Development of a virtual active fire product for Africa through a synthesis of geostationary and polar orbiting satellite data

Patrick H. Freeborn *, Martin J. Wooster, Gareth Roberts, Bruce D. Malamud, Weidong Xu

Environmental Monitoring and Modelling Research Group, King's College London, Department of Geography, Strand, London, WC2R, 2LS, UK
NERC National Centre for Earth Observation, London, UK

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A B S T R A C T

We explore the ability to enhance landscape fire detection and characterization by constructing a ‘virtual’ fire product from a synthesis of geostationary and polar orbiting satellite data. Active fire pixels detected by the Spinning Enhanced Visible and Infrared Imager (SEVIRI) and the Moderate Resolution Imaging Spectroradiometer (MODIS) were spatially and temporally collated across Africa between February 2004 and January 2005. Coincident fire pixels detected by SEVIRI and MODIS were used to populate an empirical database of frequency density (f-D) distributions of fire radiative power (FRP). Frequency density distributions of FRP measured by SEVIRI at 5.0° grid cell resolution and 15-minute temporal resolution were then cross referenced in the database to a set of counterpart f-D distributions of FRP measured by MODIS. This procedure resulted in the first generation of a ‘virtual’ fire product that exhibits the full continental coverage and high temporal resolution of SEVIRI whilst quantifying fire pixel counts and FRP with accuracies approaching those of MODIS. Diurnal cycles extracted from the virtual fire product indicate that SEVIRI measures a greater proportion of the active fire pixels and FRP potentially detectable by MODIS during the day due to the increased prevalence and stronger radiant contribution of highly energetic fire pixels. On a daily basis (sample size n = 365) the peak magnitude in the diurnal cycle of the virtual FRP occurred within the same 15-minute timeslot as in the native SEVIRI fire product. Continental-scale ignition and extinction events, however, were detected on average 44 min earlier (standard deviation s.d. = 40 min) and 137 min later (s.d. = 92 min), respectively. It is anticipated that the methodology developed here can be used to cross-calibrate active fire products between a variety of different satellite platforms.

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1. Introduction

Continued efforts to improve estimates of trace gas and aerosol fluxes from terrestrial ecosystems have increasingly relied upon Earth observing satellites to characterize biomass burning via the detection of active landscape fires. To this end, thermal remote sensing data from a variety of polar orbiting and geostationary platforms have been distilled into multi-annual and global compilations of active fire products (Arino and Rosaz, 1999; Stroppiana et al., 2000; Giglio et al., 2003; Justice et al., 2002; Mota et al., 2006). Such datasets have principally been used to investigate the spatial and temporal distributions of vegetation fires (Cooke et al., 1996; Dwyer et al., 1999, 2000; Csizsar et al., 2005; Giglio et al., 2006a; Pu et al., 2007), but active fire pixel counts have also been related to burned area (Scholes et al., 1996a; Giglio et al., 2006b) in order to estimate trace gas and aerosol emissions (Scholes et al., 1996b; van der Werf et al., 2003, 2006) via heritage calculation methods (Seiler and Crutzen, 1980). The accuracy and utility of any fire product, however, is necessarily limited by (i) the spatial and temporal resolution of the raw fire product, (ii) any subsequent re-sampling performed on the dataset prior to analysis, and (iii) the coupling of these sampling and processing artefacts with the true spatio-temporal patterns of fires on the landscape (Eva and Lambin, 1998; Laris, 2005; Korontzi et al., 2003; Kasischke et al., 2003).

Sun-synchronous polar orbiting satellites offer the advantages of global coverage, moderate to high spatial resolution, and nearly constant equatorial crossing times. However observations of fire activity from these platforms are spatially and temporally fragmented due to the swath width and revisit times of the orbital ground tracks. Methods to compensate for this underlying sampling scheme have reconstruced diurnal cycles of fire activity by using identical twin sensors aboard companion satellites (Langaas, 1992, 1993; Ichoku et al., 2008), by exploiting the overlap between adjacent overpasses (Eva and Lambin, 1998) or by taking advantage of systematic drifts in local overlap times (Giglio, 2007a). The ability to characterize diurnal cycles of fire activity using polar orbiting observations, however, typically requires large spatio-temporal windows within which to collect a statistically sufficient number of fire pixels. Increasing the sample size by aggregating fire pixels mitigates the effects of transient variations in fire behaviour, but also results in a generalized expression of the diurnal profile that...
must be assumed stable over the region of interest and static over the duration of the compositing period (e.g., over the burning season). Furthermore, the interpretation of diurnal cycles derived from polar orbit requires that fire activity be interpolated between prolonged, unevenly distributed, and depending on fire behaviour, potentially non-optimal observation times.

Geostationary sensors, on the other hand, offer identical views of the full Earth disk at high repetition rates, and are thus much more amenable for characterizing the diurnal cycle of fire activity at regional to continental scales (Prins and Menzel, 1992, 1994; Menzel and Prins, 1996; Prins et al., 1998). Unfortunately the high orbital altitude of geostationary satellites induces a “low-resolution bias” (Boschetti et al., 2004) whereby coarser ground resolution cells hinder the detection of smaller and/or less intense fires. Efforts to improve geostationary fire detection algorithms have compensated for this limitation by incorporating strategies such as bi-spectral comparisons (Dozier, 1981), optimized contextual thresholds, improved cloud screening, intra- and inter-scene illumination geometries (Roberts and Wooster, 2008), and multi-temporal tests (Calle et al., 2006; Laneve et al., 2006b; Cisbani et al., 2002). Nevertheless there is an inevitable compromise between an increased rate of detection and an increased error of commission that eventually imposes a limit of reliability on the minimum detectable fire size and intensity (Laneve et al., 2006a).

Given the opposing advantages and disadvantages associated with polar orbiting and geostationary satellites, it has been suggested for some time that the strengths of each platform could best be exploited by combining datasets (Kaufman et al., 1998; Eva and Lambin, 1998). Analyzing satellite imagery collected from multiple sensors and/or multiple platforms is a common technique that has been used to increase the sampling frequency of fire observations (Kelhä et al., 2003), to validate the performance of active fire detection algorithms (Moriette et al., 2005; Csizsar et al., 2006; Calle et al., 2008; Schroeder et al., 2008), and to cross-calibrate measurements such as fire radiative power (Wooster et al., 2003; Roberts et al., 2005; Roberts and Wooster, 2008). Rather than splicing or comparing active fire products, however, the ability to enhance fire detection and characterization through a symbiotic synthesis of polar orbiting and geostationary data (e.g., Calle et al., 2005) remains relatively unexplored.

This paper directly addresses this topic by suggesting that frequency density (F-D) distributions of fire radiative power (FRP) can serve as thermal signatures of fire activity. We propose that if two different sensors can collect a sufficient number of coincident observations of the same fire activity, then a set of concurrent and colocated fire pixels can be used to construct an empirical database of paired F-D distributions of FRP. This database can then be used to (i) directly correlate the response of one sensor to the response of another, and (ii) match a new fire signature to an archived fire signature. The potential of F-D distributions of FRP to act as a bridge between geostationary and polar orbiting platforms is explored by examining the active fire products of the Spinning Enhanced Visible and Infrared Imager (SEVIRI) and the Moderate Resolution Imaging Spectroradiometer (MODIS) over Africa between 01 Feb 2004 and 31 Jan 2005.

2. Methods

2.1. The SEVIRI and MODIS datasets

Procedures for acquiring and processing SEVIRI imagery in this work were identical to those previously described by Roberts and Wooster (2008). Full Earth disk images with a sub-satellite spatial sampling distance of 3 km and a temporal resolution of 15 min were processed between 01 Feb 2004 and 31 Jan 2005, equating to over 31,000 timeslots. Only the landmass of Africa, including Madagascar, was subject to the enhanced geostationary fire detection algorithm developed by Roberts and Wooster (2008). For each active fire pixel, the FRP in megawatts (MW) was calculated via the middle infrared (MIR) radiance method (Wooster et al., 2003). The MIR radiance method uses the measured radiance values in SEVIRI channel 4 (centred on ~3.9 μm), the coefficients for the MIR radiance algorithm specifically tailored to the SEVIRI sensor (Wooster et al., 2005), and the ground sampling area corresponding to the pixel location.

The summation of FRP over all SEVIRI fire pixels detected across Africa in a single timeslot, 2FRPSEVIRI, is defined here as the strength of the continental SEVIRI fire signal. Diurnal cycles of FRP in this work remain registered to the native time of the observation (UTC) in order to examine the chronology of simultaneous fire behaviour occurring across the entire continent (Fig. 1). Including the observation time at which the peak magnitude occurs, the diurnal cycle of 2FRPSEVIRI has several distinct temporal features that can be used to aid the interpretation of continental scale fire behaviour. These are identified as (i) the ignition time, taken as the first timeslot when 2FRPSEVIRI exceeds 5% of the peak magnitude, (ii) the extinction time, taken as the first timeslot after the peak that 2FRPSEVIRI drops below 5% of the peak magnitude, and (iii) the full width at half maximum (FWHM), which is taken as the duration between the two observations on either side of the peak that have values half of the peak magnitude. These features are labelled in Fig. 1.

Procedures for acquiring and analyzing the MODIS active fire products were again identical to those described by Roberts and Wooster (2008). The MODIS Level 2 Thermal Anomalies/Fire ‘MOD14’ and ‘MYD14’ products (Justice et al., 2002; Giglio, 2007b) were obtained from the Land Processes Distributed Active Archive Center (LPDAAC, 2008). The existing fire mask was retained at a nominal spatial resolution of 1 km × 1 km at nadir (Giglio et al., 2003). Rather than using the values of FRP provided in the active fire product (Kaufman et al., 1998), the per-pixel FRP was instead calculated via the MIR radiance method (Wooster et al., 2003). This calculation was performed using the MODIS channel 21 radiance values, the coefficients for the MIR radiance algorithm specifically tailored to the MODIS sensor (Wooster et al., 2005), and the ground sampling area corresponding to the scan angle.

All fire pixels in the native SEVIRI and MODIS datasets were subset to only those detected near simultaneously and within the same geographic area. MODIS fire pixels were temporally subset to within ±6 min of a SEVIRI scan, and were also spatially subset to the centre of the MODIS swath. The ignition time, full width at half maximum (FWHM), and the extinction time are labelled in the native SEVIRI dataset as defined in Section 2.1.
two-thirds of the MODIS swath (i.e., between view angles of ±37°) in order to remove fire pixels at the edge of the MODIS scene influenced by the ‘bowtie effect’ (Wolfe et al., 2002). Similarly, SEVIRI fire pixels were temporally subset to within ±6 min of a MODIS overpass and were spatially subset to a convex hull encompassing the concurrent MODIS fire pixels. Hereafter for clarity and brevity, the coincident subsets of the native SEVIRI and MODIS fire products are referred to as the ‘training datasets.’

Spatial summations of the FRP measured by SEVIRI and MODIS within the training datasets are expressed as \(\sigma^{\text{SEVIRI}}\) and \(\sigma^{\text{MODIS}}\) respectively. Here \(\sigma\) represents a summation within the center two-thirds of the MODIS swath. The diurnal cycle of \(\sigma^{\text{MODIS}}\) (also expressed in UTC) demonstrates that unlike SEVIRI a true continental signal cannot be measured by MODIS due to the limited swath width (Fig. 1).

2.2. Sensor-to-sensor comparisons of the active fire products

Following the procedures of Roberts and Wooster (2008), concurrent and colocated fire pixels were used to directly compare the SEVIRI and MODIS active fire products. Sensor-to-sensor ratios of fire radiative power, \(\phi^{\text{FRP}}\), were calculated for each coincident observation, and were also calculated by aggregating fire pixels in the training datasets into intervals of one day, one week, and four weeks. Ratios of FRP were calculated such that

\[
\phi^{\text{FRP}} = \frac{\sum_{i} \text{FRP}_{\text{SEVIRI}}}{\sum_{i} \text{FRP}_{\text{MODIS}}}
\]

where \(\text{SEVIRI}\) and \(\text{MODIS}\) are fire pixel indices for each sensor, \(n_{\text{SEVIRI}}\) and \(n_{\text{MODIS}}\) are the total number of fire pixels detected within the temporal interval, and \(\text{FRP}\) is the fire radiative power associated with a fire pixel detected in the temporal interval. The ratio of fire pixel counts, \(\phi_{\text{count}}\), for a particular temporal window was calculated by dividing \(n_{\text{SEVIRI}}\) by \(n_{\text{MODIS}}\). Annual ratios of \(\phi^{\text{FRP}}\) and \(\phi_{\text{count}}\) were calculated by considering all fire pixels within the training datasets.

Since fire activity varies with land cover and land use practice, the spatial pattern of the annual ratios of \(\phi^{\text{FRP}}\) were mapped at 5.0°, 1.0° and 0.25° grid cell resolutions. The spatially explicit, annual ratios of \(\phi^{\text{FRP}}\) were calculated by summing in each grid cell all fire pixels detected during the year and then dividing the SEVIRI totals by the MODIS totals. The coordinate of the northwest corner of all domains was fixed at latitude 40°N and longitude 20°W. All extents were 80° × 80° so that complete continental coverage of Africa, including Madagascar, was achieved at each of these three grid cell resolutions. Grid cells centred on latitudes of ±36° were 19% smaller by area than those centred on the equator. Grid cells between latitudes of ±18° were at least 95% of the area of those centred on the equator. Since grid cells in the latter belt contained the majority of fire pixels, latitudinal differences in the ground area enclosed within individual grid cells were not considered to significantly impact our interpretations.

2.3. Frequency density (F-D) distributions

Following the frequency magnitude analysis of burned area conducted by Malamud et al. (2005), frequency densities of FRP, \(f(\text{FRP})\), were calculated such that

\[
f(\text{FRP}) = \frac{\delta N}{\delta \text{FRP}}
\]

where the count of fire pixels, \(\delta N\), within each FRP bin were normalized by the bin width, \(\delta \text{FRP}\). Frequency density (F-D) distributions of FRP were heavy-tailed and spanned several orders of magnitude. Therefore bin widths of FRP were equivalently spaced in the log domain such that \(\log_{10}(\text{FRP}) = 0.025\). This resulted in 127 bins between 2.4 MW – 3700 MW.

Daytime and nighttime examples of SEVIRI and MODIS F-D distributions of FRP were constructed from fire pixels contained within the training datasets (Fig. 2). As stated in the Introduction, it is hypothesized here that F-D distributions of FRP can be used to summarize a collection of active fire pixels, and that similar to the amplitudes and shapes of different waveforms, F-D distributions of FRP can serve as unique thermal signatures of fire activity.

Though F-D distributions of FRP contain structural features representative of the radiative exitance from fires on the landscape, they also contain artefacts associated with the performance of the fire detection system. As Fig. 2 illustrates, F-D distributions of FRP for both SEVIRI and MODIS are left-hand truncated (i.e., exhibit a ‘rollover’ at low FRP values). This behaviour can be attributed to either (i) a self-imposed limit on the number of small and/or less intense fires that can potentially exist on the landscape, or (ii) the inability of the detection algorithms to distinguish a portion of the smallest and/or least intense fires from the non-fire background. Features of right-hand truncation (i.e., large-scale fall-off) on the other hand can be attributed to either (i) a combination of the maximum kinetic temperature and sub-pixel area that a fire can possibly achieve, or (ii) sensor saturation. Compared to the rollover exhibited by SEVIRI, the effects of left-hand truncation for MODIS tend to occur at lower FRP values due to the higher spatial resolution. In contrast to SEVIRI, the effects of right-hand truncation for MODIS are moderated by the greater dynamic range of MODIS channel 21.

2.4. The frequency density (F-D) matching technique

An empirical database of SEVIRI and MODIS F-D distributions of FRP was constructed by spatially and temporally aggregating fire pixels contained within the training datasets. The first set of paired SEVIRI and MODIS F-D distributions to populate the database were taken directly from the concurrent and colocated observations. For example the two pairs of SEVIRI and MODIS F-D distributions of FRP presented in Fig. 2 were stored in the historical database. To obtain a sufficient variety of different F-D distributions, with a wide range of in-scene FRP, a second set of paired SEVIRI and MODIS F-D distributions were calculated...
was constructed by temporally aggregating all fire pixels detected across the whole of Africa into intervals ranging from 1 h to two months in duration. To even further expand the diversity of this database, fire pixels were spatially aggregated by scanning grid cells of various sizes (ranging from 1.0° to 12.0° in one degree intervals) across Africa in increments of 0.25°. All fire pixels detected within each contiguous spatial kernel, and throughout the year, were then used to create the third set of paired SEVIRI and MODIS f-D distributions. Whereas pairs of continental scale f-D distributions were generated during the temporal aggregation, pairs of annual f-D distributions were generated during the spatial aggregation. Including all the coincident, and all the temporally and spatially aggregated fire pixels, the empirical database was populated with more than 680,000 linked pairs of SEVIRI and MODIS f-D distributions of FRP.

Next, f-D distributions of FRP in the native SEVIRI dataset were cross referenced to MODIS f-D distributions stored in the empirical database. At each of the 96 timeslots per day in the native SEVIRI dataset, fire pixels were aggregated into the same static domain of 5.0° grid cells previously defined in Section 2.2. The native SEVIRI fire pixels were then used to construct incoming SEVIRI f-D distributions of FRP, which were then matched to an archived SEVIRI f-D distribution stored in the empirical database. The SEVIRI-to-SEVIRI matches in each 5.0° grid cell were performed by first identifying only the archived SEVIRI distributions that had an in-scene FRP within 5% of the incoming SEVIRI f-D distribution. To smooth the noise between adjacent bins, and to ensure that the macroscopic features of the SEVIRI f-D distributions were more appropriately matched, a running-average filter three bins wide was passed over the SEVIRI f-D distributions. A ‘goodness of fit test’ was then applied to the smoothed SEVIRI f-D distributions, and the chi-square test statistic, \( \chi^2 \), was calculated as such:

\[
\chi^2 = \sum_{i=1}^{n_{bin}} (O_i - A_i)^2 / A_i
\]

where \( i \) is the bin index, \( n_{bin} \) is the number of bins in the frequency density distribution, \( O_i \) is the incoming (smoothed) SEVIRI frequency density in bin \( i \), and \( A_i \) is the archived (smoothed) SEVIRI frequency density in bin \( i \). Rather than strictly testing a null hypothesis, the 2% of the archived SEVIRI f-D distributions yielding the lowest \( \chi^2 \) values were pooled along with their corresponding MODIS f-D distributions. The incoming SEVIRI f-D distribution and the retrieved MODIS f-D distributions were then used to calculate the SEVIRI-to-MODIS ratios \( \phi_{\text{FRP}} \) and \( \phi_{\text{count}} \). The archived SEVIRI f-D distribution yielding the minimum \( \chi^2 \) test statistic was used to identify the best-matched \( \phi_{\text{FRP}} \) and \( \phi_{\text{count}} \). The counterpart MODIS f-D distributions associated with the lowest 2% of the \( \chi^2 \) test statistics were then used to calculate the mean, median, and interquartile range of \( \phi_{\text{FRP}} \) and \( \phi_{\text{count}} \). The latter metrics were used to quantify the uncertainty of the retrievals.

The output of the F-D matching technique is a 5.0° gridded product containing a prediction of the active fire pixel counts and FRP that MODIS would have measured if it observed Africa with continental coverage and 15-minute temporal resolution between 01 Feb 2004 and 31 Jan 2005. Although derived from actual SEVIRI observations, this remains a synthetic dataset. Therefore the output of the F-D matching technique is referred to as a ‘virtual’ active fire product.

3. Results

3.1. Measured SEVIRI to MODIS ratios

The training datasets were constructed from approximately 11% of the SEVIRI scans and 52% of the MODIS granules contained the native fire products. As such, 1.2% and 1.3% of the yearly fire pixels and yearly FRP were included in the SEVIRI training dataset, respectively, and approximately 45% and 33% of the yearly fire pixels and yearly FRP were included in the MODIS training dataset. Due to the presence of strong diurnal cycles, the daytime detections accounted for 95% of the total fire pixel counts and 96% of the total FRP in the training datasets regardless of the satellite platform. Furthermore, not a single fire pixel in the training datasets was detected between 0300 and 0630 UTC or between 1500 and 1900 UTC due to the absence of a MODIS overpass.

The SEVIRI-to-MODIS ratios of FRP measured within the training datasets were most variable on a per observation basis where \( 0.004 < \phi_{\text{FRP}} < 4.96 \). The range of instantaneous values of \( \phi_{\text{FRP}} \) narrowed as more in-scene radiant power was measured, and inevitably converged to values \( 0.4 < \phi_{\text{FRP}} < 0.9 \) for \( \sigma_{\phi_{\text{SEVIRI}}} > 1 \times 10^5 \text{MW} \) (Fig. 3a). Roberts and Wooster (2008) attribute the range and variation of \( \phi_{\text{FRP}} \) calculated on an instantaneous basis to phenomena such as false fire detections, cloud cover and heavy aerosol loadings. In addition to these explanations, dramatic fluctuations in \( \phi_{\text{FRP}} \) between consecutive MODIS overpasses, as shown in Fig. 3b, are attributed here to (i) the dynamic nature and diurnal cycle of fire behaviour, (ii) the occasionally limited number of SEVIRI and MODIS fire pixels available to calculate \( \phi_{\text{FRP}} \), (iii) the timing and ground track of the MODIS overpass, (iv) the location of the fire with respect to the sub-satellite point.

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of SEVIRI and the nadir line of MODIS, and (v) the location of the fire in relation to the point spread function of each scanning system.

The range and temporal variation of $\phi_{\text{FRP}}$ measured in the training datasets decreased as fire pixels were aggregated into daily, weekly, and four weekly intervals (Fig. 3a and b). Aggregating fire pixels into wider temporal windows served to increase the sample size available to compute $\phi_{\text{FRP}}$, and also mitigated the effects of the MODIS swath by coalescing ratios calculated at different times and thus at different locations. Based upon a visual inspection of the measured seasonal profiles presented in Fig. 3b, an interval of one week was subjectively selected as the most appropriate temporal resolution at which to analyze and interpret the SEVIRI-to-MODIS ratios. An interval of one week is assumed to be the minimum temporal window in which there were a sufficient number of fire pixels to (i) overwhelm influences of detector sensitivity, algorithm performance, and random fire behaviour at observations of low fire activity, (ii) permit an identical ground location to be sampled over the full range of MODIS viewing angles, and (iii) capture continental scale trends rather than localized patterns associated with individual swaths.

An analysis of all fire pixels in the training datasets revealed that SEVIRI detected 20% of the annual number of fire pixels and 50% of the annual FRP measured by MODIS (i.e., $\phi_{\text{count}} = 0.20$ and $\phi_{\text{FRP}} = 0.50$, respectively). Maps of the annual ratios of $\phi_{\text{FRP}}$ at 5.0°, 1.0° and 0.25° grid cell resolutions illustrate the spatial patterns of these sensor-to-sensor ratios (Fig. 4). Grid cells at 5.0° resolution spanned different land cover types, land use practices, and fire regimes and therefore failed in some respects to adequately capture the inherent spatial variability of the annual SEVIRI-to-MODIS ratios. Similar to aggregating fire pixels into wider temporal windows (as shown in Fig. 3), aggregating fire pixels into coarser grid cells homogenized ratios of $\phi_{\text{FRP}}$ which would have otherwise been dominated by localized hotspots at the sub-grid cell resolution.

Of the three spatial scales, the map of $\phi_{\text{FRP}}$ at 1.0° grid cell resolution generally provided the most coherent results. At this scale it becomes evident that the spatial variation of the SEVIRI-to-MODIS ratios is inherently coupled to the seasonal variation in fire activity. Locations of the elevated ratios in the northern hemisphere generally corresponded to the elevated ratios typically observed between November...
and January. Locations of the elevated ratios in the southern hemisphere generally corresponded to the elevated ratios typically observed during June and July.

The environmental, ecological, and cultural gradients that extend outwards from regions of high fire activity resulted in a buffer of 1.0° grid cells where MODIS detected at least one fire pixel, but SEVIRI did not. The spatial pattern of $\phi_{\text{FRP}}$ at 1.0° grid cell resolution is supported by a map of the mean FRP per fire pixel (not shown) which illustrates that areas with a lower mean FRP surround areas with a higher mean FRP. Since a lower mean FRP is a possible indication of diminished fire activity, SEVIRI is less likely than MODIS to detect biomass burning events within these ecotones.

Annual ratios of $\phi_{\text{FRP}}$ were noisiest at 0.25° grid cell resolution. Here, extreme spatial variability in the annual SEVIRI-to-MODIS ratios of FRP occurred between adjacent grid cells. This is probably due to the small sample size within each grid cell and the potential dependence of $\phi_{\text{FRP}}$ on isolated fire events. Also at this finest grid cell resolution the ratio between the perimeter and the area of the grid cell, as well as the registration of pixel centres within the grid itself became increasingly important as SEVIRI and MODIS fire pixels of the same hotspot may have been split into adjacent grid cells.

### 3.2. Matching frequency density (f-D) distributions

In order to account for the undetected presence of smaller and/or less intense fires, the f-D matching technique was applied to the native SEVIRI fire product at 5.0° grid cell resolution and 15-minute temporal resolution. Although the empirical database was populated with active fire pixels contained in the native SEVIRI dataset, the training dataset only constituted a minor fraction of the total fire pixels (12%) and timeslots (11%). Therefore we ubiquitously applied the f-D matching technique to all 96 timeslots per day in the native SEVIRI dataset – including the timeslots originally used to build the empirical database.

An example of the f-D matching technique applied within a single 5.0° grid cell and at an individual SEVIRI timeslot is presented in Fig. 5. Narrowing the 680,000 archived SEVIRI f-D distributions to only those having an in-scene FRP within 5% of the incoming SEVIRI f-D distribution revealed 7150 potential matches in the empirical database. These incoming-to-archived SEVIRI matches were further reduced to 143 based upon the lowest 2% of the $\chi^2$ test statistics. The counterpart MODIS f-D distributions associated with the 143 archived SEVIRI f-D distributions yielded a range of $\phi_{\text{FRP}}$ values with an IQR (interquartile range) of 0.30 < IQR < 0.66 and a median $\phi_{\text{FRP}}$ of 0.5. The archived MODIS f-D distribution associated with the absolute minimum $\chi^2$ test statistic yielded a best-matched $\phi_{\text{FRP}}$ of 0.65.

Iterating the f-D matching technique over all grid cells generated a map of instantaneous values of $\phi_{\text{FRP}}$ at 5.0° grid cell resolution (Fig. 6). A spatially integrated, continental scale SEVIRI-to-MODIS ratio of FRP, expressed as $\Sigma \phi_{\text{FRP}}$ was calculated for this particular SEVIRI timeslot. Here, the incoming SEVIRI f-D distributions and retrieved MODIS f-D distributions were summed over all grid cells. Then $\Sigma \phi_{\text{FRP}}$ was calculated by dividing the measured SEVIRI total by the retrieved MODIS total. Using the MODIS f-D distributions in each grid cell associated with the lowest 2% of the $\chi^2$ test statistics yielded a range of continental scale SEVIRI-to-MODIS ratios of FRP with 0.31 < IQR < 0.56, a median $\Sigma \phi_{\text{FRP}}$ of 0.44, and a best-matched $\Sigma \phi_{\text{FRP}}$ of 0.45.

Iterating the f-D matching technique over all grid cells, and then again over all timeslots in the native SEVIRI dataset yielded a temporal profile of $\Sigma \phi_{\text{FRP}}$ at 15-minute resolution (Fig. 7). Although the temporal profile of $\Sigma \phi_{\text{FRP}}$ retrieved using the f-D matching technique exhibits a diurnal cycle, the daytime and nighttime ratios cannot be statistically distinguished from one another as an overlap is possible in the interquartile range. In addition, there is considerable variation in $\Sigma \phi_{\text{FRP}}$ between consecutive timeslots. While it is expected that the uncertainty of the matches between incoming and archived SEVIRI f-D distributions will induce some temporal variation, it is unlikely that individual biomass burning events could be broad or intense enough to generate the dramatic fluctuations in the continental scale ratios as seen in Fig. 7.

A preliminary evaluation of the f-D matching technique revealed that incoming SEVIRI f-D distributions were ‘noisy’, had matches with poor $\chi^2$ values, and ultimately produced ratios of $\phi_{\text{FRP}}$ that were uncharacteristically lower than those actually measured within the training datasets. This response was attributed to the limited number of fire pixels detected within a 5.0° grid cell at 15-minute temporal resolution. Thus it was necessary to increase the sample size. To do so...
performed within individual 5.0° grid cells using only the SEVIRI 15-minute temporal resolution on 12 and 13 July 2004. The f-D matching technique was the incoming timeslot. The spatially explicit retrievals were then aggregated into the continental scale ratios of \( \Sigma_{\text{FRP}} \) shown here based upon the minimum \( \chi^2 \) test statistic (○). Also presented are the continental scale ratios of \( \Sigma_{\text{FRP}} \) associated with the median retrieval (■) as well as the interquartile range of the retrievals ( | ) based upon the lowest 2% of the \( \chi^2 \) test statistics.

The incoming SEVIRI f-D distributions were accumulated over multiple days using only the fire pixels detected in previous SEVIRI timeslots having scan times identical to that of the incoming timeslot. Aggregating fire pixels in this manner was preferred to using a continuous sequence of consecutive timeslots immediately preceding the incoming timeslot since the latter method could adversely alter the signature of the fire signal if the selection of the temporal window was too wide or if temporal changes in fire activity were too rapid.

A subsequent sensitivity analysis revealed that retrievals of \( \phi_{\text{FRP}} \) increased as the number of timeslots increased, and asymptotically approached a final value that did not change by more than ±2.0% beyond seven timeslots. Therefore incoming SEVIRI f-D distributions at 5.0° grid cell resolution were constructed by aggregating fire pixels detected over the previous seven days at the seven timeslots identical to the incoming timeslot. As such, the incoming SEVIRI f-D distributions were considered representative of the typical, weekly fire activity that occurred at the same local solar time.

Temporally accumulating SEVIRI fire pixels in the native dataset increased the sample size, produced f-D distributions with improved structural detail, and consequently improved the confidence of f-D matching technique. This resulted in a diurnal profile of \( \Sigma_{\phi_{\text{FRP}}} \) that exhibited greater separation between the daytime and nighttime ratios and also less temporal variability between consecutive timeslots (Fig. 8).

Diurnal cycles presented in Fig. 8, and to some degree those presented in Fig. 7, indicate that MODIS is relatively more sensitive than SEVIRI at night due to the prevalence of smaller and/or less intense fires for which MODIS is more adept at detecting with a higher spatial resolution. This does not suggest that the sensitivity of the SEVIRI detection algorithm degrades during the night, as it actually improves due to the increased thermal contrast between fire pixels and the relatively cool background pixels. Rather the sensitivity of the MODIS algorithm also improves during the night and subsequently outperforms the improvement of SEVIRI. Despite the temporal accumulation of SEVIRI fire pixels, chi-square test statistics were still larger and more variable at night (not shown) since incoming SEVIRI f-D distributions were ‘noisy’ and thus more difficult to confidently match to other ‘noisy’ SEVIRI f-D distributions stored in the f-D database. Poor incoming-to-archived SEVIRI matches with greater \( \chi^2 \) test statistics were most abundant in the early morning (~0500 UTC) when fire pixels from the previous day had almost extinguished, when new fires had not yet been lit, and when the sunrise began to degrade the thermal contrast between the background pixels and the weaker fire pixels.

A decrease in the \( \chi^2 \) values as the day progressed (not shown) indicates that incoming and archived SEVIRI f-D distributions were more confidently matched as (i) \( \Sigma_{\text{FRP}} \) increased, (ii) the number of in-scene fire pixels increased, and (iii) the SEVIRI f-D distributions of FRP achieved more definitive structure. The increase in \( \Sigma_{\phi_{\text{FRP}}} \) beginning at ~0600 UTC suggests that the effectiveness of the SEVIRI fire detection algorithm improves during the day with respect to that of MODIS (Fig. 8). It is suggested that the daytime response of the SEVIRI fire detection algorithm is coupled to the diurnal cycle of ambient air temperature, relative humidity and wind speed. During the day these environmental factors promote an increase in fire spread rate and intensity, and thus serve to raise pixel brightness temperatures.

Fig. 7. Diurnal profile of the continental scale SEVIRI-to-MODIS ratios of FRP (\( \Sigma_{\phi_{\text{FRP}}} \)) at 15-minute temporal resolution on 12 and 13 July 2004. The f-D matching technique was performed within individual 5.0° grid cells using only the SEVIRI fire pixels detected at the incoming timeslot. The spatially explicit retrievals were then aggregated into the continental scale ratios of SEVIRI f-D distributions stored in the f-D data-base. Poor incoming-to-archived SEVIRI matches with greater \( \chi^2 \) test statistics were most abundant in the early morning (~0500 UTC) when fire pixels from the previous day had almost extinguished, when new fires had not yet been lit, and when the sunrise began to degrade the thermal contrast between the background pixels and the weaker fire pixels.

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above the artefacts of left-hand truncation. Furthermore, since the relationship between mid-wave pixel brightness temperature and fire radiative power is non-linear, there is also a diurnal increase in the proportion of the continental scale FRP attributed to high FRP fire pixels (not shown). Since SEVIRI is more capable of detecting high FRP fire pixels, and since these high FRP fire pixels account for a greater fraction of the total radiant heat budget during the day, SEVIRI then measures a greater proportion of the FRP potentially measured by MODIS during the day.

The diurnal cycle of $\Sigma \phi_{\text{FRP}}$ retrieved from the f-D matching technique is analogous to the seasonal trend measured within the training datasets (c.f., Fig. 3b). Nighttime depression is similar to the decreased ratios measured during the spring and fall migrations of fire activity, and the daytime recovery is similar to the increased ratios measured during the northern and southern winters. To directly compare the output of the f-D matching technique with the measured ratios in the training datasets, continental scale predictions of the ‘virtual’ fire radiative power, $\Sigma \phi_{\text{VIRTUAL}}$, at each 15-minute timeslot were summed into weekly intervals to yield $\Sigma \phi_{\text{FRP}}$ at a weekly resolution (Fig. 9). Results indicate that retrievals of $\Sigma \phi_{\text{FRP}}$ at a weekly resolution were considerably flatter than the profile of ratios measured within the training dataset. Furthermore, an annual SEVIRI-to-MODIS ratio of FRP of 0.37 retrieved using the f-D matching technique was substantially lower than an annual SEVIRI-to-MODIS ratio of 0.50 actually measured within the training dataset. At this point in the analysis, discrepancies between the retrieved and measured SEVIRI-to-MODIS ratios are attributed to one or any combination of the following: (i) the performance of the f-D matching technique, (ii) the effects of expanding the spatial coverage from the centre of the MODIS swath in the training dataset to the entire continent in the native SEVIRI dataset, or (iii) the effects of increasing the temporal resolution from a maximum of 16 observations per day in the training dataset to 96 observations per day in the native SEVIRI dataset.

3.3. Synchronization of the retrieved and measured ratios

In order to isolate the performance of the f-D matching technique, the convex hulls that were originally used to subset fire pixels from the native SEVIRI dataset at timeslots concurrent with a MODIS overpass were used here instead to subset the native SEVIRI dataset at timeslots immediately preceding a MODIS overpass. This procedure permitted the f-D matching technique to be applied to SEVIRI f-D distributions that (i) were extremely similar to those SEVIRI f-D distributions having concurrent and colocated MODIS counterparts, but (ii) were not constructed from fire pixels actually contained in the empirical database. Although measurements of $\phi_{\text{FRP, SEVIRI}}$ in previous timeslots were approximately 3% less than those SEVIRI measurements, the retrieved ratios in the training dataset to the continental scale and weekly resolution (a). The discrepancy between the profile of retrieved ratios in the training dataset and the ratio of $\Sigma \phi_{\text{FRP}}$ at a weekly resolution.

Fig. 9. Seasonal profile of the SEVIRI-to-MODIS ratios of FRP, $\phi_{\text{FRP}}$. From Fig. 3, the ratios measured within the training datasets were coincident with the timing and center two-thirds of the MODIS swath, but were reduced here to weekly resolution (c). From Fig. 8, the ratios retrieved at 5.0° grid cell resolution and 15-minute temporal resolution using the f-D matching technique were reduced here to the continental scale and weekly resolution (a). The discrepancy between the profile of retrieved ratios in the training dataset and the ratio of $\Sigma \phi_{\text{FRP}}$ at a weekly resolution may be exaggerated, or moderated, the spatial variability of the median ratio and the optimized ratio. Using Eq. (4) for each diurnal cycle of the retrieved $\Sigma \phi_{\text{FRP}}$ by a scalar, which would have simply shifted the entire temporal profile either up or down, a sigmoid function was applied to the medians of the $\Sigma \phi_{\text{FRP}}$ as follows:

$$\text{optimized } \Sigma \phi_{\text{FRP}} = \frac{C}{1 + A \times \exp(-B \times \Sigma \phi_{\text{FRP}})}$$

where A, B, and C are free parameters determined based upon the best agreement between the optimised $\Sigma \phi_{\text{FRP}}$ and the rolling weekly $\phi_{\text{FRP}}$ calculated for each day of the year in the training datasets. Adjustments were made to the median $\Sigma \phi_{\text{FRP}}$ rather than the best-matched $\Sigma \phi_{\text{FRP}}$, since the reduced temporal variation of the former parameter facilitated a more consistent transformation between the retrieved median ratio and the optimized ratio. Using Eq. (4) for each diurnal cycle of $\Sigma \phi_{\text{FRP}}$ during the year generated 365 continental scale transfer functions (Fig. 10b). Then, depending on the day, the corresponding transfer function was ubiquitously applied to the median $\phi_{\text{FRP}}$ within every 5.0° grid cell in the domain.

Applying the sigmoid transfer functions either stretched, or compressed, the diurnal cycle of the median $\Sigma \phi_{\text{FRP}}$ and simultaneously either exaggerated, or moderated, the spatial variability of the median $\phi_{\text{FRP}}$ across the 5.0° gridded domain. Results of the synchronization procedure yielded an optimised set of $\Sigma \phi_{\text{FRP}}$ at 5.0° grid cell resolution and 15-minute temporal resolution that provided very strong spatial and temporal agreement with the FRP predicted by directly applying the measured ratios in the training dataset to the native SEVIRI dataset. This is evidenced by an almost 1:1 relationship for continental scale predictions of FRP at daily resolution (Fig. 10c), as well as yearly predictions of FRP at 5.0° grid cell resolution (Fig. 10d). Although the 365 daily transfer functions were developed based upon a synchronization of the spatially integrated ratios, the spatially explicit representation of these transfer functions at 5.0° grid cell resolution was presumably successful since a relatively few grid cells dominated the spatially integrated fire signal.

Diurnal and seasonal cycles of the optimised $\Sigma \phi_{\text{FRP}}$ are presented in Fig. 11. The agreement between the optimized profiles in Fig. 11 and...
the measured profiles in Fig. 3b further demonstrates the success of the synchronization procedure. Absolute differences between the optimized and measured ratios calculated at weekly resolution differed by no more than 0.10, and compared to an annual ratio of $\phi_{\text{FRP}}$ of 0.50 measured in the training dataset, the optimized ratios yielded an annual SEVIRI-to-MODIS ratio of FRP of 0.47. Interestingly, the optimized ratios of $\Sigma\phi_{\text{FRP}}$ calculated at weekly and monthly temporal resolutions were more representative of the instantaneous ratios retrieved during the daytime (Fig. 11). This suggests that cross platform relationships between satellite-based active fire products are primarily driven by the locations and timing of increased fire activity.

### 3.4. A virtual active fire product for Africa

Until now the SEVIRI-to-MODIS ratios of FRP have received the most attention since they were used to synchronize the output of the f-D matching technique with the true ratios measured in the training dataset. The tangible result of this work, however, is the ‘virtual’ active fire product. Since only the fire pixels that were detected in the centre two-thirds of the MODIS swath were used to construct the f-D distributions stored in the empirical database, predictions of fire pixel counts and FRP in the virtual fire product are representative of the near-nadir response of MODIS.

Fig. 12a illustrates that for an individual 5.0° grid cell, the prediction of FRP in the virtual fire product agrees well with the FRP actually measured by MODIS. Furthermore, summing the FRP over all grid cells

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in the domain allows for a continental comparison between the virtual fire product and the native SEVIRI fire product (Fig. 12b). As explained by the diurnal cycles of $\Sigma_{\text{FRP}}$ and $\Sigma_{\text{counts}}$, absolute differences between the daily maximums and the nightly minimums in the virtual fire product were less exaggerated than in the native SEVIRI fire product. Thus, compared to the native SEVIRI fire product, there is slightly less diurnal variation in the virtual fire pixel counts and virtual FRP.

Diurnal cycles of $\Sigma_{\text{FRP}}$ virtual also contain temporal features identical to those found in the native SEVIRI dataset, such as the time of the peak magnitude of FRP, the ignition time, the extinction time, and the duration of the FWHM. These features were compared as per their original definitions presented in Section 2.1:

- Daily peaks in the temporal profile of $\Sigma_{\text{FRP}}$ virtual occurred on average 6 min earlier ($\pm 50$ min) than peaks in the native SEVIRI fire product with most of the variation and uncertainty attributed to measurements of low fire activity.
- The onset of the FWHM during each day in the virtual fire product occurred on average 30 min earlier ($\pm 42$ min) than in the native SEVIRI fire product and terminated on average 22 min later ($\pm 41$ min) leading to an increased duration of the FWHM of approximately 52 min on average.
- Continental-scale ignition events in the virtual fire product were detected on average 44 min earlier ($\pm 40$ min) than in the native SEVIRI fire product, while extinction events were detected on average 137 min later ($\pm 92$ min).

Asymmetric differences between the detection of an ignition event and the detection of an extinction event are attributed to the contrast between an abrupt increase in the ignition signal and a slowly decaying extinction signal. At the continental scale, a rapid increase in fire activity in the morning can be caused by widespread anthropogenic practices (i.e., the start of the working day) while the evening tail can be affected by the longitudinal gradient of fire activity as fire pixels ‘turn off’ from east to west following the local sunset. The contrast between ignition and extinction is also apparent in the diurnal profiles constructed by Giglio (2007a) of the probability of observing detectable fires at the local hour for different fire affected regions throughout the world. The global occurrence of these artefacts, and the timing of these artefacts relative to the local hour, therefore suggests that temporal differences in the morning and evening fire signals are more governed by fire behaviour (i.e., flame length, fire spread rate, the predominance of flaming or smouldering combustion, etc.) and the response thereof to environmental factors such as the availability of fuel, wind speed, air temperature and relative humidity.

Arguably the most profound outcome of the f-D matching technique is a monthly shift in the peak of FRP from July, originally measured in the native SEVIRI dataset, to August (Fig. 12c). An estimated peak in fire activity in August for the southern hemisphere of Africa is consistent with the results of van der Werf et al. (2006), which is not surprising given their modelling approach was also synchronized to MODIS fire pixel counts. If MODIS is used as the standard for accuracy then this evidence suggests that between July and August, as fire pixels migrated further south and east into Mozambique and into the United Republic of Tanzania, there was an increase in the number of small and less intense fires on the landscape, perhaps due to a combination of topography, land cover, land fragmentation, and burning...
practices (Roy et al., 2005). The migration of fire activity into such a fire regime would hinder the SEVIRI active fire detection algorithm for reasons previously stated. It is possible, however, that the response of SEVIRI to any potential change in fire pattern could also be confounded by an increase in the cloud fraction over the region into which the fire pixels migrated, which would again hamper their detection by SEVIRI (Roberts and Wooster, 2008).

4. Discussion

During the construction of the empirical F-D database, the sampling frequency, pixel area, and ground coverage of the SEVIRI and MODIS sensors were less regarded as spatio-temporal constraints and more regarded as minimum resolvable units. For example, without the ability to acquire more observations, the number and variety of the F-D distributions stored in the empirical database were expanded at the post-processing level by considering the two different procedures of spatial aggregation and temporal aggregation as pseudo replicating operations. It was further assumed that (i) an annual set of coincident fire pixels could be subset and then re-assembled into distinct pairs of SEVIRI and MODIS F-D distributions, and that (ii) a sufficient variety of F-D distributions could be constructed from fire pixels detected during a MODIS overpass to represent the unobserved fire activity between gaps in the MODIS spatial coverage and temporal resolution. Resampling in this manner assumed there was no interaction between fire pixels and that F-D distributions were not altered or otherwise biased as a result of the aggregation process.

This work has examined the potential of F-D distributions of FRP to serve as unique thermal signatures of fire activity. Perhaps the most fundamental assumption of the ‘F-D matching technique’ is that each SEVIRI fire signature has a unique MODIS counterpart. Results to the contrary indicated that since similar SEVIRI F-D distributions were often statistically indistinguishable, there were often multiple MODIS F-D distributions, and hence multiple values of \( \phi_{\text{f-d}} \), retrieved for a single application of the F-D matching technique. The use of the IQR to characterize the uncertainty of the retrievals is one way to express this ambiguity (e.g., Figs. 7 and 8). In the future, it is proposed that this multiplicity could be overcome by (i) populating the database with as many different F-D distributions as possible, (ii) increasing the fidelity of the F-D distributions by using more FRP bins and narrower bin widths, (iii) using a more sensitive test statistic to match the incoming and archived SEVIRI F-D distributions, (iv) restricting the match of an incoming SEVIRI F-D distribution to an archived SEVIRI F-D distribution constructed at a certain time or from a certain geographical region, or (v) using an entirely different method to reconstruct an incoming SEVIRI F-D distribution from a set of historical fire detections.

Even if similar SEVIRI F-D distributions can be statistically distinguished, the question still remains: could a single thermal distribution on the landscape give rise to one measured SEVIRI F-D distribution and multiple measured MODIS F-D distributions? We concede that conceptually different combinations of background temperature, solar viewing geometry, and sub-pixel thermal composition could induce similarly measured F-D distributions of FRP. We also concede that conceptually similar thermal distributions on the landscape could induce a different sensor response depending on the spatial distributions of FRP about the sub-satellite point of SEVIRI, the nadir line of MODIS, and the point spread function of each scanning system. It is unclear at this point, however, how much of an effect these factors, including the time difference between observations, would have on the output of the F-D matching technique.

Since measurements of FRP depend upon fire behaviour, fuels, weather, topography, canopy cover, and more subletly, pixel area and thus the spatial distribution of fire pixels about the sub-satellite point, it is assumed that the empirical F-D database constructed in this work is endemic to SEVIRI and MODIS observations of Africa. Furthermore, due to the synchronization of the retrieved and measured ratios, the F-D matching technique is also directly tethered to observations between 01 Feb 2004 and 31 Jan 2005. Application of the synchronization procedure also assumed that at the weekly time scale the SEVIRI-to-MODIS ratios measured at the times and locations of the MODIS overpass were representative of the SEVIRI-to-MODIS ratios measured at times and locations beyond the MODIS overpass.

With regard to the grid cell resolution of the virtual fire product, it was stated in Section 3.1 that 5.0° grid cells were perhaps too large to capture the spatial variability of the SEVIRI-to-MODIS ratios measured in the training dataset, even within a yearly timeframe. The aggregation of fire pixels at this spatial scale and over multiple timeslots, however, was absolutely necessary during the application of the F-D matching technique in order to construct statistically well structured F-D distributions, and thus to facilitate confident matches between incoming and archived SEVIRI F-D distributions. Interestingly the implementation of such a coarse grid cell also compensates for the inherent inability of the F-D matching technique to identify the exact location of a ‘virtual hotspot’. The use of a 5.0° grid cell therefore allows predictions of the virtual FRP to be smeared over a broad area to account for this spatial uncertainty. Attempts to increase the spatial resolution of the virtual fire product to a 1.0° gridded domain may require a temporal window as wide as one month in order to amplify the incoming FRP signal in each 1.0° grid cell and to ensure a confident match between the incoming and archived SEVIRI F-D distributions. Since this spatio-temporal window is not practical for many applications, it is hypothesized that rather than using a static spatial domain, as implemented here, confident retrievals of \( \phi_{\text{f-d}} \) could be achieved in the future at 1.0° grid cell resolution by scanning the 5.0° kernel (and seven timeslot window) over the continent in 1.0° increments.

Whilst this work has strictly focused on a methodology to adjust a geostationary active fire product to account for the undeveloped presence of smaller and/or less intense fires, it is also true that MODIS itself is likely to miss a proportion of the most weakly burning events (Kauffman et al., 1998). Indeed the MODIS F-D distributions of FRP also exhibit characteristics of left-hand truncation (c.f., Figs. 2 and 5). If the understanding of fire behaviour is to be advanced, and the accuracy of emission inventories improved, then the spatial and temporal distribution of the fires that remain undetected by MODIS must also be quantified.

5. Conclusions

This work has demonstrated that frequency density distributions of fire radiative power have the potential to cross-reference active fire products between different spaceborne platforms. The solution developed here to relate the thermal response of SEVIRI to the thermal response of MODIS is purely empirical. As such this methodology requires a sufficient number of concurrent and collocated observations of the same fire activity. Nevertheless, the application of the ‘F-D matching technique’ to the native SEVIRI fire product resulted in the first generation of a virtual active fire product that provides estimates of fire pixel counts and FRP at 5.0° grid cell resolution, 15-minute temporal resolution and continental coverage with accuracies approaching those of MODIS. Diurnal cycles of the sensor-to-sensor ratios of fire pixel counts and FRP were shown to mimic seasonal trends in so far as SEVIRI was relatively less responsive than MODIS at times and locations of decreased fire activity. Results of the F-D matching technique, in conjunction with a synchronisation procedure, yielded an annual estimate of FRP that was approximately 6% greater than that estimated by applying the annual ratios measured in the training datasets directly to the native SEVIRI fire product. Given that an adequate number of fire pixels can be collected within a practically sized spatio-temporal window, the methodology developed in this work can be considered as a candidate for cross-calibrating active fire products generated by the forthcoming global suite of geostationary sensors.

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