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Temporal Average Estimate Algorithm for ERS-1/2

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Abstract

Spaceborne scatterometers can be used in the detection of the ice edge of the Arctic and Antarctic in order to study the effects of global warming and climate changes. Because of the non-linear properties of the SIR algorithm, errors in the imaged location of the edge can occur over areas of movement during the imaging interval. Ice growth and melting, for example, can cause errors in the detection of the actual location of an ice edge in a SIR image. A 'time-weighted average' algorithm of the σ^o values is developed to help improve the associated temporal estimate from the SIR image over areas of motion. This algorithm provides a better estimate of the temporal location of features in the SIR image for both temporally uniform and non-temporally uniform measurement distributions.

Introduction

To generate a SIR image from scatterometry data, several days worth of data are used. The resulting image is a weighted, non-linear average of the surface response over this period. Previously, the surface has been assumed to be constant during the days over which the SIR image was formed. Over areas of movement the location of the observed features in the SIR image has been assumed to be the location of the observed features at the mid-point of the time period over which the SIR image was created. Since the SIR algorithm is non-linear, however, this may not always be the case. For example, consider Fig. 1. Here we see a simulated SIR image of a fast moving edge, the linear temporal average of the edge over the six day period, and the edge at day 3 which corresponds to the location of the edge at the center of the six day period. Notice that the edges in the SIR image and in the day 3 image do not seem to correspond to each other as well as desired.

A simulation was created to evaluate the effects of the movement of a feature, specifically an edge. In this simulation, $\mathcal{A}$ and $\mathcal{B}$ truth images were created using a very fast moving edge. The speed of the edge in the simulation was set to 10 pixels ($\sim 90km$) per day to more easily show the effects of the movement. A small area in the Antarctic was used to get the time and spatial distribution of real measurements. The location of the edge in the truth images was determined by the time those measurements occured in the real data over the 6 day period. Figure 2 shows a few of the truth images over the six day period beginning at

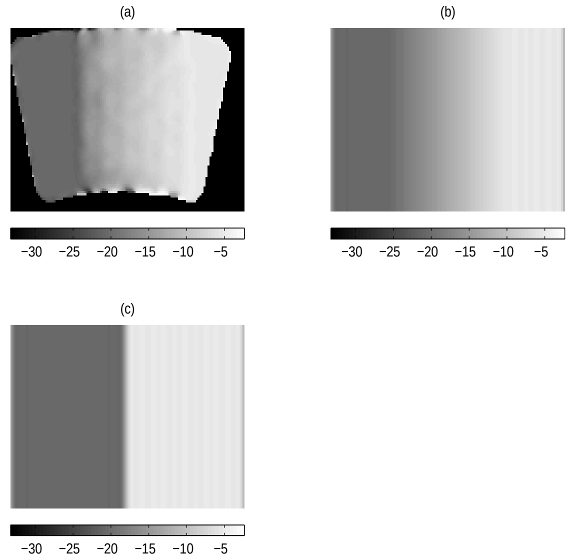

Figure 1: (a) Simulated SIR image (b) linear average image (c) filtered image at day 3.

day 0 and ending at day 6 at increments of 1/2 day. These images have been low-pass filtered to 25km resolution to aid in the comparison with the SIR images, which have approximately 25km resolution. This filtering accounts for edge ringing in the images. The unfiltered truth images were used to create simulated measurements over a six day period. A SIR image was then generated from the simulated measurements.

Figure 3 shows horizontal slices through the three different images shown in Fig. 1. Notice that the magnitude of the edge of the SIR image is higher than the linear average edge over the 6 day period. This, in effect, causes the edge of the SIR image to appear, in this case, further to the left than the average edge. (For an edge moving from right to left, i.e. growing, it would appear further to the right.) Another interpretation is shown in Fig. 4. This shows the linear average edge shifted to the left by x days. Notice that this edge is a much closer approximation to the edge of the SIR image. In other words, We can think of the edge in the SIR image as a shifted linear average. For a receding edge the average corresponding to the SIR image would be shifted to the left. For a growing edge the average would be shifted to the right. Through this observation, a time index algorithm has been developed to help with the discrepancies seen in these images. This paper will discuss the algorithm, and explain how it works. We consider some particular cases.

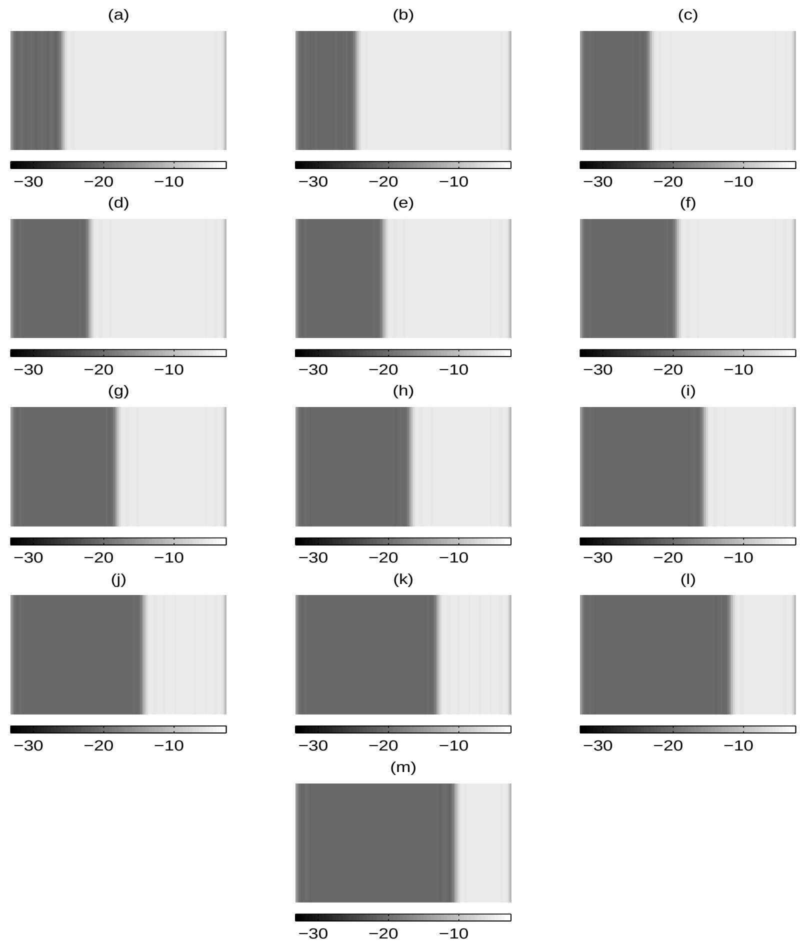

Figure 2: simulated ice edge images from (a) day 0 to (m) day 6, in 1/2 day increments.

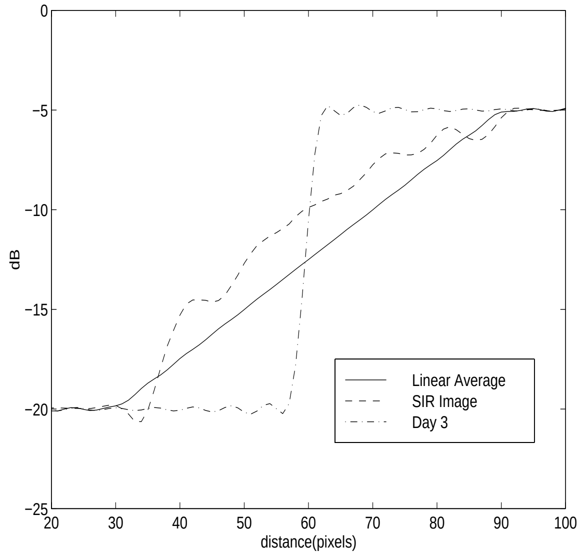

Figure 3: Ice edge of the SIR image, linear average image and filtered image at day 3

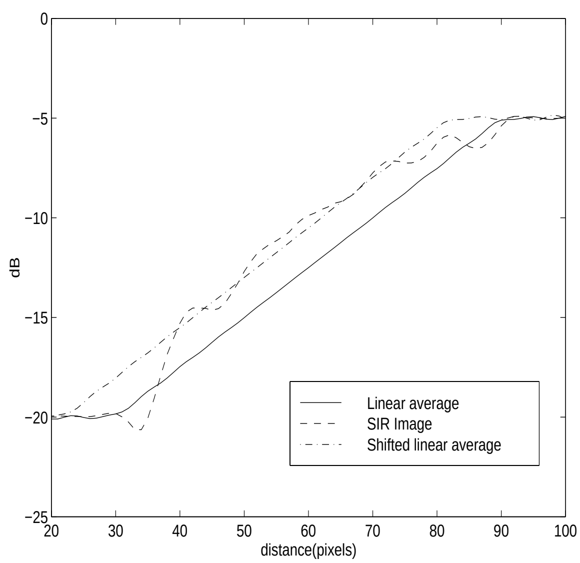

Figure 4: SIR image and linear average image shifted from the center to an earlier period.

The Time Index Algorithm

The time index algorithm provides a time value which closely corresponds to the observed temporal average of the image pixels. It provides a unique value for each pixel. The following is the algorithm for the weighted time index average, T_k, of the SIR image for the k^{th} pixel:

$$T_k = \frac{\sum_{i=1}^{n} \frac{t_i}{\widehat{\sigma_i^o}}}{\sum_{i=1}^{n} \frac{1}{\widehat{\sigma_i^o}}} \tag{1}$$

where t_i is the time of the i^{th} hit measurement and $\widehat{\sigma_i^o}$ is the $\mathcal{B}$-corrected σ^o measurement of the i^{th} hit of the pixel. $\widehat{\sigma^o}$ is computed by using the $\mathcal{B}$ values from the SIR images and plugging them into the following equation,

$$\widehat{\sigma_i^o} = \sigma_i^o + \mathcal{B}_k(\theta - 40^\circ) \tag{2}$$

where σ_i^o is the i^{th} measurement of the k^{th} pixel. The results of this algorithm is expressed as a SIR image, like that shown in Fig. 5(b), called the time index image.

For the simulation previously considered, notice in the algorithm that as time increases from the beginning of the time range to the end (in this case 6 days) the power decreases (or increases for a growing edge) over the period where the edge motion occurs. The value of each pixels in the time index image will tend towards the time over which the highest σ^o values occured over the six days, in this case, the first three days. This can been interpreted as shifting the average of the 6 day time period towards the first 3 days. In the algorithm, where no motion occurs, the time index image is the temporal average of the measurements.

To illustrate this, consider Fig. 5 which shows a simulated region with a receding edge (i.e., the edge is moving from left to right) at a rate of 10 pixels per day. Figure 5(a) shows the SIR image, while Fig. 5(d) shows the filtered truth image at day 3. Notice that the SIR image in Fig. 5(a) shows the edge to the left of the temporal average at day 3. The time index image, Fig. 5(b), shows that over the region where the edge movement occured, the "effective" time is 2.2 days instead of three. This can be best seen in Fig. 6(c), which shows a horizontal slice of the time index image. Over the region where there was movement the time index image shows that the edge corresponds to a temporal average around 2.2 days. Figure 5(c) shows the 2.2-day filtered temporal average of the edge. This appears to give a closer estimate of where the edge of the SIR image lies. In Fig. 6 we see this clearer. Fig. 6(a) shows the horizontal slice of the simulated SIR image, the filtered temporal average image at day three and the linear average image. Figure 6(b) shows the linear average image shifted to a center point that corresponds to an average day of 2.2.

Non-temporally Uniform Measurements

The simple case given above is where the time of the measurements used to create the image is evenly or uniformly distributed throughout the 6 day period. We now consider how the

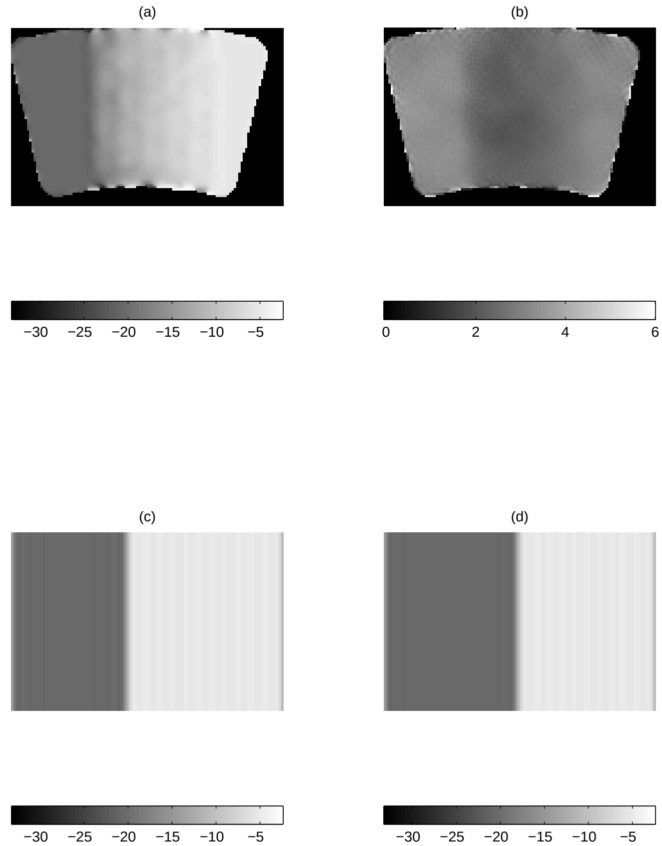

Figure 5: (a) the simulated SIR $\mathcal{A}$ image (b) time index image in days (c) filtered image at day 2.2 (d) filtered image at day 3.

algorithm behaves when the measurements are distributed differently. Figures 7, 8, 9 and 10 show the results of the algorithm with 4 different types of temporal distributions. For all of these cases the edge moves over the same distance at the rate of 10 pixels per day. In Fig. 7, the times of the measurements used to create the image occur in the first three days of the 6 day period. The time index image, Fig. 7(d), shows that over the area of edge movement, the value of the image is around 1.1 days, while over the area where there was no movement, the value of the image is around 1.5 days, which corresponds to the temporal average of the measurements 7(a). This is different then the temporal average of the edge for a uniform distribution of measurements, which occurs around three. Notice that in Fig. 7(c), the edge of in the SIR image corresponds very closely with the temporal average image of day 1.1. The linear average image shifted to correspond to day 1.1 is also shown. Figure 7(e) shows the temporal average image at day 1.1, and Fig, 7(f) shows the horizontal slice of the time index image. Figure 8 shows the results when the measurements occur between days two and four, and Fig. 9 shows the results for measurements between days 3 to 6. Finally, Fig. 10

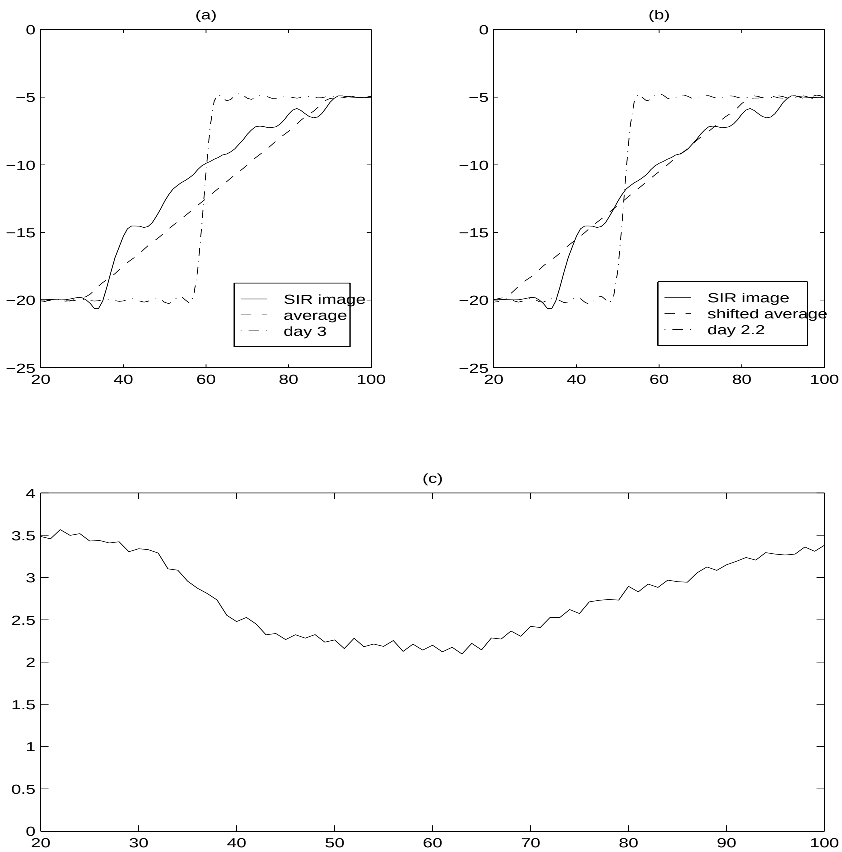

Figure 6: (a) horizontal slice of simulated SIR $\mathcal{A}$ image, filter image at day 3 and shifted average image with center corresponding to day 2.2 (b) horizontal slice of simulated SIR $\mathcal{A}$ image, filtered image at day 2.2 and shifted linear average image with center at day 2.2 (c) time index image in days.

shows a 'random' distribution of measurements between the 6 days. It is interesting to note that when the measurements are distributed through out the 6 day period, as in Fig. 10, the edge of the SIR image corresponds more closely with the shifted linear average image, while if the distribution of measurements are clustered around a few days, the edge of the SIR image will more closely resemble that of the temporal average image. Notice that for all four cases, while the temporal average of the edge for a uniform distribution of measurements occurs around day three, the time average algorithm depicts more accurately the location of the edge in the SIR image.

Conclusion

Because of the non-linear aspects of the SIR algorithm, using the center of the imaging interval is often not sufficiently accurate in determining the temporal location of an image

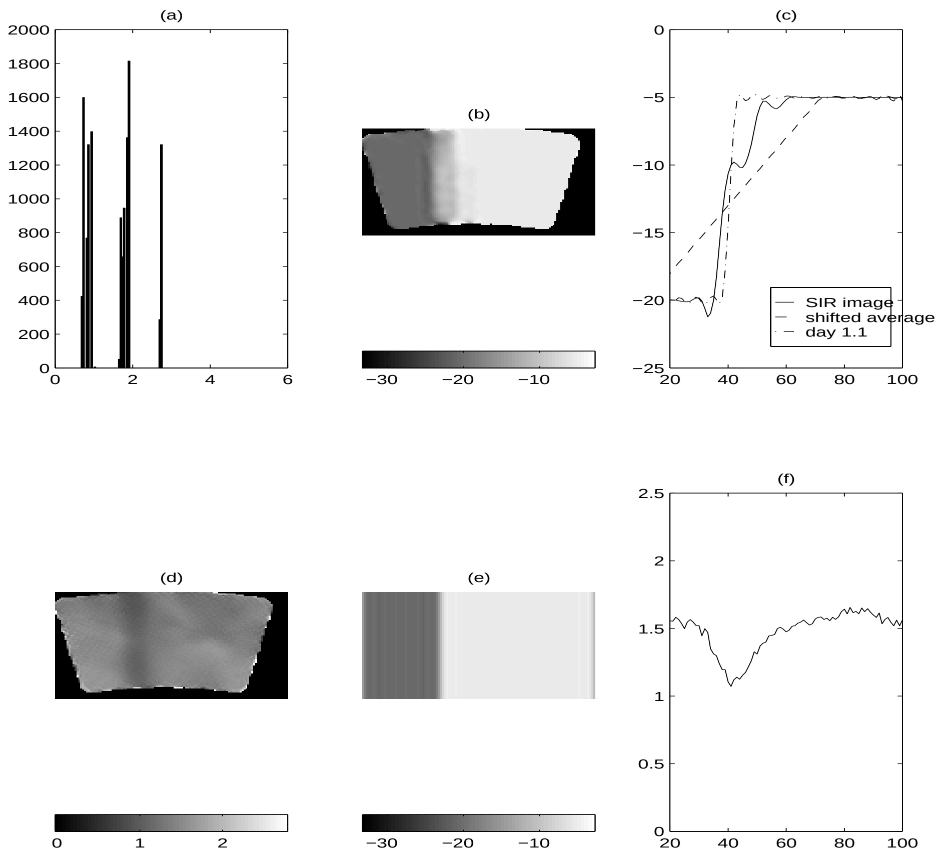

Figure 7: (a) histogram of the time of the measurements used to create image (b) SIR $\mathcal{A}$ image (c) horizontal slice of the SIR image, the filtered image at day 1.1, and the shifted linear average image with center at day 1.1 (d) time index image in days (e) filtered image at day 1.1 (f) horizontal slice of the time index image

feature in the SIR image. The time-weighted average algorithm has been developed to better determine the effective temporal reference points. The value of the time-weighted average image over the area of movement tends to the direction of brightest measurements. This holds true for a variety of measurement distributions.

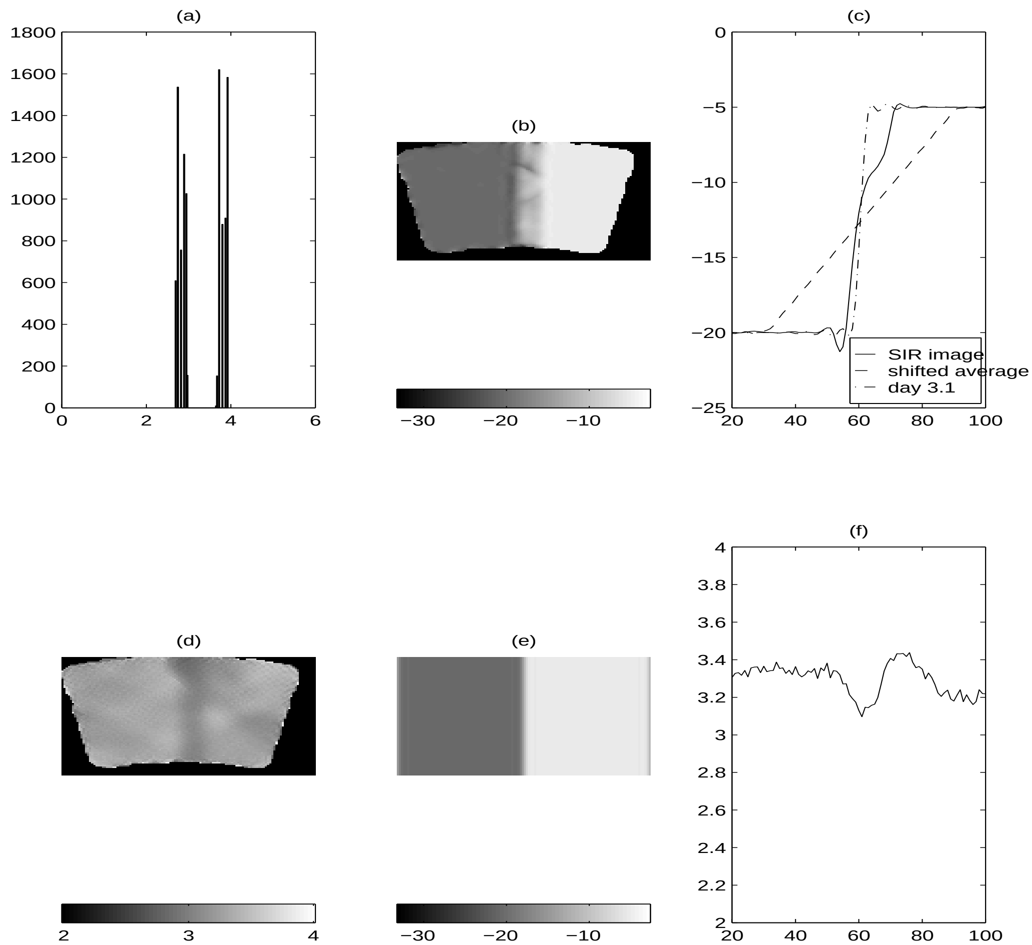

Figure 8: (a) histogram of the time of the measurements used to create image (b) SIR $\mathcal{A}$ image (c) horizontal slice of the SIR image, the filtered image at day 3.1, and the shifted linear average image with center at day 3.1 (d) time index image in days (e) filtered image at day 3.1 (f) horizontal slice of the time index image

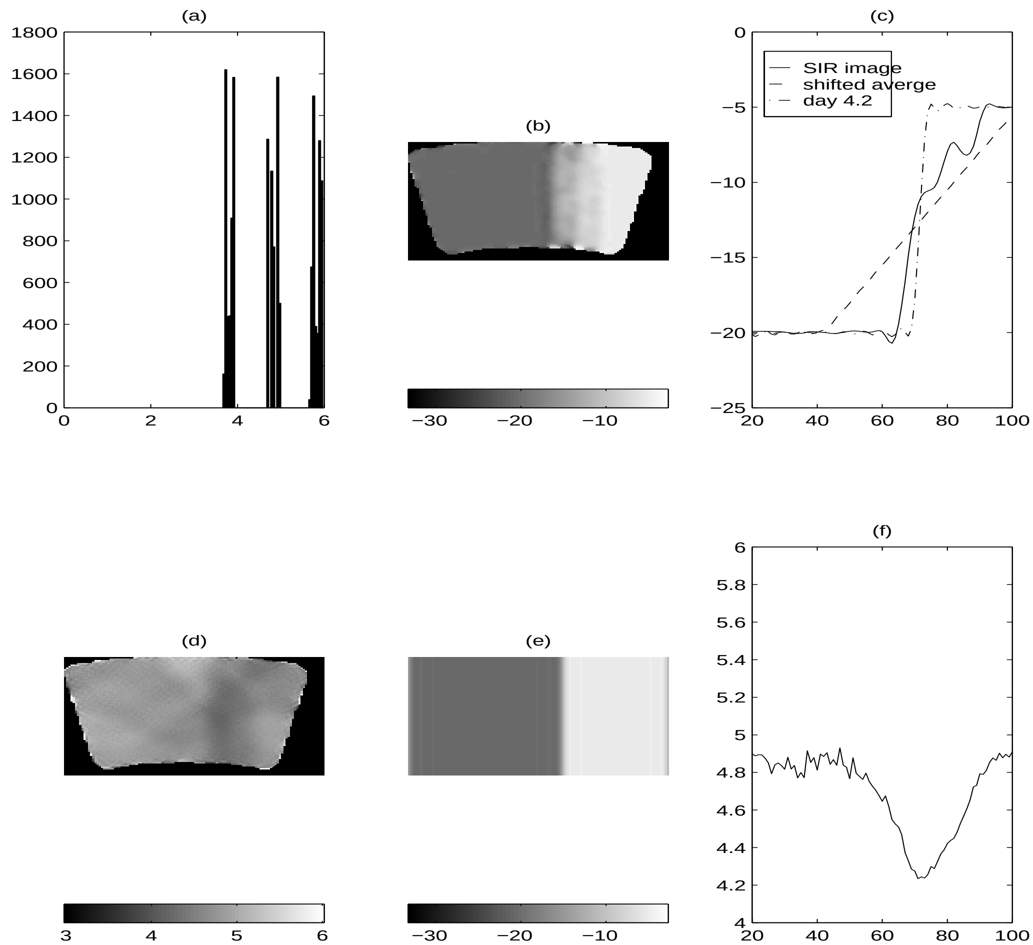

Figure 9: (a) histogram of the time of the measurements used to create image (b) SIR $\mathcal{A}$ image (c) horizontal slice of the SIR image, the filtered image at day 4.2, and the shifted linear average image with center at day 4.2 (d) time index image in days (e) filtered image at day 4.2 (f) horizontal slice of the time index image

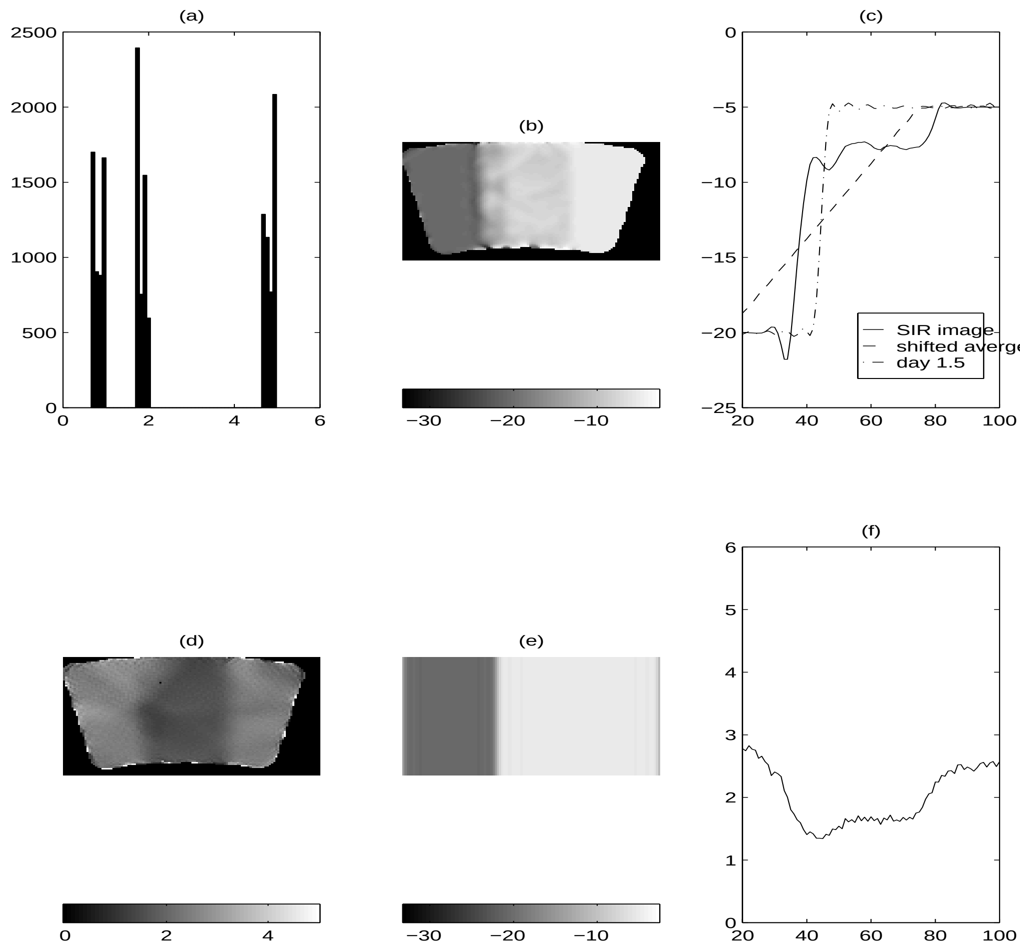

Figure 10: (a) histogram of the time of the measurements used to create image (b) SIR $\mathcal{A}$ image (c) horizontal slice of the SIR image, the filtered image at day 1.5, and the shifted linear average image with center at day 1.5 (d) time index image in days (e) filtered image at day 1.5 (f) horizontal slice of the time index image