capability in pre-processing SAR data has been out of reach without adequate, often expensive software, and technically-trained staff and 3) the availability of data has been too sparse and expensive for being used operationally for applications other than in (sub)-polar regions. This has especially been the case in developing countries. The Copernicus program, specifically the Sentinel-1A/B (S1) satellites, and recent international efforts opened for a new era of operational SAR application, data access and processing and overcome the challenges 2 and 3 above. Satellite open data cubes (ODC) [https://www.opendatacube.org/] are currently developed in several countries, including in Africa [http://www.data4sdgs.org/initiatives/africa-regional-data-cube], with the aim to provide analysis ready data (ARD) from both optical and SAR sensors. The combination of both optical and SAR generally improves the application results [Reiche et al., 2016]. However, for SAR data these ARD efforts generally aim to provide only pre-processed, i.e. radiometric, terrain and slope corrected and georeferenced, single SAR scenes or, at the best, yearly mosaics with questionable consistency and reduce little the subjective reluctance of using SAR data operationally. The purely vast quantity of single scenes therefore needs further processing in order to reduce the amount of data as well as to make the data more attractive and easier to interpret for untrained users.

In this project, we propose to develop and provide user-driven higher level Advanced Sentinel-1 ARD (ASARD) with the goal to overcome the subjective threshold and reluctance of the wider community to use SAR data because of its specific characteristics such as speckle noise, topographic and ground humidity effect and general unfamiliar appearance resulting from the unique side-looking acquisition geometry, and at the same time reduce the new overwhelming data quantity. We want to support especially African users to include Sentinel-1 data in their operations and analysis, hereby building a demand-driven approach to the data revolution in support of the Sustainable Development Goals (SDGs) [http://eohandbook.com/sdg/index.html]. Experience from several projects [f.e. Haarpaintner et al. 2018] and ODCs have shown that consistent, noise-reduced seasonal or monthly time-series as well as their statistical parameters correspond well to initial user requirements and application needs such as forest, land cover mapping and change detection for flood and forest loss detection. In addition, presented in the form of visual attractive mosaics they can also be interpreted by non-technical staff and decision makers. When processed to higher level products by applying temporal filtering, masking, corrections and combining times series, features that are hardly visible in single SAR scenes, become more obvious. For example, different vegetation features can be enhanced by using averaged SAR mosaics where the RGB (red, green, blue) layers are the co- and cross polarization channels and a normalized difference index (NDI), respectively. Moreover, other statistical parameters from time series analysis such as the minimum, maximum, and higher order statistics applied to the backscatter values can be represented in RGB, in order to visualize specific features of strong variability. Figure 2 shows an example of such representations, where rice paddies for example are clearly visible based on a statistical analysis over one year of data. We will demonstrate such ASARD products in 5 African countries with the aim to define a common standardization through user involvement. In the future, such ASARD products could be either provided operationally through Copernicus, f.e. implemented in open data cubes as standardized high-level products and/or provided as a service according to individual user requirements. This effort responds to the activity line 'EO for Sustainable Development'.

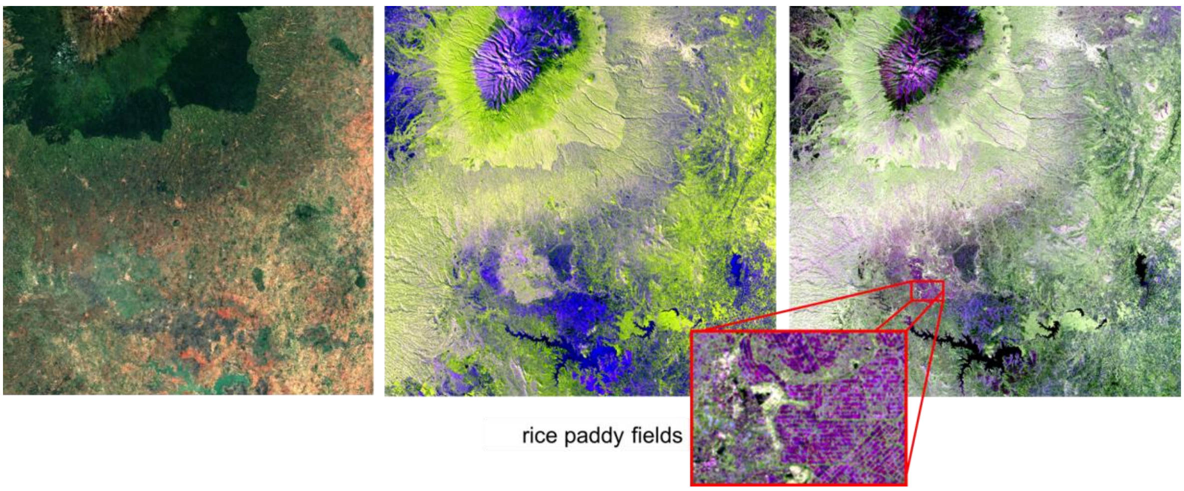


Figure 2. 1^0lat x 1^0lon area south-east of Mt. Kenia seen by (left) Sentinel-2 (https://s2maps.eu/), (middle) averaged S1 mosaic (RGB=[VV,VH,NDI=(VV-VH)/(VV+VH)]) and (right) S1 statistical composite (RGB=[VVmean,VVmin,VVmax]). Sentinel-1 data collected from Dec. 2014 to Sep. 2015.

1.5. Project work and processing logic

The project is organized in four work packages (WP 1-4), which address the scientific / technical objectives, shown in Figure 3, and WP 5 for the project management. The arrow from WP3 to WP1 symbolized the user assessment of a first deliver, in order to provide feedback and potentially input and improvement for the final delivery of the complete S1 data archive. Figure 4 shows the technical workflow in these work packages. WP1 (red) is the user interaction that provide feedback and assess the delivered products. WP2 handles the development of the processing line of the ASARD products. WP3 is responsible for the processing of the products to be delivered. Finally, the processing line developed in IDL is translated in python in order to test the processing in a cloud environment in WP4.

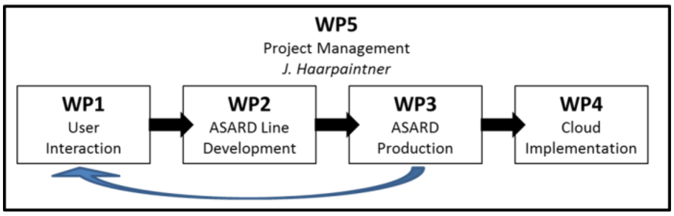


Figure 3. Work breakdown structure of the project.

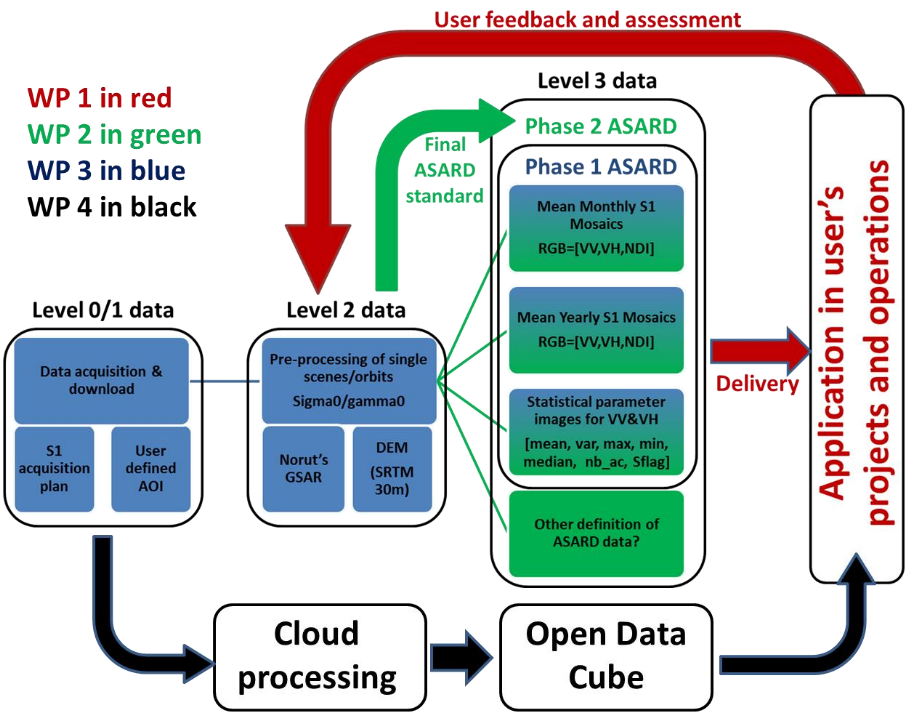


Figure 4. Proposed work logic diagram including the technical steps.

2. Users, demonstration sites and Sentinel-1 data acquisition

2.1. Users

The proposal involved originally four end users covering AOIs from five African countries, distributed over the continent: Democratic Republic of Congo (DRC), Ethiopia, Ghana, Malawi and South Africa (SA). One end user, the Committee on Earth Observation Satellites (CEOS) represented by NASA's CEOS Systems Engineering Office (SEO), participates as a link to ingest the results into the ARDC. All users are institutions working with satellite data on a daily basis and have already or are in the process to implement SAR data in their operations. A fifth user, the Centre for Remote Sensing and Geographic Information Services (CERSGIS) in Ghana was introduced in the project via CEOS. A short description of the end users follows:

Observatoire Satellital des Forêts d'Afrique Centrale (OSFAC), Democratic Republic of Congo (DRC)

OSFAC was launched as the GOFC-GOLD network for Central Africa under the Global Terrestrial Observing System (GTOS) and was legally established as a Congolese NGO in 2005 dedicated to raising awareness about satellite data and their potential applications. Its primary objective is to support the management of natural resources and promote sustainable development by producing reliable land cover products, distributing satellite data, building capacity and providing technical assistance to implementing partners. OSFAC proposed demonstration site [1] in Figure 1 in DRC.

Ethiopian Space Science and Technology Institute (ESSTI), Ethiopia

The main objectives of Ethiopian Space Science and Technology Institute(ESSTI) are to enable the country to fully exploit multidimensional uses of space science and technologies; to produce demand based knowledgeable, skilled and attitudinally matured professionals in the field of aerospace science that enable the country to become internationally competitive in the sector; to develop and strengthen space science and technology infrastructures to speed up space science and technology development in the country; and enable the country to be robust contributor for the development of aerospace science and technology. ESSTI proposed demonstration site [2] in Figure 1 in DRC.

The Council for Scientific and Industrial Research (CSIR), South Africa (SA)

CSIR is one of the leading scientific and technology research, development and implementation organizations in Africa. Its mandate is to perform multidisciplinary applied research and technological innovation in close association with national stakeholders and end-users with the aim of contributing to industrial development and improving the quality of life of South African. CSIR was interested and asked for two demonstration sites, one in Malawi ([4] in Figure 1), and one in South Africa ([5] in Figure 1).

NASA's Committee on Earth Observation Satellites (CEOS) Systems Engineering Office (NASA-SEO)

The original function of CEOS was to coordinate and harmonize Earth observations to make it easier for the user community to access and use data. CEOS initially focused on interoperability, common data formats, the inter-calibration of instruments, and common validation and inter-comparison of products. The NASA-SEO team is currently deploying National and Regional Data Cubes and specifically the ARDC with 5 countries in Africa, including Ghana. NASA-SEO proposed site [3] in Figure 1 in Ghana and assesses the Ghana ASARD products together with their partners in Ghana. CEOS also provide the capacity to ingest the Ghana ASARD products in the ARDC.

The Centre for Remote Sensing and Geographic Information Services (CERSGIS)

started as a Remote Sensing Application Laboratory in 1990 at the Department of Geography and Resource Development, University of Ghana, Legon. The Remote Sensing Application Unit developed its staff capacity to provide contractual Remote Sensing and GIS services to its clients. In 2000, the status of the Remote Sensing Application Unit changed to Centre for Remote Sensing and Geographic Information Services (CERSGIS). The change of name meant change of strategic focus from a funded establishment to a self-sustaining Non-profit Organization that focused on providing geographic information and remote sensing services for sustainable development planning and management of resources. CERSGIS joined during the project and assessed the Ghana ASARD products.

2.2. Demonstration Sites

The project has processed data over five demonstration sites with their locations shown in Figure 1 and exact UTM zones and coordinate limits listed in Table 1. The areas situated in DRC, Ethiopia, Ghana, Malawi and South Africa cover each an area of about 2° latitude x 2° longitude, in UTM projection and an image size of 12000x12000 pixels in 20m resolution, i.e. 240x240 km^2. The details of each demonstration site are specified in the Service Level Agreements and in the Annex.

Table 1. Demonstration site locations in the five countries

Site	~ lat,lon	UTM Zone	West-East	South-North
DRC	N00,E19	34S	133000 - 372980	9850000 - 10089980
Ethiopia	N08,E36	36N	670000 - 909980	708020 - 948000
Ghana	N06,W01	30N	558000 - 797980	544000 - 783980
Malawi	S16,E35	36S	574500 - 814500	8097020 - 8337000
South Africa	S25,E31	36S	169020 - 409000	7119020 - 7359000

2.3. Sentinel-1 A&B data

"Sentinel-1 (S1) is a Synthetic Aperture Radar (SAR) mission, providing continuous all-weather, day-and-night imagery at C-band (centre frequency: 5.405 GHz), operating in four exclusive imaging modes with different spatial resolutions and coverages. Dedicated to Europe's Copernicus programme, the mission supports operational applications in the priority areas of marine monitoring, land monitoring and emergency management services. The mission is based on a constellation of two identical satellites, Sentinel-1A (S1A), which was launched in April 2014, and Sentinel-1B (S1B), launched separately on 25 April 2016. In interferometric wide-swath mode, S1 can map global landmasses once every 12 days. The two-satellite constellation can theoretically deliver a six- day repeat cycle at the equator. The baseline observation scenario is pre-defined. The acquisition plan systematically makes use of the same SAR polarisation scheme over a given area to guarantee data in the same conditions for routine operational services. More information can be found at:

https://sentinel.esa.int/web/sentinel/missions/sentinel-1/observation-scenario .

Sentinel data products are made available systematically and free of charge to all data users including the general public, scientific and commercial users. All data products are distributed in the Sentinel Standard Archive Format for Europe (SAFE) format. More information can be found at:

https://sentinel.esa.int/web/sentinel/sentinel-data-access ." [ESA, online]

"The original data format used is Level-1 Ground Range Detected (GRD). "GRD products consist of focused SAR data that has been detected, multi-looked and projected to ground range using the Earth ellipsoid model WGS84. The ellipsoid projection of the GRD products is corrected using the terrain height specified in the product general annotation. The terrain height used varies in azimuth but is constant in range (but can be different for each IW/EW sub-swath).

Ground range coordinates are the slant range coordinates projected onto the ellipsoid of the Earth. Pixel values represent detected amplitude. Phase information is lost. The resulting product has approximately square resolution pixels and square pixel spacing with reduced speckle at a cost of reduced spatial resolution. For the IW and EW GRD products, multi-looking is performed on each burst individually. All bursts in all sub-swaths are then seamlessly merged to form a single, contiguous, ground range, detected image per polarisation." [ESA, https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/product-types-processing-levels/level-1]

2.4. Digital Elevation Model

The necessary digital elevation model (DEM) data has been downloaded from USGS. The NASA Shuttle Radar Topography Mission DEM (SRTM) 1Arcs (USGS) data has been used for maximum accuracy for processing in expected 20m resolution.

3. Method and Processing Steps

NORCE's (former Norut's) GSAR (in IDL) or GDAR (in python) SAR processing system is used in this project as it allows operational processing of big datasets. The system has been set-up for each region and the process has been streamlined into the three following steps:

- Data acquisition (level 1)
  - Download and uncompressing
- Pre-processing (level 1 → level 2)
  - Geocoding and radiometric calibration
  - Radiometric slope correction according to Ulander [1996].
- ASARD production (level 2 → level 3)
  - Yearly and monthly statistical analysis of data stack and mosaics production

All products are processed in their respective UTM zone in 20m resolution.

Figure 5 shows the processing line from Level-1 Sentinel-1 GRD data to pre-processed georeferenced and slope-corrected single orbit images (Level 2) and finally to the complete set of ASARD products (level 3).

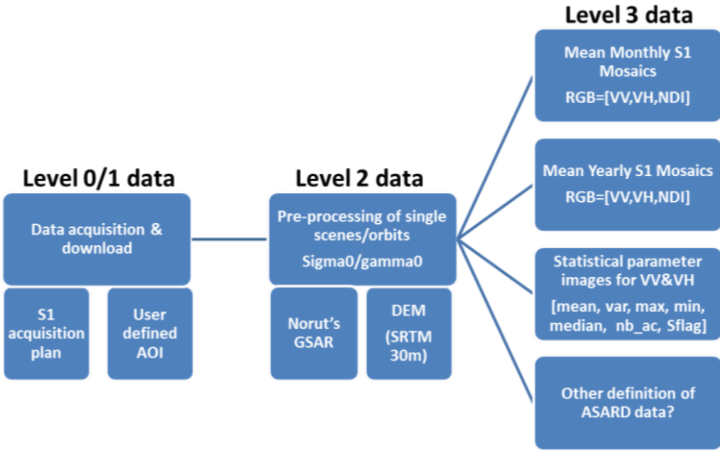


Figure 5. ASARD processing chain from GRD (level 1) to ASARD products (level 3)

3.1. Sentinel-1 acquisition

All acquired Sentinel-1A&B data over the five demonstration sites (Figure 1) have been downloaded through the Copernicus Open Access Hub [https://scihub.copernicus.eu/] or the Alaska Satellite Facility [https://vertex.daac.asf.alaska.edu/#] from the launch of Sentinel-1 in 2014 until 31 December 2019. The acquisition scenarios vary over the five sites. Table 2 summarizes the acquisitions for the years 2017 and 2018 specifying the satellite S1A or S1B, the path number, the number of orbits and the flight direction of the satellite, i.e. ascending (ASC) or descending (DES). The annex shows also the location of the paths and single scenes, as well as it shows a list specifying the dates of each acquisition for the whole period.

Depending on the number of path and orbits acquired for each site, the total amount of data varies between 500GB and 1TB per site for two years of coverage. The acquisition in between 2014 and 2016 increased from sporadic to consistent acquisitions as in 2017. 2019 acquisition followed the scheme from 2018 as both satellite S1A and S1B were fully operational. Detailed acquisition dates are provided in the Annex for each site.

Table 2. Summary of the Sentinel-1 acquisitions over the five demonstration sites.

Site	2017				2018			
	Satellite	ASC or DES	Path	nr of orbits	Satellite	ASC or DES	Path	nr of orbits
DRC	S1A	DES	036	29	S1A	DES	036	29
	S1A	DES	109	30	S1A	DES	109	30
	S1B			0	S1B			0
	S1B			0	S1B			0
Total	S1A	DES		59	S1A	DES		59
ETHIOPIA	S1A	DES	050	25	S1A	DES	050	18
	S1A	DES	152	27	S1A	DES	152	29
	S1B			0	S1B			0
	S1B			0	S1B			0
Total	S1A	DES		52	S1A	DES		47
GHANA	S1A	ASC	045	31	S1A	ASC	045	30
	S1A	ASC	147	30	S1A	ASC	147	30
	S1B	ASC	045	6	S1B	ASC	045	31
	S1B	ASC	147	30	S1B	ASC	147	30
Total	S1A/S1B	ASC		97	S1A/S1B	ASC		121
MALAWI	S1A	DES	006	26	S1A	DES	006	23
	S1A	DES	079	26	S1A	DES	079	27
	S1B	ASC	101	30	S1B	ASC	101	30
	S1B	ASC	174	31	S1B	ASC	174	30
Total	S1A/S1B	ASC/DES		113	S1A/S1B	ASC/DES		110
SOUTH AFRICA	S1A	ASC	043	31	S1A	ASC	043	30
	S1A/S1B	DES	079	27A+6B	S1A/S1B	DES	079	13A+27B
	S1A	ASC	145	30	S1A	ASC	145	31
	S1B	DES	152	7	S1B	DES	152	26
Total	S1A/S1B	ASC/DES		101	S1A/S1B	ASC/DES		127

3.2. SAR pre-processing: Geocoding, radiometric calibration, terrain and slope correction

The S1 GRD data was pre-processed with NORCE's geocoding software [Larsen et al., 2005] using the 1Arcs SRTM DEM that has been interpolated on the final 20m UTM grid using a cubic convolution resampling. Defining the 20m DEM makes sure that all pre-processed single orbits are processed on the exact same UTM grid. Header information in the S1 *.SAFE folder include the necessary parameters for radiometric calibration and the exact satellite orbit information for georeferencing and terrain correction with the DEM. GRD files are therefore directly converted into georeferenced, radiometrically corrected gamma-nought γ° radar backscatter images in dB for both polarization, co-polarization VV and cross-polarization VH, γ°(VV) and γ°(VH), respectively. Single scenes of the same orbit are directly processed together into one continuous image. Once the GRD data are processed into georeferenced and radiometric corrected images an additional radiometric slope correction according to Ulander [1996] is applied.

3.3. Processing to Advanced Sentinel-1 Analysis Ready Data (ASARD)

ASARD format

The ASARD format has been set on the following:

- Format: geotif (or ENVI format if wished)
- Projection: UTM
- Datum : WGS1984
- Resolution : 20m
- Coding: floating points (32 bits)

Each site is processed as one image of 12000x12000 pixels.

Statistical Analysis

The individual orbit images resulting from the pre-processing described in section 3 are statistically analyzed in time on a monthly and yearly basis. Using the statistical analysis tools from NORCE's GSAR software, 6 parameters can be directly extracted from a data stack: mean, variance, the number of measurements, the minimum and the maximum backscatters and an accumulated mask for SAR-layover or SAR-shadow due to topographies. In addition, the yearly median value for each pixel is extracted. In near and far range, about 100 pixels have been eliminated to reduce the most extreme border effects. Neighbouring ascending or descending satellite path have an overlay band that varies from about 1300 pixel (26 km) large at the equator to about 2450 pixel (49 km) in South Africa (highest latitude site). Pixels in this band are therefore averaged between the near and far ranges of these neighbouring paths. The statistics therefore partly reflect the difference between near and far range SAR backscatter. As we assume that S1A and S1B are calibrated to the same standard, all statistical values are calculated independent if it is S1A or S1B.

Monthly mean and yearly mean and median image mosaics

Based on the mean gamma backscatter values in VV and VH polarization, i.e. γ^0(VV) and γ^0(VH), respectively, over a monthly or yearly data stack, averaged 3 band image mosaics are constructed using the Normalized difference Index

$$\mathbf{NDI = (\gamma^0(VV)-\gamma^0(VH))/(\gamma^0(VV)+\gamma^0(VH)).}$$

The final mosaics are then

$$\mathbf{RGB = [\gamma^0(VV); \gamma^0(VH); NDI]}$$

Gamma backscatter values for both polarizations VV and VH are in dB with values greater than -30dB. “No data” pixels have the value of -50.0dB. The gamma backscatters are all averaged from radiometric, slope corrected and georeferenced single acquisitions using the SRTM-1Arcs data.

The file name convention for monthly averaged data is

[SITE]_S4R_[Latlon-Center]_S1_MOS_VVVHNDI_yyyymm_20m_UTM[zone]_[nr_of_orbits_used]_geo.tif .

The file name convention for yearly averaged and median data is

[SITE]_S4R_[Latlon-Center]_S1_MOS_VVVHNDI_yyyy_20m_UTM[zone]_[nr_of_orbits_used]_geo.tif and

[SITE]_S4R_[Latlon-Center]_S1_MOS_MED_VVVHNDI_yyyy_20m_UTM[zone]_[nr_of_orbits_used]_geo.tif

, respectively.

Table 3 specifies the name convention for each site with country code for the sites, the approximate centre location and the UTM zone used.

“yyyy” stands for the four digits of the year (2017/2018),

“mm” for the two digits of the month (01-12).

Pixels without data because of no data availability, SAR layover, or SAR shadow have the values [-50.0, -50.0].

Table 3. Name convention for the specific demonstration sites.

	[SITE]	[Lat/Lon-Center]	UTM-zone
DRC	DRC	N00-E19	34S
ETHIOPIA	ETH	N08-E36	36N
GHANA	GHA	N06-W01	30N
MALAWI	MAL	S16-E35	36S
SOUTH AFRICA	RSA	S25-E31	36S

STATISTICAL parameter images

Statistical parameters for each pixel are extracted from the whole data stack on a yearly basis and delivered as a 6 band geotif for each polarization VV and VH in float values. The name convention is for the two polarizations, VV and VH, respectively:

[SITE]_S4R_[Latlon-Center]_S1_STAT_VV_yyyy_20m_UTM[zone]_[nr_of_orbits_used]_geo.tif

[SITE]_S4R_[Latlon-Center]_S1_STAT_VH_yyyy_20m_UTM[zone]_[nr_of_orbits_used]_geo.tif

These image files include the statistical values for both polarizations (VV and VH) in the following bands:

Band 1: Average
Band 2: Variance
Band 3: Number of measurements (orbits)
Band 4: Minimum backscatter
Band 5: Maximum backscatter
Band 6: Accumulated mask, (SAR_layover = 200.0, SAR_shadow = 128.0, no_data = 32.0)

Band 1, 2, 4 and 5 are expressed in decibel (dB). (value in dB) = 10*log10(value on linear scale).

3.4. H-A-Alpha processing

Since polarimetric signatures are sensitive to the different physical and electrical properties of targets, features extracted from complex SAR images acquired at different polarizations can complement statistical features computed from amplitude Images. Therefore, polarimetric features can also be included in ASARD products. Polarimetric decompositions are the commonly used approaches to express the measured signal in terms of the scattering mechanisms [Ulaby & Long, 2014; Pottier & Lee, 2000]. Even though many of these decompositions are applicable to quad pol acquisitions, the H-A-alpha decomposition can also be applied to dual pol measurements [Cloud, 2007].

In the general case, the Entropy (H) provides information on the scattering degree of randomness. As an example, SAR images of forested areas are characterized by high Entropy values whereas the sea is characterized by low Entropy values. On the other hand, the Alpha parameter is considered as an indicator to the nature of the scattering mechanism, i.e., single bounce, double bounce or volume scattering. The Anisotropy (A) provides information on the relative importance of secondary mechanisms and has to be interpreted together with the Entropy. In the dual pol case, since the full scattering matrix cannot be measured, the H-A-Alpha parameters are used to characterize depolarization by random surfaces and volume scatterers in a limited sense [Cloud, 2007].

As the polarimetric decomposition needs single look complex data, which have a data volume about 4 times larger than the GRD, handling and processing such data is more time and power consuming.

For the purpose of demonstration, we have applied H-A-alpha dual pol decomposition to a selected acquisition in the South African datasets. We have used SNAP for the processing. Before the H-A-Alpha dual pol decomposition, debursting is applied to the dual pol SLC complex data. Based on a request from users, for a given selected area, we have processed three selected months. For each month, a monthly average of the H, A and Alpha polarimetric features were computed by first collocating the acquisitions on a common grid. Then, terrain correction is applied followed by a reprojection on a UTM grid.

4. Results

4.1. Complete set of products and data delivery

A first set of ASARD products for the years 2017 and 2018, a total of 32 products, has been delivered on March 2019. The aim was to give the users a first set to assess their usability and quality for their operations and provide a user service/product assessment (Section 5). Finally, the whole archive of Sentinel-1 data over the demonstration sites were processed until August 2019 and delivered in September 2019. A last update delivery was then done in January 2020 so that the full S1 archive for each site from 2014-2019 was available as ASARD products to the users.

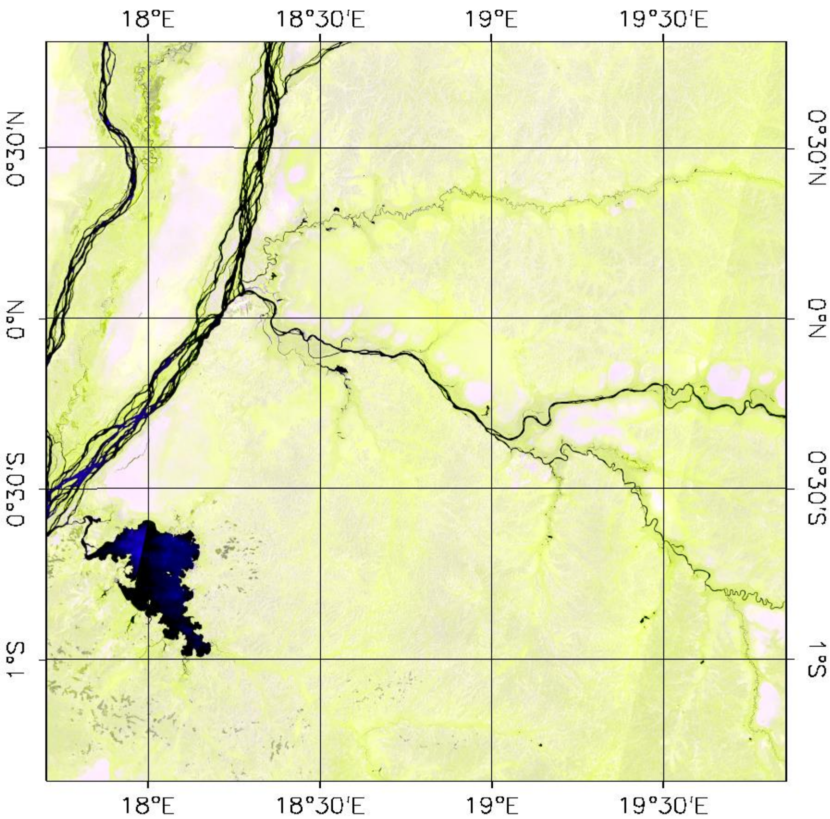
For each site, the set of products per year include therefore:

- 12 monthly averaged S1 mosaics (3 bands RGB = [γ^0(VV),γ^0(VH),NDI] in 32 bits)
- 1 yearly averaged S1 mosaics (RGB= [γ^0(VV),γ^0(VH),NDI])
- 1 yearly S1 mosaics using the median value (RGB = [γ^0(VV),γ^0(VH),NDI)
- 1 yearly statistics for the VV polarization (6 bands in 32 bits/pixel), and
- 1 yearly statistics for the VH polarization (6 bands in 32 bits/pixel).

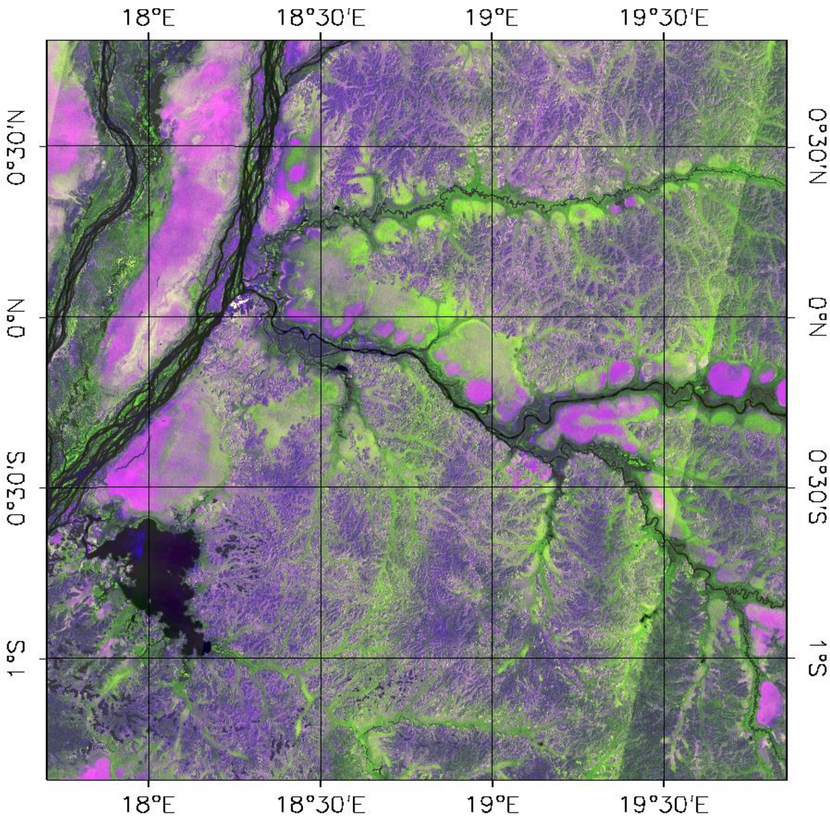
The bands of the statistic files are

- Band 1: Average
- Band 2: Variance
- Band 3: Number of measurements (orbits)
- Band 4: Minimum backscatter
- Band 5: Maximum backscatter
- Band 6: Accumulated mask (SAR-layover = 200.0, SAR- shadow = 128.0, no_data = 32.0)

Each image is 12000 x 12000 pixels, so the mosaics are about 1.7 GB each, the STAT files are 3.5 GB and the whole product set per site and per year is about 29 GB (uncompressed geotifs). gzip compression will reduce the whole data set by 10-20%.
So, for example for Ghana, the size of data to be processed for the demonstration site was 390 GB of in total 123 orbits, meaning a reduction of over 90%.
All products are delivered either through the contractor's ftp site or at the request of the user uploaded to their ftp server. ftp address and login are provided to each user.
As an example, the 2018 averaged backscatter mosaics are shown for all 5 sites in Figure 6 to Figure 10 with different colour stretching.

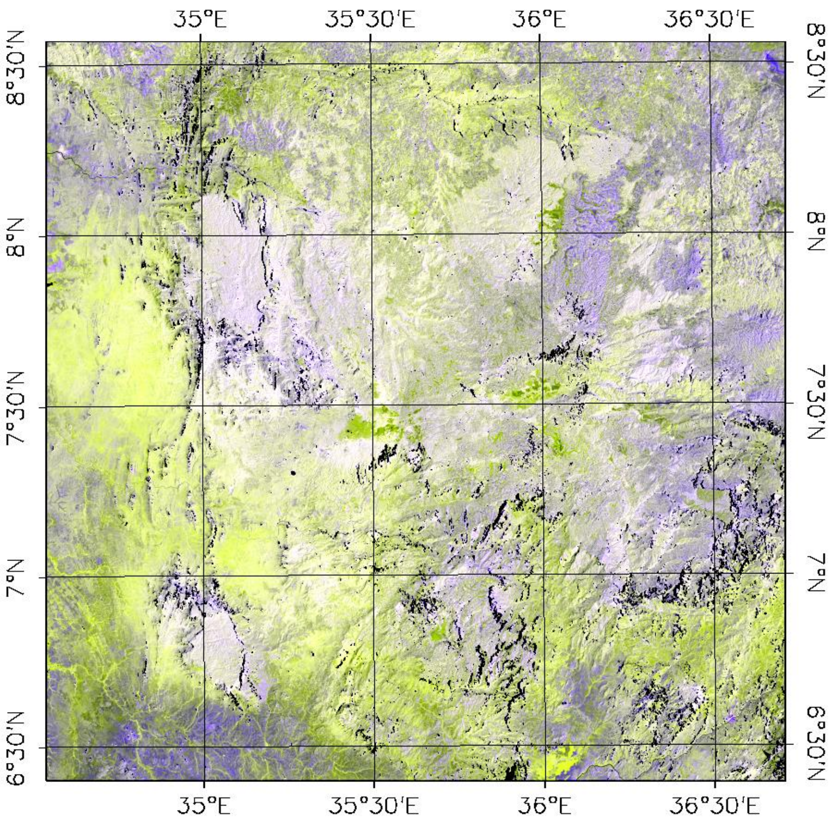


a

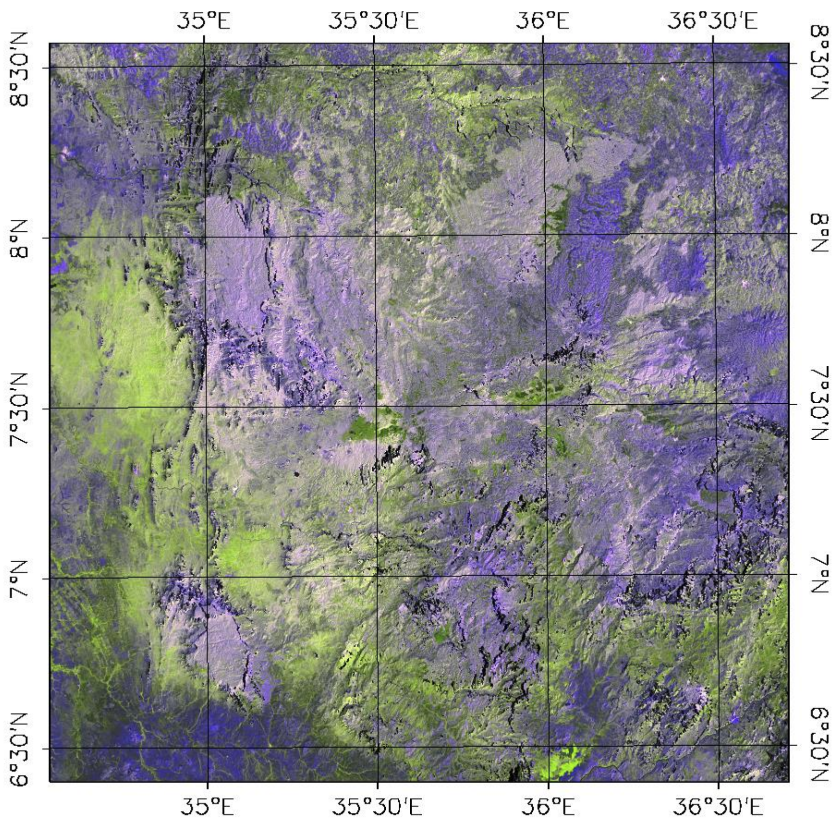


b

Figure 6. 2018 averaged backscatter mosaics over DRC with (a) linear 2% and (b) gaussian colour scaling

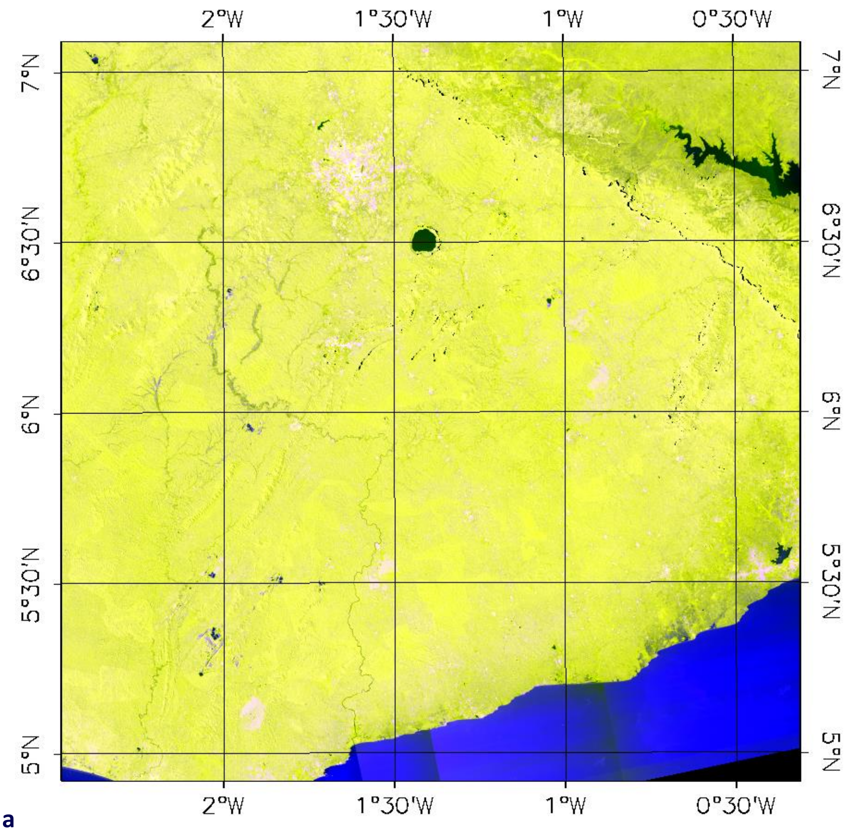


a

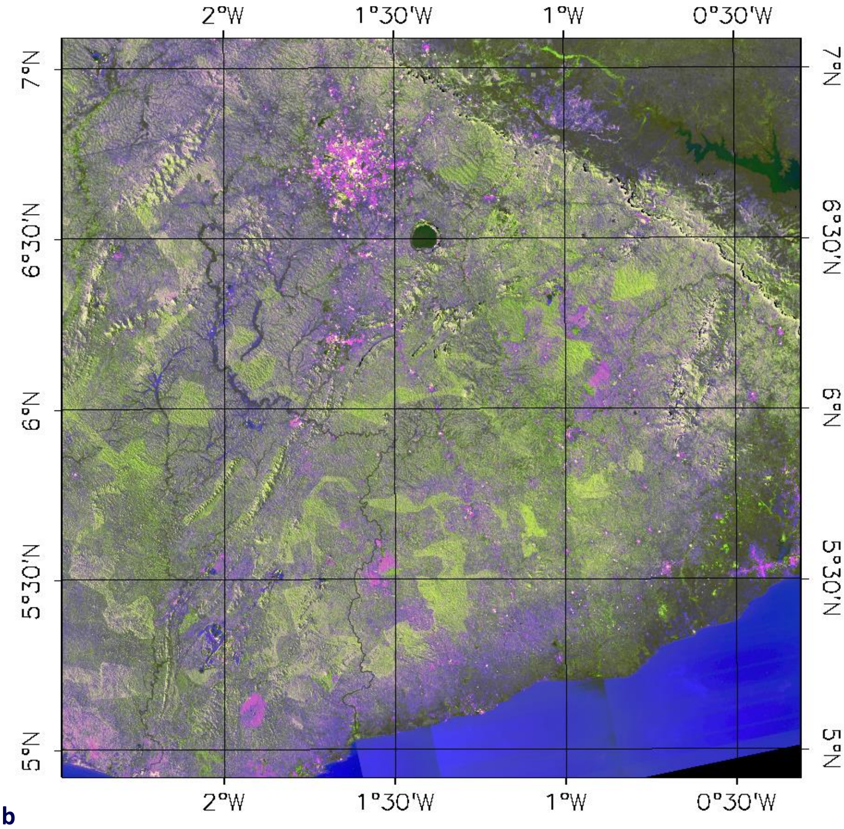


b

Figure 7. 2018 averaged backscatter mosaics over Ethiopia with (a) linear 2% and (b) gaussian colour scaling.

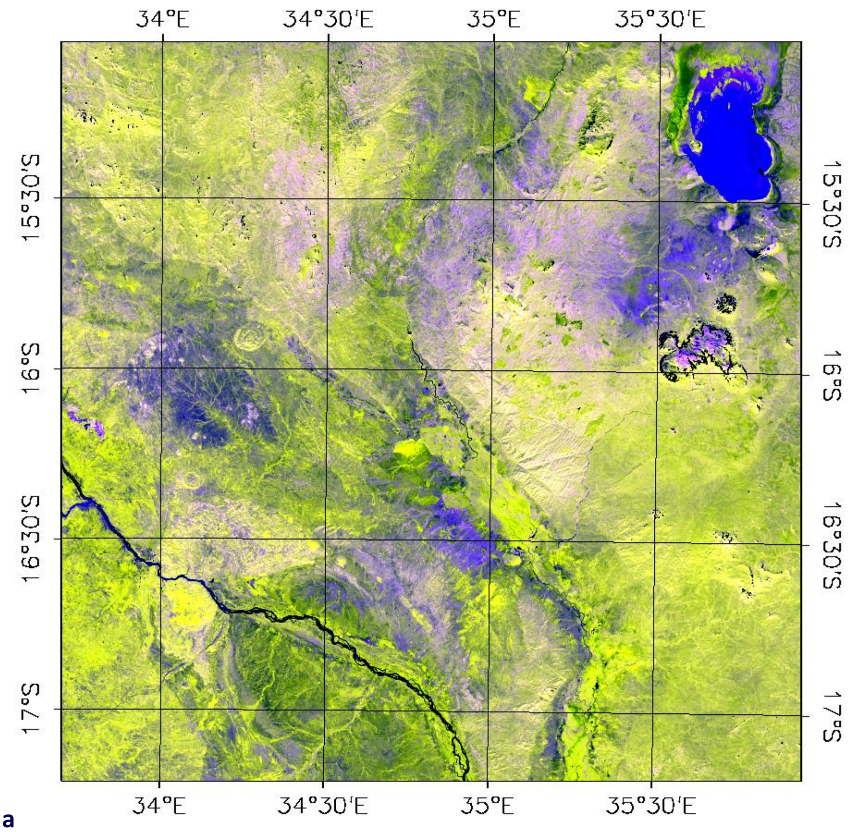


a

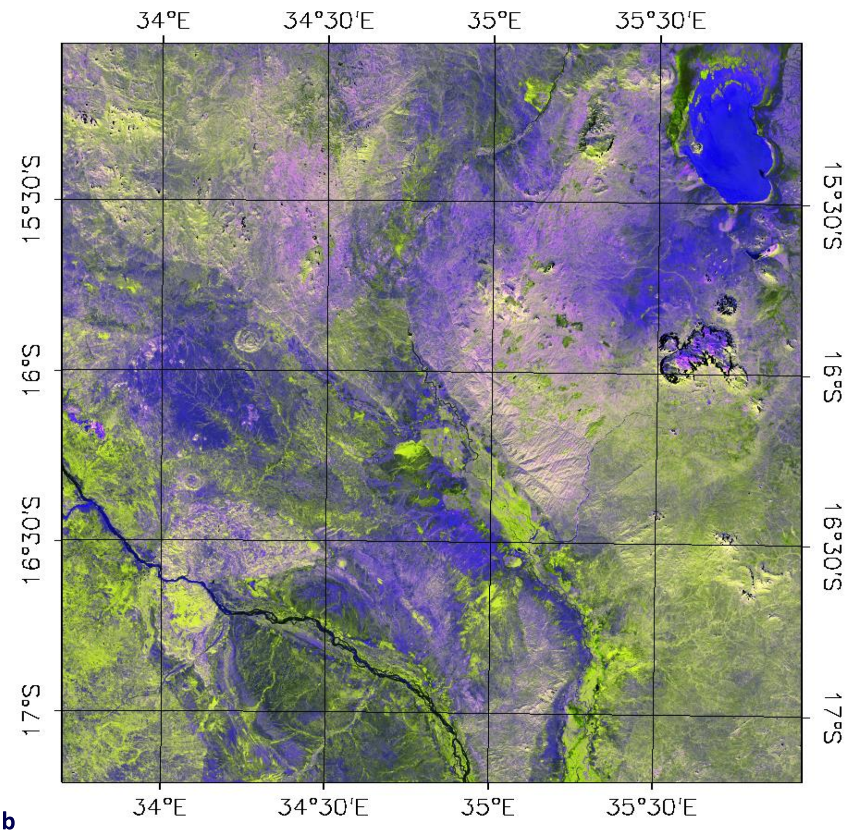


b

Figure 8. 2018 averaged backscatter mosaics over Ghana with (a) linear 2% and (b) gaussian colour scaling.



a



b

Figure 9. 2018 averaged backscatter mosaics over Malawi with (a) linear 2% and (b) gaussian colour scaling.

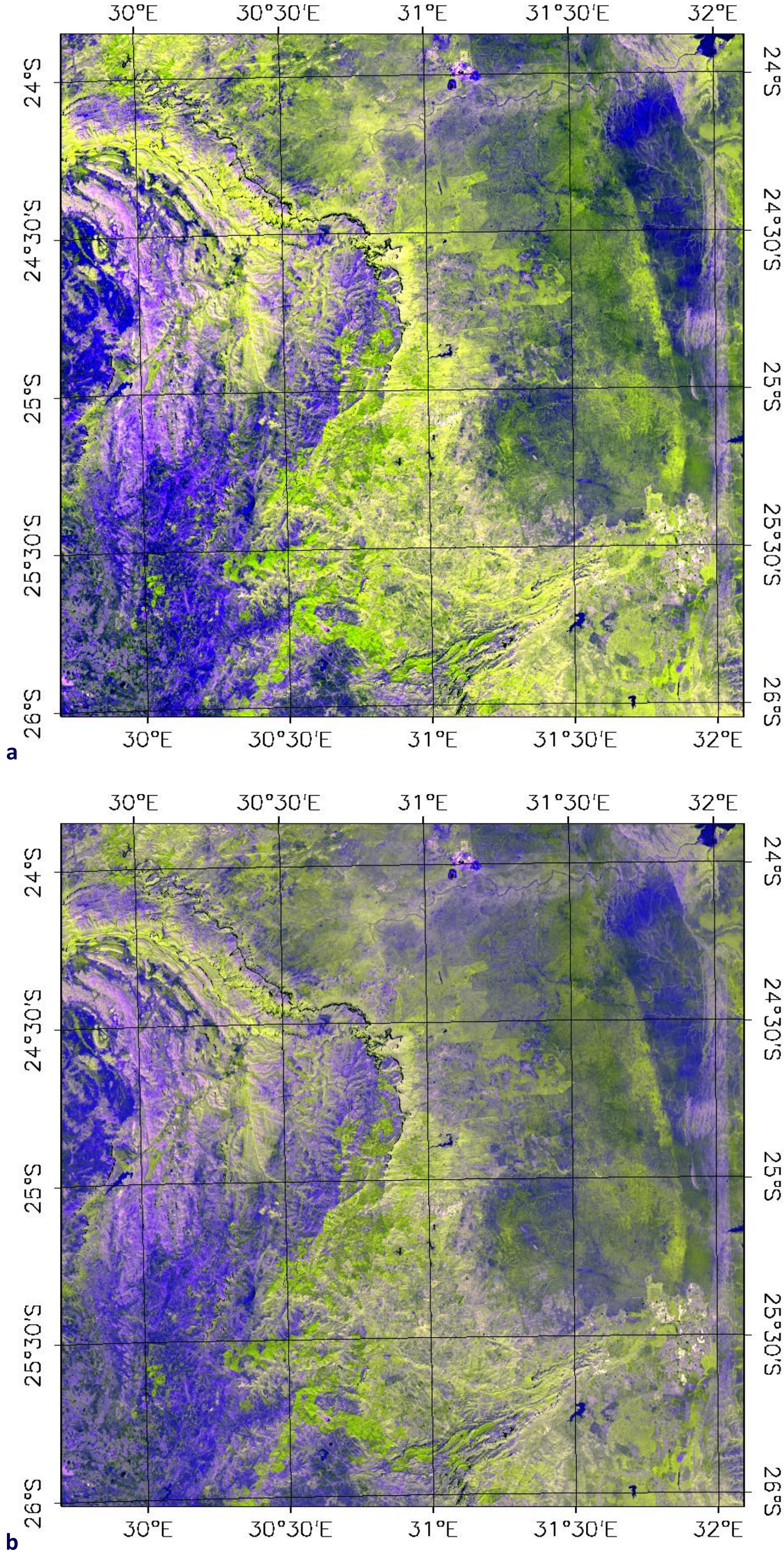


Figure 10. 2018 averaged backscatter mosaics over South Africa with (a) linear 2% and (b) gaussian colour scaling.

4.2. ASARD product availability and distribution

The products are free for distribution and the users can share them with 3rd parties.

The user and potentially 3rd parties should however inform the Service Provider (NORCE) about their use of the ASARD data. The users and potential 3rd-party users are also expected to acknowledge the Data (ESA/Copernicus) and Service Provider (NORCE) when the data and products are used, shared with third parties, published or disseminated in any other kind by stating

"**Contains modified Copernicus Sentinel-1 data [year], processed by NORCE (Tromsø, Norway) under ESA contract No. 4000125675/18/INB**".

For scientific publications, the authors can also assist and can contribute with more detailed information if the provided products have been used and were of relevance.

Products can also be made available by contacting the service provide NORCE, i.e. the author of this report.

4.3. H, A , alpha processing result for South Africa

For the year 2018, we have selected two paths, 79 and 145 for which we have processed data for three selected months, namely January, July and October. In each month a maximum of three acquisitions are available. After performing the H-A-Alpha decomposition to each dual pol acquisition, we have produced a monthly average of each of the components. For illustration, monthly averages from the two months, namely July 2018 for path 79 (Figure 11) and October 2018 for path 145 (Figure 12) are shown below. The RGB image is composed of (Backscatter, Entropy, Alpha). The intensity image is displayed for comparison.

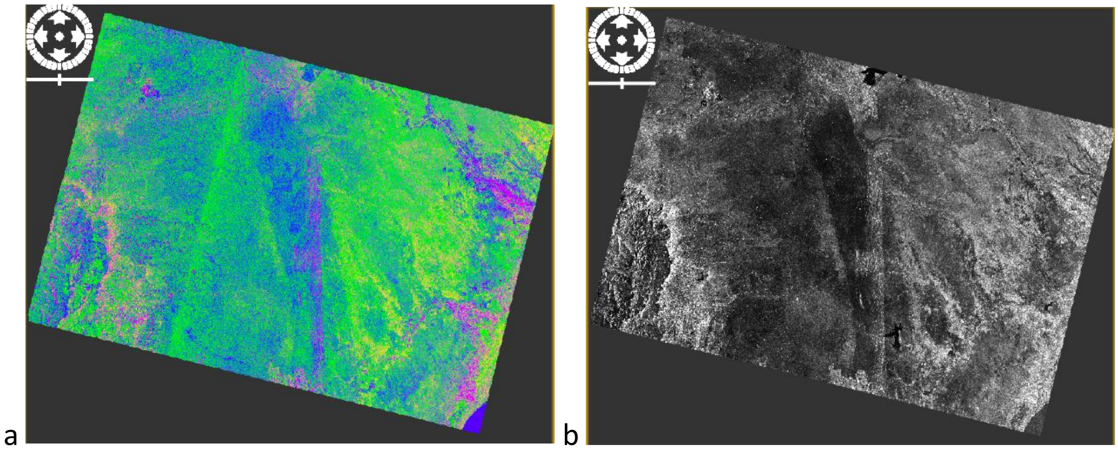


Figure 11. Monthly average of (a) H-A-Alpha decomposition displayed as RGB with R, G and B correspond to Intensity, H and Alpha respectively. (b) averaged backscatter for comparison. Data are acquired on the 4th, 16th and 28th of July 2018 over South Africa, path 79.

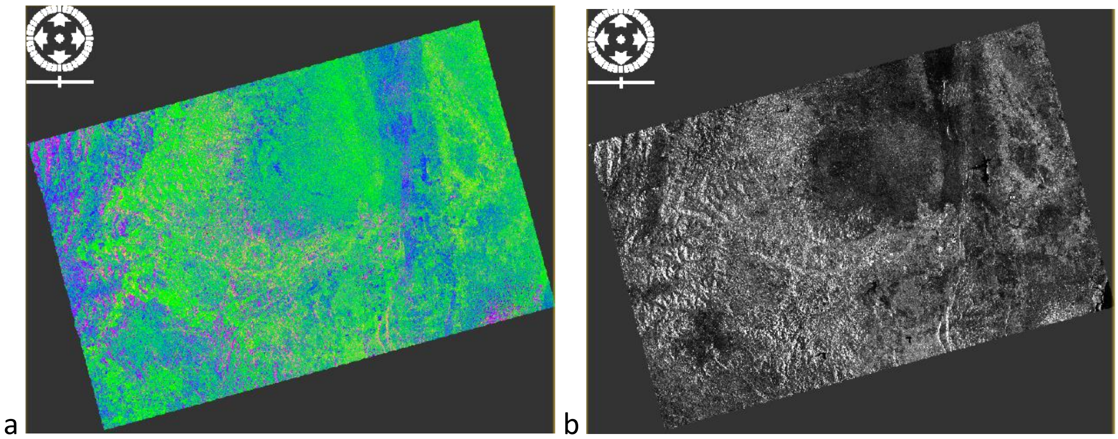


Figure 12. Monthly average of (a) H-A-Alpha decomposition displayed as RGB with R, G and B correspond to Intensity, H and Alpha respectively. (b) averaged backscatter for comparison. Data are acquired on the 4th, 16th and 28th of July 2018 over South Africa, path 79.

5. Applications of Advanced Sentinel-1 Analysis Ready Products

5.1. Forest mapping

ASARD products have already been used in several project for forest mapping at Norut/NORCE in former projects in cooperation with OSFAC in DRC. One example is during the ESA DUE Innovator III project SAR for REDD, recently published in [Haarpaintner & Hindberg, 2019]. The Mai Ndombe district was mapped and classified in a forest land cover map using both Sentinel-1 and ALOS-2 PALSAR-2 imager using wet and dry seasonal averaged backscatter mosaics or mean and variance statistics. Figure 13 shows the forest land cover maps that resulted from this study.

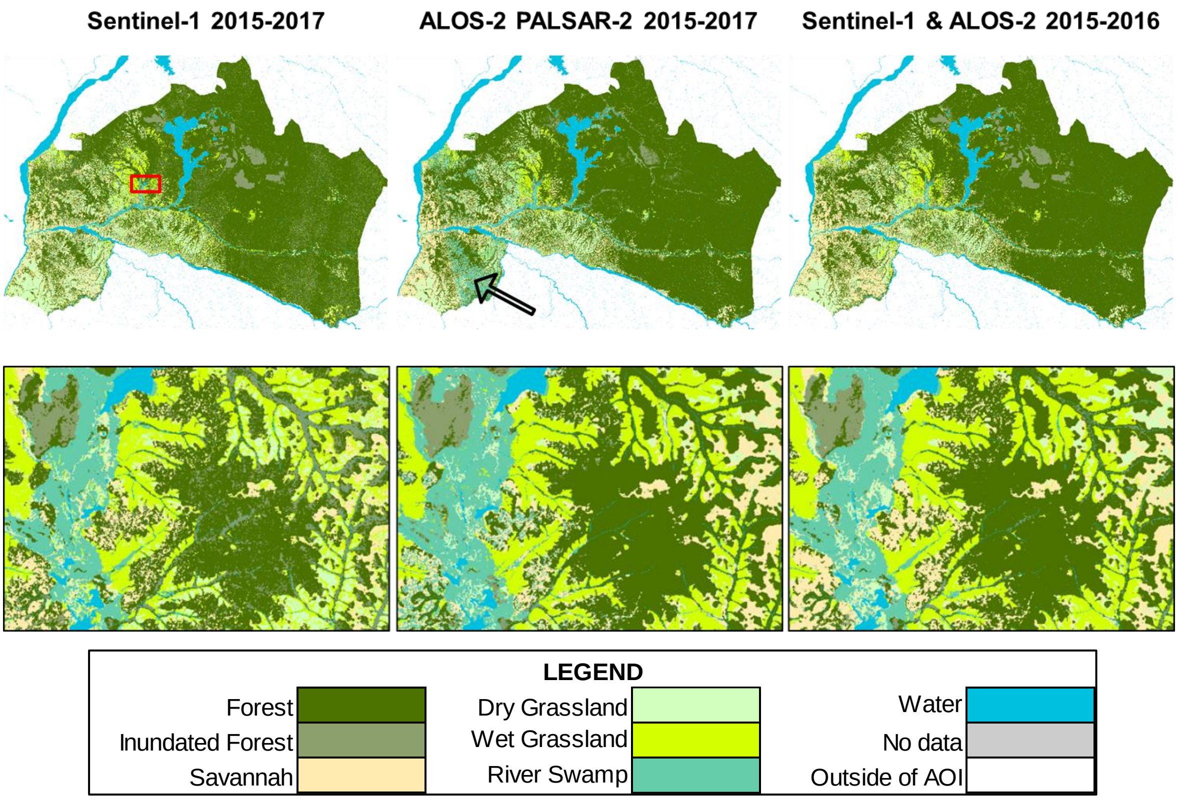


Figure 13. Maximum-likelihood classification (MLC) results for Sentinel-1, ALOS-2, and Sentinel-1/ALOS-2 combined using the multi-year (2015–2017) statistical parameters. The red rectangle indicates the position of the enlargement in the lower panels. The black arrow indicates a classification error probably due to the ALOS-2 calibration error prior to 2017.

5.2. Illegal Mining (Galamsey) Monitoring in Ghana

“Galamsey” is a local term used to refer to illegal small-scale gold mining in Ghana. Generally, it involves excavating small pits by digging or through some mechanized means in search of gold. The activity is rife in the southern part of Ghana where there are substantial deposits of gold and forest resources. Men, women and children are actors in the processing chain leading to gold mining. Beyond the dangers of land degradation, forest depletion, water contamination and biodiversity loss, the operations of the illegal miner results in fatal accidents and great economic loss to the state.

Sentinel-1 monthly and yearly averaged proved to be well suited to detect illegal mining sites in forest areas in the south of Ghana by simple thresholding the difference between monthly or yearly VH averages. Figure 14 shows an example of yearly detected mining sites and gives an idea of the scale of forest loss due to this driver.

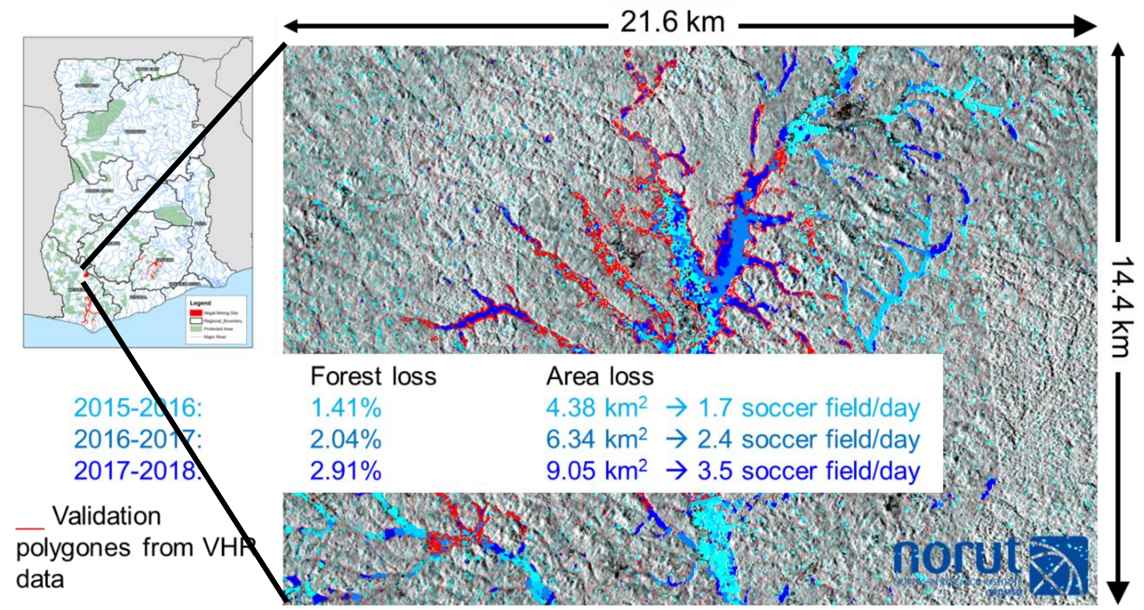


Figure 14. Yearly illegal mining site detected.

5.3. Flood mapping after cyclone Ide in Malawi / Mozambique

Likewise, flooded areas can be detected by comparison satellite data on a shorter time scale if needed. Figure 15 showed the flooded areas after cyclone Idai in Mozambique /Malawi in March 2019.

If data is processed continuously and updated at the end of the months. Such products could also be made available for near-real time operations.

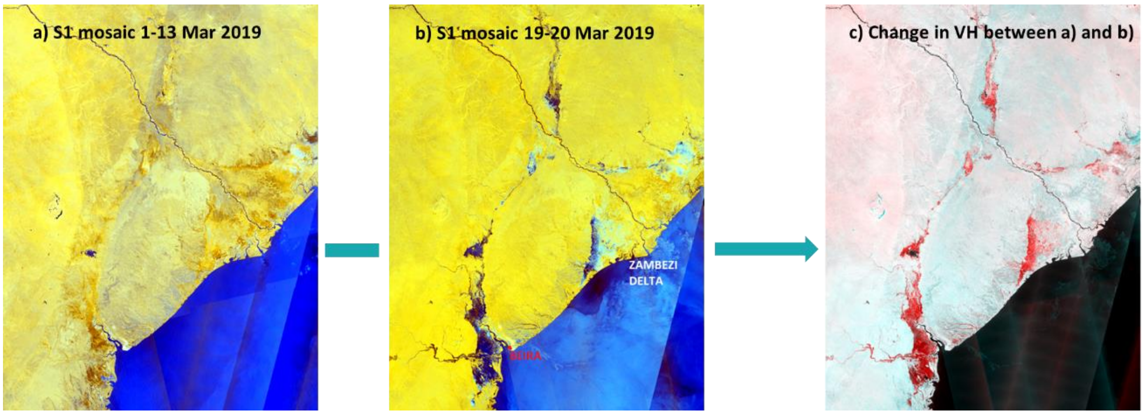


Figure 15. Flood mapping after cyclone Idai in Mozambique/Malawi (March 2019): (a&b) RGB = [γ^0(Vh),γ^0(VV),NDI], (c) Detected flooded areas in red. Contains modified Copernicus Sentinel-1 data (2019)

5.4. Savannah biomass mapping in South Africa (Report provided by the user, Russel Main (CSIR))

Background

Savannas cover extensive parts of the globe and offer up unique challenges in terms of the remote sensing of vegetation structural metrics (e.g. low biomass ranges, distinct vegetation growth forms, bi-temporal moisture patterns). The estimation of above ground woody biomass (AGB) in southern African savannas is important given i) the critical role woody biomass plays as a source of energy and timber products in the region, ii) the need to monitor processes such as bush encroachment, and iii) the combined effect of these interactions on regional savanna carbon stocks and fluxes.

Using ~54 000 Ha of savanna LiDAR-based biomass training data, in the Lowveld region of South Africa, we attempted to model and map regional-scale AGB with multi-temporal Sentinel-1 analysis ready datasets (S1 ARD).

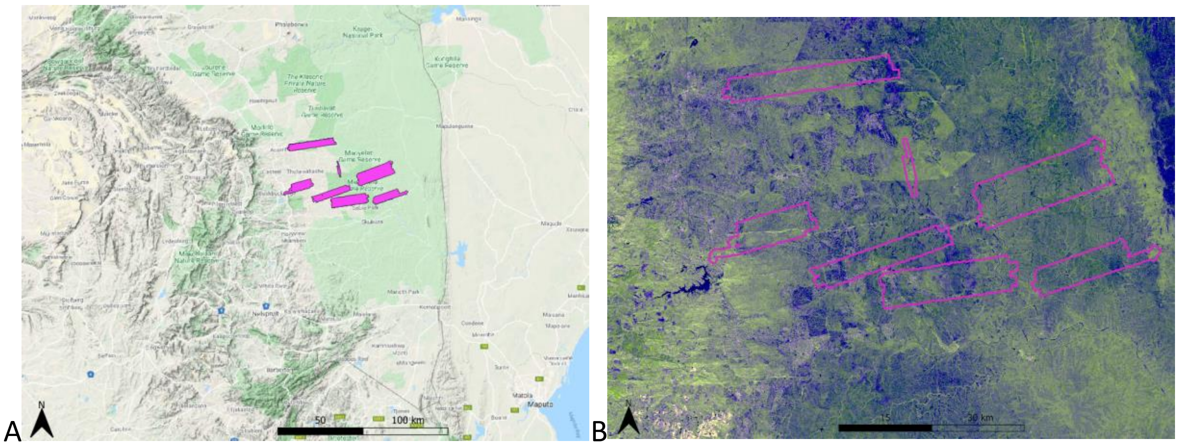


Figure 16. A) The region of study in the Lowveld region of South Africa. Pink polygons represent the LiDAR-based AGB training datasets. B) LiDAR training datasets overlaid on Sentinel-1 ARD dataset, where the RGB combination of bands is VV, VH, and NDI. The S1 ARD composite shows good discrimination of varying vegetation structures, which bodes well for modelling and mapping purposes (i.e. Shades of green = varying levels of AGB, shades of purple/blue = bare/low levels of biomass)

Datasets

LiDAR dataset

The LiDAR data was acquired in March 2012 and totalled some 54 000ha. The discrete-return LiDAR data were acquired using the Carnegie Airborne Observatory (CAO) Airborne Taxonomic Mapping System (AToMS), flown at ~2000m a.s.l, with a scan frequency of 100 Hz, laser spot spacing of 1m and point densities in excess of 5 pt/m^2 (Asner & Levick, 2012; Mograbi et al., 2015). More detailed information on the sensor and LiDAR processing is available in (Green et al., 2012). Simultaneous to the LiDAR acquisition, there was a field biomass campaign. The field plots consisted of 37 1-hectare plots that were collected during a field campaign carried out between January and March of 2012 (See Naidoo et al., 2015). A linear regression model between the field collected AGB and a LiDAR metric (Mean Height x Canopy Cover) was then applied across all 54 000ha of the LiDAR dataset. The final field-to-LiDAR regression model had the following accuracy R^2=0.78, RMSE=10.6 T/Ha, rRMSE=39.8%, Bias=0.78 T/Ha), aggregated to a 1 ha resolution.

SAR dataset

The Norwegian Research Centre (NORCE) provided Sentinel-1 (S1) analysis ready datasets (ARD), which would be the dependent variable in attempting to map the AGB. Using NORCE's GSAR processing system Level-3 mean monthly S1 mosaics have been created. These mean monthly mosaics consist of three SAR bands, namely 1) the co-polarised VV, 2) the cross-polarised VH, and the normalized difference index (NDI) of those two polarisations. It has been well established that dry season SAR data is most suited for woody structure related parameter estimation in savanna environments, therefore only the two dry seasons worth of imagery were used in this analysis (i.e. 2017&2018 months of May to September). There were 5 dry season images in each of the years, which meant 10 images in total could be combined in order to attempt to improve the model. To align with the LiDAR dataset, each SAR dataset was resampled to match the 100m resolution of the LiDAR. Obviously, there is a large temporal mismatch between the LiDAR training data (2012) and the SAR datasets (2017 & 2018) which should be considered in the interpretation of the results. However, given the scarcity of LiDAR acquisitions in these environments and the lack of significant clear-cut like changes to vegetation in the region it was assumed that the impacts on the overall results were minimal.

Methods

The statistical relationships between AGB and the SAR image scenarios were modelled using random forest (RF) models, and were assessed using regression statistics such as the correlation coefficient (R^2), the root mean squared error (RMSE), and the relative root mean squared error (rRMSE). While the cross-polarised VH is generally documented as being superior in modelling woody structure parameters in savanna, we tested different combinations of the three available bands in each mean monthly composite (i.e. VH only, VV&VH, and VV/VH/NDI). Multi-temporal combinations of C-band images are documented as being useful in reducing signal noise and improving model sensitivity to woody structure related parameters. Hence, random forest modelling was implemented on both the individual images, as well as the combination of all 10 images (across the two dry seasons). All available in the calibration stage were randomly split into training and test datasets using a 40%/60% split, and this was repeated 10 times. Meaning that the results presented below are averages of these iterations.

Results:

Table 4: Validation results for the random forest modelling of savanna AGB, using 10 S1 ARD mean monthly composites and different combinations of polarisations.

	Image	R^2	RMSE	rRMSE
VH	S1_201705	0.24	10.76	61.32
	S1_201706	0.37	9.65	54.91
	S1_201707	0.43	9.07	51.74
	S1_201708	0.45	8.94	50.81
	S1_201709	0.48	8.68	49.36
	S1_201805	0.29	10.31	58.87
	S1_201806	0.35	9.79	55.58
	S1_201807	0.41	9.32	52.93
	S1_201808	0.46	8.92	50.67
	S1_201809	0.42	9.16	52.16
	Multi-Temp	**0.63**	**7.16**	**40.66**
VV/VH	S1_201705	0.35	9.58	54.65
	S1_201706	0.46	8.70	49.51
	S1_201707	0.54	8.07	45.92
	S1_201708	0.54	8.05	45.66
	S1_201709	0.57	7.76	44.04
	S1_201805	0.39	9.35	52.97
	S1_201806	0.46	8.76	49.57
	S1_201807	0.51	8.33	47.38
	S1_201808	0.55	8.02	45.51
	S1_201809	0.53	8.16	46.39
	Multi-Temp	**0.68**	**6.71**	**37.98**
VV/VH/NDI	S1_201705	0.37	9.49	53.95
	S1_201706	0.47	8.64	48.96
	S1_201707	0.54	8.01	45.58
	S1_201708	0.55	7.94	45.28
	S1_201709	0.57	7.75	44.02
	S1_201805	0.38	9.37	53.05
	S1_201806	0.46	8.74	49.75
	S1_201807	0.51	8.29	47.20
	S1_201808	0.55	7.95	45.31
	S1_201809	0.53	8.11	46.15
	Multi-Temp	**0.67**	**6.76**	**38.50**

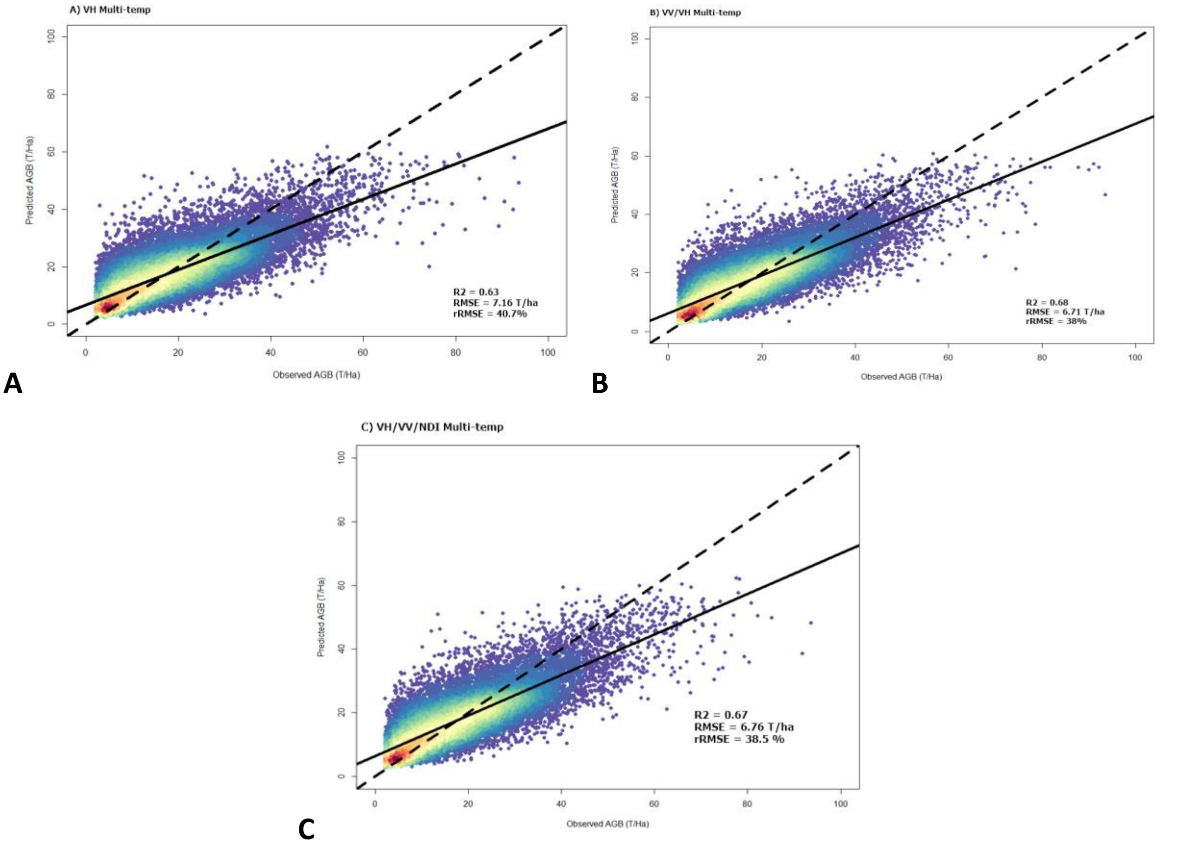


Figure 17. A - C) Validation scatterplots showing observed AGB and modelled AGB for the three multi-temporal scenarios.

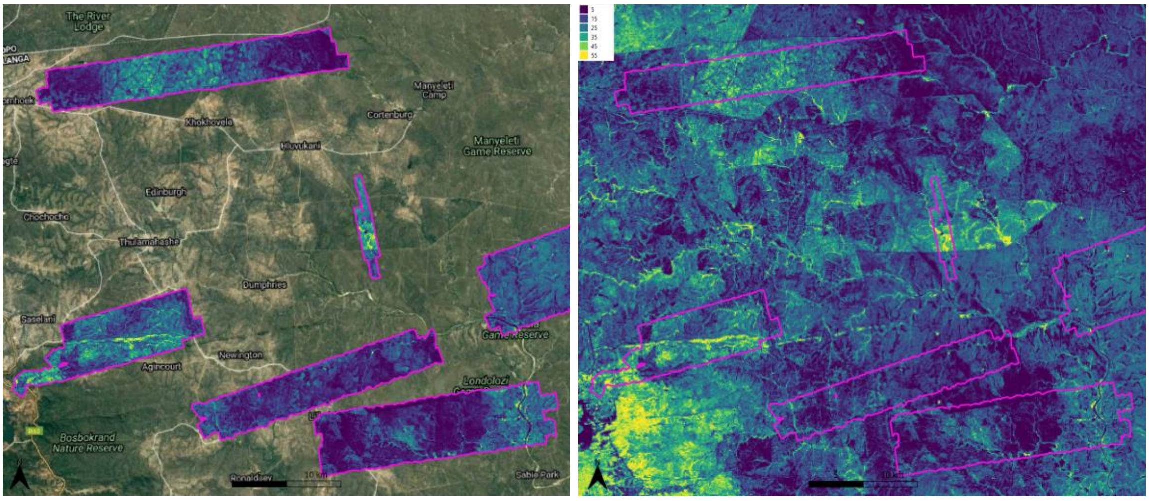


Figure 18. (A) Observed LiDAR-based AGB, (B) Modelled SAR-based AGB

Observations:

- The multi-temporal combination of images always produced higher validation accuracies than the individual images themselves.
- The September composite held the highest accuracies in all three scenarios, which is interesting in that it can be considered a 'transitional period' whereby phenologically the leaves are beginning to return to trees, while the background signal noise from soil moisture and grass is still low as the wet season rains having not yet fully returned. This is postulated to lead to a higher C-band SAR vegetation signal. This requires further/deeper investigation, but it confirms to some degree a hypothesis held, and potentially speaks to the fact that this 'transitional period' is captured in the mean monthly composites of the ARD data.
- The VV/VH combination produced marginally higher modelling accuracies than the other two scenarios.
- The overall accuracies achieved are very encouraging, and very similar to other studies in the same environment (Mathieu et al., 2013; L. Naidoo et al., 2015, 2016). Further analysis is needed to confirm validity. Similar trends in underestimation of high AGB levels and overestimation for low AGB levels were observed (See Figure 17).
- The mapped AGB results show the variation of AGB across the landscape well. Riverine areas and high AGB regions are easily distinguishable from low AGB regions. The accuracies, and model, are obviously most accurate for the range of AGB values that were used in the model (i.e. Very high AGB regions such as commercial forestry would not be very realistic.

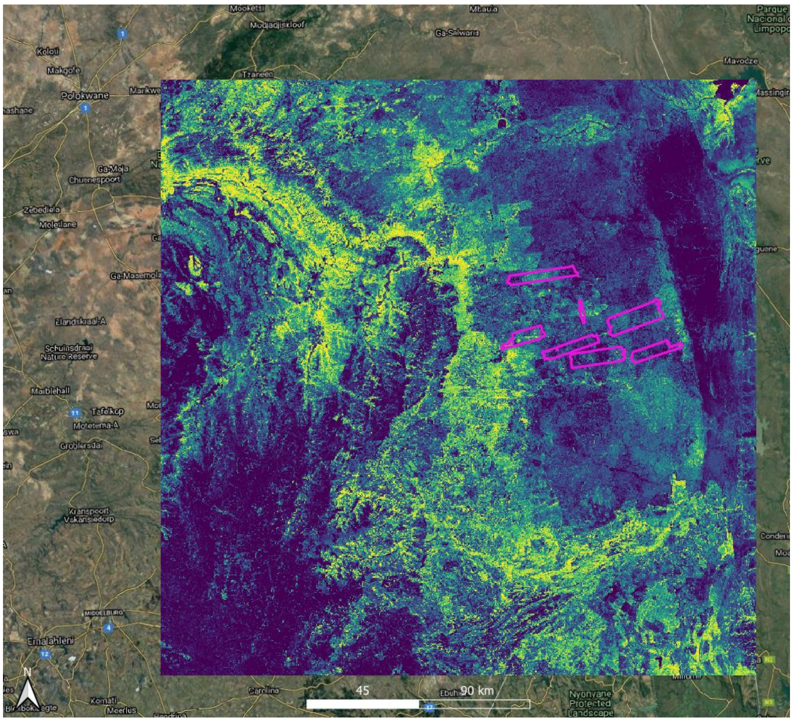


Figure 19: Regional scale AGB map for the Lowveld savanna of South Africa.

Additional Comments:

- We feel programmes such as this one, which are able to reduce/remove the barrier of entry (or 'fear factor') for using SAR, are very important. The products delivered appear to be of a high quality and are very easy to understand and use.
- Products such as these may show their greatest potential in domains that experience rapid change (i.e. logging), or where there is a longer time-series at more regional scales (i.e. National/Regional-scale bush encroachment).
- Anecdotally, we noticed the good differentiation of plantation forest species/ages in the SAR composites, something that was not as evident in Sentinel-2 optical data. This supports the SAR signal's know sensitivity to forest structure differences and may be useful in the discrimination of forest types and/or in the monitoring of growth cycles.

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Naidoo, Laven, Mathieu, R., Main, R., Kleynhans, W., Wessels, K., Asner, G. P., & Leblon, B. (2015). Savannah woody structure modelling and mapping using multi-frequency (X-, C- and L-band) Synthetic Aperture Radar data. *ISPRS Journal of Photogrammetry and Remote Sensing*, *105*, 234–250. https://doi.org/10.1016/j.isprsjprs.2015.04.007

6. Cloud processing test on CreoDIAS

6.1. Setup

Cloud setup

For a test cloud integration of SAR4Africa processing line, CreoDIAS [https://creodias.eu/] was selected. CreoDIAS is one of the Copernicus Data Access Hubs (DIAS) sponsored by ESA. CreoDIAS offers direct access to the full catalogue of Sentinel-1 imagery, and data processing is supported by the CloudFerro [https://www.cloudferro.com/] cloud hosting platform.

Within the CreoDIAS platform we set up the SAR4Africa processing line to run on a single virtual machine, with a medium spec: 4 CPUs, 8GB RAM and 16GB disk. In addition, two storage volumes were added, a 16GB SSD disk for temporary storage and a 128GB disk for processing results.

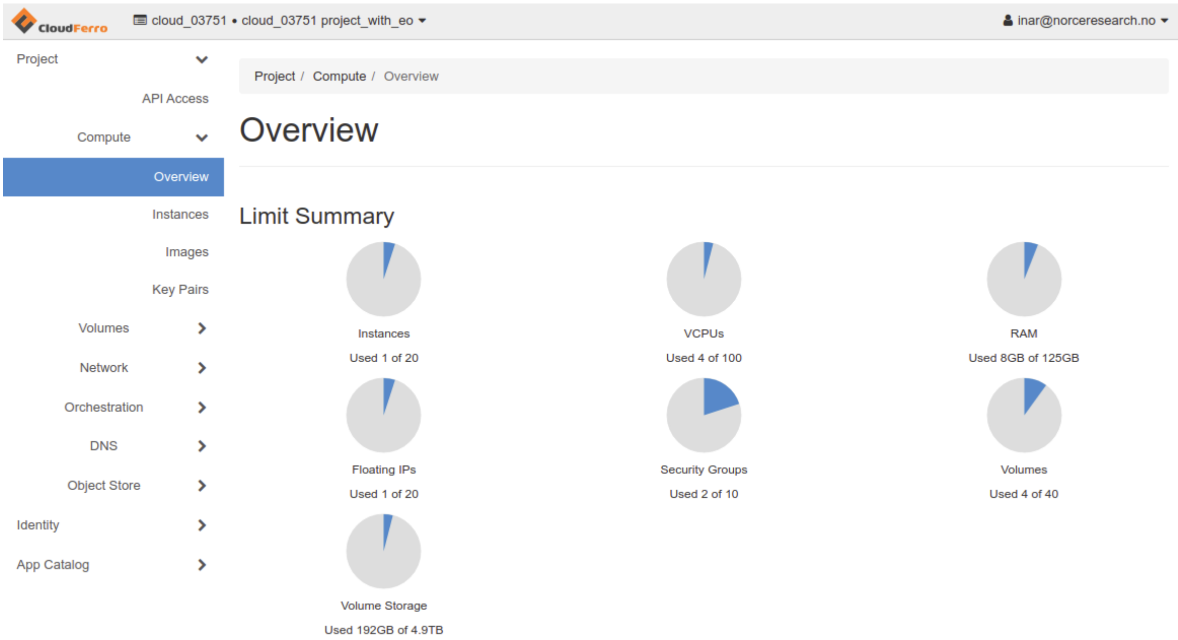

Figure 20. Screenshot of the overview of the cloud setup for the SAR4Africa processing line.

Processing line setup

The virtual machine was prepared for SAR4Africa processing by installing conda and GDAR (Generic Data Raster). GDAR is a Python programming toolkit for processing and geocoding of satellite data (and other types of raster data), developed and maintained by NORCE. Some modifications were also necessary for the SAR4Africa processing line; in particular, during processing the relevant satellite products for a given area had to be downloaded from the sentinel data catalogue and into the temporary SSD disk for effective processing.

Limitations

The pipeline is not yet set up to take advantage of search capabilities available on the platform. Instead, the processing starts with a manually prepared product list for the given area. This implies a certain manual task associated with starting processing for a given area. The processing line also runs sequentially on a single node, with the exception of geocoding function which was able to exploit the 4 CPU's in parallel. This implies that there is much to gain in efficiency and processing speed, by allowing for a greater level of parallelisation. The processing line will need restructuring to allow for such improvements.

6.2. Processing

Results

The test processing was performed for a small area in Ghana, 1000x1000 pixels of resolution 20m, thus covering 400 km^2 (Figure 21). The processing started with 264 Sentinel-1 GRD satellite products from the complete Ghana 2019 dataset, from 123 different satellite passes, out of which 46 passes are relevant for the specific area of interest, each pass including 2 relevant scenes, yielding a total number of 92 products as input to geocoding. Within each product, only the part intersecting the area of interest was actually geocoded. In total, the process (including geocoding) generated 2.8GB of data for this test area. Based on the geocoded and pre-processed data, mosaics and statistics were made for 2019, totalling 0.9 GB of data. Test results are in agreement with in-house processing results.

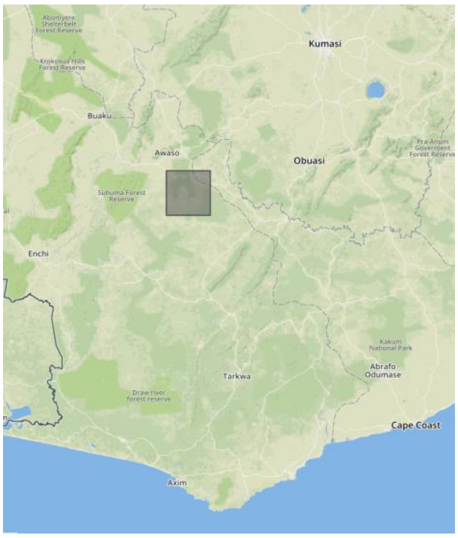

Figure 21. Test area processed on the cloud platform CreoDIAS.

Processing time

The processing line is not optimised for speed at this time (see limitations). Pre-processing and geocoding of 46 satellite passes took about 3 minutes each, for a 1000x1000 pixel area, finishing in about 3 hours. Generating statistics took another 2 hours.

Costs - processing and storage

Pricing models for the CreoDIAS platform [https://creodias.eu/billing-models, https://creodias.eu/price-list] may be quite involved, based on detailed recordings of reserved capacity as well as minute by minute resource consumption.

With the per usage pricing model, one pays primarily for the selected VM type and storage space.

- VM type eo1.large at the cost of 0.098 Euro/hour.
- 16 GB of SSD storage, at a price of 16*0.0001389 = 0.0022 Euro/hour,
- 128 GB of HDD storage, at a price of 128*0.0000556 = 0.0071 Euro/hour.

The actual processing took 5 hours, totalling about 0.5 Euro.

However, the actual cost measurement runs around the clock, and includes the time spent on configuration and development. Therefore, the cost for setting up and running this experiment is more reasonably reflected by the monthly bill for February 2019, which totalled at 20.80 Euro. To exploit the capabilities of such a computing platform more effectively, to measures are particularly important.

- Automated setup, configuration and management. By turning off services and having them turned on only when work is to be done, is a key to keeping costs down.
- Effective code ensures that processing times are not unnecessary long. For instance, in the current implementation there is no interleave between IO intensive work and CPU's intensive tasks, implying that the costly CPU will spend a significant amount of time waiting.

7. Users service and products assessment

ESA's Service Assessment Sheet (SAS) template has been used to allow collection of the users' service and product assessment. The SAS collects feed-back on the following 5 point:

- Assessment of the users' requirements
- Product compliance
- Utility assessment
- Future outlook
- Overall evaluation.

Some additional feedback was given via email or though tele-conferencing. The users' feedbacks are summarized in the following. The individual service assessment sheets from each user are available on demand.

7.1. Assessment of the user requirements

The user's requirements were agreed on in a user requirement documents (URD). It was considered clear and adequate by the users. It captured well the users' needs, clearly informed about the projects purpose and clearly described the specification of the Sentinel-1 products to be delivered.

7.2. Product compliance

Overall product compliance to the user requirements

All users agreed that the products met all the user requirements on data format, compression and delivery. It was even mentioned that the products exceed the requirements and the products have a good geolocation accuracy, good topographic correction and good spatio-temporal detail.

Product accuracy compliance to the user requirements

The users assessed also the product accuracy to be fully compliant with the user requirements and some mentioned that the accuracy was better than the products that they currently use.

Confidence in the product quality (including accuracy)

Overall, the users assessed the quality good to excellent and seemingly of higher quality that they are used to from their own processing. The delivered products appeared to have better terrain flattening in higher elevated areas than their in-house processed SAR data. It was also mentioned that the generated products present a much better visualization and output with reduced speckle compared to their in-house products. Spatial accuracy aligned well with their own products and expected trends/relationships of the SAR response to biomass are on-par with independent processing (see 5.4.)

The products are applicable for land use and land cover classification and forest monitoring.

7.3. Utility assessment

The individual responses of the users are stated per country below and reflect both the **benefit of the demonstrated service and products** and the **impact of the service and products on current end-user practices**:

DRC:

"The data received cover the entire selected area which is the Mai-Ndombe province's in the west part of the Democratic Republic of Congo. The spatial resolution is more suitable (20m) than Landsat (30m). This is very convenient for our routine forest monitoring analysis (deforestation and forest degradation). These data will be very beneficial for REDD projects in the Congo Basin." (OSFAC)

Ethiopia:

"The current analysis ready data products can benefit us through providing unavailable optical data for continuous monitoring forests in our project area. This data minimized the limitations we have in using optical data during cloudy seasons of the year." (ESSTI)

Ghana:

NASA CEOS responded that "the processed S1 data into monthly mean products allows easy use of this data for user applications. Having this data in analysis-ready data format saves the user a significant amount of time and complexity and will greatly increase the use of such data. Typical end-users in Africa would not use S1 data due the complexity of preparation. With these new datasets, users have been able to explore the potential of using S1 for studies on land change, water extent, agriculture phenology, and land classification."

CERSGIS states that "the monthly averaged- mosaics will improve the temporal resolution of our web-based system which is presently based on a yearly monitoring to map and monitor illegal mining (Galamsey) operations in the forest region of Ghana and other parts when upscaled. Presently, the Galamsey mapping and monitoring platform has not yet been deployed to end-users. The aim of this platform is to support institutional strategies to control illegal mining activities. Feedback from end – users in relation to the data will be captured and made available."

The Ghana data has been ingested in the African Regional Data Cube accessible at **http://52.54.26.108**, as well as in a dedicated Sentinel-1 Change Detection website at http://tinyurl.com/ardcs1demo .

Malawi and South Africa:

CSIR shared the products with two students who used the products in their biomass/land cover change related research. Not being proficient in SAR/SAR processing, the students were grateful for the ARD products, which would assist their entry into the SAR research domain. The products have not yet had an impact on the CSIR operations, but the products present an easier entry point for students wishing to get involved in SAR research

7.4. Future outlook

The users have been asked to provide information about

- the probability of a service integration into existing practices,
- desired service and/or products improvements, and
- need for large-scale service/product demonstration.

DRC:

"Analysis can be conducted to fill gaps from Landsat data. Radar data will help in a lot of researches regarding its potentials to provide cloud-free data. However, the availability of specific tools for radar data remains a necessity. Large-scale service and product still being a general need for the continuation for the data dissemination in the Congo Basin." (OSFAC)

Ethiopia:

ESSTI has a plan to integrate ground data, optical data and this analysis ready data for providing better services and products. They would like to get data that covers the entire country due to their limitation in accessing and downloading big data from the internet.

Ghana:

NASA CEOS: Though there is extreme value in using such monthly mean products, there is uncertainty about how such products can be routinely produced at large scales. There is a cost and complexity that is quite high for users but may be possible for the data providers or larger satellite data agencies. After significant testing, it is believed the most used product is the simply monthly mean VV and VH data. NDI and other statistical data could be derived from these monthly mean data. It is suggested that the data be separated into monthly mean VV and VH products and then a separate dataset that includes metadata such as number of measurements or mask data. Increased use of these products will demand that they be available on country-level scales to that users can create application products within their region of interest.

CERSGIS: The product can assist CERSGIS to monitor and quantify the land use/cover changes on a monthly basis. In recent times, Galamsey operation have been reported to be on-going in Northern Ghana. It will be nice to have products that cover other parts of Ghana. Products should be made available in Google Earth Engine or housed in a dedicated cloud storage for easy accessibility by all users.

Malawi and South Africa:

CSIR: "It is unlikely that the products will be integrated into existing practices in the short-term, but this is not indicative of the quality of the service/products. Weekly or bi-monthly data may be useful in agricultural settings, but we are aware of the processing/logistical constraints of such a task. There is no need for a large-scale demonstration as yet."

7.5. Overall Evaluation

DRC:

Sentinel Analysis Ready Data may be more benefit if we can get them yearly as well as Landsat data. If NORCE could make it possible that would be better. The Congo Basin is the second largest tropical rainforest in the world. Having yearly cover of radar data will be very beneficial for science and environment studies.

Ethiopia:

We are happy in getting the analysis ready data for the current project area. However, it is also equally important to get technical support for better utilization of Sentinel 1 raw datasets. We appreciate the open access policy of ESA for all of its satellite images

Ghana:

NASA CEOS: Overall, this dataset has shown the extreme value of S1 ARD and its potential use for a broad set of users. Currently, ESA does not provide S1 data in ARD format and pre-processed backscatter intensity. It is believed that this ARD product is the most usable format and one that would show great utility for the largest and most diverse set of users around the world. It is suggested that ESA make such products routinely available for user access. Monthly mean VV and VH data would be extremely valuable.

CERSGIS: Generally, the product has been found useful. It renders very fast whiles interacting with it, border noise has been well dealt with, and using NDI in RGB composites produces a better visualization. European Space Agency mission to provide free and accessible earth observation data can improve if they could organize more capacity building programs that seek to improve user knowledge in the pre – processing and utilization of SAR for environmental applications.

Given the higher accuracy of ESA datasets compared to other open source datasets, it will be interesting to have ready to use products on vegetation cover, water, land use land cover, etc.

Malawi and South Africa:

CSIR: We feel programmes such as this one, which are able to reduce/remove the barrier of entry (or 'fear factor') for using SAR, are very important. The products delivered appear to be of a high quality and are very easy to understand and use. We have just unfortunately not been able to use them to their potential. Products such as these may show their greatest potential in domains that experience rapid change (i.e. logging), or where there is a longer time-series at more regional scales (i.e. National/Regional-scale bush encroachment). Anecdotally, we noticed the good differentiation of plantation forest species/ages in the SAR composites, something that was not as evident in Sentinel-2 optical data. This supports the SAR signal's known sensitivity to forest structure differences and may be useful in the discrimination of forest types and/or in the monitoring of growth cycles.

8. Conclusion and Outlook

The project proposed monthly and yearly averaged VV/VH/NDI backscatter mosaics and statistical analysis data as Advanced Sentinel-1 Analysis Ready Data products to users for five African countries. The whole Sentnel-1 archive from the launch of Sentinel-1 until December 2019 over five 2^0 latitude x 2^0 longitude demonstration sites were processed in three deliveries. A first delivery of the year 2017 and 2018 in March 2019 gave the users the possibility to provide critical and constructive feedback and review the definition of the ASARD products. Deliver mosaics on shorter timescales, f.e. 12 days orbit cycle, was suggested. That would however more than double the data delivery in size and for regions with only one ascending or descending acquisition from one satellite mean little improvement to single scene data. The original definition was therefore kept and all additional archived data from 2014-2016 and the year 2019 was the processed and delivered. The processing line however was improved in the process.

Monthly data average 2-3 acquisitions if only one satellite is used, and acquisitions only taken on ascending or descending paths and up to theoretically 12 acquisitions if both satellites acquire in both ascending and descending orbits. If the seasonality is mainly driven by a wet and a dry season, averaging over the wet months or the dry months could therefore reduce the data further and eliminate monthly variability and further reduce the speckle. Changes between two time periods, like deforestation or flooding can be easily detected by subtracting two images in either VV, VH or both polarizations. If seasonality is reflected on monthly time steps, f.e. agriculture, the 12 monthly data sets could also be used as a time series for classification purposes.

The annex provides the meta data of the Sentinel-1 acquisition for each site specifying the dates and location of each acquisition. The users are invited to consider these meta data information when using and assessing the ASARD products.

This report also showed several applications that the users were interested in and where such data would provide essential input data. As stated in the individual service and products assessment sheets, there was a clear overall agreement by the users that such ASARD data is an important step to overcome technical and human challenges and to boost the use of Sentinel-1 in Africa. All users agreed that such data should be available operationally on a global scale.

Finally, the ASARD processing line was successfully tested to be run in the cloud on CreoDIAS, one of Copernicus' Data and Information Access Services. It is therefore be fully possible to offer such a service on a larger scale and integrate them f.e. also in open data cubes. Fully automatic cloud implementation however needs further work. The Ghana ASARD data has already been ingested in the African Regional Data Cube by NASA CEOS.

9. License, dissemination and contact information

9.1. License to use and distribute the products

This pilot service is funded through the European Space Agency's (ESA) EO Science for Society EOEP-5 BLOCK 4 program and all the products hereby mentioned are developed free of charge to the users in the context of the SAR-4-Africa (ESA-Norut contract "Advanced Sentinel-1 Analysis Ready Data for Africa") project. The right of use does not include right to license the products, but the service provider NORCE and the users are however free to share and disseminate the product to third parties under the following conditions:

- The User agrees to inform the Service Provider (see contact information below) about their and potentially 3rd parties use of the ASARD products and provide this also as basis for further input for the service and product assessment sheets to potentially improve the service.
- The Users and potential 3rd-party users agree to acknowledge the data (ESA/Copernicus) and service provider (NORCE) when the data and products are used, shared with third parties, published or disseminated in any other kind by stating

"Contains modified Copernicus Sentinel-1 data [year], processed by NORCE (Tromsø, Norway) under ESA contract No. 4000125675/18/I-NB".

- For scientific publications, offers of co-authorships would be highly appreciated if results from this project have been used and are of relevance.

9.2. Contact information

For any questions regarding this project, use of the data for scientific publication, potential co-authorships, please contact:

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P.O.Box 6434
N-9294 Tromsø
Norway
Tel.: +47 47070341
Email: jrha@norceresearch.no

10. Dissemination Activities and Package

The project has been presented at several occasions and the data products could be made available by contacting the contractor via the following:

10.1. Website

A project website has been established with google sites, available at:

https://sites.google.com/view/sar-4-africa/home

10.2. Scientific presentations and reports.

The project has been presented internationally on several occasions. A list of the presentation titles and events follows in chronological order:

- Haarpaintner, J., B. D. Killough, S. Ampofo Ofori and E.O. Boamah (2018). Advanced Sentinel-1 Analysis Ready Data for the Ghana Open Data Cube and Environmental Monitoring. *Oral presentation at 7th International Workshop on Retrieval of Bio- & Geo-physical Parameters from SAR Data for Land Applications, Oberpfaffenhofen, Germany, 12-15 November 2018.*
- Haarpaintner, J. (2019). D3.1 - Initial ASARD Product Report, Delivery 3.1 of ESA EO4SD project SAR-4-Africa, April 2019.
- Haarpaintner, J., B. Killough, R. Mathieu, L. Mane, B. Gessesse Awoke (2019). Advanced Sentinel-1 Analysis Ready Data for Africa. *Presentation at 'ESA Living Planet Symposium 2019', Milan, Italy, 13-17 May 2019.*
- Haarpaintner, J. (2019). Radar Remote Sensing for Africa and some Applications in the North. *Oral presentation at NORCE Climate Science Day, Bergen, Norway, 20 June 2019.*
- Haarpaintner, J., H. Hindberg, T.G. Yitayew, B.D. Killough, R. Mathieu, L. Mane, B. Gessesse Awoke, S. Ofori-Ampofo, E. Boamah (2019). Time-Series and Applications of Advanced Sentinel-1 Analysis Ready Data for Africa (SAR-4-Africa). *Oral presentation at joint meeting of the 21st William T. Pecora Memorial Remote Sensing Symposium (Pecora 21) and the 38th International Symposium on Remote Sensing of Environment (ISRSE-38), Baltimore (MD), USA, 6-10 Oct. 2019.*
- Haarpaintner, J., B.D. Killough, S. Ofori-Ampofo, and E. Boamah (2019). Galamsey Monitoring with Sentinel-1 in Ghana. *Oral presentation at joint meeting of the 21st William T. Pecora Memorial Remote Sensing Symposium (Pecora 21) and the 38th International Symposium on Remote Sensing of Environment (ISRSE-38), Baltimore (MD), USA, 6-10 Oct. 2019.*
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presentation at Very High-resolution Radar & Optical Data Assessment (VH-RODA) and CEOS WGCV SAR 2019 workshop, Frascati, Italy,18–22 November 2019.

10.3. Bilateral skype meetings and email exchange with users

A common user workshop was intended at the end of the project, where each user could present their use of these products. Unfortunately, because of low availabilities, several user staff change, and limited project time, it seemed to be difficult for all users to fully use the products to their potential yet. Therefore, instead of the common workshop, bilateral skype discussion were led with all available users in the middle and end of the project.

From May to September, bilateral skype discussion had the aim to ensure that all 2017-2018 products have been downloaded, were fully accessible to all users and resolve any other issues. Bilateral discussions were led with all users, but one. Email exchange has happened with all users though.

Finally, in March 2020, final skype meetings and discussion were held. At the point of writing, fruitful discussions were led with CSIR and CERSGIS with the aim to continue cooperation in the future.

We still foresee some more discussion with the other users (OSFAC, ESSTI and CEOS) in the future. There have been several occasions at conference to discuss with NASA CEOS.

All users have confirmed by written that the products have been download and NORCE will be available for further discussion beyond the end of the project.

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12. ANNEX 1: Meta data for DRC

Service Area

The area of interest (AOI) is in the southwest of the Equator province in the Democratic Republic of Congo (DRC) inside the rectangle with the geographic coordinates:

NW-corner: 0°46.5'N, 17°50.0'E
NE-corner: 0°46.5'N, 19°50.0'E
SE-corner: 1°13.5'S, 19°50.0'E
SW-corner: 1°13.5'S, 17°50.0'E
The town Mbandaka is in the west of the AOI. The AOI is shown in Figure 22.

The satellite paths over the AOI are descending paths 036 and 109 acquired by S1A.

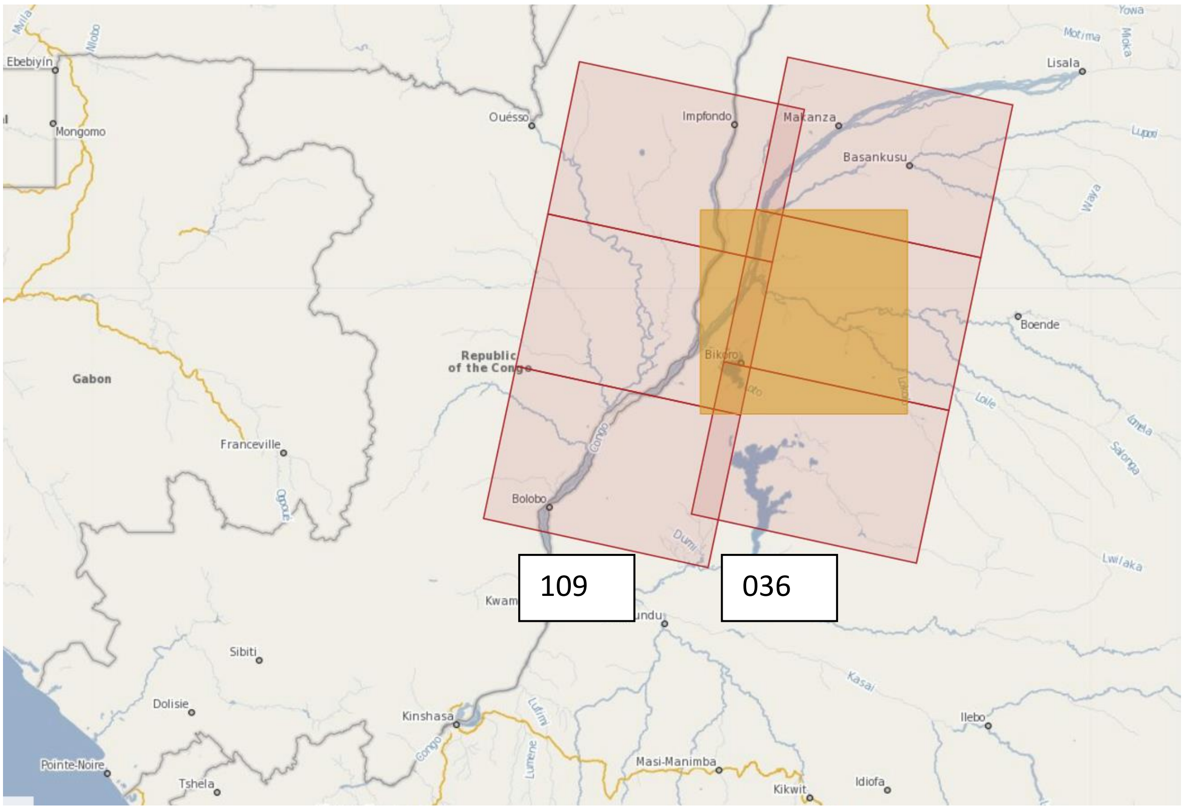

Figure 22. Service Area in the Democratic Republic of Congo in orange with S1A satellite paths acquired.

Table 5 to Table 7 detail the satellite, the date, the flying direction and the path number of each acquisition over the site in DRC for the years 2015-2019.

Table 5. 2015-2016 Sentinel-1 acquisitions over the demonstration site in DRC.

	Jan 2015 - Dec 2015					Jan 2016 - Dec 2016			
	SAT	**DATE**	**DIR**	**Path**		**SAT**	**DATE**	**DIR**	**Path**
1	S1A	20150406	DES	36	1	S1A	20160417	DES	109
2	S1A	20150411	DES	109	2	S1A	20160429	DES	109
3	S1A	20150529	DES	109	3	S1A	20160511	DES	109
4	S1A	20150622	DES	109	4	S1A	20160523	DES	109
5	S1A	20150704	DES	109	5	S1A	20160611	DES	36
6	S1A	20150716	DES	109	6	S1A	20160616	DES	109
7	S1A	20150809	DES	109	7	S1A	20160628	DES	109
8	S1A	20150821	DES	109	8	S1A	20160710	DES	109
9	S1A	20150902	DES	109	9	S1A	20160722	DES	109
10	S1A	20150914	DES	109	10	S1A	20160803	DES	109
11	S1A	20150926	DES	109	11	S1A	20160815	DES	109
12	S1A	20151008	DES	109	12	S1A	20160827	DES	109
13	S1A	20151113	DES	109	13	S1A	20160908	DES	109
14	S1A	20151125	DES	109	14	S1A	20160920	DES	109
15	S1A	20151202	DES	36	15	S1A	20161002	DES	109
16	S1A	20151207	DES	109	16	S1A	20161009	DES	36
17					17	S1A	20161014	DES	109
18					18	S1A	20161026	DES	109
19					19	S1A	20161102	DES	36
20					20	S1A	20161107	DES	109
21					21	S1A	20161119	DES	109
22					22	S1A	20161126	DES	36
23					23	S1A	20161201	DES	109
24					24	S1A	20161213	DES	109
25					25	S1A	20161220	DES	36
26					26	S1A	20161225	DES	109
27					27				
28					28				
29					29				
30					30				
31					31				
32					32				
33					33				
34					34				
35					35				
36					36				
37					37				
38					38				
39					39				
40					40				

Table 6. 2017-2018 Sentinel-1 acquisitions over the demonstration site in DRC.

	Jan 2017 - Nov 2017					Nov 2017 - Sep 2018					Sep 2018 - Dec 2018			
	SAT	DATE	DIR	Path		SAT	DATE	DIR	Path		SAT	DATE	DIR	Path
1	S1A	20170106	DES	109	41	S1A	20170910	DES	36	81	S1A	20180508	DES	36
2	S1A	20170113	DES	36	42	S1A	20170915	DES	109	82	S1A	20180513	DES	109
3	S1A	20170118	DES	109	43	S1A	20170922	DES	36	83	S1A	20180520	DES	36
4	S1A	20170130	DES	109	44	S1A	20170927	DES	109	84	S1A	20180525	DES	109
5	S1A	20170206	DES	36	45	S1A	20171004	DES	36	85	S1A	20180601	DES	36
6	S1A	20170211	DES	109	46	S1A	20171009	DES	109	86	S1A	20180606	DES	109
7	S1A	20170218	DES	36	47	S1A	20171016	DES	36	87	S1A	20180613	DES	36
8	S1A	20170223	DES	109	48	S1A	20171021	DES	109	88	S1A	20180618	DES	109
9	S1A	20170302	DES	36	49	S1A	20171028	DES	36	89	S1A	20180625	DES	36
10	S1A	20170307	DES	109	50	S1A	20171102	DES	109	90	S1A	20180630	DES	109
11	S1A	20170314	DES	36	51	S1A	20171109	DES	36	91	S1A	20180707	DES	36
12	S1A	20170319	DES	109	52	S1A	20171114	DES	109	92	S1A	20180712	DES	109
13	S1A	20170326	DES	36	53	S1A	20171121	DES	36	93	S1A	20180719	DES	36
14	S1A	20170331	DES	109	54	S1A	20171126	DES	109	94	S1A	20180724	DES	109
15	S1A	20170407	DES	36	55	S1A	20171203	DES	36	95	S1A	20180731	DES	36
16	S1A	20170412	DES	109	56	S1A	20171208	DES	109	96	S1A	20180805	DES	109
17	S1A	20170419	DES	36	57	S1A	20171215	DES	36	97	S1A	20180812	DES	36
18	S1A	20170424	DES	109	58	S1A	20171220	DES	109	98	S1A	20180817	DES	109
19	S1A	20170501	DES	36	59	S1A	20171227	DES	36	99	S1A	20180824	DES	36
20	S1A	20170506	DES	109	60	S1A	20180101	DES	109	100	S1A	20180905	DES	36
21	S1A	20170513	DES	36	61	S1A	20180108	DES	36	101	S1A	20180910	DES	109
22	S1A	20170518	DES	109	62	S1A	20180113	DES	109	102	S1A	20180917	DES	36
23	S1A	20170525	DES	36	63	S1A	20180120	DES	36	103	S1A	20180922	DES	109
24	S1A	20170530	DES	109	64	S1A	20180125	DES	109	104	S1A	20180929	DES	36
25	S1A	20170606	DES	36	65	S1A	20180201	DES	36	105	S1A	20181004	DES	109
26	S1A	20170611	DES	109	66	S1A	20180206	DES	109	106	S1A	20181011	DES	36
27	S1A	20170618	DES	36	67	S1A	20180213	DES	36	107	S1A	20181016	DES	109
28	S1A	20170623	DES	109	68	S1A	20180218	DES	109	108	S1A	20181023	DES	36
29	S1A	20170630	DES	36	69	S1A	20180225	DES	36	109	S1A	20181028	DES	109
30	S1A	20170705	DES	109	70	S1A	20180302	DES	109	110	S1A	20181104	DES	36
31	S1A	20170712	DES	36	71	S1A	20180309	DES	36	111	S1A	20181109	DES	109
32	S1A	20170717	DES	109	72	S1A	20180314	DES	109	112	S1A	20181116	DES	36
33	S1A	20170724	DES	36	73	S1A	20180321	DES	36	113	S1A	20181121	DES	109
34	S1A	20170729	DES	109	74	S1A	20180326	DES	109	114	S1A	20181128	DES	36
35	S1A	20170805	DES	36	75	S1A	20180402	DES	36	115	S1A	20181203	DES	109
36	S1A	20170810	DES	109	76	S1A	20180407	DES	109	116	S1A	20181215	DES	109
37	S1A	20170817	DES	36	77	S1A	20180414	DES	36	117	S1A	20181222	DES	36
38	S1A	20170822	DES	109	78	S1A	20180419	DES	109	118	S1A	20181227	DES	109
39	S1A	20170829	DES	36	79	S1A	20180426	DES	36	119				
40	S1A	20170903	DES	109	80	S1A	20180501	DES	109	120				

Table 7. 2019 Sentinel-1 acquisitions over the demonstration site in DRC.

	Jan 2019 - Aug 2019					Aug 2019 - Dec 2019			
	SAT	DATE	DIR	Path		SAT	DATE	DIR	Path
1	S1A	20190103	DES	36	41	S1A	20190831	DES	36
2	S1A	20190108	DES	109	42	S1A	20190905	DES	109
3	S1A	20190115	DES	36	43	S1A	20190912	DES	36
4	S1A	20190120	DES	109	44	S1A	20190917	DES	109
5	S1A	20190127	DES	36	45	S1A	20190924	DES	36
6	S1A	20190201	DES	109	46	S1A	20190929	DES	109
7	S1A	20190208	DES	36	47	S1A	20191006	DES	36
8	S1A	20190213	DES	109	48	S1A	20191011	DES	109
9	S1A	20190220	DES	36	49	S1A	20191018	DES	36
10	S1A	20190225	DES	109	50	S1A	20191023	DES	109
11	S1A	20190304	DES	36	51	S1A	20191030	DES	36
12	S1A	20190309	DES	109	52	S1A	20191104	DES	109
13	S1A	20190316	DES	36	53	S1A	20191111	DES	36
14	S1A	20190321	DES	109	54	S1A	20191116	DES	109
15	S1A	20190328	DES	36	55	S1A	20191123	DES	36
16	S1A	20190402	DES	109	56	S1A	20191128	DES	109
17	S1A	20190409	DES	36	57	S1A	20191205	DES	36
18	S1A	20190414	DES	109	58	S1A	20191210	DES	109
19	S1A	20190421	DES	36	59	S1A	20191217	DES	36
20	S1A	20190426	DES	109	60	S1A	20191222	DES	109
21	S1A	20190503	DES	36	61	S1A	20191229	DES	36
22	S1A	20190508	DES	109					
23	S1A	20190515	DES	36					
24	S1A	20190520	DES	109					
25	S1A	20190527	DES	36					
26	S1A	20190601	DES	109					
27	S1A	20190608	DES	36					
28	S1A	20190613	DES	109					
29	S1A	20190620	DES	36					
30	S1A	20190625	DES	109					
31	S1A	20190702	DES	36					
32	S1A	20190707	DES	109					
33	S1A	20190714	DES	36					
34	S1A	20190719	DES	109					
35	S1A	20190726	DES	36					
36	S1A	20190731	DES	109					
37	S1A	20190807	DES	36					
38	S1A	20190812	DES	109					
39	S1A	20190819	DES	36					
40	S1A	20190824	DES	109					

13. ANNEX 2: Meta data for Ethiopia

Service Area

The AOI in Ethiopia is the Yayu-Bonga Forest Reserve included in the 2°x2° lat/lon area with the following borders:

North border:	8.6° N
South border:	6.6° N
West border:	34.65° E
East border:	36.65° E

The AOI is shown in Figure 23.

The satellite paths covering the AOI are descending paths 050 and 152 acquired by S1A.

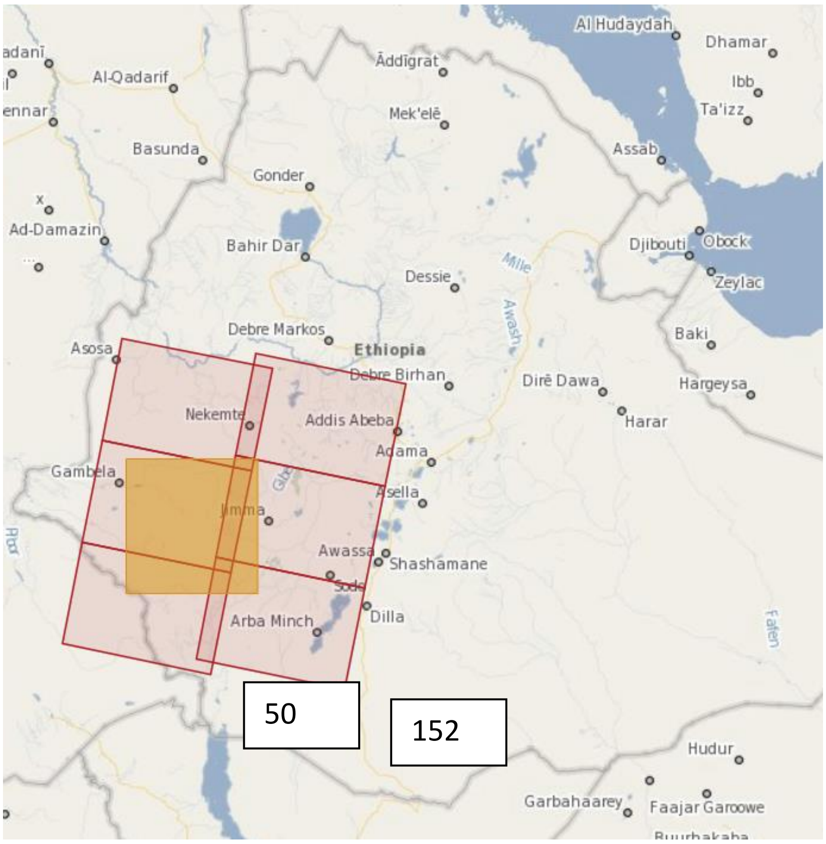

Figure 23. Service Area in Ethiopia in orange with S1A satellite paths acquired.

Table 8 to Table 10 detail the satellite, the date, the flying direction and the path number of each acquisition over the site in Ethiopia for the years 2014-2019.

Table 8. 2014-2016 S1 acquisitions over the demonstration site in Ethiopia.

Jan 2014 - Dec 2014					Jan 2015 - Dec 2015					Jan 2016 - Dec 2016			
SAT	DATE	DIR	Path		SAT	DATE	DIR	Path		SAT	DATE	DIR	Path
S1A	20141225	ASC	131	1	S1A	20150101	ASC	58	1	S1A	20160120	DES	50
				2	S1A	20150113	DES	50	2	S1A	20160408	DES	152
				3					3	S1A	20160531	DES	50
				4					4	S1A	20160713	DES	152
				5					5	S1A	20160928	DES	50
				6					6	S1A	20161005	DES	152
				7					7	S1A	20161022	DES	50
				8					8	S1A	20161029	DES	152
				9					9	S1A	20161115	DES	50
				10					10	S1A	20161122	DES	152
				11					11	S1A	20161209	DES	50
				12					12	S1A	20161216	DES	152
				13					13				
				14					14				
				15					15				
				16					16				
				17					17				
				18					18				
				19					19				
				20					20				
				21					21				
				22					22				
				23					23				
				24					24				
				25					25				
				26					26				
				27					27				
				28					28				
				29					29				
				30					30				
				31					31				
				32					32				
				33					33				
				34					34				
				35					35				
				36					36				
				37					37				
				38					38				
				39					39				
				40					40				

Table 9. 2017-2018 S1 acquisitions over the demonstration site in Ethiopia.

	Jan 2017 - Oct 2017					Oct 2017 - Jul 2018					Jul 2018 - Dec 2018			
	SAT	DATE	DIR	Path		SAT	DATE	DIR	Path		SAT	DATE	DIR	Path
1	S1A	20170102	DES	50	41	S1A	20171017	DES	50	81	S1A	20180720	DES	50
2	S1A	20170109	DES	152	42	S1A	20171024	DES	152	82	S1A	20180727	DES	152
3	S1A	20170126	DES	50	43	S1A	20171029	DES	50	83	S1A	20180801	DES	50
4	S1A	20170202	DES	152	44	S1A	20171105	DES	152	84	S1A	20180808	DES	152
5	S1A	20170207	DES	50	45	S1A	20171110	DES	50	85	S1A	20180820	DES	152
6	S1A	20170214	DES	152	46	S1A	20171117	DES	152	86	S1A	20180825	DES	50
7	S1A	20170226	DES	152	47	S1A	20171122	DES	50	87	S1A	20180901	DES	152
8	S1A	20170303	DES	50	48	S1A	20171129	DES	152	88	S1A	20180913	DES	152
9	S1A	20170310	DES	152	49	S1A	20171204	DES	50	89	S1A	20180918	DES	50
10	S1A	20170315	DES	50	50	S1A	20171211	DES	152	90	S1A	20180925	DES	152
11	S1A	20170322	DES	152	51	S1A	20171216	DES	50	91	S1A	20181007	DES	152
12	S1A	20170327	DES	50	52	S1A	20171223	DES	152	92	S1A	20181012	DES	50
13	S1A	20170403	DES	152	53	S1A	20180104	DES	152	93	S1A	20181019	DES	152
14	S1A	20170408	DES	50	54	S1A	20180109	DES	50	94	S1A	20181031	DES	152
15	S1A	20170415	DES	152	55	S1A	20180116	DES	152	95	S1A	20181112	DES	152
16	S1A	20170502	DES	50	56	S1A	20180121	DES	50	96	S1A	20181124	DES	152
17	S1A	20170514	DES	50	57	S1A	20180128	DES	152	97	S1A	20181218	DES	152
18	S1A	20170521	DES	152	58	S1A	20180209	DES	152	98	S1A	20181223	DES	50
19	S1A	20170526	DES	50	59	S1A	20180214	DES	50	99	S1A	20181230	DES	152
20	S1A	20170602	DES	152	60	S1A	20180221	DES	152					
21	S1A	20170614	DES	152	61	S1A	20180226	DES	50					
22	S1A	20170619	DES	50	62	S1A	20180305	DES	152					
23	S1A	20170626	DES	152	63	S1A	20180310	DES	50					
24	S1A	20170701	DES	50	64	S1A	20180317	DES	152					
25	S1A	20170708	DES	152	65	S1A	20180403	DES	50					
26	S1A	20170713	DES	50	66	S1A	20180410	DES	152					
27	S1A	20170720	DES	152	67	S1A	20180415	DES	50					
28	S1A	20170725	DES	50	68	S1A	20180422	DES	152					
29	S1A	20170801	DES	152	69	S1A	20180427	DES	50					
30	S1A	20170806	DES	50	70	S1A	20180504	DES	152					
31	S1A	20170813	DES	152	71	S1A	20180509	DES	50					
32	S1A	20170818	DES	50	72	S1A	20180516	DES	152					
33	S1A	20170825	DES	152	73	S1A	20180521	DES	50					
34	S1A	20170906	DES	152	74	S1A	20180528	DES	152					
35	S1A	20170911	DES	50	75	S1A	20180609	DES	152					
36	S1A	20170918	DES	152	76	S1A	20180621	DES	152					
37	S1A	20170923	DES	50	77	S1A	20180626	DES	50					
38	S1A	20170930	DES	152	78	S1A	20180703	DES	152					
39	S1A	20171005	DES	50	79	S1A	20180708	DES	50					
40	S1A	20171012	DES	152	80	S1A	20180715	DES	152					

Table 10. 2019 S1 acquisitions over the demonstration site in Ethiopia.

	Jan 2019 - Dec 2019			
	SAT	DATE	DIR	Path
1	S1A	20190104	DES	50
2	S1A	20190111	DES	152
3	S1A	20190116	DES	50
4	S1A	20190123	DES	152
5	S1A	20190216	DES	152
6	S1A	20190324	DES	152
7	S1A	20190405	DES	152
8	S1A	20190417	DES	152
9	S1A	20190429	DES	152
10	S1A	20190511	DES	152
11	S1A	20190516	DES	50
12	S1A	20190523	DES	152
13	S1A	20190528	DES	50
14	S1A	20190604	DES	152
15	S1A	20190609	DES	50
16	S1A	20190616	DES	152
17	S1A	20190628	DES	152
18	S1A	20190703	DES	50
19	S1A	20190710	DES	152
20	S1A	20190722	DES	152
21	S1A	20190727	DES	50
22	S1A	20190803	DES	152
23	S1A	20190808	DES	50
24	S1A	20190827	DES	152
25	S1A	20190901	DES	50
26	S1A	20190908	DES	152
27	S1A	20190913	DES	50
28	S1A	20190920	DES	152
29	S1A	20190925	DES	50
30	S1A	20191002	DES	152
31	S1A	20191014	DES	152
32	S1A	20191026	DES	152
33	S1A	20191031	DES	50
34	S1A	20191107	DES	152
35	S1A	20191112	DES	50
36	S1A	20191201	DES	152
37	S1A	20191213	DES	152
38	S1A	20191225	DES	152

14. ANNEX 3: Meta data for Ghana

Service Area

The area of interest (AOI) is in the south Ghana inside the rectangle with the geographic coordinates:

NW-corner: 7°0.0'N, 2°24.0'W
NE-corner : 7°0.0'N, 0°24.0'W
SE-corner: 5°0.0'N, 0°24.0'W
SW-corner: 5°0.0'N, 2°24.0'W

The AOI is shown in Figure 24.

The satellite paths covering the AOI are ascending paths 045 and 147 acquired by S1A and from October 2017 also by S1B.

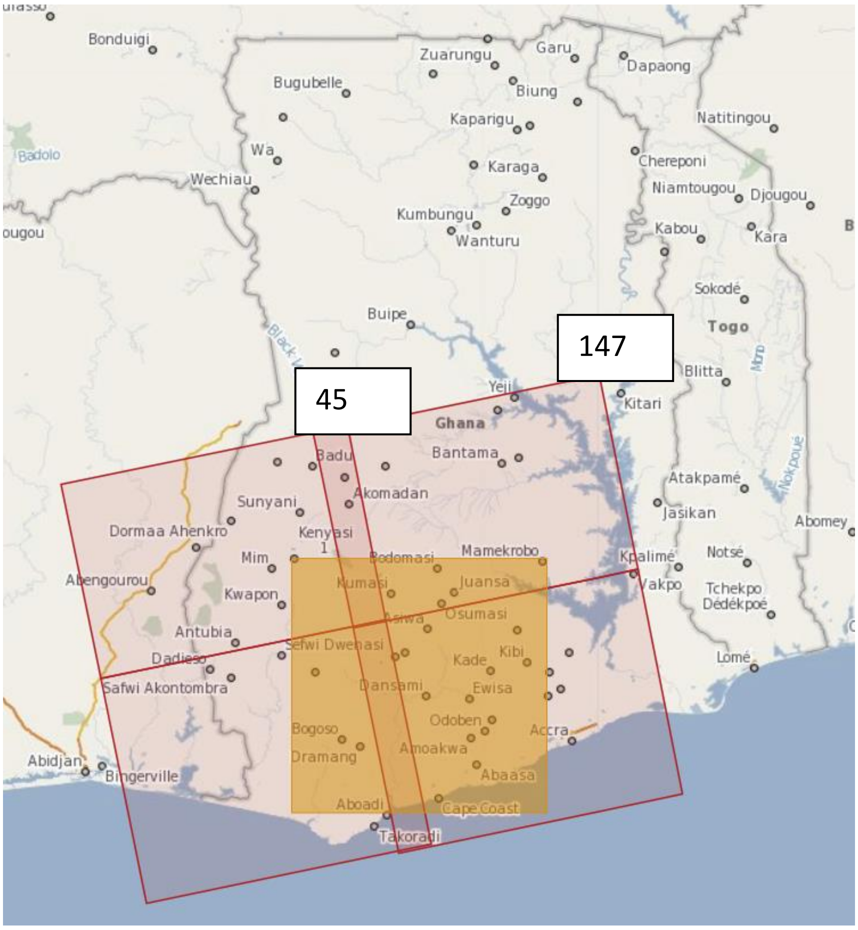

Figure 24. Service Area in Ghana in orange with S1 satellite paths acquired.

Table 11 to Table 13 detail the satellite, the date, the flying direction and the path number of each acquisition over the site in Ghana for the period 2015-2019.

Table 11. 2015-2016 S1 acquisitions over the demonstration site in Ghana.

	Mar 2015 - Dec 2015					Dec 2015 - Aug 2016					Sep 2016 - Dec 2016			
	SAT	DATE	DIR	Path		SAT	DATE	DIR	Path		SAT	DATE	DIR	Path
1	S1A	20150325	ASC	45	41	S1A	20151226	ASC	45	81	S1A	20160903	ASC	45
2	S1A	20150401	ASC	147	42	S1A	20160102	ASC	147	82	S1A	20160910	ASC	147
3	S1A	20150406	ASC	45	43	S1A	20160107	ASC	45	83	S1A	20160915	ASC	45
4	S1A	20150413	ASC	147	44	S1A	20160114	ASC	147	84	S1A	20160922	ASC	147
5	S1A	20150418	ASC	45	45	S1A	20160119	ASC	45	85	S1A	20160927	ASC	45
6	S1A	20150425	ASC	147	46	S1A	20160126	ASC	147	86	S1A	20161004	ASC	147
7	S1A	20150512	ASC	45	47	S1A	20160131	ASC	45	87	S1A	20161009	ASC	45
8	S1A	20150519	ASC	147	48	S1A	20160207	ASC	147	88	S1A	20161016	ASC	147
9	S1A	20150524	ASC	45	49	S1A	20160212	ASC	45	89	S1A	20161021	ASC	45
10	S1A	20150531	ASC	147	50	S1A	20160219	ASC	147	90	S1A	20161028	ASC	147
11	S1A	20150605	ASC	45	51	S1A	20160224	ASC	45	91	S1A	20161102	ASC	45
12	S1A	20150612	ASC	147	52	S1A	20160302	ASC	147	92	S1A	20161109	ASC	147
13	S1A	20150617	ASC	45	53	S1A	20160307	ASC	45	93	S1A	20161114	ASC	45
14	S1A	20150624	ASC	147	54	S1A	20160314	ASC	147	94	S1A	20161121	ASC	147
15	S1A	20150629	ASC	45	55	S1A	20160319	ASC	45	95	S1A	20161126	ASC	45
16	S1A	20150706	ASC	147	56	S1A	20160326	ASC	147	96	S1A	20161203	ASC	147
17	S1A	20150711	ASC	45	57	S1A	20160331	ASC	45	97	S1A	20161208	ASC	45
18	S1A	20150718	ASC	147	58	S1A	20160407	ASC	147	98	S1A	20161215	ASC	147
19	S1A	20150723	ASC	45	59	S1A	20160412	ASC	45	99	S1A	20161220	ASC	45
20	S1A	20150730	ASC	147	60	S1A	20160419	ASC	147	100	S1A	20161227	ASC	147
21	S1A	20150811	ASC	147	61	S1A	20160424	ASC	45	101				
22	S1A	20150816	ASC	45	62	S1A	20160501	ASC	147	102				
23	S1A	20150823	ASC	147	63	S1A	20160506	ASC	45	103				
24	S1A	20150828	ASC	45	64	S1A	20160513	ASC	147	104				
25	S1A	20150909	ASC	45	65	S1A	20160518	ASC	45	105				
26	S1A	20150916	ASC	147	66	S1A	20160525	ASC	147	106				
27	S1A	20150921	ASC	45	67	S1A	20160530	ASC	45	107				
28	S1A	20150928	ASC	147	68	S1A	20160606	ASC	147	108				
29	S1A	20151003	ASC	45	69	S1A	20160611	ASC	45	109				
30	S1A	20151015	ASC	45	70	S1A	20160630	ASC	147	110				
31	S1A	20151022	ASC	147	71	S1A	20160705	ASC	45	111				
32	S1A	20151027	ASC	45	72	S1A	20160712	ASC	147	112				
33	S1A	20151108	ASC	45	73	S1A	20160717	ASC	45	113				
34	S1A	20151115	ASC	147	74	S1A	20160724	ASC	147	114				
35	S1A	20151120	ASC	45	75	S1A	20160729	ASC	45	115				
36	S1A	20151127	ASC	147	76	S1A	20160805	ASC	147	116				
37	S1A	20151202	ASC	45	77	S1A	20160810	ASC	45	117				
38	S1A	20151209	ASC	147	78	S1A	20160817	ASC	147	118				
39	S1A	20151214	ASC	45	79	S1A	20160822	ASC	45	119				
40	S1A	20151221	ASC	147	80	S1A	20160829	ASC	147	120				

Table 12. 2017-2018 S1 acquisitions over the demonstration site in Ghana.

	Jan 2017 - Aug 2017					Aug 2017 - Jan 2018					Jan 2018 - Mai 2018			
	SAT	DATE	DIR	Path		SAT	DATE	DIR	Path		SAT	DATE	DIR	Path
1	S1A	20170101	ASC	45	41	S1A	20170829	ASC	45	81	S1B	20180121	ASC	147
2	S1A	20170108	ASC	147	42	S1A	20170905	ASC	147	82	S1B	20180126	ASC	45
3	S1A	20170113	ASC	45	43	S1A	20170910	ASC	45	83	S1A	20180127	ASC	147
4	S1A	20170120	ASC	147	44	S1A	20170917	ASC	147	84	S1A	20180201	ASC	45
5	S1A	20170125	ASC	45	45	S1A	20170922	ASC	45	85	S1B	20180202	ASC	147
6	S1A	20170201	ASC	147	46	S1A	20170929	ASC	147	86	S1B	20180207	ASC	45
7	S1A	20170206	ASC	45	47	S1A	20171004	ASC	45	87	S1A	20180208	ASC	147
8	S1A	20170213	ASC	147	48	S1A	20171011	ASC	147	88	S1A	20180213	ASC	45
9	S1A	20170218	ASC	45	49	S1A	20171016	ASC	45	89	S1B	20180214	ASC	147
10	S1A	20170225	ASC	147	50	S1B	20171022	ASC	45	90	S1B	20180219	ASC	45
11	S1A	20170302	ASC	45	51	S1A	20171023	ASC	147	91	S1A	20180220	ASC	147
12	S1A	20170309	ASC	147	52	S1A	20171028	ASC	45	92	S1A	20180225	ASC	45
13	S1A	20170314	ASC	45	53	S1B	20171029	ASC	147	93	S1B	20180226	ASC	147
14	S1A	20170321	ASC	147	54	S1B	20171103	ASC	45	94	S1B	20180303	ASC	45
15	S1A	20170326	ASC	45	55	S1A	20171104	ASC	147	95	S1A	20180304	ASC	147
16	S1A	20170402	ASC	147	56	S1A	20171109	ASC	45	96	S1A	20180309	ASC	45
17	S1A	20170407	ASC	45	57	S1B	20171110	ASC	147	97	S1B	20180310	ASC	147
18	S1A	20170414	ASC	147	58	S1B	20171115	ASC	45	98	S1B	20180315	ASC	45
19	S1A	20170419	ASC	45	59	S1A	20171116	ASC	147	99	S1A	20180316	ASC	147
20	S1A	20170426	ASC	147	60	S1A	20171121	ASC	45	100	S1A	20180321	ASC	45
21	S1A	20170501	ASC	45	61	S1B	20171122	ASC	147	101	S1B	20180322	ASC	147
22	S1A	20170508	ASC	147	62	S1B	20171127	ASC	45	102	S1B	20180327	ASC	45
23	S1A	20170513	ASC	45	63	S1A	20171128	ASC	147	103	S1A	20180328	ASC	147
24	S1A	20170520	ASC	147	64	S1A	20171203	ASC	45	104	S1A	20180402	ASC	45
25	S1A	20170525	ASC	45	65	S1B	20171204	ASC	147	105	S1B	20180403	ASC	147
26	S1A	20170601	ASC	147	66	S1B	20171209	ASC	45	106	S1B	20180408	ASC	45
27	S1A	20170606	ASC	45	67	S1A	20171210	ASC	147	107	S1A	20180409	ASC	147
28	S1A	20170613	ASC	147	68	S1A	20171215	ASC	45	108	S1A	20180414	ASC	45
29	S1A	20170618	ASC	45	69	S1B	20171216	ASC	147	109	S1B	20180415	ASC	147
30	S1A	20170625	ASC	147	70	S1B	20171221	ASC	45	110	S1B	20180420	ASC	45
31	S1A	20170630	ASC	45	71	S1A	20171222	ASC	147	111	S1A	20180421	ASC	147
32	S1A	20170707	ASC	147	72	S1A	20171227	ASC	45	112	S1A	20180426	ASC	45
33	S1A	20170712	ASC	45	73	S1B	20171228	ASC	147	113	S1B	20180427	ASC	147
34	S1A	20170719	ASC	147	74	S1B	20180102	ASC	45	114	S1B	20180502	ASC	45
35	S1A	20170724	ASC	45	75	S1A	20180103	ASC	147	115	S1A	20180503	ASC	147
36	S1A	20170731	ASC	147	76	S1A	20180108	ASC	45	116	S1A	20180508	ASC	45
37	S1A	20170805	ASC	45	77	S1B	20180109	ASC	147	117	S1B	20180509	ASC	147
38	S1A	20170812	ASC	147	78	S1B	20180114	ASC	45	118	S1B	20180514	ASC	45
39	S1A	20170817	ASC	45	79	S1A	20180115	ASC	147	119	S1A	20180515	ASC	147
40	S1A	20170824	ASC	147	80	S1A	20180120	ASC	45	120	S1A	20180520	ASC	45

Continuation of Table 12.

	Mai 2018 - Sep 2018					Sep 2018 - Dec 2018			
	SAT	DATE	DIR	Path		SAT	DATE	DIR	Path
121	S1B	20180521	ASC	147	141	S1B	20180930	ASC	147
122	S1B	20180526	ASC	45	142	S1B	20181005	ASC	45
123	S1A	20180527	ASC	147	143	S1A	20181006	ASC	147
124	S1A	20180601	ASC	45	144	S1A	20181011	ASC	45
125	S1B	20180607	ASC	45	145	S1B	20181012	ASC	147
126	S1A	20180608	ASC	147	146	S1B	20181017	ASC	45
127	S1A	20180613	ASC	45	147	S1A	20181018	ASC	147
128	S1B	20180619	ASC	45	148	S1A	20181023	ASC	45
129	S1A	20180620	ASC	147	149	S1B	20181024	ASC	147
130	S1A	20180625	ASC	45	150	S1B	20181029	ASC	45
131	S1B	20180701	ASC	45	151	S1A	20181030	ASC	147
132	S1A	20180702	ASC	147	152	S1A	20181104	ASC	45
133	S1A	20180707	ASC	45	153	S1B	20181105	ASC	147
134	S1B	20180713	ASC	45	154	S1B	20181110	ASC	45
135	S1A	20180714	ASC	147	155	S1A	20181111	ASC	147
136	S1A	20180719	ASC	45	156	S1A	20181116	ASC	45
137	S1B	20180720	ASC	147	157	S1B	20181117	ASC	147
138	S1B	20180725	ASC	45	158	S1B	20181122	ASC	45
139	S1A	20180726	ASC	147	159	S1A	20181123	ASC	147
140	S1A	20180731	ASC	45	160	S1A	20181128	ASC	45
141	S1B	20180801	ASC	147	161	S1B	20181129	ASC	147
142	S1B	20180806	ASC	45	162	S1B	20181204	ASC	45
143	S1A	20180807	ASC	147	163	S1A	20181205	ASC	147
144	S1A	20180812	ASC	45	164	S1A	20181210	ASC	45
145	S1B	20180813	ASC	147	165	S1B	20181211	ASC	147
146	S1B	20180818	ASC	45	166	S1B	20181216	ASC	45
147	S1A	20180819	ASC	147	167	S1A	20181217	ASC	147
148	S1A	20180824	ASC	45	168	S1A	20181222	ASC	45
149	S1B	20180825	ASC	147	169	S1B	20181223	ASC	147
150	S1B	20180830	ASC	45	170	S1B	20181228	ASC	45
151	S1A	20180831	ASC	147	171	S1A	20181229	ASC	147
152	S1A	20180905	ASC	45					
153	S1B	20180906	ASC	147					
154	S1B	20180911	ASC	45					
155	S1A	20180912	ASC	147					
156	S1A	20180917	ASC	45					
157	S1B	20180918	ASC	147					
158	S1B	20180923	ASC	45					
159	S1A	20180924	ASC	147					
160	S1A	20180929	ASC	45					

Table 13. 2019 S1 acquisitions over the demonstration site in Ghana.

	Jan 2019 - Apr 2019					Apr 2019 - Aug 2019					Aug 2019 - Dec 2019					Dec 2019 - Dec 2019			
	SAT	DATE	DIR	Path		SAT	DATE	DIR	Path		SAT	DATE	DIR	Path		SAT	DATE	DIR	Path
1	S1A	20190103	ASC	45	41	S1B	20190422	ASC	147	81	S1B	20190825	ASC	45	121	S1A	20191224	ASC	147
2	S1B	20190104	ASC	147	42	S1B	20190427	ASC	45	82	S1A	20190826	ASC	147	122	S1A	20191229	ASC	45
3	S1B	20190109	ASC	45	43	S1A	20190428	ASC	147	83	S1A	20190831	ASC	45	123	S1B	20191230	ASC	147
4	S1A	20190110	ASC	147	44	S1A	20190503	ASC	45	84	S1B	20190901	ASC	147	124				
5	S1A	20190115	ASC	45	45	S1B	20190504	ASC	147	85	S1B	20190906	ASC	45	125				
6	S1B	20190116	ASC	147	46	S1B	20190509	ASC	45	86	S1A	20190907	ASC	147	126				
7	S1B	20190121	ASC	45	47	S1A	20190510	ASC	147	87	S1A	20190912	ASC	45	127				
8	S1A	20190122	ASC	147	48	S1A	20190515	ASC	45	88	S1B	20190913	ASC	147	128				
9	S1A	20190127	ASC	45	49	S1B	20190516	ASC	147	89	S1B	20190918	ASC	45	129				
10	S1B	20190128	ASC	147	50	S1B	20190521	ASC	45	90	S1A	20190919	ASC	147	130				
11	S1B	20190202	ASC	45	51	S1A	20190522	ASC	147	91	S1A	20190924	ASC	45	131				
12	S1A	20190203	ASC	147	52	S1A	20190527	ASC	45	92	S1B	20190925	ASC	147	132				
13	S1A	20190208	ASC	45	53	S1B	20190528	ASC	147	93	S1B	20190930	ASC	45	133				
14	S1B	20190209	ASC	147	54	S1B	20190602	ASC	45	94	S1A	20191001	ASC	147	134				
15	S1B	20190214	ASC	45	55	S1A	20190603	ASC	147	95	S1A	20191006	ASC	45	135				
16	S1A	20190215	ASC	147	56	S1A	20190608	ASC	45	96	S1B	20191007	ASC	147	136				
17	S1A	20190220	ASC	45	57	S1B	20190609	ASC	147	97	S1B	20191012	ASC	45	137				
18	S1B	20190221	ASC	147	58	S1B	20190614	ASC	45	98	S1A	20191013	ASC	147	138				
19	S1B	20190226	ASC	45	59	S1A	20190615	ASC	147	99	S1A	20191018	ASC	45	139				
20	S1A	20190227	DES	139	60	S1A	20190620	ASC	45	100	S1B	20191019	ASC	147	140				
21	S1A	20190227	ASC	147	61	S1B	20190621	ASC	147	101	S1B	20191024	ASC	45	141				
22	S1A	20190304	ASC	45	62	S1B	20190626	ASC	45	102	S1A	20191025	ASC	147	142				
23	S1B	20190305	DES	139	63	S1A	20190627	ASC	147	103	S1A	20191030	ASC	45	143				
24	S1B	20190305	ASC	147	64	S1B	20190703	ASC	147	104	S1B	20191031	ASC	147	144				
25	S1B	20190310	ASC	45	65	S1B	20190708	ASC	45	105	S1B	20191105	ASC	45	145				
26	S1A	20190311	ASC	147	66	S1A	20190709	ASC	147	106	S1A	20191106	ASC	147	146				
27	S1A	20190316	ASC	45	67	S1A	20190714	ASC	45	107	S1B	20191112	ASC	147	147				
28	S1B	20190317	ASC	147	68	S1B	20190715	ASC	147	108	S1B	20191117	ASC	45	148				
29	S1B	20190322	ASC	45	69	S1B	20190720	ASC	45	109	S1A	20191118	ASC	147	149				
30	S1A	20190323	DES	139	70	S1A	20190721	ASC	147	110	S1A	20191123	ASC	45	150				
31	S1A	20190323	ASC	147	71	S1A	20190726	ASC	45	111	S1B	20191124	ASC	147	151				
32	S1A	20190328	ASC	45	72	S1B	20190727	ASC	147	112	S1B	20191129	ASC	45	152				
33	S1B	20190329	ASC	147	73	S1B	20190801	ASC	45	113	S1A	20191130	ASC	147	153				
34	S1B	20190403	ASC	45	74	S1A	20190802	ASC	147	114	S1A	20191205	ASC	45	154				
35	S1A	20190404	ASC	147	75	S1A	20190807	ASC	45	115	S1B	20191206	ASC	147	155				
36	S1A	20190409	ASC	45	76	S1B	20190808	ASC	147	116	S1B	20191211	ASC	45	156				
37	S1B	20190410	ASC	147	77	S1B	20190813	ASC	45	117	S1A	20191212	ASC	147	157				
38	S1B	20190415	ASC	45	78	S1A	20190814	ASC	147	118	S1A	20191217	ASC	45	158				
39	S1A	20190416	ASC	147	79	S1A	20190819	ASC	45	119	S1B	20191218	ASC	147	159				
40	S1A	20190421	ASC	45	80	S1B	20190820	ASC	147	120	S1B	20191223	ASC	45	160				

15. ANNEX 4: Meta data for Malawi

Service Area

The southern part of Malawi inside the rectangle with the geographic coordinates:

NE-corner: 15°09.0'S, 33°54.0'E
NW-corner : 15°09.0'S. 35°54.0'E
SW-corner: 17°09.0'S, 35°54.0'E
SE-corner: 17°09.0'S, 33°54.0'E
The AOI is shown in Figure 25.

The satellite paths covering the AOI are ascending paths 101 and 174 acquired by S1B and descending paths 006 and 079 acquired by S1A.

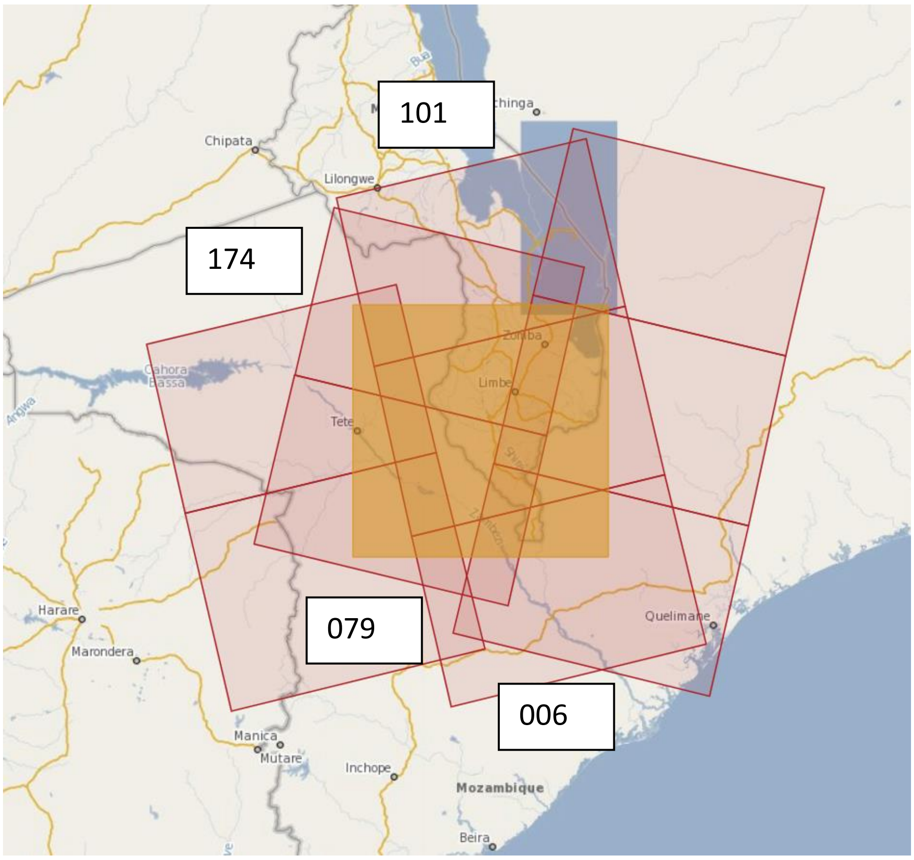

Figure 25. Service Area in Malawi in orange with S1 satellite paths acquired.

Table 14 to Table 16 detail the satellite, the date, the flying direction and the path number of each acquisition over the site in Malawi for the period 2015-2019.

Table 14. 2015-2016 S1 acquisitions over the demonstration site in Malawi.

	Jan 2015 - Dec 2015					Jan 2016 - Dec 2016			
	SAT	DATE	DIR	Path		SAT	DATE	DIR	Path
1	S1A	20150103	DES	79	1	S1A	20160104	ASC	174
2	S1A	20150422	ASC	101	2	S1A	20160128	ASC	174
3	S1A	20150427	ASC	174	3	S1A	20160221	ASC	174
4	S1A	20150901	ASC	101	4	S1A	20160316	ASC	174
5	S1A	20150906	ASC	174	5	S1A	20160409	ASC	174
6	S1A	20151024	ASC	174	6	S1A	20160428	ASC	101
7	S1A	20151117	ASC	174	7	S1A	20160503	ASC	174
8	S1A	20151211	ASC	174	8	S1A	20160527	ASC	174
					9	S1A	20160714	ASC	174
					10	S1A	20160807	ASC	174
					11	S1A	20160831	ASC	174
					12	S1A	20160924	ASC	174
					13	S1B	20161019	ASC	101
					14	S1B	20161024	ASC	174
					15	S1B	20161031	ASC	101
					16	S1B	20161105	ASC	174
					17	S1B	20161112	ASC	101
					18	S1B	20161117	ASC	174
					19	S1B	20161124	ASC	101
					20	S1B	20161129	ASC	174
					21	S1B	20161206	ASC	101
					22	S1B	20161211	ASC	174
					23	S1B	20161218	ASC	101
					24	S1B	20161223	ASC	174
					25	S1B	20161230	ASC	101

Table 15. 2017-2018 S1 acquisitions over the demonstration site in Malawi.

	Jan 2017 - Mai 2017					Mai 2017 - Sep 2017					Sep 2017 - Jan 2018			
	SAT	DATE	DIR	Path		SAT	DATE	DIR	Path		SAT	DATE	DIR	Path
1	S1B	20170104	ASC	174	41	S1B	20170523	ASC	101	81	S1B	20170925	ASC	174
2	S1B	20170111	ASC	101	42	S1A	20170528	DES	79	82	S1A	20171002	DES	6
3	S1B	20170116	ASC	174	43	S1B	20170528	ASC	174	83	S1B	20171002	ASC	101
4	S1B	20170123	ASC	101	44	S1A	20170604	DES	6	84	S1A	20171007	DES	79
5	S1B	20170128	ASC	174	45	S1B	20170604	ASC	101	85	S1B	20171007	ASC	174
6	S1B	20170204	ASC	101	46	S1A	20170609	DES	79	86	S1A	20171014	DES	6
7	S1B	20170209	ASC	174	47	S1B	20170609	ASC	174	87	S1B	20171014	ASC	101
8	S1A	20170216	DES	6	48	S1A	20170616	DES	6	88	S1A	20171019	DES	79
9	S1B	20170216	ASC	101	49	S1B	20170616	ASC	101	89	S1B	20171019	ASC	174
10	S1A	20170221	DES	79	50	S1A	20170621	DES	79	90	S1A	20171026	DES	6
11	S1B	20170221	ASC	174	51	S1B	20170621	ASC	174	91	S1B	20171026	ASC	101
12	S1A	20170228	DES	6	52	S1A	20170628	DES	6	92	S1A	20171031	DES	79
13	S1B	20170228	ASC	101	53	S1B	20170628	ASC	101	93	S1B	20171031	ASC	174
14	S1A	20170305	DES	79	54	S1A	20170703	DES	79	94	S1A	20171107	DES	6
15	S1B	20170305	ASC	174	55	S1B	20170703	ASC	174	95	S1B	20171107	ASC	101
16	S1A	20170312	DES	6	56	S1A	20170710	DES	6	96	S1A	20171112	DES	79
17	S1B	20170312	ASC	101	57	S1B	20170710	ASC	101	97	S1B	20171112	ASC	174
18	S1A	20170317	DES	79	58	S1B	20170715	ASC	174	98	S1A	20171119	DES	6
19	S1B	20170317	ASC	174	59	S1A	20170722	DES	6	99	S1B	20171119	ASC	101
20	S1A	20170324	DES	6	60	S1B	20170722	ASC	101	100	S1A	20171124	DES	79
21	S1B	20170324	ASC	101	61	S1A	20170727	DES	79	101	S1B	20171124	ASC	174
22	S1A	20170329	DES	79	62	S1B	20170727	ASC	174	102	S1A	20171201	DES	6
23	S1B	20170329	ASC	174	63	S1B	20170803	ASC	101	103	S1B	20171201	ASC	101
24	S1A	20170405	DES	6	64	S1A	20170808	DES	79	104	S1A	20171206	DES	79
25	S1B	20170405	ASC	101	65	S1B	20170808	ASC	174	105	S1B	20171206	ASC	174
26	S1A	20170410	DES	79	66	S1A	20170815	DES	6	106	S1A	20171213	DES	6
27	S1B	20170410	ASC	174	67	S1B	20170815	ASC	101	107	S1B	20171213	ASC	101
28	S1A	20170417	DES	6	68	S1A	20170820	DES	79	108	S1A	20171218	DES	79
29	S1B	20170417	ASC	101	69	S1B	20170820	ASC	174	109	S1B	20171218	ASC	174
30	S1A	20170422	DES	79	70	S1A	20170827	DES	6	110	S1A	20171225	DES	6
31	S1B	20170422	ASC	174	71	S1B	20170827	ASC	101	111	S1B	20171225	ASC	101
32	S1A	20170429	DES	6	72	S1A	20170901	DES	79	112	S1A	20171230	DES	79
33	S1B	20170429	ASC	101	73	S1B	20170901	ASC	174	113	S1B	20171230	ASC	174
34	S1A	20170504	DES	79	74	S1A	20170908	DES	6	114	S1A	20180106	DES	6
35	S1B	20170504	ASC	174	75	S1B	20170908	ASC	101	115	S1B	20180106	ASC	101
36	S1A	20170511	DES	6	76	S1A	20170913	DES	79	116	S1A	20180111	DES	79
37	S1B	20170511	ASC	101	77	S1B	20170913	ASC	174	117	S1B	20180111	ASC	174
38	S1A	20170516	DES	79	78	S1A	20170920	DES	6	118	S1B	20180118	ASC	101
39	S1B	20170516	ASC	174	79	S1B	20170920	ASC	101	119	S1A	20180123	DES	79
40	S1A	20170523	DES	6	80	S1A	20170925	DES	79	120	S1B	20180123	ASC	174

Continuation of Table 15

	Jan 2018 - Mai 2018					Mai 2018 - Oct 2018					Oct 2018 - Dec 2018			
	SAT	DATE	DIR	Path		SAT	DATE	DIR	Path		SAT	DATE	DIR	Path
121	S1A	20180130	DES	6	161	S1B	20180530	ASC	101	201	S1A	20181009	DES	6
122	S1B	20180130	ASC	101	162	S1A	20180604	DES	79	202	S1B	20181009	ASC	101
123	S1A	20180204	DES	79	163	S1B	20180604	ASC	174	203	S1A	20181014	DES	79
124	S1B	20180204	ASC	174	164	S1A	20180611	DES	6	204	S1B	20181014	ASC	174
125	S1B	20180211	ASC	101	165	S1B	20180611	ASC	101	205	S1B	20181021	ASC	101
126	S1A	20180216	DES	79	166	S1A	20180616	DES	79	206	S1A	20181026	DES	79
127	S1B	20180216	ASC	174	167	S1B	20180616	ASC	174	207	S1B	20181026	ASC	174
128	S1A	20180223	DES	6	168	S1A	20180623	DES	6	208	S1A	20181102	DES	6
129	S1B	20180223	ASC	101	169	S1B	20180623	ASC	101	209	S1B	20181102	ASC	101
130	S1A	20180228	DES	79	170	S1A	20180628	DES	79	210	S1A	20181107	DES	79
131	S1B	20180228	ASC	174	171	S1B	20180628	ASC	174	211	S1B	20181107	ASC	174
132	S1A	20180307	DES	6	172	S1A	20180705	DES	6	212	S1A	20181114	DES	6
133	S1B	20180307	ASC	101	173	S1B	20180705	ASC	101	213	S1B	20181114	ASC	101
134	S1A	20180312	DES	79	174	S1A	20180710	DES	79	214	S1A	20181119	DES	79
135	S1B	20180312	ASC	174	175	S1B	20180710	ASC	174	215	S1B	20181119	ASC	174
136	S1A	20180319	DES	6	176	S1A	20180717	DES	6	216	S1A	20181126	DES	6
137	S1B	20180319	ASC	101	177	S1B	20180717	ASC	101	217	S1B	20181126	ASC	101
138	S1A	20180324	DES	79	178	S1A	20180722	DES	79	218	S1B	20181201	ASC	174
139	S1B	20180324	ASC	174	179	S1B	20180722	ASC	174	219	S1B	20181208	ASC	101
140	S1A	20180331	DES	6	180	S1A	20180729	DES	6	220	S1B	20181213	ASC	174
141	S1B	20180331	ASC	101	181	S1B	20180729	ASC	101	221	S1B	20181220	ASC	101
142	S1A	20180405	DES	79	182	S1B	20180803	ASC	174	222	S1A	20181225	DES	79
143	S1B	20180405	ASC	174	183	S1A	20180810	DES	6	223	S1B	20181225	ASC	174
144	S1A	20180412	DES	6	184	S1B	20180810	ASC	101					
145	S1B	20180412	ASC	101	185	S1A	20180815	DES	79					
146	S1A	20180417	DES	79	186	S1B	20180815	ASC	174					
147	S1B	20180417	ASC	174	187	S1B	20180822	ASC	101					
148	S1A	20180424	DES	6	188	S1A	20180827	DES	79					
149	S1B	20180424	ASC	101	189	S1B	20180827	ASC	174					
150	S1A	20180429	DES	79	190	S1A	20180903	DES	6					
151	S1B	20180429	ASC	174	191	S1B	20180903	ASC	101					
152	S1A	20180506	DES	6	192	S1A	20180908	DES	79					
153	S1B	20180506	ASC	101	193	S1B	20180908	ASC	174					
154	S1A	20180511	DES	79	194	S1A	20180915	DES	6					
155	S1B	20180511	ASC	174	195	S1B	20180915	ASC	101					
156	S1A	20180518	DES	6	196	S1A	20180920	DES	79					
157	S1B	20180518	ASC	101	197	S1B	20180920	ASC	174					
158	S1A	20180523	DES	79	198	S1B	20180927	ASC	101					
159	S1B	20180523	ASC	174	199	S1A	20181002	DES	79					
160	S1A	20180530	DES	6	200	S1B	20181002	ASC	174					

Table 16. 2019 S1 acquisitions over the demonstration site in Malawi.

	Jan 2019 - Apr 2019					Apr 2019 - Aug 2019					Aug 2019 - Dec 2019					Apr 2019 - Aug 2019			
	SAT	DATE	DIR	Path		SAT	DATE	DIR	Path		SAT	DATE	DIR	Path		SAT	DATE	DIR	Path
1	S1A	20190101	DES	6	41	S1B	20190407	ASC	101	81	S1A	20190810	DES	79	121	S1B	20191215	ASC	101
2	S1B	20190101	ASC	101	42	S1A	20190412	DES	79	82	S1B	20190810	ASC	174	122	S1A	20191220	DES	79
3	S1A	20190106	DES	79	43	S1B	20190412	ASC	174	83	S1A	20190817	DES	6	123	S1B	20191220	ASC	174
4	S1B	20190106	ASC	174	44	S1A	20190419	DES	6	84	S1B	20190817	ASC	101	124	S1A	20191227	DES	6
5	S1B	20190108	ASC	28	45	S1B	20190419	ASC	101	85	S1A	20190822	DES	79	125	S1B	20191227	ASC	101
6	S1A	20190113	DES	6	46	S1A	20190424	DES	79	86	S1B	20190822	ASC	174	126				
7	S1B	20190113	ASC	101	47	S1B	20190424	ASC	174	87	S1A	20190829	DES	6	127				
8	S1A	20190118	DES	79	48	S1A	20190501	DES	6	88	S1A	20190903	DES	79	128				
9	S1B	20190118	ASC	174	49	S1B	20190501	ASC	101	89	S1A	20190910	DES	6	129				
10	S1B	20190120	ASC	28	50	S1A	20190506	DES	79	90	S1B	20190910	ASC	101	130				
11	S1A	20190125	DES	6	51	S1B	20190506	ASC	174	91	S1A	20190915	DES	79	131				
12	S1B	20190125	ASC	101	52	S1A	20190513	DES	6	92	S1B	20190915	ASC	174	132				
13	S1B	20190130	ASC	174	53	S1B	20190513	ASC	101	93	S1A	20190922	DES	6	133				
14	S1A	20190206	DES	6	54	S1A	20190518	DES	79	94	S1B	20190922	ASC	101	134				
15	S1B	20190206	ASC	101	55	S1B	20190518	ASC	174	95	S1A	20190927	DES	79	135				
16	S1B	20190211	ASC	174	56	S1B	20190525	ASC	101	96	S1B	20190927	ASC	174	136				
17	S1B	20190213	ASC	28	57	S1A	20190530	DES	79	97	S1A	20191004	DES	6	137				
18	S1A	20190218	DES	6	58	S1B	20190530	ASC	174	98	S1B	20191004	ASC	101	138				
19	S1B	20190218	ASC	101	59	S1A	20190606	DES	6	99	S1B	20191009	ASC	174	139				
20	S1A	20190223	DES	79	60	S1B	20190606	ASC	101	100	S1A	20191016	DES	6	140				
21	S1B	20190223	ASC	174	61	S1A	20190611	DES	79	101	S1B	20191016	ASC	101	141				
22	S1A	20190302	DES	6	62	S1B	20190611	ASC	174	102	S1A	20191021	DES	79	142				
23	S1B	20190302	ASC	101	63	S1A	20190618	DES	6	103	S1B	20191021	ASC	174	143				
24	S1A	20190307	DES	79	64	S1B	20190618	ASC	101	104	S1A	20191028	DES	6	144				
25	S1B	20190307	ASC	174	65	S1A	20190623	DES	79	105	S1B	20191028	ASC	101	145				
26	S1B	20190309	ASC	28	66	S1B	20190623	ASC	174	106	S1A	20191102	DES	79	146				
27	S1B	20190313	DES	79	67	S1A	20190630	DES	6	107	S1B	20191102	ASC	174	147				
28	S1A	20190314	DES	6	68	S1B	20190630	ASC	101	108	S1A	20191109	DES	6	148				
29	S1B	20190314	ASC	101	69	S1A	20190705	DES	79	109	S1B	20191109	ASC	101	149				
30	S1A	20190319	DES	79	70	S1B	20190705	ASC	174	110	S1A	20191114	DES	79	150				
31	S1B	20190319	ASC	174	71	S1A	20190712	DES	6	111	S1B	20191114	ASC	174	151				
32	S1A	20190320	ASC	101	72	S1B	20190712	ASC	101	112	S1A	20191121	DES	6	152				
33	S1B	20190320	DES	6	73	S1A	20190717	DES	79	113	S1B	20191121	ASC	101	153				
34	S1B	20190321	ASC	28	74	S1B	20190717	ASC	174	114	S1A	20191126	DES	79	154				
35	S1B	20190325	DES	79	75	S1A	20190724	DES	6	115	S1B	20191126	ASC	174	155				
36	S1A	20190326	DES	6	76	S1B	20190724	ASC	101	116	S1A	20191203	DES	6	156				
37	S1B	20190326	ASC	101	77	S1A	20190729	DES	79	117	S1B	20191203	ASC	101	157				
38	S1A	20190331	DES	79	78	S1B	20190729	ASC	174	118	S1A	20191208	DES	79	158				
39	S1B	20190331	ASC	174	79	S1A	20190805	DES	6	119	S1B	20191208	ASC	174	159				
40	S1A	20190407	DES	6	80	S1B	20190805	ASC	101	120	S1A	20191215	DES	6	160				

16. ANNEX 5: Meta data for South Africa

Service Area

The Ehlanzeni District in South Africa, east of Pretoria and including the southern Part of Kruger National Park. This area is inside the rectangle with the geographic coordinates:

NE-corner: 23°54.0'S, 29°54.0'E
NW-corner : 23°54.0'S. 32°06.0'E
SW-corner: 26°00.0'S, 32°06.0'E
SE-corner: 26°00.0'S, 29°54.0'E
The AOI is shown in Figure 26.

The satellite paths covering the AOI are ascending paths 043 and 145 acquired by S1A and descending paths 079 and 152 acquired by S1B. Path 072 only covers a small north-eastern area of the AOI and has not been included.

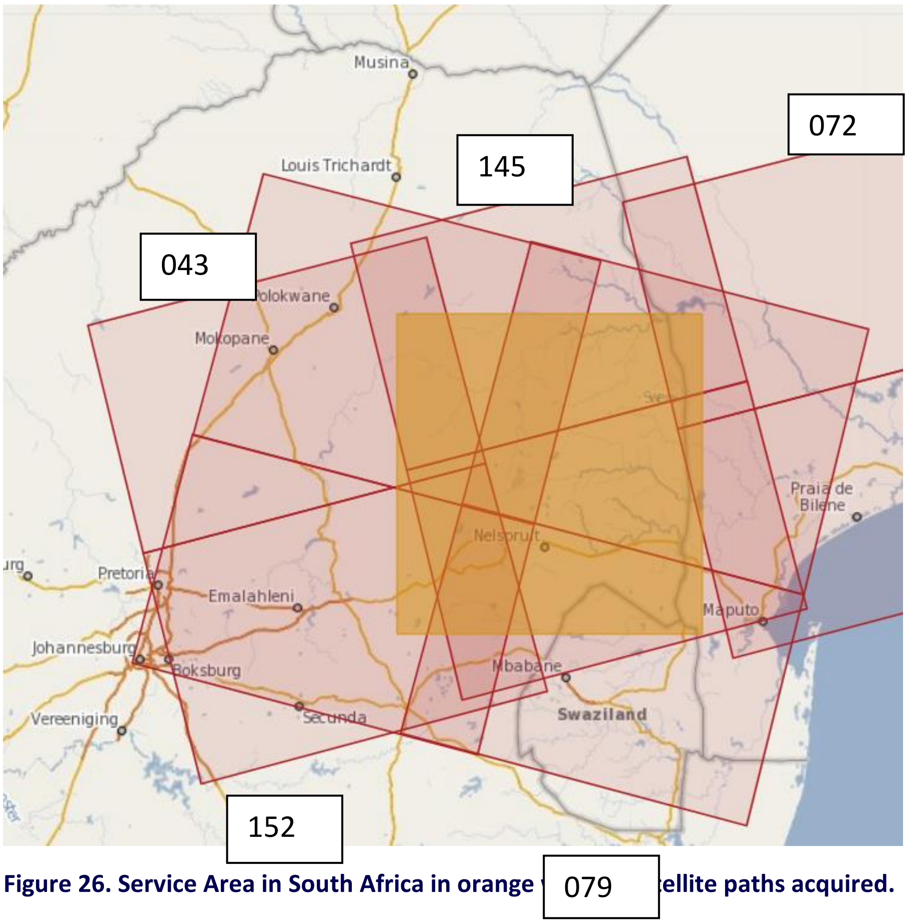

Figure 26. Service Area in South Africa in orange [illegible]ellite paths acquired.

Table 17 to Table 19 detail the satellite, the date, the flying direction and the path number of each acquisition over the site in South Africa for the period 2015-2019.

Table 17. 2015-2016 S1 acquisitions over the demonstration site in South Africa.

	Jan 2015 - Dec 2015					Dec 2015 - Sep 2016					Sep 2016 - Dec 2016			
	SAT	DATE	DIR	Path		SAT	DATE	DIR	Path		SAT	DATE	DIR	Path
1	S1A	20150320	ASC	145	41	S1A	20151226	ASC	43	81	S1A	20160910	ASC	145
2	S1A	20150325	ASC	43	42	S1A	20160102	ASC	145	82	S1A	20160915	ASC	43
3	S1A	20150401	ASC	145	43	S1A	20160107	ASC	43	83	S1A	20160922	ASC	145
4	S1A	20150406	ASC	43	44	S1A	20160114	ASC	145	84	S1A	20160927	ASC	43
5	S1A	20150413	ASC	145	45	S1A	20160119	ASC	43	85	S1A	20161004	ASC	145
6	S1A	20150418	ASC	43	46	S1A	20160126	ASC	145	86	S1A	20161009	ASC	43
7	S1A	20150425	ASC	145	47	S1A	20160131	ASC	43	87	S1A	20161016	ASC	145
8	S1A	20150430	ASC	43	48	S1A	20160207	ASC	145	88	S1A	20161021	ASC	43
9	S1A	20150507	ASC	145	49	S1A	20160212	ASC	43	89	S1A	20161028	ASC	145
10	S1A	20150512	ASC	43	50	S1A	20160224	ASC	43	90	S1A	20161102	ASC	43
11	S1A	20150519	ASC	145	51	S1A	20160302	ASC	145	91	S1A	20161109	ASC	145
12	S1A	20150524	ASC	43	52	S1A	20160307	ASC	43	92	S1A	20161114	ASC	43
13	S1A	20150527	DES	79	53	S1A	20160314	ASC	145	93	S1A	20161121	ASC	145
14	S1A	20150531	ASC	145	54	S1A	20160319	ASC	43	94	S1A	20161126	ASC	43
15	S1A	20150605	ASC	43	55	S1A	20160326	ASC	145	95	S1A	20161203	ASC	145
16	S1A	20150612	ASC	145	56	S1A	20160331	ASC	43	96	S1A	20161208	ASC	43
17	S1A	20150617	ASC	43	57	S1A	20160407	ASC	145	97	S1A	20161215	ASC	145
18	S1A	20150624	ASC	145	58	S1A	20160412	ASC	43	98	S1A	20161220	ASC	43
19	S1A	20150629	ASC	43	59	S1A	20160419	ASC	145	99	S1A	20161227	ASC	145
20	S1A	20150706	ASC	145	60	S1A	20160424	ASC	43	100				
21	S1A	20150718	ASC	145	61	S1A	20160501	ASC	145	101				
22	S1A	20150730	ASC	145	62	S1A	20160506	ASC	43	102				
23	S1A	20150804	ASC	43	63	S1A	20160513	ASC	145	103				
24	S1A	20150816	ASC	43	64	S1A	20160518	ASC	43	104				
25	S1A	20150823	ASC	145	65	S1A	20160525	ASC	145	105				
26	S1A	20150828	ASC	43	66	S1A	20160530	ASC	43	106				
27	S1A	20150916	ASC	145	67	S1A	20160606	ASC	145	107				
28	S1A	20150921	ASC	43	68	S1A	20160611	ASC	43	108				
29	S1A	20150928	ASC	145	69	S1A	20160630	ASC	145	109				
30	S1A	20151015	ASC	43	70	S1A	20160705	ASC	43	110				
31	S1A	20151027	ASC	43	71	S1A	20160712	ASC	145	111				
32	S1A	20151103	ASC	145	72	S1A	20160717	ASC	43	112				
33	S1A	20151108	ASC	43	73	S1A	20160724	ASC	145	113				
34	S1A	20151115	ASC	145	74	S1A	20160729	ASC	43	114				
35	S1A	20151120	ASC	43	75	S1A	20160805	ASC	145	115				
36	S1A	20151127	ASC	145	76	S1A	20160810	ASC	43	116				
37	S1A	20151202	ASC	43	77	S1A	20160817	ASC	145	117				
38	S1A	20151209	ASC	145	78	S1A	20160822	ASC	43	118				
39	S1A	20151214	ASC	43	79	S1A	20160829	ASC	145	119				
40	S1A	20151221	ASC	145	80	S1A	20160903	ASC	43	120				

Table 18. 2017-2018 S1 acquisitions over the demonstration site in South Africa.

	Jan 2017 - Jun 2017					Jun 2017 - Nov 2017					Nov 2017 - Feb 2018			
	SAT	DATE	DIR	Path		SAT	DATE	DIR	Path		SAT	DATE	DIR	Path
1	S1A	20170101	ASC	43	41	S1A	20170625	ASC	145	81	S1A	20171112	DES	79
2	S1A	20170108	ASC	145	42	S1A	20170630	ASC	43	82	S1A	20171116	ASC	145
3	S1A	20170113	ASC	43	43	S1A	20170703	DES	79	83	S1B	20171118	DES	79
4	S1A	20170120	ASC	145	44	S1A	20170707	ASC	145	84	S1A	20171121	ASC	43
5	S1A	20170125	ASC	43	45	S1A	20170712	ASC	43	85	S1B	20171123	DES	152
6	S1A	20170201	ASC	145	46	S1A	20170715	DES	79	86	S1A	20171124	DES	79
7	S1A	20170206	ASC	43	47	S1A	20170719	ASC	145	87	S1A	20171128	ASC	145
8	S1A	20170213	ASC	145	48	S1A	20170724	ASC	43	88	S1B	20171130	DES	79
9	S1A	20170218	ASC	43	49	S1A	20170727	DES	79	89	S1A	20171203	ASC	43
10	S1A	20170221	DES	79	50	S1A	20170731	ASC	145	90	S1B	20171205	DES	152
11	S1A	20170225	ASC	145	51	S1A	20170805	ASC	43	91	S1A	20171206	DES	79
12	S1A	20170302	ASC	43	52	S1A	20170808	DES	79	92	S1A	20171210	ASC	145
13	S1A	20170305	DES	79	53	S1A	20170812	ASC	145	93	S1B	20171212	DES	79
14	S1A	20170309	ASC	145	54	S1A	20170817	ASC	43	94	S1A	20171215	ASC	43
15	S1A	20170314	ASC	43	55	S1A	20170820	DES	79	95	S1B	20171217	DES	152
16	S1A	20170317	DES	79	56	S1A	20170824	ASC	145	96	S1A	20171218	DES	79
17	S1A	20170321	ASC	145	57	S1A	20170829	ASC	43	97	S1A	20171222	ASC	145
18	S1A	20170326	ASC	43	58	S1A	20170901	DES	79	98	S1B	20171224	DES	79
19	S1A	20170329	DES	79	59	S1A	20170905	ASC	145	99	S1A	20171227	ASC	43
20	S1A	20170402	ASC	145	60	S1A	20170910	ASC	43	100	S1B	20171229	DES	152
21	S1A	20170407	ASC	43	61	S1A	20170913	DES	79	101	S1A	20171230	DES	79
22	S1A	20170410	DES	79	62	S1A	20170917	ASC	145	102	S1A	20180103	ASC	145
23	S1A	20170414	ASC	145	63	S1A	20170922	ASC	43	103	S1B	20180105	DES	79
24	S1A	20170419	ASC	43	64	S1A	20170925	DES	79	104	S1A	20180108	ASC	43
25	S1A	20170422	DES	79	65	S1A	20170929	ASC	145	105	S1B	20180110	DES	152
26	S1A	20170426	ASC	145	66	S1A	20171004	ASC	43	106	S1A	20180111	DES	79
27	S1A	20170501	ASC	43	67	S1A	20171007	DES	79	107	S1A	20180115	ASC	145
28	S1A	20170504	DES	79	68	S1A	20171011	ASC	145	108	S1B	20180117	DES	79
29	S1A	20170508	ASC	145	69	S1A	20171016	ASC	43	109	S1A	20180120	ASC	43
30	S1A	20170513	ASC	43	70	S1B	20171018	DES	152	110	S1B	20180122	DES	152
31	S1A	20170516	DES	79	71	S1A	20171019	DES	79	111	S1A	20180123	DES	79
32	S1A	20170520	ASC	145	72	S1A	20171023	ASC	145	112	S1A	20180127	ASC	145
33	S1A	20170525	ASC	43	73	S1B	20171025	DES	79	113	S1B	20180129	DES	79
34	S1A	20170528	DES	79	74	S1A	20171028	ASC	43	114	S1A	20180201	ASC	43
35	S1A	20170601	ASC	145	75	S1B	20171030	DES	152	115	S1B	20180203	DES	152
36	S1A	20170606	ASC	43	76	S1A	20171031	DES	79	116	S1A	20180204	DES	79
37	S1A	20170609	DES	79	77	S1A	20171104	ASC	145	117	S1A	20180208	ASC	145
38	S1A	20170613	ASC	145	78	S1B	20171106	DES	79	118	S1B	20180210	DES	79
39	S1A	20170618	ASC	43	79	S1A	20171109	ASC	43	119	S1A	20180213	ASC	43
40	S1A	20170621	DES	79	80	S1B	20171111	DES	152	120	S1A	20180216	DES	79

Continuation of Table 18

	Feb 2018 - Jun 2018					Jun 2018 - Oct 2018					Oct 2018 - Dec 2018			
	SAT	DATE	DIR	Path		SAT	DATE	DIR	Path		SAT	DATE	DIR	Path
121	S1A	20180220	ASC	145	161	S1B	20180603	DES	152	201	S1B	20181008	DES	79
122	S1A	20180225	ASC	43	162	S1A	20180608	ASC	145	202	S1A	20181011	ASC	43
123	S1B	20180227	DES	152	163	S1B	20180610	DES	79	203	S1B	20181013	DES	152
124	S1A	20180228	DES	79	164	S1A	20180613	ASC	43	204	S1A	20181018	ASC	145
125	S1A	20180304	ASC	145	165	S1B	20180615	DES	152	205	S1B	20181020	DES	79
126	S1B	20180306	DES	79	166	S1A	20180620	ASC	145	206	S1A	20181023	ASC	43
127	S1A	20180309	ASC	43	167	S1B	20180622	DES	79	207	S1A	20181030	ASC	145
128	S1B	20180311	DES	152	168	S1A	20180625	ASC	43	208	S1A	20181104	ASC	43
129	S1A	20180312	DES	79	169	S1B	20180627	DES	152	209	S1A	20181107	DES	79
130	S1A	20180316	ASC	145	170	S1A	20180702	ASC	145	210	S1A	20181111	ASC	145
131	S1B	20180318	DES	79	171	S1B	20180704	DES	79	211	S1B	20181113	DES	79
132	S1A	20180321	ASC	43	172	S1A	20180707	ASC	43	212	S1A	20181116	ASC	43
133	S1B	20180323	DES	152	173	S1B	20180709	DES	152	213	S1B	20181118	DES	152
134	S1A	20180324	DES	79	174	S1A	20180714	ASC	145	214	S1A	20181119	DES	79
135	S1A	20180328	ASC	145	175	S1B	20180716	DES	79	215	S1A	20181123	ASC	145
136	S1B	20180330	DES	79	176	S1A	20180719	ASC	43	216	S1B	20181125	DES	79
137	S1A	20180402	ASC	43	177	S1B	20180721	DES	152	217	S1A	20181128	ASC	43
138	S1B	20180404	DES	152	178	S1A	20180726	ASC	145	218	S1B	20181130	DES	152
139	S1A	20180405	DES	79	179	S1B	20180728	DES	79	219	S1A	20181205	ASC	145
140	S1A	20180409	ASC	145	180	S1A	20180731	ASC	43	220	S1A	20181210	ASC	43
141	S1B	20180411	DES	79	181	S1A	20180807	ASC	145	221	S1B	20181212	DES	152
142	S1A	20180414	ASC	43	182	S1B	20180809	DES	79	222	S1A	20181217	ASC	145
143	S1B	20180416	DES	152	183	S1A	20180812	ASC	43	223	S1B	20181219	DES	79
144	S1A	20180417	DES	79	184	S1B	20180814	DES	152	224	S1A	20181222	ASC	43
145	S1A	20180421	ASC	145	185	S1A	20180819	ASC	145	225	S1B	20181224	DES	152
146	S1B	20180423	DES	79	186	S1B	20180821	DES	79	226	S1A	20181225	DES	79
147	S1A	20180426	ASC	43	187	S1A	20180824	ASC	43	227	S1A	20181229	ASC	145
148	S1B	20180428	DES	152	188	S1B	20180826	DES	152	228	S1B	20181231	DES	79
149	S1A	20180429	DES	79	189	S1A	20180831	ASC	145					
150	S1A	20180503	ASC	145	190	S1B	20180902	DES	79					
151	S1B	20180505	DES	79	191	S1A	20180905	ASC	43					
152	S1A	20180508	ASC	43	192	S1B	20180907	DES	152					
153	S1B	20180510	DES	152	193	S1A	20180912	ASC	145					
154	S1A	20180515	ASC	145	194	S1B	20180914	DES	79					
155	S1B	20180517	DES	79	195	S1A	20180917	ASC	43					
156	S1A	20180520	ASC	43	196	S1B	20180919	DES	152					
157	S1B	20180522	DES	152	197	S1A	20180924	ASC	145					
158	S1A	20180527	ASC	145	198	S1A	20180929	ASC	43					
159	S1B	20180529	DES	79	199	S1B	20181001	DES	152					
160	S1A	20180601	ASC	43	200	S1A	20181006	ASC	145					

Table 19. 2019 S1 acquisitions over the demonstration site in South Africa.

	Jan 2019 - Apr 2019					Apr 2019 - Aug 2019					Aug 2019 - Nov 2019					Nov 2019 - Dec 2019			
	SAT	DATE	DIR	Path		SAT	DATE	DIR	Path		SAT	DATE	DIR	Path		SAT	DATE	DIR	Path
1	S1A	20190103	ASC	43	41	S1A	20190424	DES	79	81	S1A	20190807	ASC	43	121	S1B	20191120	DES	79
2	S1A	20190106	DES	79	42	S1B	20190427	ASC	43	82	S1B	20190809	DES	152	122	S1A	20191123	ASC	43
3	S1A	20190110	ASC	145	43	S1A	20190428	ASC	145	83	S1A	20190810	DES	79	123	S1B	20191125	DES	152
4	S1A	20190115	ASC	43	44	S1B	20190430	DES	79	84	S1A	20190814	ASC	145	124	S1A	20191126	DES	79
5	S1A	20190118	DES	79	45	S1A	20190503	ASC	43	85	S1B	20190816	DES	79	125	S1A	20191130	ASC	145
6	S1A	20190122	ASC	145	46	S1B	20190505	DES	152	86	S1A	20190819	ASC	43	126	S1B	20191202	DES	79
7	S1B	20190124	DES	79	47	S1A	20190506	DES	79	87	S1B	20190821	DES	152	127	S1A	20191205	ASC	43
8	S1A	20190127	ASC	43	48	S1A	20190510	ASC	145	88	S1A	20190822	DES	79	128	S1B	20191207	DES	152
9	S1B	20190129	DES	152	49	S1B	20190512	DES	79	89	S1A	20190826	ASC	145	129	S1A	20191208	DES	79
10	S1A	20190203	ASC	145	50	S1A	20190515	ASC	43	90	S1B	20190828	DES	79	130	S1A	20191212	ASC	145
11	S1B	20190205	DES	79	51	S1B	20190517	DES	152	91	S1A	20190831	ASC	43	131	S1B	20191214	DES	79
12	S1A	20190208	ASC	43	52	S1A	20190522	ASC	145	92	S1B	20190902	DES	152	132	S1A	20191217	ASC	43
13	S1B	20190210	DES	152	53	S1B	20190524	DES	79	93	S1A	20190903	DES	79	133	S1B	20191219	DES	152
14	S1A	20190215	ASC	145	54	S1A	20190527	ASC	43	94	S1A	20190907	ASC	145	134	S1A	20191220	DES	79
15	S1B	20190217	DES	79	55	S1B	20190529	DES	152	95	S1B	20190909	DES	79	135	S1A	20191224	ASC	145
16	S1A	20190220	ASC	43	56	S1A	20190603	ASC	145	96	S1A	20190912	ASC	43	136	S1B	20191226	DES	79
17	S1B	20190222	DES	152	57	S1B	20190605	DES	79	97	S1B	20190914	DES	152	137	S1A	20191229	ASC	43
18	S1A	20190223	DES	79	58	S1A	20190608	ASC	43	98	S1A	20190915	DES	79	138	S1B	20191231	DES	152
19	S1A	20190227	ASC	145	59	S1B	20190610	DES	152	99	S1A	20190919	ASC	145	139				
20	S1A	20190304	ASC	43	60	S1A	20190615	ASC	145	100	S1B	20190921	DES	79	140				
21	S1B	20190306	DES	152	61	S1B	20190617	DES	79	101	S1A	20190924	ASC	43	141				
22	S1A	20190307	DES	79	62	S1A	20190620	ASC	43	102	S1B	20190926	DES	152	142				
23	S1A	20190311	ASC	145	63	S1B	20190622	DES	152	103	S1A	20190927	DES	79	143				
24	S1B	20190313	DES	79	64	S1A	20190623	DES	79	104	S1A	20191001	ASC	145	144				
25	S1A	20190316	ASC	43	65	S1A	20190627	ASC	145	105	S1B	20191003	DES	79	145				
26	S1B	20190318	DES	152	66	S1A	20190702	ASC	43	106	S1A	20191006	ASC	43	146				
27	S1A	20190319	DES	79	67	S1B	20190704	DES	152	107	S1B	20191008	DES	152	147				
28	S1A	20190323	ASC	145	68	S1A	20190705	DES	79	108	S1A	20191013	ASC	145	148				
29	S1B	20190325	DES	79	69	S1A	20190709	ASC	145	109	S1B	20191015	DES	79	149				
30	S1A	20190328	ASC	43	70	S1B	20190711	DES	79	110	S1A	20191018	ASC	43	150				
31	S1B	20190330	DES	152	71	S1A	20190714	ASC	43	111	S1A	20191021	DES	79	151				
32	S1A	20190331	DES	79	72	S1B	20190716	DES	152	112	S1A	20191025	ASC	145	152				
33	S1A	20190404	ASC	145	73	S1A	20190717	DES	79	113	S1B	20191027	DES	79	153				
34	S1B	20190406	DES	79	74	S1A	20190721	ASC	145	114	S1A	20191030	ASC	43	154				
35	S1A	20190409	ASC	43	75	S1B	20190723	DES	79	115	S1A	20191102	DES	79	155				
36	S1B	20190411	DES	152	76	S1A	20190726	ASC	43	116	S1A	20191106	ASC	145	156				
37	S1A	20190412	DES	79	77	S1B	20190728	DES	152	117	S1B	20191108	DES	79	157				
38	S1A	20190416	ASC	145	78	S1A	20190729	DES	79	118	S1B	20191113	DES	152	158				
39	S1A	20190421	ASC	43	79	S1A	20190802	ASC	145	119	S1A	20191114	DES	79	159				
40	S1B	20190423	DES	152	80	S1B	20190804	DES	79	120	S1A	20191118	ASC	145	160				

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