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Background extraction from light curves of solar millimeter emission

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Abstract. Presently, with the development of space and ground based observatories, a large amount of data are collected. The study of solar activity is very important because of its effects on Earth. The POEMAS (POlarized Emission of Millimeter Activity of the Sun) telescopes are a system of two telescopes, installed at CASLEO (El Leoncito Astronomical Complex) in Argentina, which monitor the Sun at two millimeter wavelengths (45 and 90 GHz) with polarization measurements. For the analysis of the solar flares observed by the POEMAS polarimeters at 45 and 90 GHz, it is first necessary to eliminate the background, mainly caused by instrumental effects, from the light curves of the millimeter solar emission. The objective of this work is to compare two background extraction techniques using the Kalman filter (a mathematical method that estimates the real values of the measured quantities and relative values predicting a value) and Smoothing (a filter that smoothes the noisy signal). We hope with this work to identify the best technique for extraction of the emission background considering the two methods applied to the millimeter emission of the Sun, and thus better identify the solar flares within the light curves.

Resumo. Atualmente, com o desenvolvimento de estações e observatórios espaciais e terrestres, uma grande quantidade de dados é coletada. O estudo da atividade solar é muito importante devido aos seus efeitos sobre a Terra. Os POEMAS (POlarização de Emissão Milimétrica da Atividade Solar) são um sistema de dois telescópios, instalados em CASLEO (Complexo Astronômico El Leoncito) na Argentina, que monitoram o Sol em dois comprimentos de onda milimétrica (45 e 90 GHz). Para a análise das explosões solares observadas pelos polarímetros POEMAS em 45 e 90 GHz, primeiramente é necessário eliminar o ruído de fundo, causado principalmente por problemas instrumentais, das curvas de luz da emissão solar milimétrica. O objetivo desse trabalho é comparar duas técnicas de extração de "background" usando o filtro de Kalman (método matemático que produz estimativas dos valores reais das grandezas medidas e valores relativos predizendo um valor) e Smoothing (filtro que suaviza o sinal ruidoso). Esperamos com esse trabalho identificar a melhor técnica de extração de background, considerando os dois métodos aplicados na emissão milimétrica do Sol, e assim melhor identificar as explosões solares nas curvas de luz.

Keywords. Virtual observatory tools – Sun: flares – Telescopes

1. Introduction

The POEMAS (POlarized Emission of Millimeter Activity of the Sun) telescopes installed at CASLEO The POEMAS (POlarized Emission of Millimeter Activity of the Sun), the only of its kind Valio (2013), is shown in Figure 1. Emission at 45 and 90 GHz from the Sun is continuously monitored, in right and left circular polarization. The telescopes were saw their first light in November 2011 and operated until December 2013.

Since this was a period of maximum solar activity many flares were detected during the period of operation **?**. Flares are one of the main manifestations of solar activity, when huge amounts of energy are released. This extra energy accelerates particles, heats the local plasma, and cause copious amounts of radiation, at all wavelengths of the electromagnetic spectrum. Also, during at times of maximum activity, coronal mass ejections are most frequent. These matter and magnetic fields hurled into interplanetary space may affect Earth, when ejected in our direction. Geomagnetic storms, interruption of telecommunication signals, GPS malfunctioning, and blackouts are just some of the disrupting effects.

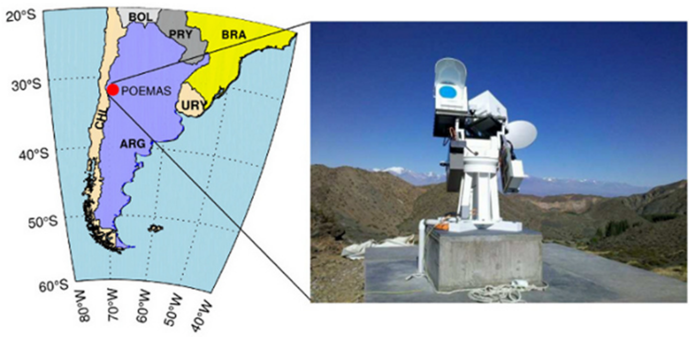

Figure 1. *Left:* Location of the CASLEO Observatory in Argentina. *Right:* The POEMAS telescopes. Valio (2013)

2. Observations

Unfortunately due to a mechanical problem with the base of the telescopes, there is a diurnal variation in the light curve flux caused by the misalignment of the telescope. Figure 2 shows the expected variation of the millimeter emission during the day as the red curve, however what is observed by POEMAS is the black curve. The variation with a drop in signal of as much as 20%, close to noon, due to instrumental problems is evident (Figure 2).

Thus, before any flare can be identified for further analysis, this daily instrumental variation needs to be corrected. Our first approach is to consider as background the average of the emission on the day before and that of the day after. This is based on the assumption that the path of the Sun on the sky has not changed during these days. Moreover, we assume that no flare has occurred on either the previous or the later days, which can be easily verified by visual inspection.

An example of this is shown in Figure 3 for the observation of the 26 (red), 27 (black), and 28th (blue) of January 2012. The idea is to take an average of the light curve of the 26 and 28th of

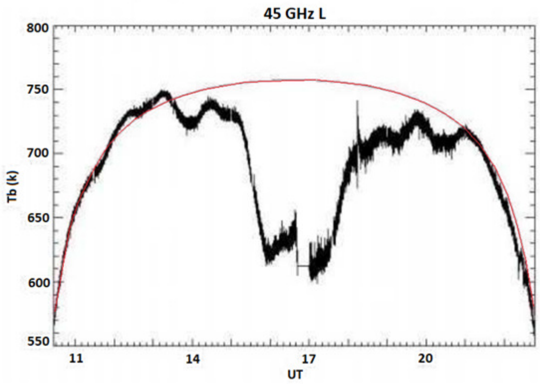

Figure 2. Observation of one full day observation of the solar flux at 45 GHz, left circular polarization (black curve) and the expected flux (rec curve).

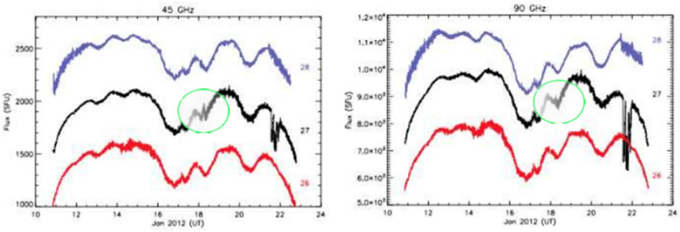

Figure 3. Light curves of the solar emission at 45 (left) and 90 (right) on 26 (red curve), 27 (black curve), and 28th (blue curve) of January 2012.

January and then subtract it from that of day 27th. The flare that occurred on the 27th is depicted by the green circle in Figure 3.

3. Background determination

However, before the background subtraction can be applied it is necessary to reduce the noise of the light curves. This can be done in at least two ways, Smoothing or Kalman filtering.

3.1. Smoothing

To smooth a data set is to create an approximate function that attempts to capture important patterns in the data while leaving out noise or other fine-scale structures or rapid phenomena Simonoff (1998). In Figure 4, we present the result of using the smoothing filter at 45 and 90 GHz with a moving average for a running mean window width of 5 (in the left column) and 15 points (in the right column). We can see that with the enlargement of the moving window. a smoother curve is obtained.

3.2. Kalman Filtering

Its purpose is to use measurements of quantities made over time (contaminated with noise and other uncertainties) and generate results that tend to approximate the actual values of the measured quantities and associated values Kalman (1960). The prediction uses the previous time state estimate to obtain an estimate of the current time state. In Figure **??** the 45 and 90 GHz light curves are shown with the use of Kalman Filtering without prediction (in the left column) and with prediction (in the right column). Kalman Filtering without prediction has a similar result to smoothing filter when using a small window. Kalman Filtering using prediction presented the best result.

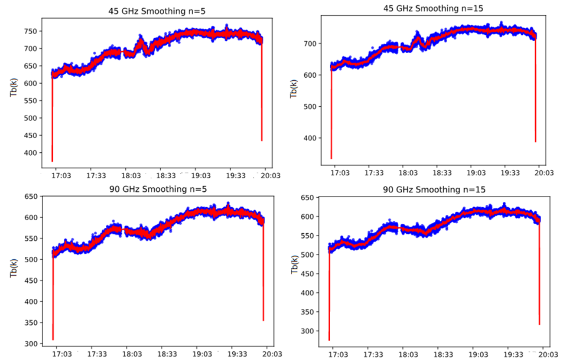

Figure 4. Smoothing of 45 (top panels) and 90 GHz (bottom panels) light curves using an average window of 5 (left) and 15 points (right).

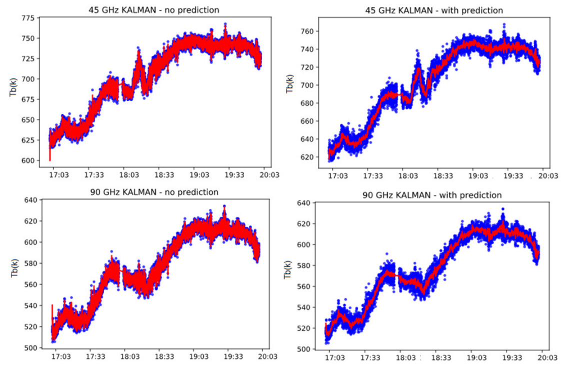

Figure 5. Kalman Filtering of 45 (top panels) and 90 GHz (bottom panels) light curves with (right) and without (left) prediction.

4. Conclusions

To better identify flares in the light curves of 45 and 90 GHz observed by POEMAS, we devised a background subtraction method. However, before the subtraction, the data has to improved by noise reduction. Two methods were tested: (1) Running mean smoothing and (20 Kalman filtering. The side effect produced by smoothing is equivalent to data loss. Kalman filtering is perfect if you understand how the system works, and can get the parameters right.

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