Interactive residual synthetic aperture radar imaging

Rick Ottolini

ABSTRACT

The synthetic aperture radar (SAR) operator can be cascaded to iteratively estimate satellite velocity and satellite altitude. As these parameters approach their optimal values, the imaging operator length shrinks, thereby increasing computation speed. A 256 sample-squared operator on a joint Convex-Sun setup takes two seconds to compute and display. The residual imaging program was adapted to Stolt migration imaging with minor changes and a similar performance.

INTRODUCTION

Prati (1988) demonstrated that SAR imaging parameters can be measured to a hundredth of a percent by reimaging until the best focused is measured. SAR datasets are huge and full reimaging is computationally expensive. However, the SAR imaging operator can be cascaded in the same way as residual seismic migration. Furthermore, as the focus improves, the operative size shrinks and computation becomes cheaper. The SAR imaging operator has the advantage over residual migration that the variation in the time dimension becomes negligible and the operator reduces to 1D.

RESIDUAL SAR IMAGING ALGORITHM

Mathematical algorithm

Rocca (1987) showed that the SAR imaging operator was analogous to seismic migration

$$\textit{diffraction} - \textit{phase shift},$$

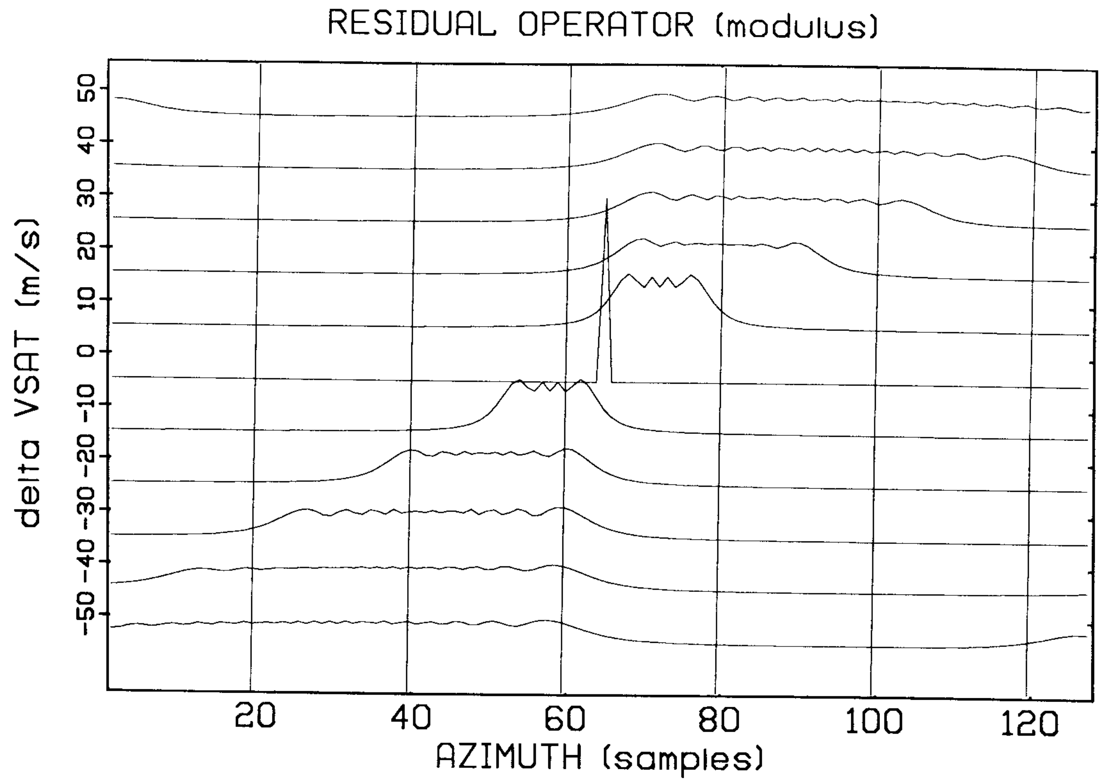

FIG. 1. Residual operators for various $\Delta VSAT$ from standard SEASAT orbital parameters of $VSAT = 7200m/s$ and $z_0 = 860000m$. Computed from the inverse Fourier transform of equation (1). Inserting a delta function into Ottolini's (1987c) SAR imaging program gives nearly identical results.

$$\exp - i\frac{z_0\omega_0}{2c}\left(\sqrt{1-\frac{c^2k_x^2}{\omega_0}}-1\right),$$

$$\approx \exp - i\frac{z_0 c}{2\omega_0}k_x^2. \tag{1}$$

where z_0 is the satellite altitude, c is the speed of radar waves, ω_0 is the central radar frequency, and k_x the azimuth of the satellite. At first glance, equation (1) appears to be constant velocity, i.e. light speed. However, the azimuthal sampling rate dx depends on the satellite velocity, $VSAT$, which is variable.

$$dx = \frac{VSAT}{shot\text{-}rate} \tag{2}$$

Rothman et al. (1985) showed the cascaded seismic migration operator to be the same as the single-step operator with the Euclidian sum of each iteration's velocity. This is also true for equation (1). However, the effective variable velocity is then $\frac{c}{dx}$ with Euclidian sum

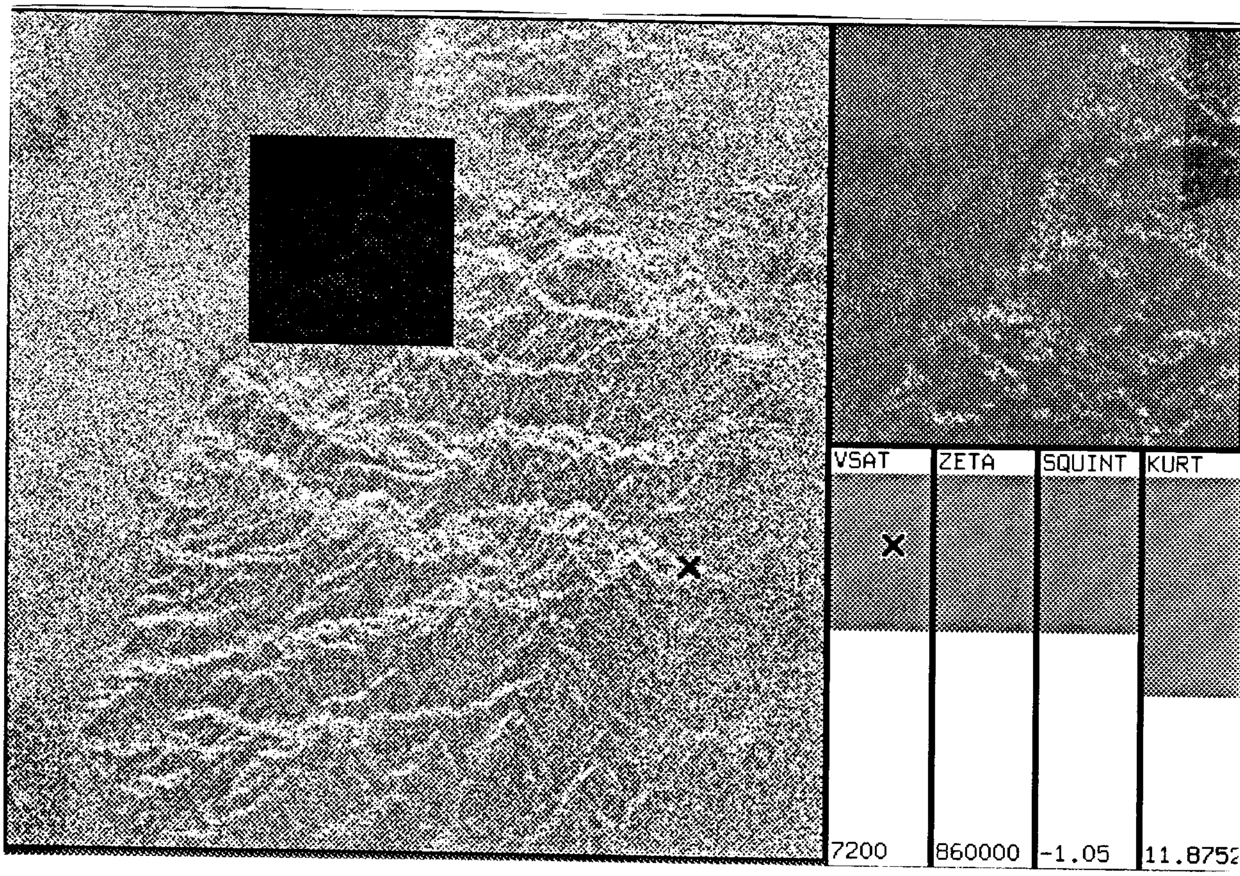

FIG. 2. Snapshot of interactive SAR imaging display. Components are labeled in Figure 3. SEASAT image is from southern Italy. Box window is 256 samples-squared.

$$\frac{c}{dx_\Sigma} = \sqrt{\frac{c^2}{dx_0^2} + \frac{c^2}{dx_i^2}}.$$

Using equation (2) and canceling gives the iterative $VSAT$ as

$$VSAT_i = \frac{VSAT_\Sigma \, VSAT_0}{\sqrt{VSAT_0^2 - VSAT_\Sigma^2}}. \tag{3}$$

The operator length for a small change in $VSAT$ is relatively short compared to the total image size. Figure 1 shows the residual image operator for small changes in $VSAT$ from normal orbital parameters. These residual operators fit easily into a few-hundred sample window of the much larger image.

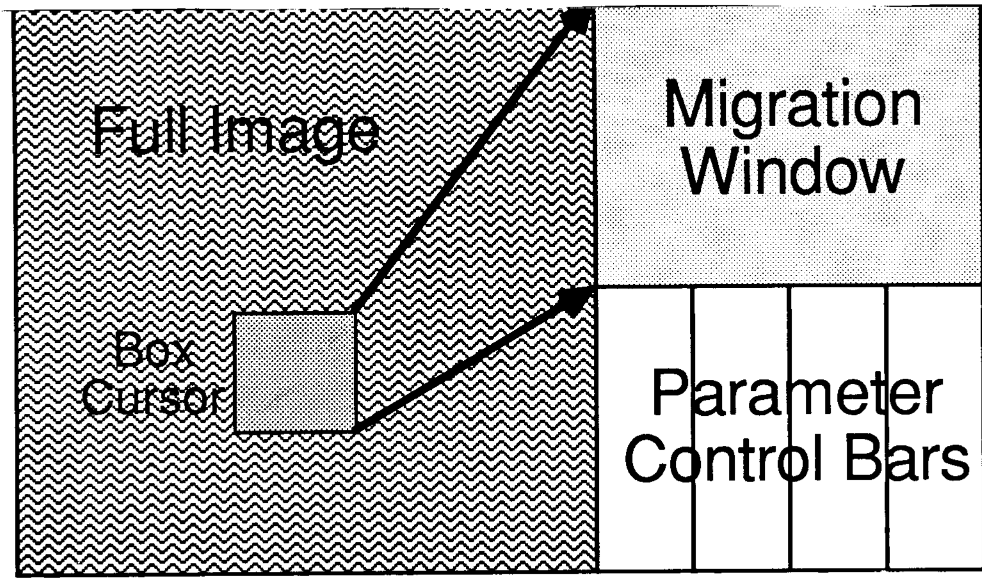

FIG. 3. Schematic description of interactive SAR or migration imaging display in Figures 2 and 4.

Computer implementation

The residual imaging algorithm was implemented as a joint Convex-Sun computer program. The image convolutions were done on a Convex supercomputer and the results displayed on a Sun workstation running X-Windows. The computer coordination mechanism and object-oriented graphics are described in Ottolini (1987a, 1987b).

A snapshot of the display screen appears in Figure 2. The various components are labeled in the cartoon of Figure 3. The program displays a full data image on the left. The data has been pre-imaged using Ottolini's (1987c) program for a best-guess parameter model. A box cursor selects the 256 sample-squared data window to be residually imaged and displays the selection on the upper right. The image parameters— satellite velocity, altitude, and skew angle— are set by sliding parameter control bars in the lower right. Immediately after the parameter(s) are adjusted by the mouse cursor, the new image is computed. The Convex computer takes a few tenths of a second to do the couple million calculations. The computations include (1) forward 1D azimuthal FFT, (2) convolution with equation 1, (3) inverse 1D azimuthal FFT, (4) measure max, mean, variance, & kurtosis of image array, (5) rasterize the image, (6) plot the image and control bars. Then it takes about a second to transmit the result to the workstation across the Ethernet.

The two-second response time is tolerable and feels like real-time imaging. Though shrinking the window box would improve speed, the image results would

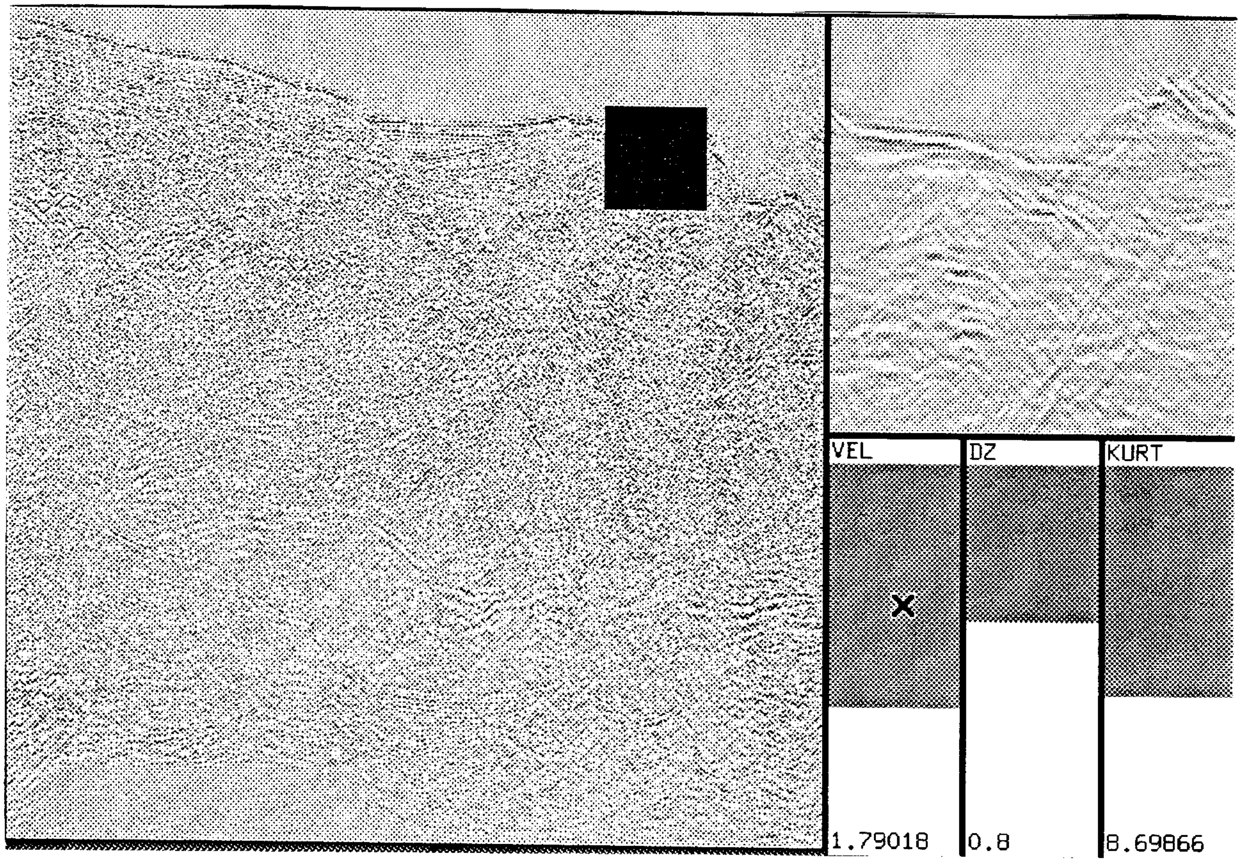

FIG. 4. Snapshot of interactive migration imaging display. Components are labeled in Figure 3. Data is JAPEX Japan Trench. Box window is 128 samples-squared.

deteriorate due to edge effects and less accurate kurtosis measure.

INTERACTIVE RESIDUAL SEISMIC IMAGING

The interactive residual SAR imaging program was adapted with minor modification for residual seismic imaging (Figure 4). A 2D Fourier domain Stolt algorithm was used. The second dimensional Fourier transforms and convolution increase computation time, so only a 128 sample-squared window is used.

CONCLUSIONS

Cascaded SAR imaging works and it is done interactively in real-time.

ACKNOWLEDGMENTS

Fabio Rocca and Claudio Prati provided useful comments. The SEASAT SAR datasets come from the Caltech Jet Propulsion Lab. The X-Windows graphics software comes from MIT.

REFERENCES

Ottolini, R., 1987a, Multi-computer seismic programs: SEP-51, p. 409-414

Ottolini, R., 1987b, Techniques for organizing interactive graphics: SEP-51, p. 421-428

Ottolini, R., 1987c, Synthetic aperture radar data processing: SEP-51, p. 205-214

Prati, C., 1988, Autofocusing synthetic aperture radar images: SEP-57

Rocca, F., 1987, Synthetic aperture radar: wave equation techniques: SEP-56, p. 167-190

Rothman, D., Levin, S.A., Rocca, F., 1985, Residual migration: application and limits: Geophysics, v. 50, p. 110-128