Quantifying the impact of cloud obscuration on remote sensing of active fires in the Brazilian Amazon

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Introduction

Vegetation fires continue to play a significant role on land and atmospheric processes globally and in particular in the tropical regions [Dwyer *et al*., 2000]. Correct quantification of fire events is essential primarily for understanding the dynamics of land use and land cover change, as well as for providing information for modeling of emission estimates from biomass combustion [Korontzi *et al*., 2004]. A major factor influencing fire numbers derived from remotely sensed imagery is the effect caused by cloud obscuration [Schroeder *et al*., 2005]. The net effect of cloud obscuration on fire detection will work as a function of the fire regime of a specific area, therefore being dependent upon the spatial and temporal fire distributions associated with human activities, and the average cloud cover fraction driven by regional climate conditions.

Here I present an approach that uses physical (precipitation) and social (fire use history) information to quantify the potential omission error associated with the cloud obscuration problem affecting satellite active fire detection data. The proposed approach is applied to a geostationary satellite fire data set in order to better characterize the cloud effect on fire detection over the entire diurnal cycle. I focus my analyses on the Brazilian Amazon basin where intense fire activity associated with frequent cloud cover results in important underestimation of vegetation fire numbers from satellite observations.

Data

Fire: The Geostationary Operational Environmental Satellite positioned at 75º longitude (GOES-East) serves as the basis for this study. The Automated Biomass Burning Algorithm (ABBA) [Prins *et al*., 1998] produced by the University of Wisconsin – Madison provides the information on active fires required for the analyses. The data set selected for use covers the period of January/2003-December/2005 and is composed of 17,520 half hourly files per year.

Precipitation: Consideration of the spatial and temporal resolution requirements suggested the use of GOES-based precipitation products in this study. Here I use a modified version of the hydroestimator product [Vicente *et al*., 1998] generated at the Center for Weather Forecasting and Climate Studies (CPTEC/INPE) which delivers daily precipitation estimates covering the area of interest.

Cloud Mask: A new cloud mask was produced to fulfill the spatial and temporal resolution requirements set by this study. The cloud mask algorithm uses fixed and dynamic tests applied to a 30day temporal profile based on 4km – 30min resolution Global-Merged Infra-Red Brightness Temperature (BT) product generated by the Climate Prediction Center (CPC/NCEP/NOAA)[http://disc.sci.gsfc.nasa.gov/data/datapool/TRMM/01_Data_Products/06_Ancillary/01_Global_MERG_IR/index.html].

Methods

A 40km grid was used to divide the region into smaller subparts. A more detailed grid of 4km in size nested on the previous one was used to represent the nominal GOES pixel map. The analyses were based on the 40km grid and the cloud obscuration verification processed for every 4km pixel and for every observation hour.

Precipitation and fire relationship: In this study, the physical condition will be primarily associated with the amount of rainfall a given area receives during the period before a vegetation fire breaks through. The climatology of precipitation and fire occurrence was extracted for each 40km cell using 2004 data. Interestingly, the curve that defines the relationship between precipitation and fires assumes a strong linear distribution when the sampling grows larger (typically for n>50) (Figure 1). A third degree polynomial was used to describe the precipitation x fire relationship.

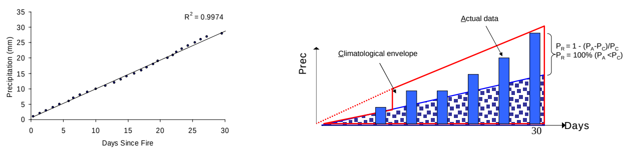

Figure 1: Mean precipitation values calculated for location z = 4785 (i.e., the reference index for an individual 40 x 40km cell) based on n = 151 active fire detections observed during 2004 (left); R^2 value refers to a linear equation. The probability of fire omission (P_R) associated with precipitation conditions was derived based on the relationship between the climatological curve and the actual data for 30days (right).

Human activity and fire use: The spatial and temporal patterns of vegetation fires observed in the region are strongly associated with human activity and the use of fires for land use and land cover change (Figure 2). Active fire records derived from GOES during 2003-2004 were used to establish the mean annual fire activity in time and space. In order to derive the temporal distribution of fires, the year was divided into 26 14-day periods. The probability distribution of fires detected during each one of the 14-day periods in relation to the 2003-2004 totals was calculated for every 40km grid cells. A random function (ξ) was used to represent fire return rate. The spatial distribution of fires was determined using the 4 x 4km grid. The cloud obscuration processing would be performed only for those areas where fire activity were reported in the reference years analyzed (2003-2004). Look Up Tables (LUTs) containing the spatial and temporal fire distribution data were created for use with the cloud obscuration processing (Figure3).

Figure 2: GOES ABBA active fire detections for year 2005 overlaid on top of the major highways network and settlement projects areas.

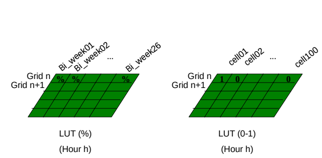

Figure 3: LUTs describing the temporal probability distribution of fires for each 26 14day periods of the year (left) and the spatial distribution of 4km pixels under the influence of fires in the reference years analyzed (right).

Cloud obscuration analysis: The methodology implemented during this study was designed to use the information derived from the previous steps for compensating year 2005 GOES fire data for the cloud obscuration problem. GOES data were processed sequentially for every acquisition hour during year 2005 totaling 17,520 observations. Given a particular observation date and time, the code will initially search for all 4km pixels that, according to both temporal and spatial historical fire distribution LUTs, have the potential to present a fire. The cloud mask product that was produced for the same year (2005) is then used to search for cloudy pixels among the previously selected ones. Two major scenarios were developed during processing, each representing distinct cloud coverage conditions (Figure 4). In *Scenario 1*, fire omission probability (P_F) is assigned based on the spatial and temporal distribution information along with the precipitation conditions. In *Scenario 2*, actual active fire detection data is used as a reference along with a hypothetical fire diurnal cycle curve (Figure 5) to assign probability of fire omission P_F as a function of the local time.

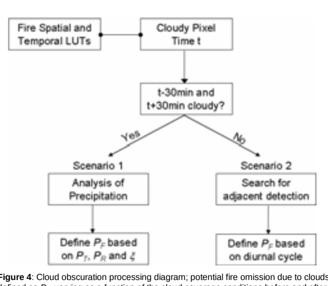

Figure 4: Cloud obscuration processing diagram; potential fire omission due to clouds is defined as P_F, varying as a function of the cloud coverage conditions before and after the observation hour (t) under consideration.

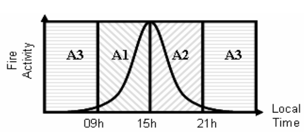

Figure 5: Stratification of the diurnal cycle of fire activity (taking into consideration the effects of temperature and humidity on fire spread) used for assigning the omission probability P_F over scenario 2.

Results

The main code was used to process data for year 2005. Each intervention produced by the code generated a fractional fire increment that was accumulated over multiple hours and days of observation and for each 4 x 4km pixel area resulting in a total number of fires potentially missed due to the presence of clouds equivalent to 115,754, or approximately 21% of the actual GOES fires detected during 2005 (544,286 total – representing ABBA's fire types 1 - 4 only; category 5 associated with low probability fires was not used) (Figure 6).

The 2005 data set was also processed using the simple approach for compensating for clouds, which is based on the assumption that fires occur at the same frequency under clouds are they do in the open. Two different grids of 40km and 120km resolution were tested in this case, the results indicating a potential fire omission of 33% and 44% respectively.

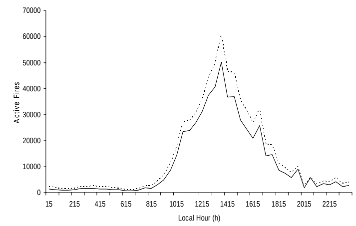

Figure 6: GOES ABBA hourly fire counts (solid line) and the accumulated hourly fire increment (dashed line) produced by the cloud obscuration methodology for year 2005.

The majority of interventions performed by the methodology were associated with the conditions described by scenario 1 (Figure 4), where all three observation hours T-30min, T, and T+30min are obscured by clouds. Average cloud coverage in the region varied between a minimum of 22% and a maximum of 78% depending on the observation hour, with the lowest values found in the areas surrounding the evergreen tropical forests in the southern and eastern parts of the basin (Figure 7). This spatial distribution of fires and cloud coverage is beneficial as it minimizes the cloud obscuration problem in areas where fire activity is most pronounced (e.g., states of Mato Grosso, Tocantins, Maranhão, and eastern Pará). Minimum cloud coverage was found to coincide with the early afternoon observation hours (Figure 8), what in fact has major implications for fire detection as it approaches the hour of maximum fire activity in the region.

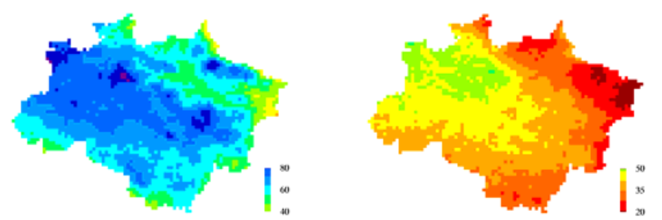

Figure 7: Average maximum (left) and minimum (right) percentage cloud coverage for all GOES observation hours across the Brazilian Amazon region; minimum values are specially important along the eastern and southern parts of the basin where fire activity is predominantly high.

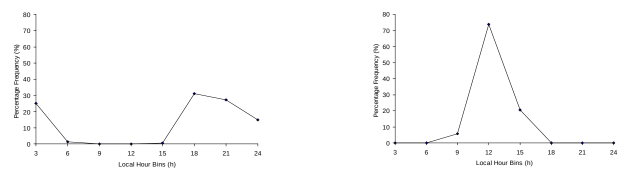

Figure 8: Frequency distribution of hours of maximum (left) and minimum (right) cloud coverage across the Brazilian Amazon region arranged in 3hour bins (based on the local hour); peak in minimum cloud coverage partially overlaps that of fire activity.

Validation

In order to evaluate the performance of the method proposed high resolution (20m) China-Brazil Earth Resources Satellite (CBERS-2) burn scar maps were produced for the state of Acre in the western Brazilian Amazon covering the 2005 fire season in the region (July-September)(Figure 9).

The ABBA GOES fire counts (excluding fire category 5) were spatially aggregated along with the burn scar areas and the fire increments produced independently by the method proposed above and the simple rule approach (using 40km and 120km grid resolutions) and error matrices were derived (Tables 1-4).

Tables 1-4: Error matrices for evaluating comission and omission errors associated with the original GOES active fire data (1), the proposed cloud obscuration method (2), and the simple rule approach with 40km (3) and 120km (4) grid cells in relation to 20m resolution CBERS data (used as our "truth" parameter).

Table1

	Fire (CBERS)	Non-fire (CBERS)
Fire (GOES)	519	8
Non-fire (GOES	727	117
	Omission: 58.3%	Comission: 6.4%

Table2

	Fire (CBERS)	Non-fire (CBERS)
Fire (GOES+Method)	698	11
Non-fire (GOES+Method)	548	114
	Omission: 44%	Comission: 8.8%

Table3

	Fire (CBERS)	Non-fire (CBERS)
Fire (GOES+Simple40km)	1116	79
Non-fire (GOES+Simple40km)	130	46
	Omission: 10.4%	Comission: 63.2%

Table4

	Fire (CBERS)	Non-fire (CBERS)
Fire (GOES+Simple120km)	1246	125
Non-fire (GOES+Simple120km)	0	0
	Omission: 0%	Comission: 100%

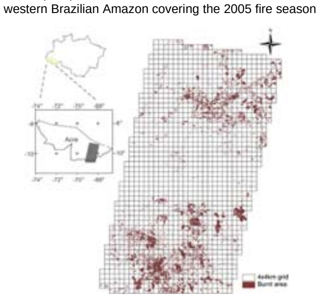

Figure 9: Validation test site over the state of Acre - western Amazon basin for assessing the performance of the cloud obscuration processing.

Conclusion:

The methodology described here was designed to address the cloud obscuration problem affecting remote sensing of active fires using high frequency geostationary observations. The use of recent historical data along with precipitation data provided means to establish the general patterns of fire use in both space and time across the entire basin, while preserving specific regional characteristics with the implementation of pixel based processing. The overall impact caused by cloud obscuration was found to be partially minimized thanks to the spatial distribution of fires across the Brazilian Amazon basin which basically coincided with the areas of minimum cloud coverage, and also thanks to the partial overlap between the hours of minimum cloud coverage and maximum fire activity. As compared to a more simplistic approach, the methodology was proven successful in reducing the omission errors while maintaining the commission errors intact.

Acknoledgements:

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