Product User Manual

PUM FRP
FIRE RADIATIVE POWER

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List of Acronyms

APL:	Algorithm Private Layer
ASCAT:	Advanced Scatterometer
ATBD:	Algorithm Theoretical Basis Document
AVHRR:	Advanced Very High Resolution Radiometer
BT:	Brightness Temperature
ECMWF:	European Centre for Medium-Range Weather Forecasts
EPS:	EUMETSAT Polar System
EUMETSAT:	European Meteorological Satellite Organisation
FRE:	Fire Radiative Energy
FRP:	Fire Radiative Power
HDF	Hierarchical Data Format
IM:	Instituto de Meteorologia (Portugal)
IR:	Infrared Radiation
LUT:	Look-Up Table
METEOSAT:	Geostationary Meteorological Satellite
MSG:	Meteosat Second Generation
MW:	megawatts
NASA:	National Air and Space Administration
NIR	Near Infrared Radiation
NWC:	NoWCasting SAF
NWP:	Numerical Weather Prediction
PCL:	Product Command Layer
PDL:	Product Data Layer
ROI:	Region of Interest
SAF:	Satellite Application Facility
SEVIRI:	Spinning Enhanced Visible and InfraRed Imager
TCWV:	Total Column Water Vapour
TIR:	Thermal Infrared
U-MARF:	Unified Meteorological Archiving and Retrieval Facility
VIS:	Visible Radiation

1 Introduction

The Satellite Application Facility (SAF) on Land Surface Analysis (LSA) is part of the SAF Network, a set of specialised development and processing centres, serving as EUMETSAT (European organization for the Exploitation of Meteorological Satellites) distributed Applications Ground Segment. The SAF network complements the product-oriented activities at the EUMETSAT Central Facility in Darmstadt. The main purpose of the LSA SAF is to take full advantage of remotely sensed data, particularly those available from **EUMETSAT** sensors, to measure **land surface** variables, which will find primarily applications in meteorology (http://landsaf.meteo.pt/).

The spin-stabilised Meteosat Second Generation (MSG) has an imaging-repeat cycle of 15 minutes. The Spinning Enhanced Visible and Infrared Imager (SEVIRI) radiometer embarked on the MSG platform encompasses unique spectral characteristics and accuracy, with a 3 km resolution (sampling distance) at nadir (1km for the high-resolution visible channel), and 12 spectral channels (Schmetz et al., 2002).

The EUMETSAT Polar System (EPS) is Europe's first polar orbiting operational meteorological satellite and the European contribution to a joint polar system with the U.S. EUMETSAT will have the operational responsibility for the "morning orbit" with Meteorological-Operational (MetOp) satellites, the first of which was successfully launched on October 19, 2006. Despite the wide range of sensors on-board MetOp (http://www.eumetsat.int/), most LSA SAF parameters make use of the Advanced Very High Resolution Radiometer (AVHRR) and, to a lesser extent, of the Advanced Scatterometer (ASCAT).

Several studies have stressed the role of land surface processes on weather forecasting and climate modelling (e.g., Dickinson et al., 1983; Mitchell et al., 2004; Ferranti and Viterbo, 2006). The LSA SAF has been especially designed to serve the needs of the meteorological community, particularly Numerical Weather Prediction (NWP). However, there is no doubt that the LSA SAF addresses a much broader community, which includes users from:

- Weather forecasting and climate modelling, requiring detailed information on the nature and properties of land.
- Environmental management and land use, needing information on land cover type and land cover changes (e.g. provided by biophysical parameters or thermal characteristics).
- Agricultural and Forestry applications, requiring information on incoming/outgoing radiation and vegetation properties.
- Renewable energy resources assessment, particularly biomass, depending on biophysical parameters, and solar energy.
- Natural hazards management, requiring frequent observations of terrestrial surfaces in both the solar and thermal bands.

- Climatological applications and climate change detection, requiring long and homogeneous time-series.
- Chemical weather and air quality, requiring information on fire detection and intensity.

Table 1 LSA SAF products operational or under-development at the beginning of the 3rd phase of the project – Continuous Development and Operations Phase (CDOP). Expected horizontal resolution and spatial coverage, generation frequency, and target accuracy are also indicated. Temporal resolution specifies the time interval to which the product applies. In the near future, the LSA SAF team plans to use AVHRR/Metop data (and ASCAT/Metop in the case of SC and SMET) for the retrieval of all the products described below.

	Product	Horizontal Resolution & Coverage	Temporal Resolution	Generation Frequency	Target Accuracy
Surface Radiation Budget	**AL** – Albedo	MSG disk	5-day & 30-day	Daily & 10-day	AL>0.15: 20% AL<0.15: 0.03
	LST – Land Surface Temperature	MSG disk / Global*	Instantaneous	15min & 12-hourly*	2 K
	DSSF – Down-welling Surface Short-wave Flux	MSG disk / Global*	Instantaneous & Daily	30 min & Daily	DSSF>200W/m^2 10% DSSF<200W/m^2 20W/m^2
	DSLF – Down-welling Surface Long-wave Flux	MSG disk / Global*	Instantaneous & Daily	30 min & Daily	10 %
Biogeophysical Parameters I	**SC** – Snow Cover	MSG disk / Global	Daily	Daily	False Alarm: 15%; Hit Rate: 80%
	ET – Soil Moisture/ Evapotranspiration	MSG disk	Daily / 30 min	Daily / 30 min	ET>0.4 mm/h: 25% ET<0.4 mm/h: 0.1 mm/h
Biogeophysical Parameters II	**FVC** – Fraction of Vegetation Cover	MSG disk / Global*	5-day & 30-day	Daily & 10-day	15%
	LAI – Leaf Area Index	MSG disk / Global*	5-day & 30-day	Daily & 10-day	1
	FAPAR – Fraction of Absorbed Photosynthetic Active Radiation	MSG disk / Global*	5-day & 30-day	Daily & 10-day	15%
	RFM – Risk of Fire Mapping	Europe	Daily	Daily	---
	FD&M – Fire Detection & Monitoring	MSG disk	15-min & Daily	15-min & Daily	---
	FRP – Fire Radiative Power	MSG disk	15-min & hourly	15-min & hourly	50%

*Global and 12-hourly products refer to retrievals from AVHRR/EPS.
**Indirectly, via other LSA SAF components (AL, DSSF, DSLF, FVC, LAI, …)
***For cloud identification and classification.

The LSA SAF products (**Error! Reference source not found.**) are based on level 1.5 SEVIRI/Meteosat and/or level 1b MetOp data. Forecasts provided by the European Centre for Medium-range Weather Forecasts (ECMWF) are also used as ancillary data for atmospheric correction.

The SEVIRI/Meteosat derived products are generated for 4 different geographical areas within Meteosat disk (**Error! Reference source not found.**):

- Euro – Europe, covering all EUMETSAT member states;
- NAfr – Northern Africa encompassing the Sahara and Sahel regions, and part of equatorial Africa.
- SAfr – Southern Africa covering the African continent south of the Equator.
- SAme – South American continent within the Meteosat disk.

MetOp derived parameters are currently available at level 1b full spatial resolution and for the processed Product Distribution Units (PDUs), each corresponding to about 3 minutes observation. Composite and re-projected products are foreseen for a later stage of the LSA SAF.

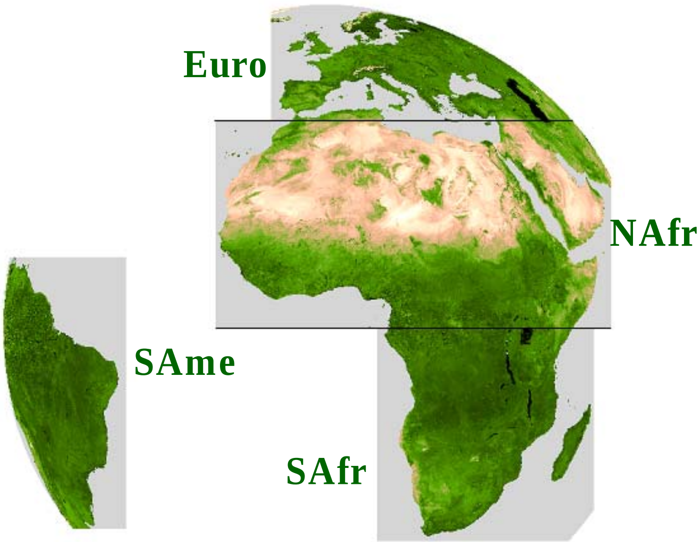

Figure 1 - The LSA SAF geographical areas.

The LSA SAF system is fully centralized at IM and is ~~will~~ be able to operationally generate, archive, and disseminate the operational products. The monitoring and quality control of the operational products, also centralized at IM, is performed automatically by the LSA SAF software, which provides quality information to be distributed with the products.

The LSA SAF products are currently available from LSA SAF website (http://landsaf.meteo.pt) that contains real time examples of the products as well as updated information.

This document is one of the product manuals dedicated to LSA SAF users. The algorithm and the main characteristics of the Fire Radiative Power product generated by the LSA SAF system are described in the following sections.

2 Algorithm Purpose

The Fire Radiative Power algorithm aims to estimate the Fire Radiative Power (FRP) generated during fire events at different temporal and spatial scales. The FRP is measured in megawatts (MW). It has been demonstrated in small-scale experimental fires that the amount of radiant heat energy liberated per unit time (the Fire Radiative Power) is related to the rate at which fuel is being consumed (Wooster et al., 2005). This is a direct result of the combustion process, whereby carbon-based fuel is oxidised to CO_2 with the release of a certain "heat yield", a fraction of which is emitted as electromagnetic radiation that can be measured with appropriate remote sensing instrumentation. Though imaging remote sensing instruments on satellites generally record EM radiation in only a part of the electromagnetic spectrum, physically-based relationships can be used to estimate radiative emission over the whole spectrum based on measurements at a limited number of wavelengths. A more detailed description of the role of FRP in the frame of CO_2 cycle analysis and the physics of the problem can be found in the Algorithm Theoretical Basis Document (ATBD, Govaerts 2006) and in the paper describing the algorithm from which the FRP pixel product algorithm was derived (Roberts and Wooster, 2008).

The temporal integration of the FRP measure over the lifetime of the burn provides a measure of the total Fire Radiative Energy (FRE), which should be proportional to the total fuel mass combusted. The simple linear relationships linking FRP, FRE and fuel consumption were first demonstrated in detail by Wooster et al. (2005):

Rate of biomass consumption (kg.sec^{-1}) = 0.368(± 0.015).Fire Radiative Power (MW)

Equation 1

Fuel biomass combusted (kg) = 0.368(± 0.015).Fire Radiative Energy (MJ)

Equation 2

The FRP measure to use in Equation (1) can be taken from the SEVIRI FRP per-pixel product, whilst the FRE measure for use in Equation (2) is the integration of the FRP over space and time (that might, for example, represent one particular fire). Examples of the method applied to SEVIRI FRP and FRE data can be found in, for example, Roberts et al (2005) and Roberts and Wooster (2008).

Once a biomass combustion rate or total is available, it can simply be multiplied by the fraction of carbon contained in the fuel (usually assumed ~ 0.47) to estimate total carbon release, or by the standard emissions factors of different species (e.g. CO_2, CO, particulate matter) in units of g of emitted per kg of fuel burned in order to estimate the emissions of those species. The standard emissions factors used in converting estimates of fuel consumption to estimates of emissions production are tabulated in Andreae and Merlet (2001) and subsequent updates. An alternative approach would be to directly relate FRP or FRE to the emissions of trace gases and aerosols, without the intermediate step of fuel consumption estimation. This requires application of dedicated "radiative emissions ratios" such as those that have been explored for smoke aerosols by Ichoku and Kaufman (2005) and for a series of trace gases and smoke aerosols by Freeborn et al (2008).

The FRP product offers thus a new way to estimate the location and amount of greenhouse gas and aerosol emissions from fires, as well as reactive gases emissions (ozone precursors particularly), based directly on measures of the actual heat released from these events, rather than relying on post-fire measures of burned area and some assumption of the fuel consumed per unit area burned.

3 Algorithm description

The FRP is estimated at two different spatial and temporal resolutions. It corresponds to two different algorithms generating two different products, i.e., a level 2 and a level 3 product.

- The **FRP_PIXEL** algorithm retrieves the FRP for detected fires at the SEVIRI pixel resolution every 15 minutes. The SEVIRI pixel size at Sub Satellite point is nominally 3x3 km. This level 2 product is pre-operational.

- The **FRP_GRID** algorithm is in charge of the estimation of the FRP at FRP_GRID_RESOL degree resolution, averaging the total FRP measured over FRP_GRID_AGV_RANGE hours. The values of these parameters are defined in MJ. In addition to FRP estimation at a different spatial and temporal resolution than the pixel product, this second process applies statistical 'correction factors' to adjust the product values for the presence of clouds (which can mask fires from the view of the sensor) and for undetected "small" fires whose FRP is below the detection limit of SEVIRI. Refer to Section 4.3 for the limitations concerning the interpretation of this product. This level 3 product is still in development. It is currently generated for validation purposes and will become available early 2009.

These two algorithms correspond to distinguished "daemons" in the LSA SAF processing environment.
From the point of view of a general task description, the FRP algorithms can be divided into three different layers. Each layer has a specific task. The Product Command Layer (PCL) is the only one communicating with the external world, i.e. the LSA SAF processing environment. The second layer, called Product Data Layer (PDL), is in charge of providing all the I/O functionalities. This is the only layer allowed in reading/writing data. The third and last layer, the Algorithm Product Layer (APL), contains the core algorithm, where all the physical retrieval is performed. The PDL and APL are completely disconnected from the LSA SAF environment. A sketch showing this layer representation is in Figure 2.

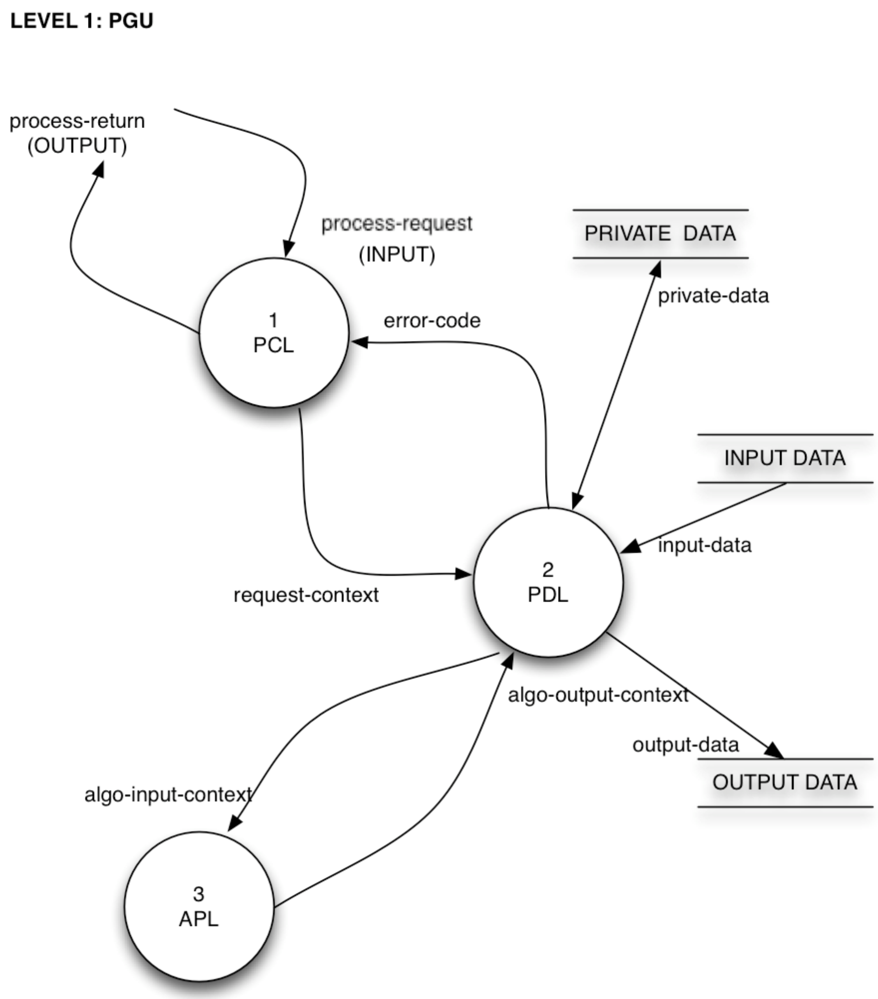

Figure 2: Representation of the three conceptual layers building up the FRP algorithm. The PCL is the only layer communicating with the outside world.

3.1 FRP_PIXEL

The estimation of FRP for a detected fire pixel requires the processing steps listed schematically in the following table.

1	*Clear sky pixel identification:*	Identification of the clear sky pixels
2	*Potential fire detection:*	Detection, using spectral and spatial filtering of the potential fire pixels
3	*Background identification:*	Identification and estimation of the pixel background radiance
4	*FRP assessment at pixel level:*	Estimation of the FRP for the pixel
5	*Apply Atmospheric correction*	Apply a correction to account for the signal attenuation

		due to the atmosphere
6	*Quality flag estimation:*	Assessment of a retrieval quality flag

Table 2 FRP_PIXEL processing steps

This product is generated by the FRP_PIXEL code for each of the 4 regions (see Section 1**Error! Reference source not found.**) defined at the LSA SAF at full spatial and temporal resolution. The list of error codes generated by the FRP_PIXEL algorithm are listed in Table 3. In case of fatal errors, the FRP_PIXEL process aborts.

ERROR CODE	MESSAGE
FRP_NOERROR	Processing :No Error
FRP_PDL_FILE_OPEN_ERROR	Fatal Error: File Open
FRP_PDL_IMGLINEHDRREAD_ERROR FRP_PDL_IMGLINEREAD_ERROR FRP_PDL_READDAM_ERROR FRP_PDL_READ_ERROR	Fatal Error: File Read
FRP_PDL_FILEWRITE_ERROR	Fatal Error: File Write
FRP_PDL_ALLOC_ERROR	Fatal Error: Memory Allocation

Table 3: FRP_PIXEL algorithm fatal errors

3.1.1 Inputs

The dynamic input files needed by the FRP_PIXEL are (for each of the 4 regions):

SEVIRI Radiance 0.6 μm	mandatory	- Residual Cloud screening
SEVIRI Radiance 3.9 μm	mandatory	- Residual Cloud screening - Pot. Fire assessment - Background assessment - FRP estimation
SEVIRI Radiance 10.8 μm	mandatory	- Residual Cloud screening - Pot. Fire assessment - Background assessment
SEVIRI Radiance 12.0 μm	mandatory	- Residual Cloud screening - Pot. Fire assessment - Background assessment
Cloud Mask from the NWC SAF	mandatory	- Cloud screening
TCVW from ECMWF	not mandatory	- Atmospheric correction

In case the TCVW is not available the processing is performed using a default value:

FRP_TCWV_DEFAULT = 20 kg/m^2

3.1.2 Private files

The FRP_PIXEL algorithm uses a set of private files for storing temporary information. The SEVIRI field of view is divided in Region of Interest (ROIs) (see

Figure 3) and for each of this ROI two files are defined. The first one (ROI_Accumulation_*NN*) contains all the radiometric and ancillary information at pixel level. The second one (FRP_Accumulation_ *NN*) contains all the variables retrieved in the APL. The suffix NN refers to the NN^{th} ROI.

PRIVATE DATA	DESCRIPTION
ROI_Accumulation_*NN*	This file contains all the row dynamic data info (counts, angles, cloud mask) and ancillary data for the *NN* region and for the complete period needed to generate the FRP
FRP_Accumulation_*NN*	This file contains the variables retrieved from the APL for the window *NN*.

Table 4: List of the FRP algorithm private data

3.1.3 Output

For each processed region, the FRP_PIXEL algorithm generates two output files:

- FRP List
- FRP Quality flag

The content of these files is described in Section 4.2.

3.1.4 Retrieval Scheme

The input information (radiances, cloud mask, geometry, TCWV, Land Cover) is stored for each ROI-Pixel and afterwards always in a ROI to Pixel driven mode the FRP and all the ancillary information listed in Table 7 are estimated. This strategy is explained in the flowchart shown in Figure 4. The core algorithm flowchart is instead shown in Figure 5

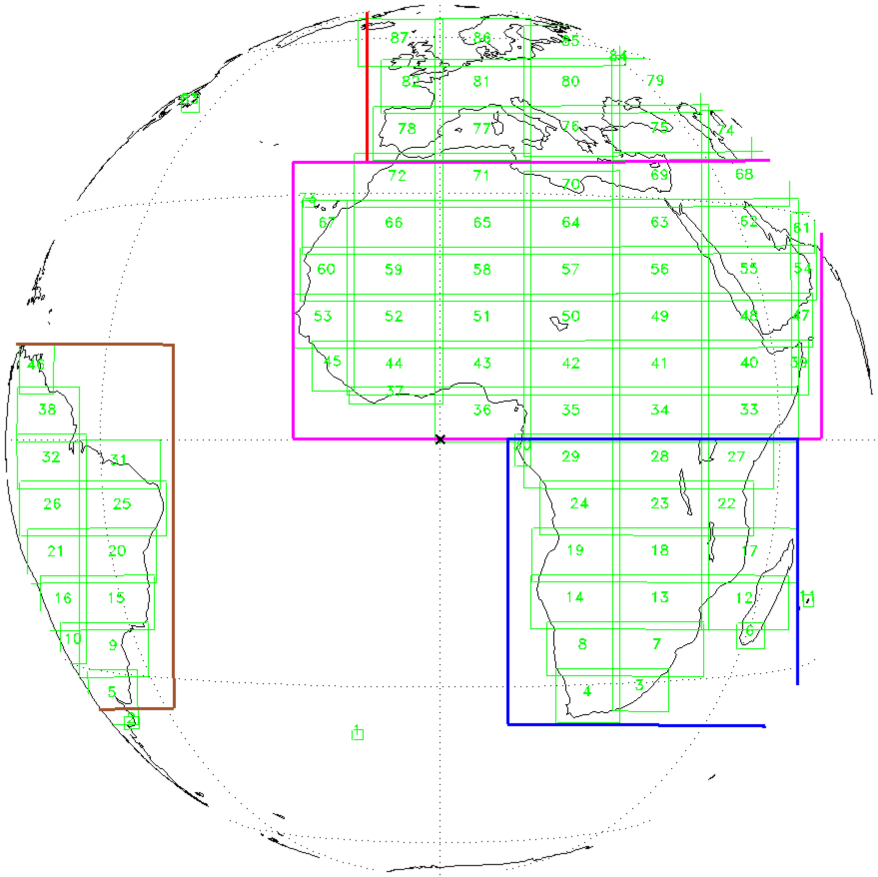

Figure 3 Definition of the FRP internal windows (in green colour) inside the LSA SAF regions, Euro (red), NAfr (magenta), SAfr (blue) and Same (brown).

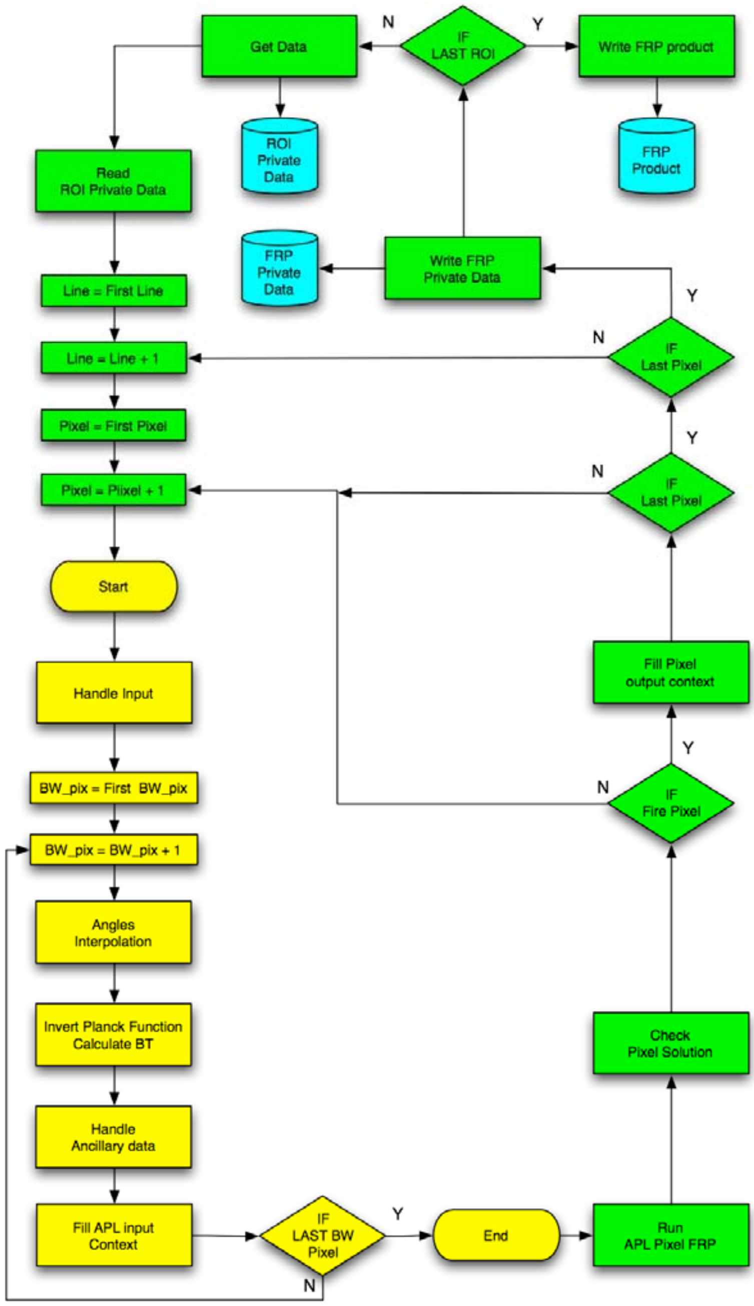

Figure 4 Data Preparation flowchart Pixel Resolution: diagram showing the Data preparation sub-layer in details for estimating FRP at pixel resolution. In yellow the data preparation flowchart and in light green the activities outside the data preparation functionality.

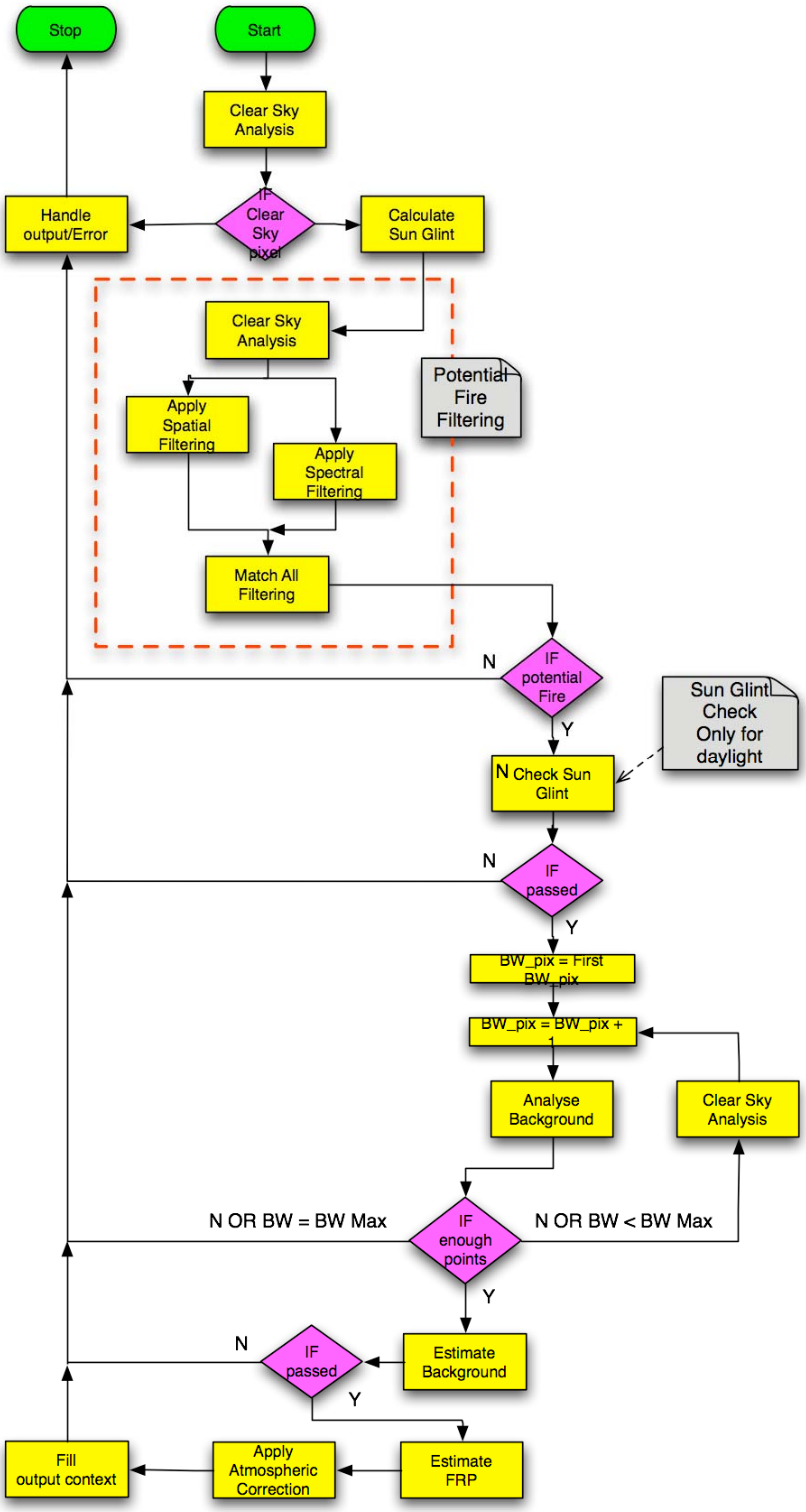

Figure 5 Flowchart showing the pixel FRP estimation algorithm

3.2 FRP_GRID

The estimation of the FRP at resolution of FRP_GRID_RESOL degree and FRP_GRID_AVG_RANGE hours requests the processing steps listed schematically in the following table.

1	*Total FRP at 1 degree*	Summation of the FRP of all fires detected in the FRP_GRID_RESOL degree box.
2	*Clear sky fraction*	Multiply for the Clear sky factor to compensate for the signal attenuation due to the presence of clouds (land fraction only)
3	*Hourly Averaged FRP*	Average the FRP measured over FRP_GRID_AVG_RANGE hours
4	*Small fires factor*	Multiply by the statistically determined factor that adjusts the observed FRP total for the additional FRP that might be present in the gird box due to the presence of (potentially numerous) small and/or low intensity fires (and thus low FRP fires) that are each below the SEVIRI detection limit.

Table 5 FRP_GRID processing steps

This product is generated for the complete SEVIRI field of view on a regular predefined grid. A flowchart showing the processing executed for the estimation of the mean grid FRP is in Figure 6. The default configuration parameters for the FRP_GRID algorithm are:

FRP_GRID_FIRST_LON	80W
FRP_GRID_LAST_LON	60E
FRP_GRID_FIRST_LAT	80S
FRP_GRID_LAST_LAT	60N
FRP_GRID_RESOL	1 degree
FRP_GRID_AGV_RANGE	1 hour

Table 6: Parameters used to define the spatial and temporal resolution of the grid FRP product.

The temporal and spatial resolution of the gridded FRP product has been defined in accordance with the user's needs, accounting for the SEVIRI coarse resolution which limits the possibility to detect small fires. Consequently, it has been necessary to apply some corrections to this product which are not reliable when applied at a spatial resolution smaller then one degree. Refer to the FRP Validation Report for additional information on this issue. Note that the modification of the FRP_GRID_RESOL and FRP_GRID_AGV_RANGE values requires a new build of the FRP_GRID executable.

3.2.1 Inputs

The dynamic input files needed by the FRP_GRID are (for each of the 4 regions and the complete hour):

- FRP product list generated by FRP_PIXEL

- FRP Quality flag generated by the FRP_PIXEL
- Latitude array at pixel level (static ancillary)
- Longitude array at pixel level (static ancillary)

The following input is given for the complete SEVIRI field of view at the default resolution of 5 degrees.

- Small Fires correction Look-up table[1] (static ancillary)

If all regions/time-steps are available the number of input files is 41.

The output for the FRP_GRID is generated even in cases where some regions/time-steps are missing. Specific values in the product warn the user if the lack of fires in a specific box was due to missing inputs or to an effective absence of fires in that area. A specific field in the product reports the number of input used for the mean temporal FRP estimation in every cell. For details refers to Section 4.3

3.2.2 Output

The output produced from the FRP_GRID consists of:

- FRP Grid

Only one "global" product is foreseen that covers the four LSA SAF processing regions. The coordinates of the grid are defined in degree**Error! Reference source not found.** and will cover according to the grid parameters already defined all the target LSA SAF processing regions. The details of this product are reported in Section 4.3

[1]This Look-up table applies a correction by estimating the FRP of the small fires missed by SEVIRI. For more details refers to the ATBD.

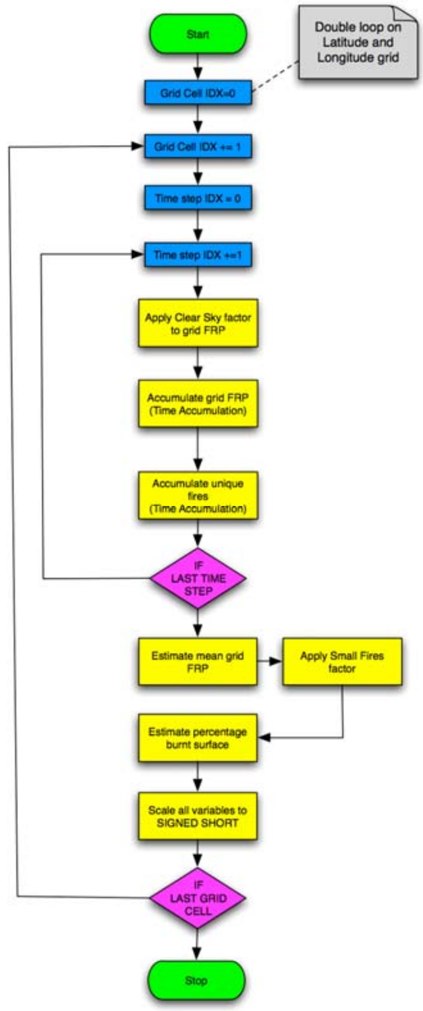

Figure 6 Flowchart showing the Grid FRP estimation algorithm

4 Output Data Description

4.1 Overview

The LSA SAF operational system processes separately the four geographical areas defined in Section 1. Information on geo-location and data distribution is available from the LSA SAF web-site: http://landsaf.meteo.pt. The FRP products are coded in HDF5 format. The HDF5 files in LSA SAF system have the following structure:

- A common set of attributes for all kind of data, containing general information about the data (including metadata compliant with U-MARF requirements);
- A dataset for the parameter values;
- Additional datasets for metadata (e.g., quality flags).

The list of global and dataset attributes is the same for all input and output files and it is detailed in the Product Output Format document (SAF/LAND/IM/POF/1.8).The HDF5 format has been developed by the National Centre for Supercomputing Applications (NCSA) at the University of Illinois. A comprehensive description is available at http://hdf.ncsa.uiuc.edu/.

4.2 FRP_PIXEL

At each time step the FRP_PIXEL algorithm generates two external output files named according to the following name convention:

- **HDF5_LSASAF_MSG_FRP_ListProduct_<Area>_YYYYMMDDHHMM**
- **HDF5_LSASAF_MSG_FRP_QualityProduct_<Area>_YYYYMMDDHHMM**

Where <**Area**>, **YYYY**, **MM**, **DD**, **HH** and **MM** respectively denote the geographical region (Euro, NAfr, SAfr, SAme), the year, the month, the day, the hour and the minute of data acquisition. The time specified in the filename refers to the beginning of the image acquisition.

The first product file contains a list of variables available for each detected fire described in Table 7.

VARIABLE	MEANING	UNITS	SCALE FACTOR	RANGE
FRP	Pixel FRP (atmosphere correction applied[2])	MW	10	> 0
FRP_SDEV	Pixel FRP Std deviation (atmosphere correction applied)	MW	1	> 0
PIXEL	Pixel (column) number value in the SEVIRI projection	p.n.	1	[1-3712]
LINE	Line number value in the SEVIRI projection	p.n.	1	[1-3712]
BW_NUMPIX	Background window number of valid pixels	p.n.	1	[15,215]
BW_SIZE	Background window Size	p.n.	1	[5,15] [3]
LATITUDE	Pixel Centre Latitude	Deg	100	[-90,90]
LONGITUDE	Pixel Centre Longitude	Deg	100	[-180,180]
FIRE_CONFIDENCE	Pixel Fire Confidence	p.n.	100	[0,1]
BT_MIR	Pixel Fire BT MIR	K	10	> 0
BT_TIR	Pixel Fire BT TIR	K	10	> 0
BW_BT_MIR	Background Mean BT MIR	K	10	> 0
BW_BTD	Background Mean BTD	K	10	> 0
PIXEL_SIZE	Pixel Size	Km^2	100	> 9
PIXEL_VZA	Pixel View Zenith Angle	Deg	100	[0,90]
PIXEL_ATM_TRANS	Atmospheric transmission factor	p.n.	10000	[0,1]
ACQTIME	Pixel Acquisition Time	UTC Time	1	[0,2359]

Table 7 FRP_PIXEL datasets stored in list format (one value for each detected fire)

The real measured value is obtained according to the following formula:

[2] Appling the aspheric correction means multiply for the inverse of the field PIXEL_ATM_TRANS saved in the product
[3] Only odd values (5,7,9,…) are permitted

Real_value = Stored_value / Scale_factor

Where the Stored_value is the value saved as 2 bytes integer in the dataset.

The ACQTIME format is HHMM. For example the time 12:14 is coded as an integer like 12x100+14 = 1214.

The second file is a 2D array with the dimension of <Area> containing the processing status of each pixel. In the latter file, the pixel size is the same as for SEVIRI (3x3 km at Sub Satellite Point).

VARIABLE	MEANING	UNITS	SCALE FACTOR	RANGE
QUALITY FLAG	Quality flag	N.A.	1	[0,255]

Table 8 FRP_PIXEL datasets stored as 2D matrix

The QUALITY FLAG stores the processing status of all pixels. This information can be very useful in case of comparison with other products and it is mandatory as input to the FRP_GRID, where the cloud fraction is needed in order to estimate the FRP at a certain resolution. The coding for the QUALITY FLAG is given in Table 9.

NAME	VALUE	MEANING
FRP_OUTSIDE_ROIS	-1	Pixels that are in the LSA SAF regions (Euro, NAfr, SAfr, SAme) but not in the internal windows considered for processing (see Figure 3).
FRP_APL_NOTPOT	0	FRP NOT Estimated: Not a potential fire pixel
FRP_APL_FRP	1	FRP Estimated: OK STATUS
FRP_APL_FRP_SAT	2	FRP Estimated with at least 1 pixel saturated 3.9 channel
FRP_APL_CLOUD	3	FRP NOT Estimated: CLOUDY PIXEL
FRP_APL_SUNG	4	FRP NOT Estimated: SUN GLINT NOK
FRP_APL_SUNGRATIO	5	FRP NOT Estimated: SUN GLINT CHANNEL RATIO NOK
FRP_APL_NOBCK	6	FRP NOT Estimated: NO BACKGROUND FOUND
FRP_APL_BCKNOT	7	FRP NOT Estimated: BACKGROUND NOT SIGNIFICANT
FRP_APL_CLOUDEDGE	8	FRP NOT Estimated: CLOUD EDGE
FRP_APL_NOTPROC	254	FRP NOT Estimated: PIXEL NOT PROCESSED

Table 9 QUALITY FLAG coding

The sequence of tests executed in the FRP_PIXEL algorithm prior to the estimation of potential fires is:

LAND → CLOUD → CLOUD_EDGE[4]

A pixel not being "land" is flagged as FRP_APL_NOTPROC if it is not cloudy and as FRP_APL_CLOUD if it is a cloud. The use of the quality indicator information is

[4] The CLOUD_EDGE test excludes from processing all the first (and second) neighbours in case of cloudy (water) pixel

particularly important for the correct interpretation of the FRP list given in Table 7. The following different cases should be envisaged:

- When the quality flag is taking one of the following two values (FRP_APL_FRP, FRP_APL_FRP_SAT), a fire radiative power value has been estimated within that pixel and it is therefore possible to estimate the corresponding pyrogenic emission of CO_2, aerosol etc.
- When the quality flag is taking the FRP_APL_NOTPOT value, it means that no fire large enough where present in that pixel to be detected by SEVIRI. However, small fires might have been present in that pixel. A statistical method is proposed in the FRP_GRID product to potentially account for those undetected small fires.
- All other quality flag values indicate that it has not been possible to detect or not the presence of a fire and associated FRP value due to for instance sun glint observation condition or the presence of cloud.

4.3 FRP_GRID

Every FRP_GRID_AVG_RANGE hours the FRP_GRID algorithm generates one external output file according to the following name convention:

- **HDF5_LSASAF_MSG_FRP_Frp_Grid_Global_YYYYMMDDSSEE**

where **YYYY**, **MM**, DD, **SS** and **EE** respectively denote the year, the month, the day, the Starting and End hour of the analysed period.

VARIABLE	MEANING	UNITS	SCALE FACTOR	RANGE
FRP	FRP at FRP_GRID_RESOL degree resolution averaged over FRP_GRID_AVG_RANGE hours	MW	10	> 0
FRP_RANGE	Difference Max - Min among all FRP grid in FRP_GRID_AVG_RANGE hours	MW	1	> 0
FRPOBS	Real measured FRP (no cloud and/or undetected small fire correction)	MW	1	>0
GRIDPIX	Number of SEVIRI pixel in the cell used for the estimation of the BURNTSURF	p.n.	1	> 0
NUMIMG	Number of images used for the temporal average	p.n.	1	>=0
NUMFIRES	Average number of fires detected in the FRP_GRID_RESOL degree box in FRP_GRID_AVG_RANGE hours	p.n.	10	>= 0
BURNTSURF	Percentage of burnt pixels within the cell in the selected average time range	p.n.	100	[0,100]

LATITUDE	Grid Latitude value (centre of the current grid cell)	Deg	100	[-90,90]
LONGITUDE	Grid Longitude value (centre of the current grid cell)	Deg	100	[-180,180]
CLEARSKYFRAC	Factor accounting for the cloud coverage in the FRP_GRID_RESOL degree box, averaged over FRP_GRID_AVG_RANGE hours (1 means cloud free)	p.n.	100	[0,1]
ATMTRANS	Average Atmospheric correction factor in the FRP_GRID_RESOL cell	p.n.	10000	[0,1]

Table 10 FRP_GRID datasets stored as 2D matrix

The real measured value is obtained according to the following formula:

Real_value = Stored_value / Scale_factor

Where the Stored_value is the value saved as 2 bytes integer in the dataset.

The value of the FRP Grid also includes the information about the reason why no fires has been found. The two possible reasons, input data missing and no detected fire in the grid cell, are coded in the product as follows:

- Input Data Not available : 32767[5]
- No fires in the grid cell : 0

The FRP_PIXEL product allows pyrogenic emissions estimation for those fires which have been detected, but suffers from some limitations due to the obscuring presence of clouds, and from the non-detection of 'small' (i.e. low FRP) fires due the coarse SEVIRI spatial resolution. For cases where meteorological clouds are coving significant fires, and/or where there are significant numbers of undetected low-FRP fires, the true pyrogenic emissions may well be underestimated when based on the observed FRP alone. This might lead to biased results when integrated over a long period or a large area.

To circumvent these limitations, the FRP_GRID product contains corrections for the fraction of the grid cell that is cloudy and therefore where no fire detection could take place. It also contains a correction for the small (low FRP) fires that cannot be detected with SEVIRI observations. Importantly the observed FRP is also obtainable from this product (i.e. the value without the correction applied). These corrections are statistical and aim at reducing the impact of these two issues (cloud and small fires) at a sub-continental scale and over a long period of time. Hence, the use of a single grid cell value for emission estimation might provide erroneous values, as the correction is only statistically valid when these emissions estimates are integrated over a large area or a long period.

The use of the FRP_PIXEL product is appropriated for the estimation of emission resulting from individual fires but, as outlined above, this product suffers from the

[5] The value saved for the "not available" data case is the Maximum signed Short value. The products are all scaled as signed short.

presence of clouds or small fires that cannot be detected by SEVIRI. In turns, the FRP_GRID product is appropriated for seasonal emission at a regional scale, but is not suitable for the estimation of emissions of single fires.

The FRP_PIXEL and FRP_GRID products could however be combined to benefit from their mutual advantages. Within each grid box of the FRP_GRID product, the FRP_PIXEL product can be used for single fire emission rate estimation with high temporal and spatial accuracy. On an hourly basis, the total fire radiative power involved in these emission rates is equal to FRP_GRID.FRPOBS.

The difference (FRP_GRID.FRP - FRP_GRID.FRPOBS) represents thus the total fire radiative power that has been added to the grid cell to correct for cloud and/or undetected small fires. It is not possible to determine where these potential fires occurred, but adding this contribution to the emission rates resulting from the individual fires present in the FIRE_PIXEL product should minimize the seasonal FRP bias at regional scale.

4.4 Summary of Product Characteristics

Product Name:	Fire Radiative Power
Product Code:	FRP (Fire Radiative Power)
Description of Product:	Estimation of the Fire Radiative Power of detected fires
Coverage:	MSG full disk (Land pixels)
Units	MW

Product Level FRP_PIXEL:	Level 2
Packaging:	Euro; NAfr; SAfr; SAme
Resolution:	Spatial: MSG full resolution (3km×3km at nadir)
Generation:	every 15 min
Accuracy:	50% at one sigma.
Product Size:	List Fire Product ~20 Kb[6]
	Quality Matrix ~ 4.3 Mb

Region	Uncompressed	Compressed
HDF5_LSASAF_MSG_FRP_ListProduct_<Area>_YYYYMMDDHHMM		
Euro	6 - 35 Kb	1 – 3 Kb
NAfr	6 - 40 Kb	1 – 10 Kb

[6] The actual size depends on the number of detected fires.

SAfr	6 - 40 Kb	1 – 29 Kb
SAme	6 - 40 Kb	1 – 4 Kb
HDF5_LSASAF_MSG_FRP_QualityProduct_<Area>_YYYYMMDDHHMM		
Euro	4.3 Mb	41 – 67 Kb
NAfr	9.8 Mb	102 – 156 Kb
SAfr	5.6 Mb	51 – 111 Kb
SAme	4.1 Mb	35 – 63 Kb

Table 11: Compressed and uncompressed size of the two FRP_PIXEL output files generated for each region.

Product Level FRP_GRID:	Level 3
Packaging:	MSG full disk (Land pixels)
Resolution:	Spatial: 1 degree (112km×112km at the Equator)
Generation:	every hour
Accuracy	TBC
Product Size:	Grid Product ~ uncompressed: 850 Kb

5 References

Andreae, M. O. and Merlet P. (2001) Emission of trace gases and aerosols from biomass burning, *Global Biogeochem. Cycles*, 15, 955–966.

Dickinson R.E., 1983: Land surface processes and climate – Surface albedos and energy balance, *Adv. Geophys.*, **25**, 305-353.

Ferranti, L. e P. Viterbo, 2006: The European Summer of 2003: Sensitivity of Soil Water Initial Conditions. *J. Climate*, **19**, 3659-3680.

Freeborn, P.H., Wooster, M.J., Hao, W.M., Ryan, C.A.,Nordgren, B.L. Baker, S.P. and Ichoku, C.(2008) Relationships between energy release, fuel mass loss, and trace gas and aerosol emissions during laboratory biomass fires*, J. Geophys. Res.,* Vol. 113, No. D1, D01102, 10.1029/2007JD008489

Govaerts, Y.M. Wooster M. Lattanzio A., Roberts G. MSG SEVIRI Fire Radiative Power (FRP) characterization Algorithm Theoretical Basis Document Version 2 , Report No EUM/MET/SPE/06/0398, 2006

Ichoku, C., and Kaufman Y. J. (2005) A method to derive smoke emission rates from MODIS fire radiative energy measurements, *IEEE Trans. Geosci. Remote Sens*., 43(11), 2636– 2649.

Mitchell, K., et al., 2004: The multi-institution North American Land Data Assimilation System NLDAS: Utilizing multiple GCIP products and partners in a continental distributed hydrological modeling system, *J. Geophys. Res*., 109, doi:10.1029/2003JD003823.

Roberts, G. and Wooster, M.J. (2007) New Perspectives on African Biomass Burning Dynamics, *EOS Tras. AGU*, 88, 369-270.

Roberts, G., Wooster, M.J., Perry, G.L.W., Drake, N., Rebelo, L-M., Dipotso, F. 2005. Retrieval of biomass combustion rates and totals from fire radiative power observations: application to southern Africa using geostationary SEVIRI Imagery. *J. Geophys. Res*., 110, doi: 10.1029/2005JD006018.

Roberts, G.J. and Wooster, M.J (2008) Fire Detection and Fire Characterization Over Africa Using Meteosat SEVIRI, *IEEE Trans on Geosci. and Remote Sens*., 46, doi: 10.1109/TGRS.2008.915751

Schmetz, J., P. Pili, S. Tjemkes, D. Just, J. Kerkman, S. Rota, and A. Ratier (2002), An introduction to Meteosat Second Generation (MSG), *Bull. Amer. Meteor. Soc*., *83*, 977-992.

Wooster, M. J., G. Roberts, G. L. W. Perry, and Y. J. Kaufman, 2005, Retrieval of biomass combustion rates and totals from fire radiative power observations: FRP derivation and calibration relationships between biomass consumption and fire radiative energy release, *J. Geophys. Res.*, 110, D24311, doi:10.1029/2005JD006318.

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Appendix A. FRP_PIXEL Version Tracker

This Section details the difference in the two FRP_PIXEL products, the list and the quality matrix according to the algorithm version

RELEASE	DATE	FRP List Change	FRP Quality Change
V0.92	20/6/2008	• FRP SDEV accounts for the atmosphere correction • Change from monochromatic to effective central wavelength in MSG radiance definition impacts FRP and FRP_SDEV value • New formula for the atmospheric correction impacts FRP and FRP_SDEV value • SAme region offset corrected impacts on the position of the fires in that region	• Water pixels screened out before cloudy pixels

Appendix B. Product Metadata – SEVIRI FRP

Table A 1 - General attributes of the files for the SEVIRI FRP product.

Attribute	Allowed Values	Data Type
SAF	LSA	String<3>
CENTRE	IM-PT	String<5>
ARCHIVE_FACILITY	IM-PT	String<5>
PRODUCT	FRP	String<79>
PARENT_PRODUCT_NAME	Cma, TCWV, Brightness Temperature	Array(4) of string<79>
SPECTRAL_CHANNEL_ID	768	Int
PRODUCT_ALGORITHM_VERSION	X.Y	String<4>
CLOUD_COVERAGE	NWC-CMa,	String<20>
OVERALL_QUALITY_FLAG	OK or NOK	String<3>
ASSOCIATED_QUALITY_INFORMATION	-	String<511>
REGION_NAME	One of: Euro, NAfr, SAfr, SAme	String<4>
COMPRESSION	0	Int
FIELD_TYPE	Product	String<255>
FORECAST_STEP	0	Int
NC	Depend on REGION_NAME (Table 4)	Int
NL	Depend on REGION_NAME (Table 4)	Int
NB_PARAMETERS	2	Int
NOMINAL PRODUCT_TIME	YYYYMMDDhhmmss	String<14>
SATELLITE	MSG*X*	Array[10] of String<9>
INSTRUMENT_ID	SEVI	Array [10] of String<6>
INSTRUMENT_MODE	STATIC_VIEW	String<511>
IMAGE_ACQUISITION_TIME	YYYYMMDDhhmmss	String<14>
ORBIT_TYPE	GEO	String<3>
PROJECTION_NAME	Geos<sub_lon>	String<15>
NOMINAL_LONG	Actual Satellite Nominal Longitude	Real
NOMINAL_LAT	Actual Satellite Nominal Latitude	Real
CFAC	13642337	Int

Attribute	Allowed Values	Data Type
LFAC	13642337	Int
COFF	Depend on REGION_NAME (Table 4)	Int
LOFF	Depend on REGION_NAME (Table 4)	Int
START_ORBIT_NUMBER	0	Int
END_ORBIT_NUMBER	0	Int
SUB_SATELLITE_POINT_START_LAT	0.0	Real
SUB_SATELLITE_POINT_START_LON	0.0	Real
SUB_SATELLITE_POINT_END_LAT	0.0	Real
SUB_SATELLITE_POINT_END_LON	0.0	Real
SENSING_START_TIME	YYYYMMDDhhmmss	String<14>
SENSING_END_TIME	YYYYMMDDhhmmss	String<14>
PIXEL_SIZE	3.1km	String<10>
GRANULE_TYPE	DP	String<2>
PROCESSING_LEVEL	02	String<2>
PRODUCT_TYPE	LSAFRP	String<8>
PRODUCT_ACTUAL_SIZE	Depends on the region	Integer > 0, encoded as String<11>
PROCESSING_MODE	N	String<1>
DISPOSITION_FLAG	O	String<1>
TIME_RANGE	15-min	String<20>
STATISTIC_TYPE	-	String<20>
MEAN_SSLAT	Depend on REGION_NAME (Table 4)	Real
MEAN_SSLON	Depend on REGION_NAME (Table 4)	Real
PLANNED_CHAN_PROCESSING	0	Integer
FIRST_LAT	0	Real
FIRST_LON	0	Real

Table A 2 - Attributes of the FRP/SEVIRI dataset.

Attribute	Description	Data Type
CLASS	Data	String, length=4
PRODUCT	FRP	String, length=3
PRODUCT_ID	235	32-bit integer
N_ COLS	Depend on REGION_NAME (Table 4)	32-bit integer
N_ LINES	Depend on REGION_NAME (Table 4)	32-bit integer
NB_BYTES	2	32-bit integer
SCALING_FACTOR	100.0	64-bit floating-point
OFFSET	0.0	64-bit floating-point
MISS_VALUE	-8000	32-bit integer
UNITS	Degrees Celsius	String, length=15
CAL_SLOPE	999.0	64-bit floating-point
CAL_OFFSET	999.0	64-bit floating-point

Table A 3 - Attributes of the FRP/SEVIRI Quality Flag information dataset.

Attribute	Description	Data Type
CLASS	Data	String, length=4
PRODUCT	Q_FLAGS	String, length=7
PRODUCT_ID	999	32-bit integer
N_ COLS	Depend on REGION_NAME (Table 4)	32-bit integer
N_ LINES	Depend on REGION_NAME (Table 4)	32-bit integer
NB_BYTES	2	32-bit integer
SCALING_FACTOR	1.0	64-bit floating-point
OFFSET	0.0	64-bit floating-point
MISS_VALUE	-9999	32-bit integer
UNITS	Dimensionless	String, length=13
CAL_SLOPE	999.0	64-bit floating-point
CAL_OFFSET	999.0	64-bit floating-point