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PAGES 369–380

New Perspectives on African Biomass Burning Dynamics

PAGES 369–370

Biomass burning is a key Earth system process and, in particular a major element of the terrestrial carbon cycle and a globally significant source of atmospheric trace gases and aerosols. Smoke emitted during combustion affects air quality, atmospheric chemical composition, and Earth's radiation budget [*Le Canut et al.*, 1996]. In terms of carbon emissions, vegetation fires are, globally and on average, believed to generate emissions equivalent to between perhaps one third and one half of those from fossil fuel combustion, and savanna fires are responsible for around 50% of the global vegetation fire carbon release [*Williams et al.*, 2007].

At the continental scale, Africa is, on average, the single largest source of biomass burning emissions, responsible for 30–50% of total global annual fuel combustion [*Andreae*, 1991; *van der Werf et al.*, 2006]. African burning is characterized by two distinct burning seasons: primarily between October and March in the Northern Hemisphere and between June and November in the Southern Hemisphere [*Giglio et al.*, 2006]. In Africa, the vast majority of fires result from anthropogenic burning, associated, for example, with farming and livestock practices. This pattern of human-initiated ignitions, together with the daily meteorological dynamics of wind and relative humidity, contribute to a strong diurnal variability in the number and extent of fires [*Edwards et al.*, 2006].

To shed further light on the quantity of carbon and other emissions released by such fires, the spatial and temporal dynamics of African biomass burning needs to be well understood. This article illustrates how relatively new satellite-based sensors and methods can be utilized to derive estimates of the rates and total amounts of biomass burnt over the African continent, which can then be used to estimate emissions magnitudes.

By G. Roberts and M. J. Wooster

Role of Earth Observation in Estimating Biomass Burning Emissions

Quantifying biomass burning emissions of carbon, trace gases, and aerosols usually requires reliable estimates of the amount of fuel combusted. Such estimates were first derived from assessments of fire return intervals (i.e., the time interval between successive fires at a given location), together with aggregated fuel loads and a combustion completeness factor describing the proportion of available fuel that actually burns. More recently, satellite-based measures of burned area have largely replaced the use of fire return interval statistics [*Scholes et al.*, 1996]. Although this modeling approach is conceptually simple, and satellites are now providing excellent burned-area data at continental scales [*Roy et al.*, 2005], the requirement to still estimate spatiotemporal variations in fuel load and combustion completeness introduces potentially large uncertainties since these parameters can be difficult to assess reliably, especially over large areas and at varying timescales.

An alternative approach is offered by the possibility of estimating fuel combustion rates more directly via measurement of the amount of energy being emitted by the fire: $(C_6H_{10}O_5)_n + O_2 + \text{ignition} \rightarrow H_2O + CO_2 +$ heat yield. *Kaufman et al.* [1996] first demonstrated that such an approach might help quantify fire aerosol emissions, while *Wooster* [2002] and *Wooster et al.* [2005] made the first comparisons between fuel consumption estimates and the radiative component of the fuel heat yield. By measuring radiative energy emissions from geostationary remote sensing satellites, very high temporal resolution information on the fire and associated emissions' diurnal cycle can be provided, and the instantaneous observations of fire radiative power (FRP; the rate of fire radiative energy emission over the full wavelength range, measured in watts) can be integrated over time to estimate total amounts of fuel consumed.

Until 2002, geostationary fire detection was only possible using data from the NOAA Geostationary Operational Environmental Satellites (GOES), positioned over the Americas, since only these provided measurements in the middle infrared (MIR; 3–5 micrometers) spectral region necessary to detect high-temperature but highly subpixel heat sources [*Robinson*, 1991; *Prins et al.*, 1998].

However, the launch of the European Organisation for the Exploitation of Meteorological Satellites's (EUMETSAT) Meteosat 8 and Meteosat 9 (formerly called Meteosat Second Generation; MSG) spacecraft in 2002 and 2005, respectively, has now brought this capability to Africa and Europe. The Spinning Enhanced Visible and Infrared Imager (SEVIRI) carried on board the MSG series has a spatial resolution of around 3 kilometers at nadir, and a full Earth disk temporal resolution of 15 minutes. Using early examples of SEVIRI data collected during the instrument's commissioning phase, together with multispectral fire pixel detection techniques similar to those used previously with polar-orbiting sensors [*Giglo et al.*, 2003] and with GOES [*Prins et al.*, 1998], *Roberts et al.* [2005] demonstrated how African fires can be detected and quantified with SEVIRI. Here we illustrate more detailed examples of African fire dynamics derived from longer-term SEVIRI fire detections made during the instrument's operational phase, and we use *Wooster et al.*'s [2005] fire radiative power measurement method to calculate fuel consumption rates and totals across large areas of the African continent.

Africa Biomass Burning Dynamics

Figures 1a and 1b present examples of SEVIRI-derived FRP measures and the equivalent continental-scale biomass combustion rates for February and August 2004, while Figure 2 indicates the locations and timings of the fires themselves.

Figures 1a and 1b illustrate the extreme diurnal variability of African biomass burning, with peak fire activity occurring daily between midday and 1500 UTC. The graphs illustrate the potential difficulties of relying solely on "nighttime only" active fire products, such as the World Fire Atlas [*Arino et al.*, 1999]. The diurnal distribution of fire activity is slightly asymmetric: It is generally left skewed and with a slightly longer tail to the right of the daily afternoon peak. Maximum combustion rates based on these observed FRP measures are equivalent to 110 tons of

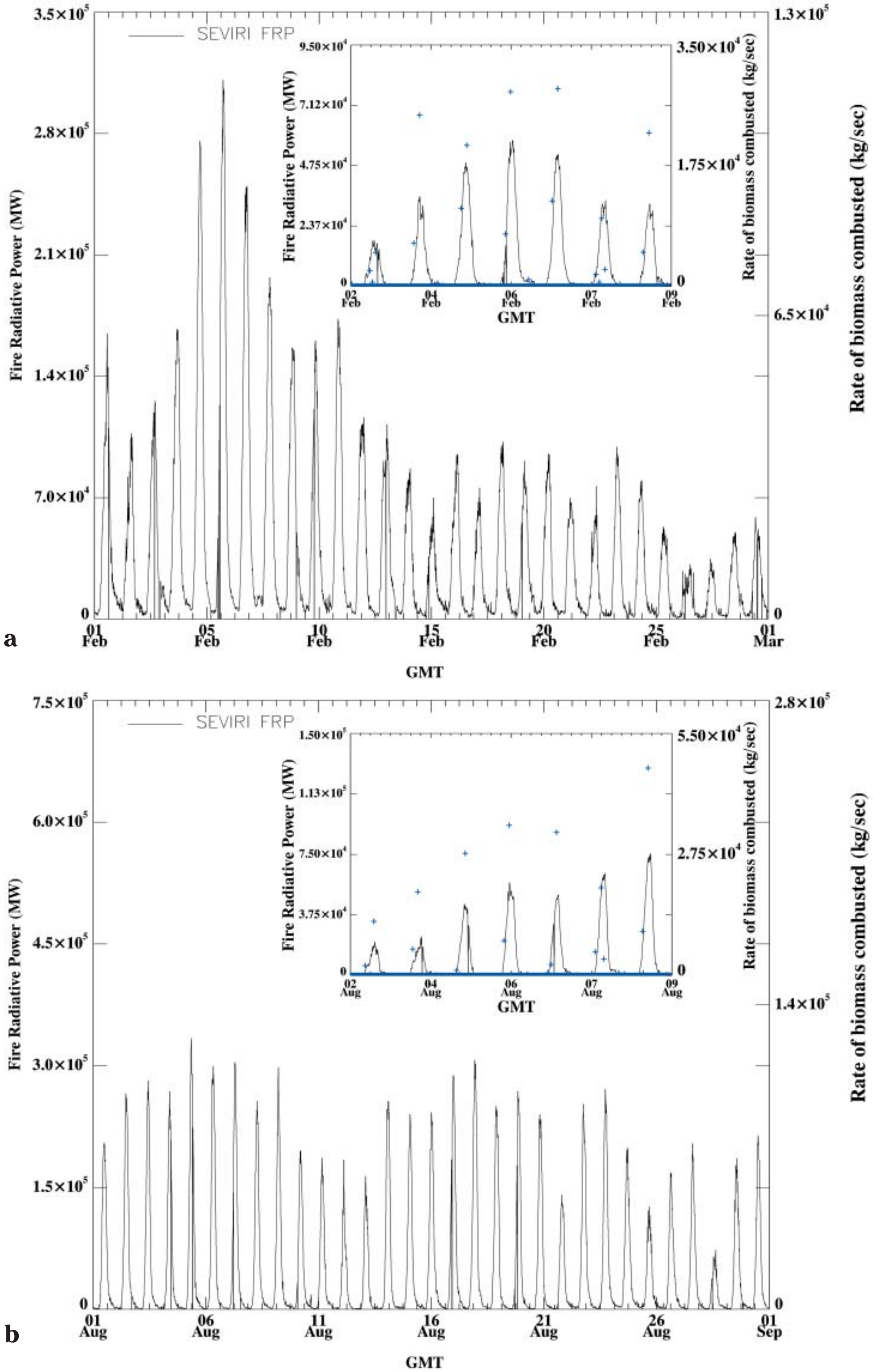

Fig. 1. (a) Spinning Enhanced Visible and Infrared Imager (SEVIRI) fire radiative power (FRP) temporal dynamics over Northern Hemisphere Africa in February 2004. The inset illustrates SEVIRI and Moderate Resolution Imaging Spectroradiometer (MODIS) FRP temporal trajectories over a 10° × 10° region centered at 5°/15° (latitude/longitude). (b) SEVIRI FRP temporal dynamics over Southern Hemisphere Africa in August 2004. The inset illustrates SEVIRI and MODIS FRP temporal trajectories over a 10° × 10° region centered at -15°/30° (latitude/longitude). Blue crosses in insets are MODIS FRP data.

biomass burning per second during both February and August. The trend in February is one of decreasing burning with time, since February is toward the end of the fire season in Northern Hemisphere Africa. The large diurnal cycle emphasizes the usefulness of these high temporal resolution data for characterizing fire dynamics, and work by *Reid et al.* [2004] has previously highlighted the predictive improvements gained by incorporating such geostationary fire detections into models of aerosol production and transport.

The Moderate Resolution Imaging Spectroradiometer (MODIS) sensor, on board the EOS Terra and Aqua spacecraft, can also be used to detect fires and make FRP measurements [*Giglio et al.*, 2007]. The inner plots in Figures 1a and 1b present FRP temporal dynamics over a $10° \times 10°$ region as observed by SEVIRI and MODIS. While each MODIS sensor typically acquires only two observations per day within this area, these do appear sufficient to broadly capture the nature of the fire diurnal cycle. Furthermore, since MODIS's nadir spatial resolution is 1 kilometer, as compared with around 3 kilometers for SEVIRI, MODIS can detect fires that are many times smaller or less strongly burning than can SEVIRI.

Each of these weaker fires emits far less radiant energy (and thus less carbon and smoke emissions) per unit of time than the larger and/or more intensely burning fires that SEVIRI can detect; however, because the smaller fires are more numerous, SEVIRI typically somewhat underestimates the true overall FRP within an area when compared with a simultaneous measure made by MODIS, as can be seen in Figures 1a and 1b. The underestimation is particularly evident around the afternoon combustion peak, when the number of fires is greatest. *Roberts et al.* [2005] found that when averaged over many days, SEVIRI underestimates regional FRP by around 40% when compared with simultaneous measurements made by MODIS, and the data in Figures 1a and 1b support this finding. Of course, the advantage of the geostationary sensors is that they also provide many dozens of observations outside of the MODIS overpass times as well, and comparisons with higher spatial resolution sensors such as MODIS can allow adjustments to be made for these "missing" fires.

The work presented here highlights the complementarity of geostationary and polar-orbiting sensors for quantifying biomass burning over Africa, and perhaps in the future over other regions as well. SEVIRI is capable of characterizing the diurnal fire cycle to an unprecedented degree of detail, while MODIS can detect many of the lower-intensity and smaller fires that remain undetected by current geostationary instruments. Integrating the SEVIRI-derived FRP measures over time provides an estimate of 33 teragrams (10^{12} grams; Tg) of biomass burned in February and 44 Tg in August. Weighting the SEVIRI-observed FRP measures by the proportion of energy omitted with respect to the simultaneous MODIS measures, the cloud fraction in a 1° grid cell (i.e., to account for potential fires that are unobserved due to obscuring cloud cover), and the atmospheric transmissivity in the SEVIRI MIR spectral channel, these estimates rise to 75 and 100 Tg, respectively (with the combustion rate measures shown in Figures 1a and 1b rising by the same factor).

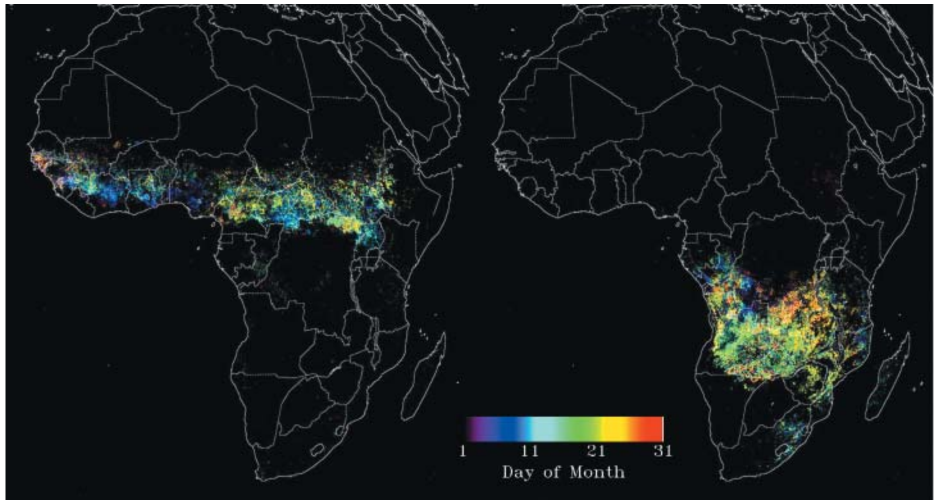

Fig. 2. SEVIRI-derived maps of active fire detections for (left) February and (right) August 2004.

The combination of SEVIRI- and MODIS-derived FRP measures provides new insight into the diurnal variability of African biomass burning. Such quantification of the combustion rate diurnal cycle, coupled with the more direct method of emissions estimation, is anticipated to lead to improvements in modeling the production and transport of biomass burning emissions of carbon, trace gases, and aerosols over Africa, the continent upon which the majority of open biomass burning occurs.

Acknowledgments

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Assessing the Publication Productivity and Impact of Eminent Geoscientists

PAGES 370–371

Publication is a critical component of modern science. By publishing their findings, scientists can ensure that their results are disseminated and substantiated. This brief report analyzes the publication and citation histories of American Geophysical Union (AGU) Fellows to elucidate different styles of productivity in the geoscience community. AGU Fellows are arguably the most eminent Earth scientists, recognized by their peers for their leadership within and outside the community.

The general rule of "publish or perish" underrates the importance of impact. Citations matter. Eminent scientists from all disciplines are more likely to have a handful of highly cited publications than to have a high number of publications [*Cole and Cole*, 1973]. Nobel Prize winners' groundbreaking research papers are usually highly cited and cited for far longer than the average paper [*Zuckerman*, 1977]. Citations are strongly correlated with other reputation-based measures of scientific quality, such as honorific awards and peer evaluations [see, e.g., *Cole and Cole*, 1973; *Cole*, 1979, 2000].

Citations can be misleading if they are interpreted as an absolute measure of quality or impact. The number of citations a publication accrues is the result of a combination of factors, such as the quality of work, the scientist's visibility, his or her integration into scientific networks, the size of the citation community, and the journal's standing and accessibility [e.g., *Creamer*, 1998; *Zuckerman et al.*, 1991]. Papers may be referenced without being read, or they may be cited for minor technical details, ancillary to the paper's central findings [*Latour*, 1987]. Self-citations can also dilute the numbers, although a study of 4816 journals found that the average self-citation rate (self-citations as a proportion of total citations) was 12.4% with a median of 9.0% [*Thomson Scientific*, 2004]. A paper with a controversial finding can garner a high number of citations in the form of negative references; however, research has shown that the frequency of negative citations is actually relatively low, especially in the natural sciences [*Small*, 1982; *Hargens*, 2000; *White*, 2000].

In an effort to evaluate criteria for success in the geosciences, we analyzed the citation and publication history of a random sample of 115 AGU Fellows. The data were collected between May 2005 and March 2006. AGU reports a membership of 48,000 scientists from around the world. According to the AGU Web site, there are more than 900 Fellows, of which fewer than 10% are women. Our sample group was composed of 69 men and 46 women. The overrepresentation of women was a deliberate effort to compile numbers that were significant enough to evaluate gender differences. The Fellows ranged in age from 15 to 48 years post-Ph.D. We built our publication and citation data set from the Institute for Scientific Information (ISI) Science Citation Index. To avoid penalizing those members who publish in publications that are not indexed by the ISI (e.g., book chapters), we used the "cited reference search" (which captures citations to book chapters and non-ISI-indexed journals) rather than the "general search."

The average AGU Fellow from our sample is 28 years post-Ph.D., has four cited publications per year, and receives 35 citations per publication (Table 1), although there is a great deal of variance in the sample. No statistically significant gender differences in productivity were observed. Similarly, productivity did not vary according to subfield (e.g., seismology, planetary science, ocean sciences, etc.). The total number of publications and citations increases with age, but the number of citations per publication is not dependent on the age of the Fellow.

To examine different publication patterns among the Fellows, we applied a method for classifying different types of scholars developed by *Cole and Cole* [1973]. Their analysis of a random sample of 499 scientists suggested that scholars can be classified into

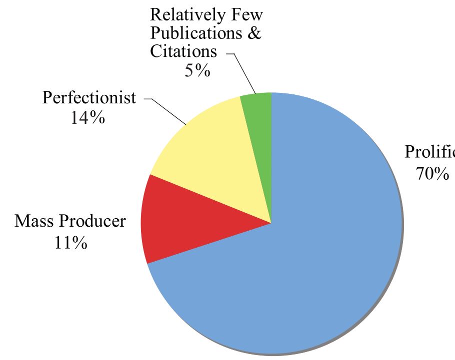

Fig. 1 AGU Fellows: different types of scholars.

four categories based on citation and publication patterns. Prolific scientists publish often and are highly cited. Mass producers publish often, but they are not cited as highly as prolific scientists. Perfectionists do not publish often, but the papers they do publish are highly cited. Silent scientists do not publish often, and when they do, their publications do not garner a significant amount of citations.

We applied this framework to the AGU Fellow sample to assess how standardized measures of productivity and quality characterize individuals considered eminent by the geoscience community (Table 2). We used a threshold of three or more cited publications per year as the benchmark of a high publication rate and a threshold of 21 citations per publication as the benchmark of a high citation rate.

These thresholds are consistent with other indicators and accepted standards. National averages of scientific publication output range from two to three publications per year per scholar [*Xie and Shauman*, 2003]. The citation threshold reflects a publication analysis produced by the University of Texas Institute for Geophysics that found an average of 16–25 citations per publication for all publications authored by scientists at the Institute [*Frohlich and Resler*, 2001].

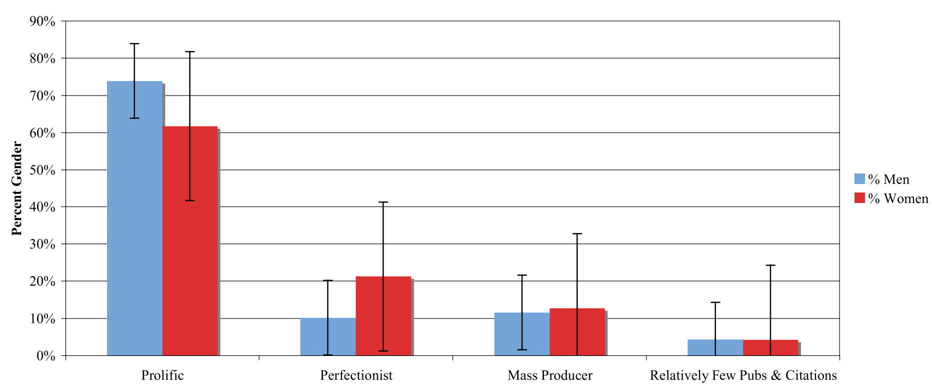

Fig. 2. AGU Fellows: gender differences among different types of scholars (N = 115).