EUROPEAN SCIENCE FOUNDATION
SETTING SCIENCE AGENDAS FOR EUROPE

Exploratory Workshop Scheme

Standing Committee for Life, Earth and Environmental Sciences (LESC)

Scientific Report

ESF Exploratory Workshop on

Improved Quantitative Fire Description With Multi-Species Inversions Of Observed Plumes

Farnham Castle (United Kingdom), 14-16 September 2009

Contents

1 Executive Summary

A recent article in the journal Science (Bowman et al. 2009) highlighted once again how smoke from vegetation fires constitutes a major source of important trace gases and aerosol particles that greatly influence the composition and functioning of the atmosphere and impacts human health and security. Recent advances in the space-based observation of open vegetation fires provide the potential for great innovation in quantifying fire emissions and other effects. New sensors and retrieval techniques open novel opportunities to derive more accurate information on fire occurrence, behaviour, severity and impacts. As an example, using the new fire radiative power observations for emission estimation bypasses the largest sources of inaccuracy of the traditional approach and introduces other, presumably smaller uncertainties. Also a multitude of satellite-based observation capabilities of the atmospheric composition in smoke plumes has been implemented during the last 10 years. At the same time, fire and atmospheric modelling capabilities have greatly improved and cover scales from chemical reactions to global long-range transport. Operational forecasting systems based on the observation and models provide real time guidance to emergency, environmental and health services related to fire spread and air quality. Furthermore, climate models now include more detailed vegetation models and their interactions with fire regimes.

The ESF LESC Exploratory Workshop: “Improved Quantitative Fire Description with Multi-Species Inversions of Observed Plumes” (Farnham Castle, UK, 14-16 September 2009) brought together scientists from nine European countries plus Brazil and the United States. They presented research on biomass burning in very diverse scientific disciplines. The discussions explored opportunities for a better quantitative understanding of the processes involved in biomass burning and searched new and innovative ways to exploit the recent developments in remote sensing, modelling and data assimilation. During the discussions, it became clear that research on wildfires has become increasingly fragmented since the 1990s because of the diversity of scientifically productive approaches to the problem. All participants agreed that a closer inter-disciplinary collaboration now bears great potential for their individual research.

There was a broad consensus that such collaboration would lead to improved quantitative air quality forecasts, assessments of global air pollution transport patterns, climate change observations, climate change predictions, and guidance for managing large-scale fire situations. Key contributions to these improvements would come from:

- the quantification of the relationships between emission factors and physical parameters that are available from remote sensing or provided from operational systems with data assimilation (e.g. humidity, accumulated precipitation, wind, spectral characteristics of fire observations, topography and vegetation characteristics),
- the derivation of estimates for other fire parameters (fuel consumption, fire spread, fire intensity and change in vegetation on longer time scales) from remote sensing data and numerical weather prediction models and
- a better integration of biogeochemical fire science with socioeconomic research and investigation of the role of driving parameters such as population density, GDP, land ownership structures and the use of wildfires as a landscape management tool.

Furthermore, the participants agreed that a coordinated and funded research network will be needed to establish the necessary inter-disciplinary collaboration in Europe, and increasingly beyond. Such a network could build on the previous achievements of field experiments during the 1990s, most of which were coordinated in the BIBEX programme, and more recent research. Coordinated activities should lead to interdisciplinary laboratory measurements and field campaigns integrating ground-based and airborne observations as well as detailed analyses of satellite data and numerical modelling results. Opportunities exist in Europe and elsewhere to organize field campaigns around prescribed burns as well as exploiting situations with very high likelihood of wildfire occurrence. Different fire regimes will need to be sampled with small experiments in, e.g., Portugal, France, Germany or Scandinavia and up-scaling to satellite-based remote sensing and the global scale will require additional large experiments. The ultimate goal would be to establish a worldwide collaboration with field experiments on different continents. Coordination is also needed to integrate the results from the laboratory and field studies into numerical systems for forecasting and monitoring atmospheric composition and land surface properties and to further improve the parameterisations for fire emissions applied in these systems.

The workshop participants plan to submit a joint proposal for an ESF Research Network for collaborative exploitation of fire experiments and model improvements as outlined above.

Further information on the workshop is available on dedicated web pages at http://www.ecmwf.int/newsevents/meetings/workshops/2009/ESF. In particular, all presentations are publicly available on the web site and the proceedings will also be made available.

2 Scientific Content of the Event

Session 1: Fire Assimilation Systems and Plume Inversions

Charles Ichoku described his work on Fire Radiative Energy (FRE) observations and observed smoke aerosol plumes, both from the satellite-based MODIS instruments. He was able to derive species-dependent "emission coefficients" that related FRP and aerosol emissions directly. This approach is contrasted with the Seiler & Crutzen (1980) and Wooster et al. approachs, which calculate emissions as product of species-dependent "emission factors" and burnt biomass estimates. The former approach calculates burnt biomass from burnt area, available fuel load and combustion efficiency, while the latter assumes proportionality with observed FRE. Charles stresses the importance of a better characterisation of fires for air-quality and climate models and advocates the advantages of the new FRE observation products for this purpose.

Frederic Chevallier presented his surface flux inversion system and demonstrated its applicability to CO2 (in the GEMS project) and to CO from African biomass burning. The surface fluxes are determined from observations of atmospheric concentrations of CO2 and CO, respectively. He sees a reduce amplitude of seasonal cycles of the North/South African fire activities.

Saulo Freitas presented the treatment of biomass burning in the operational real time forecasting system of air pollution at CPTEC/INPE in Brazil. He showed that smoke plumes occur on both local and regional scales and stressed the big influence of the initial smoke plume rise on the atmospheric fields. Consequently, his system nests a 1-d smoke plume parameterisation into the global grid. The fire source calculation is based on the Seiler & Crutzen approach.

Edward Hyer presented the FLAMBE and NAAPS systems for operational real time aerosol forecasting at the Naval Research Labs in the US. The fire source calculation is also based on the Seiler & Crutzen approach and he attributes large uncertainties to it. The system also assimilates MODIS aerosol optical depth (AOD) observations and uses this to provide feedback to the emission model, i.e. perform an inversion. However, this feedback is model dependent. It also relies heavily on the individual model, in particular its sink formulation. A comparison of the resulting total particulate matter (TPM) to the GFEDv2 inventory shows that the emission uncertainties, and the differences between bottom-up and top-down estimates of emissions in the most up-to-date systems can still reach 500%.

Joana Soares presented the IS4FIRES and SILAM systems for **Mikhail Sofiev**, who could not attend because of recently introduced complications for visa applications to the UK. The system forecasts air quality for Europe in real time and the fire source is based on the Wooster et al. approach driven by MODIS observations of thermal anomaly and FRP. A special feature is to calculate the FRP from thermal anomaly taken from a data stream without FRP product.

Johannes Kaiser presented the real time derivation of fire emissions in the GMES Atmosphere Component System (GEMS/MACC projects). It is based on the Wooster et al. approach and merges MODIS and GOES observations. A special feature of the GACS is that it assimilates observations of all the major components of the smoke plumes, i.e. aerosols, CO2 and CO, and a sensitivity of the observations of all these to the biomass burning source has been shown in GEMS.

Session 2: Fire Observations

Johann Goldammer presented "Selected Fire Highlights" from the Global Fire Monitoring Centre (GFMC), which covers all regions around the globe. He showed that climate change has already changed the fire regimes in many regions and highlighted the importance of re-growth for permanent land cover changes. Other, less recognised issues arise from the additional toxic contamination of the smoke plume originating from fires in radioactively polluted forest, e.g. around Chernobyl, and burning housing estates that have been caught in forest fires. Furthermore, the reduced visibility leads to many road and water traffic accidents in Asia. He also pointed out that European countries north of the Alps frequently use larger prescribed burns to maintain and restore biodiversity and ecosystem functioning and that these burns offer good opportunities for field measurements.

Meinrat Andreae gave an overview the composition of smoke and emphasised the dependency the flaming/smouldering (F/S) ratio and its dependency on fuel conditions, fire weather, terrain slope etc. He advocated targeted fire experiments to determine these relationships and tie them to remotely sensed proxies. Finally, he stressed that a combination of emission, injection, transport and chemical process models is required for accurate large- and meso-scale predictions of biomass smoke distributions.

Martin Wooster introduced the theory and practical issues of satellite-based observations of Fire Radiative Power (FRP) from polar orbiting and geostationary satellites. He demonstrated how such observations by MODIS and SEVIRI can be used to characterise fire regimes at high and low latitudes. The fire regime component with FRP < 10 MW below the detection limit of the current satellite instruments. Higher spatial resolution observations are needed to sample this component. The proposed German BIRD satellite would sample fires down to 1 MW and could thus contribute to the determination of site-specific emission factors.

Jose San Miguel presented the use of burnt area observations in the European Forest Fire Information System (EFFIS) at JRC. EFFIS covers the full fire cycle from danger forecast to forest fire events to active fire detection to burnt area maps to land cover damage and emission assessments to potential soil erosion estimates to vegetation regeneration and danger forecasts. It is based on national reports with resolutions down to meters and satellite observations. It service is used by forest and emergency services, e.g. to plan the distribution fire fighting planes around the Mediterranean. During the past eight years, Portugal/Spain suffered the largest damage (80% of burnt area) from forest fires in the EU in 2000-2008. Smoke plume dispersion modelling will be implemented in the EFFIS in the next couple of years by NOVELTIS, Laboratoire d'Aérologie and Cerea (Centre d'enseignement et de recherche en environnement atmosphérique).

Solene Turquety introduced the satellite-based plume observation in the thermal IR spectral range with the operational IASI instrument aboard METOP-A. Many short- and long-lived species can be detected in concentrated smoke plumes: CO, NH3, CH3OH, C2H4, HCOOH, CH3COOH, C2H2, HCN, HONO, CO2. The retrievals give good spatial and temporal coverage but lack much vertical resolution and the retrieval error is still difficult to assess. In order to provide an additional constraint and/or validation, she proposes to combine the observations with a CTM.

Session 3: Scientific Applications

Veiko Lehsten introduced the interactions of fires with JPJ-GUESS dynamic vegetation model that are implemented in the DESPITE fire model. The combined model with prescribed fire regimes is, e.g., able to reproduce the land cover distribution in Africa better than the vegetation model alone. It may improve combustion efficiency estimates with information on the fuel mix from the vegetation model.

The EU project FUME additionally accounts for the socioeconomic interactions with the fire regimes. The FIREMAN project applies simulation results in a decision making tool for politicians to inform about the expected effects of climate change and fire management, e.g. prescribed fires to reduce fire risk or fire onset at different times of the year.

Albert Simeoni introduced the physical modelling of forest fires with detailed models, which cover all spatial scales from the chemical reactions (µm) to forest fires (km) and yield a detailed description of the phenomenon, and simple models, which are fast enough to inform emergency service at field scale in real time. There is a large potential for improvements and the coupling between fire and atmosphere would aid in achieving improvements. On the other hand the detailed models could characterise the fire as a source of gases and aerosols with much detail, provided that the fuel and meteorological conditions are known.

Jim Haywood presented the modelling capabilities of pyrogenic aerosol at the UK Met Office. The aerosol used in numerical weather prediction is being updated with climatological fields from the climate model. Monthly aerosol optical depths of the climate model compare well to AERONET observations.

Guido van der Werf showed results from the upcoming GFED version 3 emission inventory, which is mostly based on burnt area observations, in contrast to version 2, which combined hot spot detections with a calibration relationship to obtain burnt areas. Bottom-up emission estimates may be limited to 30% accuracy in the near future because of large uncertainties in the emission factors, the depth of burning into soil (peat fires), the heterogeneity of the fuel load, limited spatial resolution and geo-location issues of burnt area data. The picture may be different for FRP-based emission estimates.

Martin Schultz showed that long-range transport of biomass burning plumes is frequent and that models seem to capture plumes qualitatively only if initial plume rise is accounted for and the fire data have a temporal resolution below one month. Open research questions concern the exchange between the free troposphere and the boundary layer, and thus the impact of long-range transport on local air quality at the surface. While assimilation of atmospheric constituents seems to improve the simulation of fire plumes, issues remain with respect to data coverage and cloud obscuration of fire plumes.

Jose Pereira showed that Portugal is the country with the highest fire incidence in southern Europe, considering either numbers of fires or area burnt. Forest fires represent about one third of the burnt area. The annual pyrogenic emissions are of similar magnitude as industrial and agricultural emissions in severe fire years. Since they are concentrated in time (80% of area burns in 10-15 days in summer.) and space (<1% of fires burned >90% of area in 2003.) burning areas, the air quality and environmental issues are of major concern. Most areas burn under quite specific, severe meteorological conditions, which are well characterised. His Landsat-based fire atlas covers the time period since 1975 continuously.

Patricia de Rosnay introduce the land surface analysis scheme used for numerical weather prediction at ECMWF. Currently, soil moisture is assimilated with an optimal interpolation scheme, based on the 2-m temperature and relative humidity increments of the atmospheric analysis. An Extended Kalman Filter is developed to include active and passive microwave observations of soil moisture.

Discussions and Synthesis Conclusion

The discussions evolved around open research issues on the one hand side and formulating a common vision for addressing the issues on the other hand side.

A recent article in the journal Science (Bowman et al. 2009) highlighted once again how smoke emissions from vegetation fires (in forests and other vegetation, including peatland and wetland biomes) constitute a major source of important trace gases and aerosol particles that greatly influence the composition and functioning of the atmosphere and impact human health and security. Currently observed changes of fire regimes in almost all vegetation zones are result of accumulated impacts of land-use / land-use change and human-induced climate change and reveal a trend of increasing vulnerability of ecosystems and societies to fire. Extensive application of fire in land-use change is negatively influencing biodiversity, sustainability and carrying capacity of ecosystems and perturbs global atmospheric chemistry. The most pertinent **open research issues** during the workshop discussions were:

- The apparent major discrepancy between the **emission factors** (EFs) derived in the laboratory or observed in-situ (e.g. by air-borne) and inferred from satellite observations: Flaming and smouldering fires have different EFs, which is observed in CO/CO2 ratio and the aerosol single scattering albedo. However, a method for distinguishing these fire types with satellite observations still has to be developed. Furthermore, the chemical/physical evolution of smoke on the 15-30 minute to day scale is not fully resolved. There was consensus that integrated measurement campaigns would be able to improve the EF used in the global operational systems.
- The **combustion efficiency** is another key uncertainty in emission estimates. Progress on describing this is only expected if the wider community worked together and combined in-situ observation on the ground with aircraft-based observations and various remote sensing observations. These would then need to be compared to fire spread models to improve our physical understanding of the burning process. A combination with global models would subsequently scale this understanding up to the regional regimes around the globe.
- Possible reasons for the apparent **shift between the fire activity and CO plume occurrence in South Africa** were discussed. The shift is a robust observed feature. The change of fires types with different EFs with time may play a role, as may the atmospheric circulation over South Africa, which traps emissions. Different fire types may be cause by woodlands vs. savannas burning or the onset of the raining season. Another reason may be the different vertical transport patterns in the atmosphere.
- The above issues can be also framed as a need to bridge the **gap between** the pyrogenic emissions estimated by **bottom up** models (e.g. Van der Werf 2006; Lehsten et al 2009b) calculating emissions by simulating the combustion of vegetation and **top down** approaches using inversions based on retrievals of satellite based observations of greenhouse gases, mainly CO.
- A related question that requires further research is how to **disentangle fire emissions from other sources**, for example the seasonal cycle of observed smoke may be dampened by biofuel emissions.
- Generally, a more systematic approach is needed to tie fire satellite observations which generally miss small fires and cannot observe biomass combustion in closed systems with **emission inventory estimates** which rely on often incomplete statistical data and generally neglect fires of natural origin.
- Given that the accuracy of single-species flux inversions are still being characterised, the general view was that **multi-species inversions** are too challenging in the current situation. An additional complication in CO2 inversions is introduced by the large diurnal cycle of CO2 in the boundary layer.

- The automatic operational global fire products like those from FLAMBE already provide important **tools to the fire monitoring centres** like GFMC and EFFIS. However, emergency response to fires requires data. at a higher resolution than current satellites can provide in a timely fashion.

Recent advances in the space-based observation of vegetation fires provide new potential for innovation in improving the characterization and quantification of fire emissions and effects. Present-day sensors like MODIS and SEVIRI and new retrieval techniques used for example in the fire radiative power products (e.g. Roberts and Wooster, 2008, Justice et al. 2002) provide an excellent opportunity to derive more accurate information on fire occurrence, behaviour, severity and impacts. The fire observations have recently been used to monitor and forecast atmospheric fire plumes operationally on regional and global scales (Reid et al., 2009, Freitas et al., 2005, Kaiser et al., 2009, Sofiev et al., 2009). Additionally, these systems characterise the fire plumes with the assimilation of atmospheric observations. In particular, GEMS/MACC (Hollingsworth et al., 2008) is assimilating satellite-based observations of aerosols as well as several reactive and greenhouse gases. As an example of a future application, the partitioning of carbon between aerosol, CO and CO_2 in the overall fire emissions might be determined by a concurrent inversion of plume observations of the three species. Generally, combinations of innovative observational tools and methods, as well as numerical modelling will provide improved understanding of various fire properties, such as fuel consumption, total carbon emission and its partitioning, and plume injection heights.

On the other hand, the small scale of the fire front is now better characterised than ever before. The combustion processes involved in fires are better understood (Schemel et al., 2008), the fire behaviour at laboratory (Viegas, 2004) and field (Kötz et al., 2004, Santoni et al., 2006,) scales is better described and new fire spread models are under development to provide a general description of the fire behaviour at the field scale (Filippi and Balbi, 2009). This pool of knowledge can allow bridging the gap between small and global scales in order to provide better estimation of the global fire emissions, regimes and impacts. For instance, a better understanding of the combustion dynamics (Schemel et al., 2007) can allow separating flaming and smouldering stages in a spreading fire in order to improve emission models. Smouldering combustion of peat is also a great source of greenhouse gas emission and a better understanding of the combustion dynamics can lead to a good description of the fire emissions (Rein et al., 2009).

One of the main determinants of pyrogenic emissions is the fuel load provided by the vegetation (dead or living biomass). In order to simulate these, the vegetation composition in terms of species composition as well as age class / biomass distribution has to be known. This ultimately requires a good understanding of the fire effects on vegetation and re-growth in order to correctly simulate the pre-fire conditions. An improved knowledge in these areas allows the prediction of the pyrogenic emissions and vegetation resulting from different fire application/suppression policies (Lehsten et al. 2009a). An effort to extract fire policy recommendations from modelling results for a small number of key regions is already performed in the FIREMAN project.

The participants concluded that the **open research questions could be addressed by a collaboration** that aims to:

- Determine the dependency of emission factors on parameters that are available from remote sensing or in the operational systems, e.g. humidity, accumulated precipitation, wind, spectral characteristics of fire observations, topography and vegetation characteristics.
- Determine the dependency of other fire parameters (fuel consumption, fire spread, fire intensity and change in vegetation on longer time scales) on these parameters.
- Determine the relationship between socioeconomic parameters such as population density, GDP, land ownership structures and the use and effects of wildfires as a landscape management tool.
- Thus ultimately provide better air quality forecasts, assessments of global air pollution transport patterns, climate change observations, climate change predictions, and guidance for managing large-scale fire situations.

This can be achieved through coordinated measurement campaigns consisting in prescribed burns and exploitation of wildfire opportunities. Different fire regimes will need to be sampled with small experiments in, e.g., Portugal, France, Germany or Scandinavia. A larger campaign, representative of a globally significant fire activity is envisaged in a latter part of the collaboration. To allow external colleagues to participate, a central database, providing access to the results of the experiments and advertising new ones, would be useful. The fires would need to be characterised in a multi-disciplinarily way with: firstly, observed vegetation / fuel before and after the fire, fire dynamics, spectral fire characteristics, near-field plume composition, aged plume composition and secondly, modelled characteristics with global, regional and local (fire and plume spread) models. The field campaigns would be complemented by laboratory studies of small fires and workshops would subsequently synthesise combined results. Collaboration with overseas colleagues is also seen as vital. A dedicated coordinator would have to coordinate all activities of the network.

During the 1990s the IGBP-IGAC Biomass Burning Experiment (BIBEX): "Impact of Fire on the Atmosphere and Biosphere" was conducted as activity 2.3 of IGAC Focus 2 ("Natural Variability and Anthropogenic Perturbations of Tropical Atmospheric Chemistry"). It included a number of international and interdisciplinary research campaigns in the tropics and subtropics, but also some others in the boreal zone. It included a number of international and interdisciplinary research campaigns in the tropics and subtropics, but also some others in the boreal zone:

- Southern Tropical Atlantic Regional Experiment (STARE) (Andreae et al., 1996).
- Transport and chemistry near the Equator-Atlantic (TRACE-A) (Lindesay et al., 1996).
- Southern Africa Fire-Atmosphere Research initiative (SAFARI) (Van Wilgen et al., 1997).
- Experiment for Regional Sources and Sinks of Oxidants (EXPRESSO) (Delmas et al., 1999).
- Fire Research Campaign Asia--North (FIRESCAN) (FIRESCAN Science Team, 1996).
- International Crown Fire Modelling Experiment (ICFME) (Stocks et al., 2004).
- Large Scale Biosphere-Atmosphere Experiment in Amazonia (LBA) (Avissar et al., 2002).
- Southern African Regional Science Initiative - SAFARI 2000 (Swap et al., 2003).

These research campaigns resulted in initial and broadened knowledge of:

- Characterization of the production of chemically and radiatively important gases and aerosol species from vegetation fires to the global atmosphere.
- Consequences of vegetation fire emissions on regional and global atmospheric chemistry and climate
- Short- and long term effects of fire on post-fire exchanges of trace gases between terrestrial ecosystems and the atmosphere.
- Understanding of the biogeochemical consequences of atmospheric deposition of products of vegetation fires.

Andreae and Merlet (2001) integrated the data on emissions from biomass burning that had accumulated from the BIBEX campaigns and a number of subsequent activities. The main limitation of this data is that the results were given as average values for a number of selected biomes, which does not allow a dynamic modelling of emissions as a function of ecosystem properties and fire behaviour.

During the current decade, BIBEX as a large-scale international and almost global collaborative effort was replaced by numerous small-scale projects and campaigns addressing fire ecology, fire modelling, remote sensing, etc., which produced the abovementioned new developments in the various domains. These developments would now allow the different communities to interact very productively again and determine dynamic models of fire emissions and other fire properties that were beyond the reach of BIBEX during its lifetime.

References

Andreae, M. O., J. Fishman, and J. Lindesay (1996) The Southern Tropical Atlantic Region Experiment (STARE): Transport and Atmospheric Chemistry near the Equator-Atlantic (TRACE A) and Southern African Fire-Atmosphere Research Initiative (SAFARI): An introduction, J. Geophys. Res. 101(D19), 23,519-23,520.

Andreae, M. O., Merlet, P. (2001) Emission of trace gases and aerosols from biomass burning: Global Biogeochemical Cycles, 15, 955.

Avissar, R., P. L. Silva Dias, M. A. F. Silva Dias, and C. Nobre (2002) The Large-Scale Biosphere-Atmosphere Experiment in Amazonia (LBA): Insights and future research needs, *J. Geophys. Res.* 107(D20), 8086, doi:10.1029/2002JD002704.

Bowman**,** D., Balch, J. Artaxo, P., Bond, W., Carlson, J. et al. (2009) Fire in the Earth system, *Science* 324, 481-484.

Delmas, R. A., et al. (1999) Experiment for Regional Sources and Sinks of Oxidants (EXPRESSO): An overview, J. Geophys. Res. 104(D23), 30,609-30,624.

Filippi, J.B., Balbi, J.H. (2009) Validation of a physics-based fire spread model and simulation method on a large wildfire accident. Int. J. of Wildland Fire, to appear.

FIRESCAN Science Team (1996) Fire in ecosystems of boreal Eurasia: The Bor Forest Island Fire Experiment, Fire Research Campaign Asia-North (FIRESCAN). In: Biomass burning and global change. Vol.II (J.S.Levine, ed.), 848-873. The MIT Press, Cambridge, MA.

Freitas, S.R., K.M. Longo, M.A.F. Silva Dias, P.L. Silva Dias, R. Chatfield, E. Prins, P. Artaxo, G.A. Grell, F.S. Recuero (2005) Monitoring the Transport of Biomass Burning Emissions in South America, Env. Fluid Mech. (2005) 5: 135–167.

Goldammer, J.G., and J. Penner (1998) BIBEX in the future. Int. Global Atmospheric Chemistry (IGBP) Project Newsletter IGACtivities No. 15, 19.

Hollingsworth, A., R. Engelen, C. Textor, O. Boucher, F. Chevallier, A. Dethof, H. Elbern, H. Eskes, J. Flemming, C. Granier, J.W. Kaiser, J.J. Morcrette, P. Rayner, V.H. Peuch en L. Rouil (2008) Toward a Monitoring and Forecasting System For Atmospheric Composition: The GEMS Project, Bull. Amer. Meteor. Soc., 89(8), 1147, doi: 10.1175/2008BAMS2355.1.

IGAC (1998) BIBEX Special Issue. Global Atmospheric Chemistry (IGBP) Project Newsletter IGACtivities No. 15, 1-19.

Justice, C.O., Giglio, L., Korontzi, S., Owens, J., Morisette, J.T., Roy, D., Descloitres, J., Alleaume, S., Petitcolin, F., Kaufman, Y. (2002) The MODIS fire products. RSE 83, 244.

Kaiser, J.W., M. Suttie, J. Flemming, J.-J. Morcrette, O. Boucher, and M.G. Schultz (2009) Global Real-time Fire Emission Estimates Based on Space-borne Fire Radiative Power Observations. AIP Conference Proceedings, 1100:645.

Kötz, B., Schaepman, M.E., Morsdorf, F., Bowyer, P., Itten, K.I., & Allgöwer, B. (2004) Radiative transfer modeling within a heterogeneous canopy for estimation of forest fire fuel properties, Remote Sensing of Environment, 92, 332.

Lehsten, V., Tansey, K. J., Balzter, H., Thonicke, K., Spessa, A., Weber, U., Smith, B. & Arneth, A. (2009a) Estimating carbon emissions from African wildfires. Biogeosciences

Lehsten, V., Arneth, A., Thonicke, K. & Spessa, A. (2009b subm) Tree-Grass Coexistence in Savannahs: Testing Two Mechanisms

Lindesay, J.A., M.O. Andreae, J.G. Goldammer, G. Harris, H.J. Annegarn, M. Garstang, R.J. Scholes, and B.W. van Wilgen (1996) International Geosphere-Biosphere Programme/International Global Atmospheric Chemistry SAFARI-92 field experiment: Background and overview. Special Issue TRACE-A and SAFARI, J. Geophys. Res. 101, No. D19, 23,521-23,530.

Reid, J. S.; Hyer, E. J.; Prins, E. M.; Westphal, D. L.; Zhang, J.; Wang, J.; Christopher, S. A.; Curtis, C. A.; Schmidt, C. C.; Eleuterio, D. P.; Richardson, K. A.; Hoffman, J. P. (2009) Global Monitoring and Forecasting of Biomass-Burning Smoke: Description of and Lessons from the Fire Locating and Modeling of Burning Emissions (FLAMBE) Program, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 2(2), 1, doi: 10.1109/JSTARS.2009.2027443.

Rein, G., Cohen, S., Simeoni, A. (2009) Carbon emissions from smouldering peat in shallow and strong fronts. Proceedings of the Combustion Institute, 32(2), 2489, doi: 10.1016/j.proci.2008.07.008.

Roberts, G., Wooster M.J. (2008) Fire detection and fire characterization over Africa using Meteosat SEVIRI, IEEE Transactions on Geoscience and Remote Sensing, 46, 1200, doi: 10.1109TGRS.2008.915751

Santoni, P.A., Simeoni, A., Rossi, J.L., Bosseur, F., Morandini, F., Silvani, X., Balbi, J.H., Cancellieri, D., Rossi, L. (2006) Instrumentation of wildland fire: Characterisation of a fire spreading through a Mediterranean shrub, Fire Safety Journal, 41(3), 171.

Schemel, C., Simeoni, A., Biteau, H., Riviera, J., Torero, J.L. (2008) A calorimetric study of wildland fuels, Experimental Thermal and Fluid Science, 32(7): 1381, doi: 10.1016/j.expthermflusci.2007.11.011.

Sofiev, M., R. Vankevich, M. Lotjonen, M. Prank, V. Petukhov, T. Ermakova, J. Koskinen, and J. Kukkonen (2009) An operational system for the assimilation of the satellite information on wild-land fires for the needs of air quality modelling and forecasting, Atmos. Chem. Phys., 9, 6833.

Stocks, B J., M E. Alexander, and R A. Lanoville (2004) Overview of the International Crown Fire Modelling Experiment (ICFME). Can. J. For. Res. 34 (8), 1543-1547.

Swap, R. J., H. J. Annegarn, J. T. Suttles, M. D. King, S. Platnick, J. L. Privette, and R. J. Scholes (2003) Africa burning: A thematic analysis of the Southern African Regional Science Initiative (SAFARI 2000), J. Geophys. Res. 108(D13), 8465, doi:10.1029/2003JD003747.

Viegas, D. X. (2004) Slope and wind effects on fire propagation. International Journal of Wildland Fire, 13 (2), 143, doi: 10.1071/WF03046.

Van Wilgen, B., M.O.Andreae, J.G. Goldammer, and J. Lindesay (eds.) (1997) Fire in Southern African savannas. Ecological and atmospheric perspectives. The University of Witwatersrand Press, Johannesburg, South Africa, 256 p.

Van Der Werf, G. R., Randerson, J. T., Giglio, L., Collatz, G. J., Kasibhatla, P. S. & Arellano, A. F. (2006) Interannual variability in global biomass burning emissions from 1997 to 2004. Atmospheric Chemistry and Physics, 6, 3423-3441.

3 Assessment of the Results, Contribution to the Future Direction of the Field

Feedback by Participants

The general discussion session on the final day started with a collection of the perceived most important aspects of the workshop from each of the participants. They turned out to cover different categories; with respect to the general approach of the workshop the following were named:

- interaction of people
- multitude of the aspects covered
- width of the range of the presented applications
- informative nature of presentations and discussions
- forward looking perspective of the discussions
- development of a long-term vision

The following scientific aspects have been highlighted as interesting for future research and collaborations of individual participants:

- increased vulnerability to wildfires due to climate change
- health / air quality impact of wildfires
- high resolution burned area observations
- fire spread modelling
- anthropogenic control of fire regimes

With respect to possible collaborations developing from the workshop the following aspects were highlighted:

- consensus on potential of new observation approach involving global satellites observations of fire radiative power
- need for more integration across scales and of observations and models
- potential of dynamic emission factors that are related to observable remote sensing data
- combination of fire reports and remote sensing
- FRP/FRE approach for emissions
- coordinated multi-disciplinary field campaign
- integration of fire and biogeochemical cycles
- evolution of scientific products to operational public services
- assimilation of observable remote sensing data into a model and subsequent representation as model state vector

Scientific issues that may benefit:

- feedback to vegetation & fires
- fire spread
- vegetation re-growth
- exploitation of long term observations
- combustion completeness

The informal feedback given by the participants was very positive throughout. Many stressed that they had learnt a lot from colleagues working in different fields of science whom they met for the first time.

Assessment

The workshop came at an ideal point in time because, after a period of enhanced collaboration in the BIBEX campaigns during the 1990s, various aspects of research on biomass burning have advanced more isolated and are now in excellent positions to contribute new techniques to and benefit from inter-disciplinary collaborations. The new advances include:

- Satellite-based fire radiative power observations yield more quantitative information than the traditional hot spot products and complementary quantitative information to burnt area products.
- Atmospheric forecasting systems are predicting global aerosol and CO distribution operationally and in real time for public air quality forecasts and health impact studies, based on fire observations.
- Satellite-based atmospheric composition observations determine the composition of large smoke plumes with regard to various species.
- Fire spread models are able to bridge the spatial scales from chemical reactions (μm) to individual fires (km) and inform emergency services.

- Combined vegetation and fire models are able to reproduce land cover type distributions depending on different fire regimes.
- Changes in fire regimes attributed to climate change are observed.

The workshop brought together highly distinguished researchers from nine European countries plus Brazil and the United States. They represented research on biomass burning in diverse scientific disciplines, so that many participants had never met before and had even not been aware of some of the research fields presented. The participants showed very much interest in each other's research fields and possible collaborations. It became obvious that many research fields could benefit from the new advances. Consequently, the discussions led to a broad consensus that future collaboration will aid all represented scientific fields and improve our understanding of fire processes, thus leading to improved models and predictions for immediate fire spread, air quality and health impacts of fires and the role of changing fire regimes in different climate change scenarios.

The participants agree that keeping the momentum from the workshop going will require dedicated coordinated field campaigns and regular workshops. An initial guiding question for collaboration should be to determine the dependency of emission factors for various species on globally available remote sensing products model state parameters. The collaboration should furthermore aim to bridge the gaps between the spatial scales from chemical reactions to global distributions and between the different applications in emergency response air quality forecasting and vegetation modelling in climate predictions. An additional dimension is the socioeconomic interaction.

The envisaged coordinated field campaigns involve air-borne, space-borne, and ground-based in-situ and/or remote sensing observations. By the very nature of the fires under investigation, the fires need to be contained safely and may even be a natural disaster zone. Therefore, the coordination of such campaigns entails a large workload that can only be delivered by a dedicated full-time coordinator. A relatively large ESF Research Network with a dedicated coordinator seems ideally suited for ongoing collaboration between the workshop participants and further partners. It should organise several European campaigns and evolve into a global network towards the end of its lifetime. Subsequent campaigns could then apply the developed methodology to characterise fire regimes on other continents and thus achieve a truly global picture.

Such a network might seem relatively expensive at first sight but stress that it will be an excellent investment in terms of establishing an international, long-term, multi-disciplinary collaboration that will result in an improved understanding of the earth system and also directly benefit the citizens with improved public services.

Actions from the Workshop

- Workshop proceedings with extended abstracts by the participants shall be published in the MACC report series, funded by EU's FP7 GMES project MACC.
- News items shall be published in the ECMWF Newsletter, the iLEAPS newsletter and, possibly, the EOS Transactions.
- A proposal for an ESF Research Network with the discussed scope shall be prepared and submitted.

4 Final Programme

Monday 14 September 2009

Morning	*Arrival*
12.00-13.00	*Lunch*
13.00-13.20	**Welcome by Convenors** **J. Kaiser, M. Schultz, M. Wooster** (ECMWF, FZJ, KCL)
13.20-13.40	**Presentation of the European Science Foundation (ESF)** **P. Pelkonen,** ESF Standing Committee for Life, Earth and Environmental Sciences (LESC)
13.40-17.30	**Afternoon Session: Fire Assimilation Systems and Plume Inversions**
13.40-14.00	**"Relating Fire and Plume Observations: Past Studies"** **C. Ichoku** (NASA)
14.00-14.20	**"Inversion for Carbon Source/Sink Attribution"** **F. Chevallier** (LSCE/IPSL)
14.20-14.40	**"Pyrogenic CO and Aerosol Modelling at INPE/CPTEC"** **S. Freitas** (INPE/CPTEC)
14.40-15.00	**"Visibility Forecasts at NRL"** **E. Hyer** (NRL)
15.00-15.30	*Coffee / tea break*
15.30-15.50	**"Fire Assimilation over Europe in IS4FIRES and SILAM"** **J. Soares** (FMI)
15.50-16.10	**"Fire in the GMES Atmosphere Component Service"** **J. Kaiser** (ECMWF)
16.10-17.00	**Discussion**
19.00	*Dinner, followed by informal discussions in the Great Hall*

Tuesday 15 September 2009

09.00-12.00	**Morning Session: Fire Observations**
09.00-09.20	**"Selected Fire Highlights"** **J.G. Goldammer** (GFMC/UNU/MPI Chemistry)
09.20-09.40	**"What's in the Smoke?"** **M.O. Andreae** (MPI Chemistry)
09.40-10.00	**"Active Fire Observations"** **M. Wooster** (KCL)
10.00-10.20	**"Burnt Area Observations"** **J. San Miguel** (JRC)
10.20-10.50	*Coffee / Tea Break*
10.50-11.10	**"Atmospheric Smoke Plume Observations"** **S. Turquety** (LMD/IPSL)
11.10-12.00	**Discussion**
12.30-14.00	*Lunch*
14.00-17.30	**Afternoon Session: Scientific Applications**

14.00-14.20	**"Ecological/Fire Modelling and the FUME IP"** **V. Lehsten** (U Lund)
14.20-14.40	**"Fire Spread Modelling"** **A. Simeoni** (U Corsica)
14.40-15.00	**"Pyrogenic Aerosol Impact on Climate Modeling"** **J. Haywood** (UK Met Office)
15.00-15.20	**"Fires and the Carbon Cycle"** **G. van der Werf** (U Amsterdam)
15.20-15.50	*Coffee / tea break*
15.50-16.10	**"Long-Range Transport of Fire Plumes"** **M. Schultz** (FZJ)
16.10-16.30	**"Environmental Effects of Fires in Portugal"** **J. Pereira** (IICT Lisbon)
16.30-16.50	**"Operational Surface Parameter Assimilation at ECMWF"** **P. de Rosnay** (ECMWF)
16.50-17.30	**Discussion**
18.30	*Dinner, followed by informal discussions in the Great Hall*

Wednesday 16 September 2009

09.00-12.00	**Morning Session: Synthesis Conclusions**
09.00-09.30	**Summaries of the Discussions on Days 1 & 2**
09.30-10.30	**Discussion of Future Research Paths**
10.30-11.00	*Coffee / Tea Break*
11.00-11.50	**Discussion of Future Research Paths, cont.**
11.50-12.00	**Wrap-Up**
12.00-13.00	*Lunch*
13.00	*End of Workshop and Departure*

5 List of Participants

Convenor:

1. Johannes KAISER
Research Department
European Centre for Medium-range
Weather Forecasts
Reading RG2 9AX
United Kingdom
j.kaiser@ecmwf.int

Co-Convenors:

2. Martin SCHULTZ
ICG-2
Forschungszentrum Jülich
52425 Jülich
Germany
m.schultz@fz-juelich.de

3. Martin WOOSTER
Department of Geography
King's College London
London WC2R 2LS
United Kingdom
martin.wooster@kcl.ac.uk

ESF Representative:

4.Paavo Pelkonen
Faculty of Forest Science
University of Joensuu
P.O. Box III
8010 Joensuu
Finland
paavo.pelkonen@forest.joensuu.fi

Participants:

5. Meinrat O. ANDREAE
Biogeochemistry Department
Max Planck Institute for Chemistry
P.O. Box 3060
55020 Mainz
Germany
andreae@mpch-mainz.mpg.de

6. Frederic CHEVALLIER
Laboratoire des Sciences du Climat et de
l'Environnement
L'Orme des Merisiers
Bat 701, Point courrier 129
91191 Gif sur Yvette Cedex
France
frederic.chevallier@lsce.ipsl.fr

7. Patricia DE ROSNAY
Research Department
European Centre for Medium-range
Weather Forecasts
Reading RG2 9AX
United Kingdom
patricia.rosnay@ecmwf.int

8. Saulo FREITAS
Grupo de Modelagem da Atmosfera e
Interfaces - GMAI
Divisão de Modelagem e Desenvolvimento
Centro de Previsão de Tempo e Estudos
Climáticos - INPE
Rodovia Presidente Dutra, km 39
CEP 12630-000
Cachoeira Paulista
SP
Brazil
saulo.freitas@cptec.inpe.br

9. Johann G. GOLDAMMER
The Global Fire Monitoring Center
(GFMC)
Fire Ecology Research Group
Max Planck Institute for Chemistry
c/o Freiburg University / United Nations
University (UNU)
Georges-Koehler-Allee 75
79110 Freiburg
Germany
johann.goldammer@fire.uni-freiburg.de

10. Jim HAYWOOD
Met Office W080
Cordouan 2
FitzRoy Road
Exeter EX1 3PB
United Kingdom
jim.haywood@metoffice.gov.uk

11. Edward HYER
Naval Research Laboratory
7 Grace Hopper St
Monterey CA 93943
USA
edward.hyer.ctr@nrlmry.navy.mil

12.Charles ICHOKU
Climate & Radiation Branch, Code 613.2
NASA Goddard Space Flight Center
Greenbelt MD 20771
USA
charles.ichoku@nasa.gov

13. Veiko LEHSTEN
Department of Physical Geography and Ecosystems Analysis (INES)
Centre for GeoBiosphere Science
Lund University
Sölvegatan 12
223 62 Lund
Sweden
veiko.lehsten@nateko.lu.se

14. Ilaria PALUMBO
DG Joint Research Centre - European Commission
Institute for Environment and Sustainability
Global Environment Monitoring Unit
Monitoring Of Natural resources for DEvelopment (MONDE)
Via Fermi s/n
21027 Ispra (Va)
Italy
ilaria.palumbo@jrc.ec.europa.eu

15. Ronan PAUGAM
Department of Geography
King's College London
London WC2R 2LS
United Kingdom
ronan.paugam@kcl.ac.uk

16. José Miguel PEREIRA
Department of Forestry
Technical University of Lisbon
Tapada da Ajuda
1349-017 Lisboa
Portugal
jmocpereira@gmail.com

17. Jesús SAN-MIGUEL-AYANZ
European Commission - DG Joint Research Centre
Institute for Environment and Sustainability
Land Management & Natural Hazards Unit - FOREST (TP 261)
Via Fermi s/n
21027 Ispra (Va)
Italy
jesus.san-miguel@jrc.it

18. Albert SIMEONI
Forest Fire Research Team
UMR CNRS 6134 - SPE
Universita di Corsica
BP 52
20250 Corte
France
simeoni@univ-corse.fr

19. Adrian SIMMONS
European Centre for Medium-range Weather Forecasts
Reading RG2 9AX
United Kingdom
adrian.simmons@ecmwf.int

20. Joana SOARES
Finnish Meteorological Institute
Air Quality Research
Erik Palminen Aukio
00560 Helsinki
Finland
joana.soares@fmi.fi

21. Jörg TRENTMANN
Deutscher Wetterdienst
Frankfurter Straße 135
63067 Offenbach
Germany
joerg.trentmann@dwd.de

22. Solène TURQUETY
Laboratoire de Meteorologie Dynamique
Ecole Polytechnique
91128 Palaiseau Cedex
France
solene.turquety@lmd.polytechnique.fr

23. Guido VAN DER WERF
Department of Hydrology and Geo-environmental Sciences
Faculty of Earth and Life Sciences
Vrije Universiteit
De Boelelaan 1085
1081 HV Amsterdam
The Netherlands
guido.van.der.werf@falw.vu.nl

24. Marta García VIVANCO
Atmospheric Pollution Unit
Environmental Department
CIEMAT
Avda. Complutense 22
Madrid 28040
Spain
m.garcia@ciemat.es

6 Statistical Information on Participants

Countries of Origin

(according to affiliation, including convenors and ESF representative)

1. Brazil	1
2. Finland	2
3. France	3
4. Germany	4
5. International Organisations	5
6. Portugal	1
7. Spain	1
8. Sweden	1
9. The Netherlands	1
10. United Kingdom	3
11. United States	2

Gender

• Female	5
• Male	19