ESA Climate Change Initiative – FireCCI
D2.5 Product Validation Plan

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Summary

This Product Validation Plan (PVP) describes the approaches and methods that will be used to assess the quality of regional Small Fire Dataset (SFD) BA products obtained from the FireCCI algorithms.

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Document Change Record

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Table of Contents

List of Figures

List of Tables

1 Executive Summary

This document is the *Product Validation Plan* (PVP) of the FireCCI+ Phase 2 project that outlines the approach to follow for the validation of the Burned Area (BA) products. The validation protocol defined here and implemented in the project builds on standard methods published in the literature (Padilla et al. 2015, Boschetti et al., 2016; Franquesa et al. 2020, Lizundia-Loiola et al. 2020, Stroppiana et al. 2022) and developed during previous FireCCI phases.

2 Introduction and objectives

The PVP describes the approaches and methods that will be used to assess the quality of the BA products generated during this Phase of the project. They include both global BA products (FireCCI51 and FireCCIS311), and the Small Fire Dataset (SFD).

In the case of the SFD, the three regional test sites that will be used for the BA generation (and hence the validation) are depicted in Figure 1.

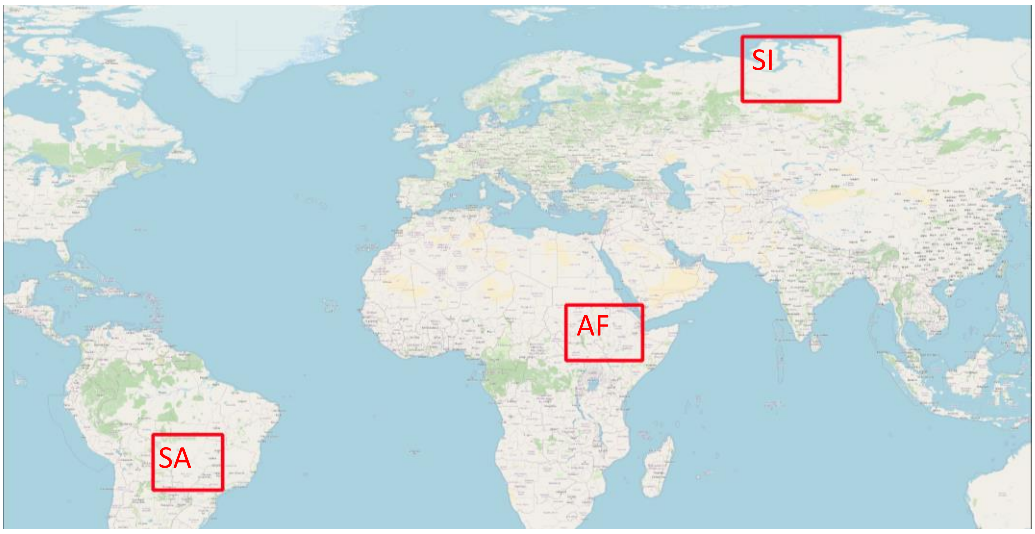

Figure 1: The location of the three study sites where the SFD BA product will be developed: Africa (AF), South America (SA) and Siberia (SI).

This validation activity aims at providing quantitative assessment of the SFD multi-annual BA product based on fire reference perimeters derived from both Sentinel-2 and Landsat image time series.

The proposed approach builds on previous FireCCI validation work carried out at the regional and global scales (Stroppiana et al., 2021, Stroppiana et al., 2022a) and on the recent scientific literature relevant to the assessment of the accuracy of large-scale burned area products derived from remotely sensed data (Franquesa et al., 2022c). Burned area products can be compared over space and time to address 1) **thematic agreement** (whether the pixel is actually burned/unburned according to the reference) and/or 2) **temporal reporting agreement** (whether the date of burn assigned to a pixel is in agreement with reference information). We refer to spatial and temporal accuracy for the former and latter, respectively, which should not be mixed up in validation to avoid bias in the estimation of accuracy metrics.

Temporal reporting accuracy can be assessed with reference information as close in time as possible on the actual date of fire occurrence; in the remote sensing BA research community this task is typically carried out using active fire detections (e.g. Boschetti et al., 2010) that can provide systematic information on fire presence.

When the information on fire occurrence is derived from image data with non-daily temporal resolution, the reporting date assigned to the burned pixels in the BA product is the observation date rather than the burn date. Moreover, due to the persistence of the burned signal and the presence of cloud coverage, observation date could be significantly later than fire date. Hence, if either the BA product or the BA reference is derived from source image data with non-daily temporal resolution, only spatial accuracy assessment can be conducted. In this document, we address the assessment of spatial accuracy of thematic BA products.

Following Franquesa et al. (2022c) and Stroppiana et al. (2022b) the assessment of spatial accuracy of burned areas will be carried out by comparison with reference perimeters derived over temporal series of input imagery over sampling units (i.e., long units) where we can quantify the spatial agreement by reducing at the same time the impact of temporal reporting accuracy.

3 Review of existing validation methods for BA products

Validation is a critical and necessary task in any EO project, as it provides a quantitative assessment of the accuracy of geo-information delivered by the product and this is particularly relevant for both scientists and end-users (Congalton and Green 1999). Review of existing validation methods for the assessment of the thematic accuracy of EO-based land products, and BA products in particular, has been addressed in the literature and in previous deliverable documents of the FireCCI+ project (Stroppiana et al. 2021, Stroppiana et al., 2022a). The scientific literature addresses all topics related to validation: protocols and strategies (CEOS-WGCV-LPV, 2009), selection of sampling sites and reference datasets (Stehman 1999, Stroppiana et al., 2022a), product spatial and temporal comparison (Foody 2004), and source of errors (Franquesa et al. 2022c).

4 Validation protocol for the SFD

The validation protocol for assessing the accuracy of the SFD BA product is composed of the following steps:

- <u>Identification of the EO source data</u>: fire reference perimeters will be derived from classification of medium resolution satellite images. In this phase Sentinel-2 and Landsat data will be considered, being the only EO missions covering the time span of the BA product to be validated (1990-2019). For the validation of the SFD BA product, we will rely on Level-2 data products available in Google Earth Engine (GEE) for Landsat-5, Landsat-8 and Sentinel-2. A preliminary analysis of data availability in GEE archive will be carried out to evaluate the number of images available for each study site given the condition on cloud cover implemented in the criteria for the definition of the long units. This analysis will also support the choice of the validation unit that could be designed over the Sentinel-2 (S2) tiles and/or Landsat frames. Alternative satellite missions will also be considered to fill temporal gaps in the historical time series only if they can provide frequent acquisitions and spatial resolution comparable to Sentinel and Landsat and/or suitable for extracting reference perimeters.
- <u>Definition of the validation units (Section 4.1)</u>: validation units will be defined spatially and temporally based on results from previous FireCCI phases (Stroppiana et al., 2022b, Franquesa et al., 2022). A validation unit is an area of

approximately ~10 000 km^2 covering both Sentinel-2 and Landsat orbits that will be fixed over the years;

- Generation of reference fire perimeters (Section 4.2): reference fire perimeters will be generated from two consecutive images acquired at the same validation unit. BA reference polygons will be combined in a synthetic layer for each unit;
- Accuracy metrics computation (Section 4.3): accuracy metrics are computed for the long units based on the error matrix (Congalton and Green 1999; Latifovic and Olthof 2004): commission error ratio, omission error ratio, Dice Coefficient (*DC*) (Dice 1945), bias and relative bias.

In this phase of the FireCCI project, validation will be carried out by employing both Sentinel-2 and Landsat image time series. Preliminarily, we will consider the two source satellite missions separately to build the fire reference perimeter dataset. At a later stage, we will also consider the opportunity of the integration of the two datasets for the overlapping time period.

4.1 Definition of the reference long units

4.1.1 Spatial definition of validation units

A **long temporal reference unit** is a spatio-temporal partition of the source EO data archive where a time series of images (Landsat and/or Sentinel-2) are acquired and processed to extract fire perimeters between the first and last date of the time period covered by the unit. The time series over each unit is composed of consecutive images where each image pair (i.e., short unit) is classified to extract burned polygons. The burned polygons preserve as date of burning the acquisition date of the short unit and are assumed to be burned only once within the time span covered by the long unit.

Spatially, each unit covers an area of ~10 000 km^2 coincident with the S2 tile area; this choice was inherited from the sampling design implemented for the validation of the FireCCISFD20 BA product (Stroppiana et al., 2022b; Chuvieco et al., 2022). To extend the validation to the pre-Sentinel-2, the same area will be covered by the Landsat reference long units. In order to select consistent validation units, only regions overlapping Sentinel-2 and Landsat orbits will be retained to assure that each unit is consistent over time (Figure 2). The resulting validation units are shown in Figure 3 for the three study sites.

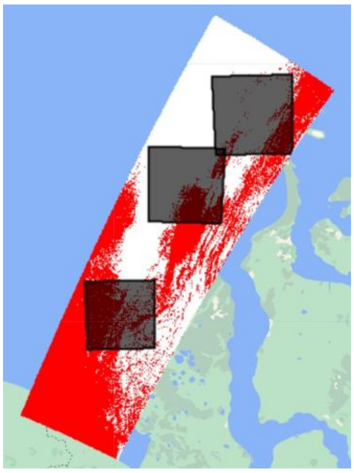

Figure 2: The overlap between S2 tiles (square black area) and the Landsat orbits imposed to have the same validation unit when extracting reference perimeters from both Landsat and Sentinel-2 data.

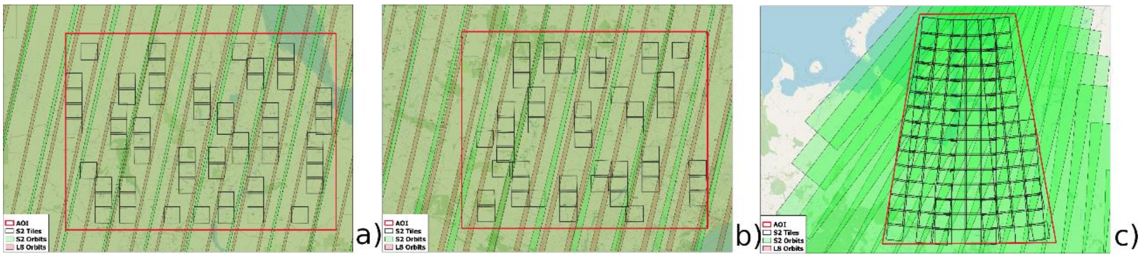

Figure 3: The overlapping regions between Sentinel-2 and Landsat orbits; the red rectangle shows the extent of the study sites where the SFD product will be delivered in Africa (a), South America (b) and Siberia (c).

The number of validation units to be selected and processed for each study site will be estimated based on the evaluation of the effort needed for the extraction of a multi-annual reference dataset. The effort is proportional to the number of validation units and the number of short units to be processed spanning multiple years. A preliminary analysis will be carried out to identify suitable long units for each study site covering the 1990-2019 time period and the number of short units (i.e. image pairs). A random sampling scheme (eventually stratified by biome) will be applied to select validation units among those that results as suitable in terms of image time series availability under the conditions outlined below.

Figure 4 depicts the distribution of the major biomes in the three study sites according to the Ecoregions 2017 map (Dinerstein et al., 2017); ecoregions were grouped based on Franquesa et al. (2020) and Boschetti et al. (2016).

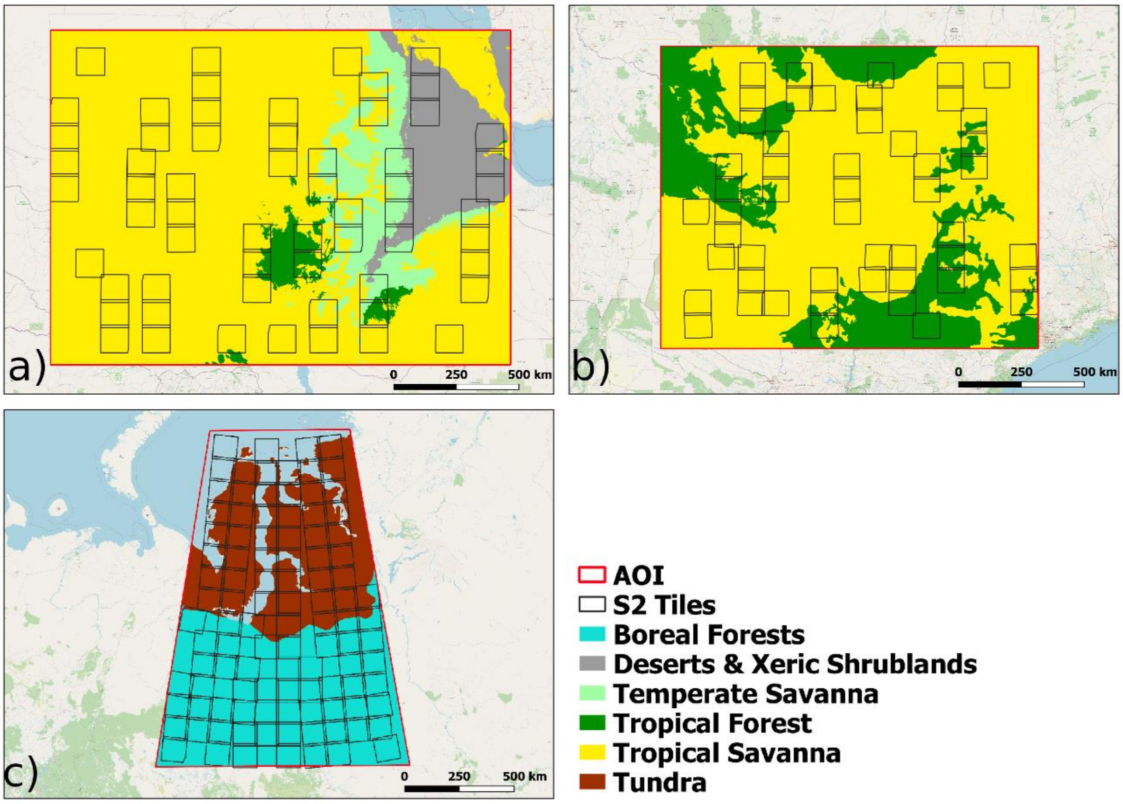

Figure 4: The biomes in the three study sites according to the Ecoregions 2017 map (Dinerstein et al., 2017) overlapping regions between Sentinel-2 and Landsat orbits; the red rectangle shows the extent of the study sites where the SFD product will be delivered in Africa (a), South America (b) and Siberia (c).

4.1.2 Temporal definition of validation units

Reference long units will be composed of time series of S2/Landsat images for each sampling unit identified based on the following criteria applied to the image time series:

1. **Cloud cover:** scene cloud cover (CC) and cumulated cloud cover (CC_{cum})
2. **Time interval** between consecutive S2 images (Δt)
3. **Length** of the time series (L)

The minimum length of the long unit will be set after preliminary analysis of image availability over the three study sites. In a previous validation scheme designed for Africa (Stroppiana et al, 2022b), these criteria were set to: $CC<15\%$, $CC_{cum}<30\%$, $\Delta t \leq 16$days, L>100days; however, in other biomes/ecosystems, where image availability could be reduced by cloud cover and burned area signal might be more persistent, these threshold values could vary.

For example, a longer time step between consecutive images in boreal biomes, where the burned area signal is more persistent, might significantly reduce the effort needed for extracting reference validation units. On the other hand, a shorter unit's length might be necessary where cloud cover is more persistent (i.e., tropical regions) and shorter time series could be available.

Figure 5 shows example validation units over the AF study site extracted with criteria 1) and 2) set on the maximum allowed cloud cover and on time interval between consecutive images (i.e., short units), respectively.

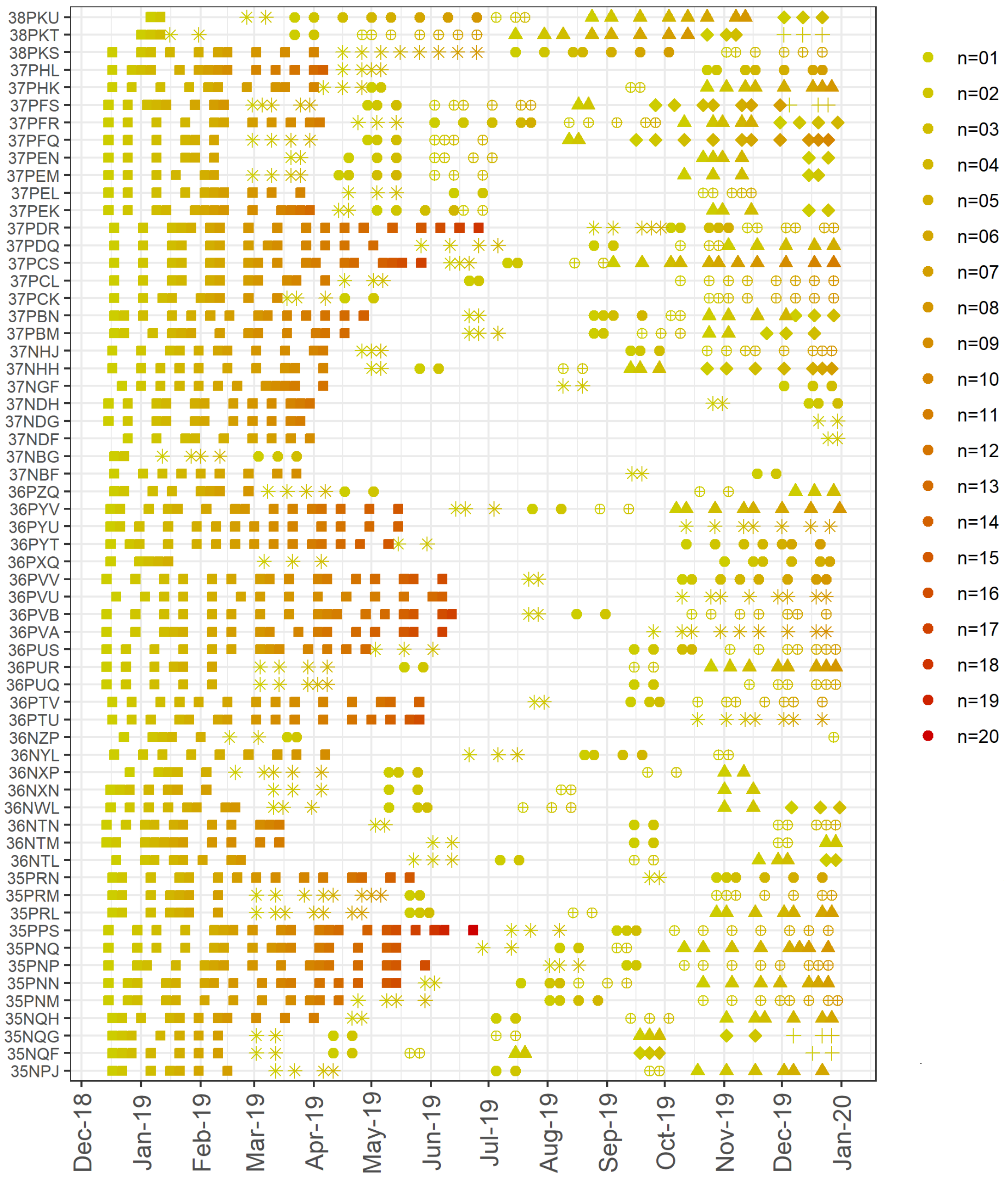

Figure 5: Dates of the long units for the S2 tiles in the African study site: each long unit is represented by a different shape and filling colour shows the cumulated number of dates for each long unit.

In this figure, all long units were retained regardless of the length L; the smallest validation unit is therefore composed of two S2 images: that is the short unit. S2 image availability in GEE for the AF study site starts from December 2018; therefore only one year is covered. In the figure, as expected due to meteo-climatic conditions, the longest units are at the beginning of the period of interest that is in fact coincident with lowest cloud cover and the fire season. Less image availability is outside the major fire season that varies from southern to northern tiles.

4.1.3 Source EO image data

In order to cover the period 1990-2019, reference validation units will rely on a multi-mission approach that exploits both Sentinel-2 and Landsat data. Landsat-8 and Landsat-

5 missions will be preferably used. Since the algorithm for the extraction of fire reference perimeters (Section 4.2) will be implemented and run in GEE, we will rely on the Level-2 products available in the GEE archive for both EO missions.

Higher resolution Sentinel-2 images will be preferably used, when available, in the most recent years and Landsat data will cover previous periods. The selection of input EO data is crucial since it influences the accuracy of fire reference perimeters and metrics. A preliminary analysis of the GEE archive pointed out that the period of interest 1990 to 2019 is not homogeneously covered by Level-2 products with significantly gaps for both Landsat and Sentinel-2 missions.

In particular, we observed that only S2 Level-2 products posterior to December 2018 are available in the GEE archive with a gap between 2003 and 2009 for Landsat data. Other archives will be queried although GEE is the priority since it offers cloud computing facilities for big data. Moreover, alternative source EO data will be investigated to fill temporal gaps in the time series. The alternative satellite missions should however have similar capabilities as Landsat and Sentinel by providing imagery through time over the same area that is necessary for building time series for the generation of the reference perimeters.

4.2 Extraction of reference perimeters

Fire perimeters will be extracted over the selected validation units relying on the methodology implemented in the previous FireCCI phase (Stroppiana et al., 2022b). Consecutive image pairs will be classified to map areas burned between the two dates (t1, t2, i.e. short unit) with a Random Forest (RF) algorithm and by collecting training polygons over burned and unburned areas. All BA output classifications for the short units over the same area will be combined to derive fire perimeters over the long unit. The algorithm flowchart is shown in Figure 6 and it is implemented in GEE with a module coded for each major algorithm's step. Input to the GEE code is the list of long units identified for each validation unit.

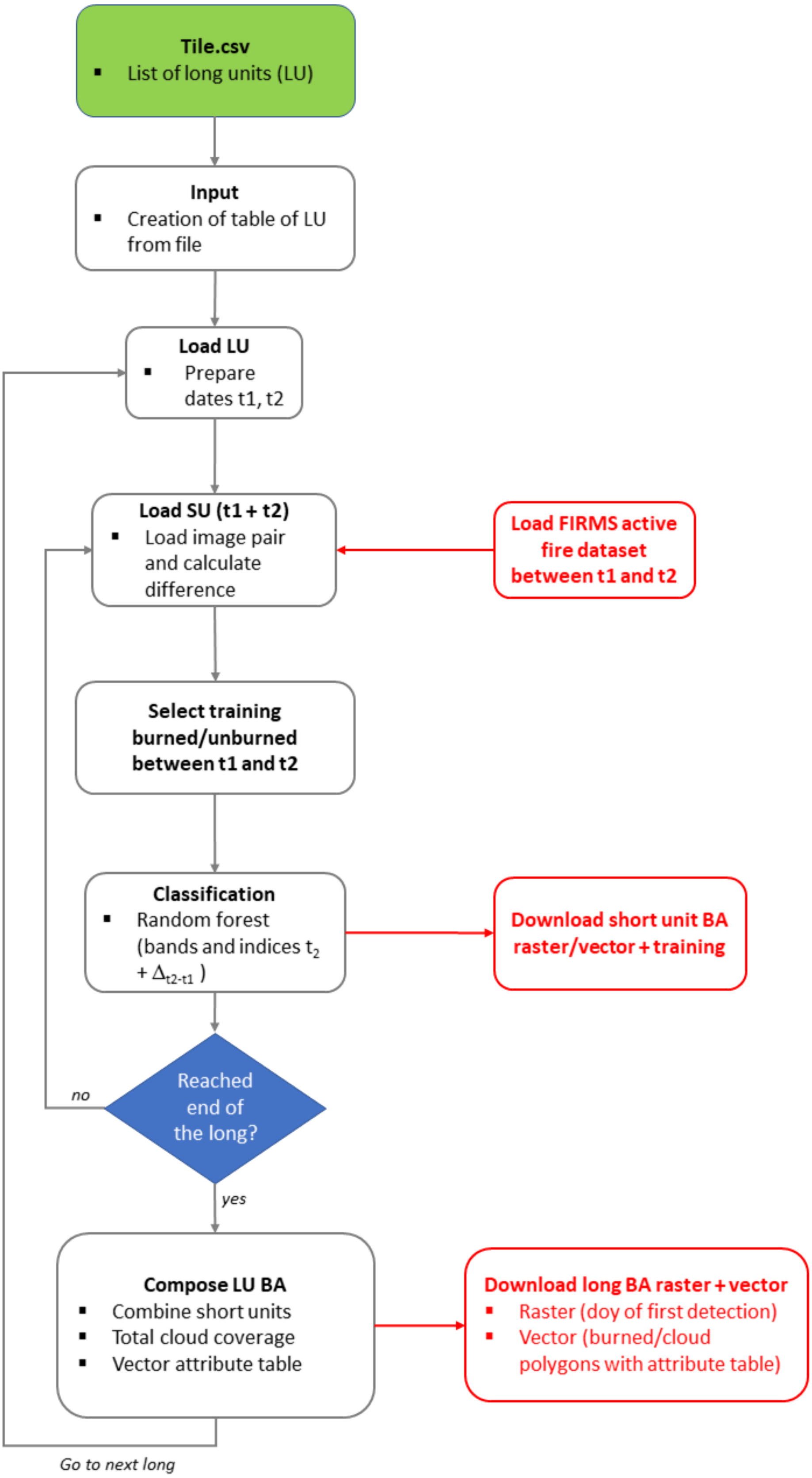

Figure 6: Flowchart of the implementation of the long unit classification to derive reference fire perimeters. The scheme is implemented in Google Earth Engine (GEE).

Figure 7 shows graphically the implementation of the classification of time series of cloud-free images for a long unit. The algorithm implemented in GEE delivered as output the BA reference perimeters as shown in the last panel of the figure.

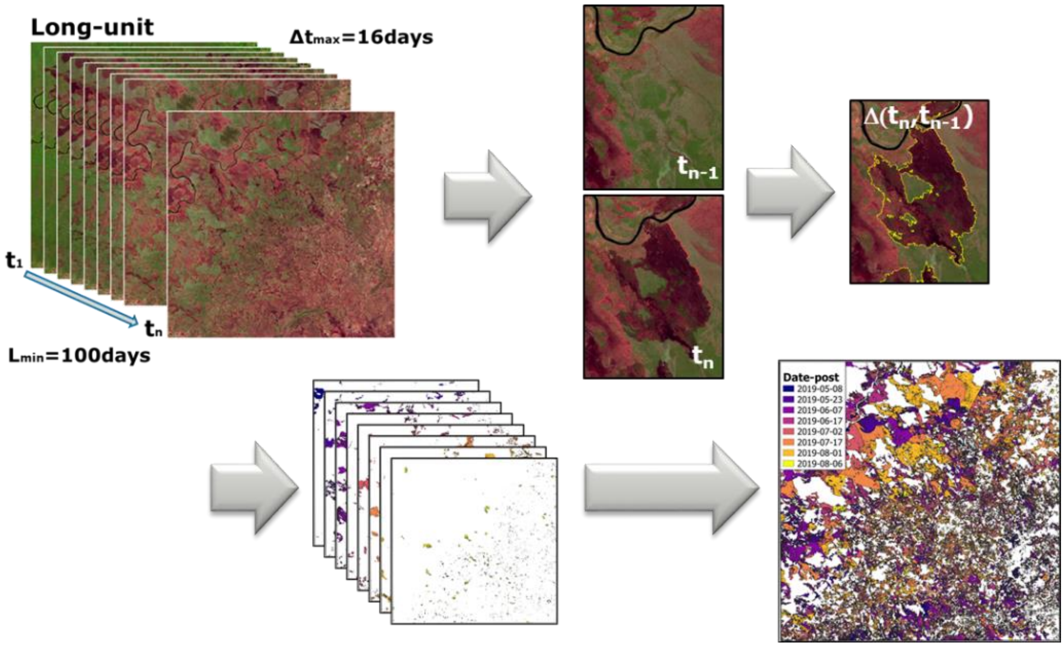

Figure 7. Implementation of the algorithm for the extraction of reference validation units from the classification of consecutive images pairs. In this figure source images are Sentinel-2.

4.3 Computation of accuracy metrics

Reference fire perimeters and SFD BA products will be compared over the study sites to compute the confusion matrix and accuracy metrics as in previous project's phases (Stroppiana et al. 2022a, Stroppiana et al. 2021): commission error ratio, omission error ratio, Dice Coefficient (DC) (Dice 1945, Padilla et al. 2015), bias and relative bias.

4.4 Selection of the validation units

Validation units will be selected to properly represent the variety of conditions that affect the accuracy of BA cartography. In the specific case of validation of the SFD BA product addressed in this section, units will be selected by stratified random sampling across ecoregions. The total effort (number of validation units for each study site) will be estimated and units will be distributed proportionally to the major ecoregions.

Since the effort for the generation of the reference dataset depends both on the number of validation units and the amount of short units within the long units identified for each of them, preference will be given to the selection of the longest possible long units in order to assess the robustness of the accuracy metrics over time.

4.5 Additional considerations

In the paragraphs above, we outlined major criteria selected for the implementation of the validation protocol. However, some issues are still under discussion and might lead to a change in the protocol proposed here.

- A validation unit is an area of approximately ~10 000 km^2 (S2 tile size) covering both Sentinel-2 and Landsat orbits that will be fixed over the years. Priority in the design of the validation protocol is to have validation units that are constant over

the years so that validation could address the robustness of accuracy metrics over time in a multi-annual dataset.
- Validation units will be defined from the intersection between S2 and Landsat orbits and giving priority to the fastest way to rapidly access the EO data archives. The best “geometrical” solution will be based on either S2 tiling system or Landsat frames depending on the estimated effort for image pre-processing.
- The analysis of image availability will be carried out in GEE by considering only Level 2 products; the effort of the validation activity will be focused on the generation of the reference perimeters. However, alternative EO archives and/or alternative satellite missions will be considered to fill temporal gaps.

5 Validation protocol for global BA products

Medium-resolution (≥250 m) global burned area (BA) products (i.e., FireCCI51 and FireCCIS311) will be validated following the validation methodology implemented by Franquesa et al. (2022a). The generation of the reference units for the validation of the global products is being done within the Copernicus Climate Change Service (C3S, Franquesa et al. 2022b).

The objective of the validation is to obtain the spatial accuracy of the pixel product and the validation methodology was designed to discriminate between classification errors from dating errors, which substantially impacts the spatial accuracy metrics estimates. Following recommended good practices validation procedures adopted by the Committee of Earth Observation Satellites (CEOS) Land Product Validation (LPV) subgroup, a probability sampling design (i.e., stratified random sampling) is used to select approximately 100 sample units that are allocated across biomes (Dinerstein et al. 2017) and fire occurrence strata for each validation year. Burned reference perimeters are obtained from multi-temporal comparison of Landsat 8 images as recommended by the CEOS LPV subgroup. The reference classification is generated using the tools implemented in the GEE cloud-computing platform (Roteta et al. 2021) to extract the areas burned from consecutive pairs of Landsat 8 images for each sample unit, which are then aggregated to obtain long temporal coverage reference units. The details of the validation methodology are available in Franquesa et al. (2022b).

Finally, BA products and reference data are compared to derive the proportion of area of agreement and disagreement of the burned and unburned classes between both datasets, obtaining the error matrices from which to estimate the accuracy metrics (i.e., commission (Ce) and omission (Oe) errors, Dice coefficient (DC) and relative bias (relB) according to the implemented sampling design. This task will be performed within the FireCCI project.

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Annex 1 Acronyms and abbreviations

AF	Africa
BA	Burned Area
Ce	Commission error ration
CEOS	Committee on Earth Observation Satellites
CSDGM	Content Standard for Digital Geospatial Metadata
DC	Dice Coefficient
ECV	Essential Climate Variables
EO	Earth Observation
ESA	European Space Agency
ESRI	Environmental Systems Research Institute
GEE	Google Earth Engine
L	Length
MCD64	MODIS Collection 5 Burned Area product using the Giglio et al. (2009) algorithm
MODIS	Moderate Resolution Imaging Spectroradiometer
Oe	Omission error ration
OLI	Operational Land Imager
PVIR	Product Validation and Inter-comparison Report
PVP	Product Validation Plan
relB	Relative bias
RF	Random Forest
S2	Sentinel-2
SA	South America
SI	Siberia
SFD	Small Fire Dataset

Annex 2 Data structure and naming convention

Reference fire perimeters are delivered as ESRI shpeafiles © (.shp), along with the auxiliary files required (.dbf, .prj, shx, .sbn, .xml). The projection is UTM, WGS84, with the UTM zone being the zone that is covered by the major part of the scene.

The following attribute fields are included in the shape file (Table 1):

- PreDate. Acquisition date of the image taken before the occurrence of the fire: yyyymmdd (year, month, day).
- PostDate. Acquisition date of the satellite image taken after the fire: yyyymmdd (year, month, day).
- PreImg and PostImg. The pre- and post-fire image names, following this format: satellitecodePathRow (e.g. LE719905). The satellite codes are given in Table 2.
- Area (in square metres, m^2)
- Category (Observation category):
    - Burned area = 1. This area includes all polygons detected as burned.
    - No-Data = 2. This area includes all polygons that could not be interpreted or were not observed by the sensor, either by clouds and/or cloud shadows, topographic shadows, smoke, or sensor errors (for instance, those caused by SLC-off problems of ETM+)
    - Unburned = 3. This area includes all polygons observed as not burned within the limits of the area covered by the image.

Table 1. Example of attribute table for BA reference fire perimeter shapefile

	category	preDate	postDate	preImg	postImg	path	row	year	area
1	2	2016-01-25	2016-02-02	LE71990502016025ASN00	LC81990502016...	199	50	2016	69300.00000000...
2	2	2016-01-25	2016-02-02	LE71990502016025ASN00	LC81990502016...	199	50	2016	544500.0000000...
3	2	2016-01-25	2016-02-02	LE71990502016025ASN00	LC81990502016...	199	50	2016	159300.0000000...
4	2	2016-01-25	2016-02-02	LE71990502016025ASN00	LC81990502016...	199	50	2016	525600.0000000...
5	2	2016-01-25	2016-02-02	LE71990502016025ASN00	LC81990502016...	199	50	2016	177300.0000000...
6	2	2016-01-25	2016-02-02	LE71990502016025ASN00	LC81990502016...	199	50	2016	506700.0000000...
7	2	2016-01-25	2016-02-02	LE71990502016025ASN00	LC81990502016...	199	50	2016	205200.0000000...
8	2	2016-01-25	2016-02-02	LE71990502016025ASN00	LC81990502016...	199	50	2016	485100.0000000...
9	2	2016-01-25	2016-02-02	LE71990502016025ASN00	LC81990502016...	199	50	2016	217800.0000000...
10	2	2016-01-25	2016-02-02	LE71990502016025ASN00	LC81990502016...	199	50	2016	465300.0000000...
11	2	2016-01-25	2016-02-02	LE71990502016025ASN00	LC81990502016...	199	50	2016	223200.0000000...

Table 2. Satellite-sensor codes naming convention

Satellite-sensor	Mission Code (MMM)	Reference system	
Landsat-8 OLI	LC8	Path (ppp)	Row (rrr)
Sentinel-2A	S2A	Relative orbit Number ROOO	Tile Number field (Txxxxx)
Sentinel-2B	S2B	Relative orbit Number ROOO	Tile Number field (Txxxxx)

The name of the .shp and associated files is defined as follows:

PRO_RD_ppprrr _yyyymmdd_ yyyymmdd (Landsat)

PRO_RD_Txxxxx_yyyymmdd _ yyyymmdd (Sentinel)

where:

PRO: project where the reference data were generated. For the fire perimeters developed within the FireCCI project, PRO=FireCCI.

RD: stands for Reference Data

ppprrr: represents the Landsat Worldwide Reference System (WRS) path and row of the scene (in the case where no Landsat imagery was used, the closest path-row is selected): ppp=path; rrr=row.

Txxxxx: represents the Sentinel-2 100x100 km Tile Number field.

yyyymmdd (year, month, day): the first one is the date of the first image used for BA detection; the second one is the date of the last image used for generating the reference fire perimeters.

The metadata of the reference files is written as an XML document following the international CSDGM and ISO 19115 standards. The metadata contains fields to cover all necessary information to be provided to external users: author names of the reference data file, affiliations/institutions, date of creation, the input data sources (names of satellite image files) and the reference of the website of the FireCCI project.