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OBSERVATION REQUIREMENTS FOR GLOBAL BIOMASS BURNING EMISSION MONITORING

Johannes W. Kaiser [1], Martin G. Schultz [2], Jean−Marie Grégoire [3], Christiane Textor [4], Mikhail Sofiev[5], Etienne Bartholomé [3], Marc Leroy [6], Richard J. Engelen [1], Anthony Hollingsworth [1]

[1] ECMWF, Reading, UK, [2] FZ Jülich, Jülich, Germany, [3] JRC, Ispra, Italy, [4] CNRS, Paris, France, [5] FMI, Helsinki, Finland, [6] Medias-France, Toulouse, France

Abstract

Biomass burning changes the land surface drastically and constitutes a significant source for atmospheric trace gases and aerosols. It is the dominant source for some aspects of atmospheric Composition variability. Therefore biomass burning and its emissions need to be observed and modelled accurately for the monitoring of the global environment.

The integrated projects GEMS and GEOLAND develop the atmosphere and land monitoring systems for the GMES initiative of the European Commission and ESA. They require the amounts of burnt biomass and emissions of various trace gases and aerosols as input from satellite observations. Furthermore, the type of vegetation burnt, the burnt area, and the injection height profile are needed. These products need to be provided globally with a spatial resolution of about 25 km. They should have a temporal resolution of few hours to one day and must be available in real-time as well as in retrospective timeseries. The latter need to cover more than ten years in a consistent way.

The products that are currently derived from fire observations do not satisfy the requirements. They are associated with large uncertainties and often inconsistent. However, the observations by several satellite instruments provide complementary information. In order to make this information available for environmental monitoring, more accurate quantitative fire products need to be derived from the existing observations. Subsequently, these products must be combined in a Global Fire Assimilation System (GFAS) that also accounts for landcover and the meteorologic conditions. Such a GFAS would be a new development. However, it is thought to be necessary to meet the fire input requirements of environmental monitoring in GMES.

INTRODUCTION

Biomass burning (BB) plays an important role in many ecosystems and destroys others irreversibly. It also contributes significantly to the global budgets of various gases and aerosols.

The smoke produced by BB can dominate regional air quality in “severe air pollution” events. While the toxic smoke is imminent in the vicinity of large fires, it has also been shown to elevate background of atmospheric pollutants after long range transport [e.g. Stohl et al. 2001, Forster et al. 2001, Andreae et al. 2001].

Emissions by BB are among the most important contributors to the global budget of various gases and aerosols. Figure 1 illustrates the magnitude of the CO emission by BB and its dominating inter-annual variability. Therefore, accurate assessment of the emissions is needed over extended periods of time for negotiations of international emission control regulations, e.g. Kyoto and CLRTAP.

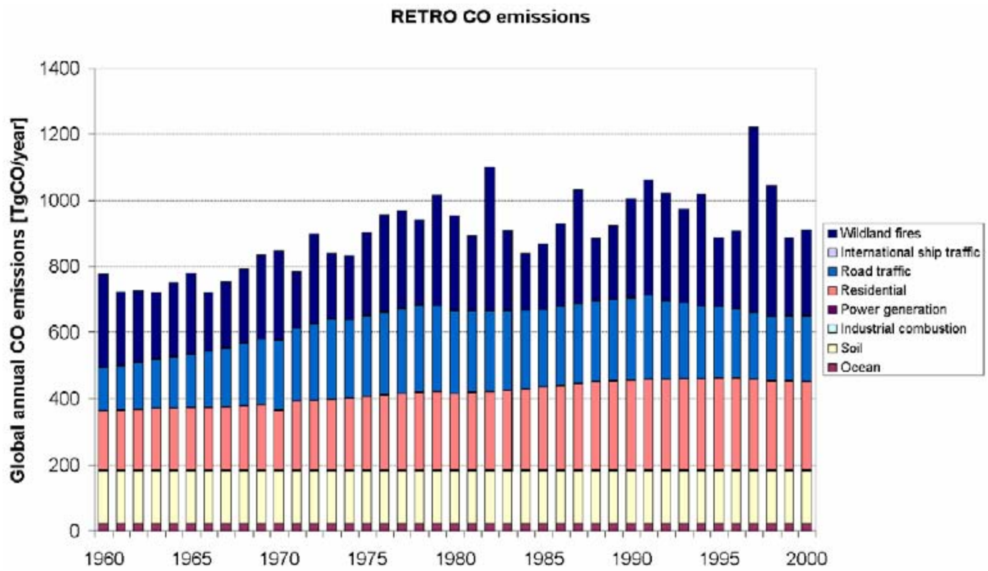

Figure 1: Source attribution of global annual CO emissions. [http://www.retro.enes.org]

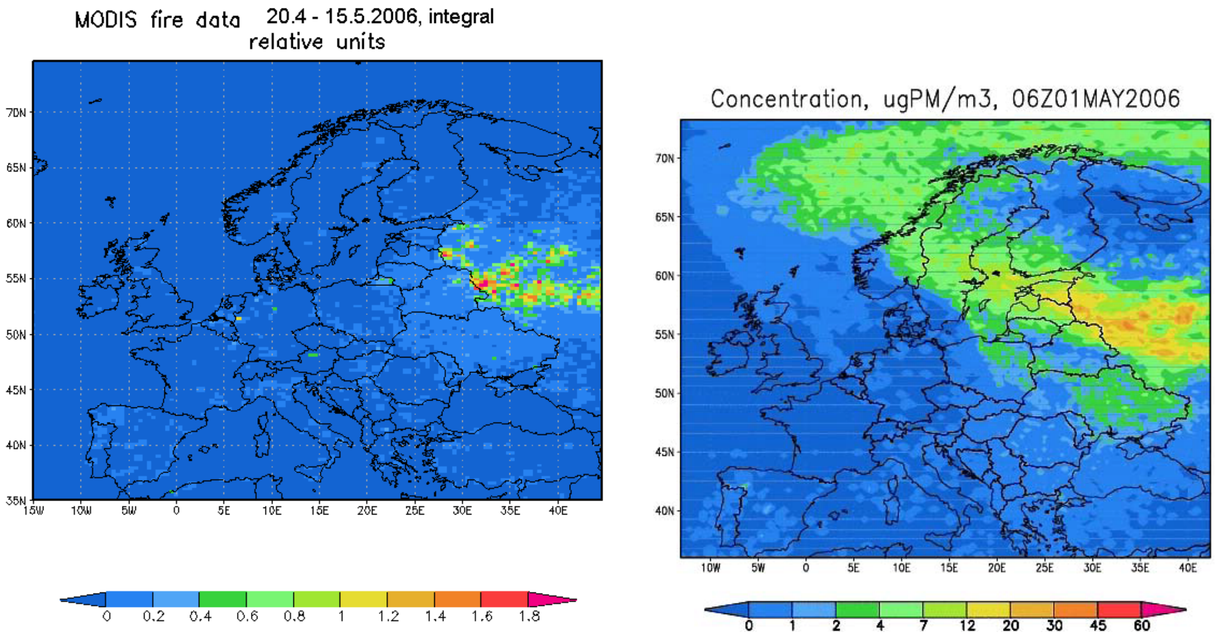

Figure 2: Fire Observations by MODIS during 20 April and 15 May 2006 (left plot) and modelled air pollution with PM2.5 on 1 May 2006 (right plot). Emission by the observed fires and atmospheric transport are modelled and forecast by the experimental fire plume forecast by the SILAM model. [http://silam.fmi.fi]

The regional and day-to-day variability of air pollution by biomass burning is highlighted in Figure 2 with a smoke plume, which originates from Russian biomass burning and is transported over Scandinavia in the course of a few days. It is obvious that fire observations need to be available in near-real time for any forecasting of air quality.

Weather is affected by BB in several ways. The radiative energy budget is perturbed by black carbon aerosols, which absorb solar radiation, in the smoke. Thus elevated smoky air is heated and surface is cooled [e.g. Konzelmann et al. 1996]. The smoke aerosols also provide cloud condensation nuclei, which initially inhibit precipitation [e.g. Andreae et al. 2004]. The direct heat release by fires can be significant, too. The combination of these effects may accelerate deep convection to form so-called “pyro-convection” above intense fires. It may overshoot into the stratosphere, thus transporting highly polluted air across the tropopause. [Andreae et al. 2004, Damoah et al. 2006]

BB affects important a priori information for the retrieval of all tropospheric trace gases and aerosols from space-borne observations: The aerosols alter the radiative transfer in all observed spectral regions. Most observations cannot, or only very coarsely, discriminate between pollution at different altitude levels. Likewise, it is very difficult to differentiate between different types of aerosols. The monitoring of BB may improve the a priori information significantly by providing the expected altitude of pollution, the likely type of aerosols, and an aerosol optical depth (AOD) estimate.

A particular challenge of the monitoring of BB lies in its highly variability on all time scales from hours to decades. Forecasting is additionally complicated by the stochastic nature of the natural fire ignition by lightning.

The ‘Global Monitoring for Environment and Security’[1] (GMES) represents a concerted effort by the European Commission and the European Space Agency. It aims at designing and establishing a European capacity for the provision and use of operational services for Global Monitoring of Environment and Security.

The atmosphere monitoring system for GMES is being developed in the Integrated Project (IP) ‘Global and regional Earth-system (Atmosphere) Monitoring using Satellite and in-situ data’[2] (GEMS). Likeweise, the GMES land monitoring system is being developed by the IP GEOLAND[3]. The interaction between both systems is being optimised in the project HALO[4]. Since BB is a major interface between the atmosphere and land monitoring systems, we analyse the requirements of GEMS and GEOLAND in this paper.

ATMOSPHERE AND LAND MONITORING REQUIREMENTS ON FIRE PRODUCTS

The GEMS project is described in more detail in, e.g., Engelen et al. [2006]. The following three objectives are relevant in the context of BB:

1. GEMS will establish a global operational system for the monitoring and forecasting of atmospheric composition.
2. GEMS will produce a global retrospective analysis of the atmospheric composition covering 2000-2007.
3. GEMS will enhance several regional air-quality forecasting systems in Europe.

In order to achieve these objectives, the fire emission products that satisfy the requirements listed in the middle column of Table 1 below need to be available. Obviously, the emitted amounts of all modelled species of gases and aerosols and the dates, times and, locations of the fires need to be known. Since the initial plume rise cannot be resolved at the model grid resolution (> 25 km for the global model), the vertical distribution of the fire emissions needs to be known, too. The fire products are required globally, with a spatial resolution of about 25 km. In order to forecast the atmospheric composition, the fire products need to be available in near-real time (NRT), i.e. about 3 hours after the observation. The production of the reanalysis of the “Envisat era” 2000-2007 results in the requirement of a long time series covering at least these eight years.

The relevant objectives of GEOLAND are

1. to model vegetation as part of the global carbon cycle quantitatively,
2. to characterise the behaviour of land cover types, and
3. to monitor land cover change.

The first objective implies that the carbon flux due to BB is quantified. The characterisation of land cover types with repeated fire events includes the description of the fire seasonality and representative values for, e.g., the fire repeat period and fire intensity. The irreversible land cover change is partially due to fires, e.g. in tropical deforestation.

In order to achieve its objectives the land cover monitoring system needs fire observation products which meet the requirements listed in the right column of Table 1. They must specify the amount of biomass and the type of vegetation burnt at any given date and location on the globe with a spatial resolution of about 25 km. A temporal resolution of about one day seems sufficient, but consistent products need to be available in long time series spanning at least ten years to facilitate trend detection.

Intermediate products that are derived from the fire observations include the diurnal cycle, the seasonal distribution, and inter-annual changes.

Table 1: Fire Product Requirements

<table>
<tr><th></th><th>GEMS</th><th>GEOLAND</th></tr>
<tr><td rowspan="5">PRODUCTS</td><td>amounts of trace gases (CO2, CH4, CO, O3, NO2, SO2,…) and aerosols emitted</td><td></td></tr>
<tr><td></td><td>amount of biomass burnt</td></tr>
<tr><td></td><td>type of vegetation burnt</td></tr>
<tr><td>date, time, and location of fire</td><td>date and location of fire</td></tr>
<tr><td>injection height profiles</td><td></td></tr>
<tr><td rowspan="2">COVERAGE</td><td colspan="2">spatial: global, consistently</td></tr>
<tr><td>temporal: > 8 years</td><td>> 10 years, consistently</td></tr>
<tr><td rowspan="2">RESOLUTION</td><td colspan="2">spatial: ≈ 25 km</td></tr>
<tr><td>temporal: 1-6 hours</td><td>1 day</td></tr>
<tr><td rowspan="2">AVAILABILITY</td><td>near-real time</td><td></td></tr>
<tr><td></td><td>retrospectively</td></tr>
</table>

OBSERVATION SYSTEM

Satellite instruments can detect the fire front during the fire, or the burnt area after the fire. The fire front emits thermal radiation, which is particularly strong in the MIR spectral window near 4 µ wavelength. Products of this type are known as “active fire”, “hot spot”, “fire pixel”, or “fire count” products. Due to the very strong signal [Zhukov et al. 2005] instruments may saturate when observing a large fire. Therefore, the active fire products traditionally distinguish only burning and non-burning pixels without giving any quantitative information which percentage of the pixel area is affected and how intense the fire is.

Two particular developments of active fire products yield quantitative information: sub-pixel area and temperature of a fire derived with the Dozier method [Dozier 1981] and Fire Radiative Power (FRP). These products require a large dynamic range of the MIR instrument channel to prevent saturation above large fires and maintain a low detection limit for small fires with small signal. Accurate detection of small fires would require a spatial resolution of < 100 m [Zhukov et al. 2005], which cannot be provided by the current observation system. Therefore, calibration with observations by research satellites like BIRD would have to be implemented.

Since the active fire observations have to be taken during the occurrence of any fire, all observations suffer from temporary cloud cover and, in particular, LEO-based observations cannot comprise all fires. ESA’s World Fire Atlas (WFA), for example, is completely insensitive to the daytime maximum of the fire diurnal cycle because it analyses only nighttime observations by AATSR aboard Envisat.

The burnt area can be detected because the burn scar’s reflectance is small, it is spectrally flat, and its bi-directional reflectance distribution function (BRDF) is flat, too. An important criterion is that the change of the observed parameter occurs suddenly in a time series. Products of this type are known as “burnt area”, “burnt pixel”, “burnt scar”, and “fire-affected area” (FAA). They can only be generated after the fire.

An advantage of the burnt area products is, that observation gaps due to cloud cover and satellite revisit time can be filled thanks to the persistence of the burn scar. However, burning of undergrowth below an intact tree cover is not detected; for example, small fires at the edge of the tropical forest are underestimated [Michel et al., 2005].

Boschetti et al. [2004] have shown that several existing products are not consistent.

The amount of burnt biomass is traditionally calculated from satellite fire observations as the product of the burnt area *BA*, the available fuel load *AFL* [mass per unit area], and the burning efficiency *f*:

$$M(biomass) = BA \times AFL \times f$$

The burnt area *BA* is either taken directly from a burnt area satellite product or inferred through scaling of an active fire product with scaling factors of various degrees of sophistication; the simplest assuming that the entire pixel is burning, the more complex ones taking into account regional variability. Note that the available fuel load *AFL* has to be provided by a dynamical global vegetation model (DGVM), which can be considered to be part of a land monitoring system, or simply by a climatology. All three factors are associated with large uncertainties.

The recent development of the fire radiative power *FRP* satellite product promises to eliminate some of the uncertainties in the calculation of the amount of burnt biomass. It can be formulated with an integral with suitable boundaries over the time *t*:

$$M(biomass) = s \times \int_t FRP$$

s is a scaling factor, which is theoretically constant in time and for all locations. The integral yields the “fire radiative energy” (FRE) for a particular period, typically the lifetime of any particular fire. This approach requires observations of *FRP* with sufficient frequency to capture its temporal evolution.

In any case, the amount of the emissions of the different gaseous and aerosol species is subsequently derived with empirical empirical emission factors *E(species)*:

$$M(species) = M(biomass) \times E(species)$$

The emission factors *E(species)* are also associated with large uncertainties since they vary with ecosystem, fire intensity, fuel humidity, and other influences.

Vertical profiles of fire emission are currently evaluated from a limited number of campaigns measuring the plumes from few record-breaking fires. The over-proportional sampling of large fires leads to a bias of the obtained elevation of the burning products to large values. The values may therefore not be applicable as default values for arbitrary fire episodes. Dynamic evaluation of the vertical profile of emission requires extensive knowledge on meteorological conditions, as well as size and intensity of each specific fire.

Current and future fire observation products for atmosphere and land monitoring are listed in Table 2. The following conclusions can be drawn:

- No current product satisfies all requirements of atmosphere and land monitoring in GMES.
- Observations from LEO and GEO satellites complement each other with good spatial coverage and resolution provided by the LEOs and good temporal resolution by the GEOs.
- Active fire and burnt area products complement each other in terms of accuracy for different fire types and, consequently, geographical regions.
- Many existing products are inconsistent.
- Several new operational products are anticipated in the next few years.
- All information required by the atmosphere and land monitoring of GMES seems to be distributed across the existing and anticipated products.

Table 2: Overview of Satellite Fire Products

NAME	REFERENCE	SENSOR(S)	COVERAGE		RESOLUTION		AVAILABILITY	STATUS
			spatial	temporal	spatial	temporal		
Active Fire Products (no quantitative information)								
MODIS active fire	http://modis-fire.umd.edu/products.asp Justice et al. [2002]	Aqua/Terra-MODIS	global	2001 – present	1 km	1 day	NRT	operational
World Fire Atlas (WFA-algo1)	http://dup.esrin.esa.int/ionia/wfa	ERS2-ATSR2, Envisat-AATSR	global	1995 - present	1 km	1 day	NRT	operational
Active Fire Monitoring (FIR)	http://www.eumetsat.int/idcplg?IdcService=SS_GET_PAGE&nodeId=522	Meteosat-SEVIRI	Africa & Europe		3 km	15 min	NRT	operational
IGBP-GFP	http://www-tem.jrc.it/ Dwyer et al. [2000]	NOAA-AVHRR	global	1992-1993	1 km	1 day	retrospectively	finished
TRMM	http://earthobservatory.nasa.gov/Observatory/Datasets/fires.trmm.html Giglio et al. [2000]	TRMM-VIRS	40˚N - 40˚S	1988-2002	2 km / 0.5˚ (sensor/ product)	1 month	retrospectively	finished
Active Fire Products with quantitative information								
WF_ABBA, Dozier method	http://cimss.ssec.wisc.edu/goes/burn/detection.html Prins et al. [2001, 2004]	GOES-E/W	N/S-America	1995-present	4 km	30 min	NRT	operational
WF_ABBA, Dozier method	Prins et al. [2001, 2004]	several GEO satellites	global		4 km	30 min	NRT	in planning
MODIS FRP	http://modis-fire.umd.edu/products.asp Justice et al. [2002]	MODIS	global	2001-present	1 km	1 day	NRT	operational
SEVIRI FRP	http://www.eumetsat.int/idcplg?IdcService=SS_GET_PAGE&nodeId=522	Meteosat-SEVIRI	Africa & Europe		3 km	15 min	NRT	under development
global FRP from GEOs	M. Wooster, private comm..	several GEO satellites	global		4 km	30 min	NRT	in planning
Burnt Area Products								
GBA1982-1999	http://www-tem.jrc.it/ Carmona-Moreno et al.[2005]	NOAA-AVHRR	global	1982-1999	8 km	1 week	retrospectively	finished
GBA2000	http://www-tem.jrc.it/fire/gba2000 Tansey et al.[2004a, 2004b]	SPOT-VGT	global	Nov1999-Dec2000	1 km	1 month	retrospectively	finished
GLOBSCAR	http://dup.esrin.esa.int/ionia/projects/summaryp24.asp Simon *et al*. [2004]	ERS2-ATSR2	global	2000	1 km	1 month	retrospectively	existing
MODIS Fire Affected Area	http://modis-fire.umd.edu/products.asp#8	Aquaa/Terra-MODIS	global	2001-present	500 m	1 day	retrospectively	under development
Global Daily Burnt Area (GDBAv1)	GDBA partnership: Leicester Univ.(UK), Louvain-La-Neuve Univ.(B), Tropical Res. Inst.(P), JRC (EC)	SPOT-VGT	global	2000-2005	1 km	1 day	retrospectively	under development
Burnt Area for GEOLAND (BAG)	http://www-gvm.jrc.it/tem/ Restricted access (GEOLAND)	SPOT-VGT	Africa & Eurasia	1998-2003	1 km	10 days	retrospectively	under development
VGT4Africa	http://www-gvm.jrc.it/tem/	SPOT-VGT	global	2005-present	1 km	1 day	NRT	under development
GLOBCARBON	http://dup.esrin.esa.it/projects/summaryp43.asp	ERS2-ATSR2, Envisat-AATSR, Envisat-MERIS, SPOT-VGT	global	1998-2007	8 km	1 month	retrospectively	under development

CONCLUSIONS

Biomass Burning (BB) emissions are needed globally in near-real time as well as in consistent multi-year time series for accurate monitoring of atmosphere and land in the GMES initiative.

No single suitable BB emission product is currently available. Principal shortcomings are accuracy, delivery time, temporal resolution, and geographical coverage. The existing fire observations complement each other to a large extend.

We conclude that the consistent fire observation product required as input for accurate global atmosphere and land monitoring can only be generated by fusion of the various fire observations (or their individual products) in a “Global Fire Assimilation System” (GFAS) built around a numerical model of the global fire activity. Such a system does not exist yet. It would also require input of the meteorological conditions and of land monitoring products like the available fuel load. It could evolve with new scientific developments and provide the best available fire products to the global and regional monitoring systems in GMES in a consistent way, cf. Figure 3.

The success of the GFAS would depend on a more complete and timely exploitation of the satellite fire observations in the operational fire products. It would benefit much from the implementation of a well-calibrated global fire radiative power product from GEO- and LEO-based observations.

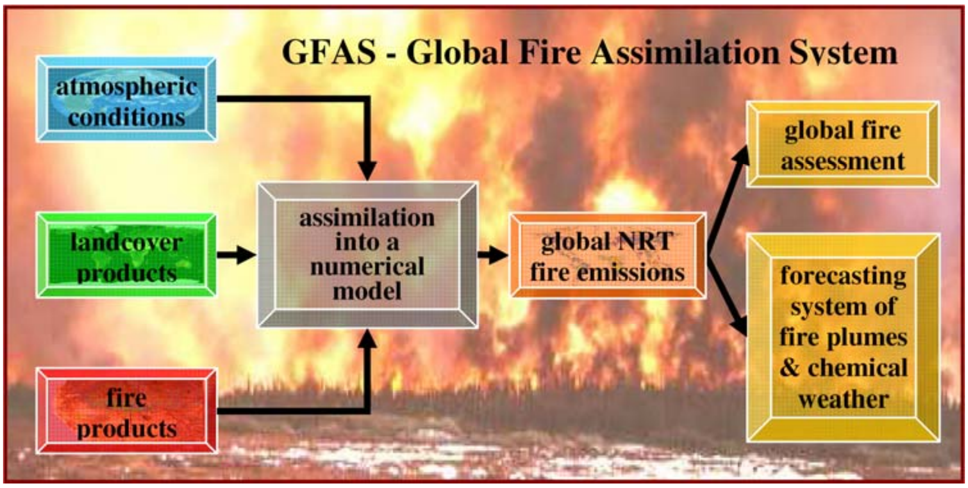

Figure 3: GFAS Interfaces

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