Removing Radiation-Induced Spikes from Fourier Transform Data

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Outline

• Radiation-induces spikes in CrIS sensor data
• Why simple impulse mask correction failed
• Model of radiation-induced spike
• Example of spike correction
• Detecting spikes through interferogram asymmetry
• Least-square fitting consideration
• Conclusions
Spike Correction Applied to CrIS

- Cross-Track Infrared Sounder (CrIS)
- The CrIS sensor is an infrared Fourier transform spectrometer.
- One CrIS instrument is currently flying on the Suomi National Polar-orbiting Partnership (S-NPP) spacecraft.
- Another CrIS instrument (J1) is being prepared for launch later this year.
- Three infrared spectral bands
  - LWIR 650-1095 cm\(^{-1}\)
  - MWIR 1210-1750 cm\(^{-1}\)
  - SWIR 2155-2550 cm\(^{-1}\)
Geographical Distribution of Interferograms with Spikes

• Larger spike distribution January to May 2015
• Many more smaller spikes
Low Earth Orbit Radiation Distribution

- Spike distribution consistent with low earth orbit radiation
- From NASA/SAMPEX satellite
SWIR Spike Size Distribution

- About 50 spikes/day – Every 3 or 4 days one that saturates system
- Many more small spikes than large spike
- SWIR is most affected (smallest detector current)
- Histogram is for December 24 and 25, 2016
Crls Data Flow

1. Detector
2. ADC
3. FIR filter
4. Decimation
5. Bit-trim
6. Downlink to ground
7. Process to spectrum

- Analog to digital conversion
- Band limits interferograms (complex output)
- Reduction factors: LW 24, MW 20, SW 26
- Interferogram compression

Limited number of diagnostic interferograms
Simple Impulse Mask Spike Correction

- CrIS was launched with a simple impulse mask algorithm.
- If the absolute value of an interferogram sample exceeded the impulse mask, the interferogram sample was set to zero.
- This algorithm caused more errors than it corrected so was disabled.
- Subsequent slides show more details.
Why Simple Impulse Mask Failed

• For regions with high spatial variability, electronic may not have stabilized at start of interferogram.
• Significant DC bias also adds to problem.
• Example where raw interferogram violates the impulse mask when no spikes are present.
• Acquired January 28, 2012.
Effects of Impulse Mask on Raw Interferogram

- Simulation using observed diagnostic mode interferogram
- Impulse error processing in connection with electronic offset makes high frequency spikes in interferogram.
- Due to interferogram offset, setting interferogram to zero causes spikes.
After Passing Through FIR Filter

- Impulse error correction causes bit-trim error in digitally filtered data.
- Without impulse error correction, FIR filter removes low frequency offsets and drift.

With impulse error correction

No impulse error correction
New Spike Correction Method

• Correction is achieved by subtracting a modeled spike from the observed interferogram.
• Least-squares fit used to determine position (time) and amplitude of spike.
• Correction over 99% effective if system not saturated.
• Radiation spike events much faster than analog electronics.
• Shape of spike is simply the impulse response of the analog electronics and the digital signal processing.
• Next several slides show the effects of the processing chain on a modeled spike.
Spike in Analog Electronics

- Modeled spike as it would appear in the analog electronics before being digitally sampled.
- Factor of 10 oversampling
SWIR Spike After Applying FIR Filter

- FIR filter broadens spike and adds fine structure
SWIR Spike After Decimation

- Decimation reduces number of sampled points by factor of 26.
- Other sampling would produce very different looking decimated interferogram.
- Information on spike position and amplitude is preserved through processing chain.
Example Spike Correction: Interferogram

- Removal of spike successful
- January 15, 2017 SWIR FOR4 FOV9
Example Spike Correction: Real Spectrum

- Real spectrum before and after subtracting modeled spike from interferogram.
- Original SDR quality control flags this spectrum as invalid.
- After correction the SDR quality flag for spectrum is good.
Example Spike Correction: Imaginary Spectrum

- Imaginary spectra
- Imaginary spectra is a good diagnostic of system performance.
- January 15, 2017, SWIR FOR4 FOV9
Spike Detection Method

- Interferogram asymmetry used to find spikes
- Because of beamsplitter dispersion and sampling, some inherent asymmetry of interferograms
- Averaging interferogram points into bins reduces asymmetry.
- Bins are typically five samples wide.

Spike size 0.0023
Asymmetric Interferogram Detection Method

- Difference between left and right side of binned interferogram.
- Peak detected by ratio of maximum to standard deviation (STD).
- Region near maximum not including in STD calculation (see right hand panel inserted text).
- Ratio above threshold considered a spike.
- NOAA/STAR has improved this binning process.
Least-Square Fitting Consideration

- Convergence of least-squares fit to global minimum depends on good starting value.
- Made more difficult because of high decimation factor and fine structure of the impulse response (many local minimums in fit).
- Magnitude of interferogram has less fine structure than complex interferogram.
- Steps used to refine position and amplitude of spikes:
  - Fourier interpolate interferogram and find peak in magnitude
  - Do least-square fit of spike in magnitude interferogram
  - Do least-square fit of spike in complex interferogram
- After correction, interferogram is checked again for spikes.
- If correction is unsuccessful, original interferogram is retained.
- Algorithm successful correction more than 99% of the time.
Magnitude Has Less Fine Structure

• Magnitude of interferogram spike much less sensitive to decimation position
Conclusion

• Radiation can cause spikes in interferograms.
• Many more small spikes than large spikes
• Simple impulse mask correction failed for CrIS
• New spike correction algorithm developed for CrIS
• Interferogram asymmetry used to detect spikes
• Model spike subtracted from interferogram
• New algorithm very effective in correcting spikes (99% successful)
• Algorithm for operational ground software has been developed.
• New algorithm will be incorporated into ground processing software.
Backup
CrIS Measurement Concept
Flow Diagram

- **Asymmetric Interferogram?**
  - yes: Find spike location
  - no: Refine spike location by interpolation

- **Calculate peak FIR Filter Decimate**
  - Least squares fit

- **Subtract modeled spike from interferogram**

- **Normal Spectral Processing**
  - Keep Correction
  - no: Reject Correction
  - yes: Asymmetric Interferogram?
Difference Between Original and Corrected

- Image at 2412 cm\(^{-1}\) brightness scale clipped
- Spikes in calibration spectra cause non-localized effects
- November 06, 2016 0400 over SAA

NEdN spec \(\approx 0.0065\) mW/m\(^2\) – sr – cm\(^{-1}\)