# ESA Climate Change Initiative – Fire_cci
# D1.1 User Requirements Document (URD)

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## Summary

This document is the version 8.1 of the User Requirements Document for the Fire_cci+ Phase 2 project. It refers to Task 1, Work Package 1000. It describes burned area requirements according to the user needs, providing background information to the data provider.

| | Affiliation/Function | Name | Date |
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| **Prepared** | CNRS | Florent Mouillot | 15/12/2022 |
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| **Accepted** | ESA - Technical Officer | Clément Albergel | 16/12/2022 |

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## Document Status Sheet

| Issue | Date | Details |
|---|---|---|
| **1.0** | 01/12/2010 | First Document Issue |
| **2.0** | 09/02/2011 | Restructured and updated Document |
| **3.0** | 08/07/2011 | Full (re)writing of sections 3, 4 and 5 |
| **3.1** | 10/07/2011 | Editorial reworking |
| **3.3** | 26/07/2011 | Layout and formal review |
| **3.4** | 31/08/2011 | Layout and formal review |
| **3.5** | 14/09/2011 | Review addressing ESA comments |
| **4.0** | 26/11/2015 | First document for Phase 2 of Fire_cci. Full (re)writing of the document |
| **4.1** | 15/01/2016 | Review addressing ESA comments |
| **5.0** | 22/09/2016 | Revised version of the document |
| **5.1** | 30/12/2016 | Addressing comments of CCI-FIRE-EOPS-MM-16-0128 |
| **5.2** | 20/12/2017 | Revised version of the document |
| **6.0** | 01/08/2019 | Full rewriting of the document synthesising all user requirement surveys with recent scientific publications and product developments |
| **7.0** | 27/11/2019 | Major reorganization of the text according to the comments on ESA-CCI-EOPS-FIRE-MEM-19-0322 |
| **7.1** | 26/03/2021 | Update of the document |
| **7.2** | 28/04/2021 | Addressing comments of Fire_cci D1.1 URD v7.1 RID |
| **8.0** | 13/12/2022 | Rewriting of the whole document |
| **8.1** | 15/12/2022 | Addressing comments of ESA's Technical Officer |

## Document Change Record

| Issue | Date | Request | Location | Details |
|---|---|---|---|---|
| 2.0 | 04/02/2011 | ESA, Fire_cci partners | Whole document | Major editing taking into account review comments by S. Plummer (ESA) and other information and feedback |
| 3.0 | 08/07/2011 | ESA, | Sections 3, 4 and 5 | Full (re)writing of indicated sections |
| 3.1 | 10/07/2011 | Fire_cci | Whole document | Editorial |
| 3.3 | 26/07/2011 | Fire_cci partners | Whole document | Literature review on user requirements and products, layout and formal review |
| 3.4 | 31/08/2011 | GAF | Whole document | Typo and grammar correction, updating references |

| Issue | Date | Request | Location | Details |
|---|---|---|---|---|
| 3.5 | 14/09/2011 | IRD, LSCE, JÜLICH | Whole document<br>Section 3.1 | Revision following review comments from Stephen Plummer (ESA), updating references,<br>Data Inter-comparison – separated paragraph introduced |
| 4.0 | 26/11/2015 | MPIC, Fire_cci partners | Whole document | New naming convention for the document<br>New format and layout<br>Full (re)writing of the document |
| 4.1 | 15/01/2016 | ESA | Sections 1, 2.1, 3, 3.1.4, 3.2, 4.1.1, 4.1.3, 4.1.5, 4.1.6, 4.2, 5.1, 5.2.4, 5.4, 5.4.1, 5.4.2, 5.4.4, 5.4.6, 6.5.<br>Table 1<br><br>Section 4.1<br>Section 5.1<br>Section 7<br>Annex 1 | Minor changes in the text<br><br><br><br><br><br>Minor changes in the line corresponding to Fire_cci<br>The sub-sections of this section were re-ordered<br>New paragraphs added<br>New references added<br>Inclusion of new acronyms |
| 5.0 | 22/09/2016 | MPIC, Fire_cci partners | Section 3<br><br><br>Section 4<br>Section 4.1.2<br>Section 4.1.4<br>Section 4.2<br><br>Section 5<br>Section 6<br>Annex 2 | Updated and expanded; characteristics of burned area products with on-going development are discusses separately from “obsolete” products<br>Updated and expanded.<br>Added description of  BB5CMIP6<br>Added description of FireMIP benchmark system<br>New web of science database query on publications using burned area information<br>Restructured, updated and synthesized<br>Restructured and updated<br>Added annex with commonly used definitions |
| 5.1 | 30/12/2016 | ESA | Section 3.1.5<br>Section 3.2<br><br>Sections 3.3, 5.1, 5.2.6<br>Section 5.2.8<br>Sections 6.1, 6.2 | Changed the reference of C-GLOPS to GIO-GL1.<br>Sentence added to better interpret the error results, and Figure 1 replaced.<br>Small changes in the text.<br><br>Last sentence deleted.<br>Information added. |
| 5.2 | 20/12/2017 | MPIC | Sections 1, 3.2, 5.2.12, 5.2.13<br>Sections 2.1, 4.1.1, 5.2.6, 5.2.14, 6, 6.2<br>Section 2.4<br>Section 3.1<br><br>Section 4.1.4<br><br>Section 4.1.5<br>Section 5.1<br><br>Section 5.2.1<br><br><br>Section 5.2.7<br><br>Section 5.2.8<br><br>Section 5.3 | Text expanded.<br><br>Small changes in the text.<br><br><br>Deleted section of structure of the document.<br>Updated tables, added new sub-sections with new products.<br>Added summary on FireMIP workshop October 2017.<br>Added study by Lehsten et al. (2010).<br>Added GCOS-200 (2016) and update FireMIP requirements, added IBBI 2017 workshop.<br>Update results from user requirement surveys, including Fire_cci product user statistics and the 2017 Fire_cci user workshop survey.<br>Expanded on explanations of what uncertainty characterisation mean.<br>Expanded on quality assurance indicator requirements.<br>Expanded on on-going user requirement surveys, including GCOS survey. |

| Issue | Date | Request | Location | Details |
|---|---|---|---|---|
| | | | Section 6.1<br>Section 6.3<br>Section 6.4<br>Annex 2<br>Annex 3<br>Annex 4 | Specified temporal resolution requirements.<br>Added uncertainty characterisation.<br>Specified ancillary data layer requirements.<br>Updated description of measurement uncertainty.<br>Added Fire_cci user survey form.<br>Added 2017 Fire_cci user workshop report |
| 6.0 | 01/08/2019 | MPIM | All sections | Rewriting of the entire document towards a user requirement document synthesis, while, at the same time, updating it for recent burned area product developments, applications and recently released scientific publications. |
| 7.0 | 27/11/2019 | ESA – MPIM | Sections 1, 2.1, 2.2, 7<br>Sections 3, 4<br><br>Section 5<br>Sections 6.2, 6.3, 6.7 | Sections updated<br><br>Information rearranged, with new sections and subsections created<br>New section added<br>Text expanded |
| 7.1 | 26/03/2021 | MPIM UAH | Sections 1, 2.1, 4.2.1, 4.2.2, 5<br>Section 3 and sub-sections<br><br><br>Section 6 and sub-sections<br><br><br>Section 7 | Minor text updates<br><br>Added information on burned area products released since the URD v7.0; moved table with outdated burned area products into the Annex<br>Text updated. Added new sub-section describing burned area product requirements for fire danger and early warning systems<br>Text updated. Added table summarising key requirements |
| 7.2 | 28/04/2021 | UAH | Table 1<br>Table 6<br><br><br>Section 8 | Some items updated<br>Identified the references with the participation of Fire_cci consortium members. Additional references were added.<br>More references added. |
| 8.0 | 28/11/2022 | CNRS | All document | Rewriting of the whole document. |
| 8.1 | 15/12/2022 | UAH | Section 5 | Section expanded. |

**Table of Contents**

# 1. Background and objectives

Burned area generated at global scale from remote sensing has emerged in the early 2000's with the MODIS sensor providing a continuous and fruitful information on its local, interannual and seasonal variations. Major applications were the global understanding of climate and human constraints on fire hazard, benchmarking of fire modules embedded in dynamic global vegetation models (DGVMs Hantson et al. 2016), biosphere atmosphere interactions, or fire/vegetation interactions. After the initial development of the MODIS burned Area dataset at 0.5° resolution (Roy et al. 2005, 2008), increasing refinements on fire detections, the inclusion of small fires hardly captured at coarse resolution (Giglio et al. 2010), the combination of fire signal as fire radiative power during fire event in addition to the post-fire surface reflectance, allowed for better characterization of the burned area. At the same time, the increasing use of these data in the scientific community, identified detection failures or data formatting issues making them hard to use for certain purposes, while the increasing computing facilities allowed for finer spatial and temporal resolution, and longer term simulations. The remote sensing scientific community then had to account for these requested user needs to deliver the most suitable dataset for the research question addressed. Since recently, the development of new sensors, better performances and increasing knowledge in signal analysis for burned area detection, could lead to a larger panel of available datasets.

The FireCCI project started in 2010 and aimed at providing original burned area datasets at the global scale based on an initial user requirement to fulfil targeted user requests not fully met in the existing panel of burned area products. Developments within this project lead to the early delivery of FireCCI41 from the MERIS sensor at 300m resolution for the period 2005-2011 (Chuvieco et al. 2016), followed by FireCCI50 (Chuvieco et al. 2018) and the current FireCCI51 (Lizundia-Loiola et al. 2020a) based on the MODIS sensors at raw spatial resolution of 250m over the period 2001-2020, fulfilling one of the user requests to get better information on small fires at finer resolution. In addition, the FireCCILT11 (Oton et al. 2021) based on the AVHRR sensor allowed for the long term burned area reconstruction since 1982 at coarse resolution (5km) prolonging backward our current understanding of burned area trends, and fulfilling the second major user request identified in URD1.0. Finally, the FireCCISFD20 (Chuvieco et al. 2022) provides a continental scale burned area dataset for Africa at 10m resolution from the Sentinel 2 sensor for the year 2019, and providing a keystone information on small fire identification.

All these datasets now differ in their resolution, their temporal coverage, their detection accuracy, and the miscellaneous information associated to these data as the quality assessment, vegetation affected, burn date, or fire intensity. In turn, end-users now face both the benefits of getting an access to various and complementary information, but also the penalty of multiplying analysis across datasets, or arbitrarily choosing one dataset over the other. In order to provide a user-based guideline to new and useful developments of burned area within the FireCCI project, we investigated how the scientific community of end-users have been aware and actually used the newly delivered BA datasets within the FireCCI project, in order to identify potential caveats to be fixed and propose new developments for the next generation of BA datasets using previous and forthcoming sensors.

To reach this goal, we combined a bibliographical review of scientific papers citing the FireCCI BA products listed above, and interviewed one of the major user group of end-user in the fire modelling community (FIREMIP) (Rabin et al. 2016) for a direct feedback on their methodological issues and concerns.

# 2. FireCCI51: a global burned area dataset 2001-2021 at pixel (250m) and grid (0.25°) resolution.

We screened the 119 publications citing Chuvieco et al. (2018) referring to the FireCCI50 delivery and the subsequent FireCCI51 (Lizundia et al. 2020a) within WOS (until October 30th 2022) and published in referenced journals. 22 citations were linked to at least one partner of the project, leaving 97 publications from independent end-users. We could classify these 119 citations into few main targets : i) 23 publications cited FireCCI51 as a reference dataset within the scientific community for information (in introduction, discussion) but did not actually use it, ii) 11 publications actually used FireCCI51 for global or regional Land/atmosphere carbon budget assessment, iii) 36 publications refer to the methodological advances developed in FireCCI51 for further use in local developments or new sensors, iv) 23 publications aimed at assessing the quality of FireCCI51 in comparison to reference data or other global burned are products, v) 7 publications assess the local or global fire weather relationships, vi) 3 publications identified global or local fire regimes, vii) 5 publications investigated fire impact and viii) 11 publications used FireCCI51 for DGVMs benchmarking. We detail below the lessons learned from how the authors cite FireCCI51.

## 2.1. FireCCI51 acknowledged as an international reference dataset

With 23 references to FireCCI51 in the scientific literature, FireCCI51 was widely cited in bibliographical reviews of keystone burned area datasets in various of research as methodological developments (Chuvieco et al. 2019), fire impacts on ecosystems (Jones et al. 2022, Konko et al. 2021, Lindersson et al. 2020, Chuvieco et al. 2020, Mayr et al. 2019, Li et al. 2022a, Xiao et al. 2022) or human societies (Bilbao et al. 2019). In these reviews, FireCCI51 was cited aside MCD64A1 (Giglio et al. 2010) derived from the MODIS sensors at 500m resolution covering the 2001-present period (The MCD64A1 (collections 5 and 6) algorithms integrate the 1 km MODIS AF product (MOD14A1 and/or MYD14A1), MODIS reflectance data, and land cover product to detect area burned (Giglio et al 2009, 2018a,b), and GFED4s (Van der Werf et al. 2017, Randerson et al. 2012) combining MCD64A1 and fire hotspots MCD14ML at 0.5° resolution but covering the 1997-present period using ATSR and TRMM and providing an indirect estimating small fires, a major advantage mostly acknowledged by end users. FireCCI51 was also acknowledged as a reference dataset (Pereira et al. 2022), when other alternative dataset were used as hotspots VIIRS or MCD14ML (Kong et al. 2022, Reddy and Sarika 2022), or local fine resolution data as Landsat or Sentinel (Sivrikaya and Kucuk 2022, Rovithakis et al. 2022, Ganem et al. 2022, Wei et al. 2021, Shirashi et al. 2021, Sibley et al. 2019), acknowledging the efforts on finer resolution (Miranda et al. 2022) provided by FireCCI51, but still insufficient for local studies (Abdikan et al. 2022).

An unexpected interest in FireCCI51, was the original validation step on fire patches and fire size distribution derived from pixel-level aggregation (further published as the FRY database by Laurent et al. 2019) cited by Mahood et al. (2022), Humber et al. (2022) and Balch et al. (2020) and implemented for MCD64A1 burned area data. This overview highlights the visibility of FireCCI51 in the scientific community within its recent delivery time and compared to the longer lasting MCD64A1 and GFED4s.

## 2.2. FireCCI51 still ongoing quality assessment

Since its delivery in 2019, FireCCI51 has been evaluated a regional or global scale with equivalent other burned area products. In the Mediterranean basin Katagis and Gitas (2022) concluded on better small fires detection but overall no major improvement compared to MCD64A1, Galizia et al. (2021a) concluded on better patch identification from pixel level MCD64A1, while Turco et al. (2019) found better correlation with national burned area statistics with FireCCI51, still warning on filtering out non forest areas and keeping statistics at coarse resolution. At national level in countries with small fires, Achour et al. (2021) and Majdalani et al. (2022) warned still the missing small fires but increasing confidence in FireCCI51 compared to MCD64A1, a significant benefit of the finer resolution in FireCCI51.

For the boreal forest, Moreno Ruiz et al. (2019) in Alaska, and Chen et al. (2021) warned of the 50% missed burned area in MCD64A1 and 40% in FireCCI51, with a lower commission error in FireCCI51. This observation, lead to new methodological developments for better accuracy in these ecosystems and provided in the local ABBA database (Chen et al. 2021), a method that could be tested and implemented in the forthcoming global burned area products and a BA database that could be used for future continental accuracy assessment.

For the tropics, acknowledged as being a critical region for burned area identification from remote sensing due to a high cloud cover, Jiao et al. (2022) identified poor but still better BA identification from FireCCI51 compared to MCD64A1, while Vetrita et al. (2021), Valencia et al. (2020), and Rodrigues et al. (2019), Campagnolo et al. (2021) or Correa et al. (2022) blamed the poor FireCCI51 accuracy in cloudy conditions. Moreno et al (2021) pointed out the highest discrepancies between MCD64A1 and FireCCI41 in the tropical forests, making this ecosystem a future target of improvement.

A major weakness of FireCCI51, but overall a common weakness on other BA products as MCD64A1, was the poor BA identification in croplands, as in wheat fields of Ukraine (Hall et al. 2021), where omission errors reached 80% and commission 75% due to high confusion with changes in reflectances due to harvest.

Beside burned area, Pinto et al. (2020) provided an evaluation of burn dates from VIIRS sensor compared to MCD64A1 and FireCCI51 and pointed out the higher uncertainty in the latter one, with major consequences on fire spread rate identifications, a keystone process in fire model benchmarking. They pave the route for combining near real time hotspots into future burned area products for a better assessment of the burn date within fire patches at the pixel-level.

Overall, FireCCI51 is now widely considered as a reference dataset for global burned area accuracy assessment and inter-comparisons with newly delivered products (Ramo et al. 2021, Boschetti et al. 2019, Moreno Ruiz et al. 2020, Oton et al. 2021, Stroppiana et al. 2022, Franquesa et al. 2020, 2022a,b, Gajardo et al. 2021, Belanguer Plomer et al. 2021), or training finer resolution semi-automated burned area detection tools at local scale (Dixon et al. 2022). These comparisons, despite being necessary for end user information, can bring confusion with an additional concern on the diverging temporal trends between FireCCI51 and other BA products (Worden et al. 2020).

## 2.3. FireCCI51 for carbon Land/atmosphere interactions

One of the main goal of generating burned area and other essential climate variables at the global for the ESA climate change initiative, is the refinement of the land/atmosphere interactions. The reference database regarding this topic is the GFED4s data, using a combined burned area from MCD64A1 and hostpots to be used in the biogeochemical model CASA (Van der Werf et al. 2017, Randerson et al. 2012) and in turn covering the 1997-present period, outcompeting FireCCI51 regarding the temporal coverage. However, an increasing number of recent studies mention FireCC51 as a potential alternative burned area data source (Silva et al. 2020, Bastos et al. 2022, Yin et al. 2020). Some authors specifically mention the weaknesses in FireCCI51 as in the Boreal region, where Romanov et al. (2022) provided, for Boreal Asia, a fire-driven carbon budget using Land Cover CCI, but intentionally preferred to use MCD64A1 with a better reliability in taking into account active fires and under cloudy conditions as stated in Humber et al (2019).

Nevertheless, FireCCI51 was recently actually used for carbon budget emissions from terrestrial burning, due to its finer resolution as in India (Karthik et al. 2022), or as an alternative data source to provide uncertainty in carbon emissions. It was mostly used in addition to the reference GFED4s burned area, or MCD64A1 (Wu et al. 2022, di Giuseppe et al. 2021, Chen et al. 2020), or the recently delivered fine resolution Landsat-based global BA product (Pessoa et al. 2021). The recent global carbon budget from Bastos et al. (2020) illustrates how the various databases now available at global scale are considered as an uncertainty information itself, actually more considered than the intrinsic uncertainty information delivered in FireCCI51 (Brennan et al. 2019). This observation points out the interest of end-users for uncertainty in the carbon budget application, but they might better understand their own uncertainty based on multiple datasets BA variations (as illustrated in Hantson et al. 2016), than the uncertainty provided (potentially not enough explained, discussed and assessed in the literature?). Efforts should be devoted by BA providers in better illustrating the impact of the intrinsic uncertainty layer, and a multisource merged product with inter-product variability might be of interest at this stage of increasing burned area datasets availability.

## 2.4. FireCCI51 as reference methodological innovation in new product developments

Our extended bibliographical review of FireCCI51 citations revealed a huge amount of studies referring to FireCCI51 for its methodological innovation and potential transposition for new sensors. Mostly, recent studies refer for FireCCI51 methodology for Sentinel 2-based burned area development at finer 10m resolution since 2018 (Farhadi et al. 2022, Roteta et al. 2019, 2021a,b, Zanetti et al. 2021, Zhang et al. 2021, Pinto et al. 2021, Pacheco et al. 2021, Knopp et al. 2020, Tanase et al. 2020, Filipponi 2019), Landsat based burned area a 30m extending back to 1984 (Zhang et al. 2020, Hawbaker et al. 2020, Bar et al. 2020, Wozniak and Aleksandrowicz 2019, Long et al. 2019, Daldegan et al. 2019), AVHRR based burned area at coarse resolution back to 1982 (Oton et al. 2019, 2021a), Synergy (Lizundia-Loiola et al. 2022, FIRECCIS310), VIIRS (Fernandez Manso et al. 2020) or MODIS improvement itself (Lizundia Loiola et al. 2020a, 2021, Campagnolo et al. 2019, De Bem et al. 2020, Belenguer-Plomer et al. 2019a,b,2021). Humber et al. (2019) also cited FireCCI51 for the relevance of fire patch identification from the pixel-level information, further developed for the MCD64A1 BA data. We can identify from these ongoing developments the user needs for finer resolution

(10m with Sentinel2 to 30m from Landsat), a longer period (back to 1982 with either Landsat at fine resolution or AVHRR at coarser resolution), or with better performances with new sensors (VIIRS).

This citation report on BA detection methods also points out FireCCI51 weaknesses and ongoing improvements on grasslands fires by using geostationary meteorological satellites (Chen et al. 2022b), and cropland burnings from Landsat (Liu et al. 2021) or Sentinel 2 (Van Dijk et al. 2021), previously pointed out in FireCCI51 intercomparisons papers as a major weakness. Ongoing developments also illustrate a keystone information missing in FireCCI51 and requested by the scientific community regarding the burn severity as reviewed in Kurbanov et al. (2022) and recently developed in the global MOSEV database (Alonso-Gonzalez et al. 2021). This request should be considered in the forthcoming developments of global BA products as an additional layer.

Finally, FireCCI51, as the other global burned area datasets, would benefit from a near real time delivery of information (Yuan et al. 2020), as already for hotspots from the FIRMS interface (https://firms.modaps.eosdis.nasa.gov/active_fire/), or EFFIS automated processing chain for Europe (https://effis.jrc.ec.europa.eu/), providing to the media or scientific community emergency data on extreme events.

## 2.5. FireCCI51 in burned area hazard and impact analysis and modelling

Beside the carbon land/atmosphere interactions assessment for which it was intially built, FireCCI51 burned area data have been widely used in fire hazard and impact analysis, and modelling, making this scientific community a group of end-users with specific requirements.

Global burned area data are widely used for large scale atmospheric impact fire hazard or continental scale extreme event analysis. FireCCI51 provides gridded monthly burned area or pixel-level daily information suitable for both analyses. FireCCI51 has recently been used aside the other global BA data GFED4s for the influence of Sea Surface Temperatures (SST) on the forthcoming fire hazard (Meng and Gong 2022) as well as atmospheric teleconnections in arctic boreal fires (Zhao et al. 2022) at coarse resolution (Tang et a. 2021). FireCCI51 provided an additional dataset for uncertainty assessment to the studies, with the sufficient and easy to access and manipulate coarse resolution dataset as provided by GFED4s. At finer temporal scale, the daily burned date of the pixel-level information was used to infer daily fire weather leading to large fires (Ermitao et al. 2022, Dong et al. 2021, Wang et al 2021, Silva et al. 2019) including heat waves and drought. Authors used the burn date as the actual burning day when this information actually refers to the date when a change in the surface reflectance was observed after the fire occurred, potentially affected by missing images or clouds. Uncertainty related to this information is covered in the FireCCI51 description paper (Lizundia-Loiola et al. 2021), but potentially hardly considered as it’s not delivered as an uncertainty layer per se. Thermal anomalies from fire hostpots MCD14ML or VIIRS (available since 2012) actually provide better accuracy in the burn date, a keystone information that should be improved or better characterized as an uncertainty layer in future developments. This information would help preventing potential fake signals in the fire weather analysis when these weather conditions can change fast from one day to the other.

Fire regime, describing the seasonal and interannual variation of burned area in a given region mostly rely on global burned area for global assessment. They actually mostly rely on MCD64A1 until now, with few examples actually using FireCCI51, potentially a neglected scientific community in the communication and dissemination strategy. Bar et al. (2021) used both FireCCI51 and MCD64A1 for fire regime characterization in Himalaya, and Lizundia Loiola et al. (2020b) use FireCCI51 for the extreme 2019 fire season in Amazonia, and Bowman et al. (2020) covered the 2019-2020 extreme fire season in Australia based on FireCCI51 data. Lourenco et al. (2023) combined FireCCI51 and the small fire database FireCCISFD11 to detect peatland fires in Angola. The use of FireCC51 in the tropics seems to be still problematic for end users. As previously pointed out for carbon budget and accuracy assessments, MCD64A1 is usually preferred due to the SWIR band with a daily revisit when cloud persistence limits imagery quality. Efforts should be devoted to increase the accuracy in this region. Some few environmental studies using FireCCI51 additionally focused on assessing the post-fire recovery in tropical forests (De Keersmaecker et al. 2022, Machida et al. 2021) and boreal forests (Cazzolla Gatti et al. 2021, Guo et al. 2021) where FireCCI51 was although previously criticized. A global assessment of fire impact on soil moisture (Sungmin et al. 2020) benefited from the CCI project combining both datasets

The fire modelling community, using climate-driven dynamic global vegetation models (DGVMs) to simulate land/atmosphere interactions and the terrestrial carbon budget including fires impacts, has been an active user group in the last years, particularly through the Fire Model Intercomparison Project (FIREMIP, Rabin et al. 2016). They use global burned area for model benchmarking along the last century and the recent decades. Early stages of the project relied on GFED4s (van der Werf et al. 2017, Randerson et al. 2012), accounting for small fires, covering the longest period since 1997, and providing a coarse resolution (0.5° and 0.25°) sufficient for the coarse resolution of the models. Since the delivery of FireCCI50 in 2018 and FireCCI51 in 2020, most publications arising from this group make the effort of using both GFED4s and FireCCI51 (Harrison et al. 2021, Seiler et al. 2021, Wu et al. 2021, Hantson et al. 2020, Lasslop et al. 2019, 2020, Forkel et al. 2019a,b,c, Teckentrup et al. 2019, De Paula et al. 2019). For this community, the GFED4s remains the dataset covering the longest period and assumed to better consider small fires. With its finer 250m resolution FireCCI51 was intended to cover the gap of MCD64A1 initially fulfilled by implementing fire hotspots into the GFED4s database. FireCCI51 did not convince yet the added value of the small fires detected at 250m resolution in this community, so an enhanced evaluation of this specific small fire part of the FireCCI51 dataset should be further provided in the forthcoming products.

## 2.6. The fire patch database FRY derived from FireCCI50

As soon as FireCCI50 was delivered, a side product of a fire patch database FRY (Laurent et al. 2018) derived from the pixel-level burn date was produced, by aggregating neighbouring pixels within a time lag lower than a given cut-off threshold into a similar fire patch. This database contains the location of fire patches globally, their morphological features, dating, and vegetation type affected, based on both FireCCI50 and MCD64A1, making FireCCI the first global database to provide an easy accessible information on fire patches globally. With 48 citations in WOS since 2018, this side product contributed to the dissemination of the FireCCI data. This initiative actually inspired subsequent studies using new pixel-aggregation methods and data formats, including easy to use shapefile polygons: the updated FRY1.2 (Laurent et al. 2019 including fire radiative power from MCD14ML) and Global Fire Atlas (Andela et al. 2019), GlobFirm (Artes et al. 2020) or FIRED (Balch et al. 2020a,b, Mahood et al. 2022), these latter ones only using MCD64A1. To date, FRY remains the only fire patch database using FireCCI data. Fire patch quality assessments were performed regarding their boundary (Humber et al. 2019), their reliability a function of fire size (Campagnolo et al.

2021, Jiao et al. 2022) and compared to referenced events in Europe (Galizia et al. 2021a, Katagis and Gitas 2021) and US (Moreno et al. 2020, Chuvieco et al. 2018) or inter-compared (Moreno et al. 2021). This database was rapidly used from the fire modelling community (Forkel et al. 2019c, Lasslop et al. 2019, Teckentrup et al. 2019) and referenced as added value to the fire science community (Chuvieco et al. 2019, 2020, Mignan et al. 2022, Da silva et al. 2019, Tacaks et al. 2021, Zhao et al. 2021, Sharma et al. 2022, Haas et al. 2022, Castro et al. 2022, Humber et al. 2022, Li et al. 2022b). This database was used for fire event analysis (rather than total burned area) in south America (Rodrigues et al. 2019, Silva et al. 2021, Santos et al. 2021, Fidelis et al. 2019), the Mediterranean basin (Curt et al. 2021, Genet et al. 2021, Galizia et al. 2021b), the boreal forest (Tomshin et al. 2021) or globally (Garcia et al. 2022, Pausas 2022, Millington et al. 2022). The pixel aggregation method has been further used with other sensors as VIIRS (Li et al. 2020, Santos et al. 2020, Pinto et al. 2021) or other (Lizundia Loiola et al. 2020, 2022). Improvements in the fire patch databases mostly came from pixel aggregation methods (particularly for multi ignitions merging into one single fire patch), fire rate of spread from fire duration (from maximum and minimum burn date within the patch), and fire intensity by merging burned area data with Fire radiative power from MCD14ML and VIIRS (Laurent et al. 2019, Jones et al. 2022). Ongoing perspectives and developments try and improve the fire dating potentially biased by image quality due to cloud cover (Pinto et al. 2020), and internal fire spreading (Huot et al. 2022, Humber et al. 2022, Chen et al. 2022a). The location of fire ignition based on the minimum fire date within the patch is also a keystone information to provide as in the Fire Atlas. This information highly depends on the quality of the burn date identification, and combining hostpots and pixel burned could refine this information. Forthcoming databases on fire patches will have to face these challenges with hopefully improved pixel-level fire dating and fire intensity, as well as new challenges in pixel aggregation for fine resolution datasets at 10m resolution from Sentinel 2, where a single fire event can be actually fragmented into smaller ones if a spatial buffer is not considered, as for example when a fire crossed a fire break as road or a small river over 1 or 2 pixels.

# 3. FireCCILT11 long term burned area from AVHRR

Among the user requirements stated in URDv1.0, a specific request on the longest as possible period was mentioned. As a response to this request, the FireCCILT11 was delivered by Oton et al. (2019,2021) to fulfil this scientific gap, when global burned area data hardly go back to 2001 (FireCCI51, MCD64A1) or 1997 (GFED4s). This recently delivered database was quickly integrated to the reference global Burned area datasets (Kurbanov et al. 2022, Chuvieco et al. 2020), with 21 citations in WOS. Mostly the innovative methodological developments were cited (De Luca et al. 2022, Abdi et al. 2022, Abdikan et al. 2022, Glushkov et al. 2022, Bas et al. 2021, Saatchi et al. 2021, De Luca et al. 2021, Peng et al. 2021, Seydi et al. 2021, Wozniak & Aleksandrovicz 2019, Stroppiana et al. 2022, Xu et al. 2022, Gaveau et al. 2022, Oton et al. 2021) for similar AVHRR development and Sentinel 2 applications. Keystone long-term fire trends could be captured (Oton et al. 2022) with their climate drivers (Descals et al. 2022), with subsequent fire effects on ecosystems and biogeochemical cycles as the land/Atmosphere carbon budget (Van Marle et al. 2022), grazing/fire interactions (Hao et al. 2021), long term post fire recovery in Boreal Forests (de Andres et al 2021) or deforestation in Amazonia (Xu et al. 2020). However, the quality and coarse resolution of this dataset can be misleading on many purposes when used as any other Burned area data at 250m/500m resolution. Giglio et al. (2022) identified caveats in the dataset, and Xu et al. (2020)'s conclusion on deforestation were controversial. The delivery of this dataset is significant step forward in understanding the long term changes in the global fire regimes but should be used carefully, and would need further quality assessment.

# 4. End-user survey: the FIREMIP modelling group

Based on our bibliographical review, we identified the FIREMIP (fire modelling intercomparison project, Rabin et al. 2016) group as an active end-user actually regularly using various global burned area data including FireCCI data.  During the October 2022 annual FIREMIP meeting, FireCCI burned are datasets (FireCCI51, FireCCILT11 and FireCCISFD20) were presented as well as forthcoming objectives. We investigated how this community welcomed the new data and their requests for future developments. Their answers confirmed our bibliographical analysis that GFED4s represents a keystone information for their analysis due the time period covered (since 1997, compared to 2001 or even 2003 for FireCCI51) and the consideration of small fires. The lack of targeted accuracy assessment on small fires in FireCCI51 make the end-user suspicious on how this additional burned area is truly related to actual small fires or an additional artificial and hardly reliable noise. In absence of demonstration of better reliability of FireCCI51 over GFED4s for small fires, the benefit of the longer period provided by GFED4s is the most valuable for their study. However, they actually inserted FireCCI51 as reference dataset in their model benchmarking as we observed in our bibliographical, and they acknowledge the benefit of the uncertainty layer. Based on these numerous datasets available, a feeling of confusion is actually mentioned on how to analyse these datasets separately and merge them to get an inter-product uncertainty value. They are impressed by the recent results coming from the newly delivered FireCCISFD20 in Africa, revisiting their model calibration, and definitely have consideration and trust in this database. They remain unfortunately unable to use it in the present form as it covers only one year in 2019. Any suggestion or dataset to readjust the historical burned area from FireCCI51 to this updated version, would be more than welcome. On the contrary, after provisional local analysis of FireCCILT11, they remain suspicious on the reliability of this database to be used for their model benchmarking in the present form.

The current formats and resolutions (0.25°) are enough regarding the coarse resolution of their models. Until now, the fire patch database is seldom used, as their models are hardly ready to be evaluated at the patch level. However, they encourage the continuing of this development, bringing insights in the fire size distribution, rate of spreads and fire durations, as well as fire intensity (median within the patch) at the global level that might of interest for some models.

# 5. Synthesis and recommendations

We aimed here at synthesizing the user feedbacks from the FireCCI efforts in providing new burned area datasets to the scientific community. We investigated how the data have been used across various applications, and how they have been evaluated in their local accuracy. This fruitful investigation was complemented by a user survey from the modelling community FIREMIP, an active end user group. Regarding the low usage of FireCCI data in the environmental impacts and fire hazard, we should devote more time in disseminating to this community.

From our analysis, we propose the following recommendations:

- Pixel-level information at 250m (FireCCI51) and 20m (FireCCISFD20) have been highly used and cited as a main recent achievement, revisiting ecosystem functioning and atmospheric impacts associated to fires. Spatial and temporal extension of FireCCISFD20 to the global level, and near real-time updates of FireCCI51 will increase further studies and key findings on fire impacts.

- At the grid level (0.25°), a main goal, if reachable, would be to propose a corrected (even extrapolated with associated uncertainty) BA information accounting for the quality of the FireCCISFD20 for 2019 applied to the long-term coverage of FireCCILT11 or FireCCI51, so that the now acknowledged significant underestimation of coarse resolution BA dataset would be adjusted over the whole 2001-present period.
- A better demonstration of the significant improvement in small fire detection from FireCCI51 compared to GFED4s would better convince the users on the benefits of this dataset. At the grid level (0.25°), extending back to 1997 with a similar approach as GFED4s would also be a significant added value.
- Improvements of the FireCCI51 and forthcoming burned area products in cloudy areas as the tropics or the boreal forest based on local methodological developments would greatly enhance its use for these regions.
- Information on fire severity is one of the new keystone variable requested by users, and initiated in the MOSEV database that should be implemented in the forthcoming global burned area datasets.
- Uncertainty in the burn date was assessed but users would benefit from it being inserted as an additional uncertainty layer at the pixel level. Improvements would be welcome for daily fire weather identification, fire spread, and pixel aggregation into patches.
- A merged product at the pixel-level and grid-level combining the main existing current BA datasets (MCD64A1, GFED4s, FireCCI51) including the inter-product uncertainty would benefit the end-user community, now facing a large panel of information from which they have to choose or perform multiple impact studies.
- Fire patch identification from pixel-level information is a significant side dataset that should be continued and updated with better information on the dating, duration, shapefiles and rate of spread, and ignition point, in an easy to use format (yearly shapefile and attribute table), as well as synthetic information on fire size distribution, mean fire size, intensity, duration/rate of spread at 0.25° or 0.5°.

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## Annex 1: Acronyms and abbreviations

| | |
|---|---|
| AVHRR | Advanced Very High Resolution Radiometer |
| BA | Burned Area |
| CASA | Carnegie-Ames-Stanford-Approach |
| CCI | Climate Change Initiative |
| DGVMs | Dynamic Global Vegetation Models |
| EFFIS | European Forest Fire Information System |
| ESA | European Space Agency |
| EU | European Union |
| FireMIP | Fire Model Intercomparison Project |
| FIRMS | Fire Information for Resource Management System |
| FRP | Fire Radiative Power |
| GFA | Global Fire Atlas |
| GFED | Global Fire Emissions Database |
| HS | Hotspot |
| LTDR | Land Long Term Data Record |
| m | Metres |
| MIPs | Model Intercomparison Projects |
| MODIS | Moderate Resolution Imaging Spectroradiometer |
| NASA | National Aeronautics and Space Administration |
| NOAA | National Oceanic and Atmospheric Administration |
| TRMM | Tropical Rainfall Measuring Mission |
| URD | User Requirements Document |
| VIIRS | Visible Infrared Imaging Radiometer Suite |
| WoS | Web of Science |