Fire Radiative Power Products: GOES-R and Himawari Satellites

Product User Manual

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Executive Summary

This document describes the Fire Radiative Power (FRP) Product generated on an operational basis from the two Geostationary Operational Environmental Satellites (GOES) operated by NOAA (USA) and the Himawari satellite operated by JMA (Japan). FRP describes the overall rate of radiative energy emission from landscape fires, which in turn is related to the combustion rate of vegetation and the rate of emission of smoke to the atmosphere. The GOES satellites cover the Americas and the Himawari satellite covers much of Asia, and both offer much higher temporal sampling than polar orbiting systems, albeit at a lower spatial resolution. GOES-R and Himawari are also a significant advance on the prior GOES-Imager and MTSAT systems operated previously by NOAA and JMA in the past as the operational geostationary satellites. These new generation satellites offer more spectral channels as well as higher spatio-temporal resolutions, and thus the potential to obtain a far more temporally consistent view of FRP evolution over the diurnal cycle, and improved chances of detecting fires between instances of cloud cover, compared to both polar orbiters and the prior geostationary systems. The GOES and Himawari FRP products are derived using a version of the Geostationary Fire Thermal Anomaly (FTA) algorithm developed by King's College London for use with data from the Meteosat satellite, and which is used to generate the Meteosat FRP-Pixel Products at the EUMETSAT Land Surface Analysis Satellite Application Facility (LSA SAF) headquartered at IPMA (Lisbon). As such, the GOES and Himawari FRP-Pixel Products contain information on the detected fire pixels, their FRP and an uncertainty estimate. They also contain information on the underlying characteristics of the data from which these values were obtained, such as the classification of every pixel in the imaging disk into cloud, land, water, fire etc - so as to enable the identification of "no-fire" information as potentially being due to cloud cover rather than the confirmed absence of fire. The GOES and Himawari FRP-Pixel products are available in near real time and have a temporal resolution of 15 and 10 minutes respectively, providing almost continuous observations of fires when they are cloud free.

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Introduction

This document describes the Fire Radiative Power (FRP) Product generated in Europe on an operational basis from the latest generation Geostationary Operational Environmental Satellites (GOES) operated by NOAA and the Himawari satellite operated by JMA (Japan). The GOES and Hiamawari FRP-Pixel product is generated at the full spatio-temporal resolution of the GOES observations using the algorithms and techniques originally developed by King's College London to generate the Meteosat FRP-Pixel Product (Wooster et al., 2015), then initially adapted to data from the GOES imager (Xu et al., 2010) and then to the latest Generation GOES-R series and Himawari (Xu et al., 2017). Thus the GOES, Himawari and Meteosat FRP-Pixel products are largely compatible in type, information content and file structure - albeit covering different areas of the planet. Since the AHI imager onboard Himawari is indeed very similar to the ABI imager onboard GOES-R, in term of both spatial and temporal resolution, we cover the GOES and Himawari FRP products in one user manual.

FRP describes the overall rate of radiative energy emission from landscape fires, which in turn is related to the vegetation combustion rate (Wooster et al., 2005). Thus the characterization of the radiative power of active fires allows for the near real time quantification of open biomass burning from satellites (Roberts and Wooster, 2008, Kaiser et al. 2012). Though geostationary coverage is limited at high latitudes, and they generally offer lower spatial resolutions and larger minimum FRP detection thresholds compared with polar-orbiting satellites, geostationary platforms provide observations with much higher temporal sampling and thus allow the estimation of fire emissions to the atmosphere more frequently and more consistently spaced in time over the full diurnal cycle, and also offer many more opportunities to catch fires burning between instances of cloud cover.

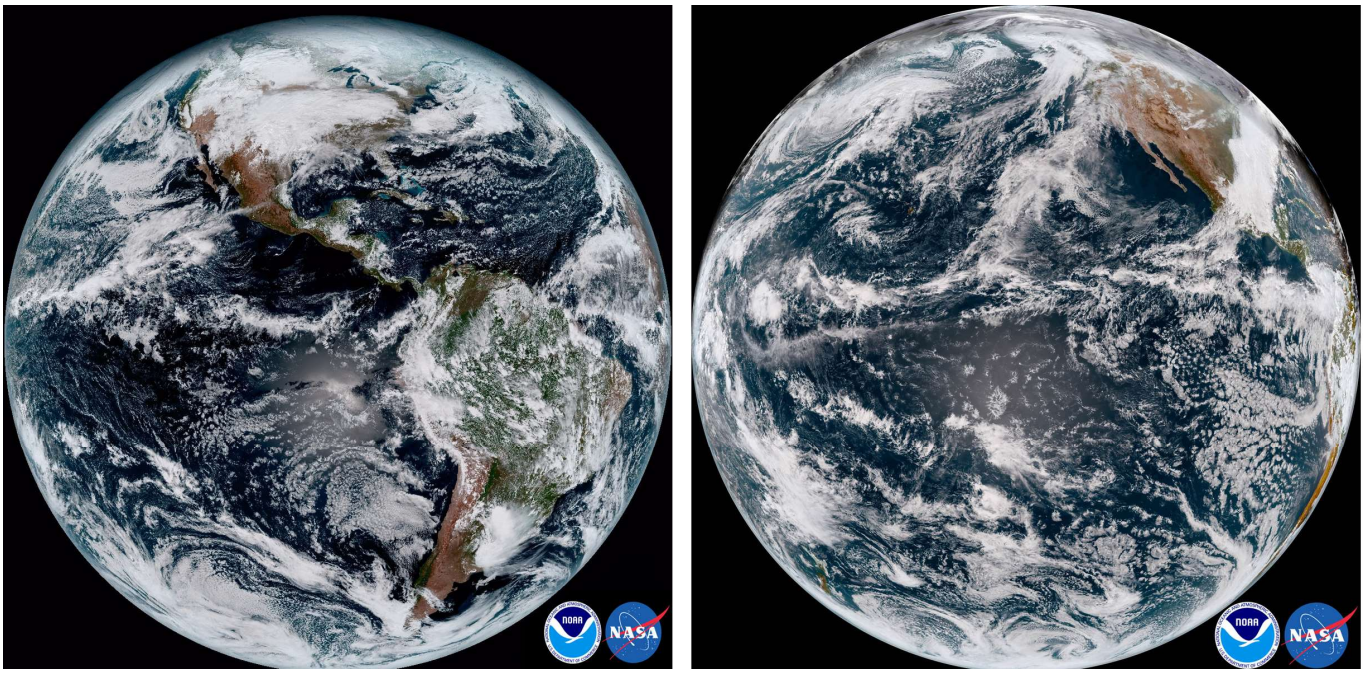

Figure 1 Full disk area coverage of GOES-East and GOES-West, respectively.

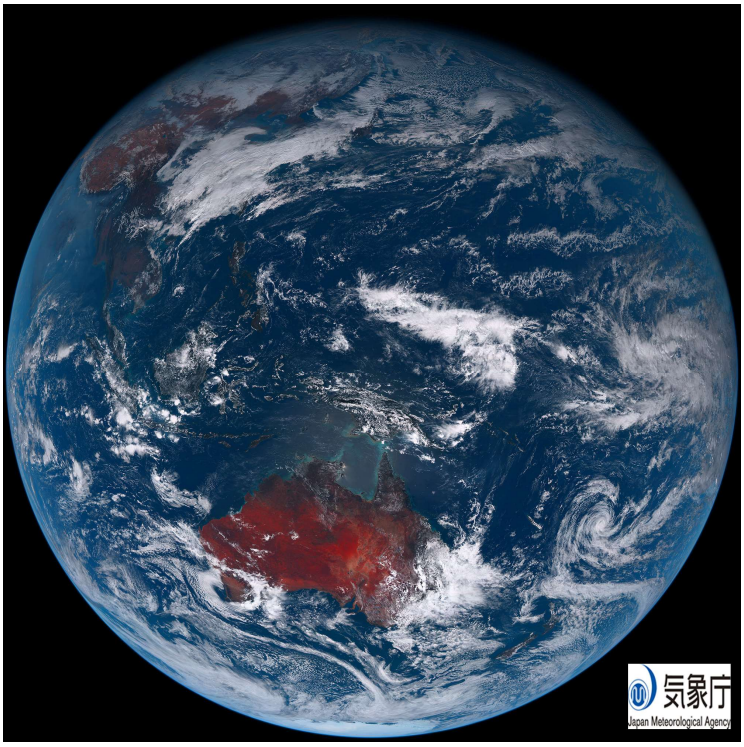

Figure 2. Full disk area coverage of Himawari-8.

GOES Fire Radiative Power Product and Algorithm Description

For the GOES FRP-Pixel product running on data from the GOES-R satellites, active fires within the GOES Advanced Baseline Imager (ABI) footprint are detected using data from both the GOES-East and GOES-West satellites using an updated version the spatio-contextual algorithm described in Xu et al. (2010), itself a version of the Geostationary Fire Thermal Anomaly (FTA) active fire detection algorithm of Wooster et al. (2015) used with Meteosat, and then the FRP of the detected fire pixels is estimated using the MIR radiance approach of Wooster et al. (2005). The Himawari FRP-Pixel product algorithm is very similar, and detailed in Xu et al. (2017). The coverage of the full disk GOES imagery is shown in Figure 1 and available every 15-mins; with the Himawari data every 10 mins.

Since FRP is based on the identification of active fires and estimation of their respective radiative energy release rat on a per-pixel basis from (primarily) the instruments thermal infrared bands, the products spatial resolution corresponds to that of the (coarser) GOES and Himawari middle- and longwave infrared channels, with a pixel area of around 2.0 km x 2.0 km at sub-satellite point. A basic fire detection algorithm flow is provided in Table 1. See Xu et al. (2010 & 2017) for a full description of the FTA algorithm used to generate these products, and details of their performance (including comparison to simultaneous MODIS FRP observations etc).

Table 1. GOES FRP-PIXEL processing steps, see Xu et al. (2010 and 2017) for more details.

1	*Clear sky pixel identification:*	Identification of the clear sky pixels. A cloud mask together with some conditions on the radiance and ratio of the input channels are used for this purpose.
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. A square window region ranging in size from 5x5 to 15x15 pixels surrounding the potential fire is analysed according to a set of conditions on both brightness temperature and radiance.
4	*FRP assessment at pixel level:*	Estimation of the FRP for the fire pixels. It is proportional to the middle infrared radiance difference between the potential fire pixel and the mean radiance of the background window in the 3.9 μm channel.
5	*Apply Atmospheric correction*	Calculate and apply a correction to account for fire signal attenuation due to the atmosphere.
6	*FRP uncertainty assessment*	The random error on the FRP retrieval is estimated using the standard error propagation formula.
7	*Detection confidence estimation:*	A value between 0 and 1 is assigned to each detected fire pixel. Higher values correspond to higher detection confidences (which are typically higher FRP fire pixels). The GOES FRP-PIXEL product confidently detects active fire pixels whose FRP exceeds ~ 40 MW.

GOES and Himawari FRP-PIXEL Product

The GOES and Himawari FRP-PIXEL product contains information on the final set of pixels identified as containing actively burning fires (so-called 'fire pixels'), including their FRP (in MW) and an estimate of their FRP uncertainty. It also reports the classification of each pixel in the processed region (fire pixel, non-fire pixel, cloudy pixel etc),

The GOES FRP-PIXEL product is generated for the full disk every 15 minutes, whilst the Himawari FRP-PIXEL product is generated every 10 minutes.

Product Inputs

The dynamic input files used to generate the FRP-PIXEL products are:

GOES or Himawari Radiance 0.6 μm	mandatory	- Residual cloud screening
GOES or Himawari Radiance 3.9 μm	mandatory	- Residual cloud screening - Potential fire pixel assessment - Background window assessment - FRP estimation
GOES or Himawari Radiance 10.8 μm	mandatory	- Residual cloud screening - Potential fire pixel assessment - Background assessment
Total Column Water Vapour (TCVW) from ECMWF	not mandatory	- Atmospheric transmission correction

In cases where the TCVW data are not available at the time of processing, a default value is used: FRP_TCWV_DEFAULT = 20 kg m^{-2}

Product Outputs

The output of this processing currently includes two different files for the Himawari, GOES-East and GOES-West observations:

- CAMS__<Sat_ID>_FRP-PIXEL-ListProduct_<AREA>_<yyyymmddhhmm>.h5
- CAMS__<Sat_ID>_FRP-PIXEL-QualityProduct_<AREA>_<yyyymmddhhmm>.h5

Where:

- Sat_ID is "HMWR", "GOES-16" or "GOES-17"
- AREA is "HMWR-FD", "GOESW-FD" or "GOESE-FD" standing for GOES-E/W Full Disk
- <yyyymmddhhmm> is the date and observation time of the product

Example:

The GOES West full disk data at 11:30 on 20 Feb. 2020 will be named as *CAMS__GOES17_FRP-PIXEL-ListProduct_GOESW-FD_202002201130.h5* for list product and *CAMS__GOES17_FRP-PIXEL-QualityProduct_GOESW-FD_202002201130.h5* for Quality product.

These files are in HDF5 format and related to the active fire detections and FRP values:

- FRP-PIXEL List Product File: This has the format of a list, with information provided only at the locations of confirmed active fire pixels having an FRP value. There is therefore one entry in the list for every fire pixel having an estimated FRP. For each fire pixel in the list, the FRP and an exhaustive list of other relevant information, such as the fire pixel background window mean temperature, is provided.

- FRP-PIXEL Quality Product File: This has the format of a matrix whose dimensions are equal to the size of the region for which the product is generated (full disk or single geographic region). For each pixel in the region, the Quality Product File provides the pixel status in relation to the fire product, i.e. whether it contains a detected fire, a cloud, confirmed as not containing a fire, was not processed etc etc.

The full information content of both the List and Quality Product files is described in Tables 2 and 3. The FRP List Product has a small file size and it is intended for users who only need to know where and when a fire pixel has been detected, and what the FRP value and uncertainty the pixel is estimated to have. Other users may need to know more detail and for each pixel in the disk whether or not it is classed as an active fire, such as the reason why no fire has been detected in a specific pixel (e.g., cloud cover, sunglint etc). For these users the larger FRP Quality Product files are available to use.

GOES and HIMAWARI FRP-PIXEL List Product File

The GOES and Himawari FRP-PIXEL List Product Files contain a list of variables available for each detected active fire pixel, as described in Table 4. These data are the same as those stored in the Meteosat SEVIRI FRP-Pixel product file available from the EUMETSAT LAS SAF (https://landsaf.ipma.pt/en/), and the reader is referred to Wooster *et al.*, (2015) [including the Supplement found therein] for a detailed description of the estimation of these fields and their full meaning. Figure 3 shows an example of the FRP-PIXEL list product as viewed with HDFview.

VARIABLE	MEANING	UNITS	SCALE FACTOR	RANGE
FRP	Pixel FRP (with atmospheric correction applied [1]). This variable contains the Fire Radiative Power estimate for the detected fire pixel.	MW	10	> 0
FRP_UNCERTAINTY	FRP random error estimate. This contains error estimate associated with retrieved FRP, derived from combination of uncertainties in FRP coefficient, fire pixel radiance, fire pixel background estimate, and atmospheric transmission. See Wooster *et al.* (2015).	MW	100	> 0
ERR_FRP_COEFF	Relative uncertainty (in the range 0 to 1) of the FRP coefficient used in the Planck Function approximation	p.n.	10000	0.1
ERR_BACKGROUND	Relative uncertainty (range 0 to 1) derived	p.n.	10000	>0

[1] Appling the atmospheric correction means the per-pixel FRP based on the top-of-atmosphere radiances has been multiplied by the inverse of the field PIXEL_ATM_TRANS, whose value is also saved in the product so that it can be removed if desired.

	from variation in fire pixel background window			
gERR_ATM_TRANS	Relative uncertainty (range 0 to 1) in atmospheric transmission	p.n.	10000	>0
ERR_VERT COMP	Relative uncertainty (in the range 0 to 1) of the water vapour column total used in the atmosphere transmission	p.n.	10000	>0
ERR_RADIOMETRIC	Relative uncertainty (in the range 0 to 1) derived from the uncertainty in the fire pixel spectral radiance measure	p.n.	10000	>0
ABS_PIXEL	Pixel column number value in the SEVIRI projection	p.n.	1	[1-5500][2]
ABS_LINE	Pixel line number in the SEVIRI projection	p.n.	1	[1-5500]
BW_NUMPIX	Number of valid pixels in the background window used for the estimation of the background temperature.	p.n.	1	[15,215]
BW_SIZE	Background window size in pixels.	p.n.	1	[5,15] [3]
LATITUDE	Fire pixel centre latitude	Deg	100	[-90,90]
LONGITUDE	Fire pixel centre longitude	Deg	100	[-180,180]
FIRE_CONFIDENCE	Fire pixel confidence estimate (in the range 0 to 1)	p.n.	100	[0,1]
BT_MIR	MIR band fire pixel BT (3.9 micron)	K	10	> 0
BT_TIR	LWIR band fire pixel BT (10.8 micron)	K	10	> 0

[2] The maximum ABS_pixel could vary depend on the satellites. For GOES is 5424; for Himawari-8 it is 5500.
[3] Only odd values (5,7,9,…) are permitted

BW_BT_MIR	Mean BT of the background window pixels in the MIR band.	K	10	> 0
BW_BTD	Mean BTD of the background window pixels (where BTD is the BT difference between MIR and LWIR channels)	K	10	> 0
PIXEL_SIZE	Pixel Area. The pixel area depends on the distance of the pixel from sub-satellite point.	km^2	100	> 9
PIXEL_VZA	View zenith angle. Estimated using real mean satellite position during acquisition of the current image.	Deg	100	[0,90]
PIXEL_ATM_TRANS	Atmospheric transmissivity in the 3.9 micron band. Used to take into account the decrease of the radiometric signal from the surface due to the atmosphere absorption.	p.n.	10000	[0,1]
ACQTIME	Pixel Acquisition Time. The ACQTIME format is HHMM. For example the time 12:14 is coded as an integer like 12x100+14 = 1214.	UTC Time	1	[0,2359]
RAD_PIX	Spectral radiance of the fire pixel in the MIR (3.9 micron) band.	$MW/(m^2.sr.cm^{-1})$	10000	>0
STD_BCK	Mean absolute deviation of MIR radiance of the background windows pixel	$MW/(m^2.sr.cm^{-1})$	10000	>0

Table 2. Information stored in the FRP-PIXEL List Product file (one value for each detected fire pixel).

The real measured or estimated value of the variable is obtained from the values stored in the FRP-PIXEL List Product file by applying the following scaling formula:

$$Real\_value = Stored\_value / Scale\_factor$$

Where the Stored_value is the value saved as a two byte integer in the List Product file.

ABS_PIXEL and ABS_LINE are the pixel and line number in the native GOES ABI or Himawari AHI images. Since the satellite imaging nadir point is not fixed in the unresampled data like it is for the level 1b resampled Meteosat SEVIRI imagery used to generate the Meteosat FRP-PIXEL product at the LSA SAF, the maximum number of ABS_PIXEL in the GOES and Himawari FRP-Pixel products can vary.

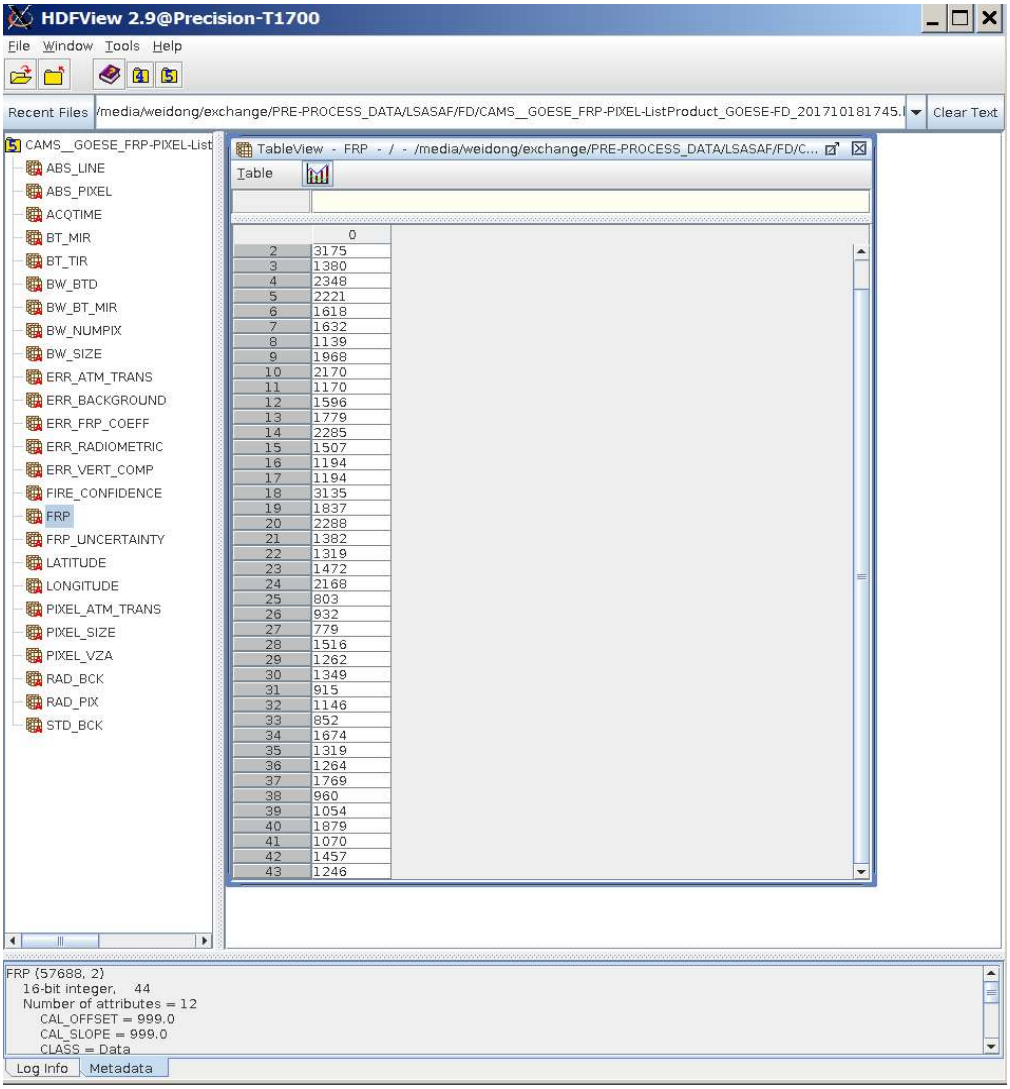

Figure 3. Example of an FRP-PIXEL List Product file structure, as viewed with HDFView. Each row in this depiction shows the FRP value of a different confirmed active fire pixel with a scale of 10.

GOES and HIMAWARI FRP-PIXEL Quality Product File

The Quality Product file is a 2D array with the dimensions of each geographic area under analysis, for example, GOES Full disk is 5435 × 5435 pixels (5500 ×500 for Himawari). The Quality product contains the final output processing status of each GOES pixel. In this file, the pixel size is the same as for the native GOES area images (i.e. a pixel spacing of 2.0*2.0 km at the sub satellite point).

The QUALITYFLAG stored in the FRP-PIXEL Quality Product file records the processing status of all pixels in the geographic area under study, including active fire pixels and those where no active fire has been detected. The Quality Product information can be very useful for certain types of processing. For example, when FRP data is used in the CAMS Global Fire Assimilation System a measure of cloud cover is required in order to provide an estimate of the potential FRP obscured by cloud. The coding for the QUALITYFLAG is given in Table 3.

NAME	VALUE	STATUS	REASON
FRP_APL_NOTPOT	0	FRP NOT Estimated	Not a potential fire pixel.
FRP_APL_FRP	1	FRP Estimated	Successful fire detection and FRP estimation.
FRP_APL_FRP_SAT	2	FRP Estimated	FRP estimated but with a saturated 3.9 micron channel signal.
FRP_APL_CLOUD	3	FRP NOT Estimated	The pixel is classed as cloud contaminated - fire detection was not attempted.
FRP_APL_SUNG	4	FRP NOT Estimated	The pixel is classed as being affected by sun glint due to the sun-land-sensor angular condition - fire detection was not attempted.
FRP_APL_SUNGRATIO	5	FRP NOT Estimated	The SUNGRATIO test failed.
FRP_APL_NOBCK	6	FRP NOT Estimated	It was not possible to define the background temperature of the candidate potential fire pixel.
FRP_APL_BCKNOT	7	FRP NOT	The signal of the potential fire pixel was

		Estimated	not sufficiently above that of the background window – so the pixel was not confirmed as a true fire.
FRP_APL_CLOUDEDGE	8	FRP NOT Estimated	No fire detection took place because the pixel is too close to a cloud or water edge (this class was used in previous versions of the FRP-PIXEL products, but is not used in version 2.0 onwards (i.e. since end 2015)
FRP_APL_BADINPUT	9	FRP NOT Estimated	Some input files are incomplete or corrupted .
FRP_APL_WATER	10	FRP NOT Estimated	Water body and so not processed for fire detection, introduced in version 2.0.
FRP_APL_WATEREDGE	11	FRP NOT Estimated	No fire detection took place because the pixel is close to a water body.
FRP_APL_NOTPROC	254	FRP NOT Estimated	The pixels have not been processed (i.e. they are urban, snow and ice or other non-processed pixels).
FRP_OUTSIDE_ROIS	255	FRP NOT Estimated	Celestial background (outside the full disk area, introduced in version 2.0)

Table 3. Coding flags used within the FRP-PIXEL Quality Product files.

Figure 4 shows an example FRP-PIXEL Quality Product file, derived from a full-disk GOES image collected at 18:00 UTC on 30 Sep. 2019. At left is the full disk data, whereas at right is a zoom over South America. Figure 5 shows and example of the FRP signatures recorded during the 2020 Australian fires in the Himawari FRP-PIXEL product.

Figure 4. Example of the coding flags (Table 3) contained within the Quality Product from a GOES East image collected at 18:00 UTC on 30 Sep. 2019.

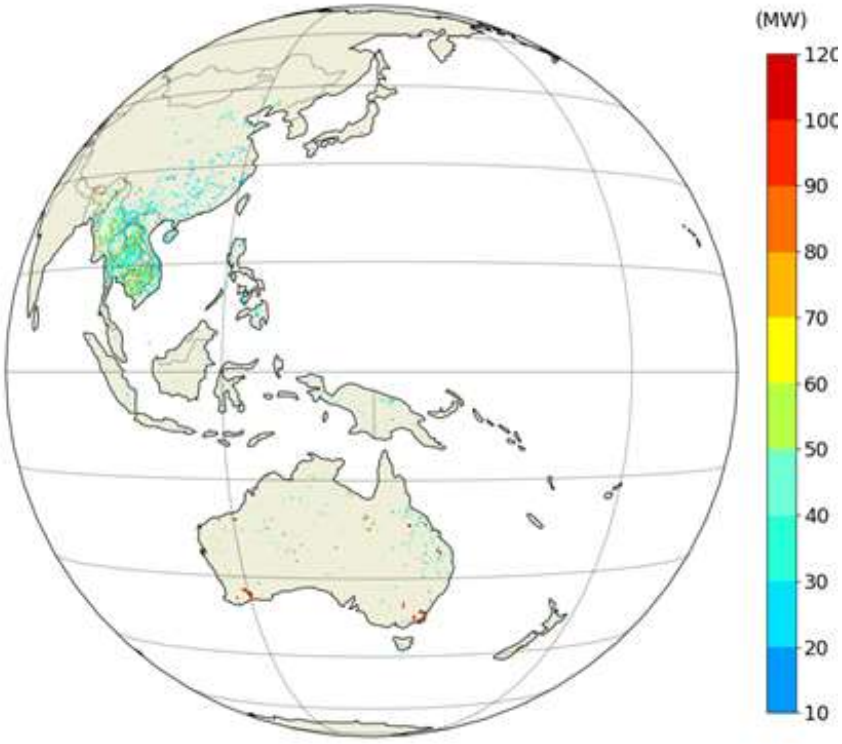

Figure 5. Example of the FRP signatures recorded in the Himawari FRP product during the 2020 Australian fires.

If a pixel is not classed as a "land pixel", then it is flagged as FRP_APL_NOTPROC in the Quality Product (Table 3). If it classed as a 'cloud pixel' then it is flagged as FRP_APL_CLOUD. For some users and application, the use of this type of quality indicator information is particularly important for the correct interpretation of the FRP list given in Table 5. The following different cases can be envisaged:

- When the quality flag takes one of the following values (FRP_APL_FRP, FRP_APL_FRP_SAT) the pixel can be considered as containing an active fire, and an FRP value is estimated. From these data it is possible to estimate the combustion rate and thus the corresponding pyrogenic emission of carbon, CO_2, CO, CH4, aerosol etc.

- When the quality flag takes the FRP_APL_NOBCK value the pixel was classed as a potential fire pixel, but it was not possible to confirm whether or not it was a true fire pixel due to an inability to estimate the average signal of the surrounding background window.

- When the quality flag takes the FRP_APL_BCKNOT value the pixel was classed as a potential fire pixel, but then was not confirmed as a true fire pixel as the pixels signal was raised insufficiently above that of the background window average.

- When the quality flag takes the FRP_APL_NOTPOT value, it means that there was no fire present in the pixel, or any fire that was present had a signal that was too weak to be detected, so the pixel was not picked out as a potential fire pixel (and was thus not confirmed as a true fire pixel either). It is possible that small and/or lower intensity fires might have been present in the pixel, but they remained undetected.

- When the quality flag takes one of the following values (FRP_APL_CLOUD, FRP_APL_SUNG, FRP_APL_SUNGRATIO, FRP_APL_WATEREDGE, FRP_APL_BADINPUT), it was not possible to apply the fire detection scheme of the FTA algorithm due to, for instance, a sun glint condition or to the presence of meteorological cloud cover.

Product Distribution

The GOES and Himawari FRP-Pixel data are available in Near Real Time via ftp from the following site:

geoland2.meteo.pt

Login: frp_public

Password: frp

ftp://frp_public:frp@geoland2.meteo.pt

The data files are separated by satellite data streams in the following directories:

GOESE
GOESW
HMWR

The above address maintains all data produced within the previous 15 days. All the generated files (from 2014 onwards) are archived, and can be ordered off-line by email to:

isabel.trigo@ipma.pt or operations.copernicus@ipma.pt

Users of the GOES FRP-Pixel Product are asked to reference the following work when describing the GOES and Himawari FRP-Pixel Products:

Xu, W., Wooster, M. J., Roberts, G., and Freeborn, P. (2010). New GOES imager algorithms for cloud and active fire detection and fire radiative power assessment across North, South and Central America. *Remote Sensing of Environment*, 114, 1876-1895.

Xu, W., Wooster, M.J., Kaneko, T., He, J., Zhang, T. and Fisher, D., 2017. Major advances in geostationary fire radiative power (FRP) retrieval over Asia and Australia stemming from use of Himarawi-8 AHI. *Remote Sensing of Environment*, 193, pp.138-149.

The GOES FRP-Pixel Products are archived locally at IPMA and available at the ftp site indicated above. They are compressed (.bz2) HDF5 format files, and to uncompress please use:

bunzip2 <filename>

or bzip2 –d <filename>

Further documentation/software on compression at: http://www.bzip.org/

A sample of python code to read the GOES-FRP Product List and Quality Product files has been prepared by King's College London and can be downloaded from:

https://landsaf.ipma.pt/staticData/SAF_FRP_read.py

The products are listed and can be accessed through the CAMS catalogue at https://atmosphere.copernicus.eu/catalogue#/; select Product Family "Fire Emissions".

Product Timeliness

The GOES and Himawari FRP-Pixel products are available in Near Real Time (NRT). Under nominal production, the timeliness – time lag between the most recent satellite image needed to generate the product and availability to users – is below 3 hours.

In case of failure in the processing chain, data may still be back-processed up to 3 working days prior to the current NRT date.

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Xu, W., Wooster, M. J., Roberts, G., and Freeborn, P. (2010). New GOES imager algorithms for cloud and active fire detection and fire radiative power assessment across North, South and Central America. *Remote Sensing of Environment*, 114, 1876-1895.

Xu, W., Wooster, Kaneko T., He J., Zhang T., Fisher D. (2017). Major advances in geostationary fire radiative power (FRP) retrieval over Asia and Australia stemming from use of Himarawi-8 AHI. *Remote Sensing of Environment,* 193, 138-149