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FIRE RADIATIVE POWER PRODUCT IN THE LAND SAF

The Fire Radiative Power is related to the rate at which the fuel biomass is being consumed. This is a direct result of the combustion process, whereby carbon-based fuel is oxidised with the release of a certain ‘heat yield’. Measuring this FRP and integrating it over the lifetime of the fire therefore provides a measure of the total Fire Radiative Energy, which should be proportional to the total fuel mass combusted. This paper reports on the prototyping of such product at EUMETSAT and its implementation on the Land SAF operational system.

Fire Radiative Power Product in the Land SAF

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1 BACKGROUND AND SCOPE

"Forest fire" has been agreed as a MSG day-2/priority3 product during ST6 37. Since "forest fire" encompasses many different types of products and associated applications, a better definition of a SEVIRI-based fire product was necessary. In September 2001, Pereira and Govaerts (2001) identified potential fire applications for MSG, essentially as follows:

- Over Europe: a near real-time fire risk assessment product
- Over Africa: active fire detection and burned area mapping, with emphasis on a better documentation of fire impact on climatic, atmospheric and ecological processes.

The authors insisted on the importance of the relevance of the products, such as for example the creation of user-friendly products adapted to the needs of the science and fire management community. The concept of real-time forest fire products has been further analysed by Dr. S. Flasse as a visiting scientist in 21-23 May 2003 (Flasse, 2003).

In April 2004, S. Flasse moved a step forward towards the definition of a "forest fire" product, analysing, in the light of SEVIRI actual characteristics, relevant applications from possible SEVIRI fire products (Flasse, 2004). Fire Radiative Power (FRP) was proposed as the most appropriate product that can be derived from SEVIRI observations, with relevant applications related to the science community interested in modelling of the carbon cycle. The development of such product has been endorsed in September 2005 by SWG-19 (paper EUM/STG/SWG/19/05/DOC/02) following a presentation given by Prof. M. Wooster who demonstrated, in the context of a MSG RAO project (Roberts *et al.*, 2005), the possibility to derive this product from SEVIRI observations with an accuracy similar to that of MODIS for fires capable of being detected by SEVIRI.

An operational version of this algorithm, referred to as the Fire Thermal Anomaly (FTA), was prototyped at EUMETSAT in 2006 (Govaerts *et al.*, 2006) and its accuracy verified against the original KCL (Lattanzio 2006) against both Meteosat-8 and -9. During this exercise, a discrepancy between SEVIRI band 3.9 onboard Meteosat-8 and -9 occurring at high temperature has been identified (Lattanzio and Govaerts, 2006). The FTA algorithm is currently being used for the generation of a long-term validation data set.

Late 2006, an external study (EUM/MET/SOW/05/0384), referred to as the FREEVAl study, has been initiated at EUMETSAT aiming at (i) evaluate the FRP product currently prototyped at EUMETSAT and (ii) define user's requirements for Fire Radiative Power derived from Meteosat-8/9 data at EUMETSAT that would support operational applications.

During its 5th meeting held in Brussels on 22 February 2007, the Land SAF IOP steering group welcomes this initiative and recommends the next SG (CDOP) to endorse this activity. This document provides to the STG/SWG technical and scientific information on this activity.

2 FIRE RADIATIVE POWER CONCEPT

It has been demonstrated in small-scale experiments that the amount of radiant energy liberated per unit time during a vegetation fire (the so-called Fire Radiative Power) is related to the rate at which the fuel biomass is being consumed (e.g. Wooster *et al.,* 2005). This is a direct result of the combustion process, whereby carbon-based fuel is oxidised (burnt) with the release of a certain 'heat yield'. Measuring this FRP and integrating it over the lifetime of the fire therefore provides a measure of the total Fire Radiative Energy (FRE), which should be proportional to the total fuel mass combusted (M). Current methods to obtain M are based largely on burned area mapping approaches, with necessary assumptions on fuel density and combustion completeness (which may vary with land-cover/climate/timing-of-fire). The FRP approach in theory circumvents the requirement to make these assumptions, providing a variable that is more directly related to the amount of combusted biomass. Geostationary observations allow high temporal frequency FRP measurements, and thus the ability to estimate FRE via temporal integration. The main limitation of geostationary observations is likely to be the fact that the larger pixel sizes (compared to polar orbiting systems) will result in a larger fraction of the smaller and/or less intensely burning fires going undetected.

3 THE FTA ALGORITHM

The FRP product is derived using a so-called Fire Thermal Anomaly (FTA) algorithm, the first stage of which is the detection of all 'fire pixels' within the image that are believed to contain actively burning fires. The detection process is based mainly on testing for elevated MIR spectral channel radiances, along with a number of other tests to discriminate fires from other phenomena that may induce similarly elevated MIR channel signals. Specular reflections and cloud edges can present a similar signature to fires under certain daytime conditions, so a cloud mask is used to identify and remove cloud-contaminated pixels from the analysis.

The fire detection algorithm implemented for use with SEVIRI is an evolution of that described in Roberts *et al*. (2005), and is based on the principles used to generate active fire detections within the MODIS fire products. The algorithm works mainly on statistics derived from the 3.9 µm and 11.0 µm brightness temperatures, and their differences. On a first pass a series of absolute thresholds are used with these data to detect "potential" fire pixels, which are then further assessed as 'true' or 'false' fire detections based on a series of further "contextual" tests whose thresholds are adjusted based on statistics derived from the immediately neighbouring non-fire "background" pixels. Background pixel statistics are obtained from a window surrounding each potential fire pixel, commencing as a 5×5 matrix and being expanded until sufficient window pixels are not themselves classed as potential fire pixels (or clouds). Each potential fire pixel must pass all tests to be confirmed as a "true" fire pixel, and a confidence measure is also assigned to the detection.

The second stage of the FTA algorithm is the derivation of FRP at all fire pixels. This is carried out using the MIR radiance method which assumes FRP is proportional to the difference between the observed fire pixel radiance in the SEVIRI middle infrared (MIR, 3.9 µm) channel and the 'background' radiance that would have been observed at the same location in the absence of fire. This background radiance is at present derived from the set of fire- and cloud- free pixels surrounding each fire pixel.

The development of the FTA algorithm has been based on specific design aiming at separating the scientific processing of the data, i.e., the extraction of physical quantity as described in the ATBD (Govaerts et al., 2006) from the data access and result storage. Such concept has been developed to allow FTA to be operated in different "processing environments", e.g., development (prototyping) or operational systems. To this end, the FTA algorithm has been organised into three major layers, each of which being responsible for a specific task:

- Product Control Layer (PCL) This layer handles the orders or triggering events received from the processing environment in which FTA is operated and provides back to this environment information on its state. When a data processing order is received, it is passed to the Product Data Layer.
- Product Data Layer (PDL) This layer is responsible for collecting all the data needed by the retrieval algorithm. It is called by the PCL when a task is received. It requests to the processing environment the required data and provides back the results. This layer verifies that all the requested data are available and perform some sanity check on their quality. When all the data have been collected and controlled, it calls the Algorithm Private Layer to actually perform the requested task. It reports any problem to the processing environment through the PCL.
- Algorithm Private Layer (APL) This layer is responsible for the mathematical handling of the observations. It is composed of the assemblage of mathematical modules as described in the ATBD used to solve the physical problem associated with the requested task. The APL is totally independent from the types of processing environment. It should thus not contain any direct communication with this environment.

Such layered approach is expected to be **less efficient** in terms of CPU time but **more effective** in terms of development, implementation, improvement, and maintenance costs than an implementation where such mechanism would not be used.

4 THE LAND SAF SYSTEM

The Land-SAF operational system is fully centralised at IM and has been specifically developed on site by EDISOFT/SKYSOFT for this purpose. This system comprises two operational chains – one dedicated to the processing of SEVIRI/Meteosat level 1.5 data acquired through a receiving station, and another for the processing of products based on AVHRR/EPS level 1b data received via EUMETCast. The Land-SAF system also includes a parallel chain for algorithm testing and validation. The formats of input, internal, and output data are described in the Product Output Format Document. All Land-SAF products generated by the operational system are archived at IM. (Pre-)Operational products disseminated in HDF5 format via ftp (off-line dissemination) or via EUMETCast (in NRT). The latter will also be included in the UMARF catalogue.

The Land-SAF system runs on distributed LINUX servers, was designed to be as much as possible platform independent. The Land-SAF system was also developed to easily accommodate modifications to any of its modules, or to easily include new software modules corresponding to new products, during the system lifetime. The system design makes use of standard languages available in all computer and operating system (C++, JAVA, XML), and uses CORBA standard for communication among components. The operational chains are provided with hardware redundancy capability.

This system allows basic monitoring of product providing gross checking of algorithm values. It is the responsibility of IM to maintain this system, whereas scientific algorithms are maintained and improved by their respective developers. In particular, product developers supplies software and algorithm versions for integration in the Land-SAF operational system, following the guidelines of the Software Development Guidelines Document [AD 1] and in the Algorithm Plugging Interface Document [AD 2]. This interface is composed of a dedicated wrapper which communicates with the scientific algorithms through a limited number of basic instructions to start, stop an algorithm or collect information about its status. This communication between the wrapper and FTA is performed by the FTA Product Control Layer on the FTA side.

HDF5 is the main format used by the Land-SAF system. All input data, i.e, satellite observations, ECMWF forecasts, are converted into HDF5 format and interpolated to the satellite projection, when needed. This format is also used to store all the internal products such as the emissivity to harmonise information exchange between algorithms. Specific Land-SAF libraries are available to access and generate these HDF5 files in a standardised way. In FTA, the Product Data Layer is responsible for all

HDF5 I/O handling. During the local prototyping of the algorithms and their validation, developers have access to a dedicated Land-SAF server where the last 5 days of input and internal products are available.

The integration of a new algorithm in the Land-SAF system includes the following steps:

1 Standalone mode – brief test of the algorithm in the Land-SAF environment

2 2.1 Integration into the parallel chain
  2.2 Verification of the algorithm output (1-2 weeks)

3 Integration into operational chain
  3.1 FTA is archived
  3.2 FTA is validated and subject to an Operational Readiness Review (ORR)
  3.3 When recommend by ORR evaluation board, FTA will be approved to become (pre-) operational by the Land-SAF Steering Group
  3.4 FTA is then distributed to users – in NRT via EUMETCast or off-line via ftp.

5 FORESEEN APPLICATIONS AND SYNERGY WITH OTHER LAND-SAF PRODUCTS

The amount of fuel burned (M) is already the key variable used to estimate the production of aerosols, trace gases and carbon emissions from fire; via the use of so-called 'emissions factors' (representing the amount of each species emitted per unit mass of dry fuel burnt). Given existing methodologies to estimate emissions of these pollutant species from fuel combustion measures, estimates derived from FRP retrievals can thus be inserted into current methods for trace gas/aerosol/carbon emissions from fires. The following non-exhaustive list therefore identifies a series of potential applications for the FRP information derived operationally (consistently, continuously and over sufficiently long time-scales) from SEVIRI.

(i) Air quality forecasting (aerosols/relevant trace gases). Operational 'real-time' schemes such as the EU-funded GEMS/MACC project (led by ECMWF). Here the interest is in using information on fire timing, location and production rate of key chemical species as sources for input into the atmospheric chemistry and transport models used to provide short-term forecasts of 'air quality'. Industrial sources of these emissions are relatively well characterised in space and time, whereas biomass burning sources are highly variable with large variations on short (~ hourly to daily) timescales and thus require careful consideration for accurate modelling. This application would require near real time access to data.

(ii) Carbon cycle assessment and modelling. Biomass burning is a key process by which terrestrially stored carbon is released into the atmosphere (primarily as carbon dioxide; CO_2). Since biomass burning activity shows large i.e. ~ order of magnitude variations, so does the carbon released from these fires. As one consequence of this, the annual increase in carbon dioxide concentration in the atmosphere shows significant inter-annual variability. However, it is uncertain exactly how much of this variability is due to fire, and how much to other mechanisms (e.g. climate related variations in vegetation growth, soil microbial processes etc). Coupled models of the land-atmosphere system are attempting to better understand these processes, with one aim to be able to represent the inter-annual variability of atmospheric CO_2 increase (and ultimately to forecast this far into the future, based on projected changes in climate). Therefore information on the amount of carbon released by fire to the atmosphere is key to this modelling and understanding. One organisation involved in such research is the Centre for Terrestrial Carbon Dynamics (CTCD), funded by the UK Natural Environment Research Council (NERC) and led by the Centre for Earth Observation Science at the University of Sheffield. This application is unlikely to require real time data access.

(iii) Fire activity models. Linked to (ii) is the fact that forecasts of future land-atmosphere interactions will require careful representation of biomass burning, for example to represent emissions of pyrogenic carbon and to identify regions where significant and semi-permanent fire-related changes in landcover may be expected (e.g. conversion from forest to grasslands). A number of vegetation fire models (including the stages of ignition, progression, and combustion) are available to represent regional to global patterns of fire. These models require validation, and long-term fire-related observations from satellites, which are seen as the key validation data source. One such model is the SPITFIRE model developed by Max Planck Institute of Biogeochemistry and the University of Bristol. This application will not require real time data access.

An external study (FREEVAL), funded by EUMETSAT, is currently ongoing to evaluate the benefit of the FRP products to support such type of applications and include, among other participants, ECMWF, UK Met office, the Institute for Chemistry and Dynamics of the Geosphere – Troposphere, Research Center Jülich, and King College London.

The validation of the FRP product is expected to be finished by the end of the year in the framework of the FREEVAL study. The ORR is currently foreseen around March 2008. The FRP product generated by the LSA system will complement a comprehensive suite of operational surface products to the benefit of the user's community.

The FTA product fits well into the strategy of the most recent Land-SAF phase – the CDOP – initiated in March 2007. Following demands from environment monitoring and risk management (e.g., GMES requirements), the Land-SAF opened a new line of research related with forest fire applications to explore (i) the capability of SEVIRI/Meteosat to detect and monitor active fires, particularly over Africa, leading to the operational generation, archiving and dissemination of the Fire Detection and Monitoring (FD&M) product; and (ii) signals of vegetation water stress on SEVIRI channels (0.8, 1.6, and 3.9 μm), to follow its variability in space and time, and to produce meaningful danger of fire rating, or Risk of Fire Mapping (RFM), for (Southern) Europe. Although these new parameters are currently under development, the first prototypes are expected to be delivered during 2007. It is the aim of the Land-SAF to verify and guarantee the consistency of all fire-related products generated by the operational system.

6 CONCLUSIONS

The Land-SAF system architecture is very versatile and new algorithms can be very easily plugged into the processing system at IM. It represents therefore an ideal facility to host such type of new algorithm that might require frequent updates driven by the fast evolution of user's needs. This collaboration will thus strengthen the position of the Land SAF with respect to the user's community and other land surface product providers, which will place the Land SAF in a strong position in the framework of future GMES activities (i.e, GEOLAND 2). This new type of direct technical collaboration between EUMETSAT and the SAFs will also contribute to finding a balanced definition of future EUMETSAT-SAF interactions in preparation of the MTG era. Additionally, it is expected that this product will lead to new applications. In particular, this product will be used by consortium such as GEMS to estimate the aerosol and greenhouse gases emitted by wild fires.

7 REFERENCE DOCUMENTS

[AD 1] Software Development Guidelines Document, (SAF/LAND/IM/SDGD/1.6; Issue 1.6 of November 2003);

[AD 2] Algorithm Plugging Interface Document, (SAF/LAND/IM/APID/1.6; Issue 1.6 of November 2003);

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