White Paper on a NASA Fire ESDR

1. Name: The Fire ESDR (consisting of two sub-records active fire and burned area)

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The need exists for satellite information on the occurrence of fires on the land surface since fire changes the surface cover type and properties and releases trace gases and particulate matter into the atmosphere, affecting ecosystem functioning and composition, hydrological processes, atmospheric chemistry, air quality and climate. Fire is an important ecosystem disturbance with varying return frequencies, resulting in land cover alteration and change on multiple time scales. Fire is a widely used land management tool and in some areas is an indicator of land use change and human activity. Fire is used for clearing and preparing of agricultural land, maintaining pastures, hunting and removing crop residue. Fire can also have adverse impacts on human health, livelihoods and economies. Wildfires have become increasingly a significant hazard at the suburban-wildland interface. Satellite derived fire information can be used for improved fire and land management. Satellite detection of thermal anomalies associated with active volcanoes is important for monitoring purposes and because of the consequences that volcanic emissions have on the Earth's climate, including ozone destruction and the temporary lowering of global temperatures.

3. Scientific rationale and importance of measurement and expected end uses (both basic and applied science)

Several of the science questions posed in the NASA Research Plan and CCSP Strategy Document pertain to fire and their emitted products. Rather than listing these broad questions, we have identified some of the more pressing fire-related science questions that need addressing:

- What is the role of fire (wildfire and controlled fire) on biogeochemical cycling (e.g., carbon cycle)?
- Where are the fire sources (locations), what is their timing, seasonality and interannual variability and what are the impacts of fire on atmospheric composition (aerosols and trace gases)?
- Are there regional feedbacks between fire and climate change?
- With changing climate and land use practices, how are global fire regimes (e.g., type of fire, timing, distribution, frequency, intensity) changing and are new ecoregions (e.g. tropical and boreal peatlands) becoming more fire prone?
- What is the relationship between catastrophic fire and biodiversity?

Different aspects of fire are pertinent to the NASA Science Focus Areas of Carbon Cycle, Ecosystems and Land Use, Water and Energy Cycle and Atmospheric Composition. In addition, there are a number of applications questions which NASA, in partnership with operational agencies can address:

- How can fire management be improved to reduce wildfire hazards?
- How can fire management be modified to improve regional air quality?

- Can fire management practices be modified to reduce negative impacts on ecosystems, carbon emissions and sequestration and water quality?
- How can satellite derived information be used to more effectively allocate resources for fire management, fire fighting and decision support and provide increased warning of fire-related air pollution episodes?

In addition, different aspects of fire are pertinent to several of the NASA Applications Focus Areas including Disaster Management, Air Quality, Water Management, Carbon Management and Ecological Forecasting.

There are currently a number of different users of NASA fire data, including global change and atmospheric modelers and analysts, those developing periodic global and regional environmental assessments, national, regional and local fire and resource managers, non-government organizations, academic researchers, and the general public. The development of fire monitoring from space and the heritage sensing systems are described at the MODIS fire web site (http://modis-fire.umd.edu). The range of data products and delivery systems supported by NASA and its partner agencies must be geared to meeting the wide-ranging needs of this diverse user community.

4. Scientific requirements for the measurement

The scientific requirements for satellite fire data have been well documented. A number of international initiatives have been developed over the last few years to document the requirements for fire data from space, in the framework of the international observing system initiatives. The Terrestrial Observation Panel for Climate (TOPC), a joint committee of GCOS/GTOS, identified the need for active fire and burned area products with specified temporal and spatial resolutions. These requirements were enhanced by the Terrestrial Observation of Carbon Working Group. The need for long term fire data products was identified in the Global Climate Observing System (GCOS) Implementation Plan. The task was taken up by the Fire Implementation Team of GOFC/GOLD (http://gofc-fire.umd.edu), a project of the Global Terrestrial Observing System (GOFC Strategy). Most recently, GOFC/GOLD in cooperation with the TOPC has developed refined requirements for the Committee on Earth Observation Satellites (CEOS) to submit to the Conference of the Parties for the UN Framework Convention on Climate Change. The NASA ESDR for fire has been informed by these international efforts and in turn will contribute to meeting these internationally specified requirements.

There is a need to distinguish between user needs emanating from the science and applications communities, with the primary distinction being the timeliness of the data delivery required. The data delivery requirements for the applications community, concerned with strategic fire management, is to receive new data on a daily basis, or at best within a few hours of acquisition and to have summaries at periods during the fire season and on an annual basis for planning and reporting purposes. The CEOS Disaster Management Support Group set the requirement for data delivery within 15 minutes of the start of the fire (Dull and Lee, 2001). This latter requirement can only be met by continuous monitoring by a high spatial resolution, geostationary capability, or by aircraft or UAV's, in areas where fire has already broken out. This is clearly a goal for developed countries with fire fighting capabilities, but for countries with large tracts of territory where fire management is either infeasible or only targeted at key valuable resources, the delivery requirements are less stringent.

For NASA Fire ESDRs we are concerned with generating consistent and long term global products of active fires (including fire radiative power - FRP) and burned area (fire affected areas). MODIS has provided the first science quality moderate resolution instrument for global fire monitoring. Recognizing that previous and planned satellites have diverse sensing characteristics, it is important to recognize the inevitability of dynamic product continuity when using these various satellite systems to create a long time-series. We also recognize that at the regional scale, alternative approaches may be feasible and that algorithms can be optimized for local and regional conditions.

In the context of science applications, detection of active fires has several uses: (i) as an indicator of daily, seasonal and inter-annual variability in fire activity regionally and globally, and trends associated with climate and climate change; (ii) as part of the validation process for fire affected (burned) area; (iii) as a way to determine more precisely the timing of burning for burned area products generated periodically during the burning season. (iv) as an integral part of some burned area mapping algorithms, v) to estimate FRP, which has been shown to correlate with instantaneous rate of combustion (Wooster et al., 2005) and emission rates. This correlation represents a major benefit in that it does not rely on difficult-to-acquire ancillary data on fuel load and combustion completeness factors in order to convert the remotely sensed measure into a trace gas emissions estimate.

Burned area, sometimes termed fire-affected area, can be combined with other information (burn efficiency, available fuel load) to estimate emissions of trace gases and aerosols. Measurements of burned area can be used as a direct input (driver) to climate and carbon cycle models, or, when long time series of data are available, to parameterise climate-driven models for burnt area (the latter approach is how fire is dealt with in many climate and biospheric models).

The requirements for science can be summarized as follows:

i) Active Fire and Fire Radiative Power

- Middle infrared & thermal long wave sensors that will not saturate for the largest expected fires (assumed temperature at 1000K)
- geolocated to a fraction of a 1km pixel
- solar and viewing geometry
- optically thick cloud mask
- land/water mask
- 1 km global spatial resolution (GOFC 1999 requirement)
- 24 hour detection summary (the most stringent requirement is for active fire detection within 15 min for fire fighting applications)
- Products are needed at full resolution (1km) and summarized at 0.5 degrees
- Validation - simultaneous high spatial resolution sensing (20-30 m) is needed for active fire validation (e.g., ASTER).
- other parameters required
    - time of overpass

- instantaneous and time integrated fire radiative power as a measure of fire emissions

ii) Burned Area (aka. Fire Affected Area)

- atmospherically corrected reflectance, visible to short wave infrared, thermal
- geolocated to a fraction of a 500m pixel
- solar and viewing geometry
- optically thick cloud mask
- 500 m globally (GOFC 1999 requirement)
  - 30 m for regional and local mapping – (the most stringent requirement is for high resolution data within 2-3 days for rapid post-fire assessment)
- Monthly product as inputs to emission models recognizing the seasonality of fuel moisture, emission factors, and combustion completeness
- Products to be provided at full resolution and summarized at 0.5 degrees
- Validation – high resolution imagery (20-30 m) to be acquired one month apart

5. Approach to generating the ESDR

5.1.Active Fire and Fire Radiative Power

For active fire detections and the calculation of fire radiative power, the accepted approach is to use data from the middle infrared in combination with thermal and visible data to limit false detections. The heritage to the algorithm lies in AVHRR-based fire detection approaches. The current algorithm is mature and the approach has been well documented (e.g., Giglio *et al*., 2003). A multiyear product from MODIS designed for use by global modelers is currently available (Giglio *et al*., 2006a). Fire radiative power is a relatively new quantity, derived using observations at 4 microns, providing information on fire intensity (Wooster *et al.*, 2006). A global product has been developed and FRP is being evaluated as a direct way to quantify rates and totals of biomass consumed. For the ESDR, the algorithm and data processing must account for instrument calibration, geolocation, masking of clouds and water bodies.

The accuracy of the current MODIS active fire product has been evaluated at Stage 1 and Stage 2 and validation is nearing completion. Estimates of the accuracy of the current product are expressed in the form of summary statistics of coincident 30 m resolution active fire observations from the Terra/ASTER sensor (Csiszar *et al*., 2006). These results, combined with simulations, indicate that in many biomes the minimum flaming (~800-1000K) fire size detectable at 50% probability with MODIS is on the order of 100 m^2. The validation of FRP, including the development of a consensus validation method, is still ongoing, and has currently been limited to relatively small scales.

To generate a long-term, science quality, homogeneous active fire data record, a number of issues related to inter-satellite and inter-sensor continuity need to be addressed. In this process the advancement of technology and the consequent improvement of data quality and the availability of an increasing number of sensors need to be considered. Specifics of such dynamic continuity for fire products need to be defined. A fundamental component of this process is product validation, which also allows the linkage of products from different sensors. It is critical that the radiometric characteristics of the sensor(s) used for active fire detection remain consistent and are monitored. As polar-orbiting active fire observations represent a limited sampling of the diurnal cycle of fire activity, stable satellite orbits are also required and ideally at least one of the crossing times should be close to the diurnal fire peak.

The ESDR for active fire should include a full resolution daily product and a coarser summarized product at 0.5 degrees containing metrics required by the modeling community.

5.2 Burned (Fire Affected) Area

A consistent multi-year Burned Area product is a high priority for the global change modeling community. The Burned Area ESDR needs to be generated using a fully automated algorithm. The suggested approach is to use the current MODIS algorithm (Roy *et al*, 2005). This algorithm models the bidirectional effects in moderate resolution time series, identifies changes and persistence in the signal characteristic of burned area and maps the fire affected area at 500 m. The algorithm uses surface reflectance data in the visible, NIR and SWIR as input. The current MODIS burned area algorithm has been developed and tested and is being run under MODIS Collection 5. The accuracy of beta versions of the MODIS burned area product has been assessed for selected regions, by comparison with Landsat data distributed over a range of representative conditions (Stage 2 Validation), indicating that the MODIS product captures more than 85% of the total area burned. As this is the first collection for this product it is anticipated that refinements will be made based on user feedback and reprocessing will be needed. For example, it is intended to combine active fire information in the burned area product in the MODIS Collection 6 reprocessing.

The generation of the burned area product requires accurate geolocation and band-to-band registration. There is the possibility of extending the MODIS global burned area record using the AVHRR 1 km global data set collected by the EDC DAAC, however close attention will need to be given to preprocessing and the consistency of the data record. There have been attempts to map global burned areas from the AVHRR GAC record, however the resolution and spatial averaging mitigate against accurate area estimation.

Major requirements for the creation of a science quality burned area long term data record are the provision of the necessary input observations and the inclusion of burned area among the systematically generated and validated data products by the various space and operational agencies. GOFC-GOLD Fire can be instrumental in advocating and coordinating efforts to develop a burned area data record from upcoming sensors. In particular, the continuity of the ESDR should be developed using the NPP and NPOESS VIIRS instruments.

6. Intended sources for the measurement

This white paper focuses on global products from polar orbiters but it should be recognized that at the local scale other sources of data or approaches can be considered, for example generating burned area using high resolution (Landsat class) data. Similarly, global algorithms can be adapted for local conditions to give improved results.

6.1 Sources for the Active Fire ESDR

Regional active fire products are being generated by Geostationary systems using similar algorithms to those identified above and validation of the geostationary products are in progress. Through the international GOFC/GOLD program there is an initiative to coordinate a global network of geostationary satellites providing active fire detection with a 15-30 minute frequency, however at this stage this is not a viable source of global data. There are several possible sources for active fire data, but currently MODIS is the only system providing both day and nighttime active fire detections globally and which has the spectral band characteristics (specifically wide dynamic range MIR and TIR channels) necessary to derive unsaturated FRP measurement for almost all detected events. It is recommended that the global Fire ESDR start with MODIS and continue with the NPP and NPOESS VIIRS. Other sources can be considered to supplement these primary sources but the case needs to be made as to the value added from the science perspective.

The AVHRR provides the longest record of mid-IR terrestrial observations, but the 3.9 micron channel saturates at a low level, the 1 km data have not been collected globally, and the drift of the satellite orbit provides an inconsistent data record. However, the global 1 km data set collected by the EDC DAAC does provide global coverage for the early 1990's. With the future plans to acquire global 1 km data from the NOAA AVHRR and METOP, then these data could contribute to a global data record. The global ATSR data go back to 1996 and provide a consistent source of nighttime fire observations. However, since the diurnal fire cycle is at it minimum at night, this record will very much represent a limited sample of the true fire magnitude. The U.S. Air Force Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) can detect small fires at night via low light imaging in the visible wavelength region. These data could contribute to a global fire ESDR extending the MODIS time series, again assuming that account is made of the timing of the overpass and the diurnal cycle of fire activity. The development of multi-source fire products is one of the goals of GOFC/GOLD fire and currently this is being developed regionally in the context of direct broadcast fire applications. A consistent global 'science-quality' multi-source fire product remains an area for research and development.

6.2 Sources for the Burned (Fire Affected) Area

There have been efforts in Europe to develop a global burned area product. A global burned area product developed from AVHRR 8 km (1981-1999) data by the Joint Research Centre, Ispra has severe limitations for science use due to inaccuracies in detection resulting from the aggregation of the GAC data and calibration consistency issues. Regional 1 km AVHRR burned area data sets have not been generated on a systematic basis nor validated. A global 1 km data set from the AVHRR might be used to generate the product, but careful evaluation of the geolocation and reflective band calibration would be required. Two global burned area products were developed using European data for year 2000, the GBA2000 product from SPOT-VEGETATION data, and the GLOBSCAR product from ESA ATSR data. Systematic intercomparison of these products, neither of which has been validated, shows major inconsistencies at regional and continental levels (Korontzi *et al.* 2004, Boschetti *et al*. 2006).

A combination of active fire and burned area is needed in the ESDR. Global cloud analysis indicate that persistent cloud-cover will restrict MODIS burned area mapping (and active fire detection) in parts of equatorial West Africa, equatorial South America, Southern and Southeast Asia, and Boreal regions in Eurasia and Canada (Roy *et al*., 2005). In these persistently cloudy regions active fires may be detected in the few cloud-free overpasses and because of the reduced sensitivity of the active fire ESDR to optically thin cloud and smoke. Recent development of an interim global burned area product based on the MODIS Active Fire and Vegetation Continuous Fields products also indicates this need (Giglio et al. 2006b).

As with the Active Fire ESDR**,** the development of multi-source burned area products remains an area for research and development. The MODIS burned area approach provides a route for the use of multiple data sources and observations of varying degrees of uncertainty within a rigorous statistical framework. Fusion of measurements sensed by operational polar-orbiting and geostationary satellites is of future research interest.

7. Necessary supporting activities, tasks

Monitoring product calibration will be a necessary ongoing activity to address product consistency. Validation is a critical supporting activity and it will be essential that the ESDR be validated at Stage 3 (a global, statistically robust accuracy assessment). Validation of the active fire ESDR requires high spatial resolution (20-30 m) acquisitions distributed over a global range of conditions, including actively flaming & smoldering fires, and a sensor in the MIR that does not saturate below ~1300 K with simultaneous (seconds-minutes) cloud free, acquisition. For the active fire ESDR, it is recommended that a comprehensive global validation of MODIS TERRA be undertaken using ASTER. Comparisons can then be made between AQUA and compatible sensors on satellites operated by other space agencies. The absence of a high resolution sensor collocated with MODIS AQUA and VIIRS presents a challenge for validation. The approach currently envisioned is a cross comparison between VIIRS and MODIS; ideally MODIS TERRA will be operating at the same time as the VIIRS but may well not be the case. A further possibility is to acquire under flights coincident with the VIIRS overpass, with an airborne sensing system capable of monitoring fires (e.g. the MAS system). For Burned Area it is recommended that validation be undertaken according to the protocol developed in the framework of GOFC/GOLD (Roy *et al.* 2005). High spatial resolution (20-30 m) acquisitions distributed over a global range of conditions in the visible to thermal wavelengths. Two cloud free acquisitions are needed 8-32 days apart collected within the burning season. For the period up to 2003, Landsat 7 is the instrument of choice and there are sufficient data in the archive to allow a Stage 3 validation. For the period after the scan line corrector malfunction data from other high resolution sensors are needed for validation. However, given the large task of global validation, it is recommended that international collaboration be continued by GOFC/GOLD and the CEOS Land Product Validation (LPV) working group, engaging regional scientists in the development and sharing of the validation data sets.

8. Relationships to other products and programs (of other agencies, international, etc.)

It is assumed that NOAA will be the provider of satellite data to the civilian applications user community in the NPOESS era. It is therefore important that discussions are held with NOAA in terms of transitioning the functionality of the fire monitoring systems designed for applications users developed by NASA. Although NOAA currently provides MODIS data to applications users, efforts to transition the enhanced functionality of the NASA MODIS Rapid Response system have failed to date, due to a lack of NOAA funding commitment. In contrast the Web Fire Mapper developed with NASA support to provide fire data to a wide range of users in a Web GIS format is currently being transitioned to the UN FAO supported by the NASA Applications program.

Intercomparison will be needed between the Collection 5 MODIS burned area product and the ESA GLOBSCAR/GLOBCARBON products, following the procedures developed by Boschetti et al. (2004). Fire data products are envisioned as part of the GEOSS and as inputs to the UN FCCC. The Fire ESDRs as outlined above would meet the requirements of these organizations. International coordination of fire monitoring associated with the ESDR should be conducted in the framework of GOFC/GOLD Fire (http://gofc-fire.umd.edu).

9. Associated activities

For the VIIRS active fire product, research is needed to address on board aggregation and product validation. In particular, if MIR and TIR channels with suitable dynamic ranges were available, enhanced active fire characterization methods such as those reported in Zhukov et al. (2005) would likely be possible if the data were analysed prior to aggregation. A burned area product will be needed from the VIIRS to extend the MODIS product. To extend the ESDR beyond the current systems, there will be a need for the sensor saturation requirements for active fire monitoring and FRP derivation to be included in the next sensor design for NPOESS VIIRS (Block 2 instrument). To contribute to active fire and FRP validation, the LDCM sensor should include the capability for fire detection in the SWIR, based on experience gained with ASTER and even more usefully a wide dynamic range channel in the MIR.

10. Key citations

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