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# CRISM Hyperspectral Data Filtering with Application to MSL Landing Site Selection

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## I. Background

- Over the course of the Mars Reconnaissance Orbiter (MRO) Primary Science Phase (PSP) and the ongoing Extended Science Phase (ESP) the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) has operated with an IR detector temperature between ~107 K and ~127 K (Figure 1). This ~20 K range in operational temperature has resulted in variable data quality, with observations acquired at higher IR detector temperatures exhibiting a marked increase in both systematic and stochastic noise (e.g. Figures 15, 16, 17).
- Here we report on the development and implementation of a custom filtering procedure for CRISM IR hyperspectral data that is suitable for incorporation into the CRISM Reduced Data Record (RDR) calibration pipeline.

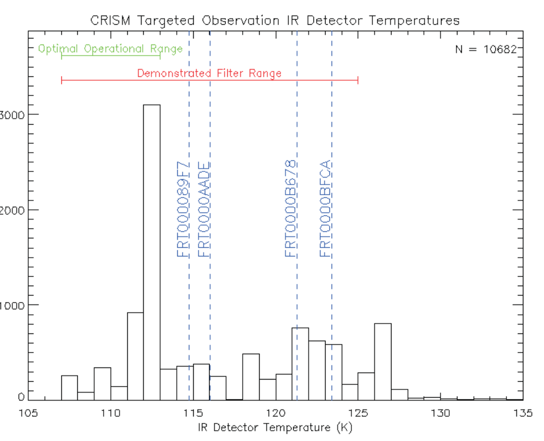



**Figure 1. (Right)** CRISM hyperspectral targeted observation (FRT, HRL, HRS) IR detector temperature distribution for MRO PSP and ESP. The optimal IR detector operating temperature range [107 K, 113 K] is indicated in green. The IR detector temperature range [107 K, 125 K] over which the CRISM hyperspectral data filtering procedure has been demonstrated is indicted in red. The IR detector temperature at the time of four MSL candidate landing site CRISM observations (Section VI) is indicated in blue.

## II. Hyperspectral Data Filtering

- The CRISM hyperspectral filtering procedure is designed to retain high frequency spatial/spectal information that is consistent with the local data statistics while removing high frequency systematic and stochastic noise. This is accomplished through the calculation of an artifact-free low spectral frequency reference cube and the serial application of custom filtering procedures (the Ratio Shift Correction (RSC) and the Iterative Kernel Filter (IKF)) to the hyperspectral data cube in a reference cube normalized ratio space.

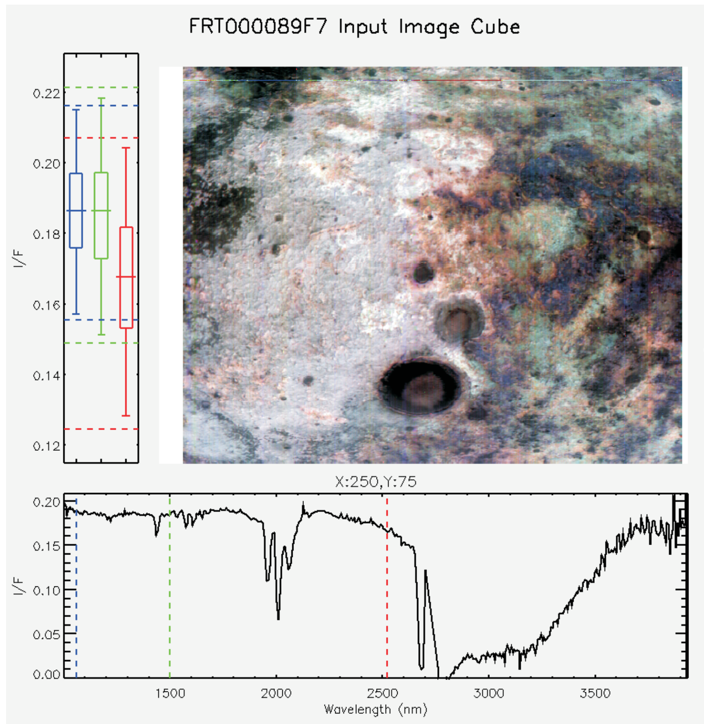
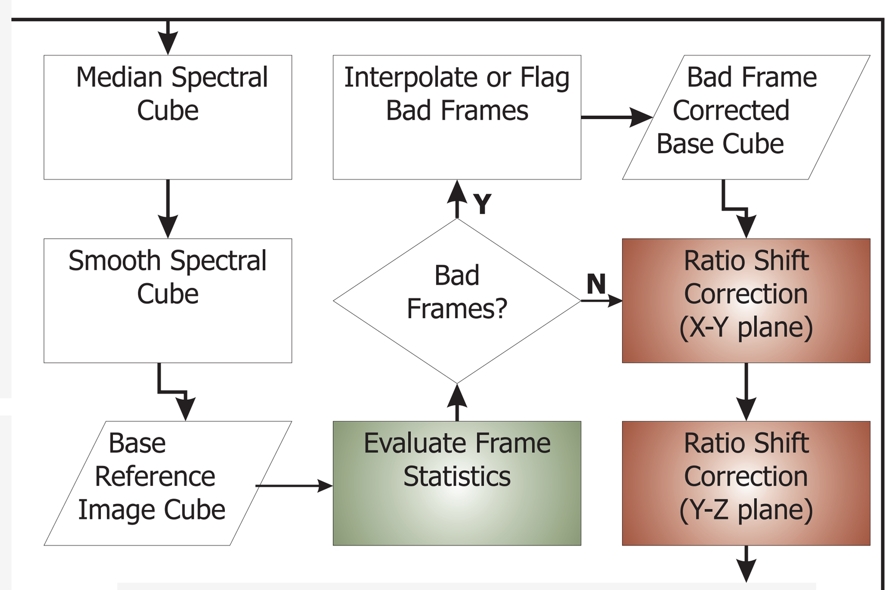



**Figure 2. (Left)** CRISM IR observation FRT000089F7. An RGB composite (R:2530 nm; G:1507 nm, B:1080 nm), RGB band I/F distribution boxplots and stretch limits, and a representative single pixel spectrum are shown. This observation includes the center of the Mawrth Vallis MSL candidate landing ellipse (-18.97° E, 24.01° N).

- The hyperspectral data filtering process begins with a CRISM TRDR I/F image cube (Figure 2) and ends with the Restored cube (Figure 8). The flowchart below illustrates the filtering process with intermediate products (Figures 3-7). A ratio of the input to output cubes is presented in Figure 9. Select filtering modules are described in Sections III, IV, and V.



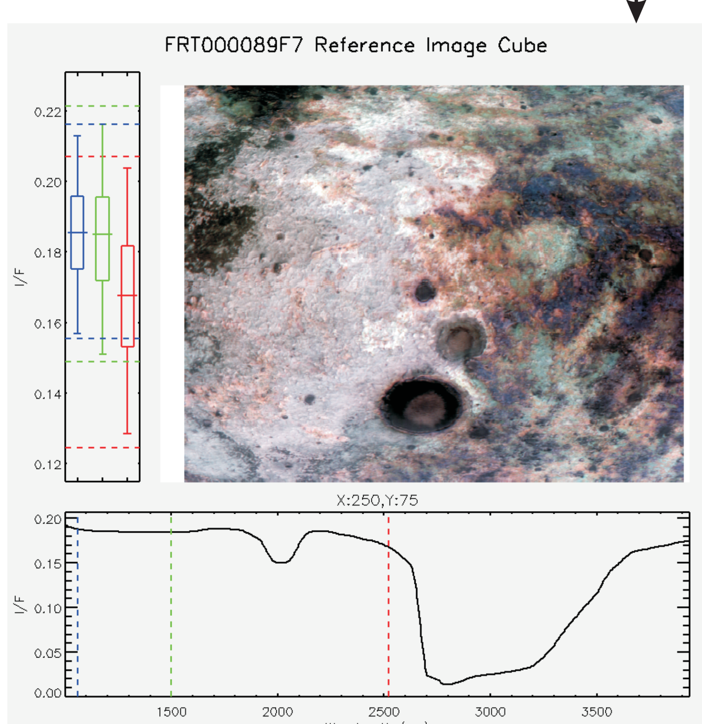
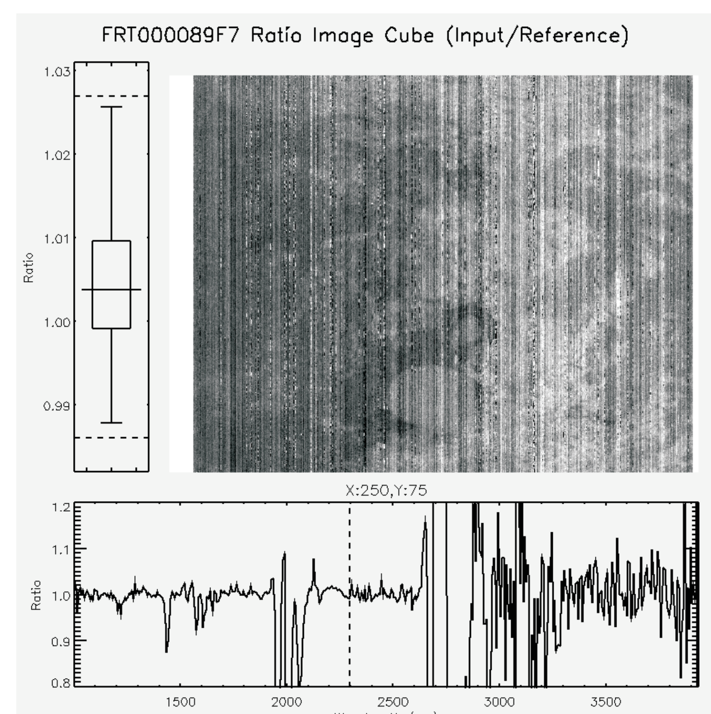



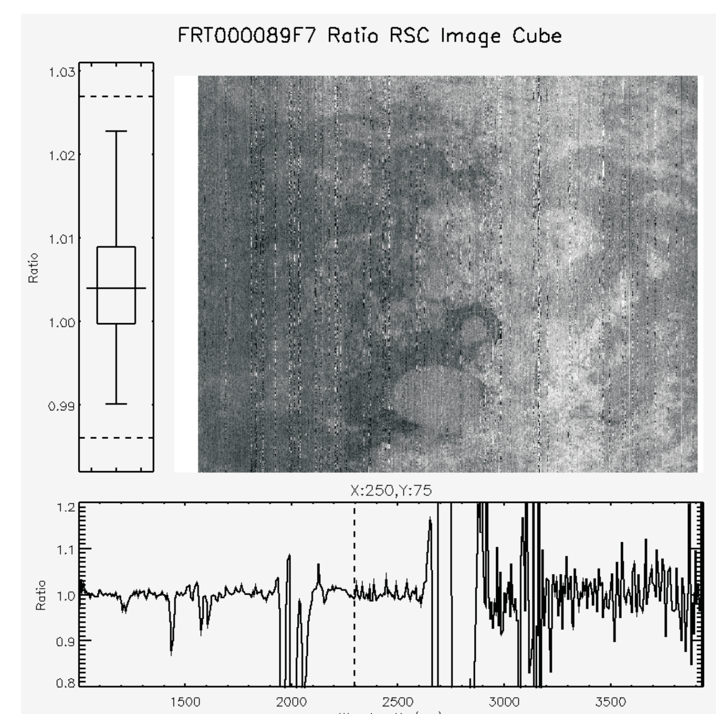

**Figure 3.** Reference image cube for CRISM IR observation FRT000089F7. The reference cube retains the low frequency spectral information and should be as artifact-free as possible. Any residual noise in the reference cube will be propagated back into the filtering result.

Resolve RSC Cube
x
Reference Cube




Input Cube
/
Reference Cube

**Figure 4.** Ratio image cube for CRISM IR observation FRT000089F7. Band 240 (2298 nm) is shown. All of the high frequency spectral information in the input image cube (Figure 2) has been propagated into the ratio cube. Both of the dominant CRISM IR noise components are visible: systematic column-oriented striping and stochastic noise spikes.




Ratio Shift Correction (X-Y plane)

**Figure 5.** Ratio RSC image cube for CRISM IR observation FRT000089F7. The Ratio Shift Correction has mitigated the high spatial frequency systematic column-oriented striping. The width of the data distribution has been reduced as compared to the Ratio cube (Figure 4).

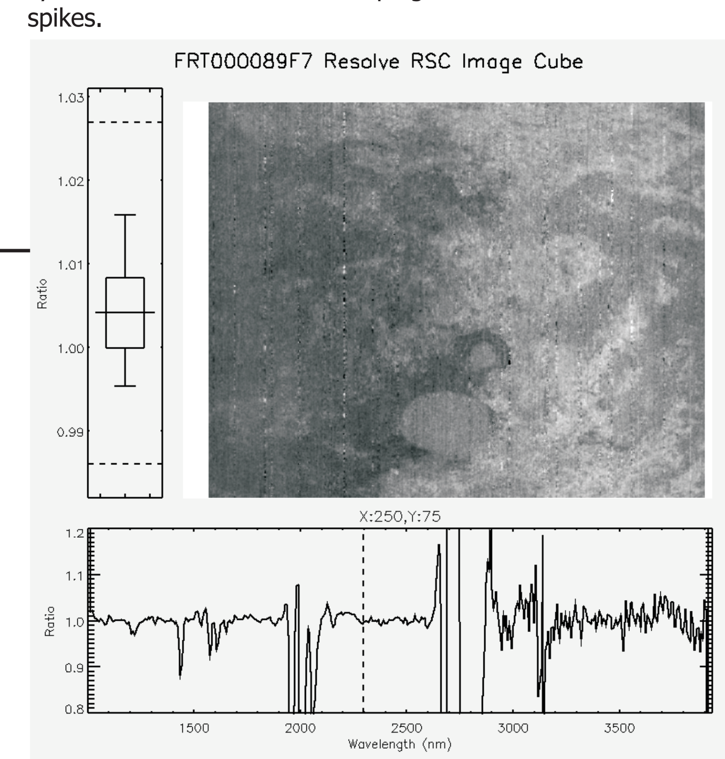



**Figure 7.** Resolve RSC image cube for CRISM IR observation FRT000089F7. The application of the RSC procedure with a constrained cross track model has corrected the subtle column-oriented banding present in the Resolve cube (Figure 6) without compromising real scene cross track variability.

Ratio Shift Correction (X-Y plane)

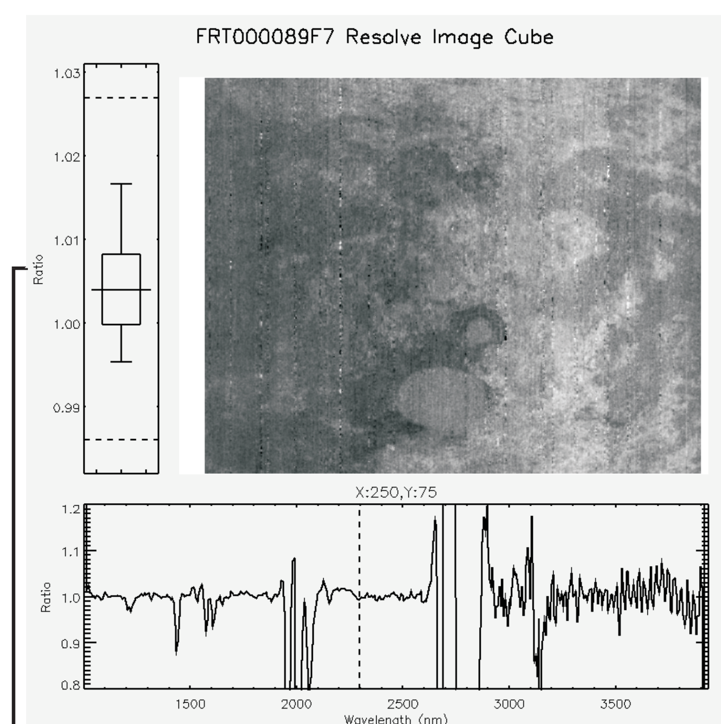



**Figure 6.** Resolve image cube for CRISM IR observation FRT000089F7. The Iterative Kernel Filter has mitigated the majority of the non-systemtic noise and further reduced the width of the data distribution as compared to the Ratio cube (Figure 4).

Iterative Kernal Filter

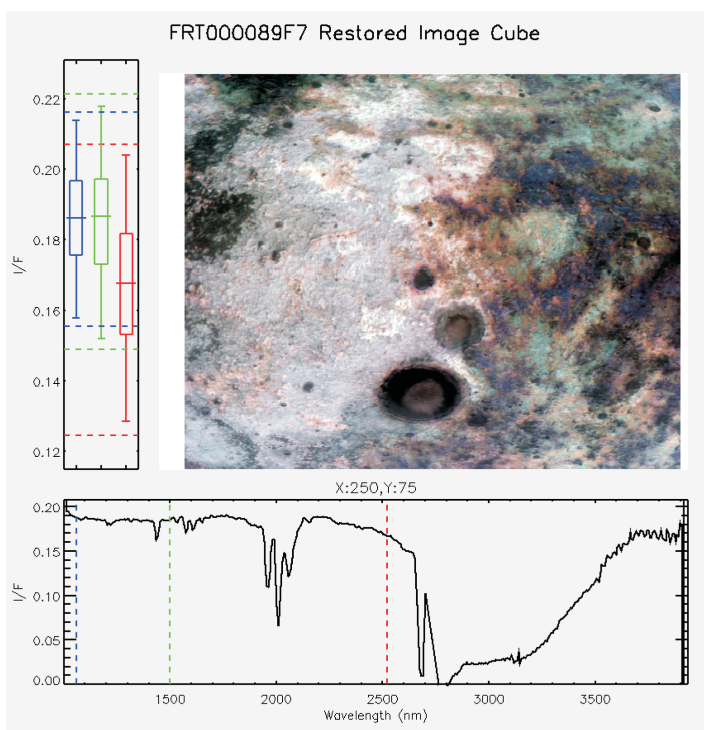



**Figure 8.** Restored (output) image cube for CRISM IR observation FRT000089F7.

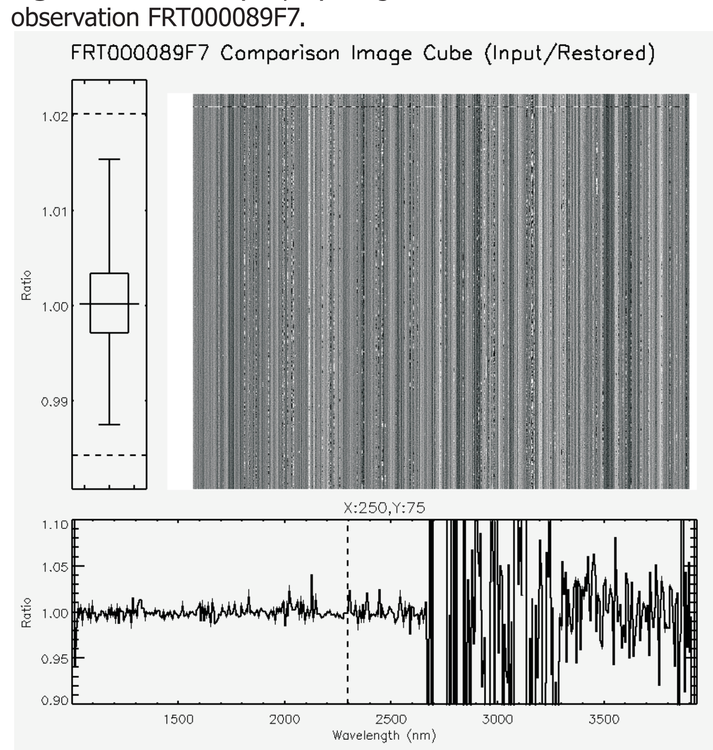



**Figure 9. (left)** Comparison image cube [Input image cube (Figure 2) / Restored image cube (Figure 8)] for CRISM IR observation FRT000089F7. The spatial and spectral impacts of the hyperspectral filtering procedure are evident. The comparison cube in conjunction with Figures 2 and 8 demonstrates that the hyperspectral filtering procedure is successfully removing high frequency spatial/spectral noise, but retaining high frequency structure that is statistically supported - e.g. the narrow atmospheric $CO_2$ absorptions at ~ 2000 nm and additional minor gas absorptions at shorter wavelengths.

## VI. MSL Landing Site Selection

- CRISM hyperspectral data filtering procedure as applied to observations of the Eberswalde Crater, Holden Crater, Gale Crater, and Mawrth Vallis (see Figures 2, 8) MSL candidate landing sites (center of current landing ellipse for each site).
- Comparisons of RGB composites (R:2530 nm; G:1507 nm, B:1080 nm) are shown with I/F distribution boxplots for each RGB band and a representative single pixel spectra for the input (left image of pair) and filtered (right image of pair) hyperspectral image cubes.

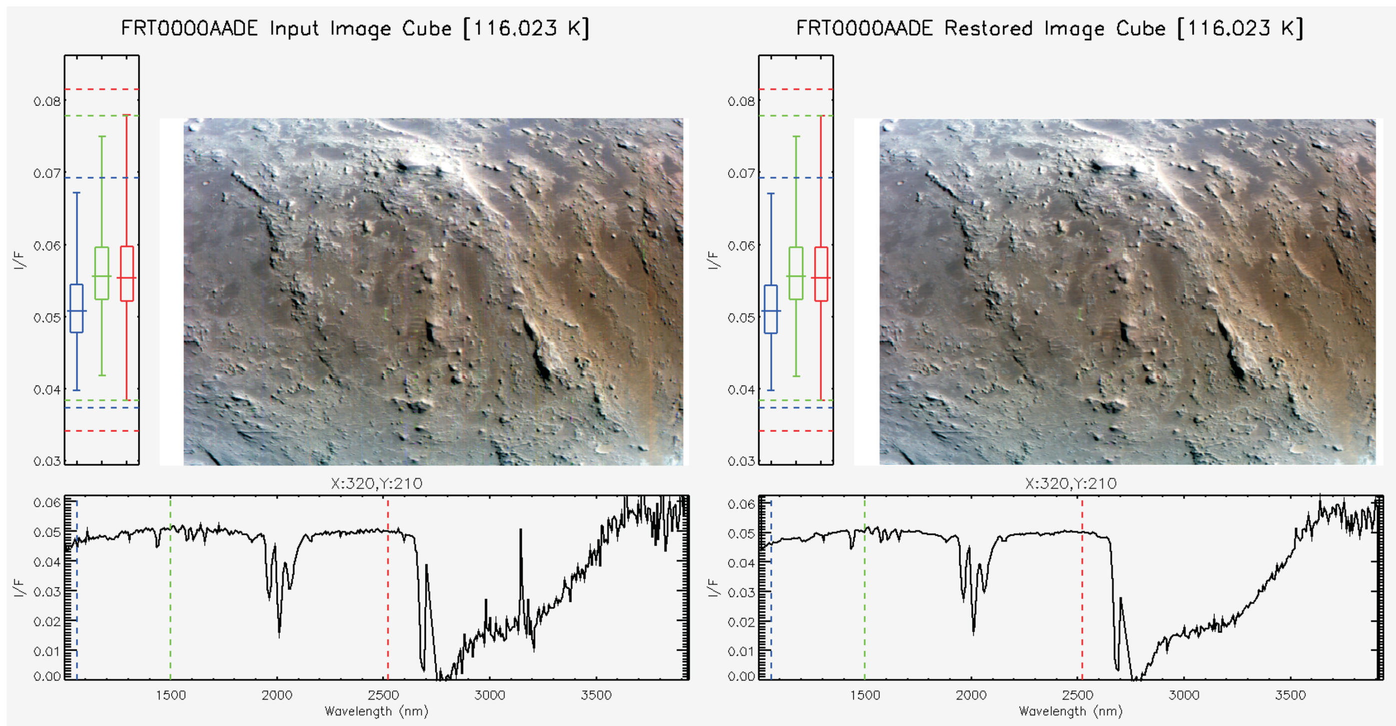



**Figure 15.** CRISM IR observation FRT0000AADE: Eberswalde Crater MSL candidate landing ellipse (-33.27° E,-23.86° N).

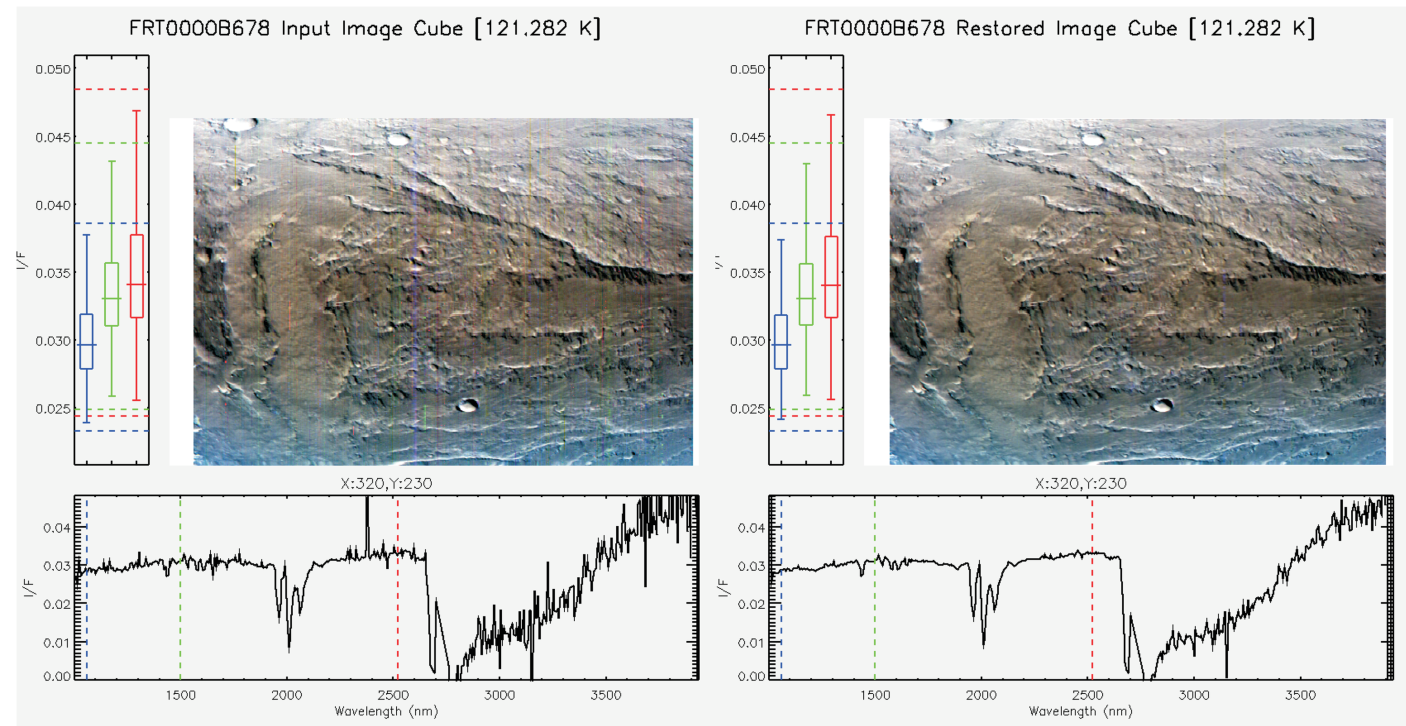



**Figure 16.** CRISM IR observation FRT0000B678: Holden Crater MSL candidate landing ellipse (-34.90° E,-26.37° N).

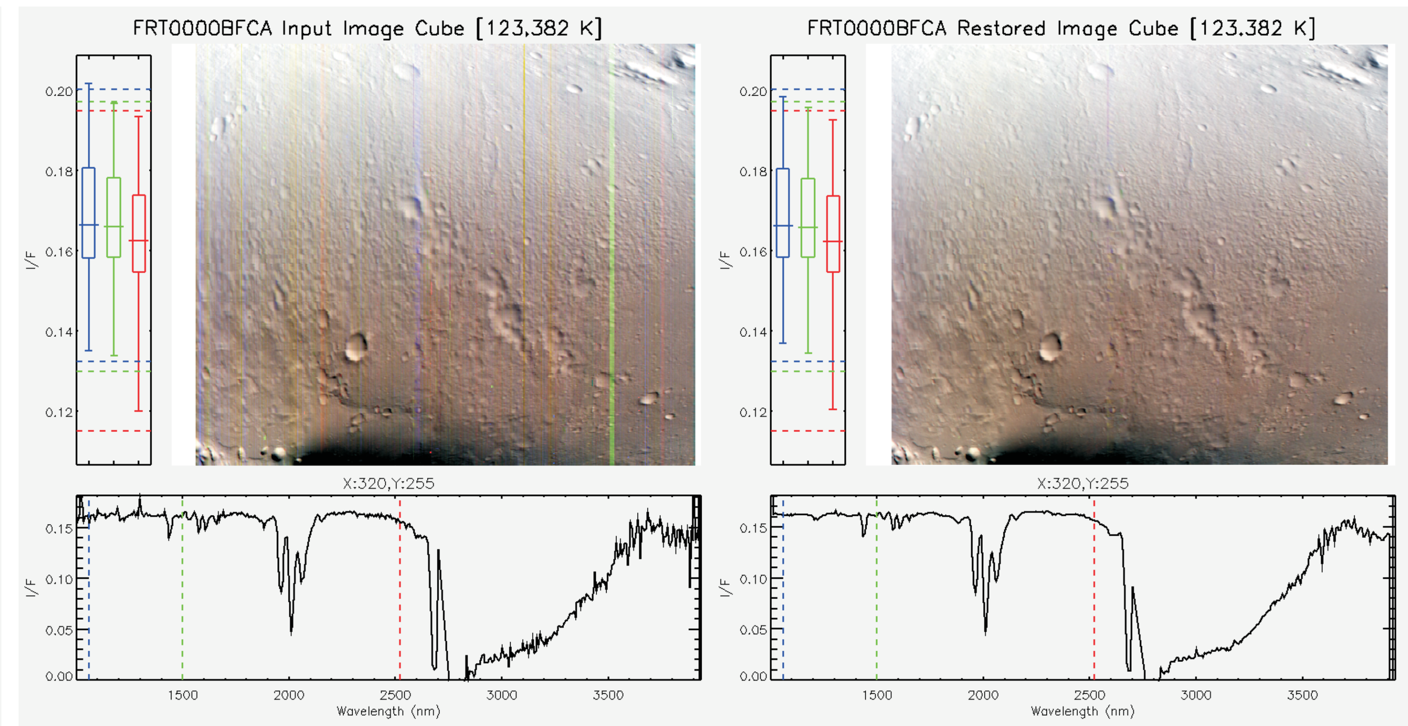



**Figure 17.** CRISM IR observation FRT0000BFCA: Gale Crater MSL candidate landing ellipse (137.42° E,-4.49° N).

## III. Frame Statistics Evaluation

The Frame Statistics Evaluation identifies bad frames by investigating frame percentile statistics (Figure 10).

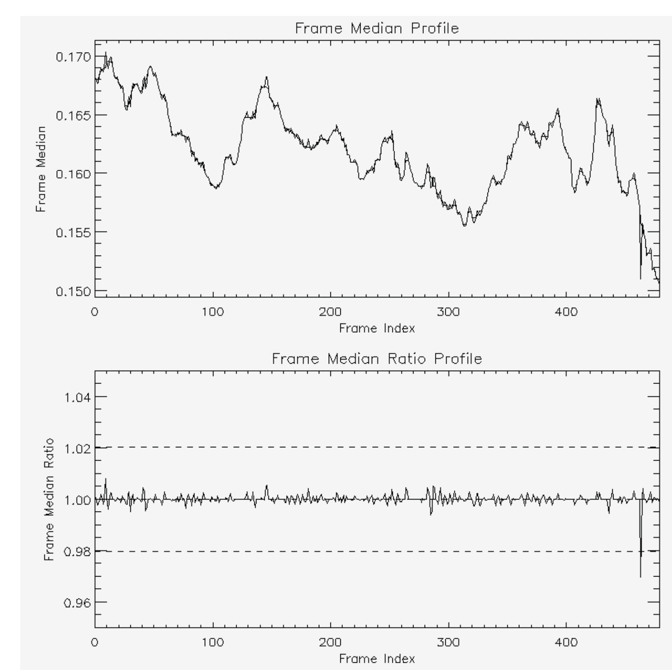



Figure 10. Detection of bad frames. **(Top)** Median I/F value (all wavelengths) vs. frame index. A 5-point median is used to detrend the profile. **(Bottom)** Normalized frame median profile with outlier threshold indicated (dotted lines). Frames with a test statistic that exceeds the threshold are conditionally interpolated (e.g. Figure 2) or flagged as unrecoverable and excluded from subsequent data processing. In this example frame 463 was determined to be anomalous.

## IV. Ratio Shift Correction (RSC)

The Ratio Shift Correction (RSC) isolates and mitigates systematic column-oriented noise. The correction is employed multiple times over the course of a complete filtering run, with the procedure control parameters adjusted to the immediate data processing requirements. The effect of RSC on a CRISM Ratio cube band is shown in Figure 11.

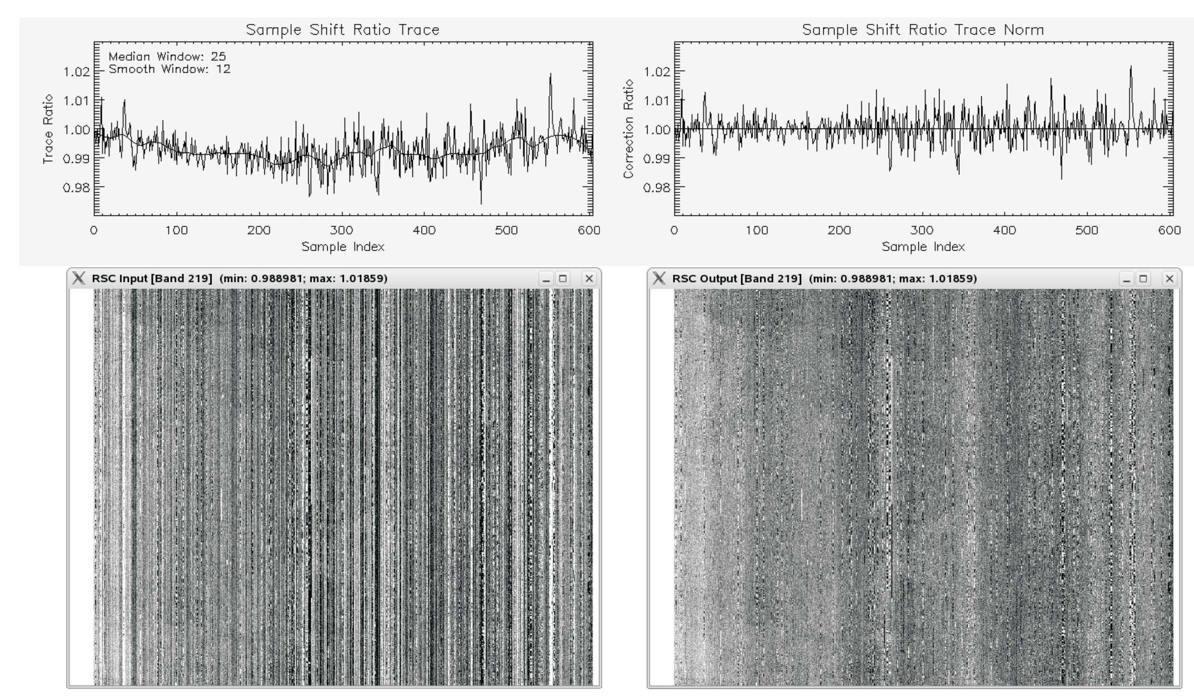



**Figure 11. (Lower Left)** Example RSC input band. This is band 219 from the FRT00089F7 Ratio image cube shown in Figure 4. **(Upper Left)** Sample shift ratio trace plot for the RSC input band with the cross-track model specified by the RSC control parameters. The trace is a multiplicative accumulation of the input band column-to-colum ratio median values. The cross track model in this example was calculated by the serial application of a sliding median window (width = 25) and sliding mean window (width = 12) (i.e. a boxcar average). **(Upper Right)** The normalization of the cross-track trace to the model produces the 1-D profile of the RSC correction band. **(Lower Right)** Example RSC output band. This is band 219 from the FRT00089F7 Ratio RSC image cube shown in Figure 5. The residual vertical banding is a result of the control parameter specification - the median window width is the largest length scale that can be addressed by the correction.

## V. Iterative Kernel Filter (IKF)

The Iterative Kernel Filter (IKF) identifies and corrects non-systematic noise through the application of an iterative-recursive kernel modeling procedure which employs a formal statistical outlier test (Grubbs test with a default alpha value of 0.95) as the iteration control and recursion termination criterion. This allows the filtering procedure to make a statistically supported determination between high frequency (spatial/spectral) signal and high frequency noise based on the information content of a given multidimensional data kernel. The governing statistical test also allows the filtering procedure to be self regulating and adaptive to the intrinsic noise level in the data. Figures 12, 13, and 14 detail the behavior of the IKF procedure.

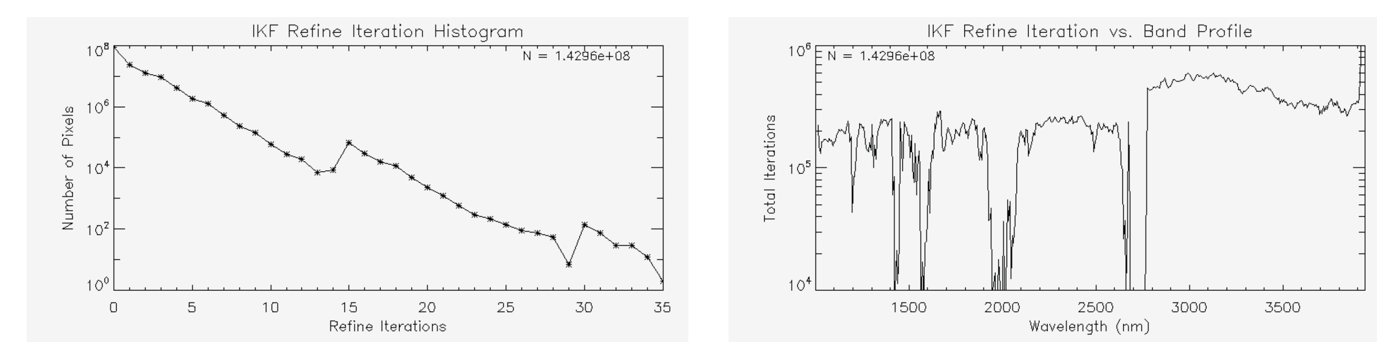



**Figure 12.** Iterative Kernel Filter (IKF) iteration profiles for the FRT000089F7 filtering run. **(Left)** Iteration histogram. The majority of the kernel models are either not modified or only minimally iterated. **(Right)** Spectral model iteration profile. The increased number of model iterations required at longer wavelengths is consistent with CRISM instrument characteristics.

**Figure 13.** IKF band 219 iteration count **(Left)** and model residual maps **(Right)**.

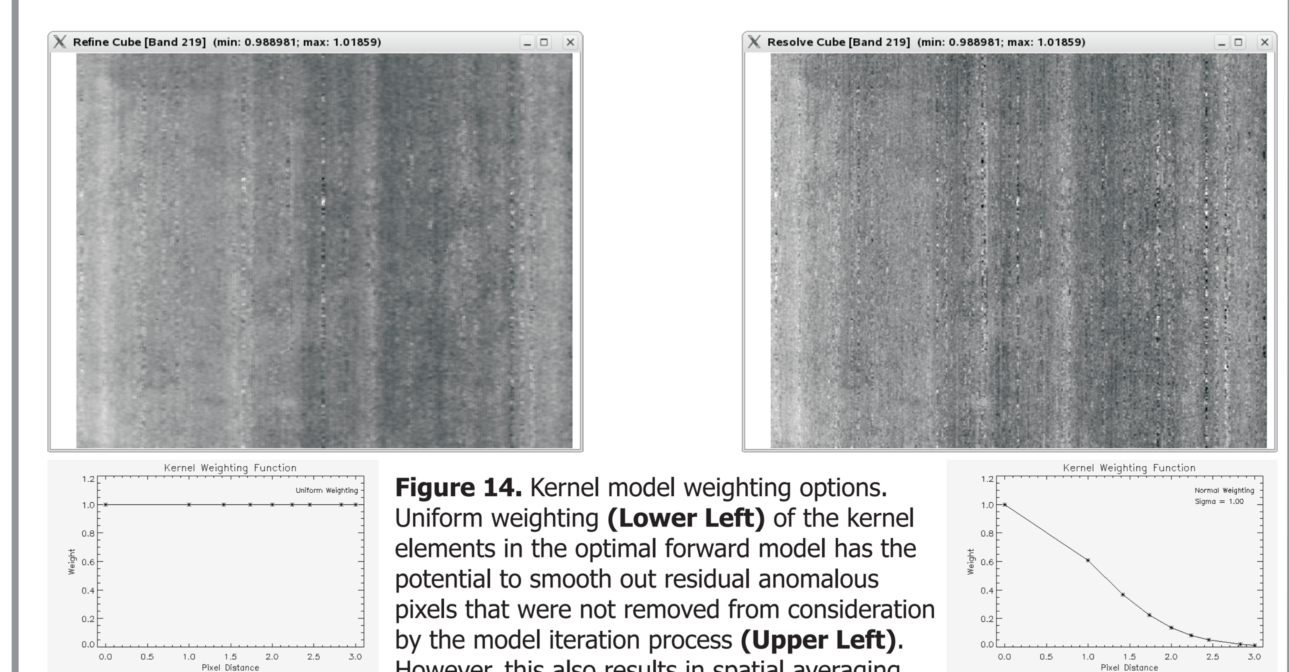



**Figure 14.** Kernel model weighting options. Uniform weighting **(Lower Left)** of the kernel elements in the optimal forward model has the potential to smooth out residual anomalous pixels that were not removed from consideration by the model iteration process **(Upper Left)**. However, this also results in spatial averaging akin to the action of a low pass filter. Normal weighing of the kernel elements **(Lower Right)** retains pixel-to-pixel spatial and spectral structure, but does not significantly modify residual anomalous pixel values **(Upper Right)**. Normal weighing was used in the data filtering runs presented in Figures 8, 15, 16, and 17.