Using the Constant MTF Interpolator to Reduce Aperture Size in Imaging Systems

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Background

- Traditional interpolators reduce the MTF of an image by a different amount for each interpolation distance.
  - The Constant MTF (CMTF) interpolator imposes the same MTF effects on imagery under all conditions.
- Constant MTF interpolator briefed at JACIEs in 2012 – 2013
- NASA Earth Sciences Technology Office (ESTO) funded a study to Lockheed Martin Civil Space and Serious Science, LLC to study CMTF benefits to Landsat (NASA grant #NNX15AV75G.)
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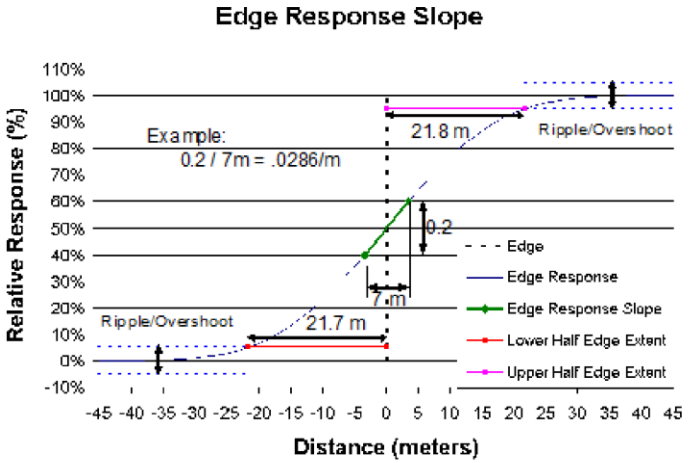
Relevant Landsat Performance Requirements

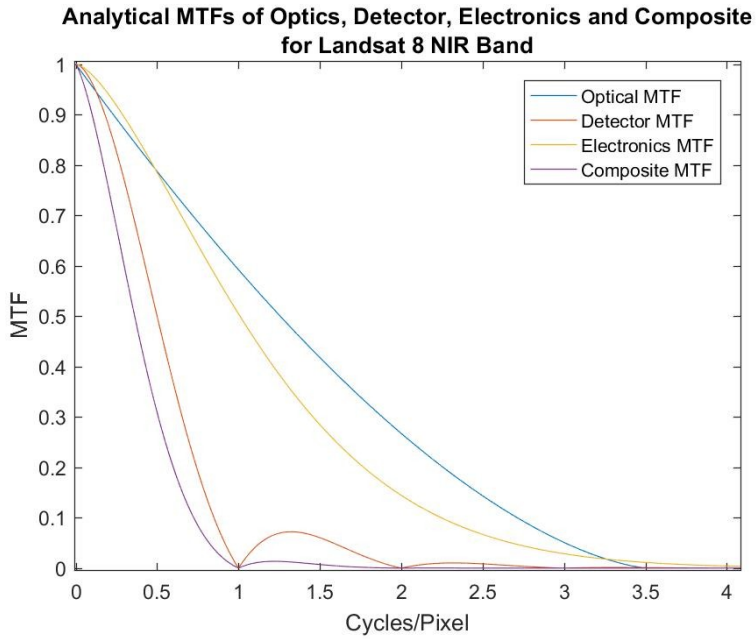
- Relative Edge Response (RER) and Half Edge Extent (HEE)
  - Used in place of MTF
  - Like MTF, performance gets worse with increasing wavelength.
    - Aperture size (f-number) must be designed for longest wavelength spectral band to meet Landsat requirements
      - RER increases and HEE decreases with decreasing aperture and increasing f-number
      - SNR decreases with aperture
  - Requirements are on the L1R product, not the resampled product.

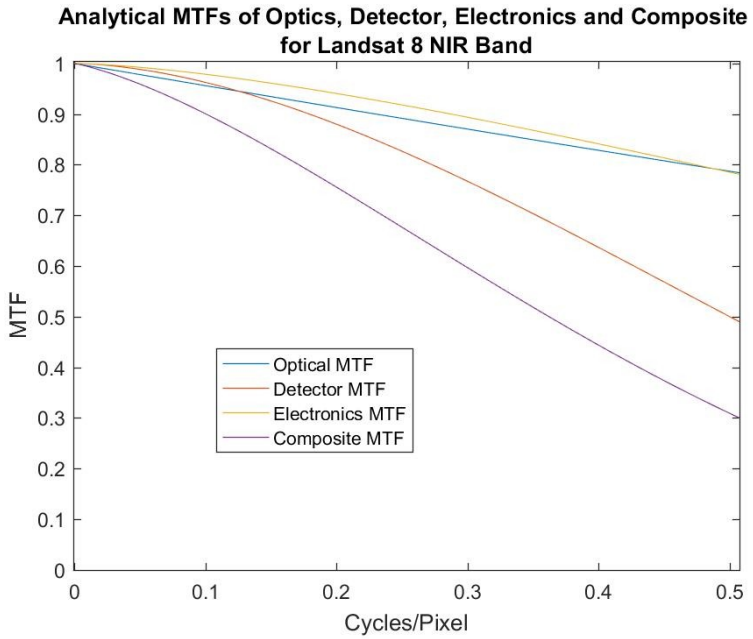
Spectral Band	Relative Edge Response (1/meters) @ GSD	Half Edge Extent (meters)	SNR@Ltyp	SNR@Lhigh
Coastal	0.027	23	130	290
Blue	0.027	23	130	360
Green	0.027	23	100	390
Red	0.027	23.5	90	340
NIR	0.027	24	90	460
Cirrus	0.027	27	50	N/A
SWIR 1	0.027	28	100	540
SWIR 2	0.027	29	100	510
Pan	0.054	14	80	230



Source: LDCM Operational Land Imager Requirements Document

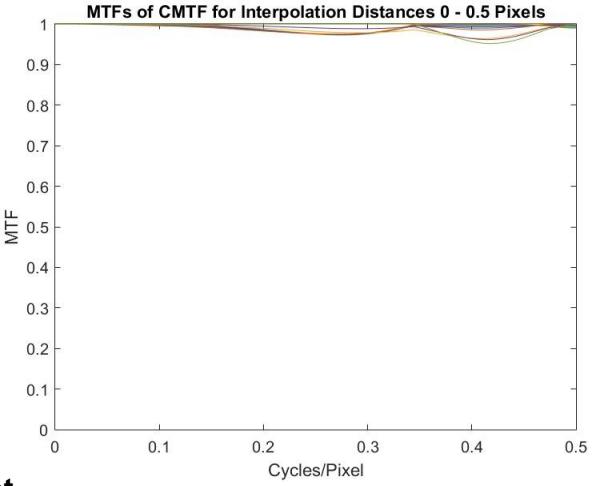
Instrument System MTF Performance Is the Product of Multiple Contributors

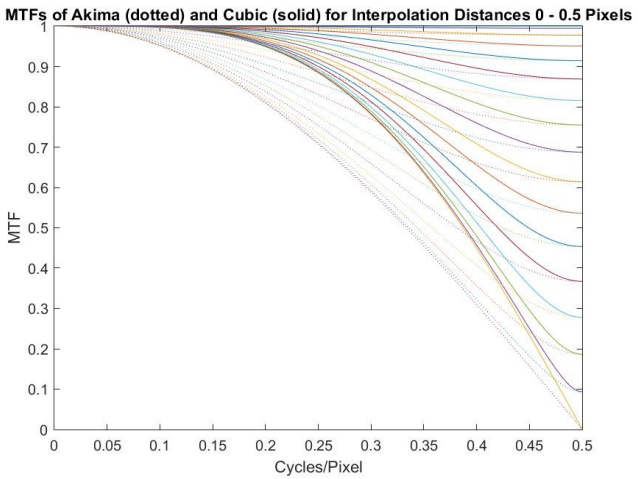




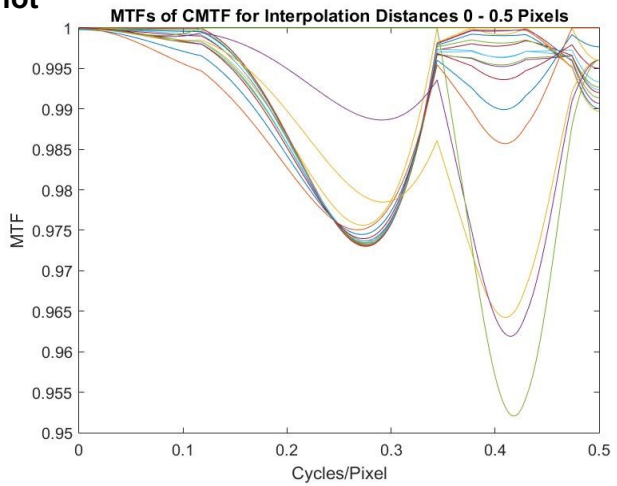
Comparison of the MTF Performance of CMTF to Cubic and Akima

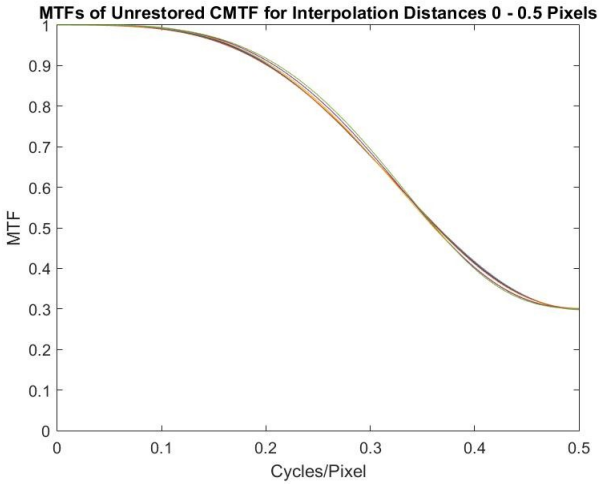
CMTF with Restoration



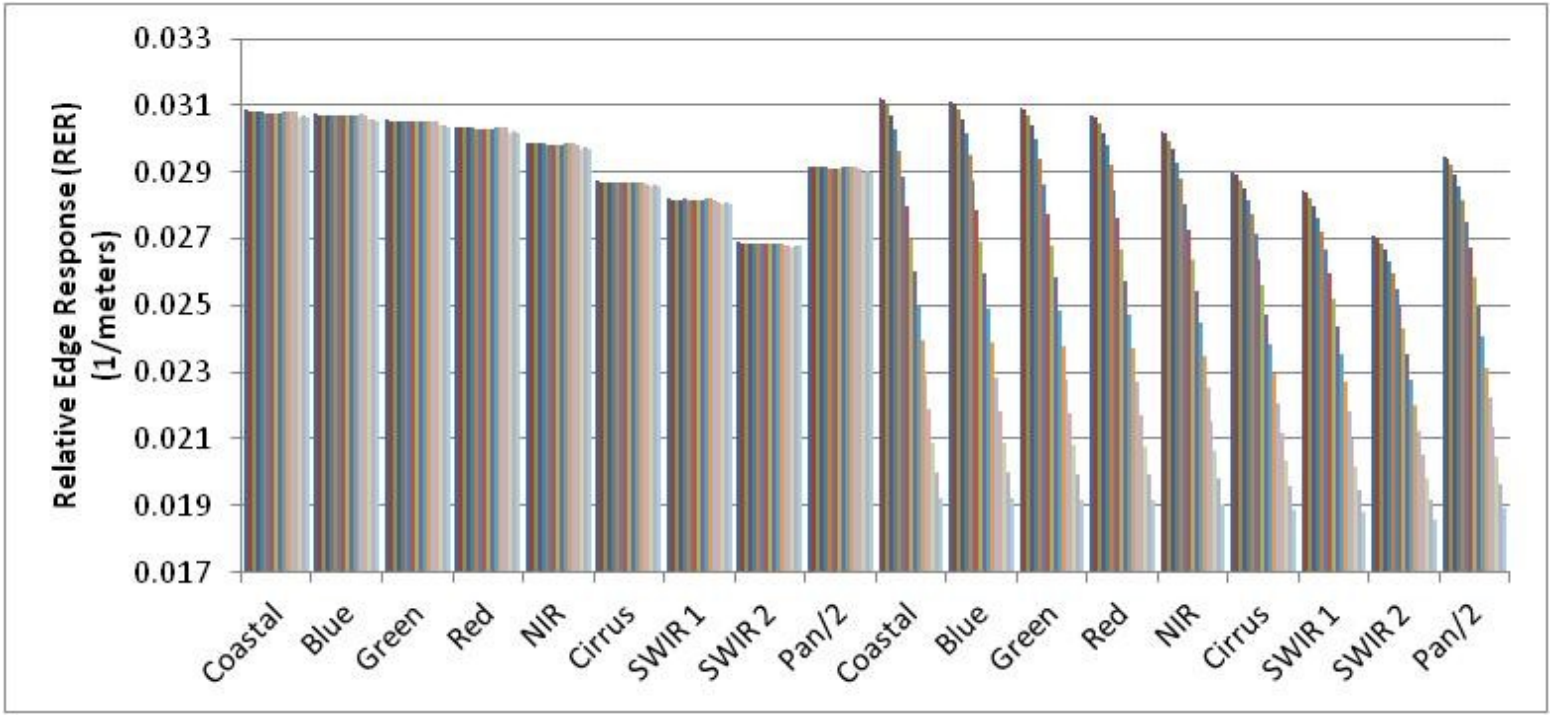


Zoomed Plot





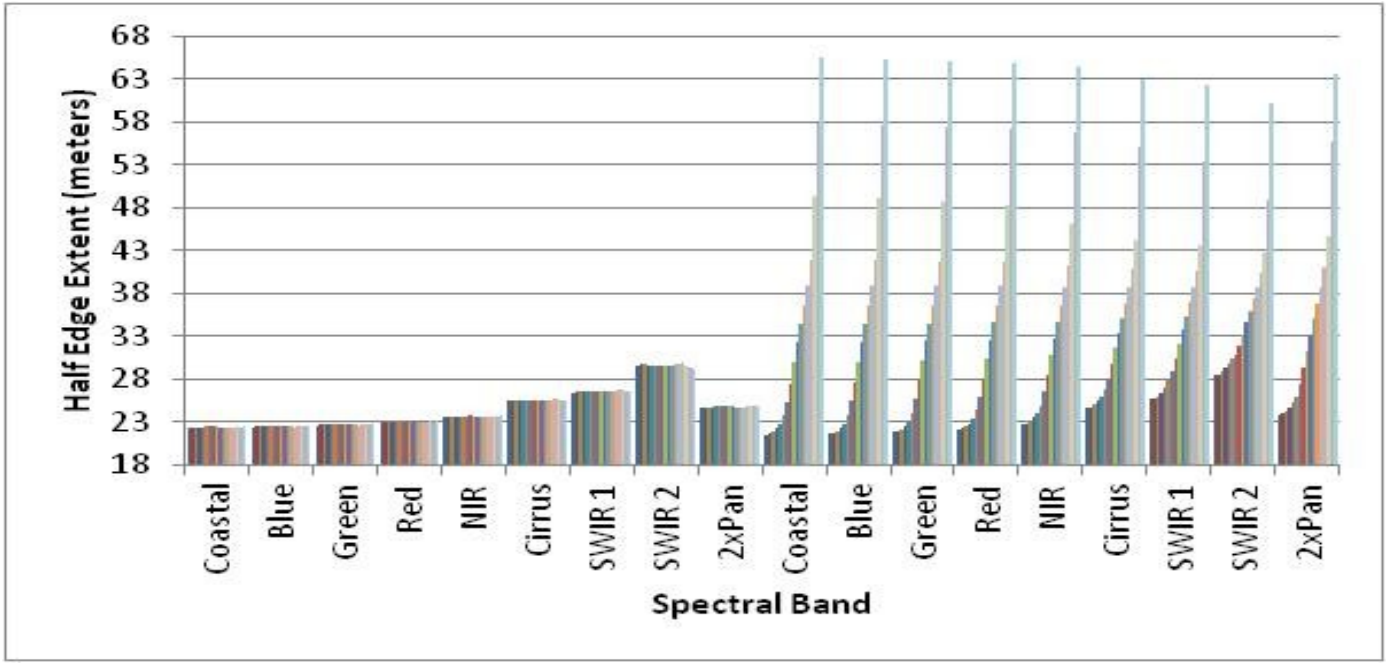
Restored CMTF and Cubic Impact to Relative Edge Response, Along Track



- First 9 groups are CMTF. One group per spectral band.
- Second 9 groups are cubic. One group per spectral band.
- Each group displays results for interpolation distances of 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 13,15,16, 32nds of a pixel
- Pan band results are divided by two for display on same graph as other spectral bands.

Unlike cubic, CMTF enables L1R RER requirements to be met almost all of the time in L1T products.

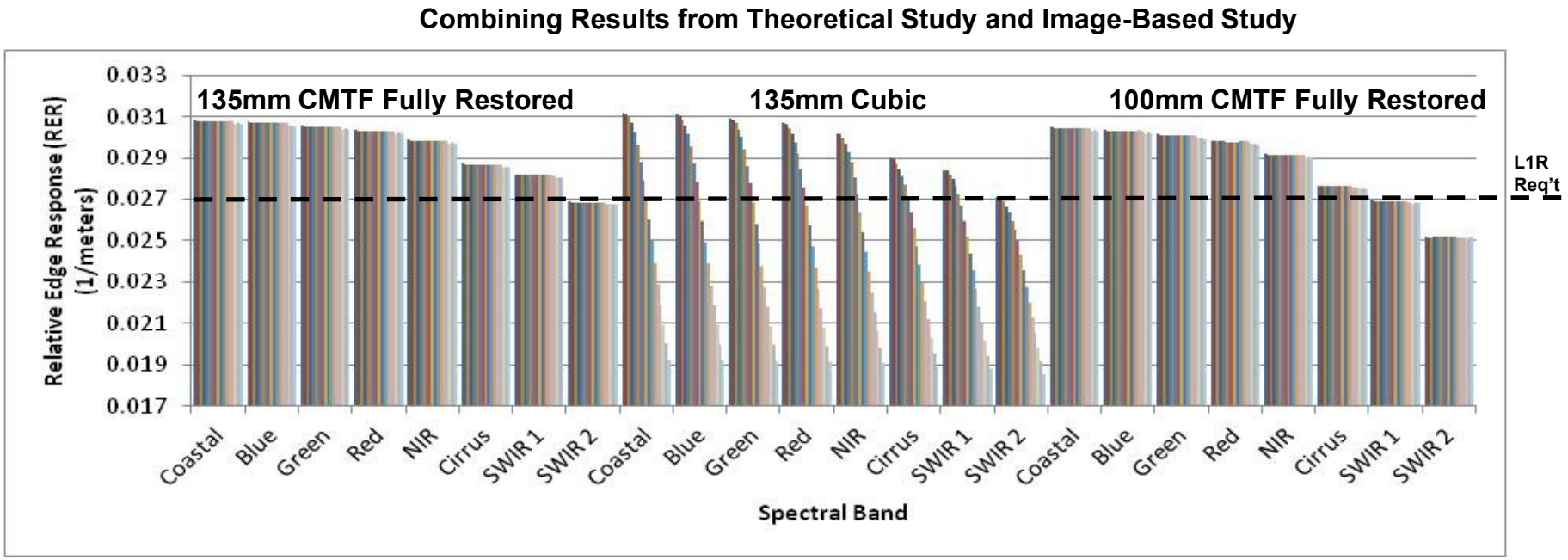
Restored CMTF and Cubic Impact to Half Edge Extent, Along Track



- First 9 groups are restored CMTF. One group per spectral band.
- Second 9 groups are cubic. One group per spectral band.
- **Each group displays results for interpolation distances of 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 13,15,16, 32nds of a pixel**
- Pan band results are multiplied by two for display on same graph as other spectral bands.

Unlike cubic, CMTF enables L1R HEE requirements to be met almost all of the time in L1T products.

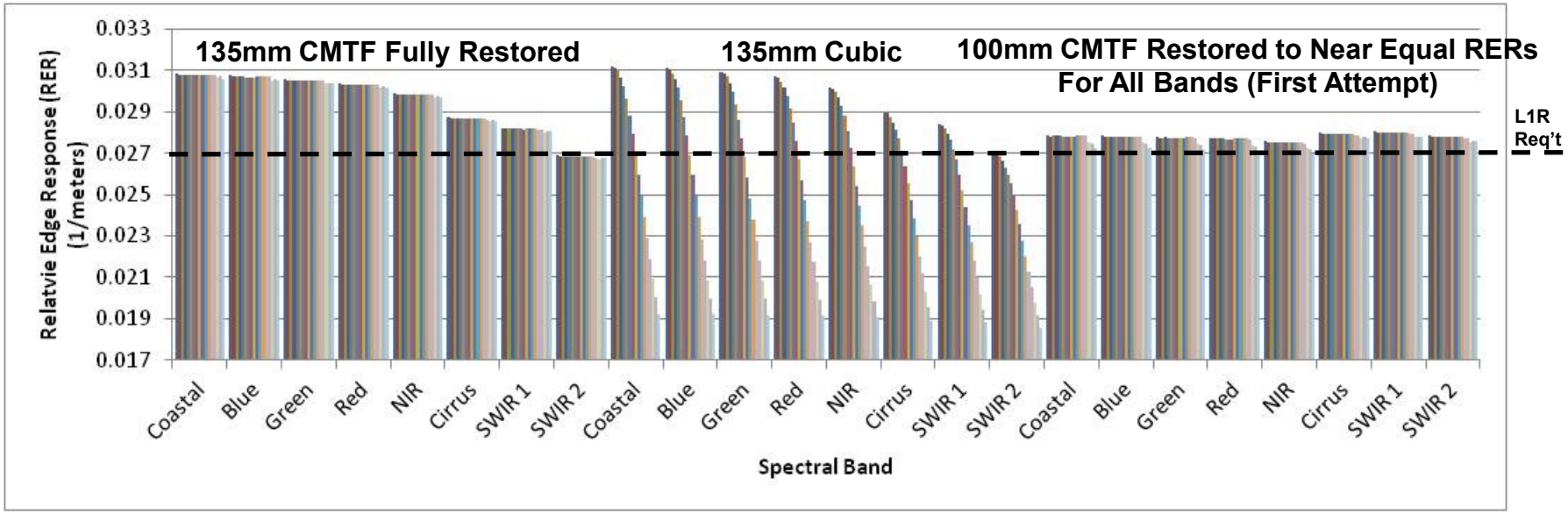
135mm Restored CMTF and Cubic and 100mm Fully CMTF Restored, Along Track



Fully restored CMTF with a 100mm aperture provides larger RER than average RER with Cubic and 135mm aperture.

135mm Restored CMTF, Cubic and 100mm CMTF Restored to Near Equal RERs, Along Track

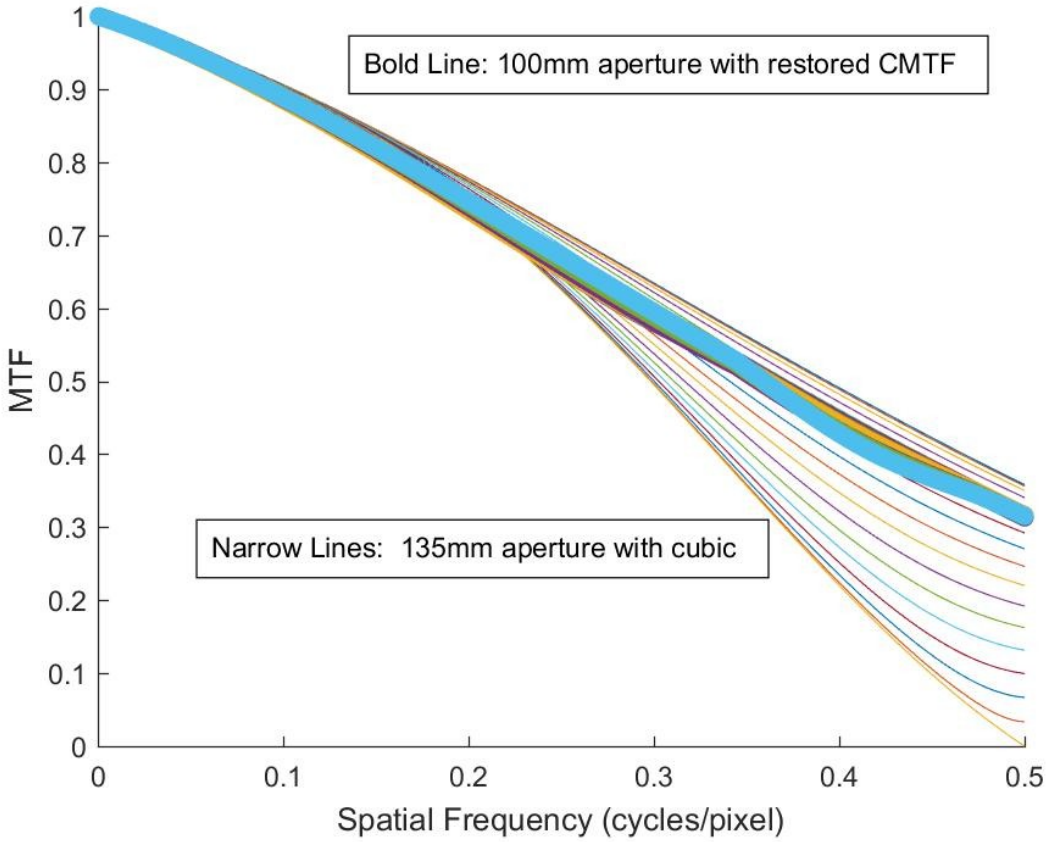
Combining Results from Theoretical Study and Image-Based Study



- **CMTF allows some flexibility to selectively adjust the MTF of the final product.**
- **MTF of different spectral bands can be adjusted independently.**
- **Lowering the RER of the first few bands increases their SNR**
- **Over-restoring or under-restoring CMTF to modify RERs will increase radiometric errors**
  - **Determining the exact impact on SNR and radiometric error for particular RER/MTF characteristics could be performed in follow-on studies.**

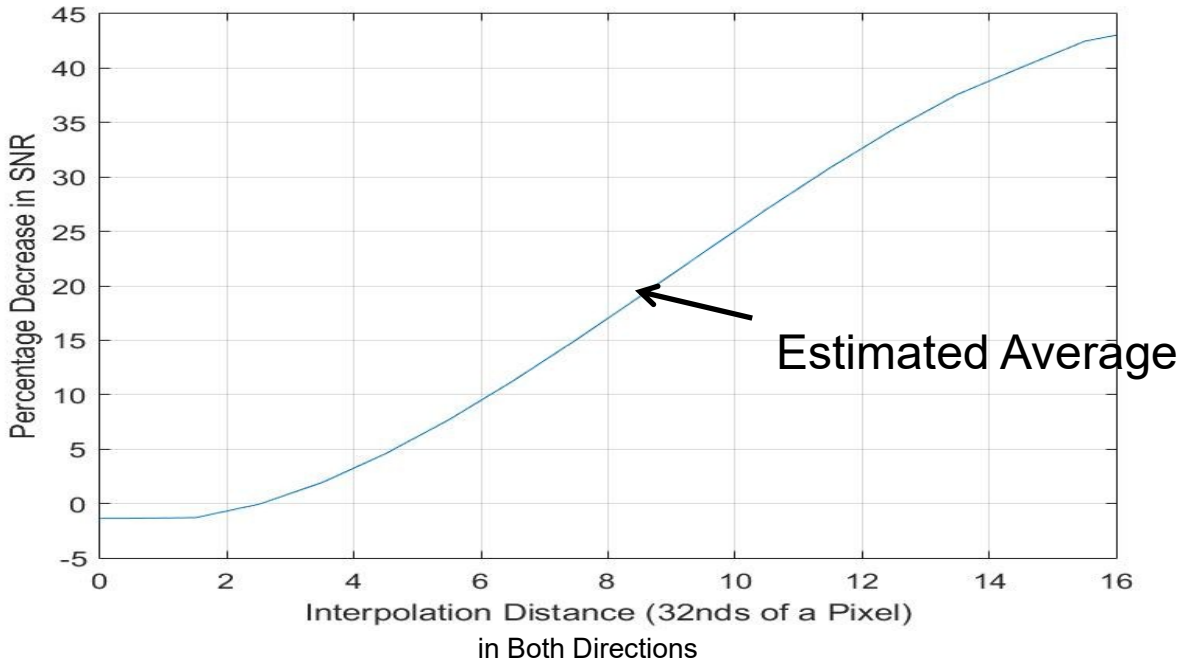
Tradeoffs between RER, SNR and overshoot can be performed to optimize performance.

Comparison of End Product MTFs for Different Apertures and Resamplers



Difference between bold line and top narrow line is essentially the difference in MTFs between unresampled 135mm aperture and 100mm aperture for 2.2um band.

Percent Decrease in SNR Using Fully Restored Bi-CMTF Over Bi-Cubic



- CMTF results in a lower SNR because cubic filters out noise as well as sharp responses
- CMTF results in about the same SNR as the L1R unresampled product.
- SNR with CMTF is slightly higher than in L1R and cubic for 0, 1/32 and 2/32 pixels because CMTF has a slight low pass filtering effect at those distances.
- If CMTF only restored to average cubic MTF, then the average SNR of both will be the same.

Summary

- Resampling is one of biggest drivers of MTF in an instrument.
- CMTF provides the capability to,
  - Minimize system MTF variability
  - Maintain the MTF of a larger aperture system
  - Reduce imager aperture size
    - Reducing aperture size reduces instrument weight and volume.
    - Aperture reduction may require methods to offset the decrease in SNR (e.g. integration time, TDI, etc.)
- Further information on CMTF can be obtained at http://serioussciencellc.com/publications.html or from earlier JACIE proceedings

Placement Error of a Step Function Is Typically Less for CMTF than for Cubic

Placement error is defined as the difference between the desired position of an interpolated Ideal edge and the true position of the edge after interpolation

Note: Placement error increases with MTF. Sharpening increases placement error.