INNOVATIVE IMAGING & RESEARCH

Landsat 8 Per-Pixel Radiometric Uncertainty Algorithm

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Overview and Approach

- Currently developing algorithms to estimate radiometric uncertainties of Landsat 8 L1T and L2 products (OLI and TIRS)
  - Presentation is limited to L1T OLI radiometric uncertainty
  - L8 Cal/Val Algorithm Development Document (ADD) processing algorithms used to calculate partial derivatives and build up uncertainty estimates
- Develop signal-dependent, per-pixel radiometric uncertainty (L1R)
  - Include radiance/reflectance gain uncertainty (SI uncertainties)
  - Integrate updated per-detector radiometric noise model
- Propagate radiometric uncertainty through interpolation (L1T)
  - Landsat resampling algorithm, including intrinsic interpolation errors
  - Coupled radiometric and geometric uncertainty
  - Identify pixels affected by saturation

Landsat, U.S.G.S. "Landsat 8-9 Calibration Validation Algorithm Description Document—Version 3.0, Document Number LDCM-ADEF-001." US Geological Survey: Sioux Falls, SD, USA (2013).

Uncertainty Algorithm – Relationship to Previous Work

- Gorroño et. al developed the S-2 Radiometric Uncertainty Tool (RUT)
  - Emphasized SI traceability based on first principles
  - Produced per-pixel radiometric uncertainty but did not include resampling

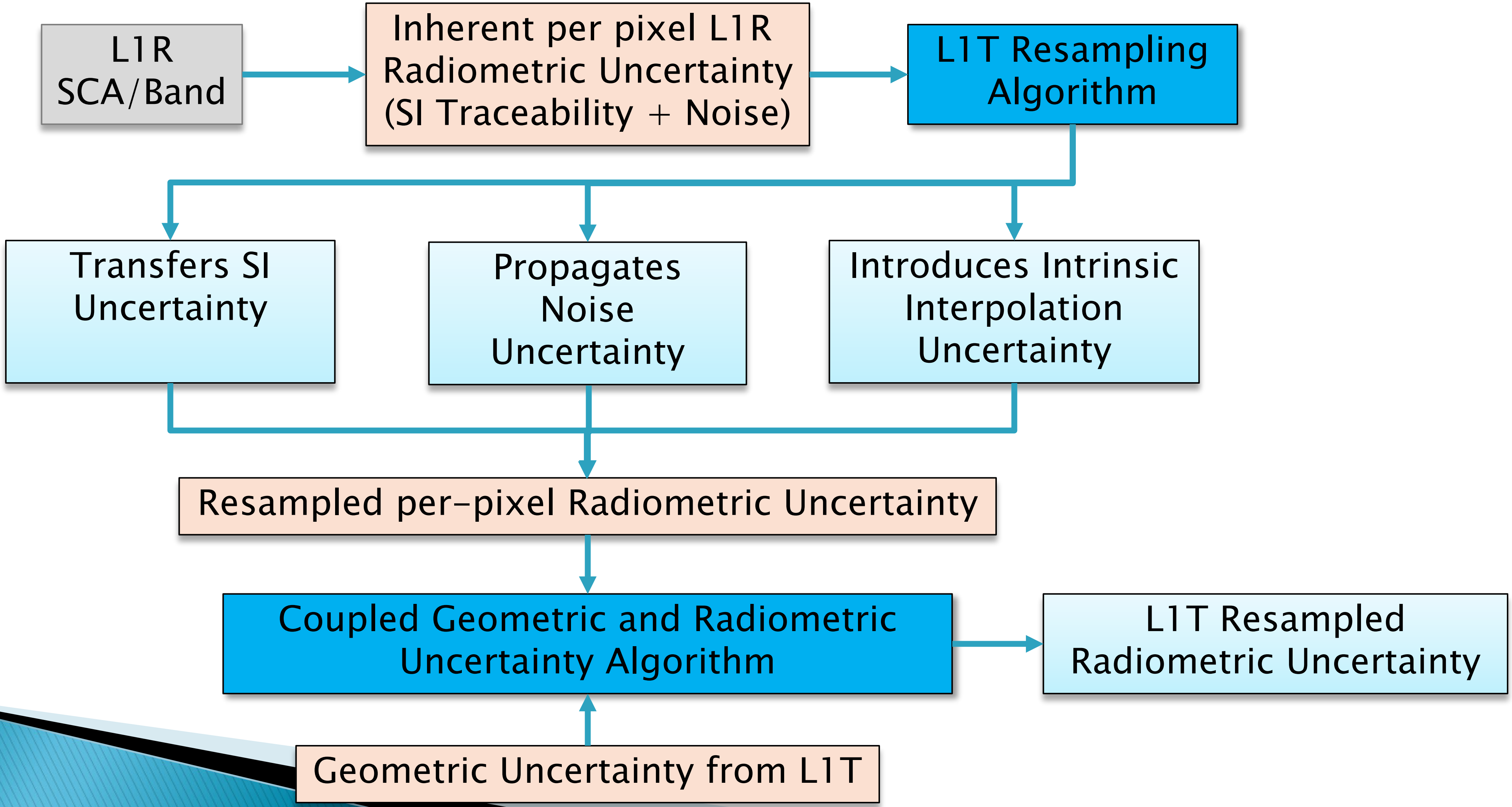
Gorroño, Javier, Ferran Gascon, and Nigel P. Fox. 2015. "Radiometric Uncertainty per Pixel for the Sentinel-2 L1C Products." In Proceedings of SPIE

- Developed a similar uncertainty propagation framework for L8 with additional extensions
  - SI traceability provided by Ball Aerospace
  - Greater emphasis on interpolation related errors
    - Intrinsic interpolation error
    - Sensor noise propagation
    - Coupling of geometric and radiometric uncertainties

ISO Guide to the Expression of Uncertainty of Measurement

$$u^2(y) = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i}\right)^2 u^2(x_i) + \sum_{i=1}^{N} \sum_{j \neq i=1}^{N} \frac{\partial f}{\partial x_i} \frac{\partial f}{\partial x_j} u(x_i, x_j)$$

L1T Radiometric Resampling Uncertainty



When Does Each Component Matter?

- SI radiometric uncertainty
  - Dominant term for most scenes
  - Only driver on uniform scenes
- Sensor noise (e.g., read noise, fixed pattern noise, photon noise, …)
  - Increases with low signal
  - Important for low light level/dark scenes
- Intrinsic interpolation uncertainty and coupled geometric/radiometric uncertainty
  - Larger over strong radiance/reflectance gradients
  - Increases near sharp transitions/features

L1R (Inherent) Radiometric Uncertainty

SI Radiometric Uncertainty

Sensor Noise

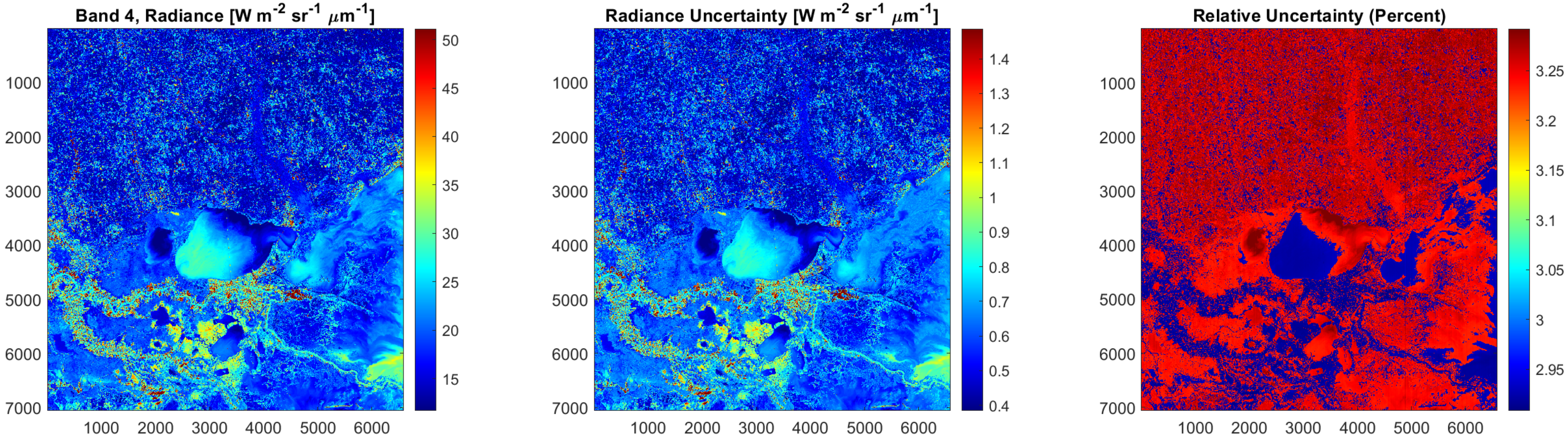
Inherent L1R Per Pixel Radiometric Uncertainty

- OLI L1R radiometric uncertainty combines SI traceable gain uncertainty and radiometric noise model
  - Ball Aerospace provided pre-launch SI traceable uncertainty values depend on image radiance (2.9 – 4.5%) or TOA reflectance (1.7–2.8%)
  - Per-detector radiometric noise radiance dependent model (Most cases <1%)
- OLI inherent radiometric uncertainty can be estimated for L1R radiance or reflectance output

$$u(i,j) = \sqrt{\left(\frac{\rho_{noise}(i,j)}{\rho(i,j)}\right)^2 + (\rho_{SI}(i,j))^2} \quad \text{or} \quad u(i,j) = \sqrt{\left(\frac{L_{noise}(i,j)}{L(i,j)}\right)^2 + (L_{SI}(i,j))^2}$$

where,
u = relative radiometric uncertainty
i, j = L1R pixel position
ρ, L = input reflectance or radiance
ρ_{noise}, L_{noise} = reflectance or radiance noise
ρ_{SI}, L_{SI} = reflectance or radiance SI gain uncertainty

L1R TOA Radiance Uncertainty (Inherent)



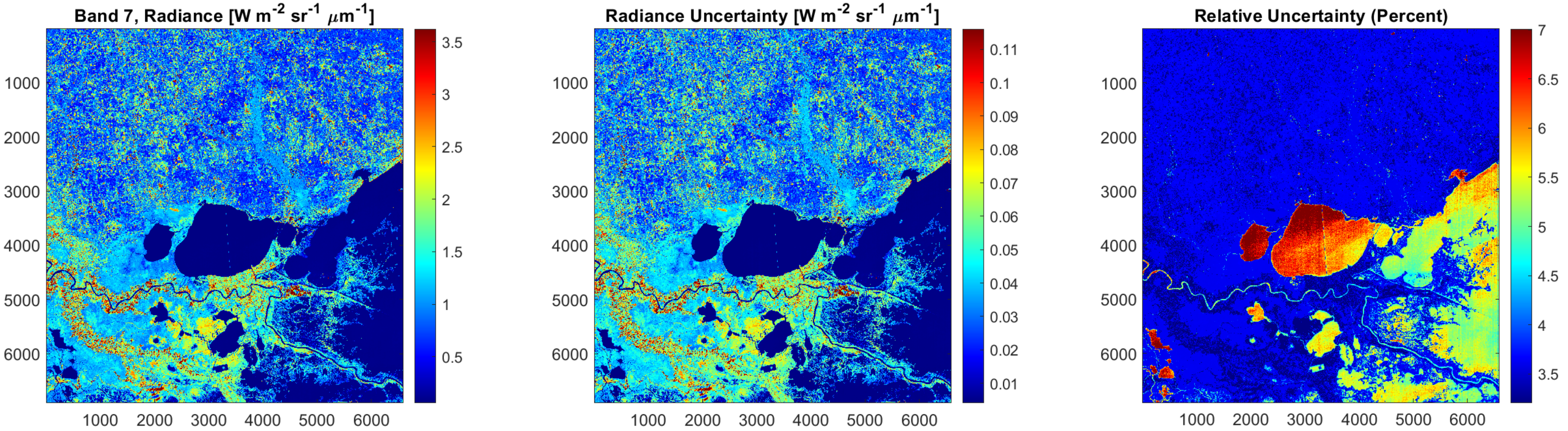
Band 4 $L_{typical}$=22 $Wm^{-2}sr^{-1}um^{-1}$

SI radiance uncertainty at/above $L_{typical}$ = 2.9%
SI radiance uncertainty below $L_{typical}$ = 3.3%

SI uncertainty dominates throughout the scene

Lake Pontchartrain P22/R39 - Red (Band 4)
TOA Radiance Absolute and Relative Uncertainty

L1R TOA Radiance Uncertainty (Inherent)



Band 7 $L_{typical}$ radiance = 1.7 $Wm^{-2}sr^{-1}um^{-1}$
(corresponds to reflectance = 0.0633)

SI radiance uncertainty at/above $L_{typical}$ = 3.2%
SI radiance uncertainty below $L_{typical}$ = 3.6%

Low signal in SWIR shows increased relative uncertainty due to noise

Lake Pontchartrain P22/R39 - SWIR2 (Band 7)
TOA Radiance Absolute and Relative Uncertainty

Resampling Uncertainty

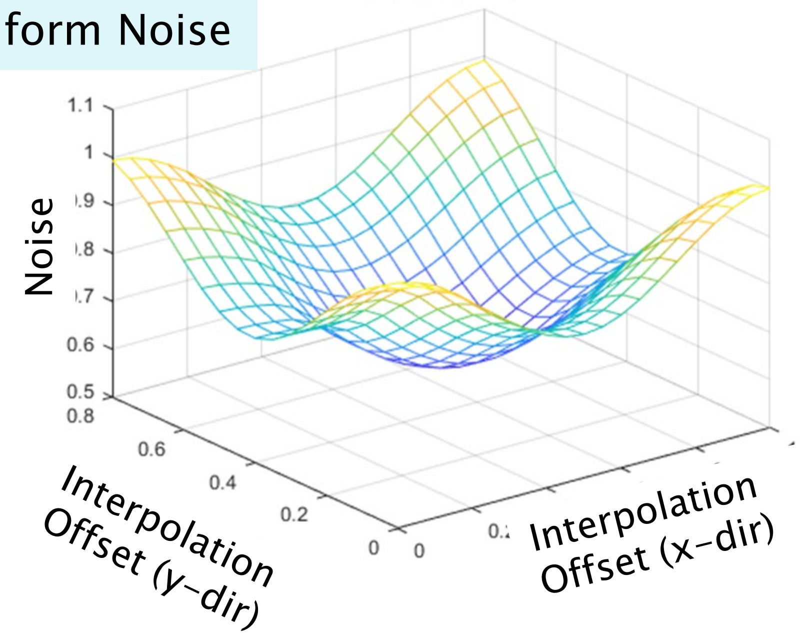
SI Uncertainty Transfer

Noise Uncertainty Propagation

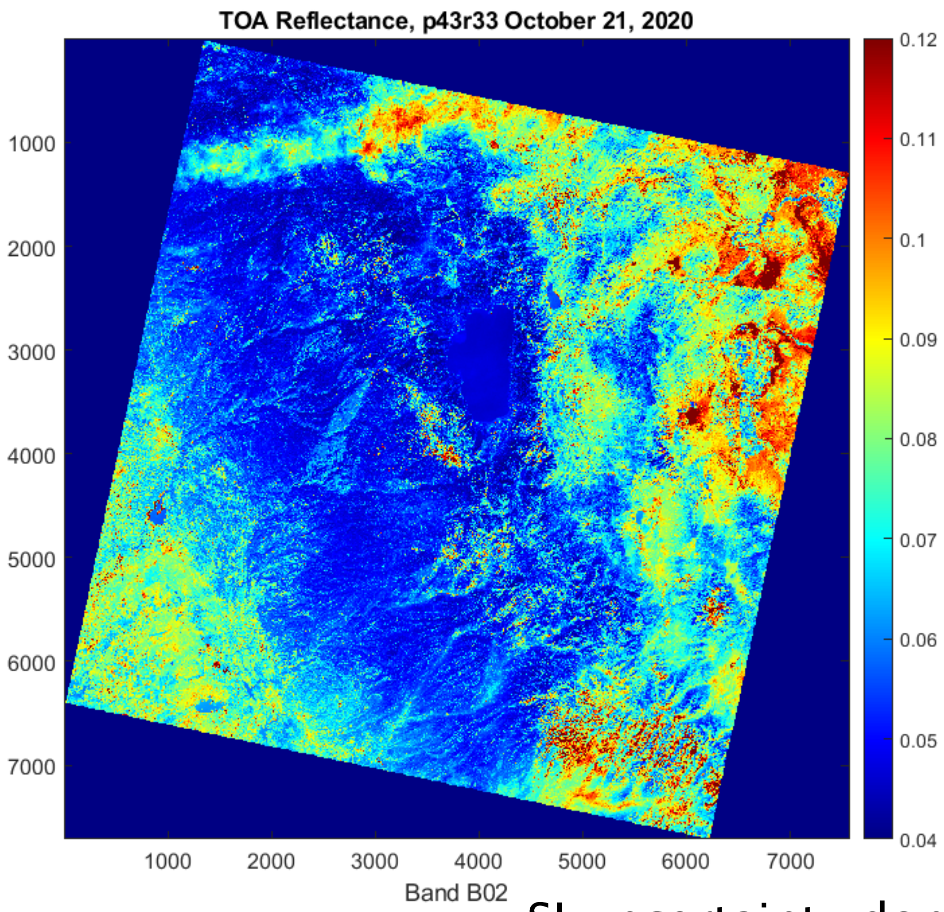
Sensor Noise Propagated through Resampling

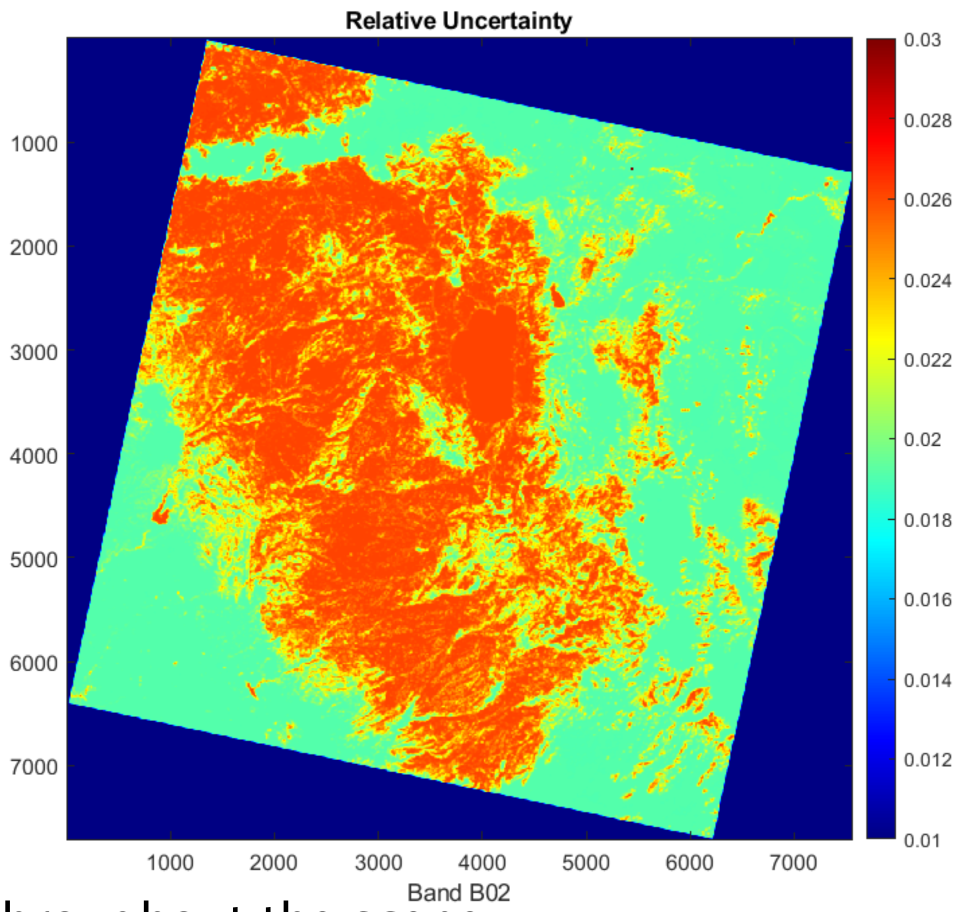
- Landsat 8 L1R data is resampled to L1T using cubic convolution (in the line or in-track direction) followed by modified Akima (in the sample or cross-track direction) interpolation
  - 24 pixels are used in the interpolation
  - Interpolation offsets and kernel weights are defined for every pixel

Interpolated Uniform Noise



Resampled Radiometric Uncertainty –TOA Reflectance (SI and Propagated Noise)

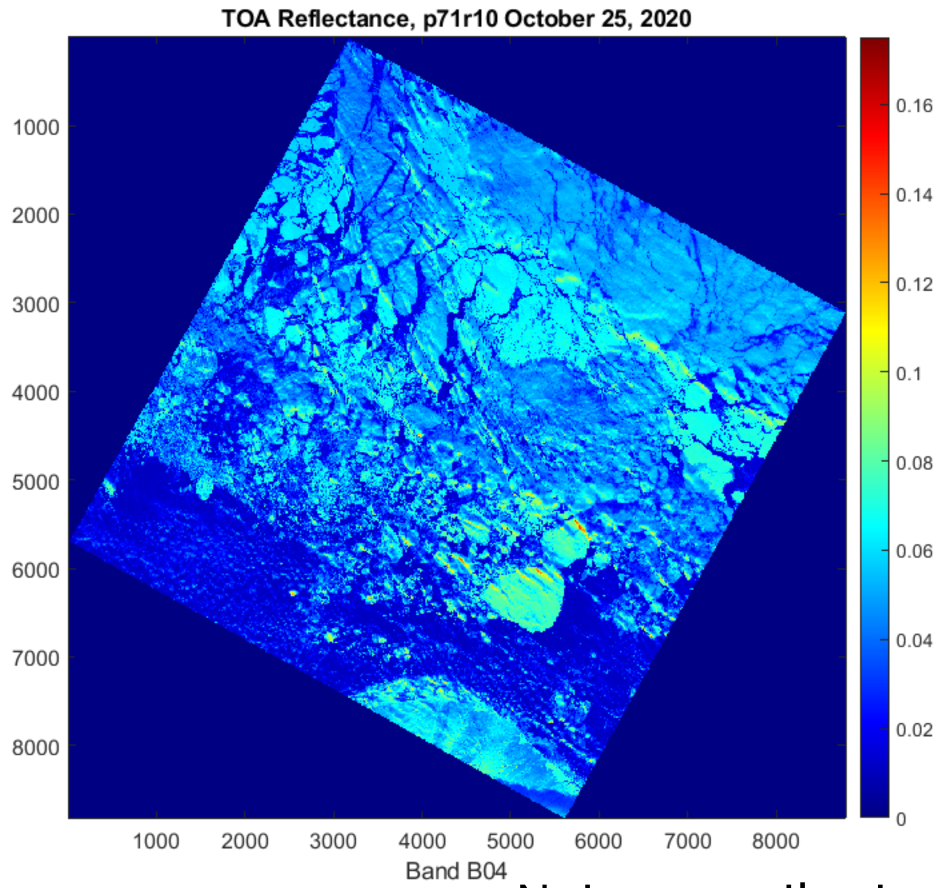


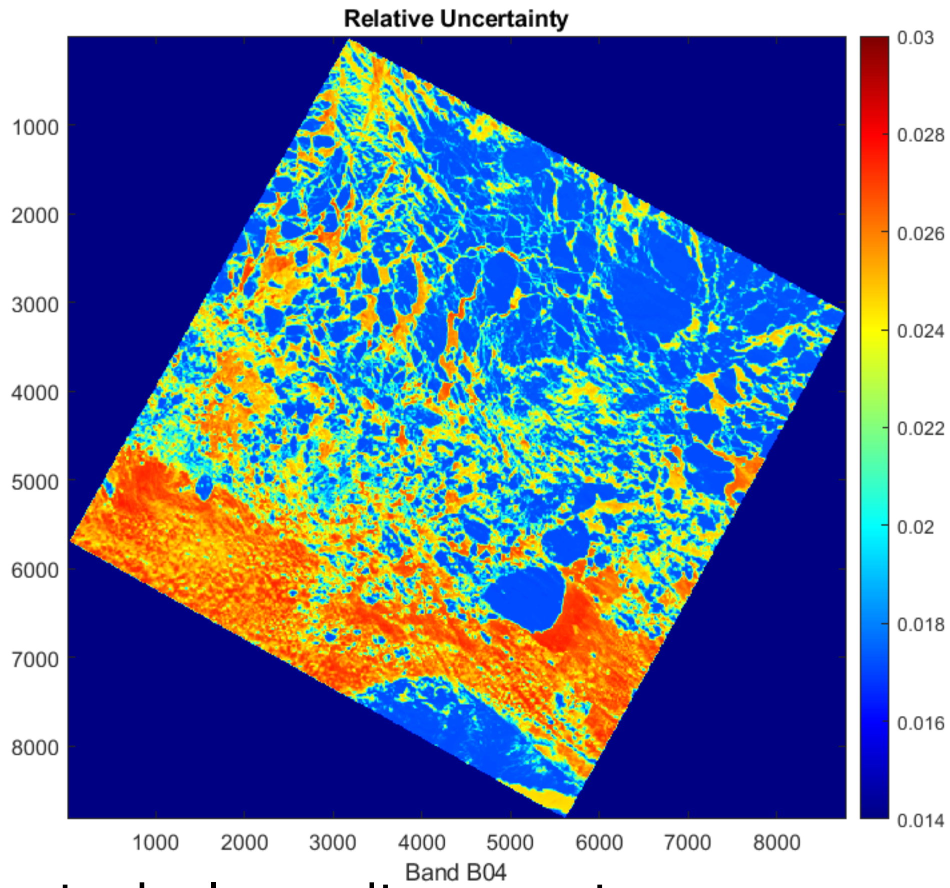


SI uncertainty dominates throughout the scene

Lake Tahoe P43/R33 - Blue (Band 2)

Resampled Radiometric Uncertainty –TOA Reflectance (SI and Propagated Noise)





Noise contribution apparent in the low radiance region

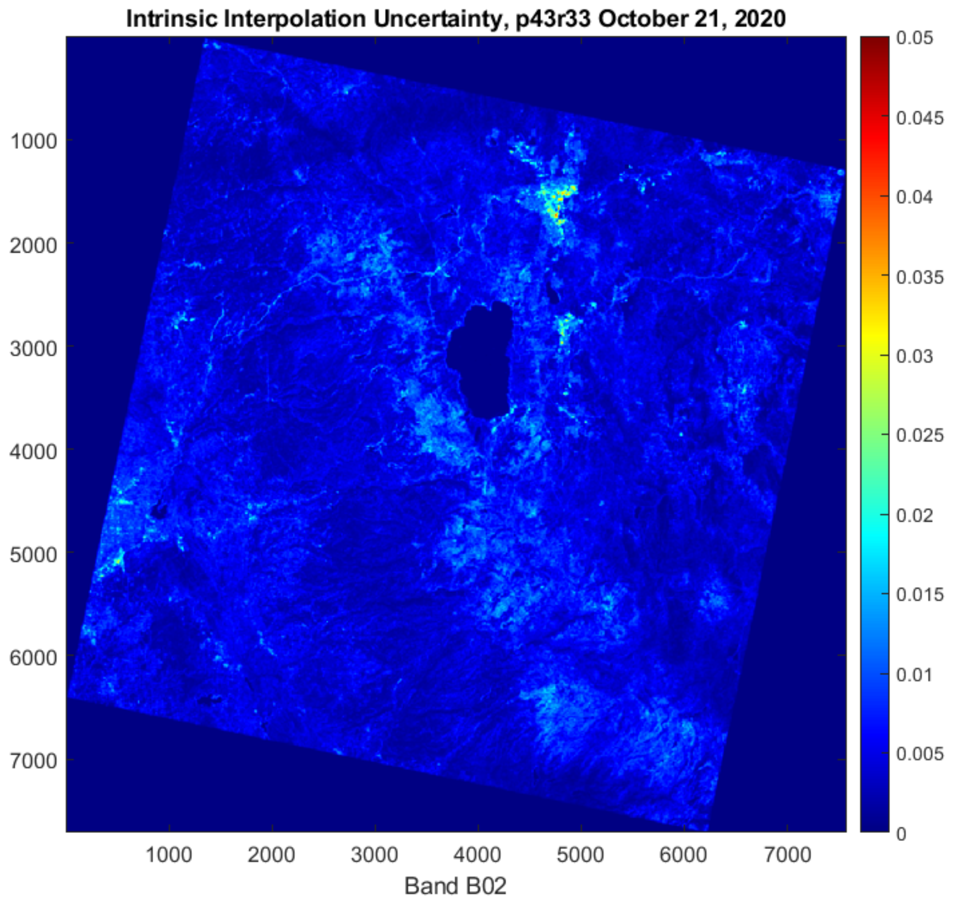
Artic North of Alaska P71/R10 - Red (Band 4)

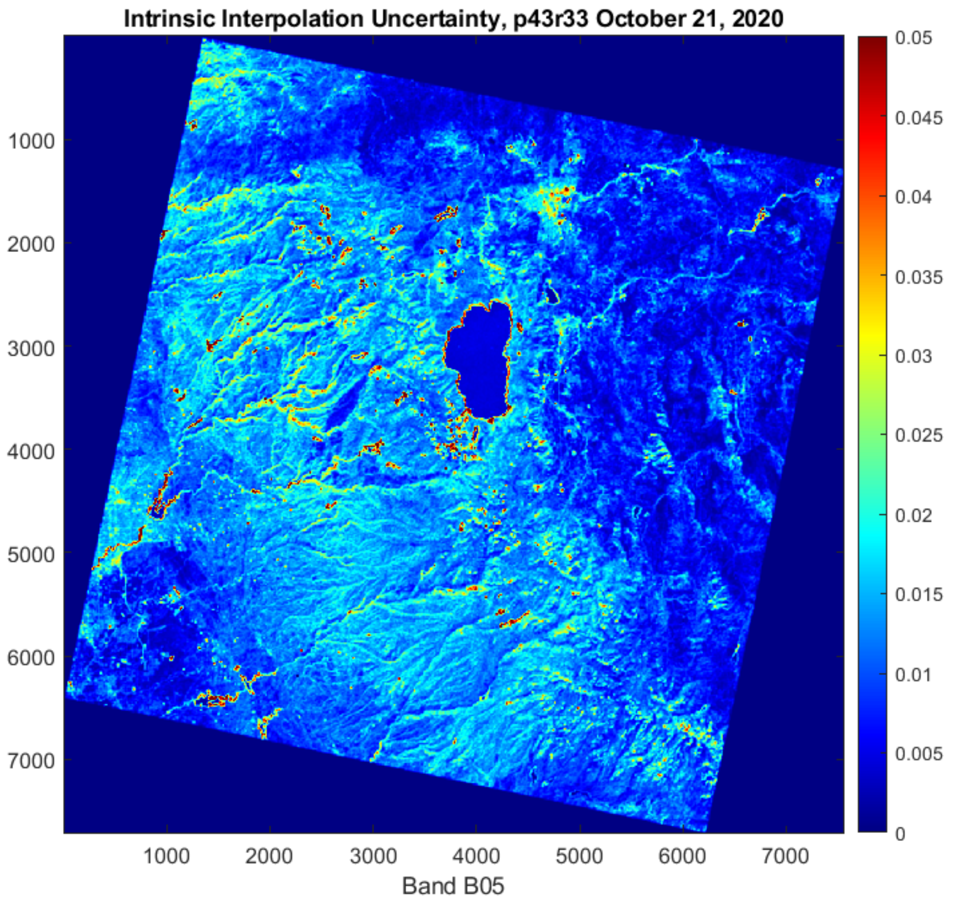
Intrinsic Interpolation Uncertainty

Intrinsic Interpolation Uncertainty Overview

- There is an inherent uncertainty in the estimation of values using interpolation
  - Interpolation errors are dependent on interpolator, signal shape (which is not known), interpolation offset and sampling
    - Large errors occur for rapidly changing regions (edges) due to large slopes and aliasing
  - Modified Akima (uneven spacing) and cubic convolution interpolator uncertainties are different due to mathematical formulation
- Built an uncertainty model to populate a look-up-table (LUT) based on the slopes of the intervals of each interpolator

Intrinsic Interpolation Example





Lake Tahoe P43/R33 - Blue Band 2 (left) and NIR Band 5 (right)

Coupled Geometric and Radiometric Uncertainty

Coupled Geometric and Radiometric Uncertainty

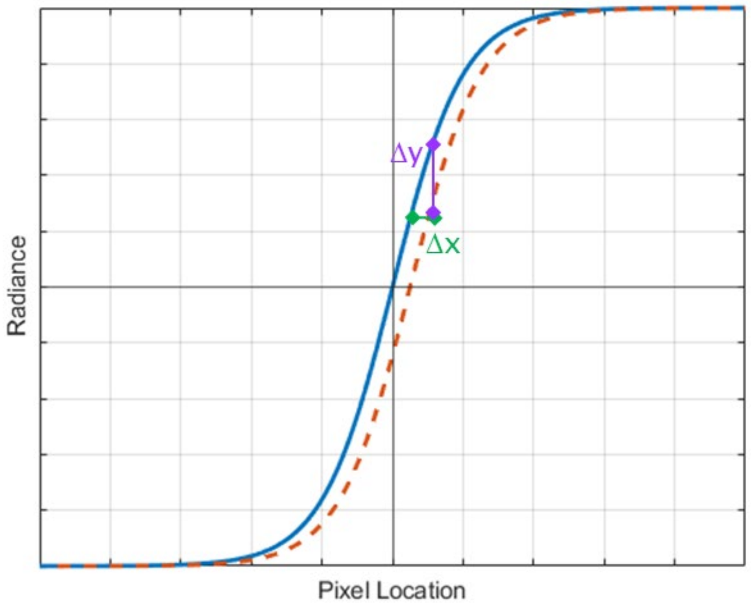
- Although each image is orthorectified, there are differences between different acquisitions of the same path/row
  - Estimated by L1T geometric uncertainty
- Geometric differences affect the interpolation of the L1R data and the estimation of radiometric uncertainty
  - Expect larger effect around features such as edges
- The coupled geometric and radiometric uncertainty is what geometric uncertainty introduces to the radiometric uncertainty during interpolation
  - Combines geometric uncertainty with the gradient of L1T image

Coupled Geometric And Radiometric Uncertainty

- The radiometric uncertainty due to positional variation is estimated as the product of the geometric uncertainty and the slope of the data (the gradient of the image)
  - There are two directional terms for positional displacement, dx and dy, and two directional terms in the gradient, $(\partial\rho/\partial x)$ and $(\partial\rho/\partial y)$

$$u_{coupled} = \sqrt{\left(\frac{\partial\rho}{\partial x}dx\right)^2 + \left(\frac{\partial\rho}{\partial y}dy\right)^2}$$

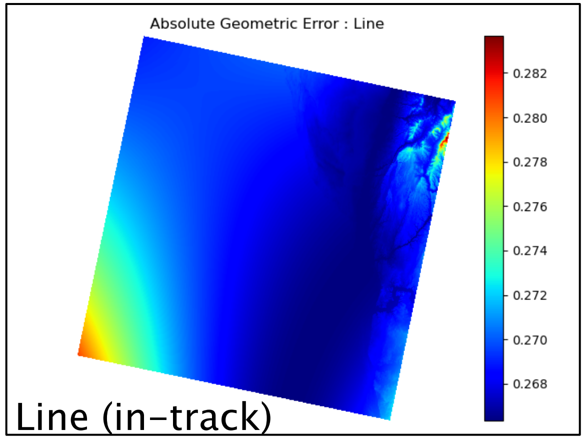
Coupled Uncertainty of an Edge

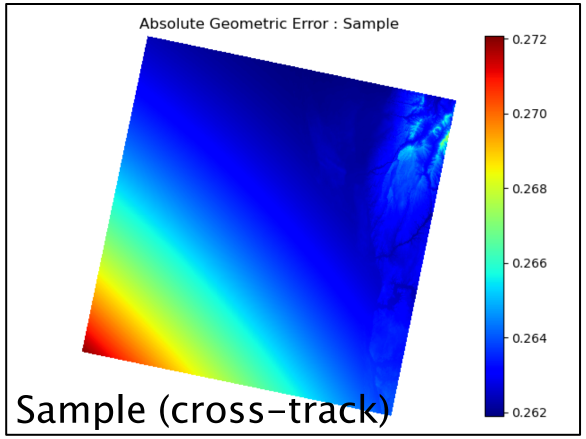


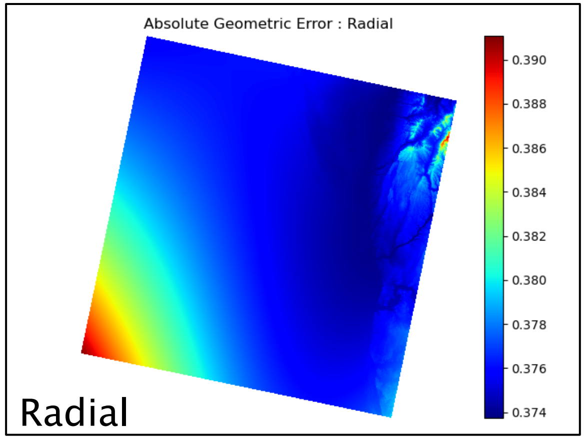
Geometric Uncertainty

- A geometric uncertainty algorithm was developed that uses GCPs directly from the Image Assessment System (IAS)
  - Produces absolute and relative geometric uncertainty

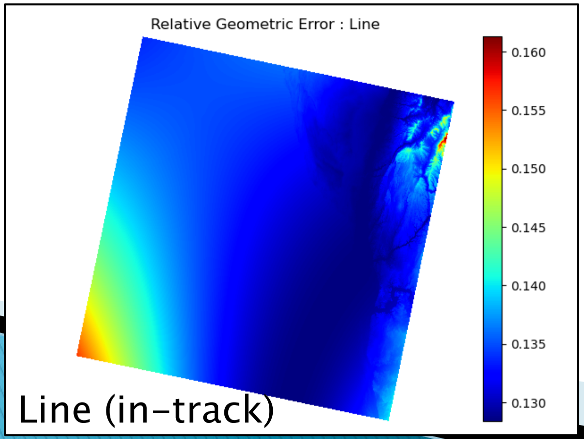
Absolute Geometric Uncertainty

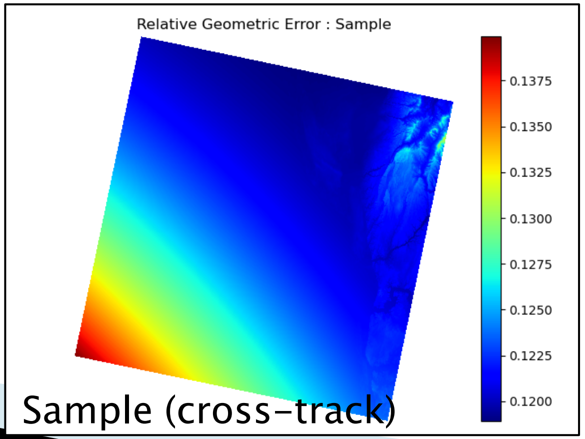


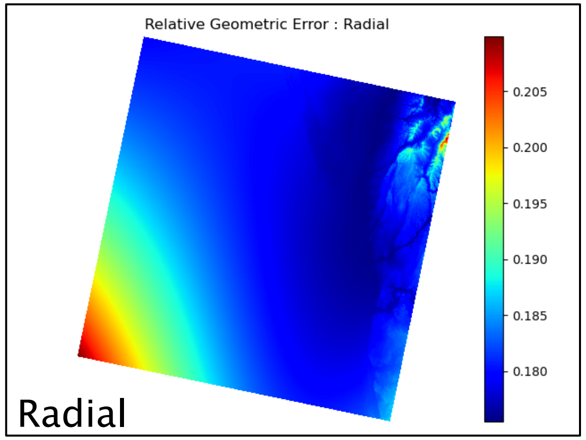




Relative Geometric Uncertainty

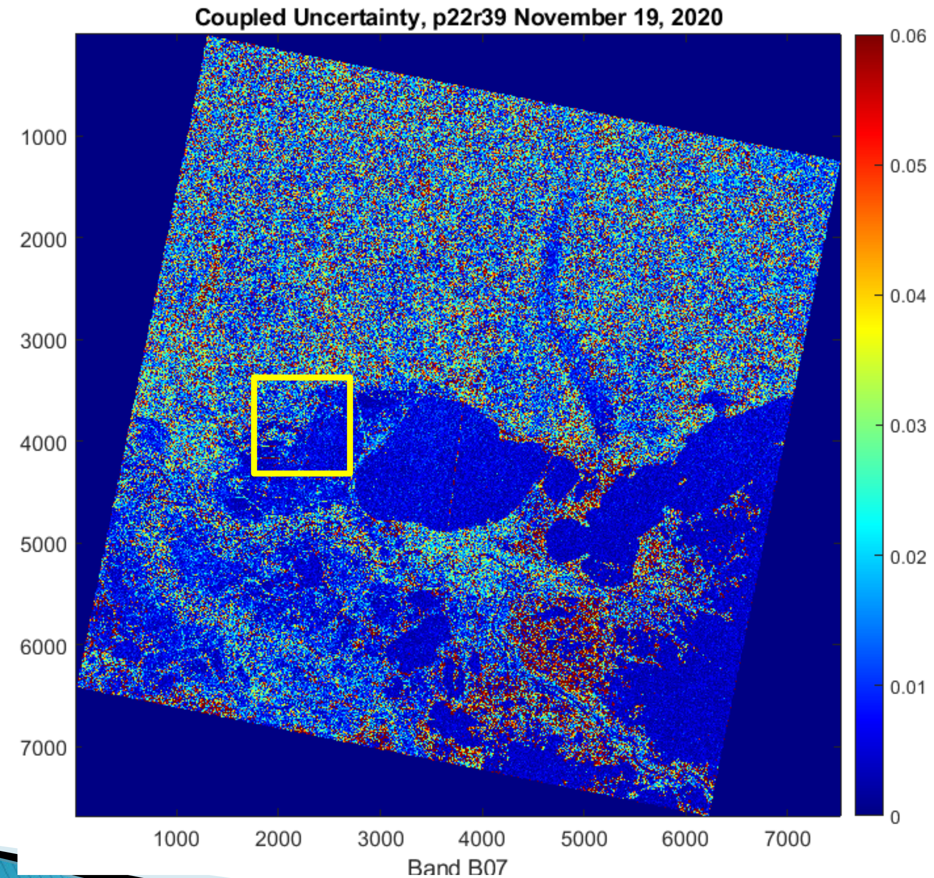


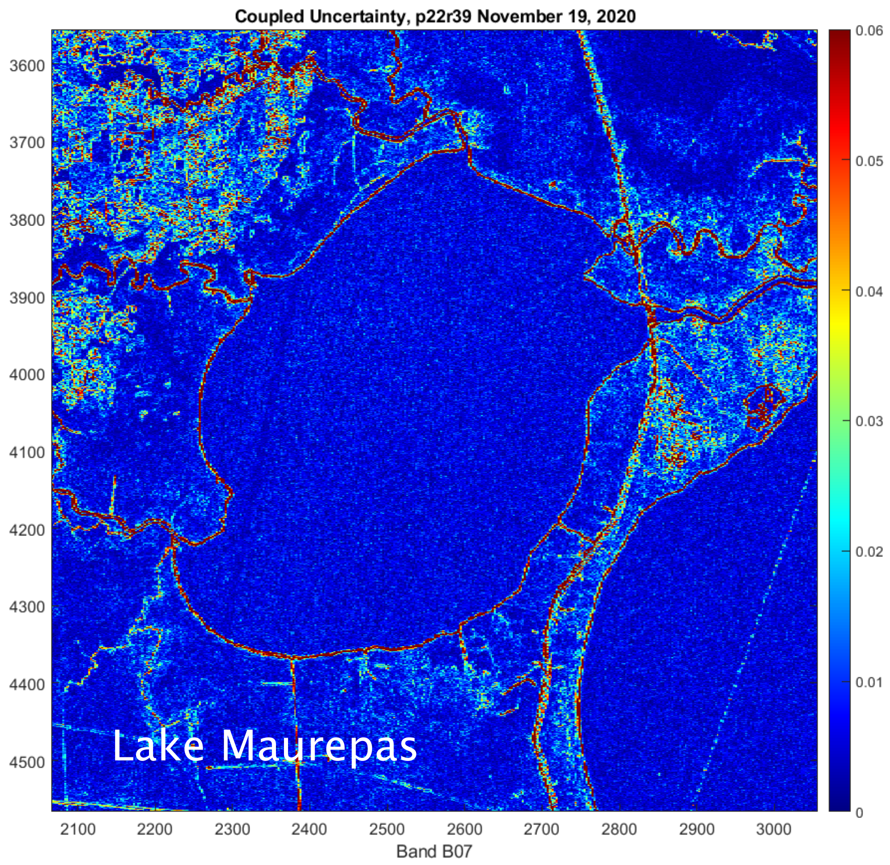




Coupled Geometric and Radiometric Uncertainty

Lake Pontchartrain P22/R39 - SWIR 2 (Band 7)





Combined L1T Radiometric Uncertainty

Combined L1T Radiometric Uncertainty

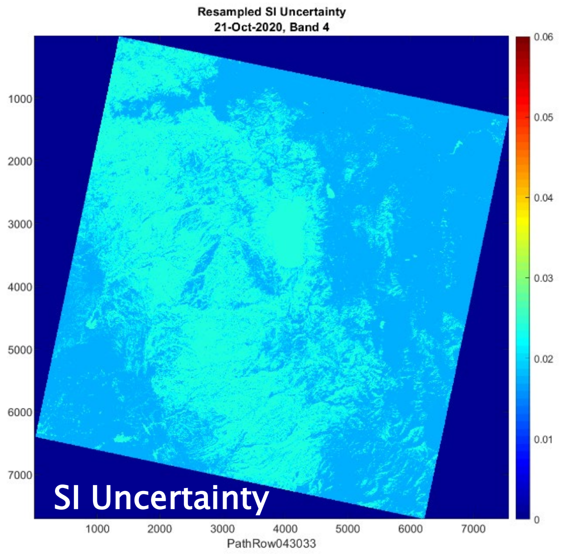
- The final radiometric uncertainty is the combination (root sum of the squares) of the uncertainty from all sources

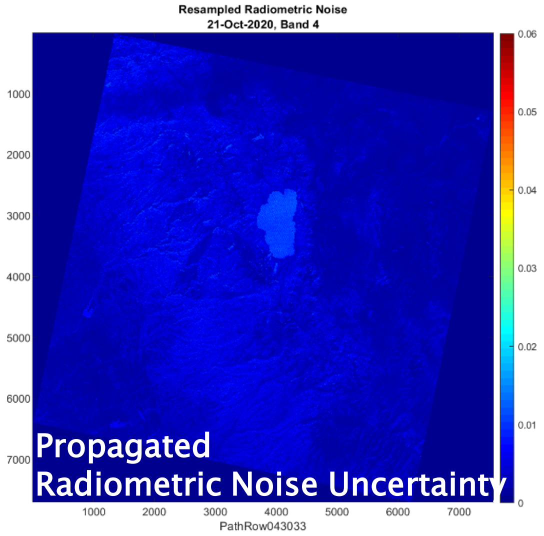
$$\sigma_{total} = \sqrt{\sigma^2_{SI\ uncertainty} + \sigma^2_{noise} + \sigma^2_{intrinsic} + \sigma^2_{coupled}}$$

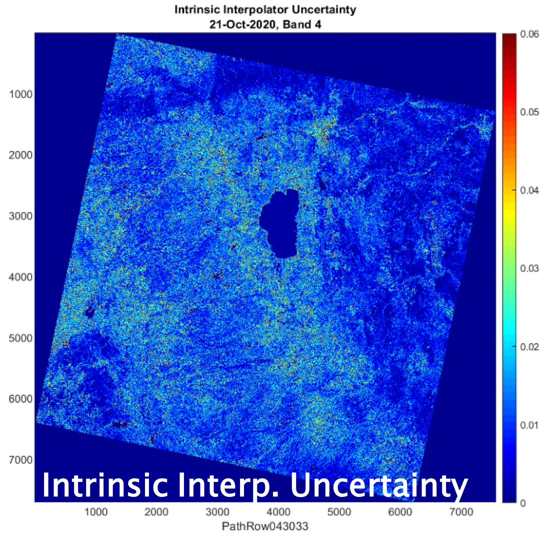
Where:

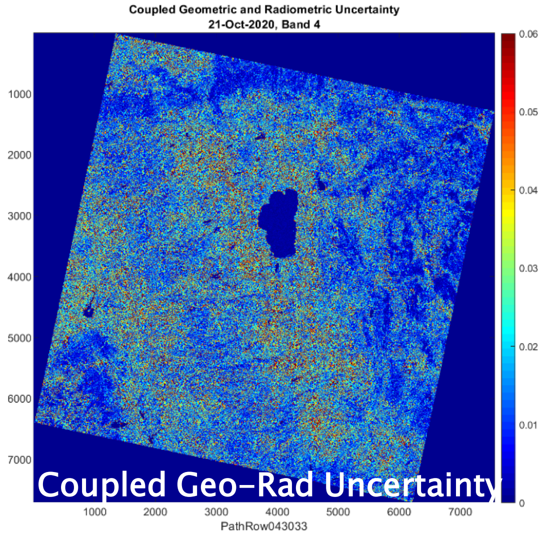
$\sigma_{SI\ uncertainty}$ = SI uncertainty
σ_{noise} = Resampled sensor noise
$\sigma_{intinstic}$ = Intrinsic interpolation uncertainty
$\sigma_{coupled}$ = Coupled geometric and radiometric uncertainty

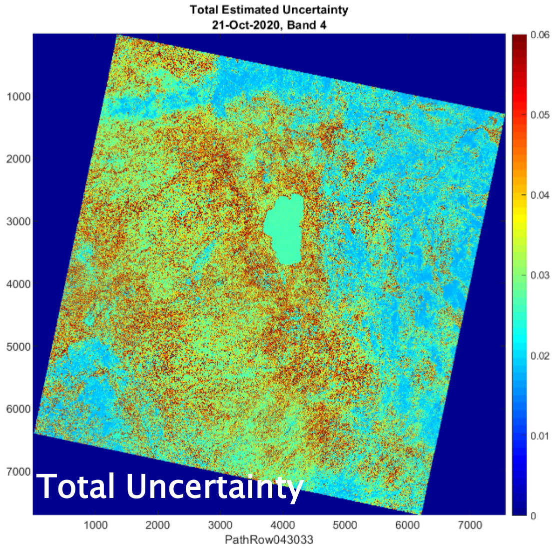
Uncertainty Component Images











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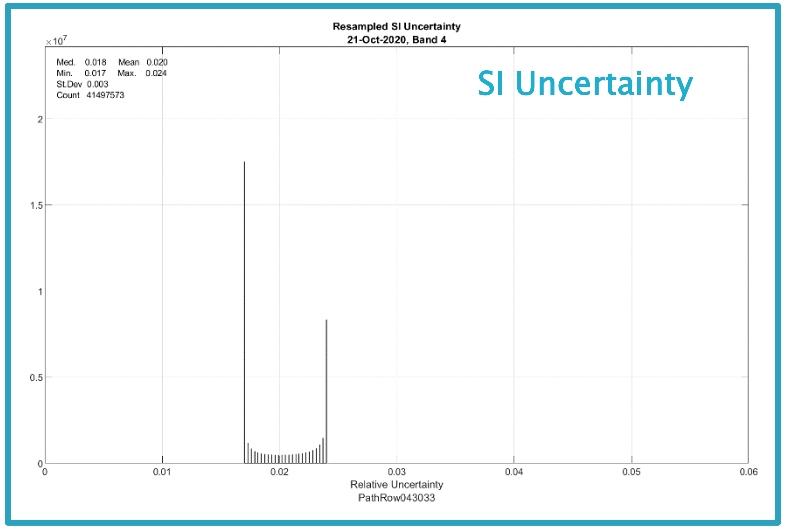
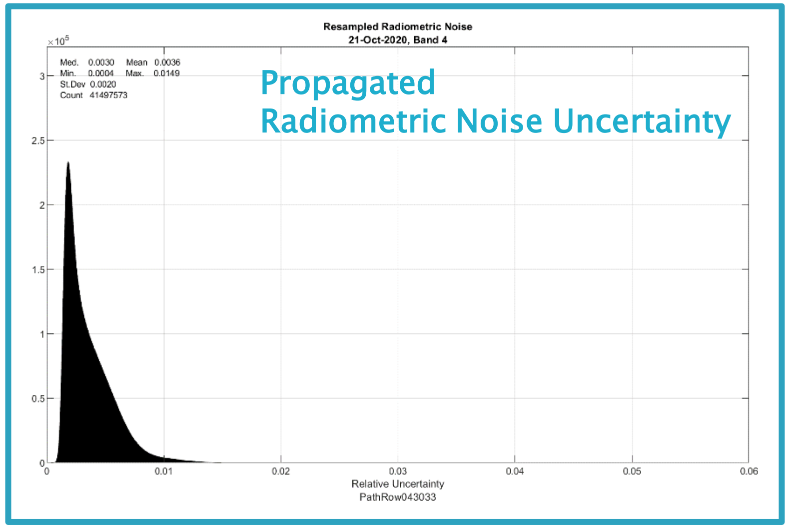
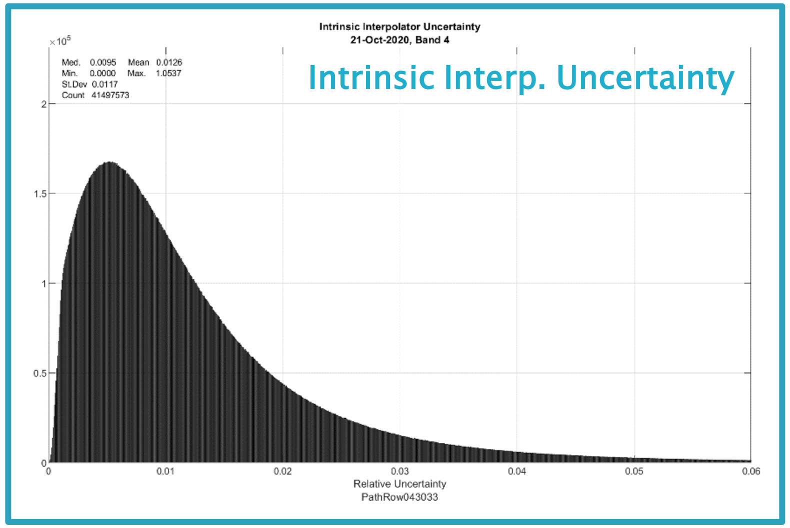
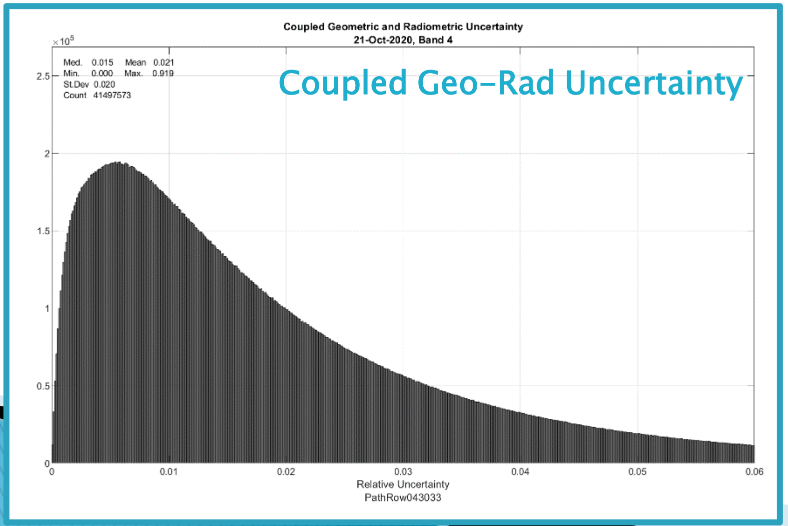
Red (Band 4)

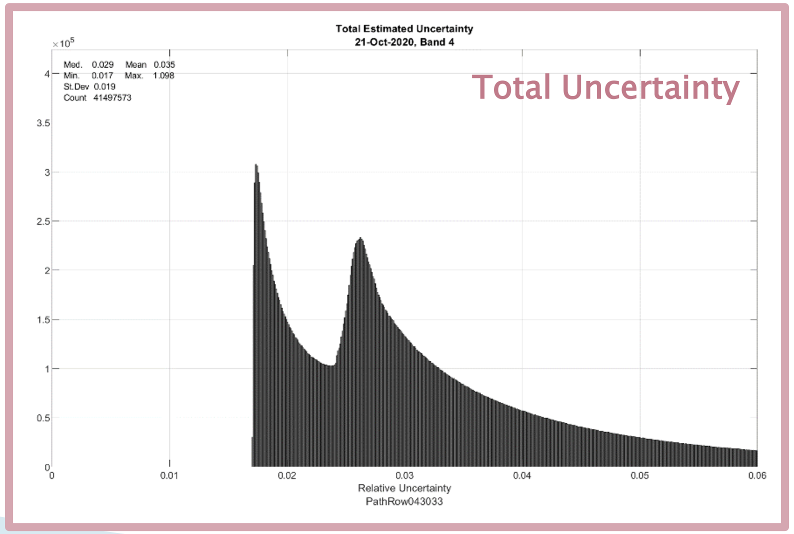
Uncertainty Component Histograms











P43/R33
October 21, 2020
Red (Band 4)

L1T Radiometric Pixel Uncertainty Summary

- An initial L1T radiometric pixel uncertainty algorithm is being developed with a goal to help users better understand uncertainties
  - Algorithms being developed for OLI and TIRS L1T products
  - Validation is underway, but not complete
  - Aliasing has not been directly considered, but is indirectly included in the intrinsic interpolation uncertainty (in-progress)
    - OLI simulations using high resolution imagery such as WorldView can be used to understand impact of aliasing for different feature types
- The algorithm is being expanded to address L2 processing

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