Characterising Fire Hazard from Temporal Sequences of Thermal Infrared MODIS Measurements

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1 Introduction

Vegetation moisture and temperature are the most variable factors determining fire hazard. Prolonged heat and absence of rainfall drive vegetation into water stress conditions; this leads to an increase (anomaly) of vegetation temperature that can be recorded by remote sensing instruments. Since stressed vegetation is more prone to fire, there might be a potential role for Earth observation technologies in mapping fire hazard.

To identify anomalies, reference temperatures against which evaluate current measurements must be defined. The HANTS (Harmonic ANalysis of Time Series) algorithm may accomplish this task, but its effectiveness in providing a reference useful for the assessment of fire hazard is still unexplored.

The objective of the present research was to characterise fire hazard from anomalies of daily land surface temperature (LST) derived from MODIS measurements. Since maps of HANTS coefficients provide a detailed description of the spatial and temporal pattern of surface temperatures, their potential to explain spatial patterns of fire events was also investigated.

2 Materials and methods

The research focussed on Campania, Italy (13595 km²). The Italian Forest Corps provided a dataset of more than 4400 fire records covering years between 2000 and 2006. Data included date and time, coordinates, duration, extent and presumed causes of each event. A collection of daily Terra-MODIS LST data from 2000 to 2006 was used for our analyses.

The HANTS algorithm handles the Fourier analysis as a curve-fitting problem. Basing on an iterative approach, invalid observations are removed and the best fitting series is identified. Series comprising three harmonics (365, 180 and 120 days) were fit to the data with two methods: separately on each yearly sequence of LST data; on the whole 2000-2006 dataset to construct daily maps of reference temperature.

Yearly maps of Fourier coefficients were classified by segmenting their values. Spatial patterns of fire number and burnt area were assessed in terms of selectivity, i.e. by understanding whether in each class fire incidence is higher (preferred) or lower (avoided) than expected from a random null model. Daily maps of thermal anomalies (TA) were computed by subtracting the daily reference temperature from current MODIS LST. Cumulated thermal anomalies (CTA) were calculated as the sum of all the observed thermal anomalies from the day when the thermal anomaly was first recorded in a pixel up to the current day.

The values of TA and CTA were sampled at fire's location in the day previous to the event, and evaluated against fire size by calculating the conditional mean fire size observed when the TA (CTA) was larger of the considered value. Similarly, the conditional proportion of large fires (> 16 ha) was calculated.

3 Results

Fires are selective towards Fourier coefficients, and tend to prefer areas where the mean temperature and the amplitude of the first harmonic have higher values, and to avoid low values. Fires also prefer areas where the amplitudes of the second and third harmonic are low, and where the phase of the second harmonic is high. Mean fire size shows selectivity only towards the amplitude of the second harmonic (see table below).

<table>
<thead>
<tr>
<th>Number of fires</th>
<th>Mean fire size (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>2013</td>
</tr>
<tr>
<td>2-3</td>
<td>570</td>
</tr>
<tr>
<td>&gt;3</td>
<td>28</td>
</tr>
</tbody>
</table>

Daily maps of thermal anomalies (left, below) and cumulated thermal anomalies (right) carry different information (date is 15 July 2001 in the example).

With increasing values of thermal anomaly, the conditional mean fire size increases (left, below). A similar trend is observed with the conditional fraction of fires larger than 16 ha (right).

Increasing values of cumulated thermal anomaly lead to larger fires (left, below). As opposed to TA, the ranges of values of mean fire size and fraction of large fires that can be mapped from CTA are considerably larger.

4 Discussion

Mean annual temperature and the amplitudes of the three harmonics used in the Fourier analysis determine spatial patterns of fire occurrence. The only phase component of the Fourier analysis related to fires incidence is that of the first harmonic: a larger number of fires is observed where the phase is higher, i.e. when a prolonged warm season occurs.

Anomalies of LST are related to the fire size that can be expected in a given area, with CTAs being more sensitive than TAs. CTA is a measure of heat "accumulated" in a certain area, providing more direct information on the prolonged exposure of vegetation to stress conditions. This is reflected in the prediction of expected mean fire size over two orders of magnitude, allowing the production of more meaningful fire hazard maps as compared to TA.