A workable background removal scheme for SMEI?

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1 Introduction

This document describes a revised scheme of background modeling for SMEI sky maps. In an earlier document ("*Thoughts on background removal in SMEI*" May 2004) I described some initial attempts to subtract a background model defined in coordinates fixed to the celestial sphere. This unfortunately suffered from several major drawbacks:

1. The transforms and interpolation were computationally very expensive (well over a day of processing to generate a year of models).
2. Even when this was done, the registration of the stellar images was not quite good enough. In particular there was a "ring and dot" structure caused by a slight broadening in the images in the model maps.
3. The size and shape of bright stars in the sky maps has changed over the course of the mission due to changes in the processing.
4. The "solar" component of the background tends to vary monotonically or nearly so for long periods, particularly at low latitudes. A median filter does not have any effect on data which varies monotonically over a scale greater than the filter width. As a result features at low latitudes were suppressed.

As remarked before, the aim of this is to produce a system of background subtraction which will in principle allow the detection of slow-moving features such as CIR's and also allow us to see the true extent in elongation of transient structures.

2 Method

Conceptually the backgrounds are divided into three components each of which is determined in different ways. The manner in which these are separated from the original data and combined into a set of background images is summarized in Figure 1 and described in more detail below.

2.1 Baseline Data

As with the earlier attempts, I have started with a set of median images made one for each solar longitude value in the data processing. This produces **approximately** one median image per day (for convenience these will be called daily medians although this is not exact). Medians were chosen as these are less sensitive than means to wild data points (such as in the cases where an image claims to have a different pointing from that which it actually has).

2.2 The Galaxy

The contribution from the Galaxy (plus the Magellanic Clouds and major star clusters) is relatively smooth and is fixed in celestial coordinates. Because of its smoothness precise sub-pixel registration is less critical than is the case with stars.

To generate a model for the Galaxy, I took the full set of daily medians up to the time of analysis (2003 day 40 to 2004 day 125), and transformed these from solar-ecliptic coordinates to ecliptic coordinates and reprojected them into a cartesian projection with a 0.25 degree resolution using the `MIN_CURVE_SURF` routine. I then determined the 10^{th} percentile image of this stack. If it were not for the registration problems and the shape changes this image could be used as the basis for subtracting all the 'celestial' components of the background[1].

To separate the stars and the galactic component, I used a median filter and also a boxcar smoothing, both with the same size. In the examples here, a width of 11 pixels was used although this can be adjusted if desired.

[1] This is why the celestial image FITS files have 3 planes, one for bright stars high, one for low state and the third plane for all data. This analysis uses only the third plane.

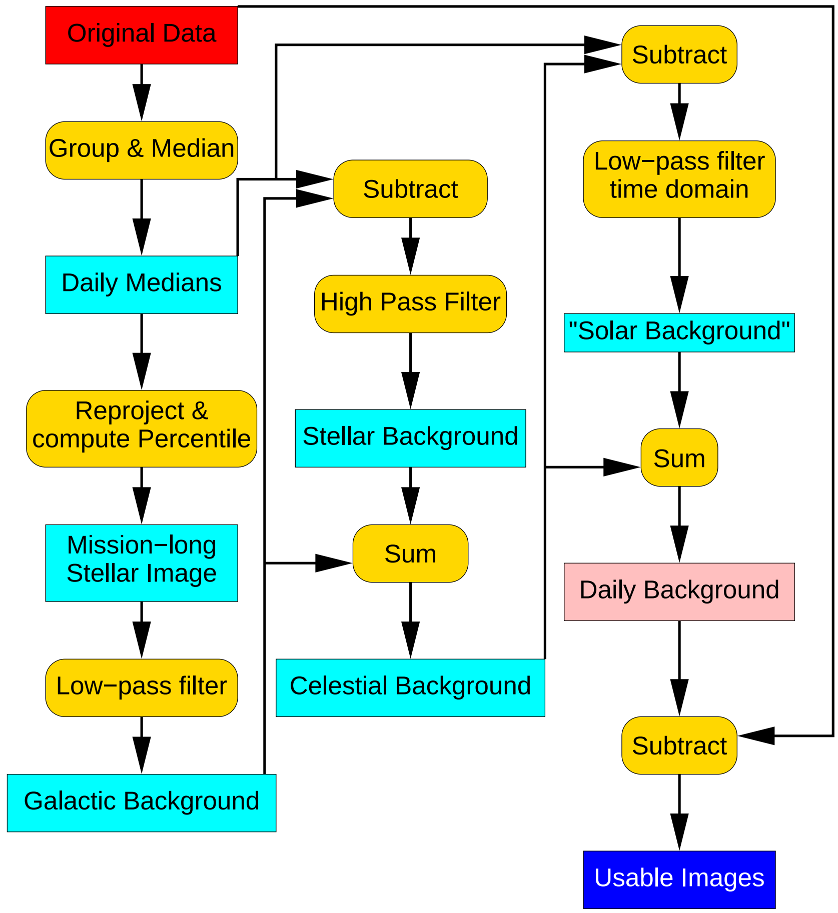

Figure 1: Schematic illustrating the process of generating the background images.

2.3 The Stellar Component

Like the Galaxy (§2.2) the stars are fixed in celestial coordinates and move relative to the Sun. However unlike the Galaxy they have small spatial scales which means that small errors in positioning the model star in the image can result in large residuals. However stars, planets and man-made space objects are the only bright features with small scales. It is therefore possible to to generate a map of stars and planets from the daily median images without reference to other days.

This is done by the simple expedient of taking the daily median image, subtracting the smoothed galactic contribution and then passing a median filter over the resulting image. The stellar map for the day is then the difference between the original galaxy-subtracted daily median and the median filtered image. These two components (the galactic and stellar) are added together to give the total celestial contribution to the background for the day (Figure 2).

The residual contains the "solar" background components and the signal that we wish to measure.

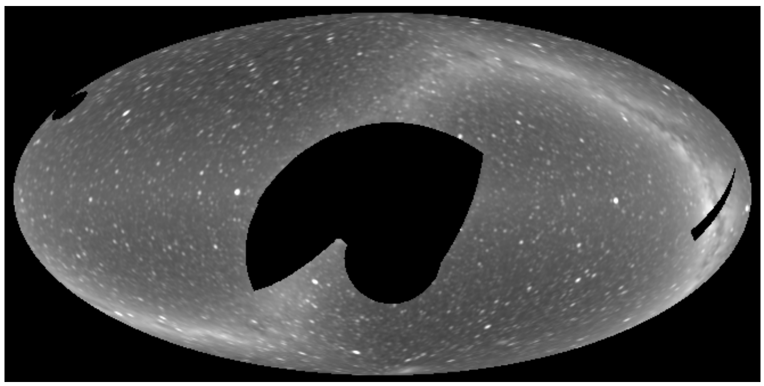

Figure 2: The stellar and galactic components of the background model for day 149 of 2003 (logarithmically scaled from 10 to 1000).

2.4 The Solar Backgrounds

The "solar" contributions to the backgrounds are many and various, including zodiacal light, gegenschein, stray light as well as instrumental effects such as dark current. These contributions should be relatively slowly varying in time. Therefore to generate a "solar background" image for each day, I take the residual images after removal of the galactic and stellar components and then use a time-domain median filter to separate the slowly-varying backgrounds from the more rapidly varying heliospheric signals (Figure 3).

The background to be subtracted from an individual image is then the sum of the three components (Figure 4). As can be seen, some stellar component (particularly near the galactic centre) does leak into the solar component.

The length of the time-domain median filter is the parameter which requires the most tuning as different filtering scales allow different structures to be seen. In particular using too short a filter will cause slow-moving features such as CIR's

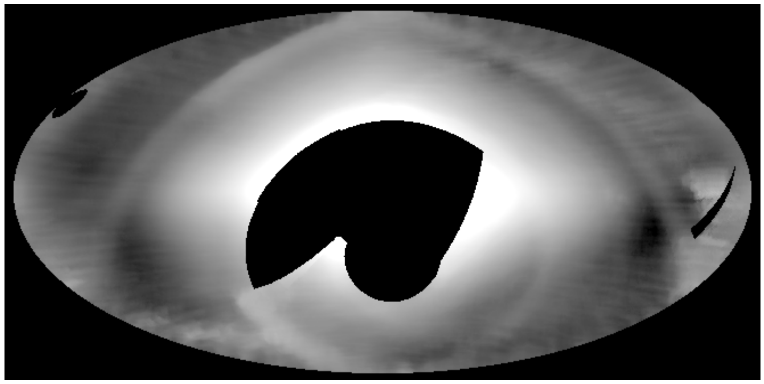

Figure 3: The “solar” component of the background model for day 149 of 2003 (plus 4 and then logarithmically scaled from 1 to 100).

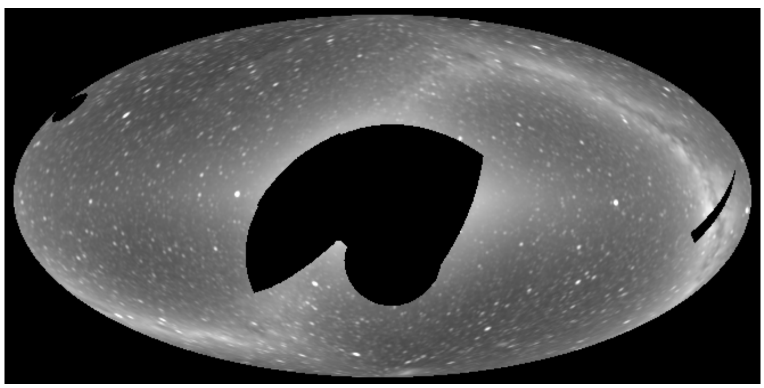

Figure 4: The final background model for day 149 of 2003 (logarithmically scaled from 10 to 1000).

to be lost, while too long a filter can result in large residuals particularly due to drifts in the Camera 3 dark charge.

The models so-far defined are listed in Table 1.

3 Results

Figures 5 and 6 show one image from the May 29 2003 halo event with the background subtracted with a model generated as described above and also a running

Table 1: The background models generated to date

Model	Median	Smoothing	Star Scale	Galactic Scale
1	15	none	15	11
2	27	none	15	11
3	15	none	21	11
4	27	none	21	11
5	7	none	15	11
6	7	none	21	11
7	15	11	21	11

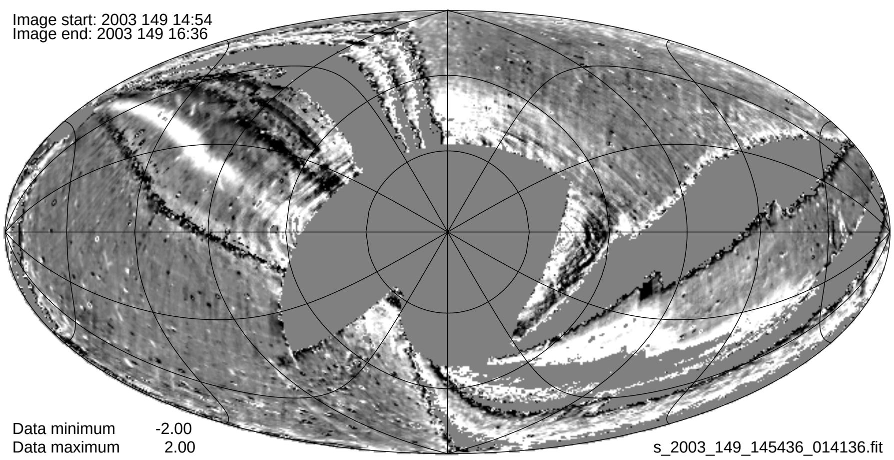

Figure 5: An image from the May 29 2003 halo event, made using background model number 6 (Table 1). The image uses a range of ± 2 ADU with a cutoff at ± 5 ADU.

difference. It is clear that the transient appears much more strongly in the background model than it does in the running difference. This is somewhat tempered by the fact that the background is somewhat noisier in the model subtraction than in the running difference. The erosion of the back of the transient by the running difference is very well illustrated by the plots in Figure 7 which compares radial profiles from the two subtraction techniques.

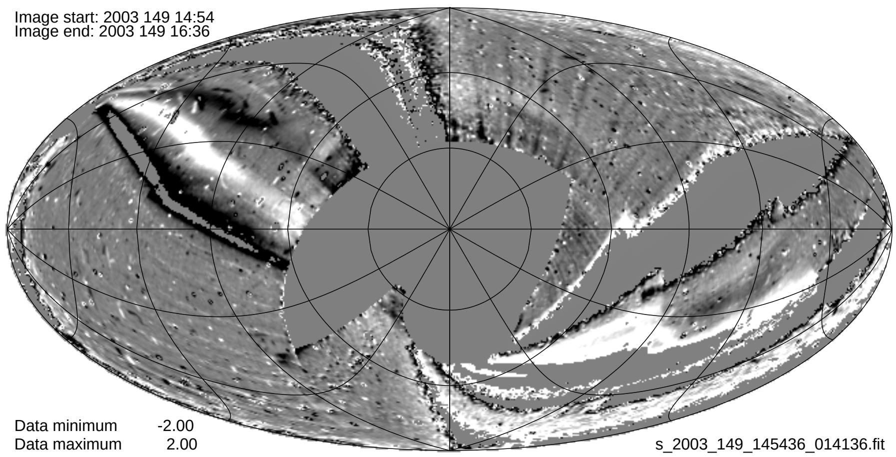

Figure 6: The same image as Figure 5, but using a running difference for background removal.

4 Conclusion

It appears that the procedure describe above provides a usable empirical method of subtracting backgrounds from SMEI images to allow us to see structures without the inevitable artefacts of running differences. It is probable that running differences will still retain a rôle in SMEI image display, but for many purposes the current models look to be better.

It appears probable that to do much better would require a more consistent baseline image set and probably the subtraction of the stars (and particle removal) to take place in the CCD image plane rather than in the final map plane.

4.1 Advantages over Running Differences

- Does not produce false decrements where an enhancement is present in the previous image.
- Can potentially detect slow-moving features.
- Has some success in excluding planets.
- No unusable image on pointing shift.

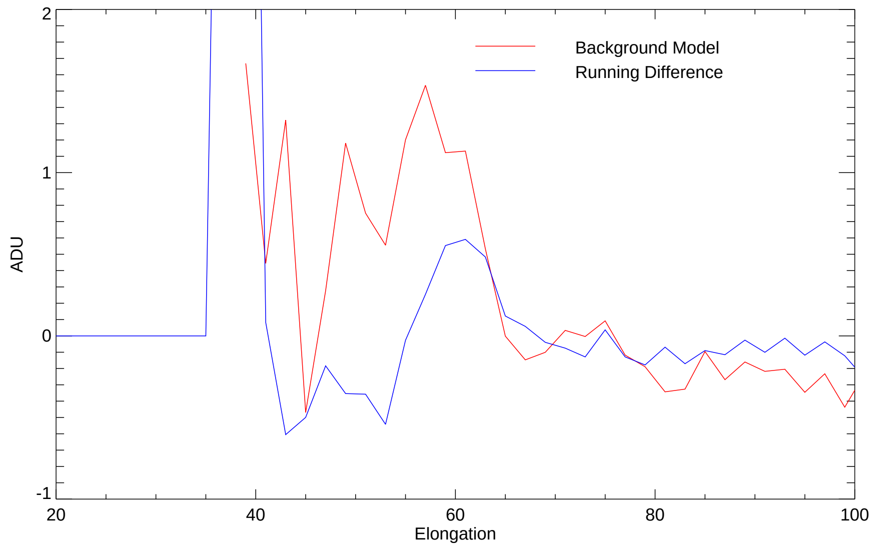

Figure 7: Radial profiles through the image shown in Figures 5 and 6 for both subtraction methods. The profile has a resolution of 2 degrees in elongation and covers a position angle range from 320 to 325 degrees (anticlockwise from North).

4.2 Disadvantages over Running Differences

- Needs a large database of background models.
- The background model can only be finalized weeks after the fact (median width plus smoothing width days).

5 Using it

The latest versions of the `sswidl` SMEI display (0.5.0 and above) have support for subtracting background models. However owing to the size of the database of background images these are not distributed with the software. The models can be downloaded from `rsync://lnxl.sr.bham.ac.uk/Back`[2]. They need

[2]From the command line a suitable command would be
`rsync -rv rsync://lnxl.sr.bham.ac.uk/Back .`

to be placed in the directory `${SSWDB}/smei/Background_models`, or the directory where they are should be linked there.

The background subtraction only makes use of the first 2 planes of the original FITS images, and in the `sswidl` display package only alters the “processed” plane.