GFAS-CLIM Product User Manual

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1. Introduction

This document describes the dataset generated from the development version of GFAS-CLIM. The product specifications and detailed description is provided in the subsequent sections.

2. Aims and Objectives:

Forest fires always have been an essential part of the ecosystem. For certain ecosystems, a natural fire occurring periodically, every year to several centuries, is vital for the maintenance and regeneration of the local vegetation. Over the last few decades, human intervention and climate are increasingly contributing to the disruption the natural fire regimes, and a global surge in the large-scale episodic fires has been observed. The emissions fluxes from the fire, in turn, affect the future climate. Currently, the CO2 emissions from landscape and biomass burning are equivalent to 50% of those originating from fossil fuel combustion (Bowman et.al., 2009). Smoke particles also intervene in the atmospheric radiation budget and cloud condensation. Soot particles over snow and ice increase the absorption of solar radiation and contribute to the rapid melting of the Artic. Due to the complex interaction of the vegetation fires with the climate, Global Climate Observing System (GCOS) considers fire disturbances as one of the Essential Climate Variables (ECVs) which are important for sustainable climate monitoring.

The MODIS FRP based Global Fire Assimilation System (GFAS) provides real-time biomass burning emissions and this methodology was originally developed for smoke emissions calculation in the Copernicus Atmosphere Monitoring Service (CAMS). GFAS-CLIM is a new implementation of the GFAS algorithm which targets towards meeting the GCOS ECV requirements for frequency, resolution and uncertainty characterisation. The first version of GFAS-CLIM is a baseline implementation of the algorithm in the PC-based development version of GFAS. This PC based version is used in CAMS for implementing and testing improvements in GFAS before migration to the operational production system at ECMWF. To adapt the GFAS-CLIM for climate applications, we have incorporated new developments to improve the temporal and spatial resolutions. Furthermore, we are working on implementing the additional option of retrospective analysis that uses an Kalman Smoother for observation gap filling.

The GFAS-CLIM dataset provides FRP analysis and emission fluxes. Some potential users of this data can be air quality modellers, researchers/academicians for analysing climatic trends and risk assessment.
3. Overview of the GFAS-CLIM products:

The present version of GFAS-CLIM provides FRP analysis and subsequent emissions for Carbon. Table 1 provides an overview of the dataset.

Table 1: Specifications of the GFAS-CLIM dataset.

<table>
<thead>
<tr>
<th>Dataset</th>
<th>GFAS-CLIM v1.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Period</td>
<td>2005 – 2011</td>
</tr>
<tr>
<td>Input Satellite Data</td>
<td>MOD14 MODIS FRP observations</td>
</tr>
<tr>
<td>Format</td>
<td>Grib/ netCDF</td>
</tr>
<tr>
<td>Frequency</td>
<td>Hourly</td>
</tr>
<tr>
<td>Area</td>
<td>Global</td>
</tr>
</tbody>
</table>

Filename conventions

- **Gridded Products:**
  - X = 1 Aqua, 2 Terra
  - YYYYMMDD/HH3X/parameterID.*

- **GFAS Analysis:**
  - YYYYMMDD/HH30/ parameterID.*

- **Emission Fluxes:**
  - YYYYMMDD/HH30/ parameterID.*

| Experiment ID | hr01 |

The products in GFAS-CLIM are identified according to their ECMWF GRIB parameter database. The following table gives a description of parameter IDs for all GFAS-CLIM products:

Table 2: GFAS-CLIM product GRIB IDs with their standard names and units.

<table>
<thead>
<tr>
<th>Parameter ID</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>210099</td>
<td>gridded FRP areal density</td>
<td>W m-2</td>
</tr>
<tr>
<td>210097</td>
<td>Inverse variance of wildfire radiative power</td>
<td>m4 W-2</td>
</tr>
<tr>
<td>210087*</td>
<td>Wildfire fraction of observed area</td>
<td>dimensionless</td>
</tr>
<tr>
<td>210079</td>
<td>Wildfire viewing angle of observation</td>
<td>deg</td>
</tr>
<tr>
<td>210098</td>
<td>Number of positive FRP pixels per grid cell</td>
<td>dimensionless</td>
</tr>
<tr>
<td>210101</td>
<td>Wildfire radiative power maximum</td>
<td>W</td>
</tr>
</tbody>
</table>
FRP Analysis

<table>
<thead>
<tr>
<th>ID</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>210099</td>
<td>FRP areal density analysis</td>
<td>W m-2</td>
</tr>
<tr>
<td>210097</td>
<td>Inverse variance of wildfire radiative power</td>
<td>m4 W-2</td>
</tr>
<tr>
<td>210039</td>
<td>gridded Wildfire radiative power - nighttime</td>
<td>W m-2</td>
</tr>
<tr>
<td>210037</td>
<td>Inverse variance of wildfire radiative power - nighttime</td>
<td>m4 W-2</td>
</tr>
<tr>
<td>210059</td>
<td>gridded Wildfire radiative power - daytime</td>
<td>W m-2</td>
</tr>
<tr>
<td>210157</td>
<td>Inverse variance of wildfire radiative power - daytime</td>
<td>m4 W-2</td>
</tr>
</tbody>
</table>

Dry matter Combustion and Emission Fluxes

<table>
<thead>
<tr>
<th>ID</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>210100</td>
<td>Wildfire combustion rate</td>
<td>kg m-2 s-1</td>
</tr>
<tr>
<td>210080</td>
<td>Wildfire flux of carbon Dioxide</td>
<td>kg m-2 s-1</td>
</tr>
<tr>
<td>210081</td>
<td>Wildfire flux of carbon monoxide</td>
<td>kg m-2 s-1</td>
</tr>
<tr>
<td>210091</td>
<td>Wildfire flux of black carbon</td>
<td>kg m-2 s-1</td>
</tr>
</tbody>
</table>

*this grib ID is different from the ECMWF grib parameter database.

4. Description of GFAS-CLIM:

In this section, we describe the different parameters in the GFAS-CLIM dataset.

4.1. Gridded Products:

Before assimilating the FRP observations from MODIS instruments, the Collection 6 MODIS FRP products (Giglio et al. 2016) are aggregated to a temporal and spatial resolution of 1 hour and 0.05 deg respectively. Before gridding, the MODIS FRP observations are also corrected to account for the attenuation of the thermal signal by the atmosphere.

<210099>: The FRP areal density ($q_j$) is expressed as the ratio of the sum of per-pixel FRP individual pixel area ($A_i$):

$$q_j = \frac{\sum_{i \in j} FRP_i}{\sum_{i \in j} A_i}$$  \hspace{1cm} (1)

<210079>: Viewing zenith angle of observations is defined as the mean of the viewing zenith angles of per-pixel FRP observations in each global grid cell ($j$).

<210077>: Fraction of the observed area is defined as

$$\gamma_j = \frac{\sum_{i \in j} A_i}{A_j}$$  \hspace{1cm} (2)
Uncertainty estimates are expressed as the inverse of the variance of $\rho_j$

$$\frac{1}{\sigma_{\rho j}^2} = \frac{(\sum_{i \in j} A_i)^2}{\sum_{i \in j} \sigma_{FRP_i}^2} \gamma_j$$  \hspace{1cm} (3)

These uncertainty estimates are used for a combined representation of the FRP density estimates from multiple platforms and also serve as weights during the optimal interpolation.

Number of positive FRP pixels per grid cell is simply the sum of the total number of per-pixel FRP observations in each global grid cell ($j$)

Wildfire radiative power maximum is the maximum among the per-pixel FRP observations in each global grid cell ($j$)

4.2 FRP Analysis:

Satellite observations contain gaps, mostly due to cloud cover. In the present version of GFAS-CLIM, a persistence model in Kalman filter is used for filling the gaps (Kaiser et. al., 2012). The fire behavior follows a diurnal cycle, hence the daytime and the night-time analysis fields are estimated separately. These two estimates are combined through a diurnal cycle formalism (Kaiser et al., 2017) to generate the final FRP field. As an ongoing development, we are implementing a Kalman Smoother based approach to fill in the data gaps.

The FRP density analysis at time $t$ is calculated (separately for day-time and night-time) through optimal interpolation with the observations and using uncertainty estimates as weights:

$$\hat{\rho}_t = \hat{\sigma}_t^2 (\hat{\sigma}_t^{-2} \hat{\rho}_t + \hat{\sigma}_t^{-2} \hat{\rho}_t)$$  \hspace{1cm} (4)

This final field is defined by combining the day and time time FRP analysis through a diurnal cycle parameterization (Kaiser et al., 2017).

The uncertainty of the FRP analysis are computed as

$$\hat{\sigma}_t^{-2} = \hat{\sigma}_t^{-2} + \hat{\sigma}_t^{-2}$$  \hspace{1cm} (5)

where, $\sigma_t^{-2} = \sigma_{t-1}^{-2} + \sigma_t^{-2}$  \hspace{1cm} (6)

The FRP analysis for the day-time. The day-time window is defined from 0900 hrs to 2100 hrs solar local time.

The uncertainty estimation corresponding to the FRP analysis day-time.
The FRP density analysis for the night-time. The night-time window is defined from 2100 hrs to 0900 hrs solar local time.

The uncertainty estimation corresponding to the FRP analysis night-time.

Figure 1: Daily average Fire radiative power density (FRP) analysis from GFAS-CLIM for 18 June 2017 at 0.1deg resolution

4.3 Emission Fluxes:

The emission fluxes are estimated from the dry matter combustion rate and emission factors. The current version of GFAS-CLIM uses emission factors for eight different fuel types. These eight fuel types are based on dominant fire type in GFEDv3.1 and organic soil and peat maps (Kaiser et al., 2012). GFAS-CLIM has the option to define emission fluxes for 40 species, but in the present dataset, only fluxes for burnt Carbon are provided.

Dry matter combustion rate is derived from FRP using conversion factors $ ((\beta_i))$ defined according to the land cover type $(l \in [1,8])$ (Kaiser et al., 2012)

$$ f(DM) = \sum_{i=1,8} \delta_{i,l} \beta_i \hat{\rho} $$

The overall emission flux density for the burnt carbon is calculated using the dry matter combustion rate density and the emission factor for burnt Carbon.

The FRP uncertainty estimate can also be used as relative quality indicator for the dry matter combustion and carbon flux fields.
5. Known Limitations:

- Though the algorithm aims at covering the data gaps with assimilation techniques, any cloud cover can affect the performance of the methodology. For example, the lack of observations in a persistence model can cause the fire to persist even beyond the actual time frame of the observed activity.
- Spurious signals due to volcanoes, gas-flares, are masked out in the product. But few signals from new sites of gas-flares, reflectance from solar-panels, thermal anomalies from industries can also contribute to FRP as spurious signals.
- Fires which start and end between the MODIS sampling frequency do not get adequate representation in GFAS-CLIM.
- Due to the data assimilation approach, fire activity does not end abruptly for extinguished fires. Instead, it decreases exponentially with a time scale that is inversely proportional to the cloud-free observation frequency.
- The FRP-DM conversion factors and carbon emission factors for individual fire events are still uncertain by at least 30% and more. The uncertainties are larger for peat fires.

6. Data dissemination and support:

The GFAS-CLIM dataset is available on request via ftp.
For further technical support regarding the GFAS-CLIM dataset or the methodology, please contact:

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7. References: