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# Characterization of the tropical diurnal fire cycle using VIRS and MODIS observations

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**Abstract**

Seven years of data from the Tropical Rainfall Measuring Mission (TRMM) Visible and Infrared Scanner (VIRS) were used to characterize the average diurnal fire cycle in 15 regions of the tropics and sub-tropics. Bias errors in the resulting diurnal cycles were either avoided or removed through a combination of judicious region selection and the application of corrections to compensate for cloud obscuration and time-dependent “blind spots” in the fire-detection capability of the VIRS sensor. Supplementary data from the Moderate Resolution Imaging Spectroradiometer (MODIS) on board NASA’s Terra satellite aided this process. In all regions, the local time of peak burning fell between 13:00 and 18:30, with fire activity peaking distinctly earlier for the heavily forested regions. The time period of the central 50% of total daily fire activity varied from a minimum of 1.3 h in North Central Africa to a maximum of 5.5 h in Eastern Australia. In general, shorter periods of burning were associated with greater tree cover. Using the diurnal cycles obtained for each region, an analysis of the drift in the local overpass times of the NOAA-7 through NOAA-14 afternoon satellites was performed. Results show that very large, spurious trends are likely to occur in a long-term Advanced Very High Resolution Radiometer (AVHRR) fire record due to differences in diurnal sampling over time.


*Keywords:* Fire; Biomass burning; Diurnal cycle; MODIS; VIRS

## 1. Introduction

The demand for improved information on regional and global fire activity in the context of land use and land cover change, ecosystem disturbance, climate modeling, and natural hazards has generated considerable interest in obtaining reliable fire-related information from spaceborne sensors. A number of satellite-based fire data sets have consequently been produced over the past decade. These include the Advanced Very High Resolution Radiometer (AVHRR) global fire product (Stroppiana et al., 2000b), the Along-Track Scanning Radiometer (ATSR) night-time fire product (Arino and Rosaz, 1999), the Visible and Infrared Scanner (VIRS) monthly fire product (Giglio et al., 2003), the Moderate Resolution Imaging Spectroradiometer (MODIS) global fire product (Justice et al., 2002), the Geostationary Operational Environmental Satellite (GOES) Wildfire Automated Biomass Burning Algorithm (WF ABBA) fire product (Prins et al., 1998), and the Defense Meteorological Satellite Program (DMSP) Operational Line-scan System (OLS) fire product (Elvidge et al., 1996). An important difference among these sensors is that each provides a different sampling of the *diurnal fire cycle*, i.e. the variation in fire activity with respect to the local time of day. The ATSR and OLS, for example, are restricted to nighttime fire detection, while the Terra and Aqua MODIS instruments sample morning and early afternoon fires, respectively. Any meaningful intercomparison of fire activity across sensors must take these sampling differences into consideration. Similarly, any fusion of active fire observations from multiple sensors requires consideration of the diurnal fire cycle.

Knowledge of the diurnal fire cycle should also help improve our understanding of land use and land cover change. Different types of burning (agricultural waste, lightning-induced, land use, prescribed burns, etc.) are thought to have different diurnal fire signatures. A more utilitarian application would be to facilitate the use of historical AVHRR active fire data sets. The

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local overpass time of each of the NOAA platforms gradually drifted following their launch (Csiszar et al., 2003), and is likely to have introduced significant biases in the long-term AVHRR fire record. Knowledge of the diurnal fire cycle might allow the normalization of different AVHRR active fire data sets to a consistent point in this cycle.

In this paper, the diurnal fire cycle in the tropics and subtropics is characterized using observations made with the Tropical Rainfall Measuring Mission (TRMM) VIRS sensor, supplemented with fire data from the Terra MODIS instrument. In Section 2, a brief survey of previous remote-sensing-based studies of the diurnal fire cycle is provided. Section 3 contains a description of the input data used in this study. A brief discussion of the sampling characteristics of the VIRS instrument is provided in Section 4. In Section 5, a methodology for extracting the diurnal fire cycle is described, with an emphasis placed on bias sources and the mitigation of these biases. Results are presented, on a regional basis, in Section 6. Finally, in Section 7, the implications of these findings are discussed within the larger context of long-term global fire monitoring.

## 2. Previous work

Both anecdotal evidence and regional satellite-based studies have established that a diurnal burning cycle exists in Africa and South America. Primary examples include the following.

(1) Prins and Menzel (1992) used observations from the Geostationary Operational Environmental Satellite (GOES) Visible Infrared Spin Scan Radiometer Atmospheric Sounder (VAS) to monitor biomass burning in South America. The VAS has two channels of primary importance to fire detection: a 3.9 μm channel having 13.8 km × 13.8 km spatial resolution, and an 11.2 μm channel having 6.9 km × 6.9 km spatial resolution at the subsatellite point. The authors examined the diurnal variation in fire activity as measured by the absolute number of fire pixels detected in VAS imagery acquired on 14 August 1983 at 12:31, 15:31, 18:31, and 21:31 UTC, and note a strong diurnal variation in detected fire pixels, with the maximum occurring at 15:31 UTC (12:31 local time) and the minimum at 21:31 UTC (18:31 local time).

(2) Langaas (1992) used a field study employing 26 foresters in The Gambia to survey local fire activity at the four NOAA-9 and NOAA-11 overpass times (02:30, 08:30, 14:30, and 20:30 local time) each day over a 2-week period from 7 to 20 March 1988. The peak in number of active fires occurred at 14:30, with 8.5 times the number of fires that were observed at the 02:30 minimum. Langaas also used NOAA-10 and NOAA-11 AVHRR data acquired at 20:30 and 02:30, respectively, to identify active fires in Senegal and The Gambia for eight dates in December 1989 and March 1990. He reported that ~2.7 times as many fire pixels were recorded during the 20:30 overpass.

(3) Cahoon et al. (1992) examined the temporal and spatial distribution of fires in Africa during 1986 and 1987 with nighttime OLS data. They concluded, contrary to their expectations, that a strong diurnal burning cycle did not exist because so many fires were detected in the nighttime imagery. In a subsequent letter, Langaas (1993) questioned this conclusion based on earlier work using satellite imagery and field observations (Langaas, 1992).

(4) Prins and Menzel (1994) used 5 days of GOES-7 VAS observations acquired between 31 August and 7 September 1983 at 12:30, 15:30, and 18:30 UTC to examine the diurnal fire cycle in South America. In addition to using the VAS to detect active fires, Prins and Menzel estimated the average temperature and instantaneous sub-pixel area within each fire pixel using the technique of Dozier (1981) and Matson and Dozier (1981). By summing these sub-pixel areas within each VAS image, Prins and Menzel found the peak in total instantaneous fire area occurred at 15:30 UTC, corresponding to a local time of approximately 12:30. Note that each of the VAS images spanned more than 30° in longitude, meaning that the local solar time varied by more than 2 h across each image.

(5) Menzel and Prins (1996) used observations from the GOES-8 Imager to quantify the diurnal fire cycle during the week of 5–11 September 1994. This instrument, called simply Imager, was a successor to the VAS with an improved spatial resolution of 4 km for both its 3.9 and 10.7 μm channels. Using observations spaced 3 h apart at 12:00, 15:00, 18:00, and 21:00 UTC, Menzel and Prins found the peak of burning to occur at 18:00 UTC. The authors note that this result differs from their earlier findings obtained with the lower-resolution GOES-7 VAS for the 1983 burning season (Prins and Menzel, 1994).

(6) Eva and Lambin (1998) examined the diurnal burning cycle in the Central African Republic (CAR) using 1 month of AVHRR LAC data acquired between 22 December 1993 and 27 January 1994. The authors exploited the fact that the width of the AVHRR swath caused significant overlap to occur between consecutive orbits, allowing a portion of the diurnal cycle to be sampled. They considered two land cover classes within CAR, open savanna and woodland/agriculture, and found that the peak in burning took place in the early afternoon for both classes. Early morning fires were confined to open savanna. The authors note that restricting fire observations to nighttime satellite overpasses can severely underestimate fire activity, and that, within their region of study, nighttime fires exhibit a different spatial distribution than daytime fires.

(7) Pack et al. (2000) used data from the constellation of geosynchronous Defense Support Program (DSP) infrared surveillance satellites to monitor biomass burning in southern Africa. These satellites, which were designed to detect rocket launches and nuclear explosions, image almost the entire terrestrial surface at the astounding rate