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# An Update on the Constant MTF Interpolator: A Resampler with Minimal MTF Losses

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# What Is An Image Resampler?

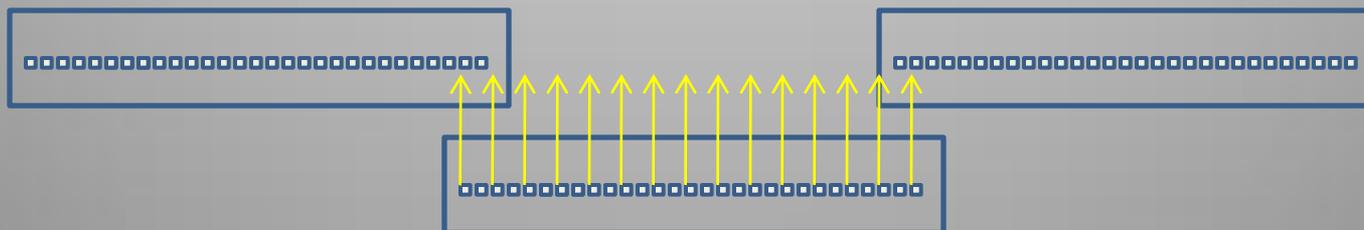


- An algorithm that uses a combination of pixel values to estimate new image values at locations in a grid that do not necessarily correspond to the pixel locations in the original map.
- This often requires an interpolation of values to locations in between the originally spaced pixels.

# Use of Resampling Interpolators in Imagery



- Zoom in / zoom out
- Rotation
- Map projections / Warping
- Band-band / image-image registration
- Adjusting for sensor chip offsets and misalignments
- Almost any type of geometric correction





# Form of Interpolators

Interpolators are normally implemented as a convolution kernel that is a function of interpolation (pixel shift) distance

Pixel Shift	Cubic Convolution Coefficients			
1/32	-0.0147	0.9976	0.0175	-0.0005
3/32	-0.0385	0.9793	0.0632	-0.0040
5/32	-0.0556	0.9447	0.1212	-0.0103
7/32	-0.0668	0.8961	0.1894	-0.018
9/32	-0.0726	0.8356	0.2655	-0.0284
11/32	-0.0740	0.7655	0.3473	-0.0388
13/32	-0.0716	0.6880	0.4326	-0.0490
15/32	-0.0661	0.6052	0.5193	-0.0584

# The Problem with Most Interpolators



- All interpolators are low pass filters
  - Interpolators always blur the image and therefore,
    - Reduce interpretability
    - Reduce sharpness
- No interpolator is geometrically perfect
  - There is always a slight difference between the desired and actual pixel shift
- Common interpolators induce a different blur / MTF reduction based upon the degree of pixel shift
  - Creates a different MTF at every point in an image
  - Increases difficulty of estimating MTF from targets in collected images

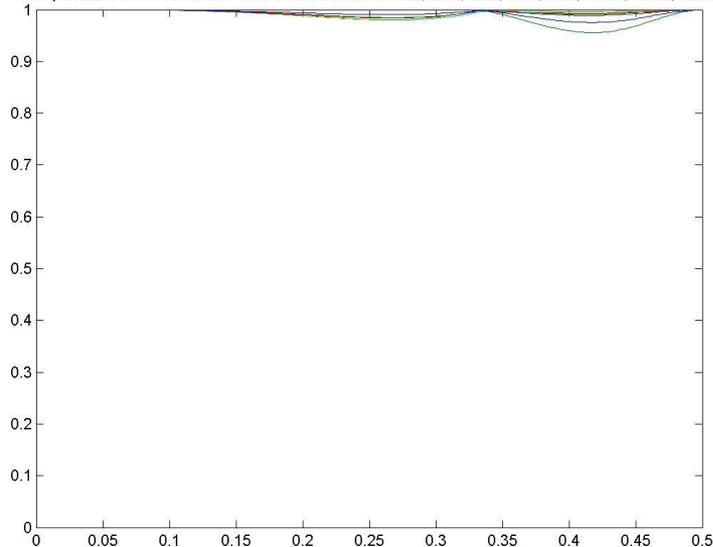
**No single sharpening filter, blind deconvolution, or process can correct for the variable blur from most interpolators.**

# Constant MTF Interpolator Was Developed to Correct the Flaws in Common Interpolators



- Virtually constant MTF across different pixel shift distances
  - Other interpolators impose a different MTF for each interpolation distance
  - A single MTFC (either convolution or FFT) compensates for all interpolations in an image
    - NOT A SHARPENING FILTER. It restores radiometric values to their pre-resampled values.
- Minimal geometric errors

Compensated 6 Element CMTF MTFs for Pixel Shifts 1/32, 3/32, 5/32, 7/32, 9/32, 11/32, 13/32, 15/32

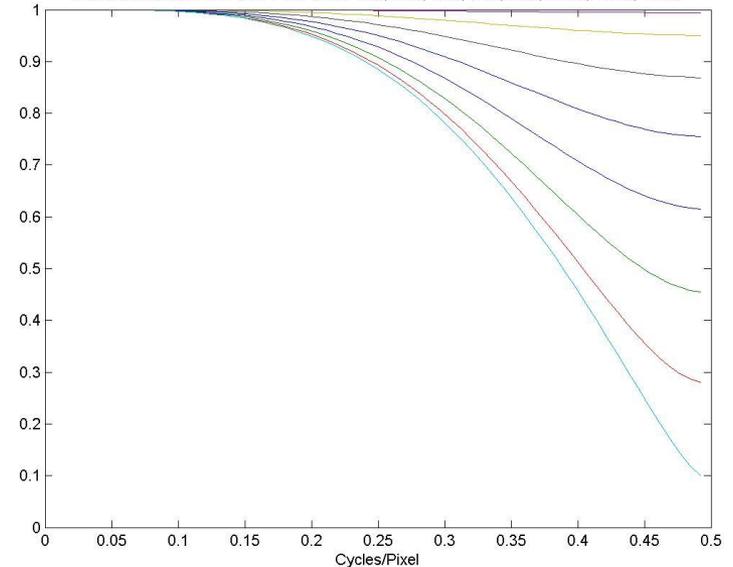


CMTF MTFs

6 Element Kernel

With Inverse MTF Compensation Applied

Cubic Convolution MTFs for Pixel Shifts 1/32, 3/32, 5/32, 7/32, 9/32, 11/32, 13/32, 15/32



Cubic Convolution MTFs

# What's New?

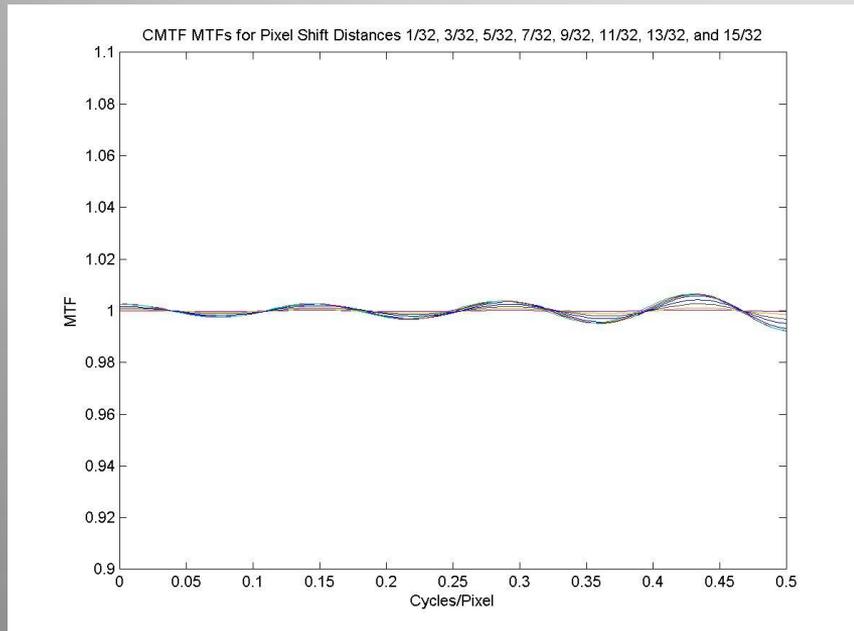


- An alternate, 14 element kernel was created that does not require compensation
  - Blackbridge was kind enough to beta test one of the interpolators with RapidEye imagery
    - Some of this was briefed at JACIE 2013 by Andreas Brunn
- Significantly improved the performance of the 6 element kernel CMTF
- Performance comparisons have been made between CMTF and other interpolators on images
- Geometric placement error results has been refined

# 14 Element Constant MTF Coefficients Were Developed for Those That Cannot Apply an MTFC



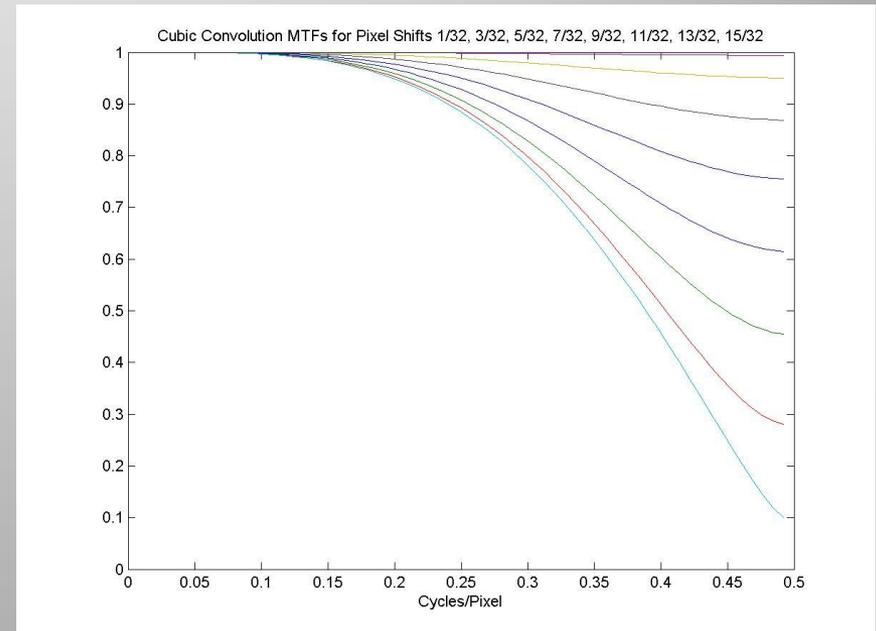
- MTFs across all pixel shift distances of  $1.00 \pm 0.003$
- Geometric error almost always better than that of cubic



CMTF MTFs

14 Element Kernel

No Compensation Necessary



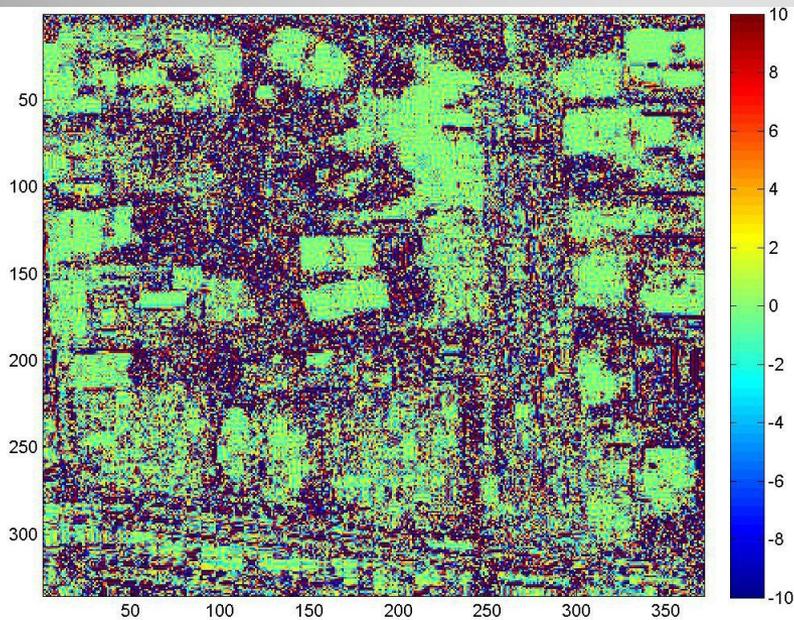
Cubic Convolution MTFs

# Sample Test Image for Multiple Interpolations Analysis

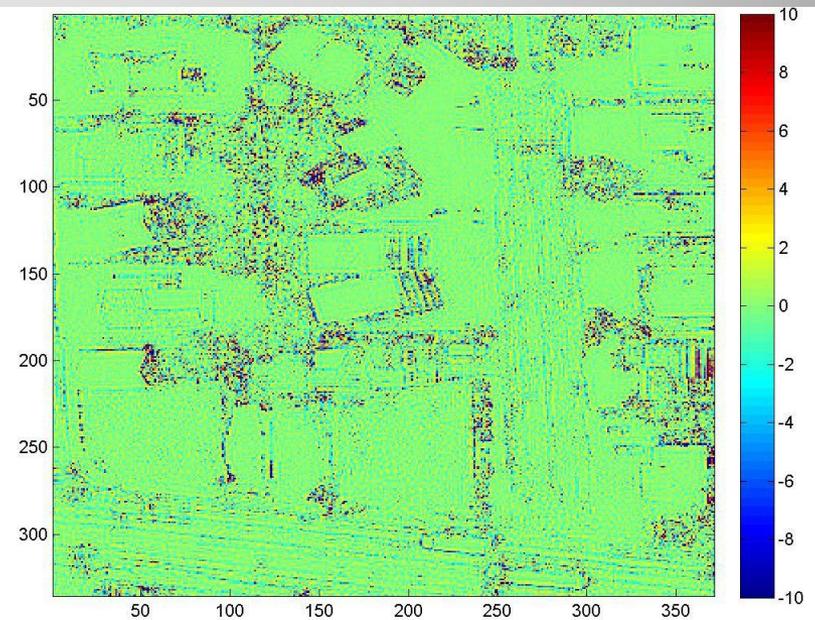


# Cubic vs. CMTF 6

Percent Difference Between Original Image and Image Interpolated  
3/32, 5/32, 7/32, -15/32, 1/32, 1/32, 11/32, and -13/32 Pixels in X and Y Directions



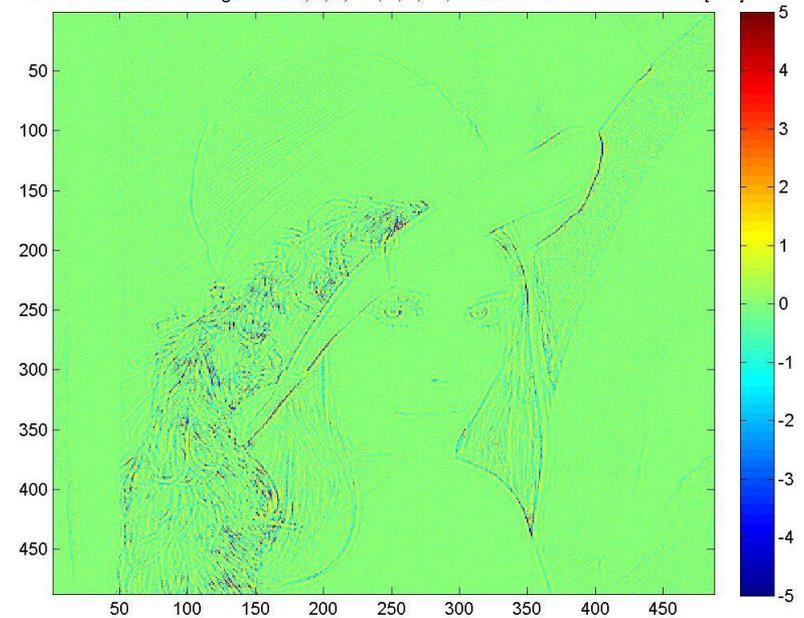
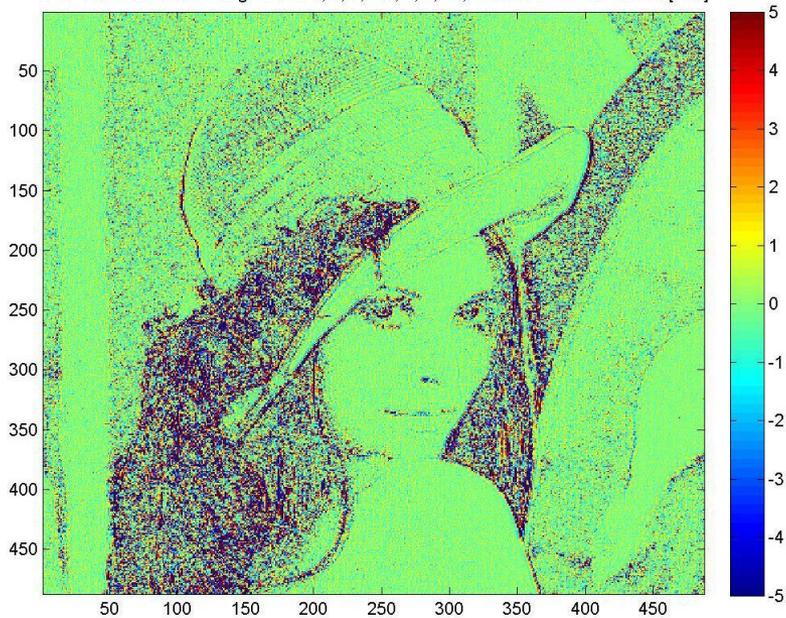
Standard Deviation = 7.2%



Standard Deviation = 1.3%

# Cubic vs. CMTF 6

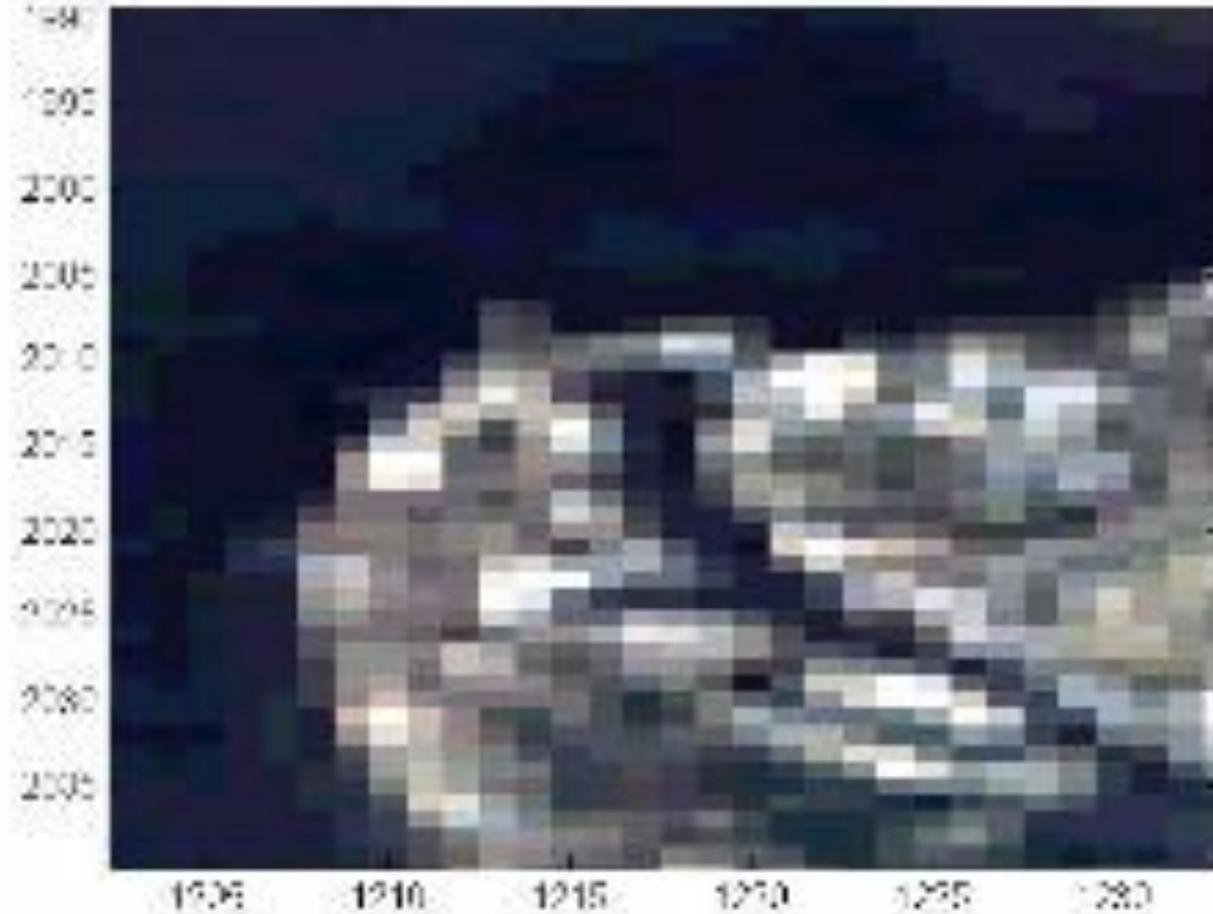
Percent Difference Between Original Image and Image Interpolated  
 $3/32$ ,  $5/32$ ,  $7/32$ ,  $-15/32$ ,  $1/32$ ,  $1/32$ ,  $11/32$ , and  $-13/32$  Pixels in X and Y Directions



# Comparison of Unresampled and Cubic Resampled Simulated Landsat Image



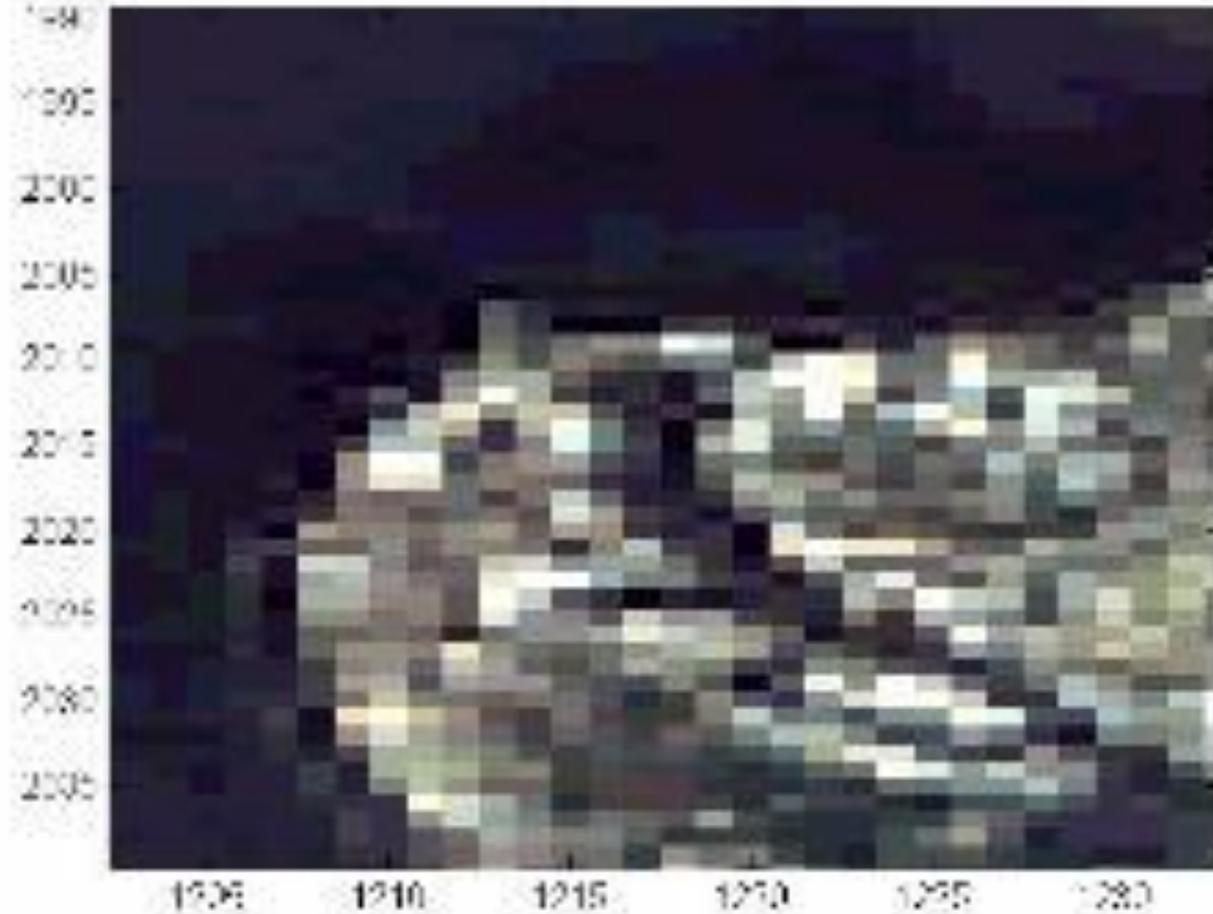
Interpolated 11/32 of a pixel in X and Y directions



# Comparison of Unresampled and CMTF 14 Resampled Simulated Landsat Image



Interpolated 11/32 of a pixel in X and Y directions



# RapidEye Image Segment Selected for Analysis

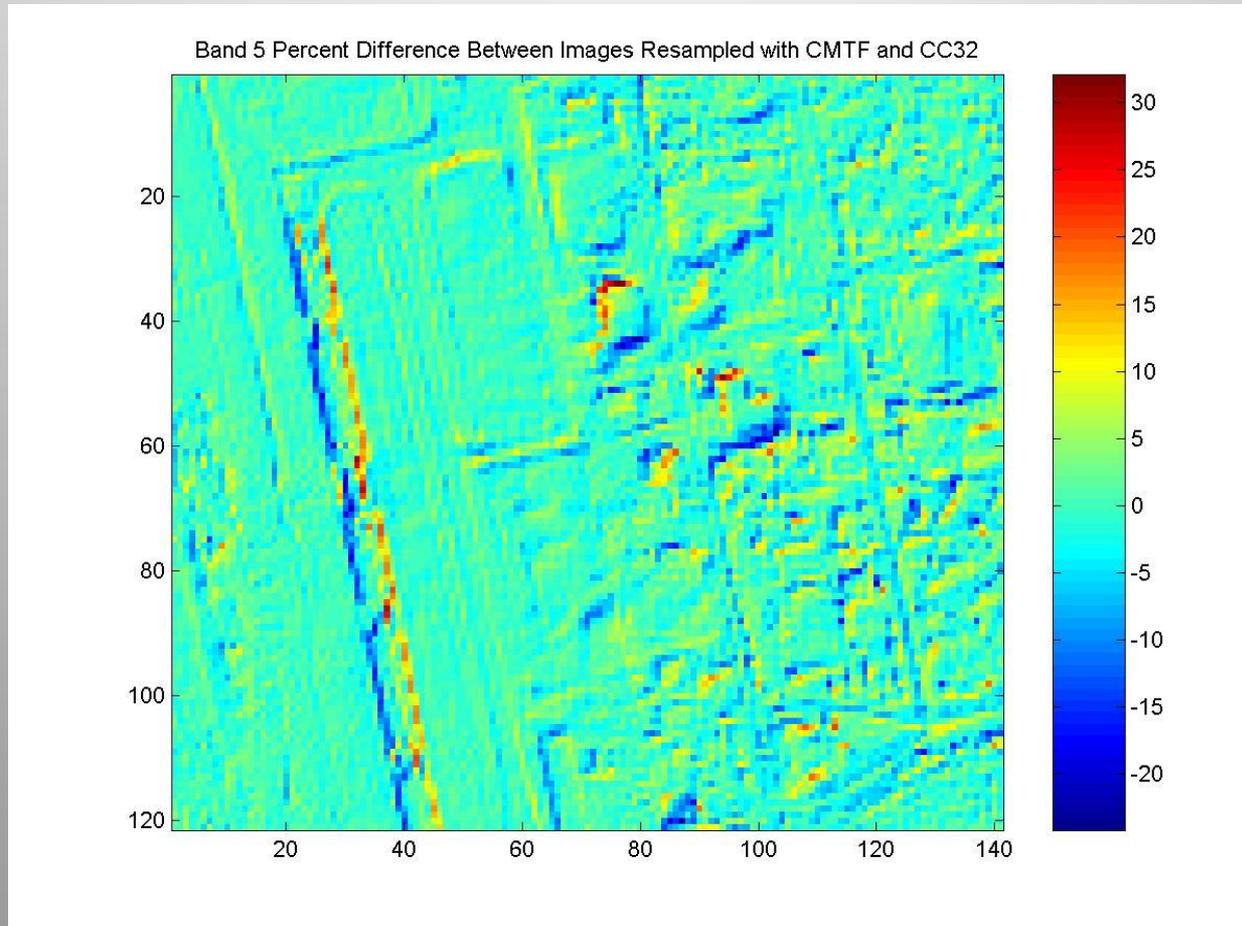


Original Band 1 Unresampled Image



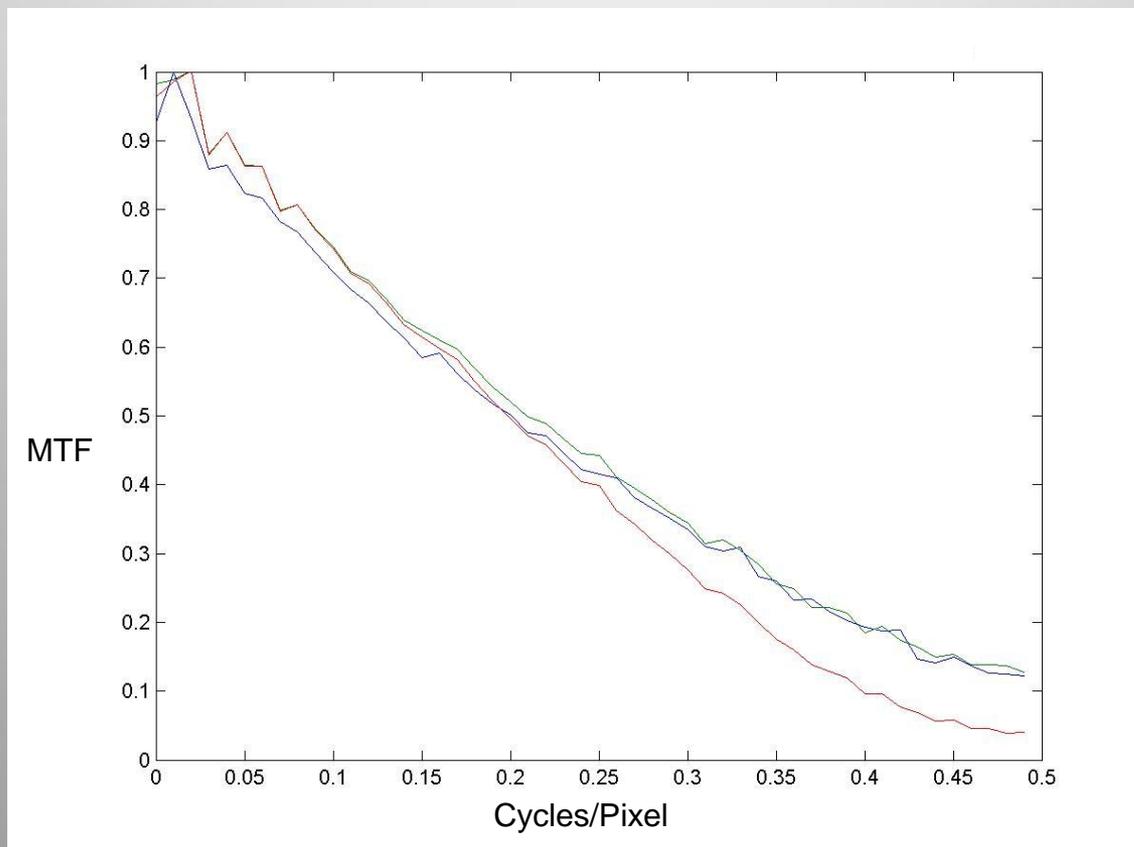


# % Radiometric Error Introduced by Using Cubic Instead of CMTF



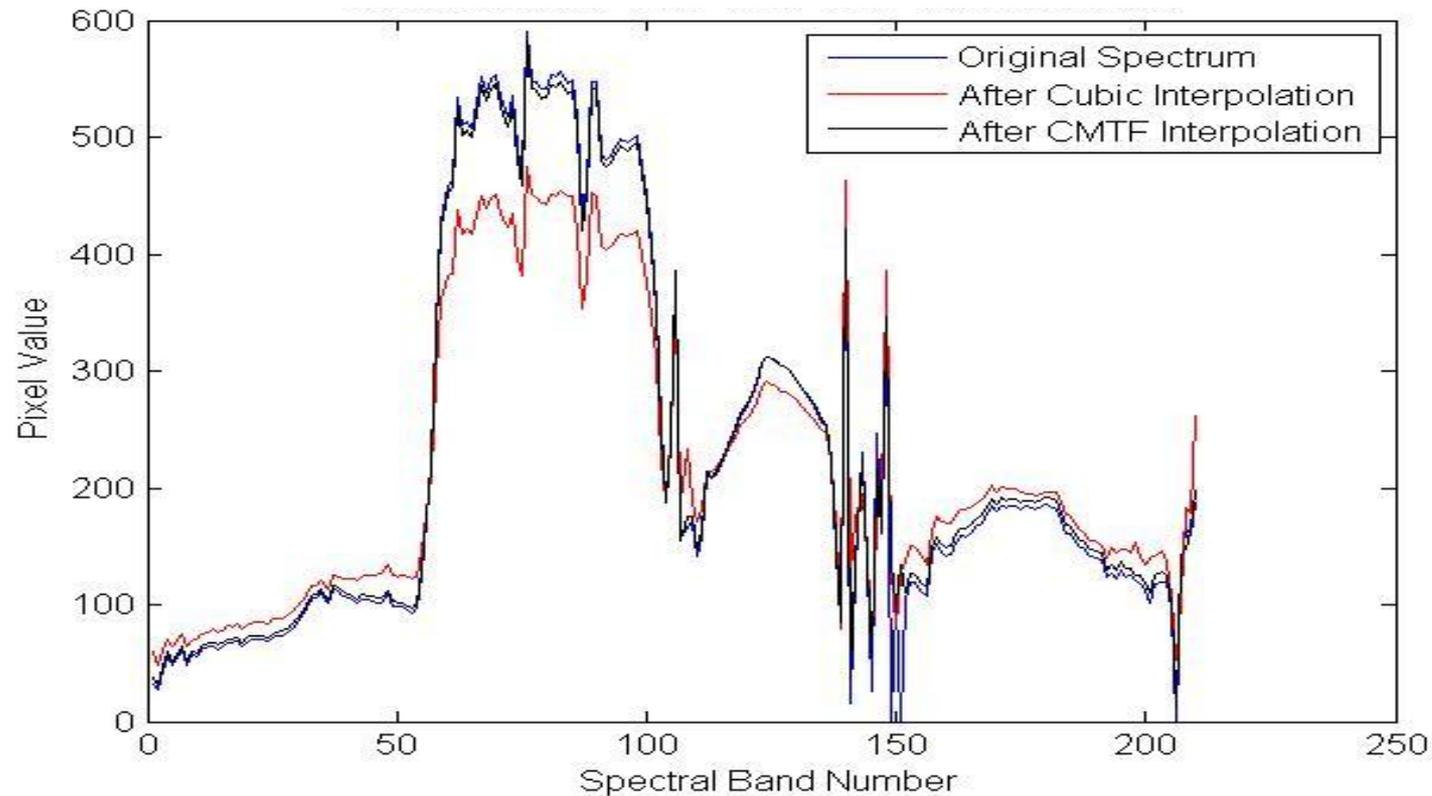
RapidEye Band 5, 14 Element CMTF

# Cross Track MTF Measurements with Cubic and CMTF



Measured MTFs from RapidEye Band 4  
Unresampled (Blue), Cubic (Red), CMTF (Green)  
Target: Lake Pontchartrain Causeway

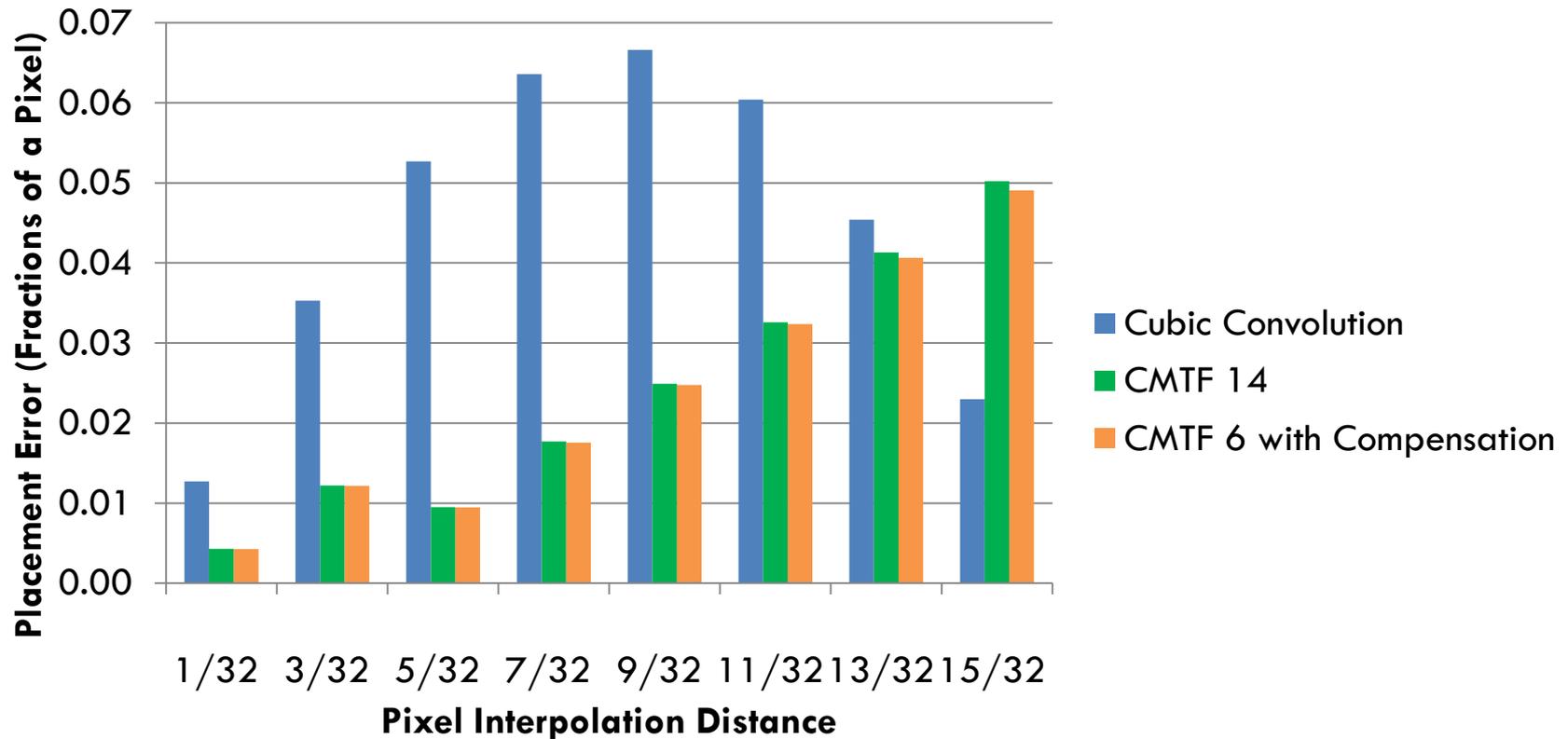
# Interpolation Can Also Affect Spectral Signatures



**Spectra of Tree Next to Parking Lot in an AVIRIS Image After Spatial Interpolations of  $9/32$ ,  $1/32$ ,  $1/32$ , and  $-11/32$  of a Pixel In X and Y Directions**



# Geometric Placement Error Comparison Against a Perfect Step Function



- Any compensation or sharpening increases placement error proportional to the strength of the filter
- Sharpening the cubic results in increased placement and radiometric error.

# Summary



- Two versions of the Constant MTF interpolator have been developed
  - 6 element kernels that require compensation
  - 14 element kernels that do not require compensation
- Both provide better performance than all other interpolators
  - Image quality is not degraded
  - Radiometric accuracy is preserved, unlike other interpolators
  - Geometric placement accuracy is much better
  - Spectral signatures are preserved in multispectral and hyperspectral images



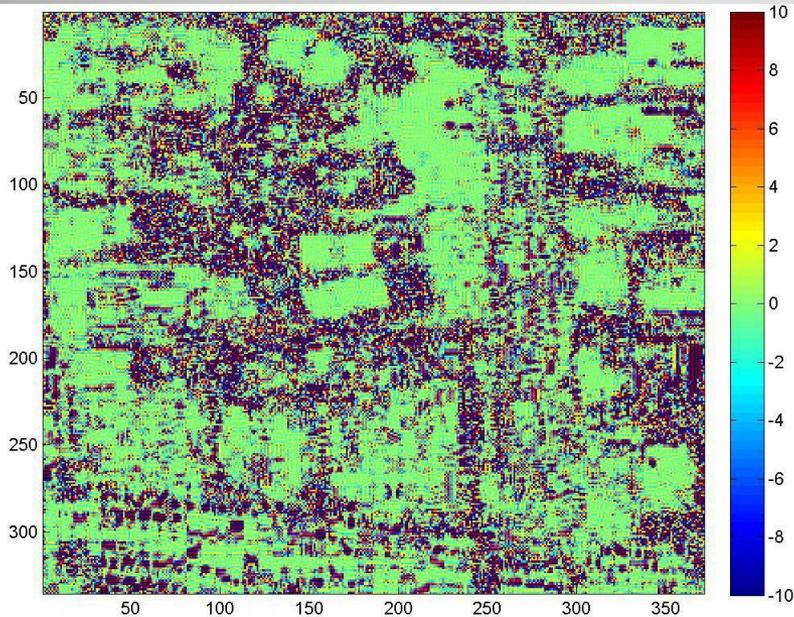
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# Supplemental Slides

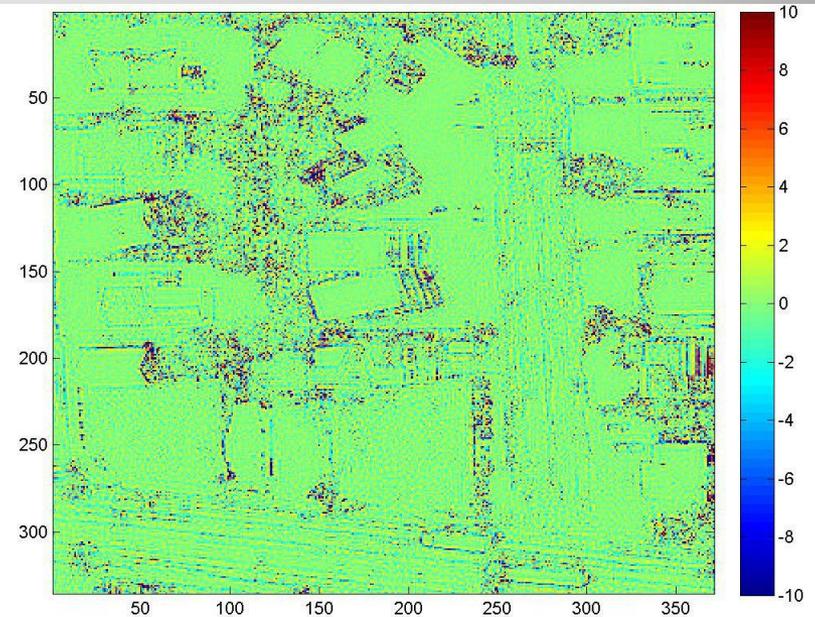


# 14 Element Lagrange vs. CMTF 6

Percent Difference Between Original Image and Image Interpolated  
3/32, 5/32, 7/32, -15/32, 1/32, 1/32, 11/32, and -13/32 Pixels in X and Y Directions



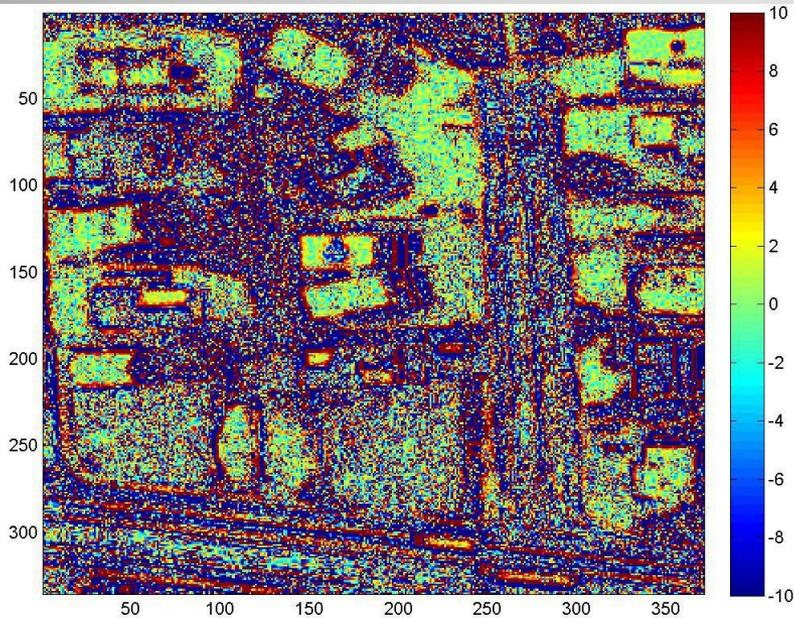
Standard Deviation = 5.1%



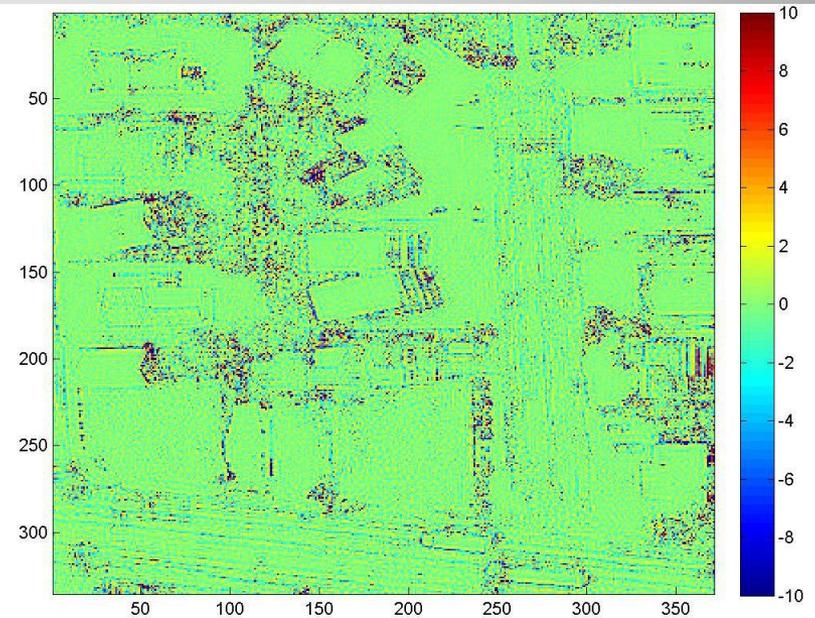
Standard Deviation = 1.3%

# B-Spline vs. CMTF 6

Percent Difference Between Original Image and Image Interpolated  
3/32, 5/32, 7/32, -15/32, 1/32, 1/32, 11/32, and -13/32 Pixels in X and Y Directions



Standard Deviation = 11.5%

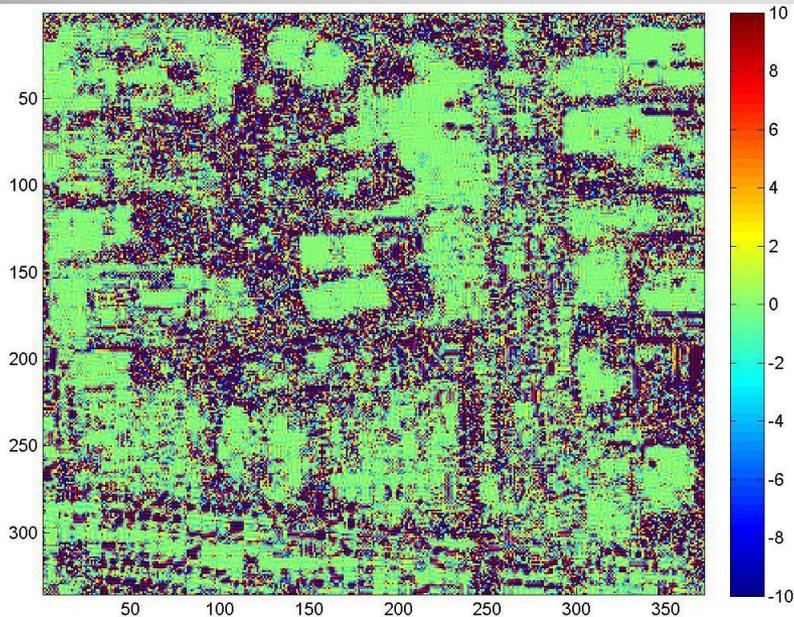


Standard Deviation = 1.3%

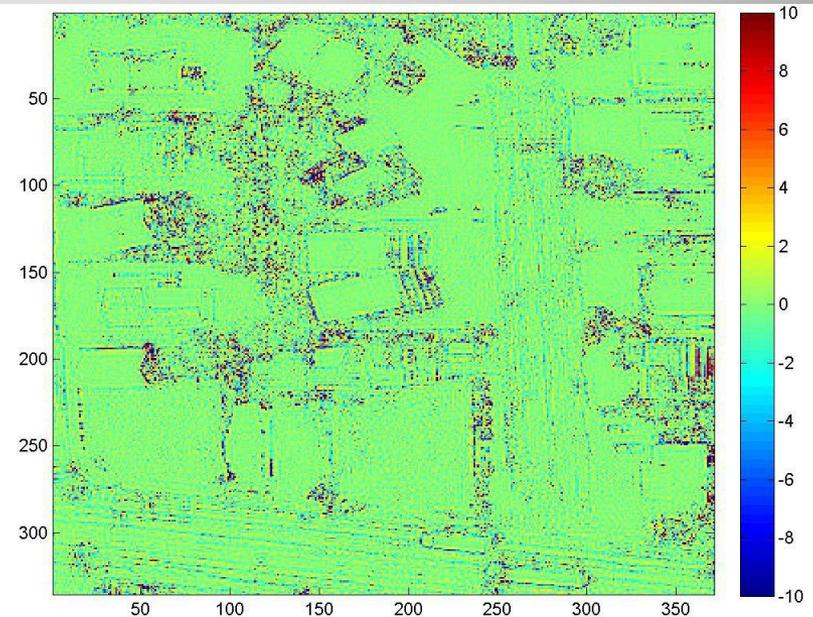
# Compensated B-Spline vs. CMTF 6



Percent Difference Between Original Image and Image Interpolated  
3/32, 5/32, 7/32, -15/32, 1/32, 1/32, 11/32, and -13/32 Pixels in X and Y Directions



Standard Deviation = 5.6%

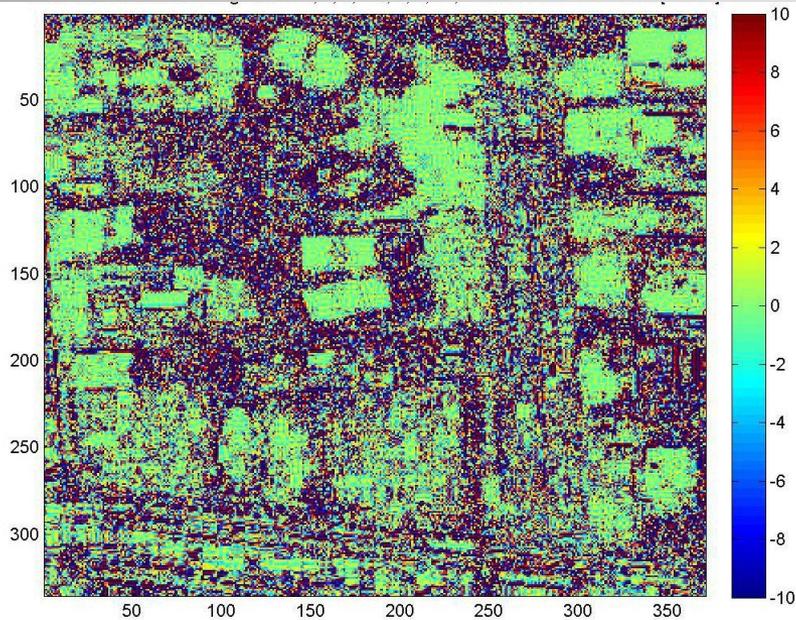


Standard Deviation = 1.3%

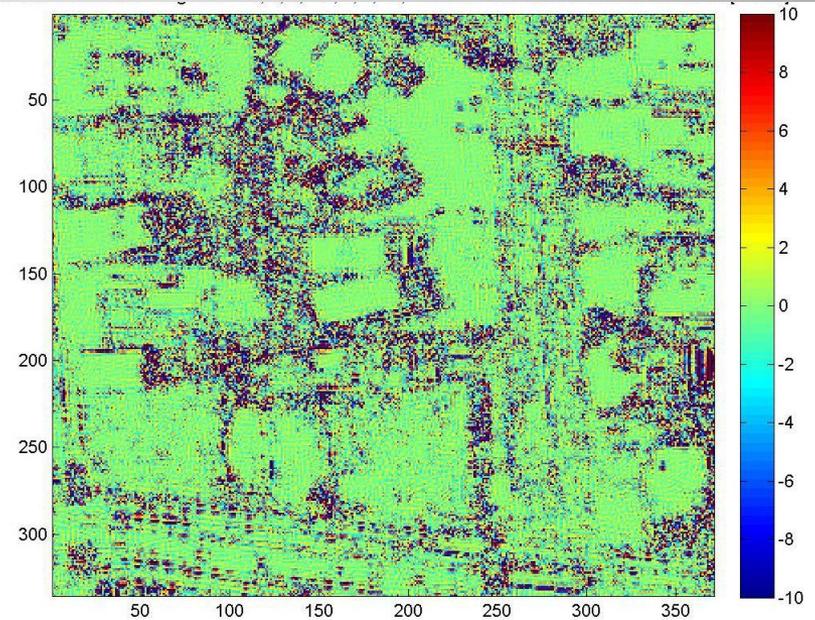
# Cubic vs. CMTF 14



Percent Difference Between Original Image and Image Interpolated  
3/32, 5/32, 7/32, -15/32, 1/32, 1/32, 11/32, and -13/32 Pixels in X and Y Directions

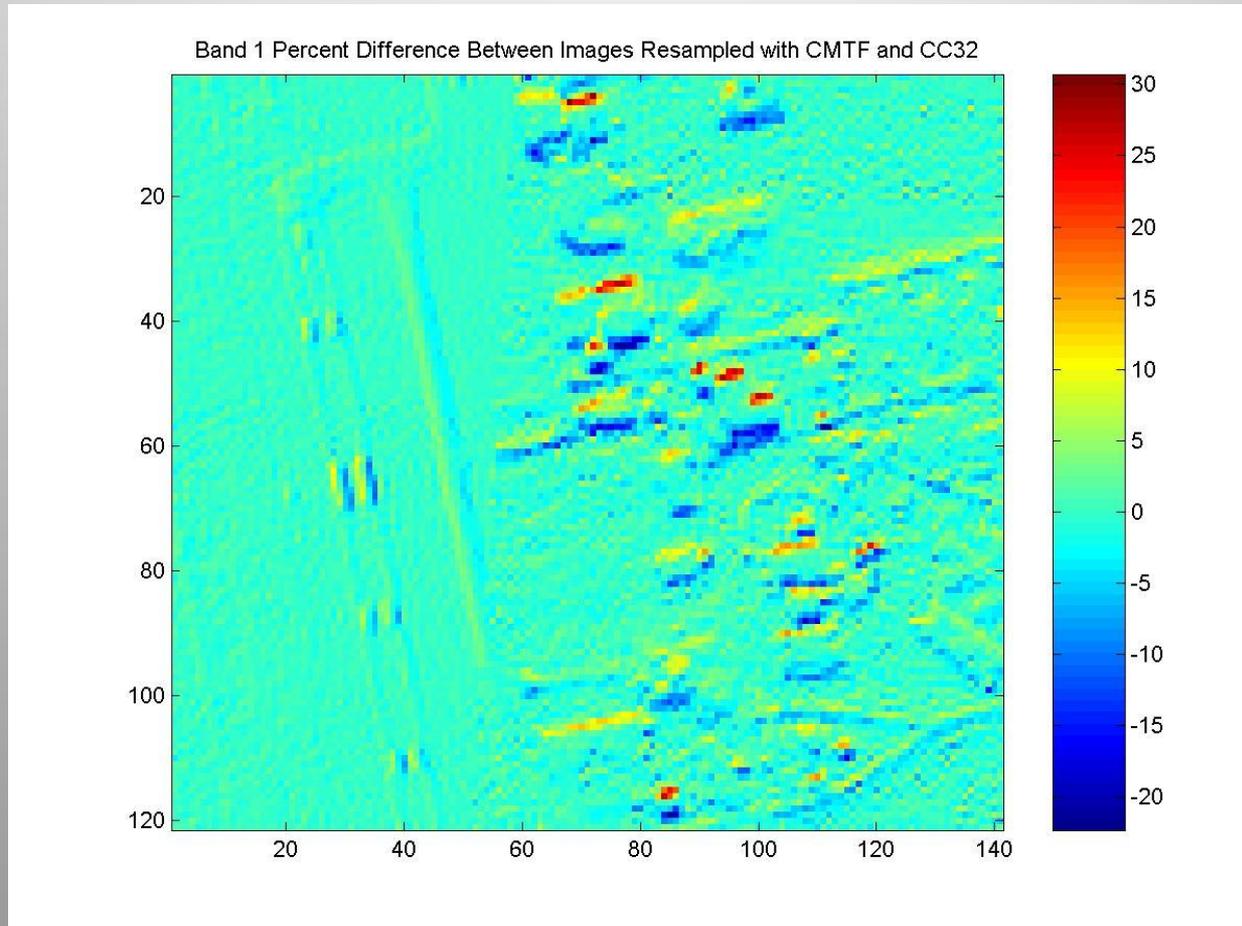


Standard Deviation = 7.2%



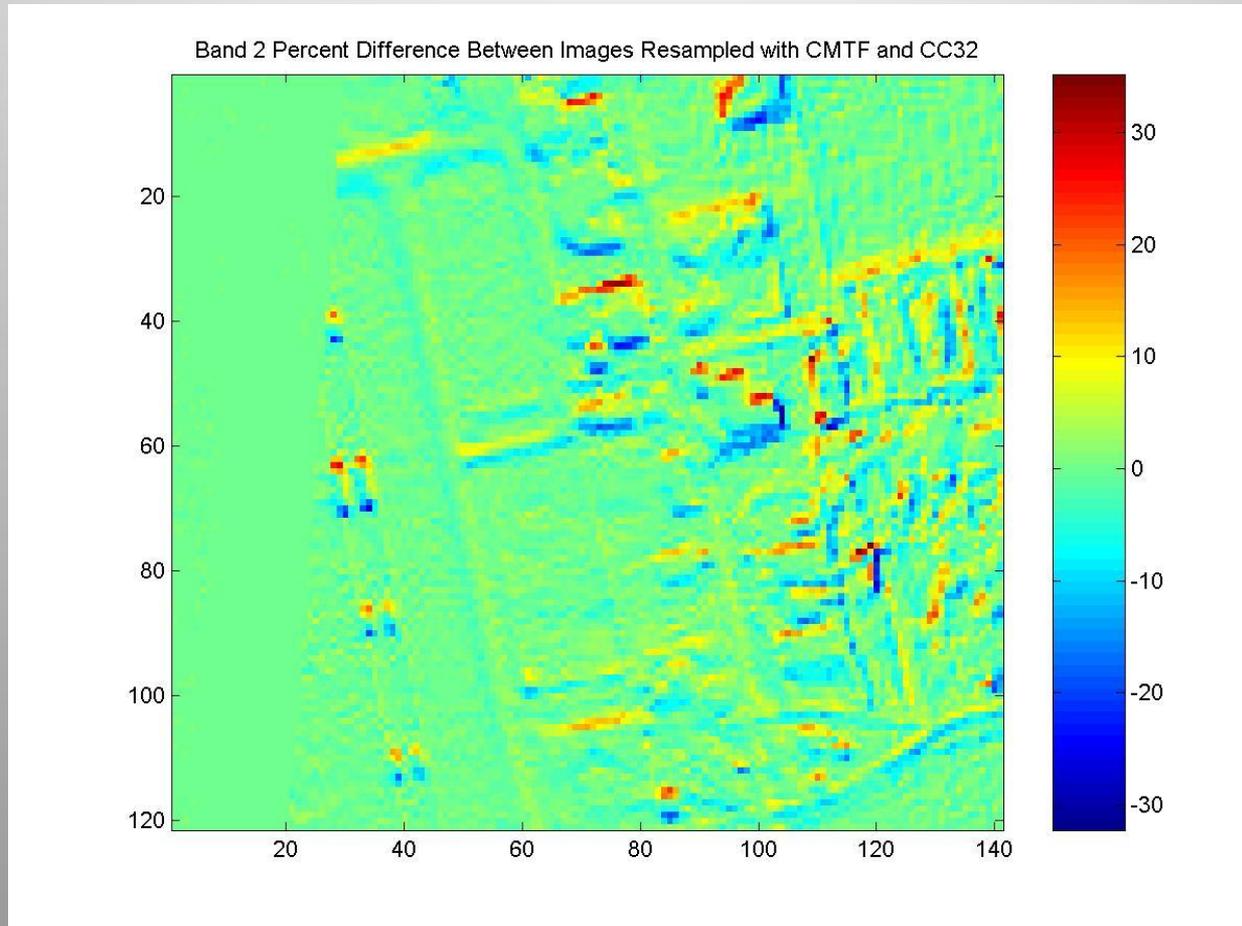
Standard Deviation = 2.9%

# % Radiometric Error Introduced by Using Cubic Instead of CMTF



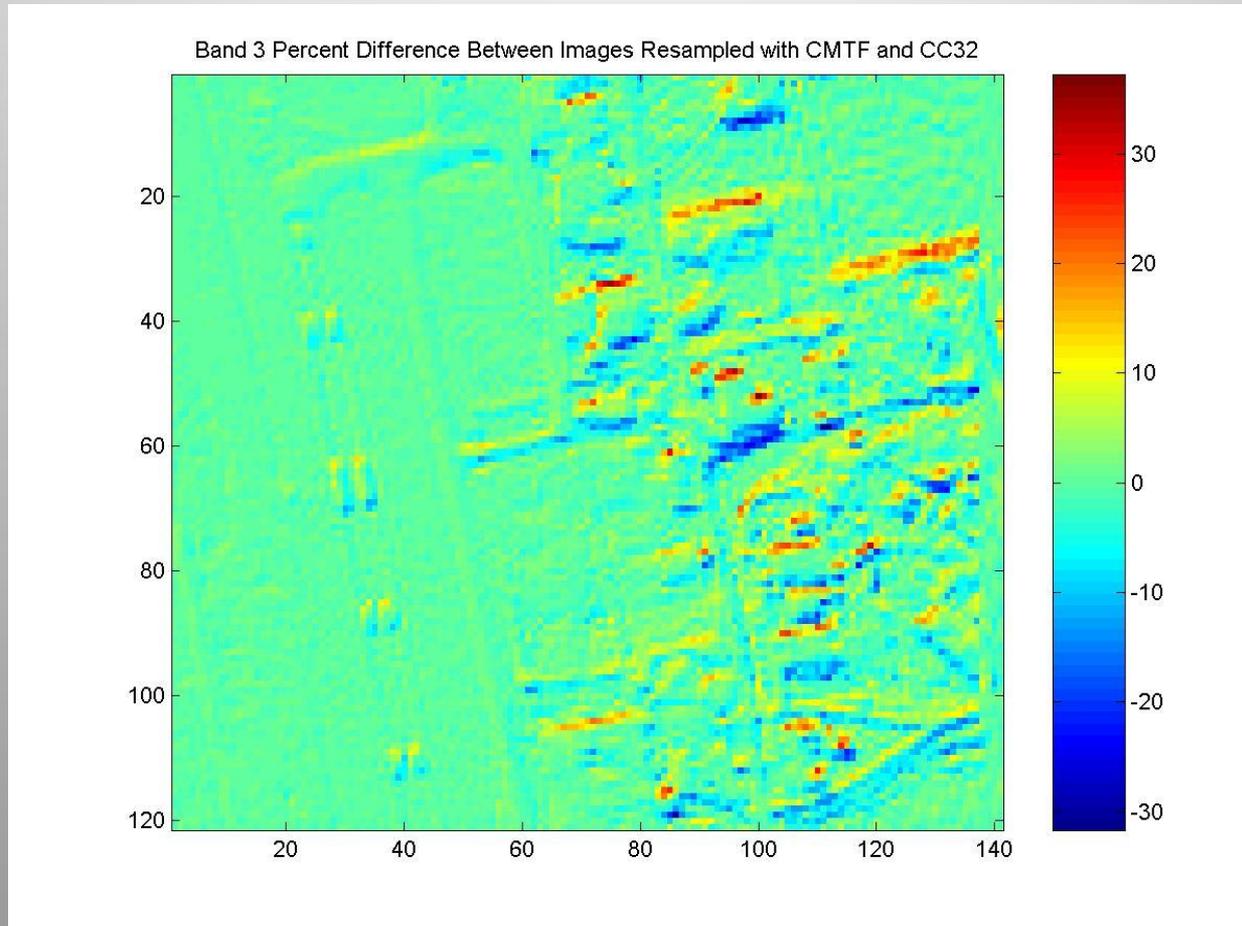
RapidEye Band 1, 14 Element CMTF

# % Radiometric Error Introduced by Using Cubic Instead of CMTF



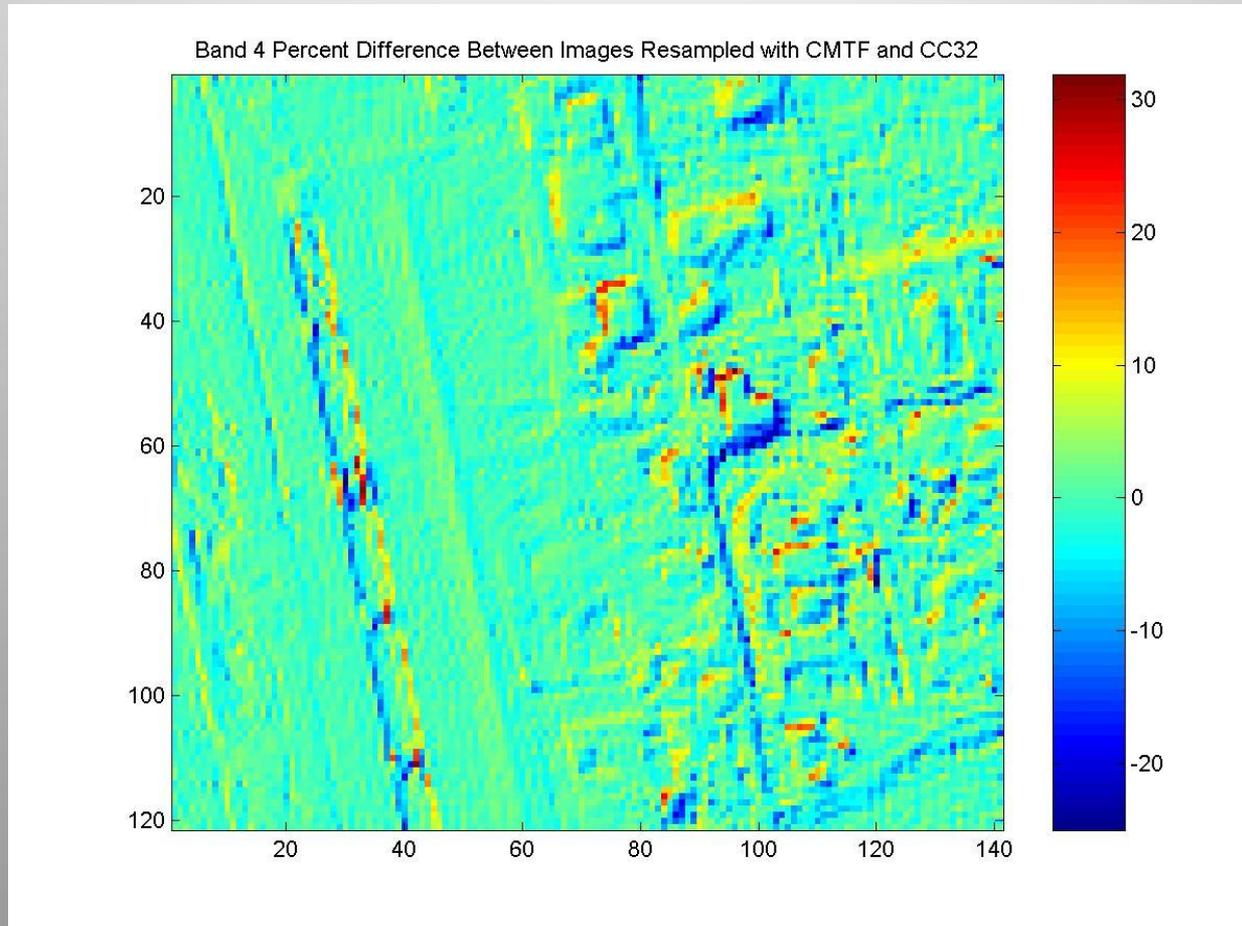
RapidEye Band 2, 14 Element CMTF

# % Radiometric Error Introduced by Using Cubic Instead of CMTF



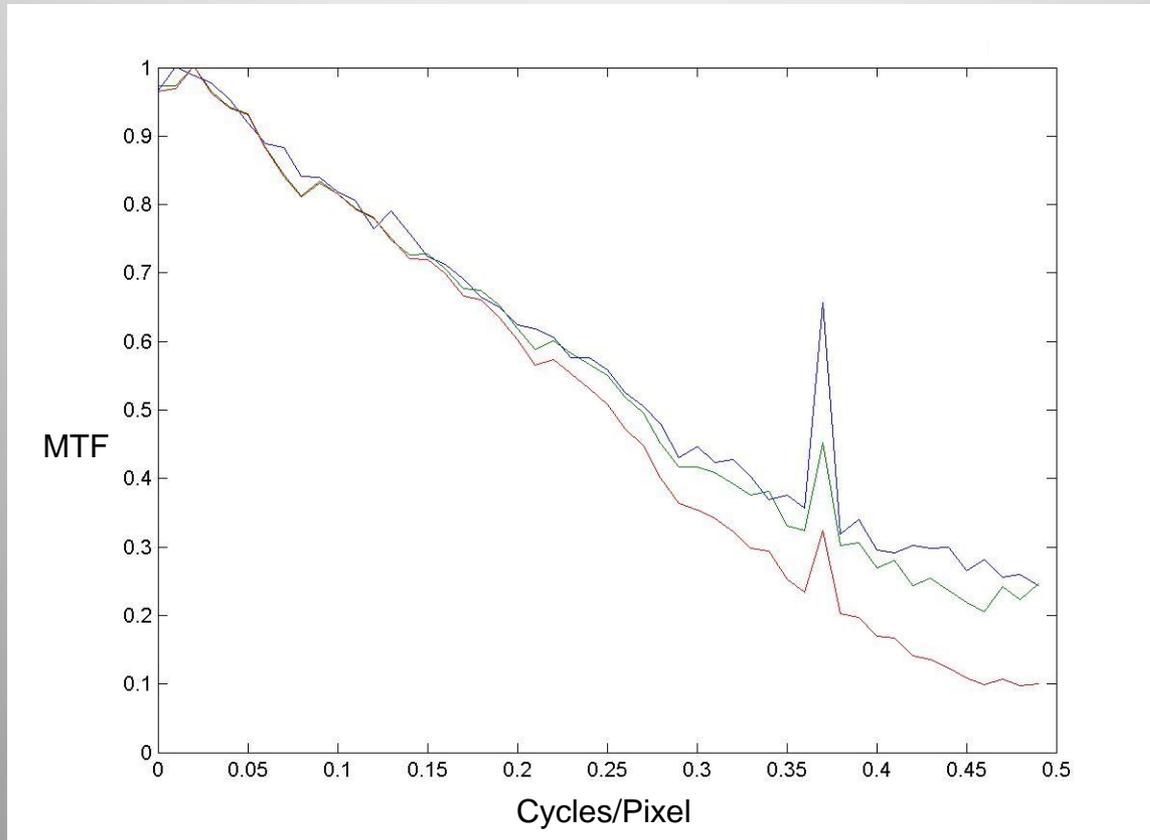
RapidEye Band 3, 14 Element CMTF

# % Radiometric Error Introduced by Using Cubic Instead of CMTF



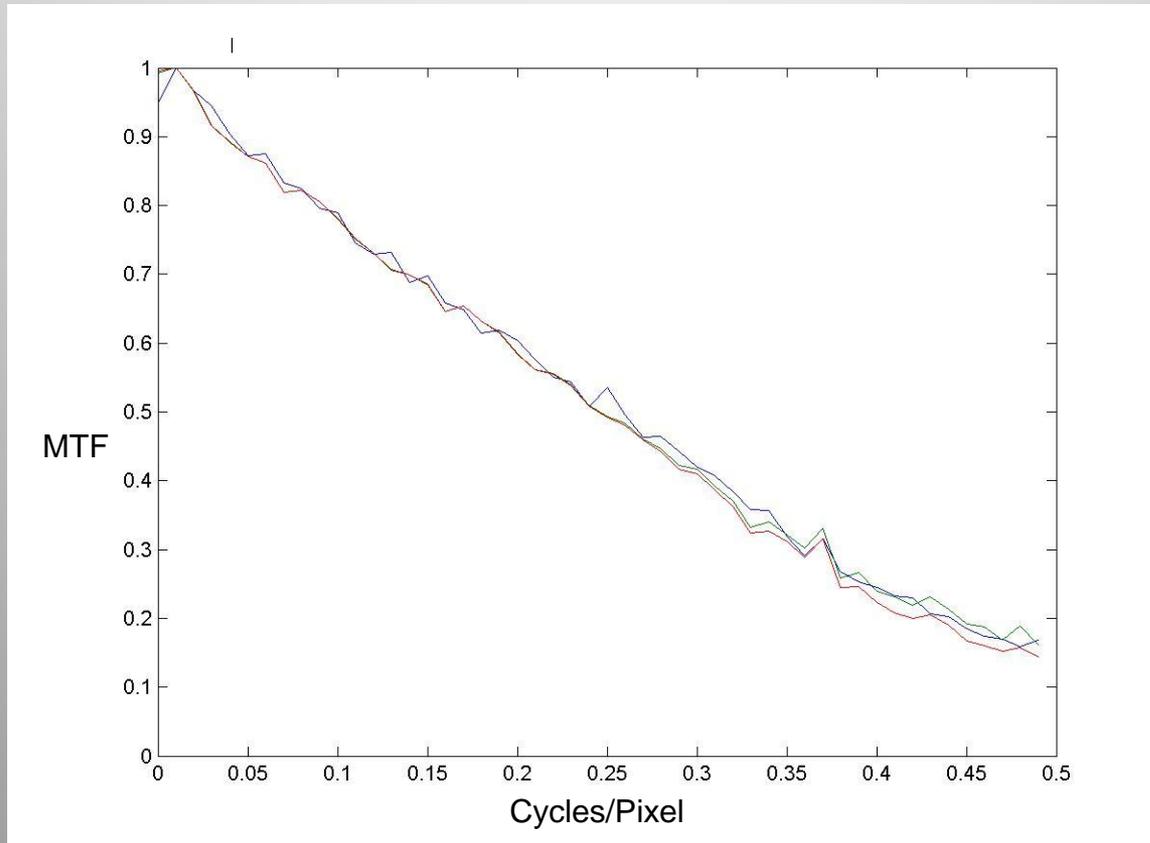
RapidEye Band 4, 14 Element CMTF

# Cross Track MTF Measurements with Cubic and CMTF



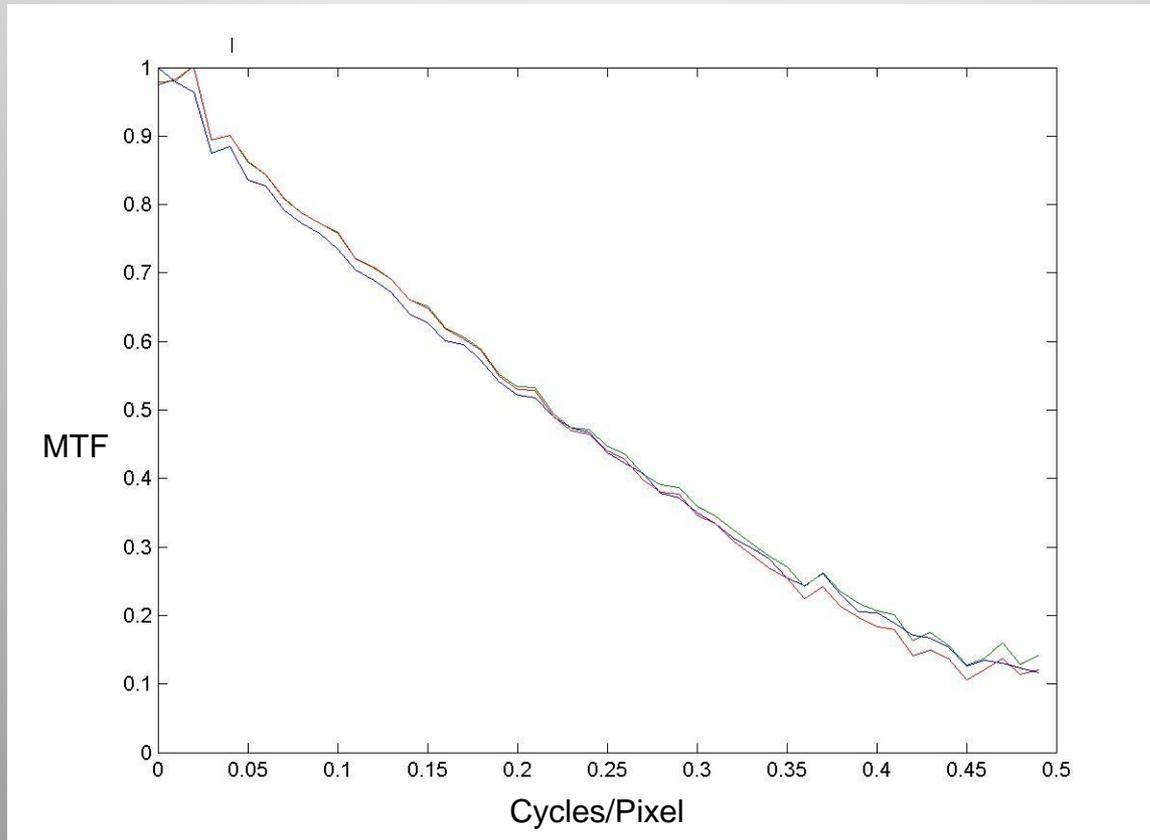
Measured MTFs from RapidEye Band 1  
Unresampled (Blue), Cubic (Red), CMTF (Green)  
Target: Lake Pontchartrain Causeway

# Cross Track MTF Measurements with Cubic and CMTF



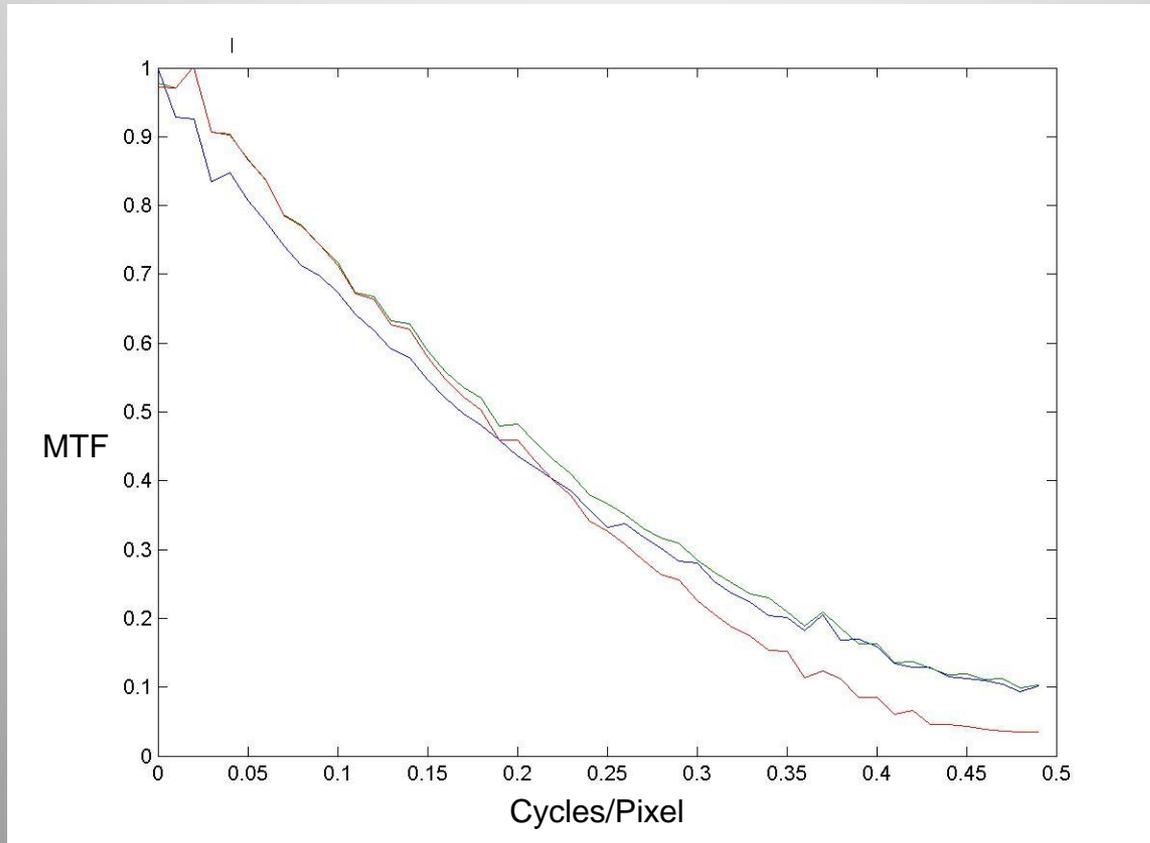
Measured MTFs from RapidEye Band 2  
Unresampled (Blue), Cubic (Red), CMTF (Green)  
Target: Lake Pontchartrain Causeway

# Cross Track MTF Measurements with Cubic and CMTF



Measured MTFs from RapidEye Band 3  
Unresampled (Blue), Cubic (Red), CMTF (Green)  
Target: Lake Pontchartrain Causeway

# Cross Track MTF Measurements with Cubic and CMTF



Measured MTFs from RapidEye Band 5  
Unresampled (Blue), Cubic (Red), CMTF (Green)  
Target: Lake Pontchartrain Causeway