ESA Climate Change Initiative – Fire_cci
D1.2 Algorithm Development Plan (ADP)

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Summary

This Algorithm Development Plan (ADP) describes the way in which the Fire_cci algorithms are developed, as well as the specifications of the derived products.

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1 Executive Summary

This document is the Fire_cci Algorithm Development Plan (ADP) corresponding to the indicators to carry out the different versions of the BA algorithms, following the Fire_cci technical proposal and the user requirements analysis. Following the new version of the User Requirements Document (URD, Heil and Pettinari 2021), this document also includes the main updates in product specifications from the last version of the Product Specification Document (PSD, Chuvieco et al. 2017).

2 Introduction

The ESA CCI initiative stresses the importance of providing a higher scientific visibility to data acquired by ESA sensors, especially in the context of the IPCC reports. This implies to produce consistent time series of accurate Essential Climate Variables (ECV) products, which can be used by climate, atmospheric and ecosystem scientists for their modelling efforts. The importance of keeping long-term observations, along with consistent multi-sensor with uncertainty characterisation, and the international links with other agencies currently generating ECV data is also stressed.
The fire disturbance ECV identifies burned area (BA) as the primary fire variable. Accordingly, the Fire_cci project focuses on developing and validating algorithms to meet GCOS ECV requirements for (consistent, stable, uncertainty-characterised) global satellite data products from multi-sensor data archives (GCOS 2016).
In order to generate a long and consistent time series of BA products, which can be used by scientists for their modelling efforts, it is necessary to develop BA algorithms that are able to cope with the changes in sensor design and platform characteristics, including developing products for more than one sensor.

3 Algorithm development phases

3.1 Coarse resolution BA algorithms

3.1.1 MODIS VNIR

No updates of this algorithm are expected during the Fire_cci+ project. As described in the technical proposal, the latest version of this algorithm –used to generate the FireCCI51 (Lizundia-Loiola et al. 2018) was adapted to the characteristics of the SYN product. The FireCCI51 product is publicly available through the CCI Open Data Portal (ODP, https://climate.esa.int/en/odp/#/dashboard, last access April 2021) for the period 2001-2019.

This product is also available at the Copernicus Climate Change Service (C3S, https://cds.climate.copernicus.eu/cdsapp#!/dataset/satellite-fire-burned-area?tab=overview, last access April 2021). Here the product is identified as version 5.1.1cds, and is available as NetCDF files both for the pixel and grid product (at the ODP the pixel product is provided in GeoTIFF format). C3S is the operational climate service to which the pre-operational products developed within CCI are transferred for further processing and archiving.

3.1.2 Sentinel-3 SYN

The FireCCIS310 BA algorithm is based on the one developed for processing the MODIS 250m resolution bands. This algorithm is patch-based and provides contextual analysis to adapt thresholds to the local characteristics of burned areas. The original MODIS algorithm only requires active fire information and near-infrared (NIR) reflectance. Since the algorithm offers a high adaptability, the idea was to analyse first how the new inputs affected its results, without changing the main structure. It was necessary to understand those effects to be able to provide improvements. Once SYN data was available, the following development tests were performed:

1. Analyse the most convenient band for BA thresholding. A separability analysis was carried out, from a statistical sample of burned and unburned pixels. Different inter-class measurements were used to identify the most sensitive band for discriminating burned and unburned pixels. General discrimination power was measured. The results showed that along raw reflectance bands the NIR was the band with the highest separability.
2. The impact of using more than one thresholding band was tested, including different spectral indices using both NIR and SWIR information. Since SYN data include 21 bands, a wide variety of spectral indices can be used to better discriminate burned and unburned pixels. Similarly to 1, a separability analysis was conducted to determine the most suitable one. Well-known indices previously used in BA detection, such as the NBR, NBR2 and MIRBI, were tested. The results showed that the NBR2 was the vegetation index that provided the best separability, even more than the raw NIR band.
3. Temporal compositing is a critical step in our algorithm, as it reduces commission errors caused by sensor noise and cloud contamination. The last version of the algorithm uses a minimizing criterion to select the most suitable date. Therefore, the most useful vegetation index (NBR2), which like the NIR drops after a fire event, was integrated in the algorithm to produce new composites to analyse their performance. Since the burned signal lasts longer in the NBR2 than in the NIR, a new compositing technique based on multi-temporal changes was developed. The comparison with the original compositing technique showed that the multi-temporal approach was more suitable for burned area detection.
4. In the previous version of the algorithm, the uncertainty was given as a probability of burn derived from a logistic regression, using as input 4 variables: number of valid observations, NIR reflectance, NIR drop and distance to the nearest potential active fire (Lizundia-Loiola et al., 2018). Although this first approach helped us to understand how each variable affects the final uncertainty, it was not enough to analyse how the errors were propagated throughout the algorithm. Since a step-by-step mathematical error propagation is not feasible in algorithms that rely on thresholding processes (Merchant et al., 2017) we are assessing an uncertainty characterisation approach based on reference perimeters (obtained independently from this algorithm).
5. In the previous phase, MODIS active fire information was used as input for the FireCCI50 and FireCCI51 products. However, the current life expectancy of Terra and Aqua is estimated to be 2020 and early 2020s, respectively. So we changed the active fire information source to VIIRS on board Suomi-NPP, considering that SLSTR active fire product and NOAA-20 VIIRS product are not available for the full study period. The overlapping year (2019 due to the availability of SYN data) has been used to see the impact of changing this sensor. The latter offers active fire information at 375 m, while MODIS offers at 1000 m. This means a potential increase in the detection of small fires that could be undetectable in our current spatial resolution. However, this was compensated by the enhanced capability of the NBR2 to detect BA and, hence, to apply a stricter active fire filtering.

6. Once we had understood the impacts of the previous changes, the idea was to improve the thresholding approach changing, if necessary, how the unburned and burned samples were selected and combined. The sampling was made in the burned case using the active fires and in the unburned case using those pixels that were at some specific distance from the active fires. It was necessary to assess if the distances proposed for MODIS (250m) continued being the most suitable ones for SYN (300m) and, thus, these distances were adapted accordingly. Besides, the mathematical expression that combined median and mode of the burned and unburned sample, respectively, was evaluated and replaced by the Otsu thresholding (Otsu, 1979).

3.1.3 LTDR

The Fire_cci+ project continued improving the LTDR algorithm developed during Fire_cci Phase 2 (Otón et al. 2019). The following modifications were performed:

1. The algorithm has been improved and the whole time series (1982-2018) was reprocessed.
2. In the new product (FireCCILT11), some inputs and criteria have been modified. FireCCI51 was used for training instead of MCD64A1. Land Cover information was updated and annual data used. Some new criteria to detect clouds were included, and databases were updated with more years and new yearly profiles.
3. The Random Forest model was improved, using a new language (Python) and library (Scikit-learn) instead of the previous package randomForest (R). Two kinds of models were developed, one model for global fires and another model for boreal fires, which were underestimated in the FireCCILT10 Beta product. Furthermore, some of the main parameters (number of samples in each tree or weight of burn class) were improved.
4. The thresholding approach, the Solar Zenith Angle correction and the BA proportion assignment were adapted for each month and continental region.

The details of the modified algorithm are explained in the product ATBD (Otón and Chuvieco 2021).

At the moment, having access to active fire information has been discarded because Channel 3 presents inconsistencies and different degrees of saturation. Also, auxiliary records (SST_cci and Cloud_cci) have been considered and evaluated, but those data have been discarded because they were not consistent with the NASA LTDR product.

3.1.4 Merged reflectance

A single year (2019, due to data availability) has been selected to analyse the impacts of using different input data in the classification accuracy. The objective of the merging algorithm is to generate a global coverage of stable continuous reflectance values with minimum uncertainty that preserves possible changes due to both disturbances (i.e., fires, insect attacks, logging) and phenological changes in land cover type, for a NIR spectral band. The inputs of the algorithm are Terra and Aqua MODIS and Sentinel-3 SYN surface reflectance products corresponding to the NIR band.

The main steps of the process are:

1. Harmonization of the MODIS and SY_2_SYN products
2. Generation of Random Forest models for each day
3. Generation of the merged surface reflectance for the NIR band for each day

4. BRDF normalization of the time series for each year.

3.1.5 Merged BA products

In this case, the merging is done at product level, meaning that a single grid cell will be created from information of BA derived from different sensors: Terra MODIS (FireCCI51), Sentinel-3 SYN (FireCCIS310), and LTDR (FireCCILT11). The estimations are based on linear regression models.

A backcasting approach is being performed to extend to the past the information of FireCCI51 based on the FireCCILT11 product. This entails:

1. Stratification according to biomes or global regions (Giglio et al. 2010)
2. Seasonal decomposition: analysis of the time series to determine the seasonal component, if exists.
3. Apply standard and/or machine learning methods to obtain a new data series
4. Analyse mutual information as uncertainty estimator

3.2 Medium resolution BA algorithms

3.2.1 Sentinel-2 Optical data

The algorithm used during the Fire_cci Phase 2 project with Sentinel-2A MSI images over Africa (Roteta et al. 2019) has been slightly adapted to create the FireCCISFD20 product for Sub-Saharan Africa for the year 2019. The only changes from the previous processing come from updates in the input data: L1C Sentinel-2A & B are used instead of L1 data from only the A satellite, and the hotspots are those of VIIRS instead of MODIS.

3.2.2 Sentinel-1/2 SAR-Optical algorithm

Three test sites over Africa were selected to test the algorithm, taking into account the cloud cover of each area, to assess the performance of SAR data when optical data is not available. The BA mapping algorithm identifies changes in C-band backscatter and surface reflectance associated with burning events. The algorithm considers i) multi-temporal changes of incoherent SAR-based metrics (VV and VH backscatter coefficients and their ratio VH/VV) and ii) changes in surface reflectance (individual bands and derived indices). For algorithm training, ancillary information on thermal anomalies (hotspots) and land cover are also used. The algorithm uses a Convolutional Neural Network (CNN) method.

Three CNN algorithms were trained and analysed: SAR based (S-1), optical based (S-2) and SAR and optical (S-1 + S-2). The latter algorithm was based on feeding both radar- and optical-derived metrics (e.g. backscatter coefficient, surface reflectance, indices) into the CNN training. The details of the algorithm are included in the SAR-Optical ATBD (Belenguer-Plomer and Tanase 2020).

4 Updates of the PSD

The following sections summarize the changes applied to the new products compared to the product specifications indicated in Chuvieco et al. (2017).

4.1 Product naming convention

The Fire_cci products are identified using a long name (e.g. Fire_cci MODIS burned area product version 5.1), and a short name (for the previous case, FireCCI51). The short names were requested by the CRG to simplify referring to the products in graphs and tables, both in internal reports and in communications and peer review publications.

The naming convention adopted for the Fire_cci BA products that are being produced during Fire_cci+ Phase 1 are presented in Table 1.

Table 1: Fire_cci products naming convention

Name of the product	Sensor	Temporal series	Geographical coverage
FireCCISFD20	S2 A+B	2019	Sub-Saharan Africa
FireCCIS1S2AF10	S1 + S2	2019	3 study sites in Africa
FireCCILT11	AVHRR LTDR	1982-2018	Global
FireCCIS310	S3 SYN	2019	Global
FireCCIS311	S3 SYN	2019-2020	Global
FireCCIMR10	MODIS+S3 SYN Reflectance	2019	Global
FireCCI60	AVHRR+MODIS+S3 SYN BA	1982-2020	Global

4.2 Data requirements for BA products

4.2.1 Input data

In addition to the input sensors described in the latest version of the DARD (Pettinari et al. 2017), the generation of new products for Fire_cci+ will require using Sentinel-3 (S3) data. This satellite was primarily designed as an ocean mission, but it also provides very useful data for atmospheric and land applications. The first satellite of this mission (Sentinel-3A) was launched on 16 February 2016, with a second satellite (Sentinel-3 B) launched on 25 April 2018, on the same orbit but flown 140° out of phase. The orbit is sun-synchronous, with a height of 814.5 km, an inclination of 98.65° and a repeat cycle of 27 days, crossing the equator at around 10:00 am local solar time. S3 includes 7 instruments: OLCI, SLSTR, SRAL, MWR, DORIS, LRR and GNSS. For Fire_cci+ only the first two sensors will be used.

The Ocean and Land Colour Instrument (OLCI) sensor is a follow up version of ENVISAT MERIS, and it includes, amongst others, the bands that were defined for the MERIS sensor. It is a push-broom instrument with 5 camera modules sharing the field of view (FOV), each one with a FOV of 14.2° and a 0.6° overlap with its neighbours. The whole FOV is shifted across track by 12.6° away from the Sun to minimise the impact of Sun glint. It has a swath of 1270 km, and a native resolution of ~300 m, and it provides global land coverage at the equator in 2.2 days with one satellite and in 1.1 days with two satellites.

The Sea and Land Surface Temperature Radiometer (SLSTR) is a dual view (near-nadir and backward views) conical imaging radiometer aboard Sentinel-3 satellites, which provides continuity to the ENVISAT AATSR instrument. Its dual view scan has a swath width of 1420 km at nadir and 750 km backwards.

The OLCI OL_1_ERF product in conjunction with the SLSTR SL_1_RBT product are the input data of the Synergy (SYN) products.

The SYN product used in the BA algorithm is the Level-2 SYN (SY_2_SYN), which contains surface reflectance and aerosol parameters over land, provided on the OLCI image grid, similar to the OLCI Level-1B product (~300m), for the sun-reflective channels of SLSTR (S1 to S6 for both nadir and oblique views except S4) and for all OLCI channels except for the oxygen absorption bands Oa14, Oa15 and Oa20. It also includes Aerosol Optical Thickness (AOT) at a wavelength of 550 nm and an estimated Aerosol Angstrom

Exponent at the same wavelength (https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-synergy/product-types/level-2-syn, last access April 2021).

SYN data is freely available, and can be downloaded from the Copernicus Open Access Hub (https://scihub.copernicus.eu/dhus/#/home, last access April 2021).

4.2.2 Global Land cover map

As requested by the users, land cover information complements the information included in BA products, in addition to be used by BA algorithms to reduce commission errors and improve processing efficiency. In addition, as requested in the URD, our products use the ESA's CCI Land Cover product v2.0.7 (, https://climate.esa.int/en/projects/land-cover/, last access April 2021). This product includes annual land cover maps from 1992 to 2015 (ESA 2017). For years following 2015, the C3S land cover product v2.1.1 (Defourny et al. 2019), which is the continuation of the moderate-resolution LC_cci product, is used (https://cds.climate.copernicus.eu/cdsapp#!/dataset/satellite-land-cover?tab=overview, last access April 2021). In all cases, the land cover corresponding to the year prior to the BA detection is used.

4.2.3 Active Fires

Active fire information is used in many algorithms as the first step of burn area detection, for the identification of burned seeds and dates of burn. In previous versions of the BA algorithms, MODIS active fire products (MCD14ML Collection 6, https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms/mcd14ml, last access April 2021) were used.

Current versions of the algorithms also use the Visible Infrared Imaging Radiometer Suite (VIIRS) active fire data at 375m spatial resolution (VNP14IMGTML, https://viirsland.gsfc.nasa.gov/PDF/VIIRS_activefire_User_Guide.pdf, last access April 2021). The VIIRS sensor is on board the Suomi National Polar-orbiting Partnership (Suomi NPP) and NOAA-20 weather satellites. It was launched on Suomi NPP on 28 October 2011, and on NOAA-20 on November 18, 2017.

This information is available from January 2012 to the present (for the Suomi NPP data), with NOAA-20 available since January 2020, and it is freely downloadable from https://firms.modaps.eosdis.nasa.gov/download/ (last access April 2021). The data used is the "standard science quality data", produced with a 2-3-month lag from detection, and which is more stable than the Near Real Time products.

4.2.4 Reference BA information

The details of the reference data to be used, along with the methods for the validation, are described in Stroppiana et al. (2021).

4.3 Updates in Product Specifications

The same terms of reference previously used for Fire_cci products continue to be used. Pixel and grid products are generated from the results of the BA algorithms, in monthly files.

For pixel products, at least three layers are generated, including (as in previous versions) the date of detection, the confidence level, and the burned land cover. The exception is the FireCCILT11, which does not include the burned land cover layer, due to the much coarser resolution of the AVHRR-LTDR reflectance compared to the land cover information. This product, however, includes two additional layers: number of observations in the month, and burned area per pixel (as in this case, contrary to the rest of the BA products, it is considered that the proportion of area burned in a pixel is smaller than 100%).

Pixel products are delivered in GeoTIFF format, as requested by the users of the product (see Section 5.2.11 of Heil et al, 2017). They use the geographic coordinate system (GCS) based on the World Geodetic System 84 (WGS84) reference ellipsoid and using a Plate Carrée projection. To facilitate handling the results, the world product is split in several tiles. Considering recent impacts of fires on Greenland, this continent has been added to the distribution of tiles (Figure 1). The new distribution is summarized in Table 2.

Table 2: Geographical distribution of BA tiles for the pixel product

Areas	Name	Upper left		Lower right	
1	North America	180°W	83°N	26°W	19°N
2	South America	105°W	19°N	34°W	57°S
3	Europe & Northern Africa	26°W	83°N	53°E	25°N
4	Asia	53°E	83°N	180°E	0°N
5	Sub-Saharan Africa	26°W	25°N	53°E	40°S
6	Australia & New Zealand	95°E	0°N	180°E	53°S

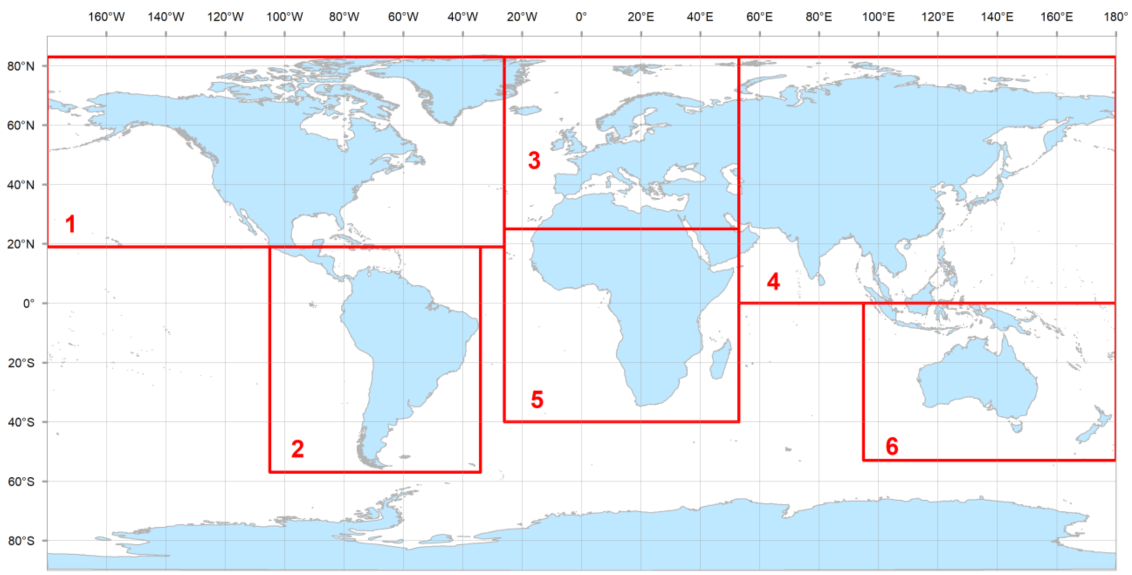

Figure 1: Geographical distribution of subsets for the global BA product

The BA pixel products generated from medium-resolution sensors (S2, S1), are delivered in geographical tiles of 5x5 degrees (see Figure 2). The tiles to be provided cover only those corresponding to the African continent.

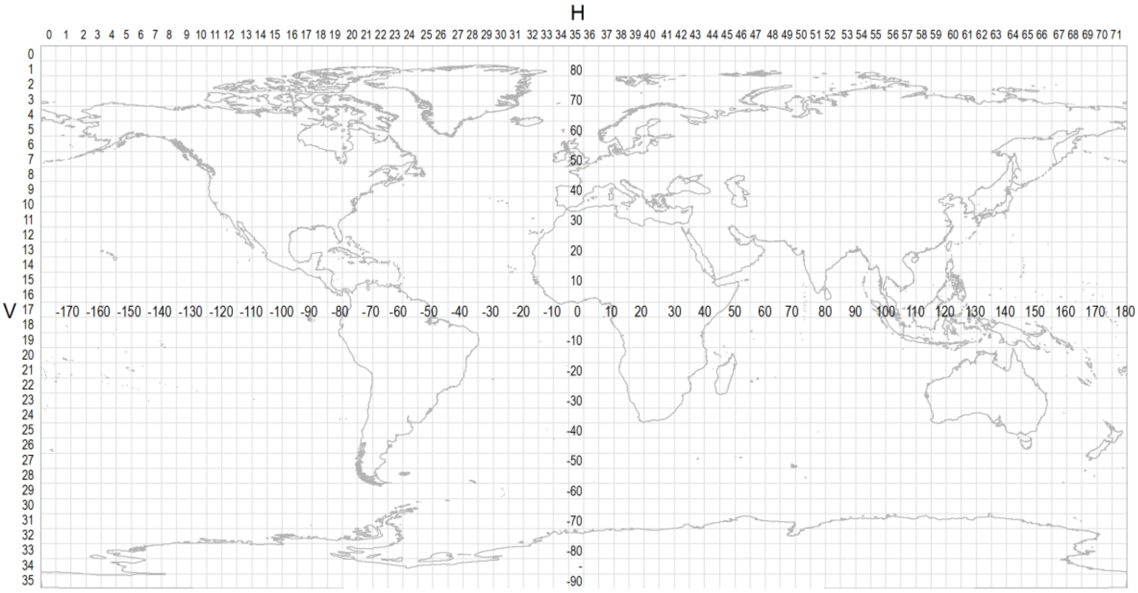

Figure 2: Geographical distribution of tiles for medium-resolution products

The grid products are offered in NetCDF-CF format at 0.25 x 0.25 degrees of resolution, with 0.05 x 0.05 degrees for the medium resolution products. Grid attributes are the same as in previous versions of the BA products, with the exception of the number of burned patches layer, which has been removed, as it was not found very useful to the end users (see Section 6.8 of Heil and Pettinari, 2021). An exception to this rule is the FireCCILT20, because the coarse resolution of the input data hinders the possibility to obtain reliable burned land cover information. For this product, the land cover layers are not present.

4.4 Data dissemination for all products

The final versions of the BA products, both in pixel and grid format, are available through the Fire_cci project website (https://climate.esa.int/en/projects/fire/data/, last access April 2021). Standard products are also available through the CCI Open Data Portal FTP (ftp://anon-ftp.ceda.ac.uk/neodc/esacci/fire/, last access April 2021).

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Annex 1: Acronyms and abbreviations

AATSR	Advanced Along-Track Scanning Radiometer
ADP	Algorithm Development Plan
AOT	Aerosol Optical Thickness
AVHRR	Advanced Very High Resolution Radiometer
BA	Burned Area
C3S	Copernicus Climate Change Service
CCI	Climate Change Initiative
CNN	Convolutional Neural Network
CRG	Climate Research Group
CRS	Coordinate Reference System
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
ECV	Essential Climate Variables
ENVISAT	ENVIronmental SATellite
ERS	European Remote sensing Satellite
ESA	European Space Agency
EU	European Union
FOV	Field of View
FTP	File Transfer Protocol
GCOS	Global Climate Observing System
GCS	Geographic Coordinate System
IPCC	Intergovernmental Panel on Climate Change
LC_cci	CCI Land Cover project
LRR	Laser RetroReflector
LTDR	Long Term Data Record
MERIS	Medium Resolution Imaging Spectrometer
MODIS	Moderate Resolution Imaging Spectroradiometer
MSI	MultiSpectral Instrument
MWR	MicroWave Radiometer
NASA	National Aeronautics and Space Administration’s
NDVI	Normalized Difference Vegetation Index
NetCDF	NETwork Common Data Format
NIR	Near InfraRed
NPP	National Polar-orbiting Partnership
ODP	Open Data Portal
OLCI	Ocean and Land Colour Instrument on board Sentinel-3
PSD	Product Specification Document
RF	Random Forest
S1	Sentinel-1
S2	Sentinel-2
S3	Sentinel-3
SAR	Synthetic Aperture Radar
SAR-O	SAR-Optical
SFD	Small Fire Database
SLSTR	Sea and Land Surface Temperature Radiometer
SRAL	Synthetic Aperture Radar Altimeter
SST	Soil Surface Temperature
SYN	Synergy
VIIRS	Visible Infrared Imaging Radiometer Suite
WGS84	World Geodetic System 1984