Climate Change Initiative Extension (CCI+) Phase 1

New Essential Climate Variables (NEW ECVS)

High Resolution Land Cover ECV (HR_LandCover_cci)

Data Access Requirement Document

(DARD)

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Changelog

Issue	Changes	Date
1.0	First version.	02/04/2019
1.1	Updated version according to CCI_HRLC_Ph1_Milestone1_RID-ESA.xlsx and comments in PM2.	12/04/2019
2.0	Added section with the description of the Medium resolution Copernicus Global Land Cover (CGLC) Map.	03/01/2020

Detailed Change Record

Issue	RID	Description of discrepancy	Sections	Change
1.1	DARD-1	Sentinel-2 Level-1B is not distributed to the users.	2.2	Removed Level-1B.
	DARD-2	B12 is missing.	2.2	Added B12.
	DARD-3	Landsat-7 was launched in April 1999 and not Landsat-8.	3.1.1.1	Update with correct launch dates of Landsat-7 and 8.
	DARD-5	In the HRLC historical map (1990-2015) it is not reported the 1995 period (1990-1995).	4	Added missing period with SPOT data.
	PSD-2	As suggested by O. Arino in the PM1 (AI#11), check if SPOT data are available in the ESA archive over Africa at 10m resolution. Usage of SPOT data should have the priority on Landsat ones.	3.1.2	Added section 3.1.2 with spatial/temporal detail on SPOT data and analysis related to HRLC products.

Contents

1 Introduction

1.1 Executive summary

Activities carried on during the first year of activity for the joint requirements analysis and development of the processing chain included detailed analysis of input data requirements and availability in order to address the main technical requirements of the project. The required high geometrical resolution, the overall period of observation (from 1990 and on) and periodicity of LC maps to be produced make the images provided by optical missions (e.g., Landsat and Sentinel) essential in addressing several technical requirements of the project. The main constraint of this project is the trade-off between the temporal resolution of the final HRLC maps and the availability of cloud-free optical images. SAR images can mitigate the absence of regular optical acquisitions but they cannot replace them for land cover classification purposes. Therefore, checking data availability on candidate regional areas is needed for a correct planning of the data analysis phase.

The document presents for both products categories to be delivered in the project, i.e., a HRLC Static Map for 2018 and a historical record of LC and LCC products from 1990 to 2015, a detailed analysis of input data technical specifications and their availability.

1.2 Purpose and scope

The Data Access Requirement Document (DARD) identifies all the data that are needed as input to perform the CCI HRLC project and it follows the preliminary analysis given in Technical Proposal [AD1]. This document lists all:

- Level 1 products from both ESA and Third Party Missions;
- ancillary data (this will be integrated in future versions of the document);
- in situ observation data sources as well as higher-level products needed for product inter-comparison (this will be integrated in future versions of the document);
- historical archives and currently operational sources (this will be integrated in future versions of the document).

For each data source, the DARD includes:

- information about the originating system;
- identification of the data class (in-situ, EO, model);
- specification of the sensor type and key technical characteristics;
- information about data availability and coverage (times-scale, geographic, temporal);
- estimates of the data quantity;
- indication of data quality and reliability;
- description of the ordering and delivery mechanism (this will be integrated in future versions of the document);
- identification of access conditions and pricing (this will be integrated in future versions of the document).

1.3 Applicable documents

Ref.	**Title, Issue/Rev, Date, ID**
[AD1]	CCI HR Technical Proposal, v1.1, 16/03/2018

1.4 Reference documents

Ref.	**Title, Issue/Rev, Date, ID**

1.5 Acronyms and abbreviations

AMI	Active Microwave Instrument
ASAR	Advanced Synthetic Aperture Radar
BOA	Bottom of Atmosphere
CCI	Climate Change Initiative
DARD	Data Access Requirement Document
ECV	Essential Climate Variables
ERS	European Remote Sensing
ETM	Enhanced Thematic Mapper
GCOS	Global Climate Observing System
HR	High Resolution
LC	Land Cover
LCC	Land Cover Change
MGRS	Military Grid Reference System
MR	Medium Resolution
MSS	Multispectral Scanner
NIR	Near infrared
SAR	Synthetic Aperture Radar
SoW	Statement of Work
SWIR	Short-wave infrared
TIRS	Thermal Infrared Sensor
TOA	Top of Atmosphere
TM	Thematic Mapper
UTM	Universal Transverse of Mercator
VHR	Very High Resolution
WGS84	World Geodetic System 1984

2 Static High Resolution Land Cover Map Data Requirements

The project output described in this section is the HRLC Static Map of three key areas in Amazon, Africa (Sahel band) and Siberia for year 2018. This product is generated using both Sentinel-1 and Sentinel-2 sensors. The classification map will be used as a reference static input for historical reconstruction of LC and LC change.

2.1 Medium Resolution Copernicus Global Land Cover (CGLC) Map

To generate a large training database of labeled samples, the team is leveraging on the 2015 Copernicus Global Land Cover (CGLC) map delivered by the Copernicus Global Land Service (CGLS). The CGLC map was selected as the best candidate for the land cover reference map, due to its: i) good spatial resolution (100 m), ii) detailed hierarchical legend that includes many classes that are in common with the last version of the CCI HR legend, and iii) relatively recent temporal coverage (2015).

This global land cover product is a medium resolution map having a spatial resolution of 100 m. The map is produced by considering the time series of multispectral PROBA-V 100 m images, a dataset of more than 140 K crowd-sourced (Geo-WIKI) land cover training points and other ancillary data. Since ground truth points were collected through manual visual interpretation of Google Maps and Bing images at 10 m spatial resolution (crowd-sourced Geo-WIKI), the CGLC product at 100 m derives also information about the fractional cover layers for the ten base land cover classes: forest, shrub, grass, moss and lichen, bare and sparse vegetation, cropland, built-up / urban, snow and ice, seasonal and permanent inland water bodies. Moreover, the CGLC product provides a forest type layer offering twelve types of forest, quality indicators for input data (data density indicator), for the discrete map (probability) and for six of the fractional cover layers.

The CGLC map provides discrete classification at three levels according to Land Cover Classification System (LCCS) developed by the United Nations (UN) Food and Agriculture Organization (FAO). While in the first level the map presents the main twelve land cover classes (i.e., forest, shrub, herbaceous vegetation, herbaceous wetland, moss and lichen, bare / sparse vegetation, cultivated and managed vegetation - cropland, built-up, snow and ice and permanent inland water bodies), in the third level more detailed information are available by distinguishing 23 classes. For instance, the forest classes are divided into six types of closed and six types of open forest.

The validation of CGLC product was performed by using independent validation data of around 21 600 samples generated in collaboration with experts. The overall accuracy of the CGLS 100m map is equal to 80.2 % +/-0.7 % depending on the continent. The highest classification accuracy (>85%) is achieved for the forest, snow/ice, bare /sparse vegetation, and permanent water. For the herbaceous vegetation, croplands, urban CGLC achieve moderate accuracy, the lowest accuracy of (<65%) is performed for herbaceous wetland, lichen and moss and shrubs.

2.2 Optical EOS High Resolution Data

The optical processing chain for the HR Static Map takes as input Sentinel-2 images from year 2018.

2.2.1 Sentinel-2

The Copernicus Sentinel-2 mission comprises a constellation of two polar-orbiting satellites placed in the same sun-synchronous orbit, phased at 180° to each other. Its wide swath width (290 km) and high revisit time (10 days at the equator with one satellite, and 5 days with 2 satellites under cloud-free conditions which results in 2-3 days at mid-latitudes) are fundamental for the requirements of the HRLC product to be produced. The coverage limits of Sentinel-2 acquisitions are between latitudes 56°S and 84°N, so within project requirements (Siberian study area northern limit is 79°N).

Sentinel-2 data available to users are Level-1C and Level-2A. Level-1C products provide ortho-rectified Top-Of-Atmosphere (TOA) reflectance, with sub-pixel multispectral registration. Level-2A products provide ortho-rectified Bottom-Of-Atmosphere (BOA) reflectance, with sub-pixel multispectral registration. A scene

classification map (cloud, cloud shadows, vegetation, soils/deserts, water, snow, etc.) is included in the product. Sentinel-2 image characteristic are listed in Table 1.

Table 1. Sentinel-2 imagery technical specifications.

Bands	Sentinel-2 A		Sentinel-2 B		Resolution [m]
	Central Wavelength [nm]	Bandwidth [nm]	Central Wavelength [nm]	Bandwidth [nm]	
B1 - Coastal aerosol	442.7	21	442.2	21	60
B2 - Blue	492.4	66	492.1	66	10
B3 - Green	559.8	36	559.0	36	10
B4 - Red	664.6	31	664.9	31	10
B5 - Vegetation red edge	704.1	15	703.8	16	20
B6 - Vegetation red edge	740.5	15	739.1	15	20
B7 - Vegetation red edge	782.8	20	779.7	20	20
B8 - NIR	832.8	106	832.9	106	10
B8A - Narrow NIR	864.7	21	864.0	22	20
B9 - Water vapour	945.1	20	943.2	21	60
B10 - SWIR (Cirrus)	1373.5	31	1376.9	30	60
B11 - SWIR	1613.7	91	1610.4	94	20
B12 – SWIR	2202.4	175	2185.7	185	20

Specific project requirements related to uncertainty definition and integration of enhanced algorithms with respect to those available in literature put as requirement Level-1C data as input to the optical processing chain.

Quality control report of Sentinel-2 imagery is provided monthly in Data Quality Reports providing information on the monitoring and measurement of L1C and L2A product performances against proposed specifications related to geometric and radiometric performances. The reports also document observed anomalies and known issues, the list of defective pixels, and any processing chain improvements resulting in an increment of the Processing Baseline.

Sentinel-2 products are a compilation of elementary granules of fixed size, along with a single orbit. A granule is the minimum indivisible partition of a product (containing all possible spectral bands). Granules, also called tiles, are 100x100 km^2 ortho-images in UTM/WGS84 projection. The typical Level-1C product size is ~600 MB per each 100x100 km^2 tile.

The following tables describe the characteristics (Table 2) and the availability (Table 3) of Sentinel-2 images to be used in HRLC Static Map optical-based processing chain.

Table 2. Characteristics of optical data input to the processing chain for the HRLC Static Map 2018.

Product	Source	Specification	Temporal coverage	Quantity	Comment
Sentinel-2 Level-1C	ESA	4 bands (10m) 6 bands (20m) 3 bands (60m) 5 days revisit time MGRS grid 100x100 km^2	2018	Amazon 65 TB Africa 111 TB Siberia 158 TB	

Table 3. Availability of optical data input to the processing chain for the HRLC Static Map 2018.

Product	Availability	Conditions	Req. subset	Purpose/Timeliness
Sentinel-2 Level-1C	Available on Copernicus	Conditions of use defined by ESA Sentinel data policy, i.e. redistributable	2018	Main source of data for optical-based static map.

	Open Access Hub			

2.3 SAR High Resolution Data

The SAR processing chain for the HR Static Map takes as input Sentinel-1 images from year 2018.

2.3.1 Sentinel-1

The Copernicus Sentinel-1 mission comprises a constellation of two polar-orbiting satellites operating day and night performing C-band synthetic aperture radar imaging in four exclusive imaging modes with different resolution (down to 5 m) and coverage (up to 400 km). It provides dual polarisation capability, very short revisit times and rapid product delivery. For each observation, precise measurements of spacecraft position and attitude are available. Sentinel-1 works in a pre-programmed operation mode to avoid conflicts and to produce a consistent long-term data archive built for applications based on long time series.

Available acquisition modes and resolutions are: (i) Strip Map Mode: 80 km swath, 5x5 m spatial resolution, (ii) Interferometric Wide Swath: 250 km swath, 5x20 m spatial resolution, (iii) Extra-Wide Swath Mode: 400 km swath, 20x40 m spatial resolution, and (iv) Wave-Mode: 20 x 20 km, 5x5 m spatial resolution.

Four different types of product are available: Level-0 Raw, Level-1 Single Look Complex (SLC), Level-1 Ground Range Detected and Level-2 Ocean. Specific project requirements related to uncertainty definition and integration of enhanced algorithms with respect to those available in literature put as requirement Level-1 data as input to the SAR processing chain. Level-1 SLC products consist of focused SAR data geo-referenced using orbit and attitude data from the satellite and provided in zero-Doppler slant-range geometry. The products include a single look in each dimension using the full transmit signal bandwidth and consist of complex samples preserving the phase information. Level-1 GRD products consist of focused SAR data that has been detected, multi-looked and projected to ground range using an Earth ellipsoid model. Phase information is lost. The resulting product has approximately square spatial resolution pixels and square pixel spacing with reduced speckle at the cost of worse spatial resolution. GRD products can be in one of three resolutions: Full Resolution (FR), High Resolution (HR) and Medium Resolution. The resolution is dependent upon the amount of multi-looking performed. Level-1 GRD products are available in MR and HR for IW and EW modes, MR for WV mode and MR, HR and FR for SM mode.

The following tables describe the characteristics (Table 4) and the availability (Table 5) of SAR images to be used in HRLC Static Map SAR-based processing chain.

Table 4. Characteristics of SAR data input to the processing chain for the HRLC Static Map 2018.

Product	Source	Specification	Temporal coverage	Quantity	Comment
Sentinel-1 L1 IW GRD HR Product	ESA	10 m pixel size Full Swath C Band SAFE format	2015 - 2018	6.5 TB	Geographical coverage is different in different test areas.

Table 5. Availability of SAR data input to the processing chain for the HRLC Static Map 2018.

Product	Availability	Conditions	Req. subset	Purpose/Timeliness
Sentinel-1 L1 IW GRD HR Product	Available on Copernicus Open Access Hub	Conditions of use defined by ESA Sentinel data policy, i.e. redistributable	2014 - 2018	Main source of data for SAR-based static map.

3 Historical High Resolution Land Cover Map Data Requirements

The project output described in this section is the HR historical record of LC products every 5 years from 1990 to 2015 and of LCC on a yearly basis for the same period. These products are related to three sub-regions of the ones covered by Static Maps. LC and LCC products are generated using Landsat-5 to 8 images and ERS, ASAR, and Sentinel-1 data.

3.1 Optical EOS High Resolution Data

3.1.1 Landsat

The Landsat Project is a joint initiative of the U.S. Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA). Since 1972, Landsat satellites have created the longest continuously-acquired space-based, moderate-resolution data archive. Landsat-1 through 5 carried the Landsat Multispectral Scanner (MSS). Landsat-4 and 5 carried both the MSS and Thematic Mapper (TM) instruments. Landsat-7 uses the Enhanced Thematic Mapper Plus (ETM+) scanner. Landsat-8 uses two instruments, the Operational Land Imager (OLI) for optical bands and the Thermal Infrared Sensor (TIRS) for thermal bands. The band designations and pixel sizes for the Landsat instruments are listed in Table 6.

Table 6. Landsat imagery technical specifications.

Mission	Bands	Wavelength [µm]	Resolution [m]
LANDSAT-5	B1 - Blue	0.45 - 0.52	30
	B2 - Green	0.52 - 0.60	30
	B3 - Red	0.63 - 0.69	30
	B4 - NIR	0.76 - 0.90	30
	B5 - SWIR 1	1.55 - 1.75	30
	B6 - Thermal	10.40 - 12.50	120* (30)
	B7 - SWIR 2	2.08 - 2.35	30
LANDSAT-7	B6 – Thermal	10.40 - 12.50	60* (30)
	B8 - Panchromatic	0.52 - 0.90	15
LANDAT-8	B1 - Ultra Blue (coastal/aerosol)	0.435 - 0.451	30
	B2 - Blue	0.452 - 0.512	30
	B3 - Green	0.533 - 0.590	30
	B4 - Red	0.636 - 0.673	30
	B5 - NIR	0.851 - 0.879	30
	B6 - SWIR 1	1.566 - 1.651	30
	B7 - SWIR 2	2.107 - 2.294	30
	B8 - Panchromatic	0.503 - 0.676	15
	B9 - Cirrus	1.363 - 1.384	30
	B10 - Thermal 1	10.60 - 11.19	100* (30)
	B11 - Thermal 2	11.50 - 12.51	100* (30)

The optical processing chain for HR historical LC maps takes as input Landsat images from all missions, i.e., 5,7,8. Therefore, consistency among products is required. It is possible to get this requirement satisfied by ingesting images from Landsat Tier-1 collection. Landsat scenes with the highest available data quality are placed into Tier-1 and are considered suitable for time-series processing analysis. Tier-1 includes Level-1 Precision Terrain (L1TP) processed data that have well-characterized radiometry and are inter-calibrated across the different Landsat sensors. The geo-registration of Tier-1 scenes is consistent and within prescribed tolerances [<=12 m root mean square error (RMSE)]. All Tier-1 Landsat data can be considered radiometrically calibrated and geolocated consistently across the full collection for all the sensors.

The following tables describe the characteristics (Table 7) and the availability (Table 8) of optical images to be used in HR historical record of LC products optical-based processing chain.

Table 7. Characteristics of optical data input to the processing chain for the HR historical record of LC products 1990-2015.

Product	Source	Specification	Temporal coverage	Quantity	Comment
LANDSAT-5 Tier-1	USGS	7 bands (30m) 16 days revisit time WRS-2 path/row	1985 - 2012	Amazon 5 TB Africa 3 TB Siberia 2 TB	
LANDSAT-7 Tier-1	USGS	7 bands (30m) 1 panchromatic (15m) 16 days revisit time WRS-2 path/row	1999 - today	Amazon 8 TB Africa 6 TB Siberia 3.5 TB	
LANDSAT-8 Tier-1	USGS	8 bands (30m) 1 panchromatic (15m) 2 thermal (100m) 16 days revisit time WRS-2 path/row	2013 - today	Amazon 6 TB Africa 6.3 TB Siberia 5 TB	

Table 8. Availability of optical data input to the processing chain for the HR historical record of LC products 1990-2015.

Product	Availability	Conditions	Req. subset	Purpose/Timeliness
LANDSAT-5 Tier-1	USGS	Conditions of use defined by USGS Landsat data policy, i.e. redistributable	1985 - 2012	
LANDSAT-7 Tier-1	USGS	Conditions of use defined by USGS Landsat data policy, i.e. redistributable	1999 - today	
LANDSAT-8 Tier-1	USGS	Conditions of use defined by USGS Landsat data policy, i.e. redistributable	2013 - today	

3.1.1.1 Spatial and temporal image coverage

One of the main challenges in this project is related to mapping of LC and LCC in the historical period 1990-2015 using high resolution images, specifically using Landsat images as primary source of information. This implies low temporal resolution, especially in the period 1990-2000, being Landsat-7 only launched in April 1999 and Landsat-8 in February 2013. In order to provide a comprehensive illustration of the spatial and temporal coverage of the Landsat images available in archive, we propose in the following tables: (i) spatial histograms of image coverage and (ii) temporal charts of image products and related cloud coverage, for different five-year periods. Cloud cover information is retrieved through Landsat products metadata information. This analysis back-propagates to 1985 (first full year of Landsat production) and provides first assessment for the possibility of extending the temporal span of HRLC historical products back to 1985. The legend in temporal charts of image products assigns each image a colored label based on cloud coverage as: 0%-25%, 25%-50%, 50%-75%, 75%-100%.

Table 9. Spatial and temporal Landsat-5 image availability for the period 1985-2000 over the Siberian area for HRLC historical reconstruction.

1985-1989	1990-1994	1995-1999

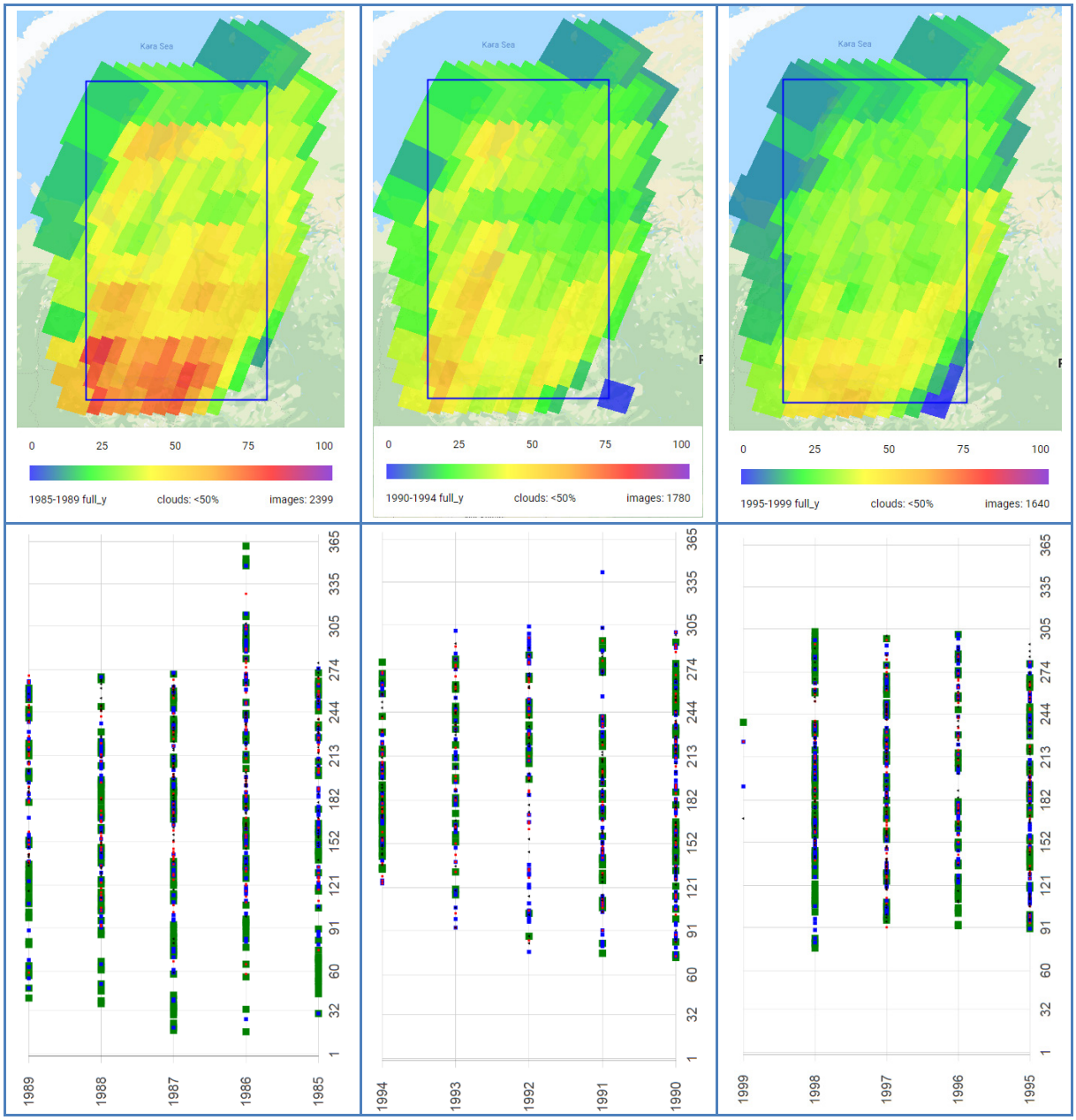


Table 10. Spatial and temporal Landsat-5 image availability for the period 1985-2000 over the Amazonian area for HRLC historical reconstruction.

1985-1989	1990-1994	1995-1999

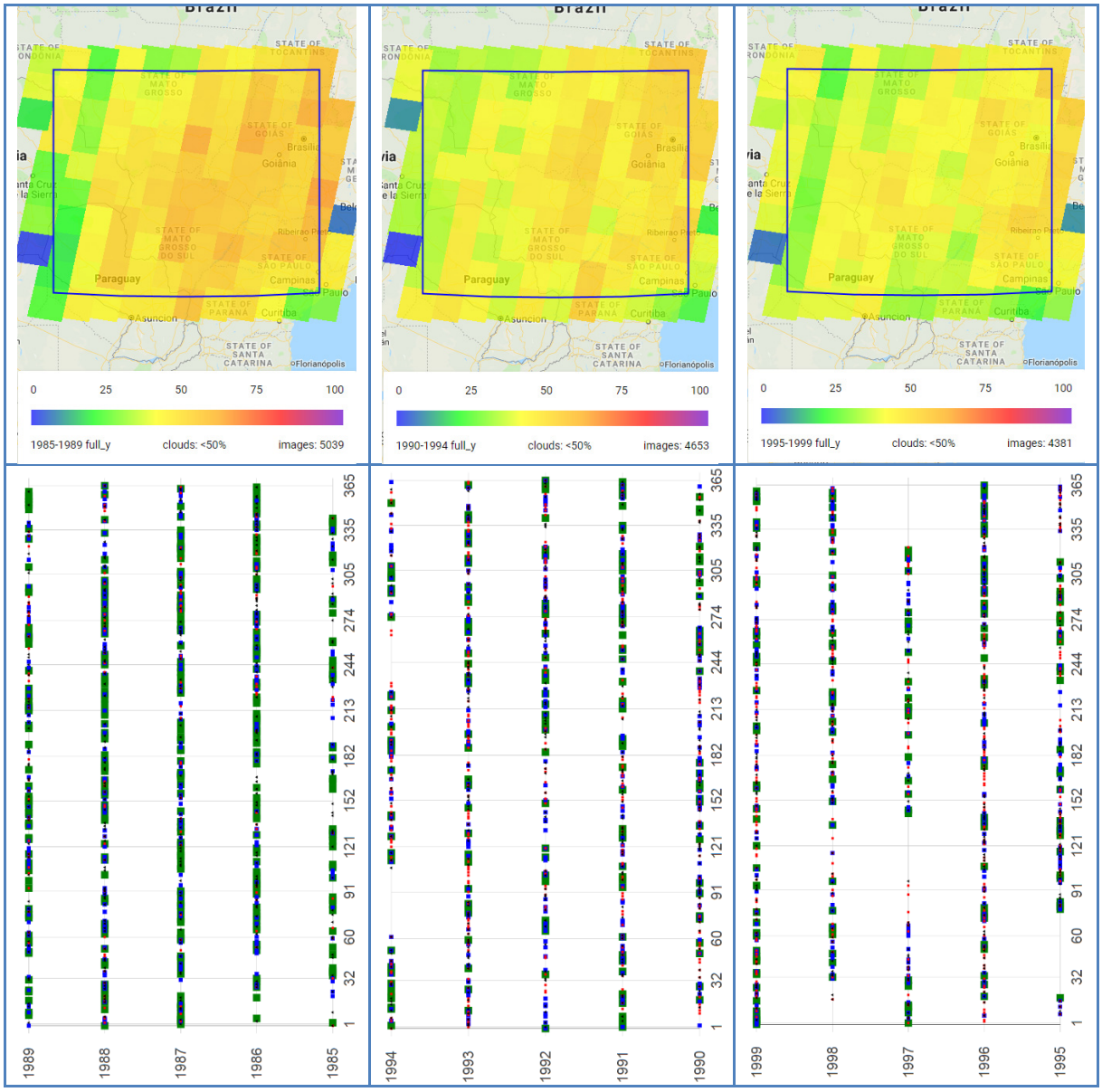
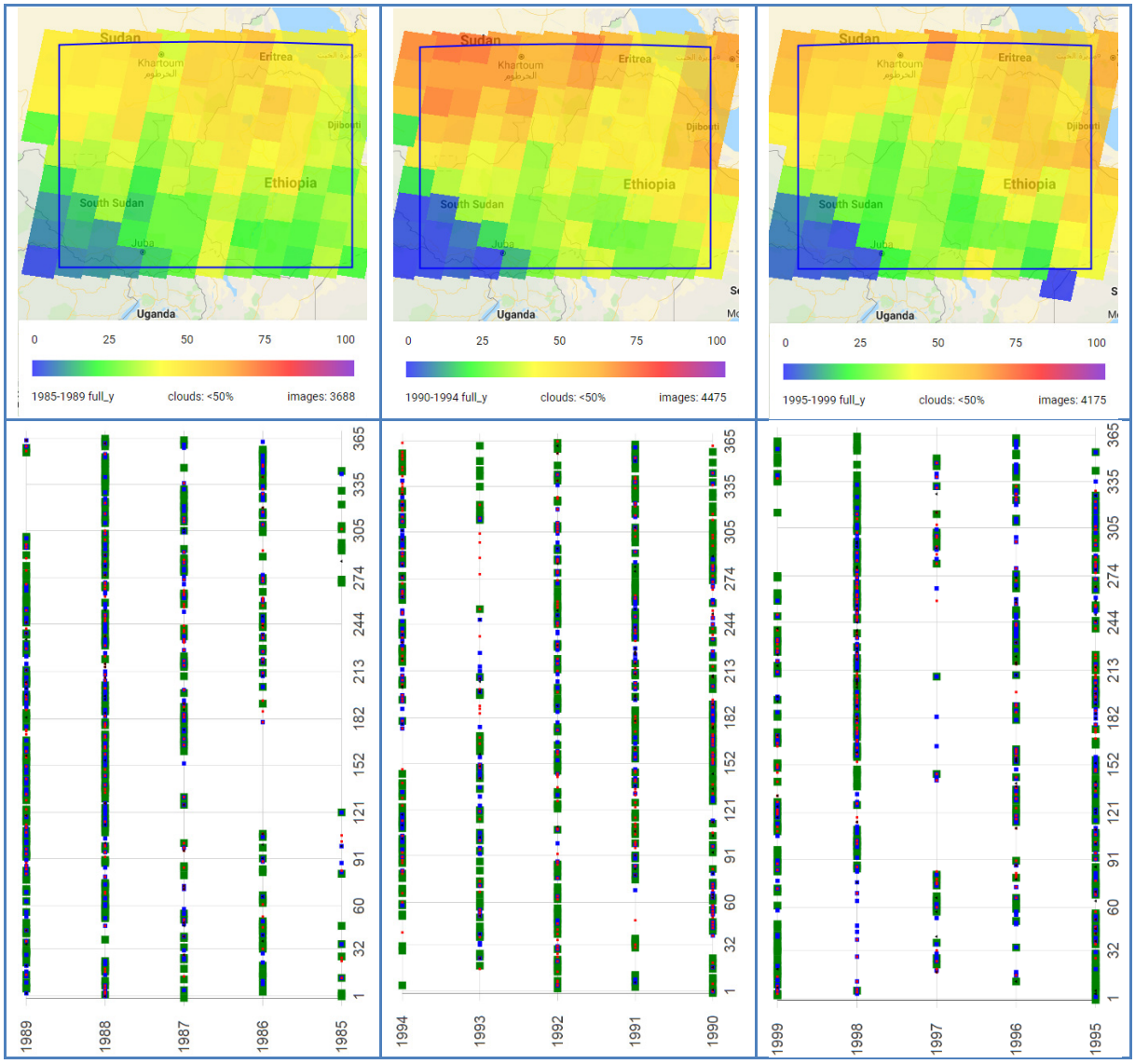


Table 11. Spatial and temporal Landsat-5 image availability for the period 1985-2000 over the African area for HRLC historical reconstruction.

1985-1989	1990-1994	1995-1999



3.1.2 SPOT

There have been five SPOT (Satellite Pour l'Observation de la Terre) satellites launched from 1986 to 2015, providing medium to high resolution of the Earth's surface. SPOT 1, 2 and 3 carried a multi-spectral and panchromatic sensor on board. SPOT 4 was successfully launched in March 1998 with an additional Short Wave Infrared band. Compared to its predecessors, SPOT-5 has improved to a higher ground resolution. The SPOT satellites orbit at an altitude of 822km. SPOT scene sizes are typically 60km by 60km (vertical viewing) or 60km by 80km for oblique viewing. The optical imaging instruments (HRVs) are steerable to either side of the ground track - east to west - by up to 30 degrees.

In view of the fact that the products for the historical reconstruction will be delivered at 30m resolution, we see SPOT images provide greater spatial detail and they are a valuable source of information. However, Landsat will be considered the primary source of information for the production. This choice is mainly motivated by the significantly different spectral resolution available in the considered sensors. As a matter of fact, Landsat provides richer spectral detail making the fulfilment of the target classification legend (to be defined soon) affordable. The Consortium is not confident that the spectral detail available in SPOT would be enough to discriminate the different classes foreseen. In conclusion, SPOT will be the first complementary source of data where Landsat coverage will show spatial gaps. The band designations and pixel sizes for the SPOT instruments are listed in Table 12.

Table 12. SPOT imagery technical specifications.

Mission	Bands	Wavelength [µm]	Resolution [m]
SPOT-1,2,3	B1 - Green	0.50 - 0.59	20
	B2 - Red	0.61 - 0.68	20
	B3 - NIR	0.79 - 0.89	20
	P - Panchromatic	0.51 - 0.73	10
SPOT-4	B4 - SWIR (others same as SPOT-1,2,3)	1.58 – 1.75	20
SPOT-5	B1 - Green	0.50 - 0.59	10
	B2 - Red	0.61 - 0.68	10
	B3 - NIR	0.78 - 0.89	10
	B4 - SWIR	1.58 – 1.75	20
	P - Panchromatic	0.48 - 0.71	5

3.1.2.1 Spatial and temporal image coverage

In view of the discussion above and the problematic situation of the Landsat data availability in the southern part of the African region for historical reconstruction (cfr. Table 11), we include here a brief analysis of SPOT-1,2,3,4 data availability in the critical area for the period 1985-1999. The geometry in which data availability is checked is illustrated in Figure 1 in light blue.

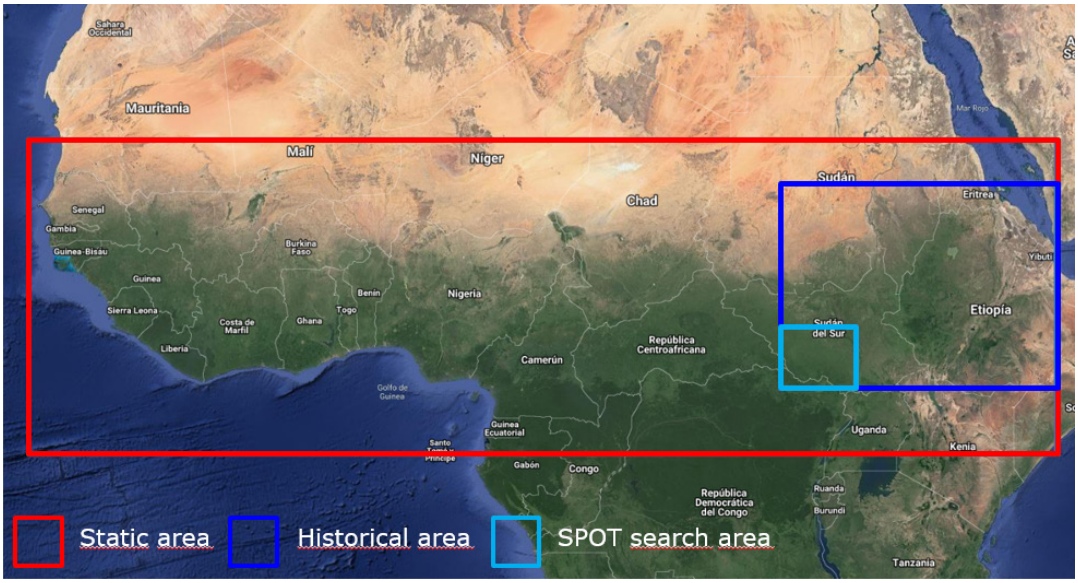


Figure 1. SPOT imagery search area for the estimation of data availability in the historical period 1985-2000.

The extension of the search area is 100x100km^2. The number of products available is reported in Table 13, where images included in the list are only those with cloud cover percentage between 0-90%. On average the cloud coverage of listed products is around 40%.

Table 13. Temporal SPOT-1,2,3,4 image availability for the period 1985-2000 over the African sub-area (south-west) for HRLC historical reconstruction

Year	SPOT-1 tiles	Year	SPOT-2,3 tiles	Year	SPOT-3,4 tiles
1985	0	1990	0	1995	96
1986	118	1991	19	1996	41
1987	20	1992	3	1997	0
1988	62	1993	17	1998	40
1989	101	1994	27	1999	73

3.2 SAR High Resolution Data

The SAR processing chain for the HR historical record of LC products takes as input Sentinel-1, ERS and ASAR images from different years. Detail on Sentinel-1 products are given in Section 2.3. ERS and ASAR data are described below.

3.2.1 ERS

ERS was the first ESA program in Earth observation with the overall objectives to provide environmental monitoring, in particular in the microwave spectrum. The ERS program was composed of two missions, ERS-1 (1991-2000) and ERS-2 (1995-2011). The ERS-1 satellite carried five sensors: an Active Microwave Instrument (AMI) including a radar imager (SAR) and a scatterometer, a radar altimeter (RA), a radiometer (ATSR), a microwave sounder (MS) and range equipment (PRARE). The ERS-2 satellite carried an additional sensor, the Global Ozone Monitoring Instrument (GOME).

The AMI comprised two seperate radars: Synthetic Aperture Radar (SAR) and Wind Scatterometer. These enable three modes of operation: Image Mode, Wave Mode (both performed by the SAR) and Wind Mode (performed by the Wind Scatterometer). The ERS missions were mainly operated in a 35-day repeat cycle. In addition, a 3-day cycle (ice phase) was followed by ERS-1 in 1992 and 1994 and by ERS-2 in 2011. ERS-1 had also a 168-day repeat cycle (geodetic phase) in 1994 and 1995. Both ERS-1 and ERS-2 were operated in a 1-day difference (known as tandem mode) from 1995 to 2010 to develop SAR interferometry applications.

SAR works on C band (5.3 GHz) in VV polarisation at bandwidth 15.5A ± 0.06 MHz, swath width is 100km. In image mode the SAR provides high resolution two-dimensional images with a spatial resolution of 26 m in range (across track) and between 6 and 30 m in azimuth (along track). Image data is acquired for a maximum duration of approximately ten minutes per orbit. SAR wave mode provides two-dimensional spectra of ocean surface waves. For this function the SAR records regularly spaced samples within the image swath. The images are transformed into directional spectra providing information about wavelength and direction of wave systems. Instrument accuracy varies across thematic classes: landscape topography 3m, bathymetry 0.3m, sea ice type: 3 classes, sea surface wind speed: 3m/s, significant wave height 0.2m.

ERS products are available in several modes including: raw data products (RAW), precision image (IMP), single look complex (IMS), geocoded imagery (IMG), medium resolution products (IMM) and wavemodes WVW, WVI, WVS.

3.2.2 ASAR

The Advanced Synthetic Aperture Radar (ASAR), operating at C-band, ensured continuity with the image mode and the wave mode of the ERS-1/2 AMI. ASAR was an active radar sensor on-board the ESA satellite ENVISAT which was operational from 2002 to 2012. ASAR features enhanced capability in terms of coverage, range of incidence angles, polarisation, and modes of operation. This enhanced capability is provided by significant differences in the instrument design: a full active array antenna equipped with distributed transmit/receive modules which provides distinct transmit and receive beams, a digital waveform generation for pulse "chirp" generation, a block adaptive quantisation scheme, and a ScanSAR mode of operation by beam scanning in elevation. ASAR used an active planar phased-array antenna, operating at 5.331 GHz, with incidence angles of between 15° and 45°. ASAR products are available in several modes as listed in Table 14.

Table 14. Specifications of ASAR products.

Product ID	Description	Nominal resolution range x azimuth [m]	Pixel spacing [m]	Coverage Range x azimuth [m]	Equiv. n. looks
IMP_1P	Image Mode Precision	30 x 30	12.5	56-100 x 100	>3
IMS_1P	Image Mode Single-Look Complex	9 x 6	natural	56-100 x 100	1

IMM_1P	Image Mode Medium resolution	150 x 150	75	56-100 x 100	40
APP_1P	Alternating Polarisation Precision Image	30 x 30	12.5	41-106 x 100	>1.8
APS_1P	Alternating Polarisation Single-Look Complex	9 x 12	natural	41-106 x 100	1
APM_1P	Alternating Polarisation Medium resolution	150 x 150	75	41-106 x 100	50
WSM_1P	Wide Swath Mode Medium resolution	150 x 150	75	400x 400	11.5
WSS_1P	Wide Swath Mode Single-Look Complex	11.5-20 x 117	7.8x80	400x 400	1
GM1_1P	Global Monitoring Mode Image	1000 x 1000	500	400x 400	7-9
WVI_1P	Wave Mode Imagette and power spectrum	9 x 6	natural	5 x 5	1
WVS_1P	Wave Mode Image Spectra	-	-	5 x 5	-
WVW_2P	Wave Mode Ocean Wave Spectra	-	-	5 x 5	-

The following tables describe the characteristics (Table 15) and the availability (Table 16) of the SAR satellite data to be used in HR historical record of LC products SAR-based processing chain.

Table 15. Characteristics of SAR data input to the processing chain for the HR historical record of LC products 1990-2015.

Product	Source	Specification	Temporal Coverage	Quantity	Comment
ENVISAT ASAR ASA_WSS_1P	ESA	8x80m pixel size Full swath C band N1 format	2002- 2010	310 GB	Temporally and spatially sparse dataset
ENVISAT ASAR ASA_IMP_1P	ESA	12.5m pixel size Full swath C band N1 format	2002- 2010	500 GB	Temporally and spatially sparse dataset
ERS 1/2 SAR SAR_IMM_1P	ESA	75-m pixel size Full swath C band E2 format	2002- 2010	210 GB	Temporally and spatially sparse dataset
ERS 1/2 SAR SAR_IMP_1P	ESA	12.5-m pixel size Full swath C band E2 format	2002- 2010	350 GB	Temporally and spatially sparse dataset
Sentinel-1 L1 IW GRD HR Product	ESA	10 m pixel size Full Swath C Band SAFE format	2015-2018	4.7 TB	Geographical coverage is not uniform across test areas

Table 16. Availability of SAR data input to the processing chain for the HR historical record of LC products 1990-2015.

Product	Availability	Conditions	Req. subset	Purpose/Timeliness

ENVISAT ASAR ASA_WSS_1P	Available on ESA Earth Online	Conditions of use defined by ESA Sentinel data policy, i.e. redistributable	2002- 2010	Quality to be checked, datasets used to fill, when possible, gaps by other data sets
ENVISAT ASAR ASA_IMP_1P	Available on ESA Earth Online	Conditions of use defined by ESA Sentinel data policy, i.e. redistributable	2002- 2010	Main sources for historical mapping
ERS 1/2 SAR SAR_IMM_1P	Available on ESA Earth Online	Conditions of use defined by ESA Sentinel data policy, i.e. redistributable	2004- 2010	Datasets used to fill, when possible, gaps by other data sets
ERS 1/2 SAR SAR_IMP_1P	Available on ESA Earth Online	Conditions of use defined by ESA Sentinel data policy, i.e. redistributable	2004-2010	Main sources for historical mapping
Sentinel-1 L1 IW GRD HR Product	Available on Copernicus Open Access Hub	Conditions of use defined by ESA Sentinel data policy, i.e. redistributable	2014-2018	Main sources for historical short-term mapping

4 Validation Data

The main source of information for the validation activity of the project consists of Very High Resolution (VHR) optical imagery given that it contains sufficient detail to perform accurate evaluations. The characteristics of the potential datasets that are required to validate the CCI HRLC products and activities are listed in Table 17. For each CCI HRLC product/activity and study site, Table 18 specifies the requirements in terms of data quantity and time period concerned.

Given the high quality and spectral resolution of the WorldView data, it is preferred for the validation of the HRLC Static Map 2018 as well as the validation of the scattered landscape of the African Sahel back to 2010. For 2000 and 2005, only IKONOS data are available. Among the potential very high resolution imagery, no preference is shown for the validation of the Amazon and North Eastern Siberia areas in 2015 and 2010. This leaves some flexibility for the repartition of Third Party Missions quota of data. SPOT data, at 20 m spatial resolution, are the only Third Party mission available to validate the HRLC maps of 1995 and 1990.

Table 17. Specifications of the potential very high resolution imagery to be used for validation.

Product	Resolution [m]	Temporal coverage	Spatial coverage	Data availability
WorldView-1/-2/-3	0.5, 0.46, 0.31	2007 - present	Global	Third Party Missions
Pleiades	0.5	2011 - present	Global	Third Party Missions
GeoEye-1	0.41, 1.65	2008 - present	Global	Third Party Missions
IKONOS	0.82	1999 - 2008	65N, 9S, 8W, 75E	Third Party Missions
SPOT (1 to 4)	20	1986-2002	Global	Third Party Missions

Table 18. Characteristics of the dataset that will be used for the CCI HRLC product and activity evaluation. VHR products names are abbreviated: WorldView (WV), Pleiades (P), GeoEye (G), Ikonos (I), SPOT (S).

HRLC product or activity	Year needed	Site	VHR data	Quantity of near-nadir scenes (10x10 km^2)
HRLC Static Map 2018	2018 or more recent	Amazon	WV	50
		African Sahel	WV	50

		Siberia	WV	50
HRLC historical map (1990-2015)	2015	Amazon (zoom)	WV or P or G	25
		African Sahel (zoom)	WV	25
		Siberia (zoom)	WV or P or G	25
	2010	Amazon (zoom)	WV or P or G	25
		African Sahel (zoom)	WV	25
		Siberia (zoom)	WV or P or G	25
	2005	Amazon (zoom)	I	25
		African Sahel (zoom)	I	25
		Siberia (zoom)	I	25
	2000	Amazon (zoom)	I	25
		African Sahel (zoom)	I	25
		Siberia (zoom)	I	25
	1995	Amazon (zoom)	S	25
		African Sahel (zoom)	S	25
		Siberia (zoom)	S	25
	1990	Amazon (zoom)	S	25
		African Sahel (zoom)	S	25
		Siberia (zoom)	S	25
RR exercise	To be defined	Amazon (zoom)	WV or P or G	25
		African Sahel (zoom)	WV or P or G	25
		Siberia (zoom)	WV or P or G	25

5 Inter-Comparison Data

The inter-comparison between different existing products can be very informative for the final users being able to help in detecting anomalies and outliers and in understanding the effects of different assumptions in the product generation.

The activities related to the inter-comparison of the HRLC delivered within the project and other products can be summarized into the following steps: (i) accurate inventory and identification of data available for comparison; (ii) processing for datasets harmonization; (iii) evaluation of agreement/disagreement between the datasets; (iv) detection of possible model patterns of disagreement.

A key point for the inter-comparison is to ensure a similar spatial resolution between the datasets being evaluated, thus only datasets with resolution equal or better than 30m should be considered. According to this spatial resolution requirement, in Table 19 a set of global land cover datasets have been preliminary identified as candidates for the benchmark is listed.

Table 19. Characteristics of the datasets identified as candidates for benchmarking activities.

Global map	Resolution [m]	Year	Spatial coverage	Data availability	Reference
GlobeLand30 (GL30)	30	2000, 2010,2015	Global	Available upon agreement	[1]
FROM-GLC	30	2010, 2015	Global	Freely available	[2]
Global Urban Footprint	12	2011	Global	Freely available upon request for non-commercial and scientific purposes	[3]
Global Human Settlement Layer	20	2016	Global	Freely available	[4]

(GHS BUILT-UP GRID S1)					
Global Surface Water	30	1984 - 2015	Global	Freely available	[5]
Forest / Non-Forest map	25	2007 – 2010 2015 - 2016	Global	Freely available	[6]
Tree canopy cover	30	2000	Global	Freely available	[7]
Global forest cover gain	30	2000-2012	Global	Freely available	
Global forest cover loss	30	2000-2015	Global	Freely available	
TerraClass Dataset	30	2004, 2008, 2010, 2012, 2014	Brazilian Amazon	Freely available	[8]

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