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Airborne Hyperspectral Activities at the NRC Flight Research Laboratory

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IDEAS+ L1 Meeting

Davos, Switzerland

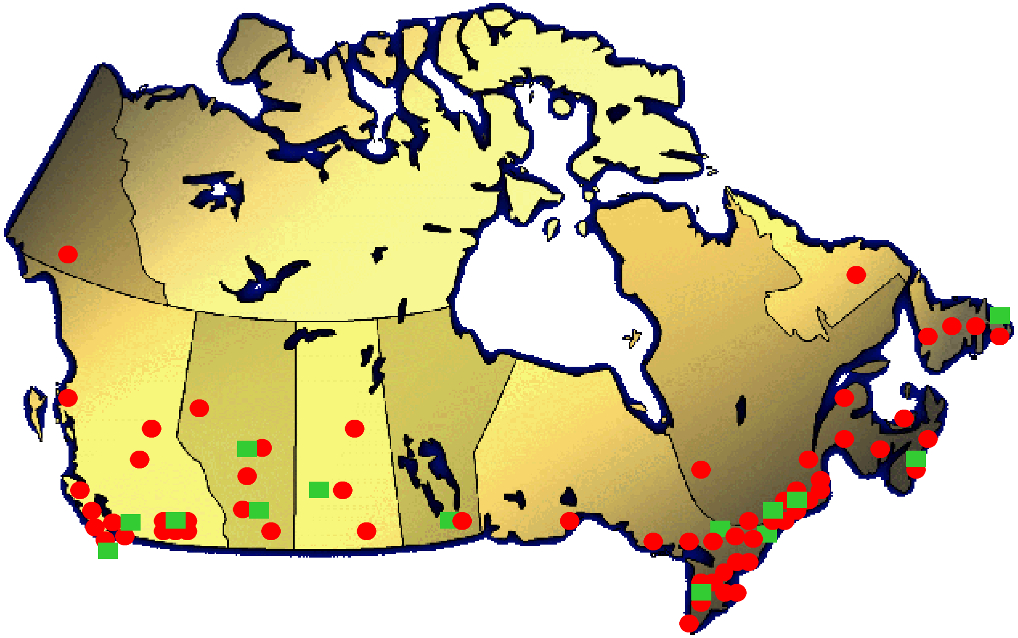
Dec 8 - 9, 2015

Outline

- NRC / Aerospace / Flight Research Lab. / Airborne Research
- Airborne Hyperspectral at FRL – CASI / SASI
- Hyperspectral Imagery Calibration Issues
  - Spectral Calibration / Alignment
  - SpectroRadiometric Calibration
    - EO, DC, FSS, SL, DL
  - Geometric Calibration Approach/Assessment
  - SNR Modelling and Assessment
- Field Spectroscopy
  - Measurement issues
  - Reference panel calibration
- Mission Planning
  - CASI/SASI pixel spacing/resolution
  - Time of Day (SZA) considerations

National Research Council of Canada (NRC)

- Federal Government Agency
- 4,500 full-time employees, 1,000 guest workers
- Labs and facilities across Canada
- Network of technology advisors to support small business



Mandate: "The Council has charge of such matters affecting scientific and industrial research in Canada as may be assigned to it by the Governor in Council"

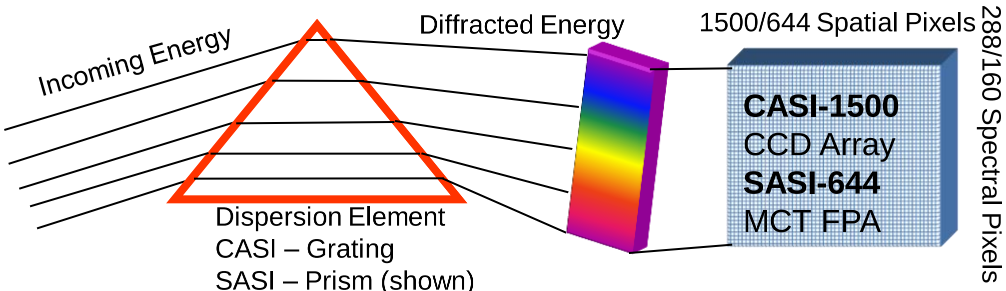
Flight Research Laboratory (Aerospace Portfolio)
Our Aircraft Fleet

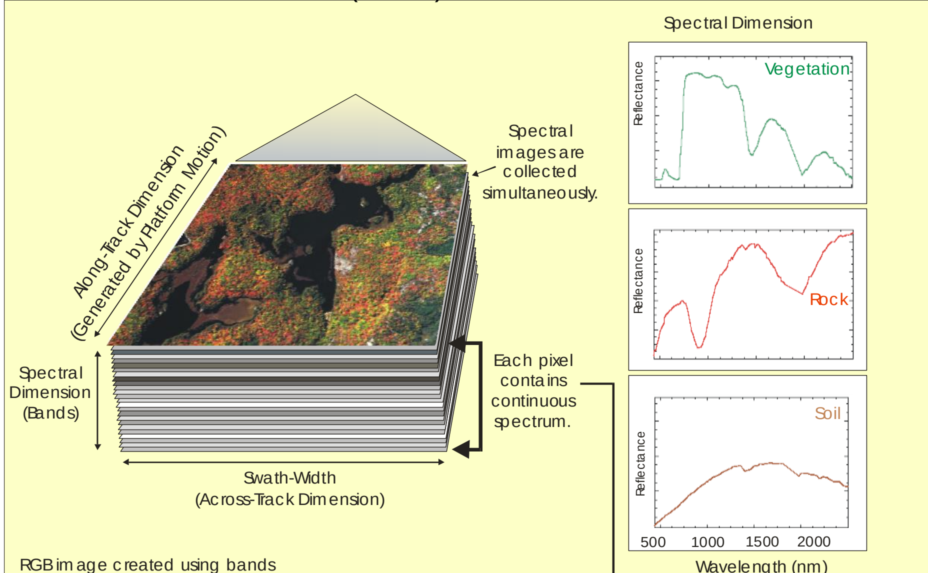
Airborne Hyperspectral Capability

CASI-1500 Compact Airborne Spectrographic Imager	SASI Shortwave Airborne Spectrographic Imager
Vis/NIR (365 nm - 1050 nm)	SWIR (850 nm - 2500 nm)
Pushbroom	Pushbroom
39.9 degree FOV	39.7degree FOV
1.2 mrad IFOV	1.14 mrad IFOV
f3.5 - f18.0	f1.8
1500 spatial pixels	644 spatial pixels
288 spectral channels	160 channels
14 bit	14 bit
Variable Frame Rate	16.7 ms Frame Rate
CMIGIT III GPS/INS	CMIGIT III GPS/INS

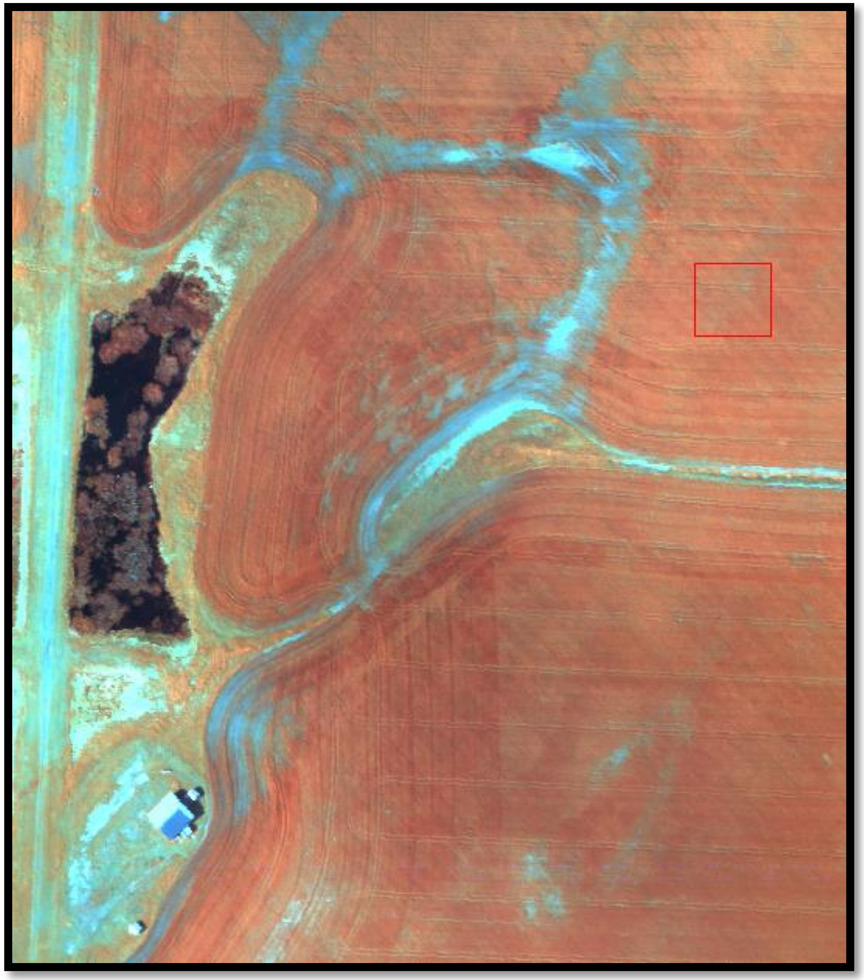
Hyperspectral Process

Spectral method: recording the reflected radiation from a target with a CCD or FPA





RGB image created using bands corresponding to wavelengths: R-650, G-557, B-465 nm.



Georectified Shortwave Infrared image with R = 1051nm, G = 1623nm and B =2121 nm.

Hyperspectral History at FRL

2001

- Hyperspectral activities started by George Leblanc with a couple of students and borrowed data sets
  - "Precise Ferrous Mineral Species Identification with Airborne Hyperspectral and Aeromagnetic Data"

2002

- Funding obtained for the purchase of a Shortwave infrared Airborne Spectrographic Imager (SASI)
- Order placed with ITRES Research Ltd for a customized SASI

2003

- SASI received
- SASI installed on Convair 580

2004 – 2007

- Problems identified in spectroradiometric calibration process
  - Solutions eventually identified and developed with ITRES
- Bundling process to perform Geometric Correction, as developed by ITRES, implemented and tested

2007

- **22" belly port** installed in Twin Otter
- Twin Otter rack built to co-install CASI sensor head along side the SASI

2008

- **SASI ready for project deployment!**
- York University CASI (original model) co-installed

Hyperspectral History at FRL – (2008 – Present) Highlights

2008 (CASI1)

- Agricultural Grip Project with Agriculture and AgriFood Canada, Natural Resource Canada
- Commissioning of the **Green Belt Farm (GBF) bundling calibration site**
- Identification of **Spectral Shift** issue

2009 (CASI2)

- Initiated Forensic Remote Sensing Work – Mass Graves

2010 (CASI1)

- Single graves test site

2011 (CASI1)

- James Bay Greenhouse Gas Mission (JBGHG)

2012 (CASI-1500)

- Single graves test site

2013 (CASI-1500)

- Mission Airborne Carbon 13 (MAC13) – Deployment to Costa Rica
- Mass graves test site

2014 (CASI-1500)

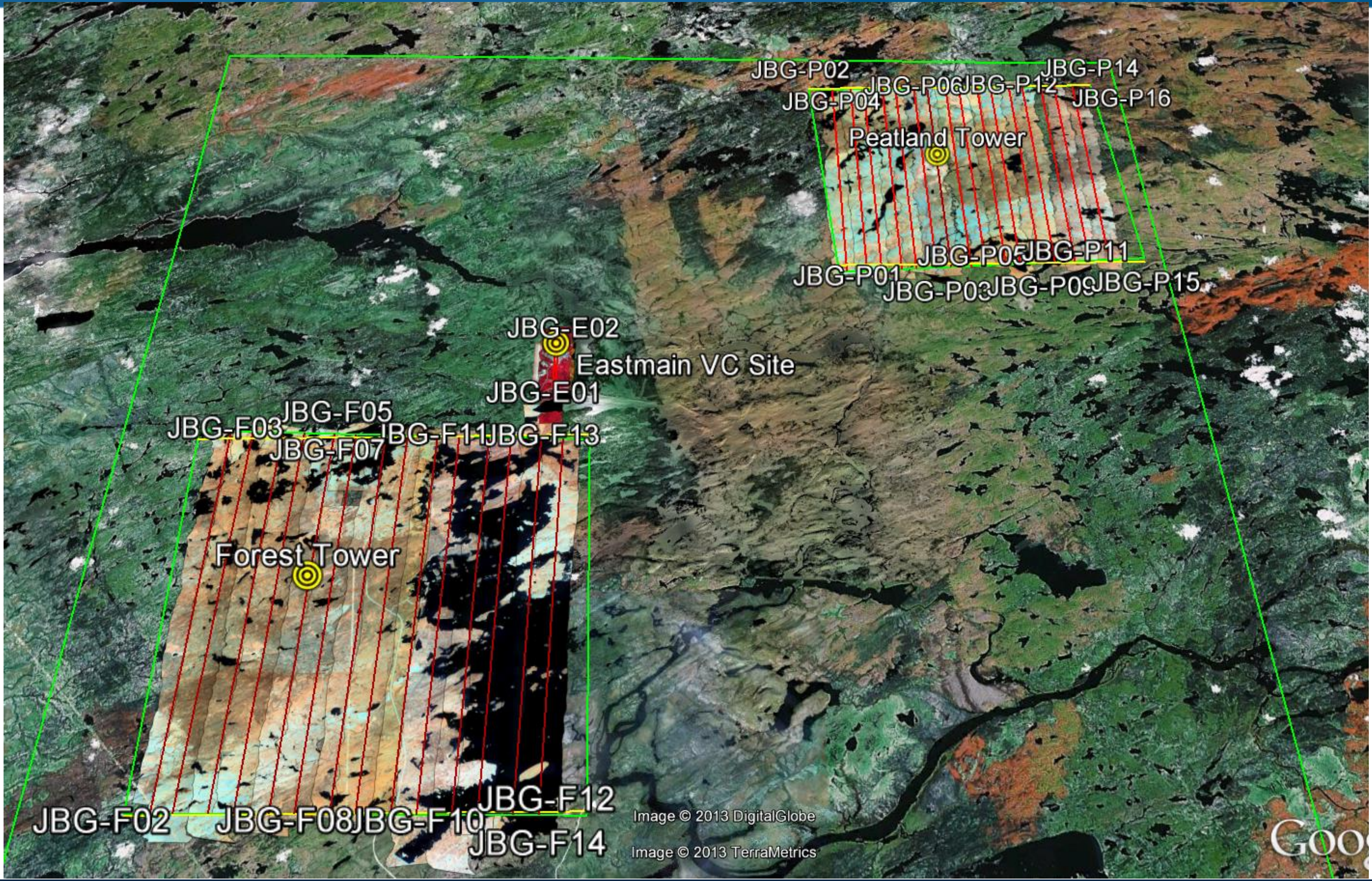
-

2015 (CASI-1500)

- Pre Mission - Mer Bleue Arctic Surrogate Simulation Study

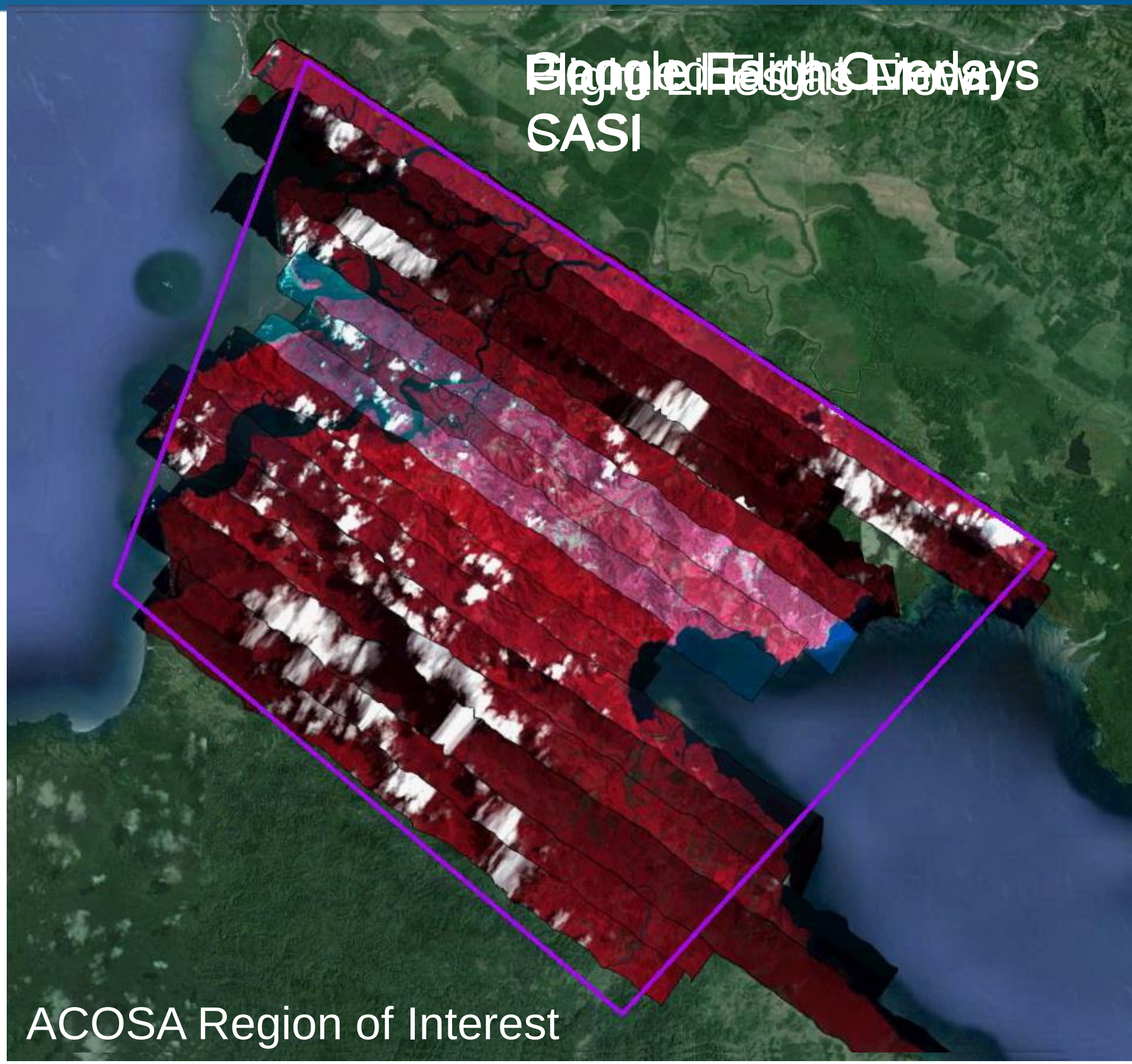
James Bay Greenhouse Gases Mission – July 2011

James Bay Greenhouse Gases Mission – July 2011

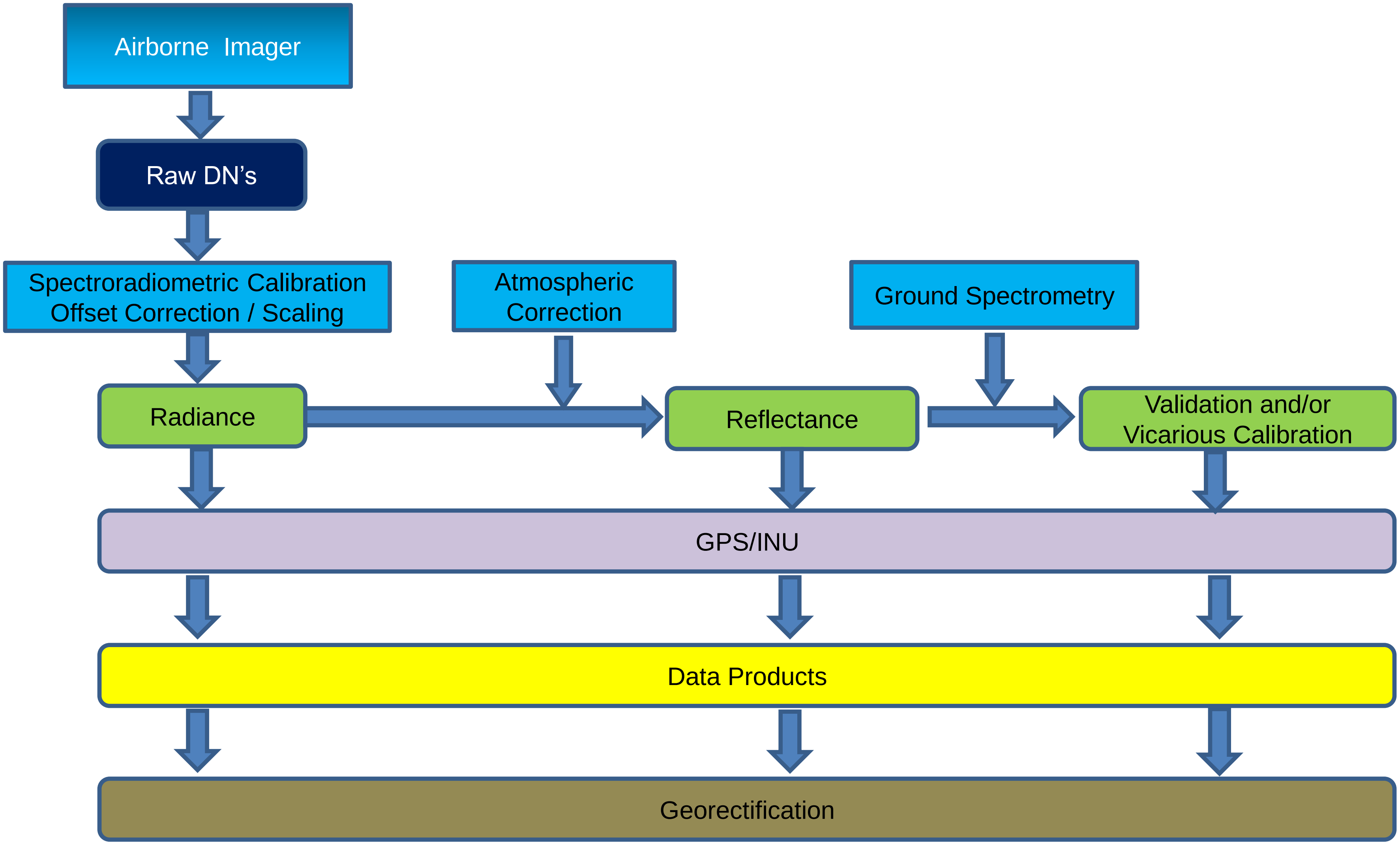


Mission Airborne Carbon 2013 (MAC13) – April 2013 - Costa Rica

Mission Airborne Carbon 2013 (MAC13) – April 2013 - Costa Rica



Simplified Schematic of Hyperspectral Processing



SASI SpectroRadiometric Calibration

- Original spectroradiometric calibration proved to be challenging
  - One of first two SASI units developed
  - Unique MCdT FPA
  - extremely sensitive FPA (thermal blocker required to remove spectral contamination)
  - Customized model

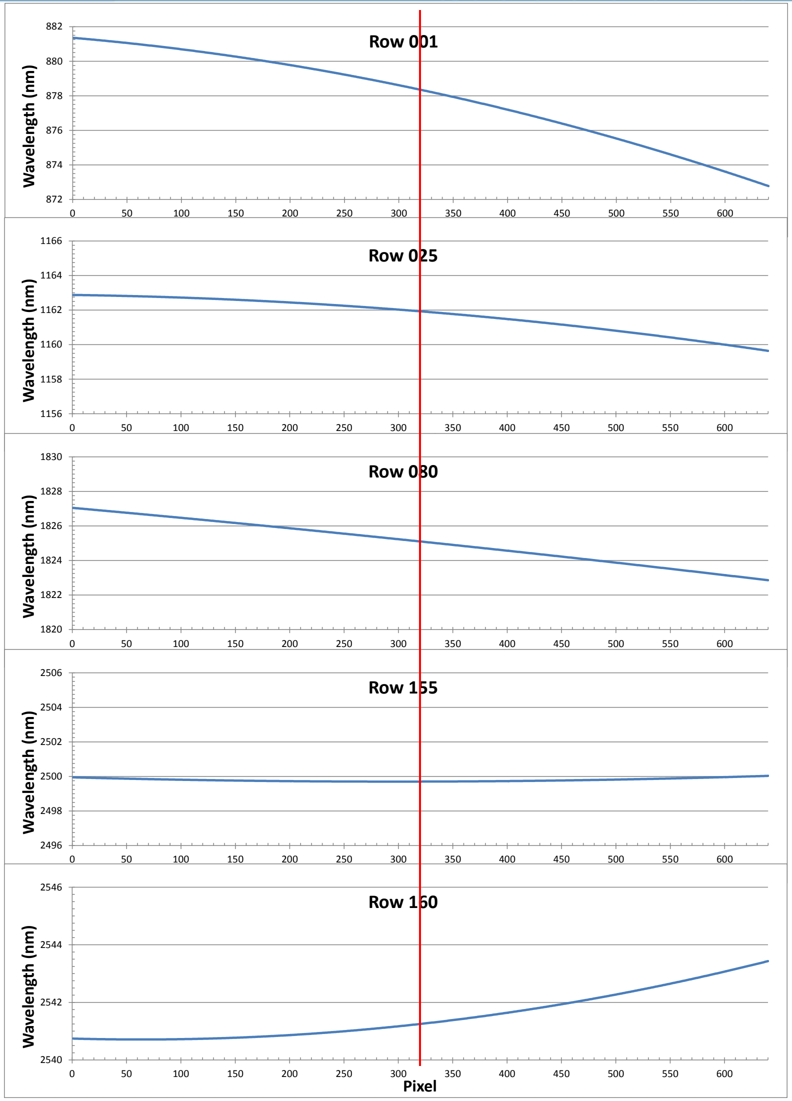
- 6 years and many laboratory calibration efforts finally resulted in a confident spectroradiometric calibration

CASI / SASI SpectroRadiometric Calibration

- The Spectral Sensitivity of each and every pixel is determined in the calibration process as transferred from a calibrated 20” integrating sphere
- Radiometric calibration of the hyperspectral imagery is performed by the ITRES program RadCorr by:
  1. Removal of the unwanted signal contributions associated with each pixel:
     - Electronic Offset
     - Dark Current
     - Frame Shift Smear
     - Scattered Light
     - 2^{nd} Order Diffracted Light – CASI Only
  2. Scaling the offset corrected signal by the radiometric sensitivity coefficient

CASI / SASI Spectral Calibration

- The central wavelength position of each and every pixel is also determined in the calibration process - each column of the SASI FPA has a unique spectral profile
- This presents a challenge in how the spectral dataset is presented in raster based image analysis programs such as PCI and ENVI
- This is handled by the ITRES program **SpecCor**:
  1. specify a target spectrum – normally use column 320 spectra
  2. resample each column to the target spectrum
  3. save resampled data to image file for subsequent analysis



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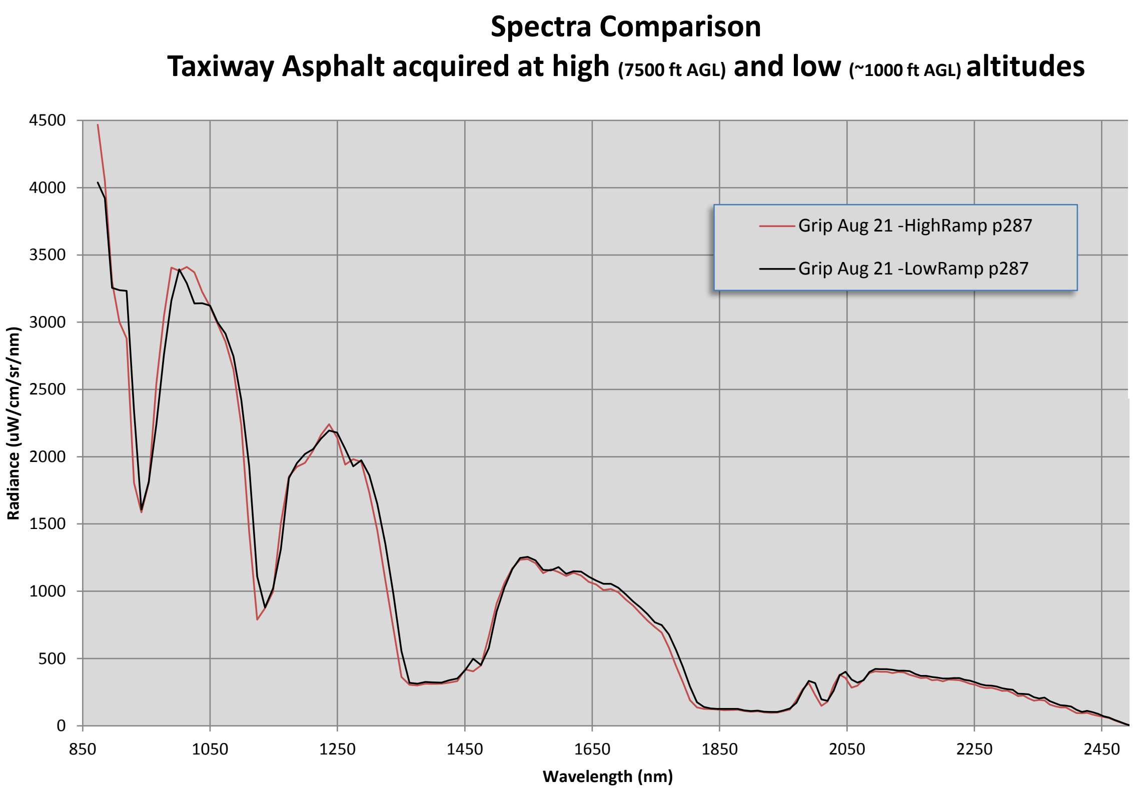
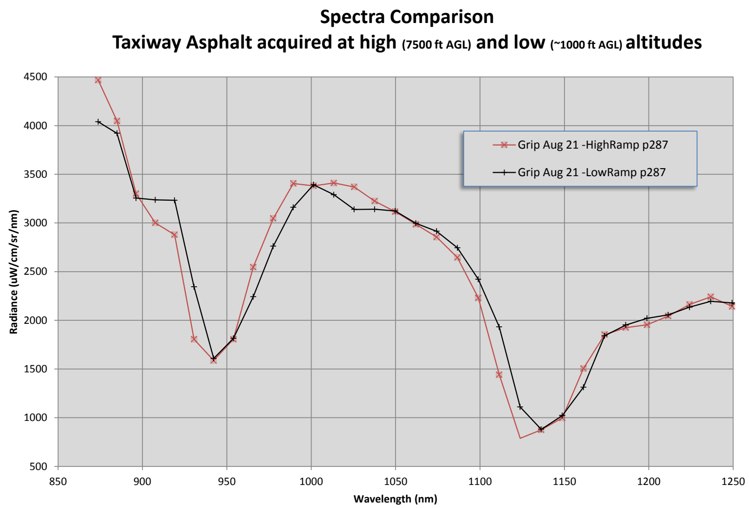
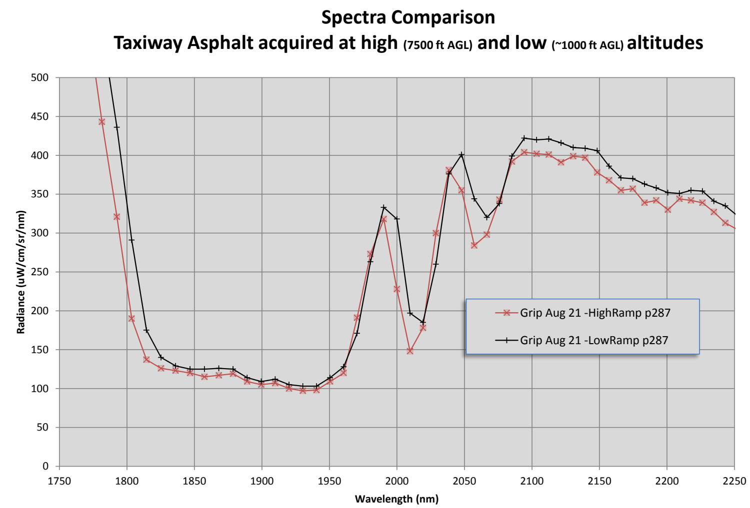
SASI Spectral Shift - CalibCor

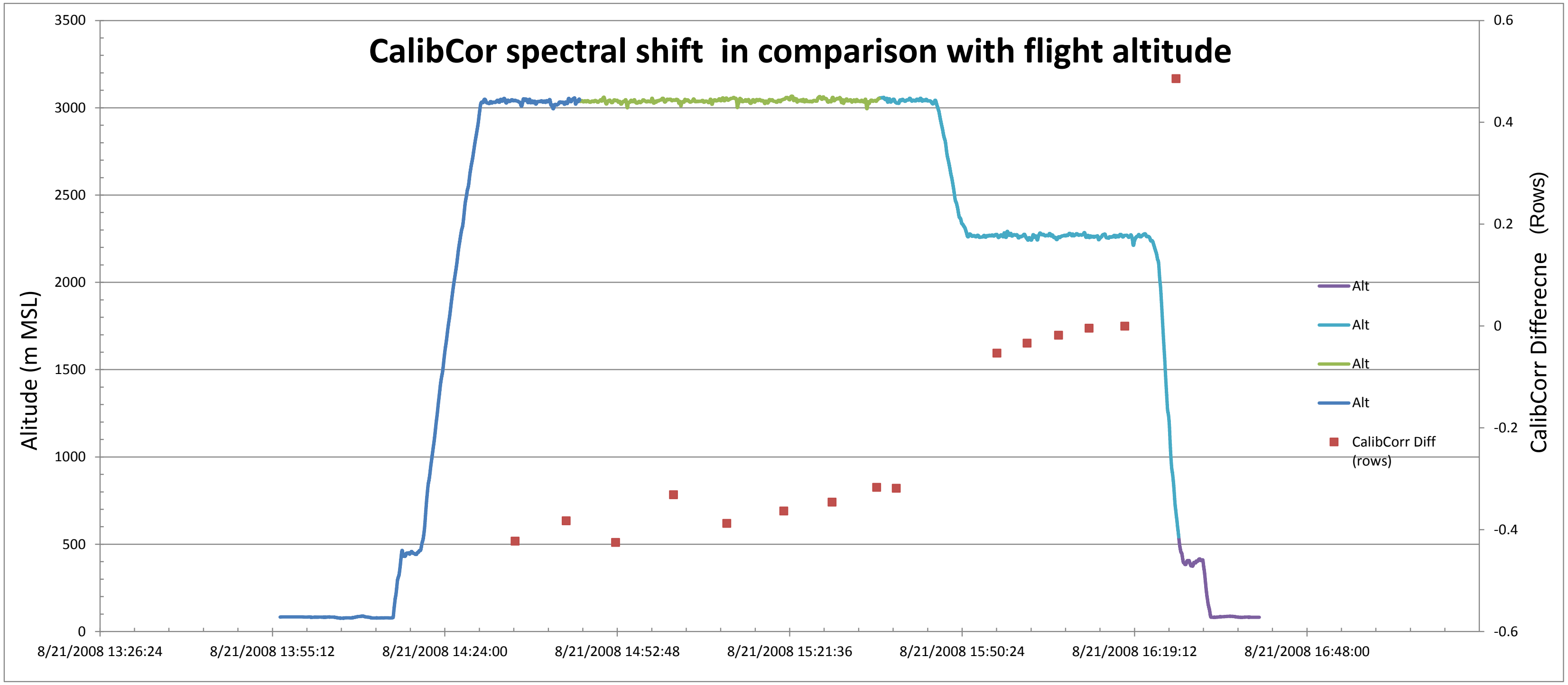






SASI Spectral Shift - CalibCor

- Discussions with ITRES lead to the implementation of a proprietary process known as **CalibCor** to be perform prior to the radiometric or spectrometric calibration.
- Using known atmospheric features, **CalibCor** identifies a spectral shift that was determined to be common to all pixels and channels within an image.
- Modifications are then made to the Radiometric Sensitivity Coefficient file to accommodate the shift.



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Validation of SASI Spectral Calibration

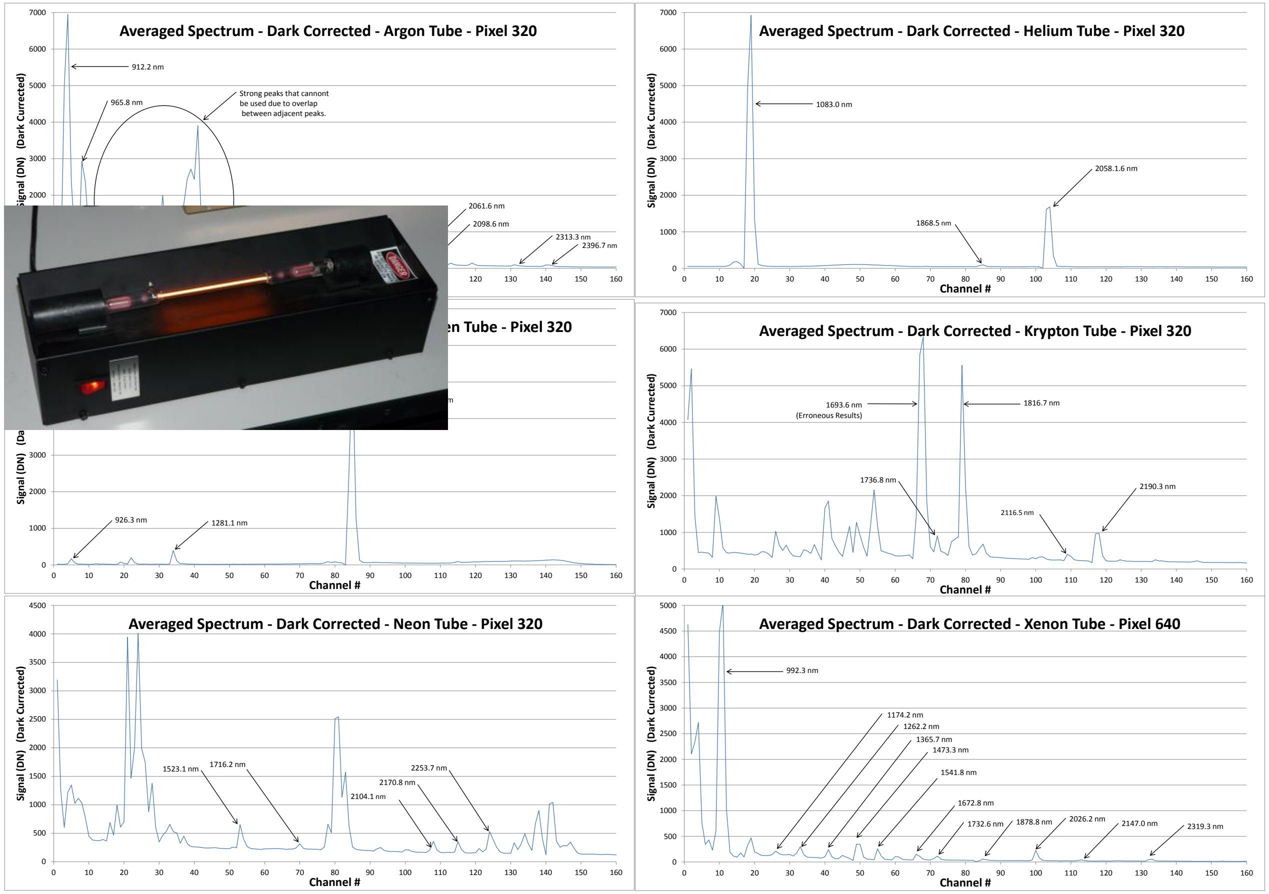
- One of the more straight forward ways to identify a calibration issue is to identify spectral misalignments

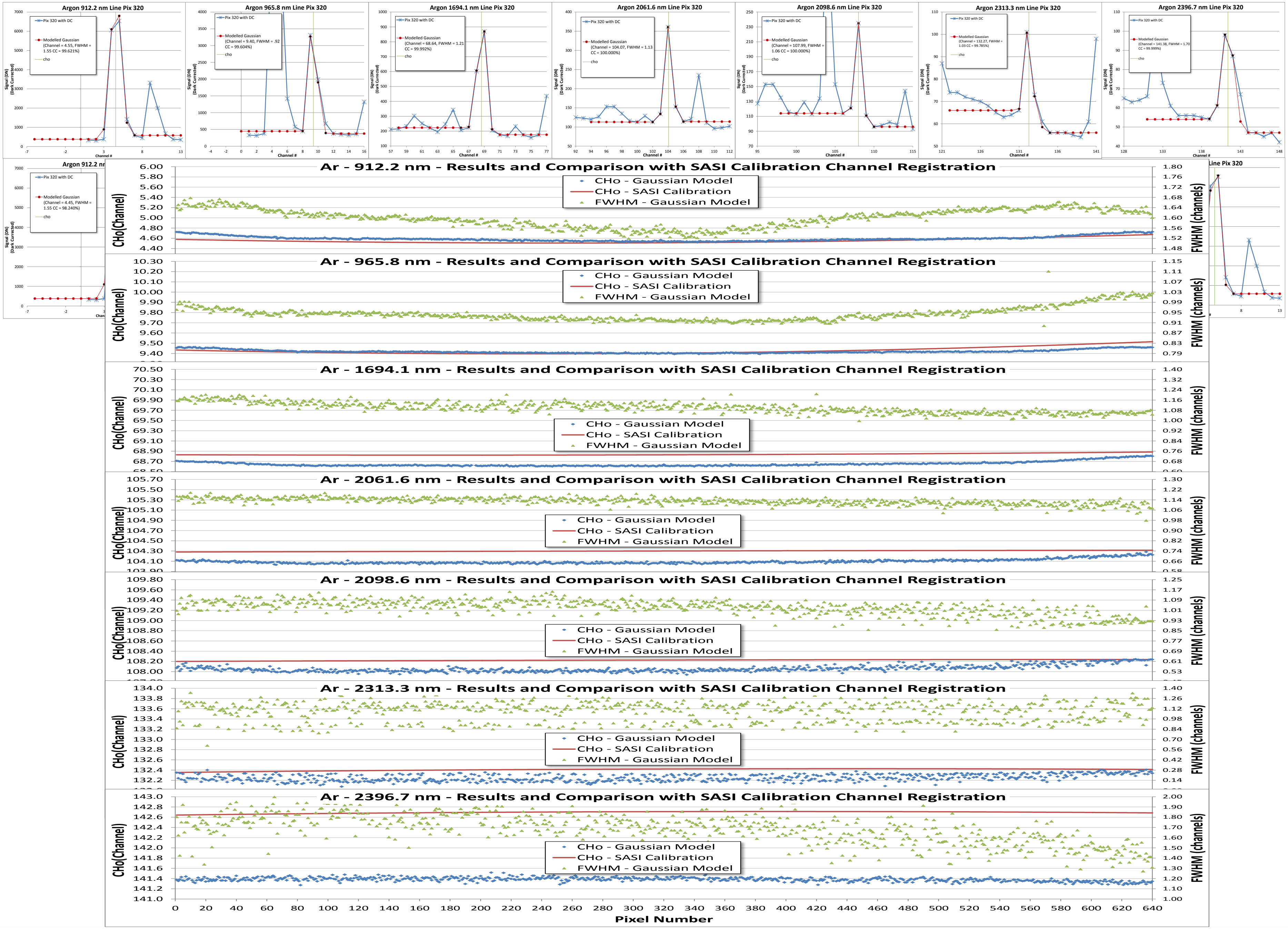
- Upon return of the SASI following calibration, a validation of the wavelength calibration was desired
  - Are we happy with the wavelength calibration?
  - Did anything happen during shipping?

- A methodology making use of inexpensive yet spectrally reliable spectral emission tubes was devised and implemented following the last SASI calibration

- Spectral imagery was acquired in the lab of 6 emission tubes containing a total of 34 clearly identifiable spectral peaks within the SASI wavelength regions

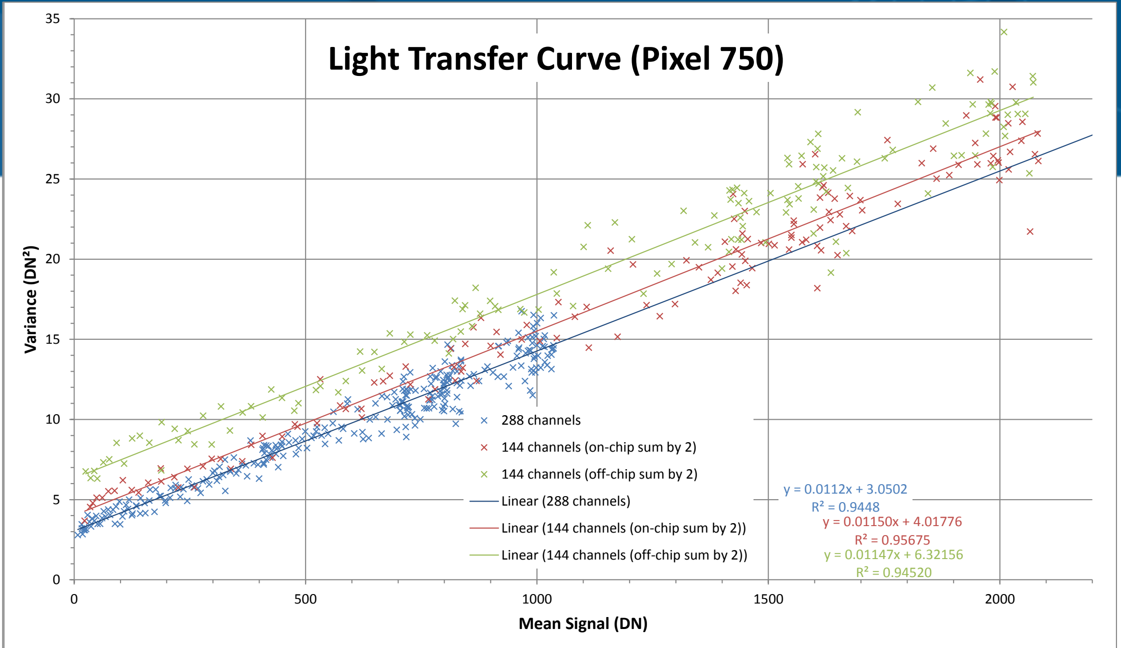
- For each spatial pixel (640), a Gaussian model was used to fit the data for each spectral peak resulting in an estimate of the centre wavelength and FWHM

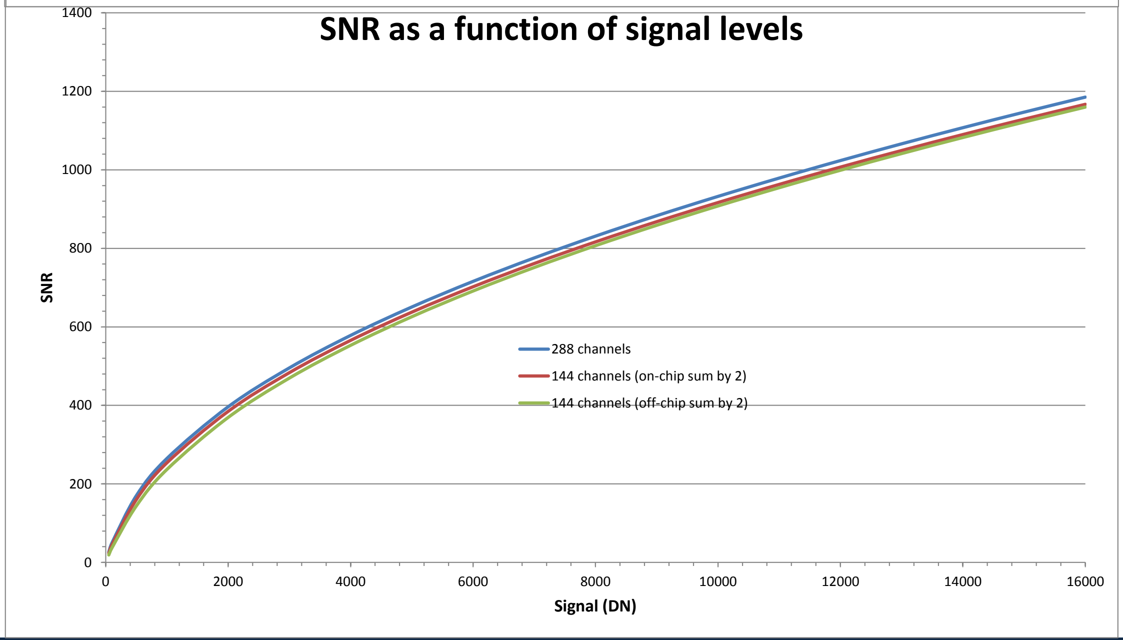



Argon 912.2 nm Line Pix 320
Argon 965.8 nm Line Pix 320
Argon 1694.1 nm Line Pix 320
Argon 2061.6 nm Line Pix 320
Argon 2098.6 nm Line Pix 320
Argon 2313.3 nm Line Pix 320
Argon 2396.7 nm Line Pix 320
Pix 320 with DC
Modelled Gaussian
cho
Signal (DN) (Dark Corrected)
Channel #
Ar - 912.2 nm - Results and Comparison with SASI Calibration Channel Registration
Ar - 965.8 nm - Results and Comparison with SASI Calibration Channel Registration
Ar - 1694.1 nm - Results and Comparison with SASI Calibration Channel Registration
Ar - 2061.6 nm - Results and Comparison with SASI Calibration Channel Registration
Ar - 2098.6 nm - Results and Comparison with SASI Calibration Channel Registration
Ar - 2313.3 nm - Results and Comparison with SASI Calibration Channel Registration
Ar - 2396.7 nm - Results and Comparison with SASI Calibration Channel Registration
CHo - Gaussian Model
CHo - SASI Calibration
FWHM - Gaussian Model
CHo(Channel)
FWHM (channels)
Pixel Number

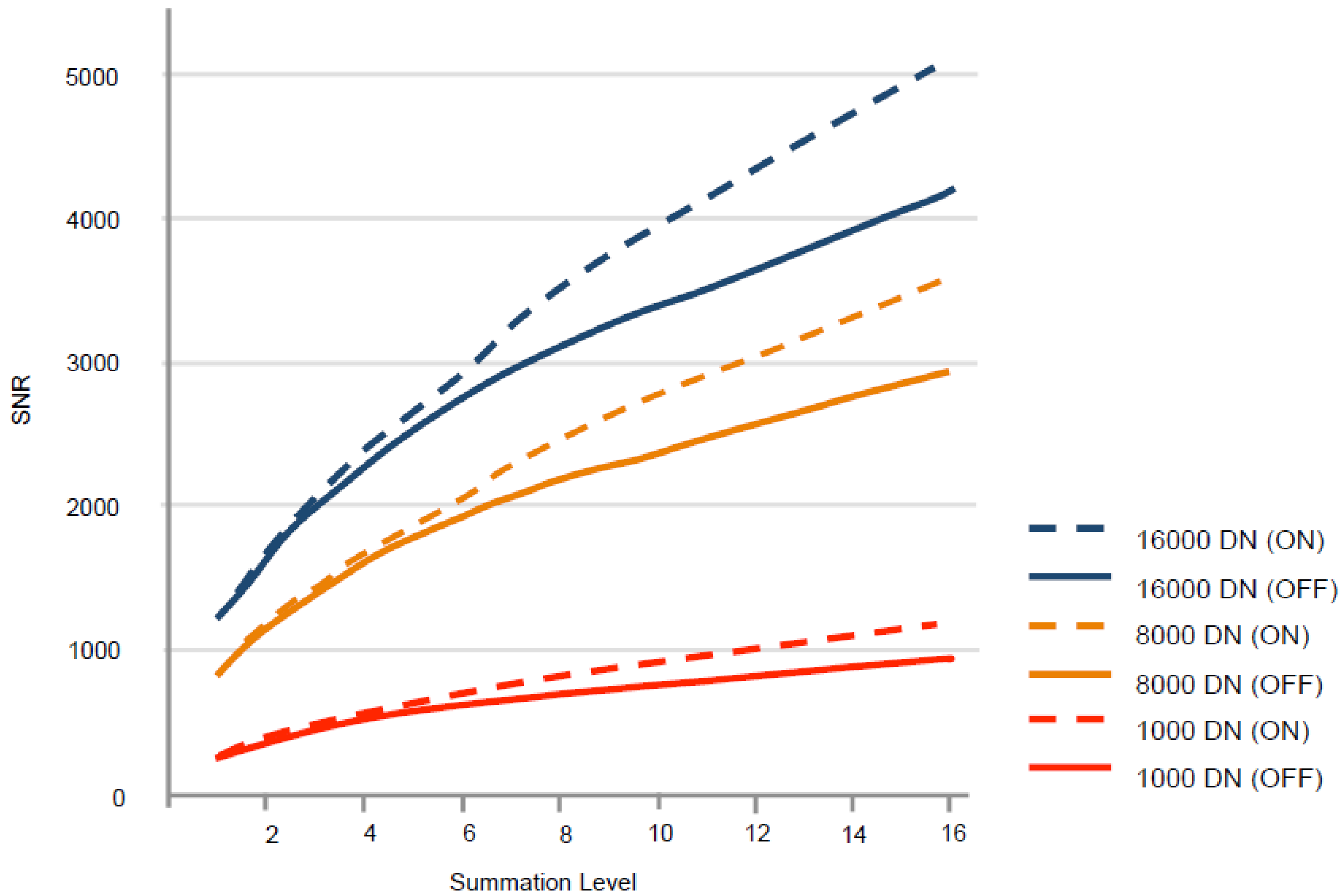
CASI 1500 SNR Issues

- As a spectrally programmable instrument, one of the problems commonly encountered in preparing for an airborne mission is to define the "band set" to be implemented
- Summing rows into broader bands is a common method for improving the signal levels and as a consequence the SNR of the imagery
- However the noise floor of the CASI instruments is known to be very low – specified by the manufacturer as < 2.0 DN for the CASI 1500
- **Question - What is the consequence on the image SNR levels of acquiring full spectral information allowing the researcher to implement band summation in post processing as opposed to summing on-chip?**
- A set of CASI 1500 laboratory images was acquired of a stable radiance source (integrating sphere) using band sets of 1 (288 channels), 2 (144), 3 (96), 4 (72), 6 (48), 8 (32), and 16 (18) rows per channel
- A Light Transfer Curve (LTC) methodology was applied to each of the data sets to determine the system read noise and system gain. From these parameters the noise levels can be reliably calculated for any signal level through full well.
- The sum by 1 data set was processed to simulate the sum by 2, 3, 4, 6, 8, 16 data sets and the LTC processed applied to the resulting images.
- SNR curves as a function of signal levels were then compared.





CASI 1500 SNR Issues



Spectroradiometric Calibration

Radiance = (Raw Signal – Offset Signal) x RSC

Offset Signal = EO + DC + FSS + SL + DL

Where

RSC = Radiometric Sensitivity Coefficient

EO = Electronic Offset

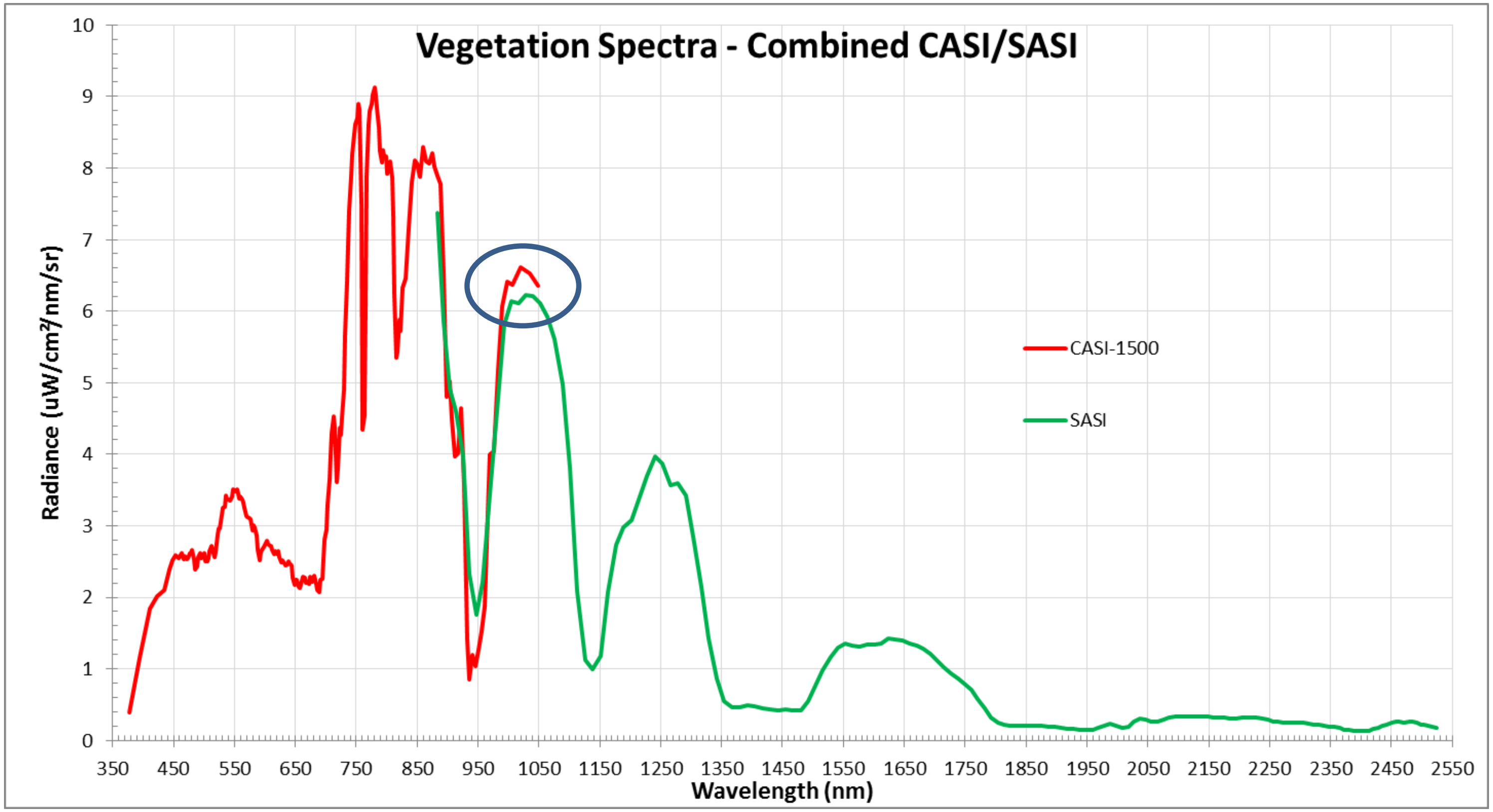
DC = Dark Current

FSS = Frame Shift Smear (CCD only)

SL = Scattered Light

DL = 2nd order diffracted light

Offset Correction



CASI Offset Correction Frame Shift Smear

FSS is offset introduced by spectral smear during the transfer of the image region pixels into the storage region

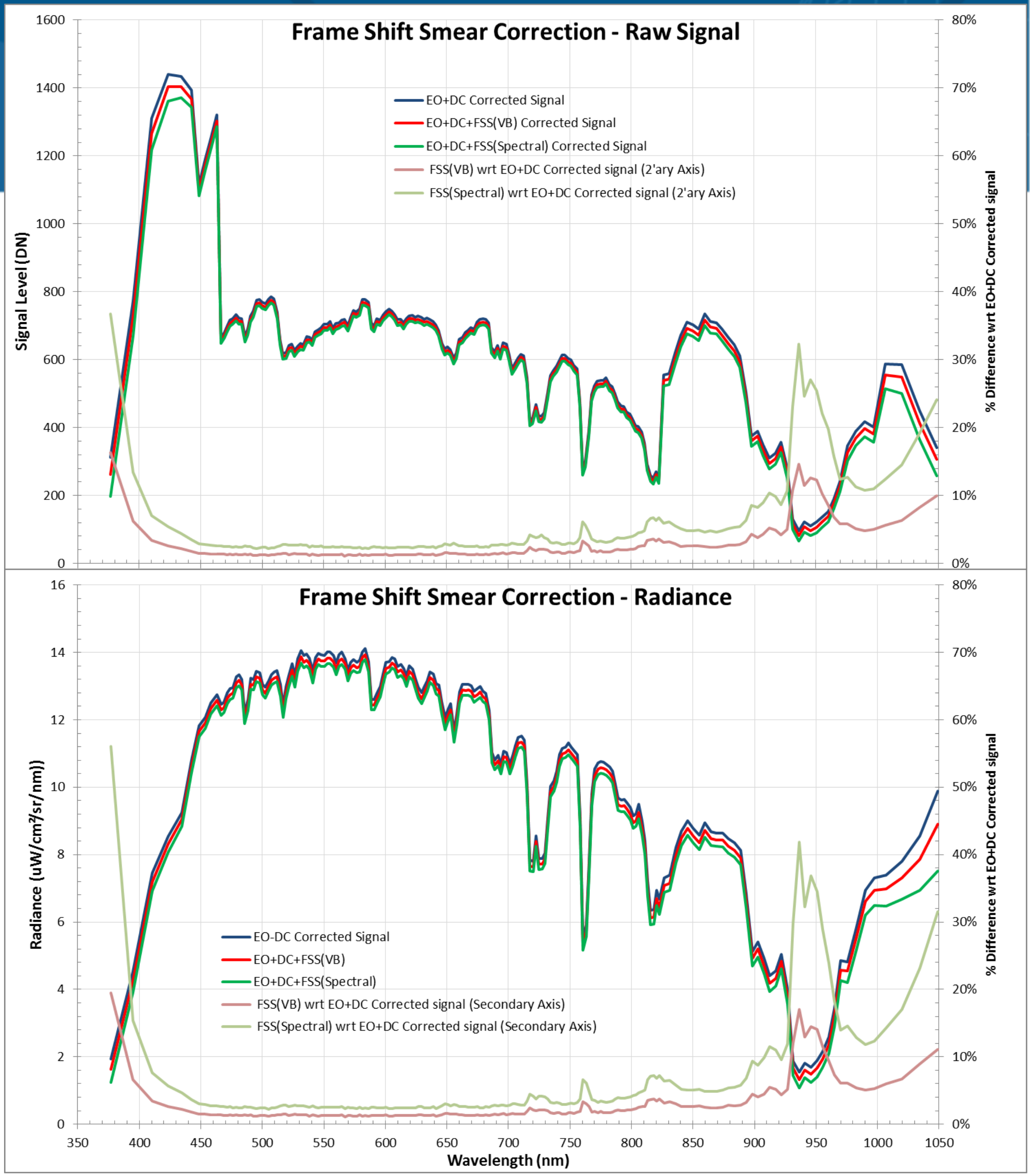
2 FSS Approaches
- Virtual Band (VB)
- Spectral Mode (Spectral)

FSS(VB) approach used in the past as multispectral band sets were typically used.

With CASI-1500, full spectral content with full spatial retrieval is possible. Therefore FSS(Spectral) can be implemented.

FSS(Spectral) is theoretically should provide a better **estimate** of the FSS

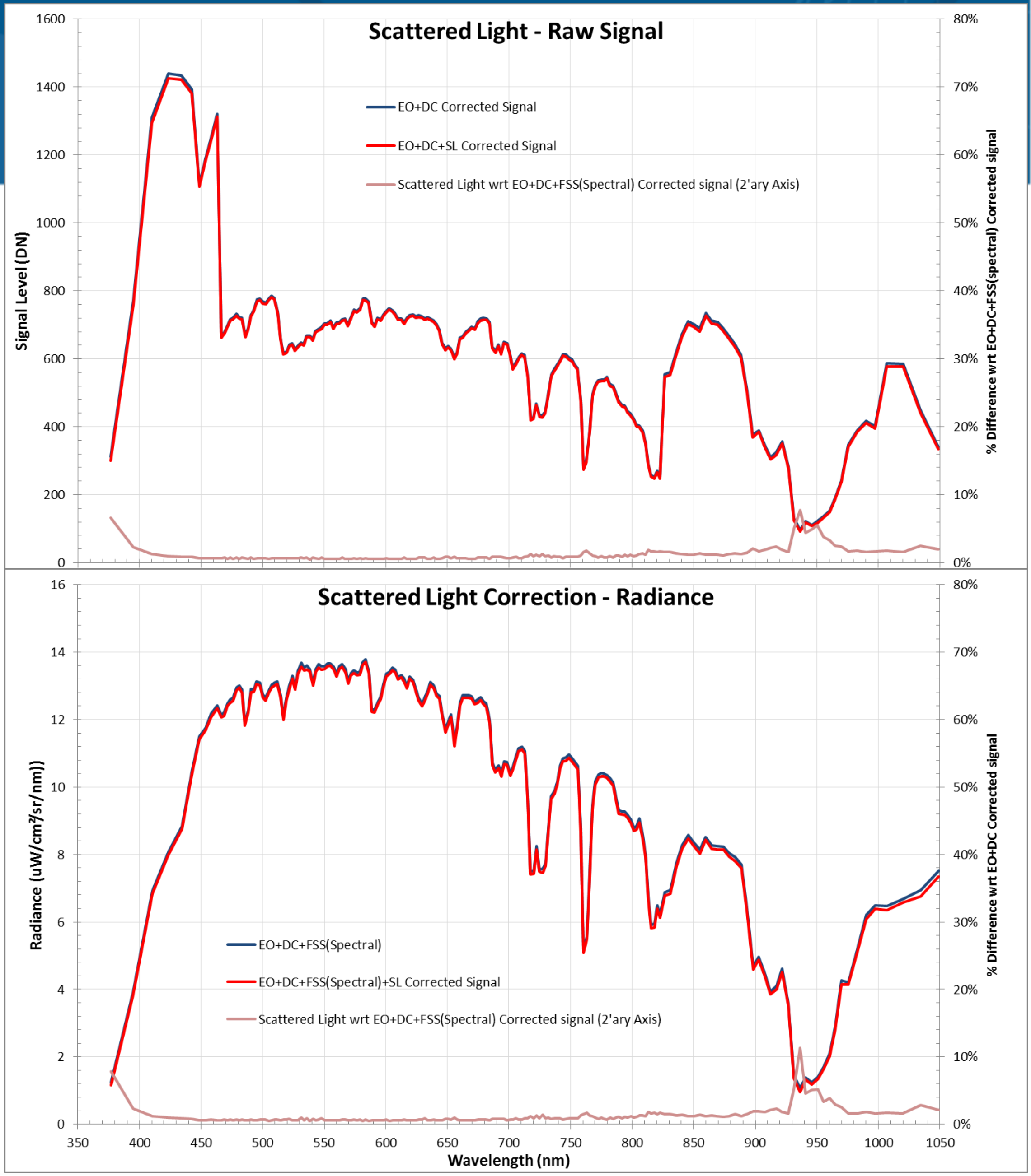
Due to the constantly changing image, a first order estimate of the FSS is all that can be achieved.



CASI Offset Correction Scattered Light

Internal scattered light is estimated on CASI CCD using shielded pixels at the edge of the FOV.

Once again, this is only a first order estimate of this effect.



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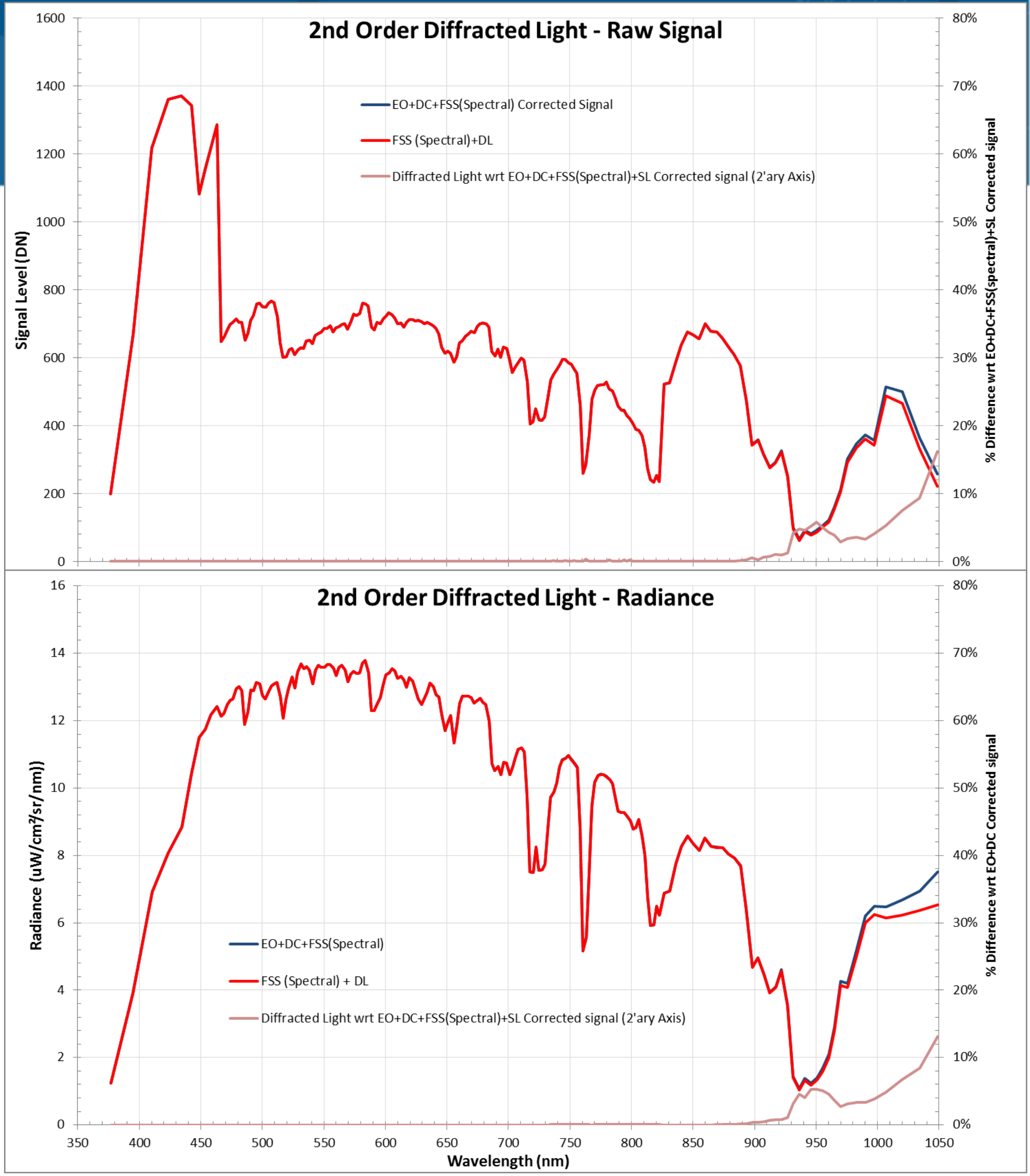
CASI Offset Correction
2nd Order Diffracted Light

A sophisticated physical model of the 2nd order scattered light diffracting off the CASI grating was recently developed by ITRES Research Ltd.

The model is proprietary but the impact of applying the DL offset correction can be seen here in the upper wavelengths.



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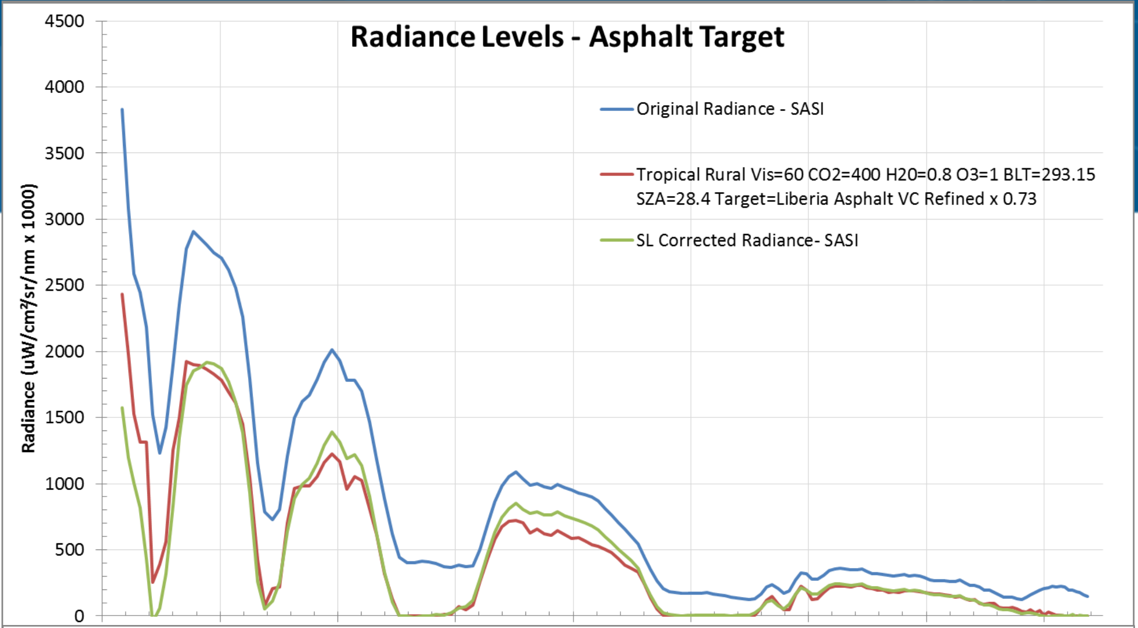
SASI Offset Correction

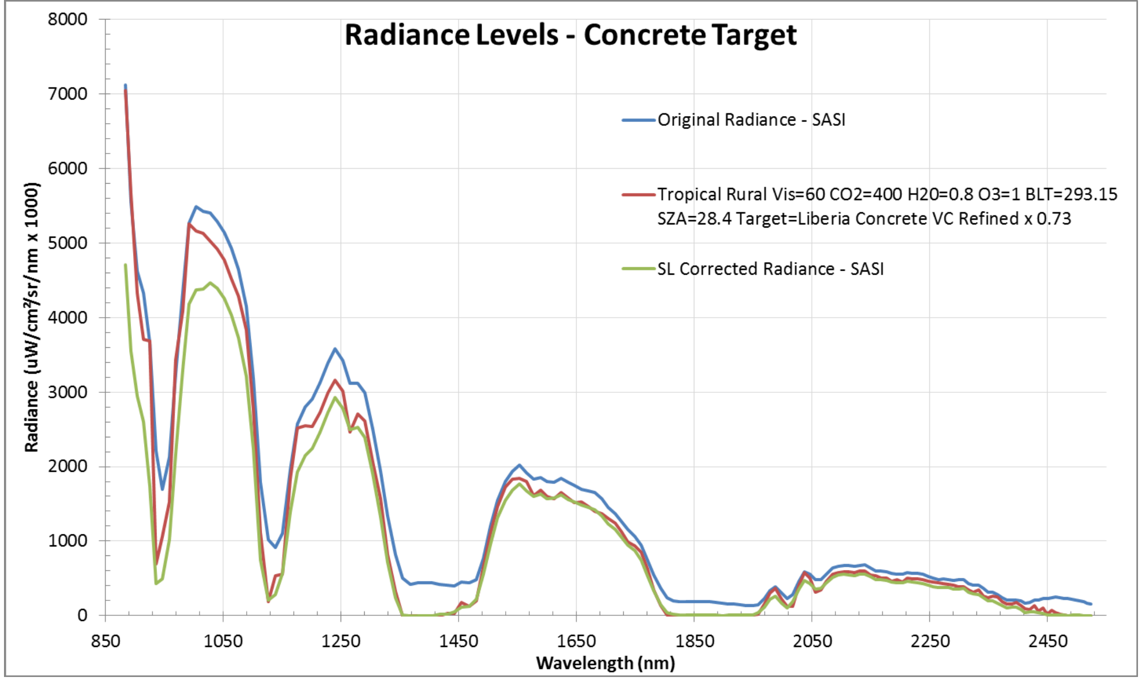
FSS does not apply to Focal Plane Arrays such as those used in the SASI Instrument – FPAs use direct sampling of the sensor element.

2nd order DL not an issue in Prism based instruments.

The FPA architecture does not allow for SL estimation in the manner performed in the CASI.

Evidence suggestive of a SL issue is apparent in the results.





Spectroradiometric Calibration

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Offset Signal = EO + DC + FSS + SL + DL

Where

- RSC = Radiometric Sensitivity Coefficient
- EO = Electronic Offset
- DC = Dark Current
- FSS = Frame Shift Smear (CCD only)
- SL = Scattered Light
- DL = 2^{nd} order diffracted light

Spectroradiometric Calibration – RSC

- Spectroradiometric Calibration of both CASI and SASI performed by ITRES Research Ltd.
- Transfer Source: Labsphere CSTM-LR-20-M with 150W Lamp (2 lamps available)
- Transfer Source Calibration: Labsphere NIST Traceable
- Custom Port reducer to improve sphere efficiency
- Sphere calibration is performed and reported at 10 nm spacing
- However the calibration data file is provided with 1 nm spacing
  - 10nm → 1 nm conversion done by cubic spline interpolation

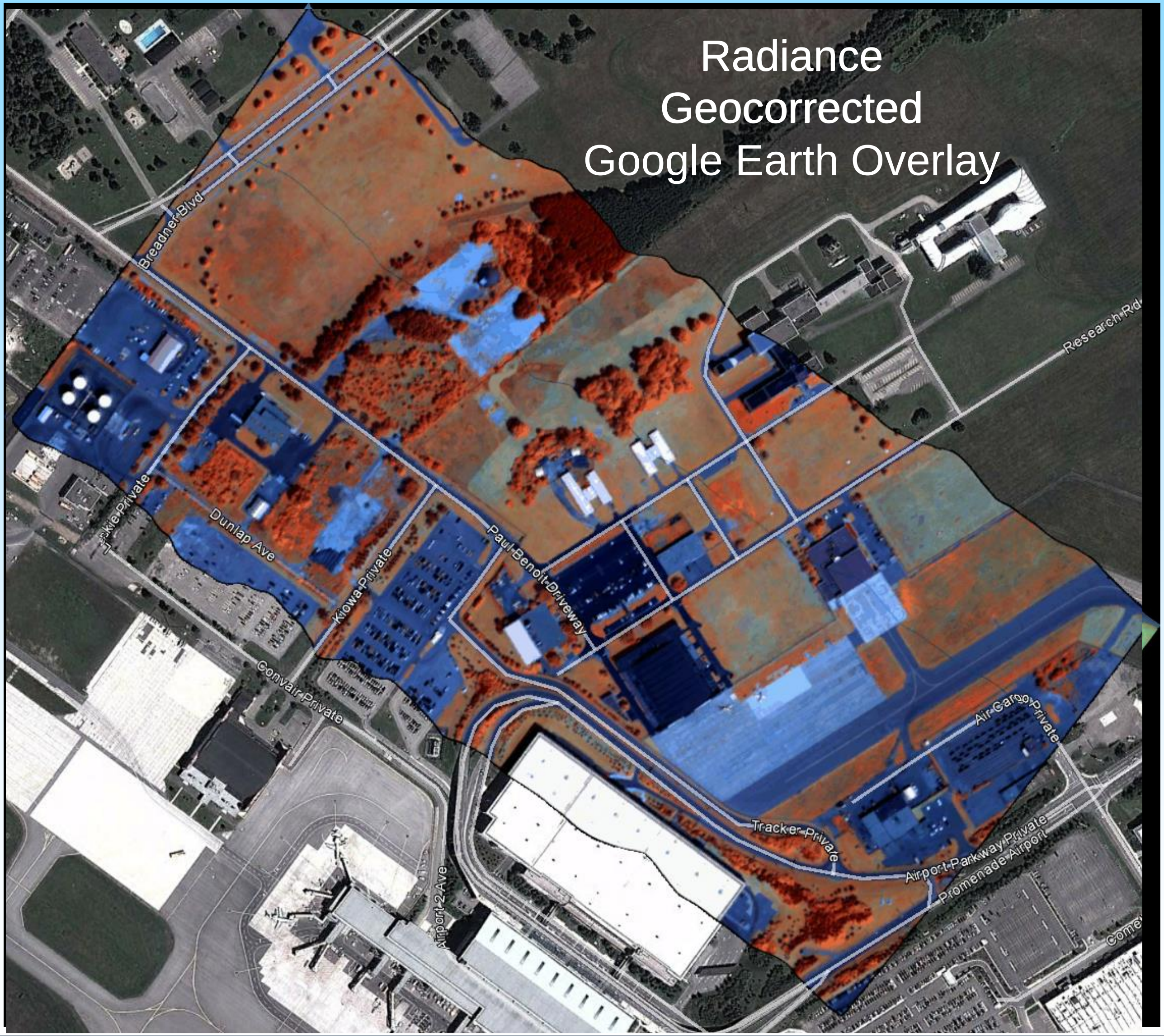
Spectroradiometric Calibration – RSC

- March 2015 CASI/SASI calibration
  - Joined the calibration effort along with our new SVC 1024i field spectrometer in an effort to close the loop between the calibration of the airborne instruments and the field spectrometer.
- Identified a strange spectral ringing in the SASI results
  - Ringing not apparent in the SVC spectra of the calibration sphere.
- Traced the source of this issue to the 10→1 nm interpolation
- ITRES change their procedure to use the 10 nm IS calibration data rather than the 1 nm
  - Use their own interpolation scheme.
- Results verified by comparison with SVC results as well as through observations of a high temp Black Body source.

Bundling Adjustment Approach to Geocorrection

- A method to solve the basic problem in Photogrammetry and Array Image analysis of having the imaging system acquire true ground coordinates of any imaged point.
- Requires IMU data comprised of GPS (X, Y, Z, Time) and INS (Pitch, Roll, Heading, Time) be acquired and synchronized with the hyperspectral imagery.
- The Bundling Calibration requires that a number of spatially offset parallel and orthogonal flight lines be acquired of a number of accurately know, clearly identifiable, ground control points (GCPs).
- Prior to 2008 a number of points around the NRC Uplands Campus had surveyed and used for bundling procedure.
- In 2008, the Greenbelt Farm (GBF) belonging to AAFC was identified as an ideal site to use for the bundling sights.
- In conjunction with the GRIP Biomass project being undertaken with AAFC and CCRS (NRCan), a ground survey campaign providing high accuracy positional information (0.4 m horizontal, 0.6 m vertical) of 178 points was performed with the assistance of the Geodetic Survey of Canada (NRCan).
- This data set allowed the accuracy of the geocorrection process to performed in a consistent, highly accurate manner.

SASI Imagery – Uplands Campus – July 12th, 2013



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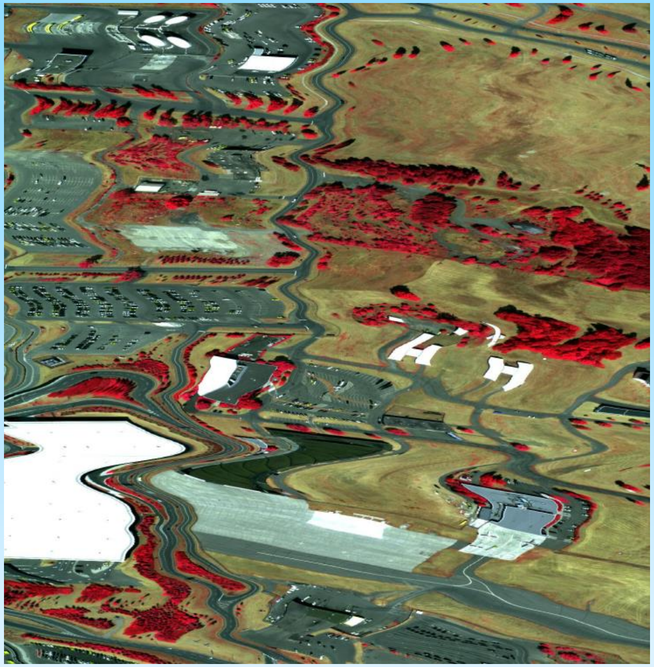
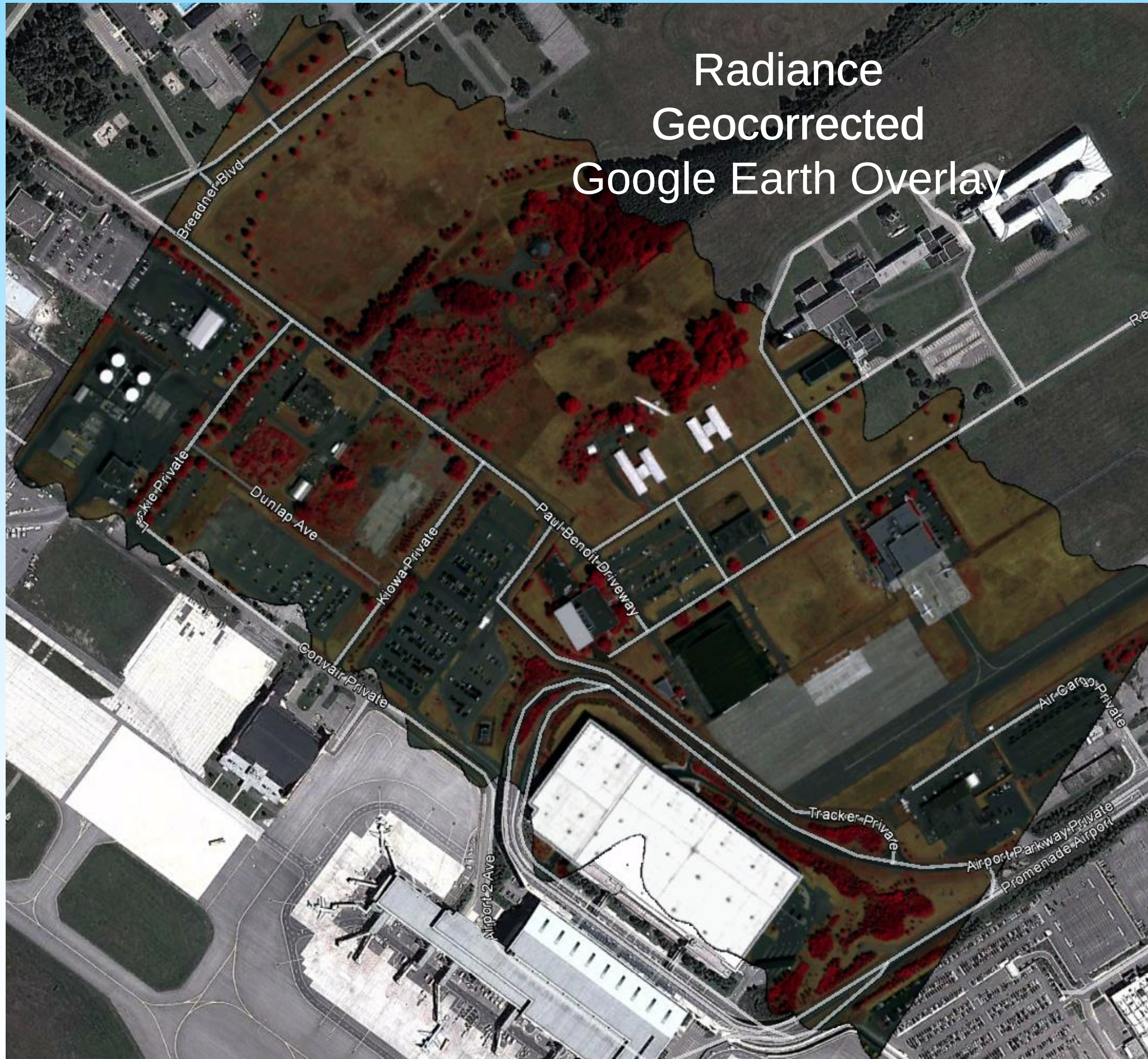
CASI 1500 Imagery – Uplands Campus – July 20th, 2012



Radiance
Pre-Geocorrection



Radiance
Geocorrected
Google Earth Overlay

Geocorrection Considerations – System Upgrade

IMU	C-Migits III	Honeywell 1700
GPS Receiver		Novatel OEM6 GPS with GLONASS L1/L2 receiver
GPS antenna	Single Frequency passive	Dual frequency active (allows for ionopshic delay correction)
Accuracy (no post processing)	5 m positional (xyz) 0.3° pitch/roll 0.6° heading	3 m positional (xyz) 0.05° pitch/roll 0.1° heading
GPS post processing	None	Differential (Kalman smoother)
Accuracy (post processing)	NA	1 cm horizontal (xy) 2 cm altitude (z) 0.01° for pitch/roll 0.02° for heading
CASI/SASI Geocorrection Accuracy	5 – 10 pixels	TBD

Field Spectroscopy
Panel Substitution Methodology (PSM)

$$R_T(\lambda) = \frac{S_T(\lambda)}{S_R(\lambda)} \times R_R(\lambda)$$

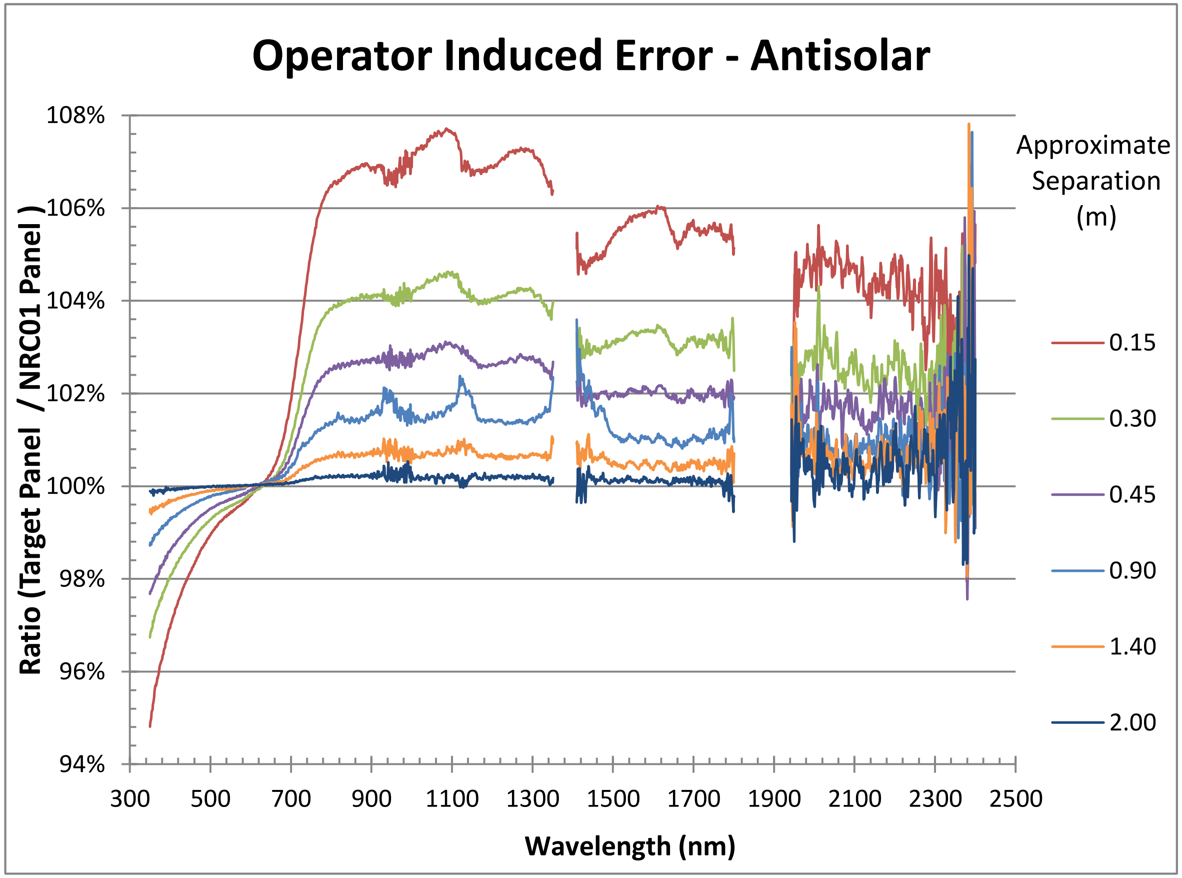
where

- $R_T(\lambda)$ = Target Reflectance
- $R_R(\lambda)$ = Reference Panel Reflectance
- $S_T(\lambda)$ = Target Signal
- $S_R(\lambda)$ = Reference Panel Signal

- Radiometric System Linearity
- Instrument Stability
- Stability of Illumination conditions between reference and target measurements.
- Spectral Reflectance of the reference
- Field-of-View (Target homogeneity)

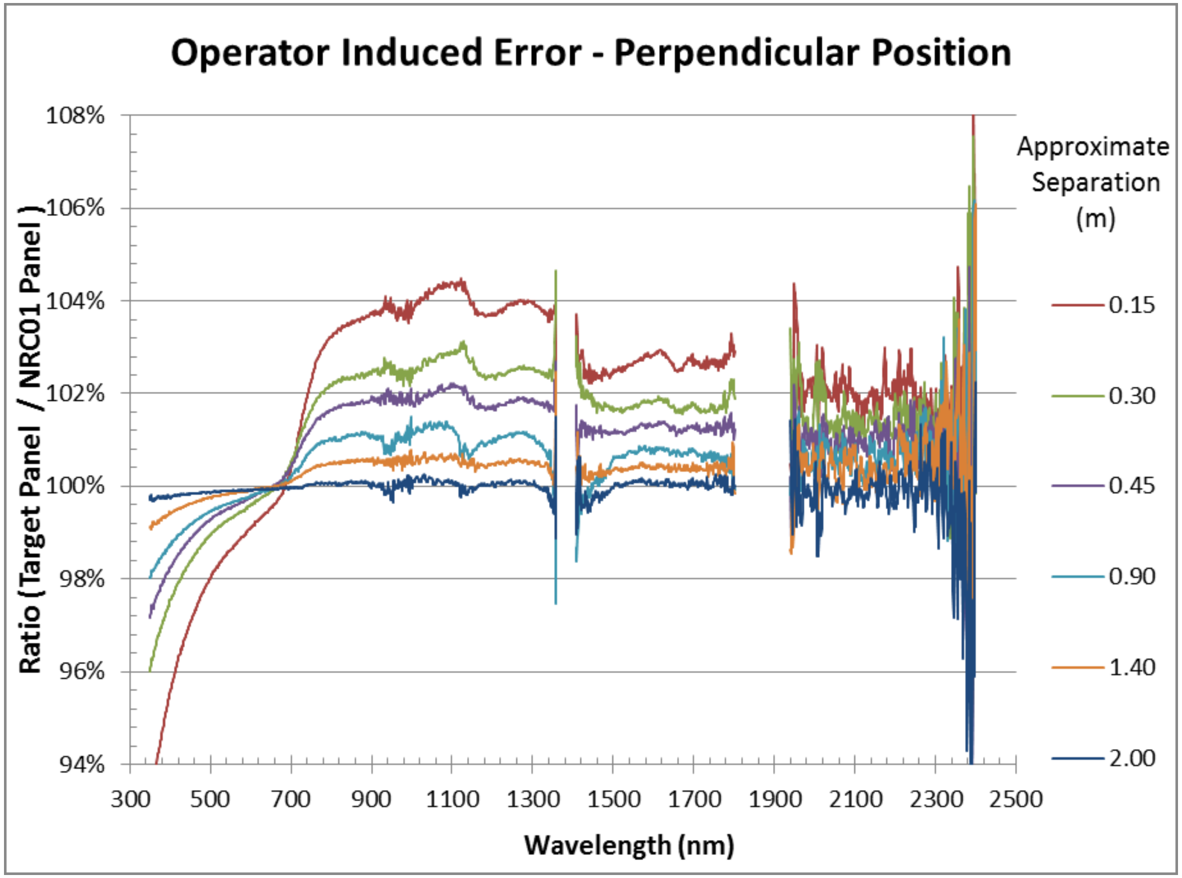
Operator Proximity: Antisolar Position

Operator separation: 10+ m
(alternate reference)

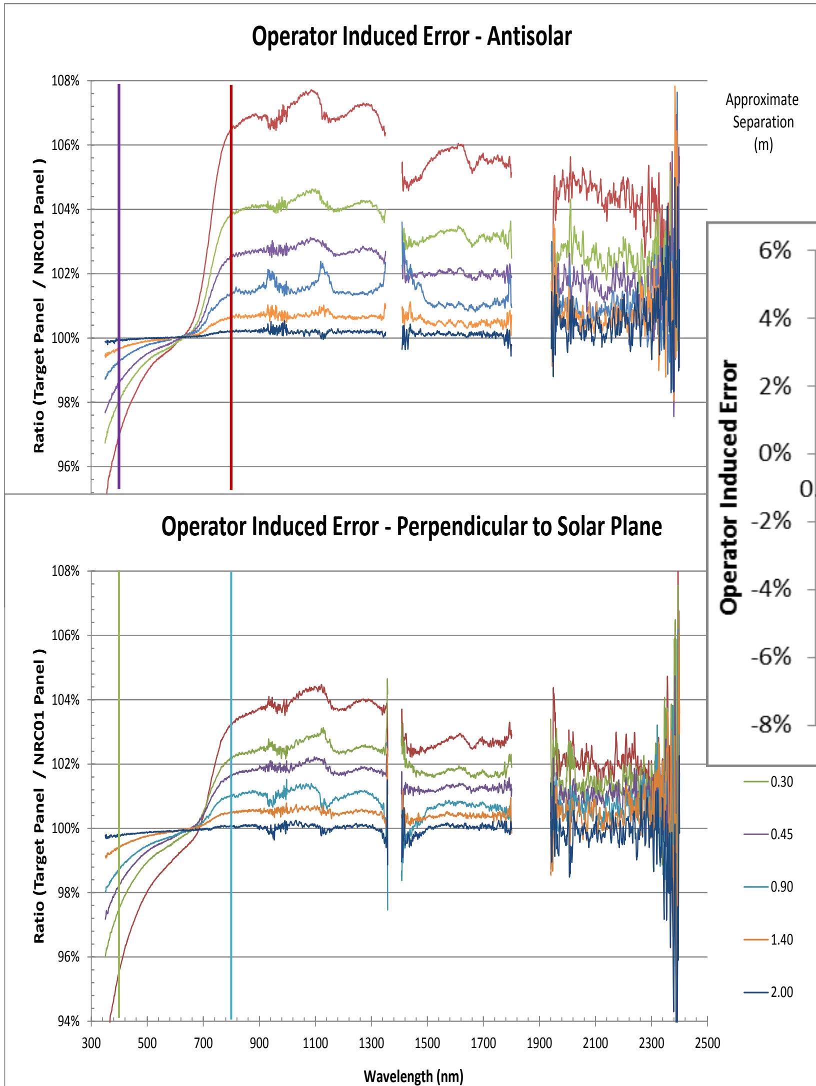


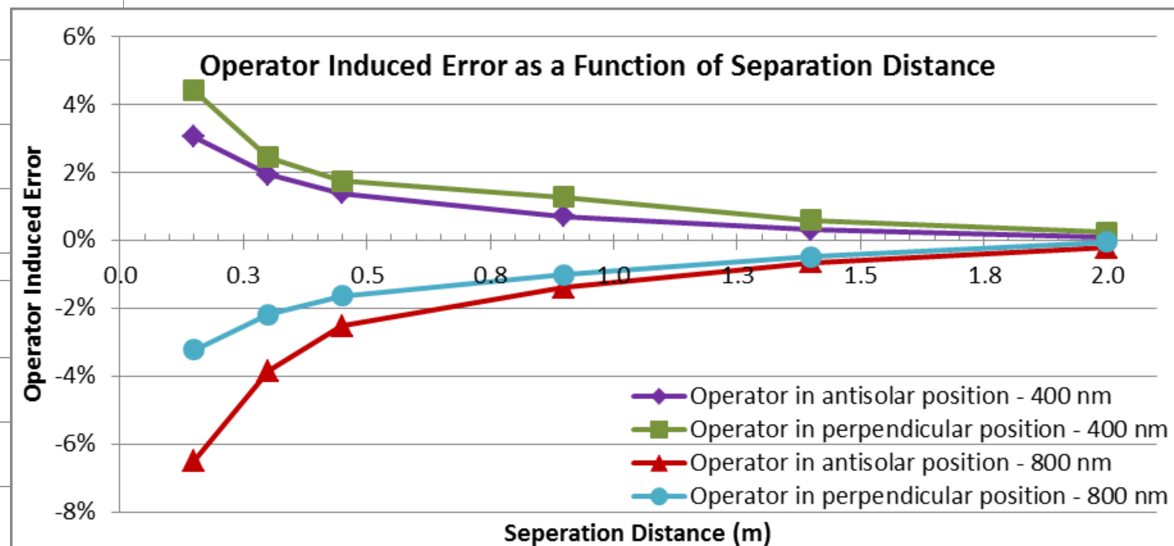
Operator Proximity: Perpendicular Position

Operator separation: 10+ m
(alternate reference)

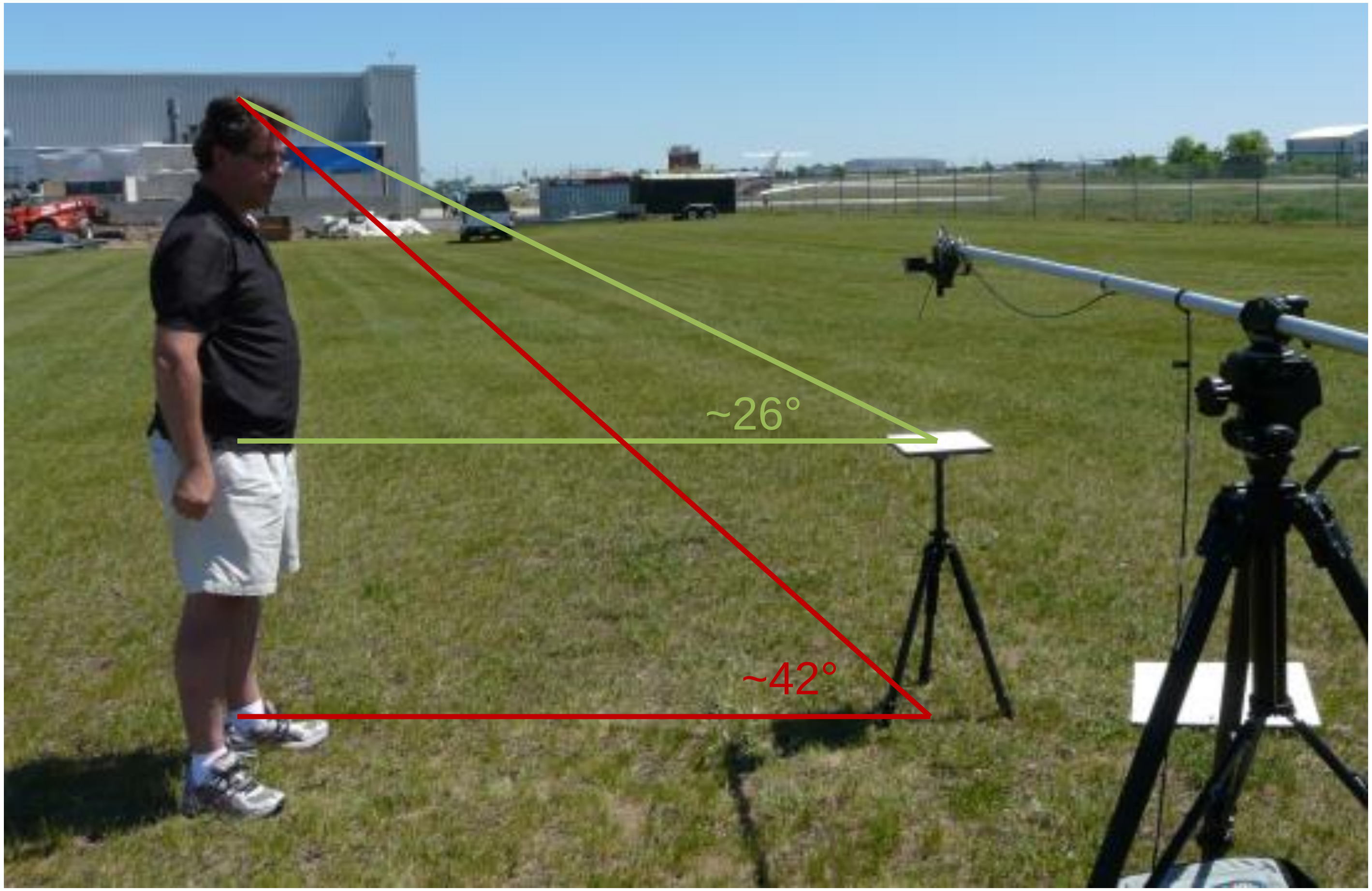


Operator Induced Error as a Function of Separation Distance

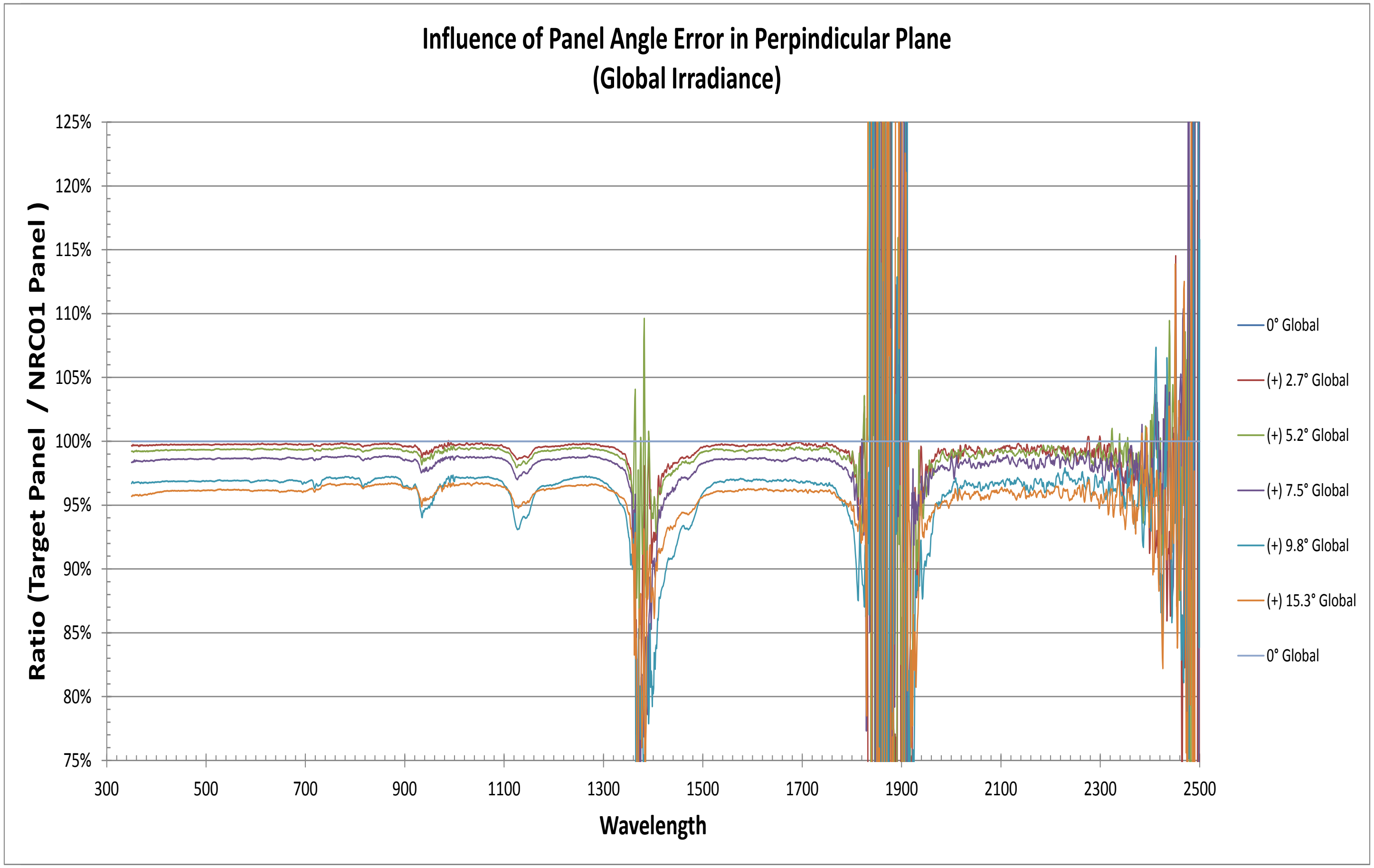




Same separation distance, different reference/panel heights



Measurement error due to panel tilt



Field Spectrometer Deployment Photos From Google Images

Field Spectroscopy
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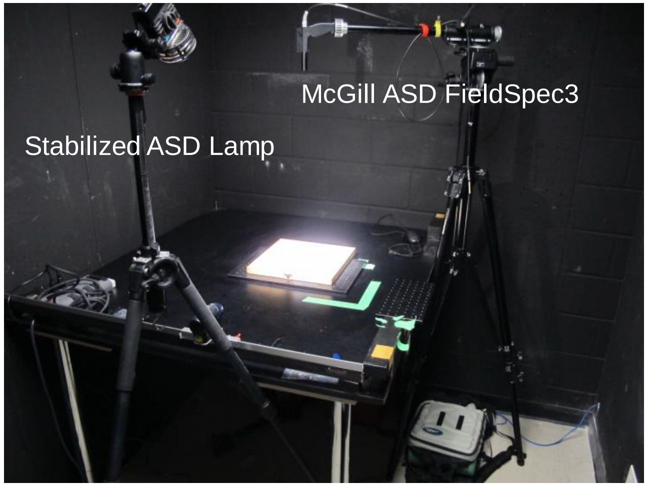
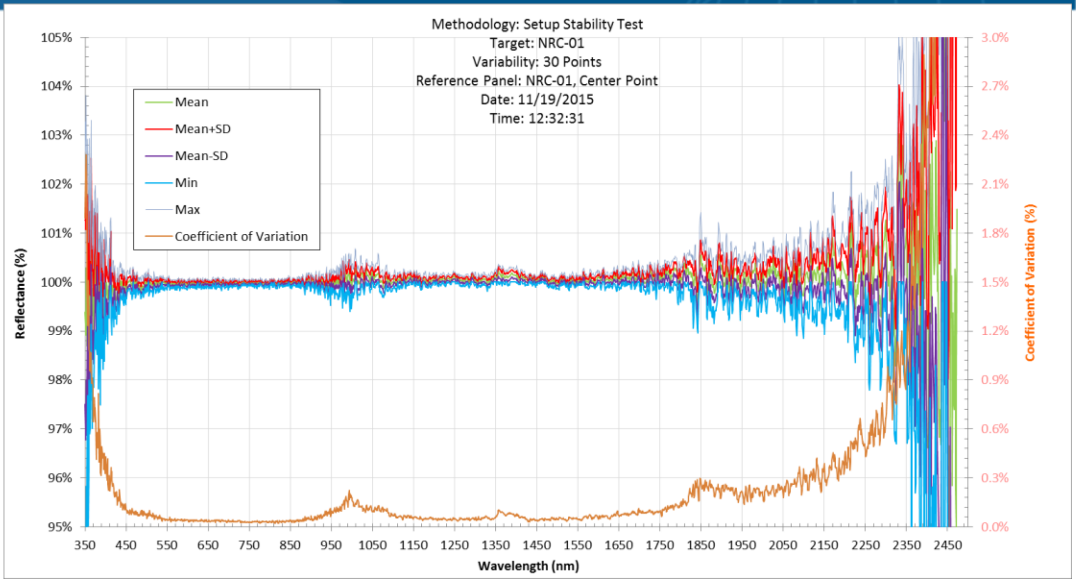
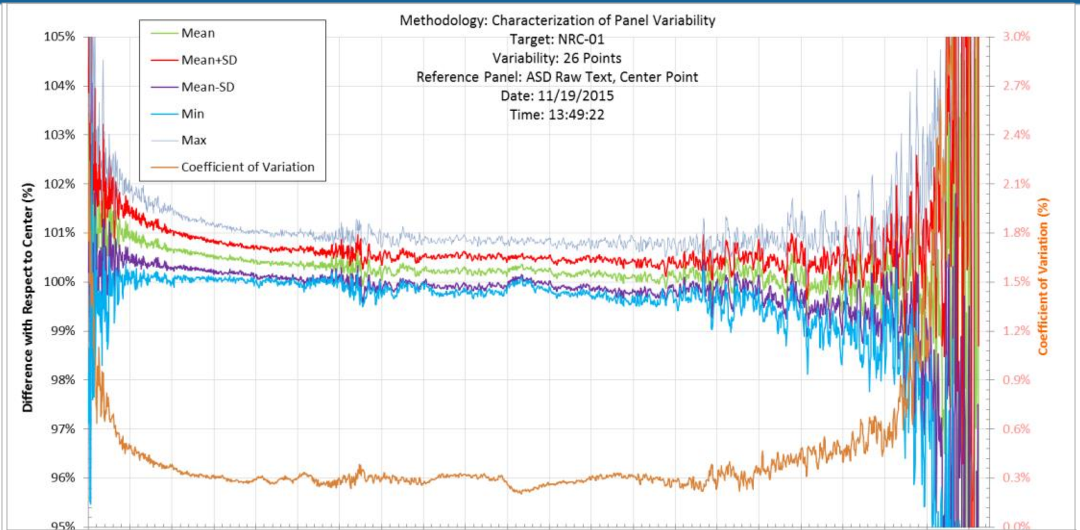
- Radiometric System Linearity
- Instrument Stability
- Stability of Illumination conditions between reference and target measurements.
- Spectral Reflectance of the reference
- Field-of-View (Target homogeneity)

Panel Characterization
Experimental Setup - Stability Tests



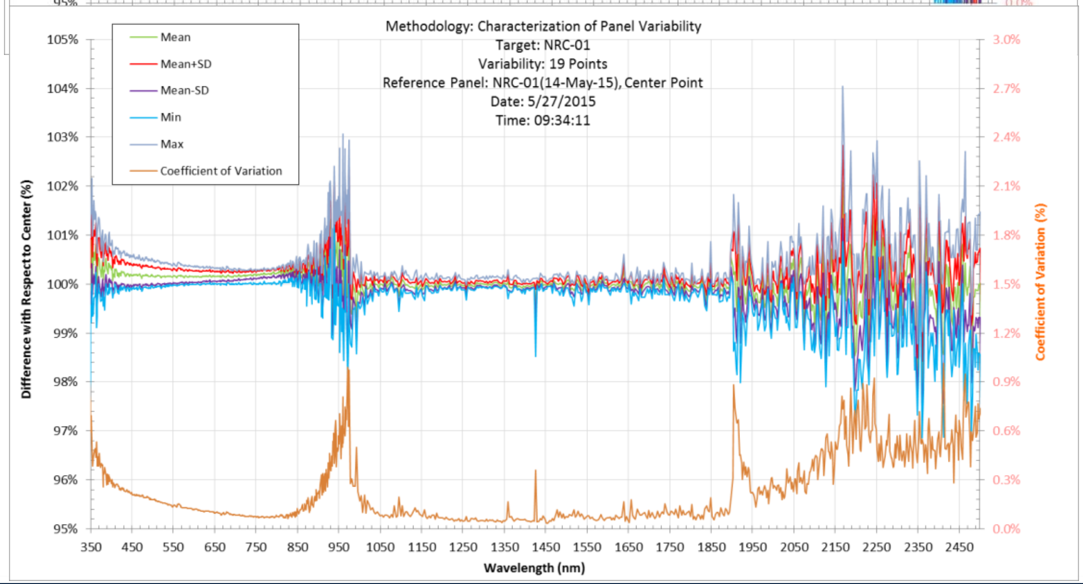


Panel Characterization
Panel Uniformity Check



McGill ASD FIeldSpec3
ASD Lamp

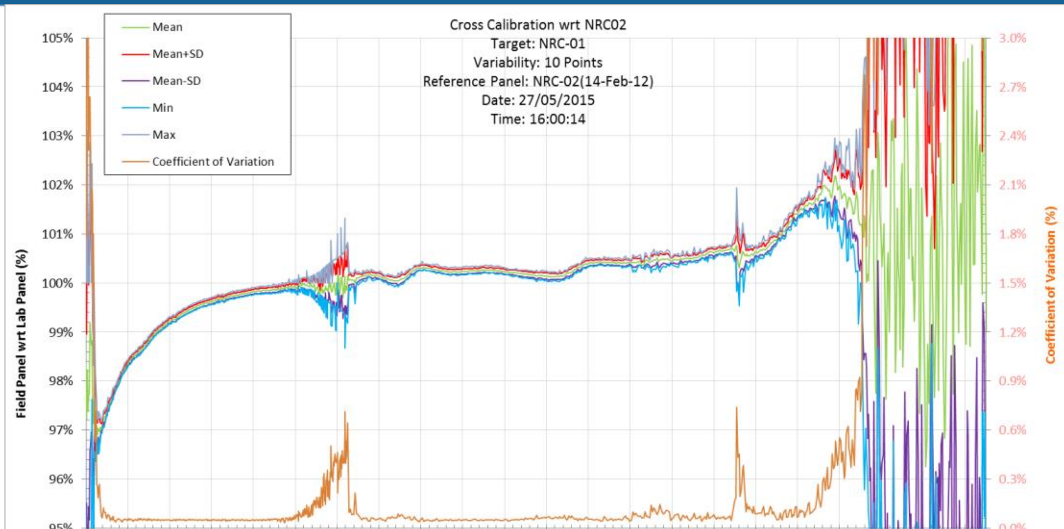
Panel: NRC-01
Field Reference Panel
Well used in the field but in good shape

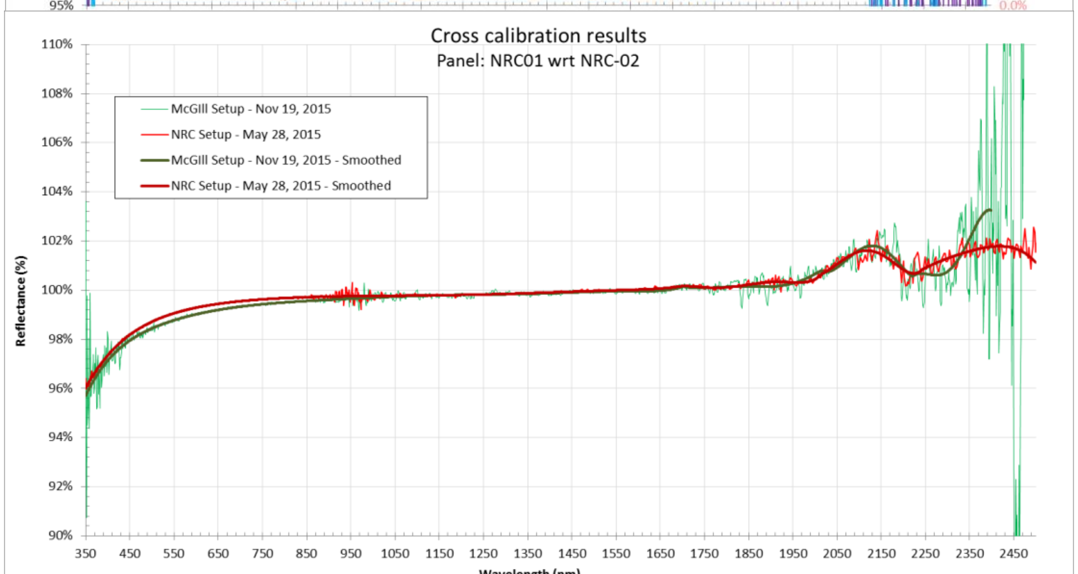


NRC SVC 1024i
750W FEL Stabilized PS

Panel: NRC-01
Field Reference Panel
Well used in the field but in good shape

Panel Characterization
Cross Calibration





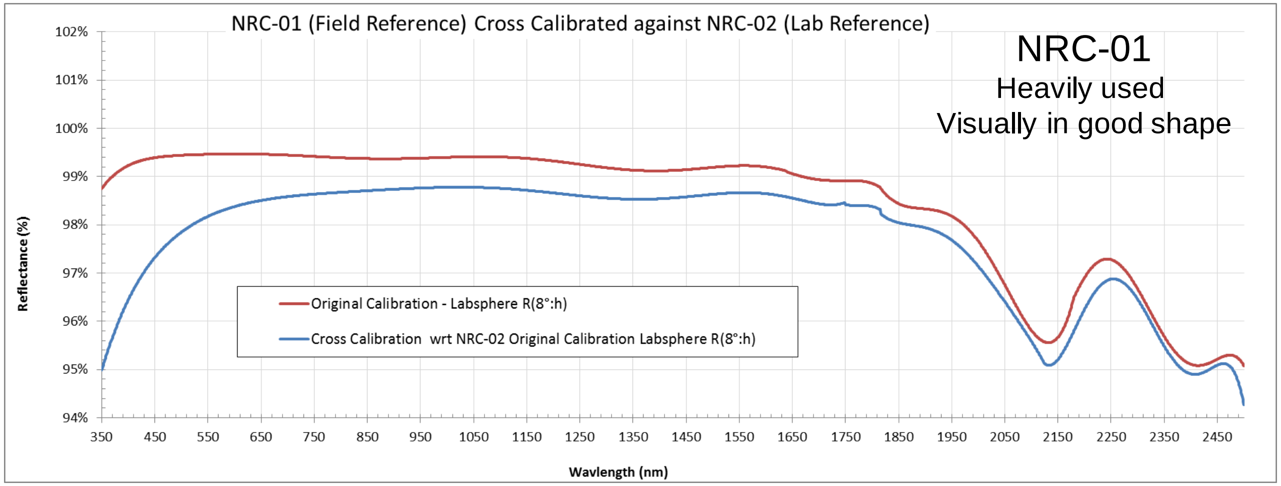
NRC SVC 1024i
750W FEL Stabilized PS

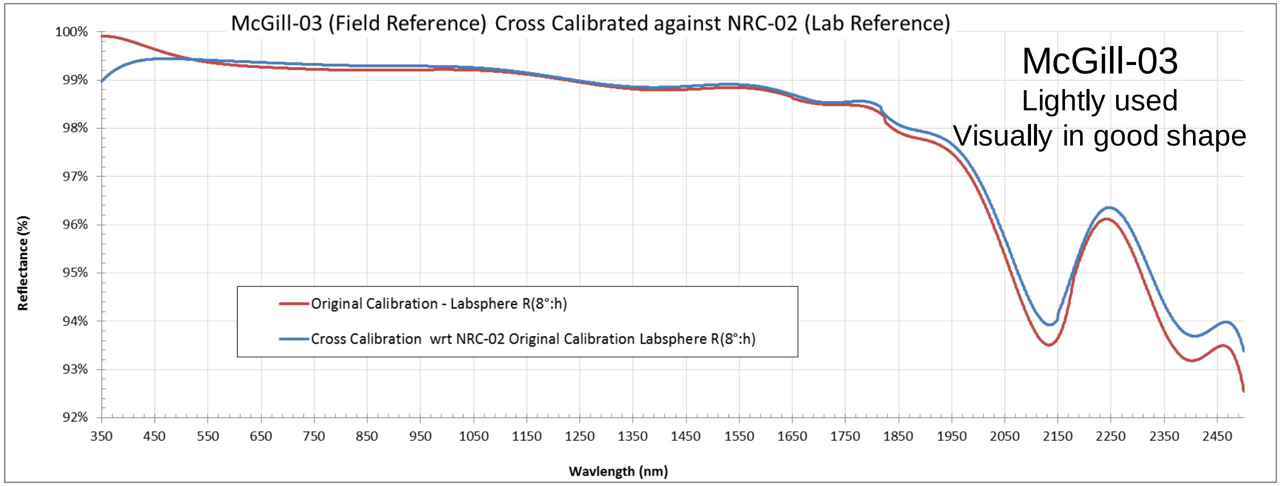
Panel: NRC-01 wrt NRC-02

Panel: NRC-01 wrt NRC-02

Original Ratio (noisy)
from both setups
and fits to data (smooth

Panel Characterization Cross Calibration





<u>Next Step</u>

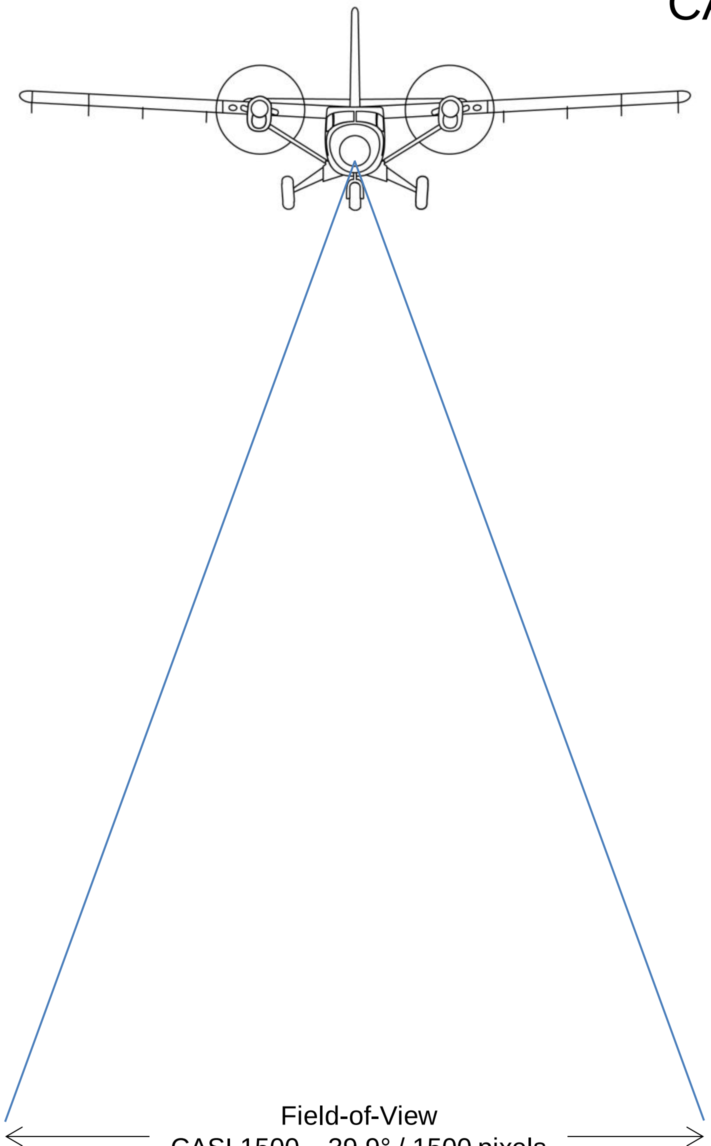
Calibration of Lab Reference and 1 Field Reference Panel (validation target) at University of Arizona Dark Lab.

Cross calibration will then be tied to NIST Spectral Reflectance Standard.

How close are the ground spectra derived from different field spectrometers and/or reference panels?

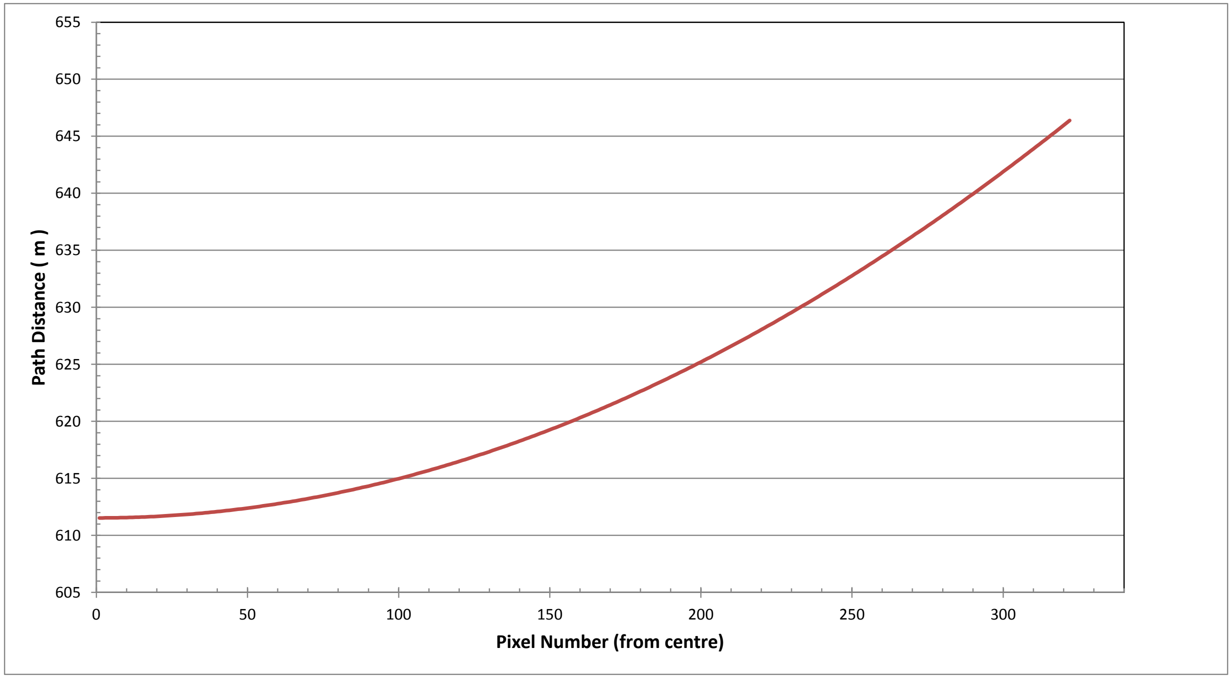
- Experimental data acquired May 27, 2015
  - Clear, stable, sky conditions
  - 2 Field Spectrometers
    - McGill ASD Field Spec3, NRC SVC-1024i
  - 4 Panels
    - NRC-02, McGill-03, CCRS-01, CCRS-07
  - 4 Homogenous Targets
    - Concrete, Asphalt, Black Tarp, Grey Tarp
    - Precise co-alignment of instruments
- Results TBD
  - Comparison of spectra using:
    - Original reference panel calibrations
    - Cross calibrated reference panel calibrations (wrt our lab reference)
    - Cross calibrated reference panel calibrations (wrt University of Arizona reference and NIST)
- Redo with 4 instruments
  - Original 2 + NRCan ASD FieldSpec4 + NRCan SVC-1024i

CASI/SASI Across Track Geometry

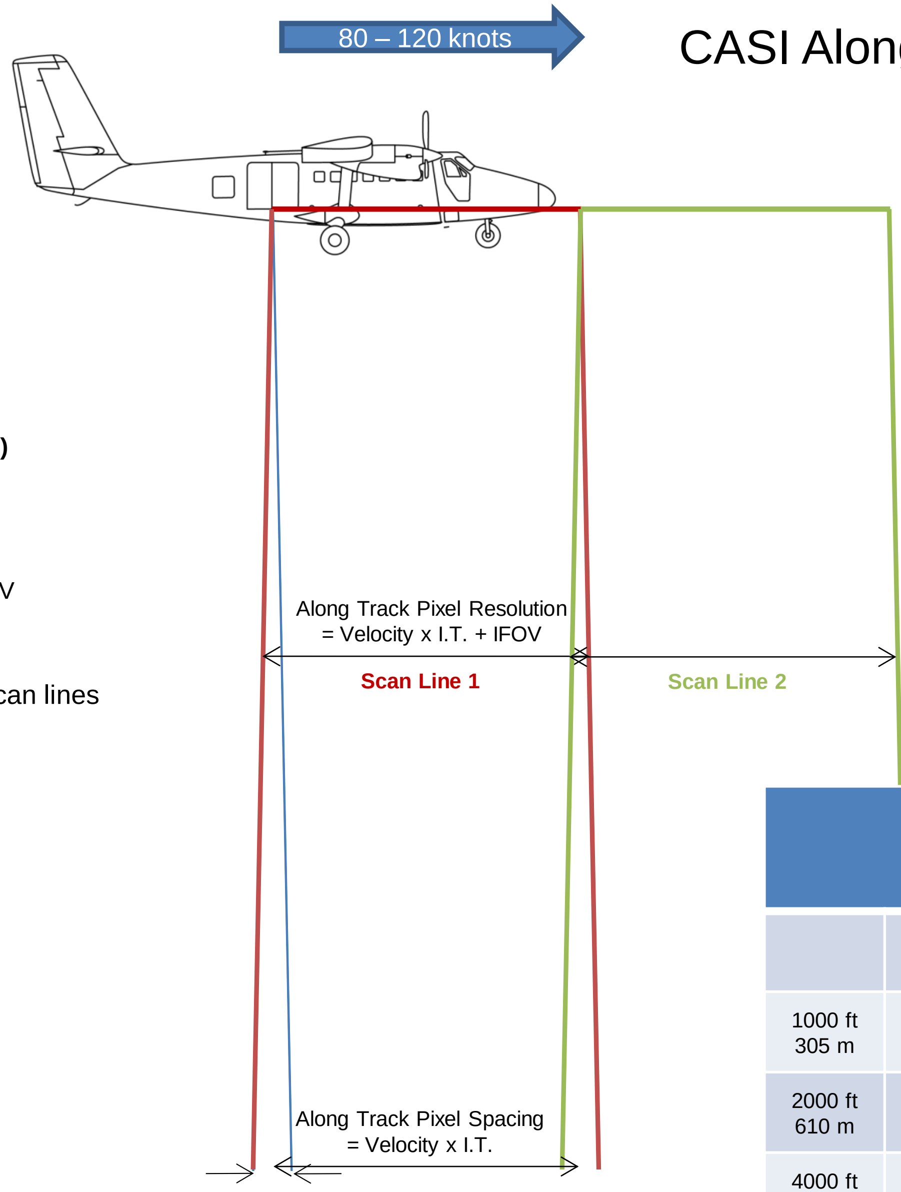


		CASI/CASI2	CASI 1500	SASI
# of pixels		512	1500	644
Field of View (°)		37.7	39.9	39.7
Altitude (AGL) 1000 ft 305 m	Pixel FOV (m)	0.41	0.15	0.33
	Swath Width (m)	209	224	209
2000 ft 610 m	Pixel FOV (m)	0.42	0.30	0.65
	Swath Width (m)	417	449	417
4000 ft 1220 m	Pixel FOV (m)	0.84	0.60	1.3
	Swath Width (m)	834	898	834
8000 ft 2440 m	Pixel FOV (m)	1.68	1.20	2.6
	Swath Width (m)	1668	1796	1668

CASI 1500/SASI Across Track Geometry



CASI Along Track Geometry



Along Track Pixel Spacing

Proportional to Velocity and I.T.

Independent of Altitude

IFOV

Proportional to Altitude

Instantaneous Field-of-View (IFOV)

CASI 1500 - 0.49 mRad

SASI – 1.14 mRad

Therefore

↑ in altitude results in

For both CASI and SASI at nadir

Along Track IFOV = Cross Track IFOV

↑ in IFOV and

↑ in relative overlap between adjacent scan lines

Pixels are never square!

CASI Instruments

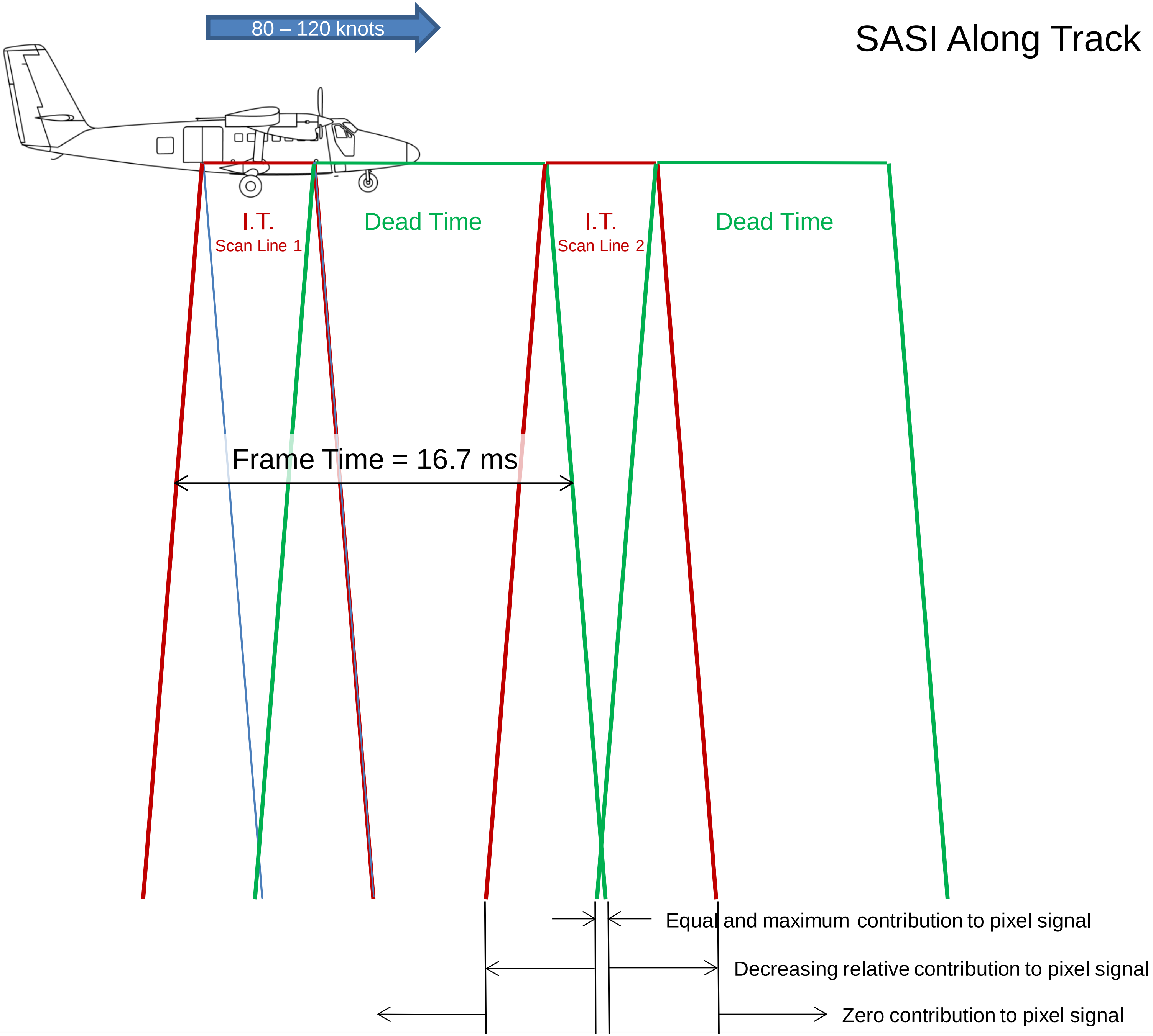
I.T. = Frame Time

SASI

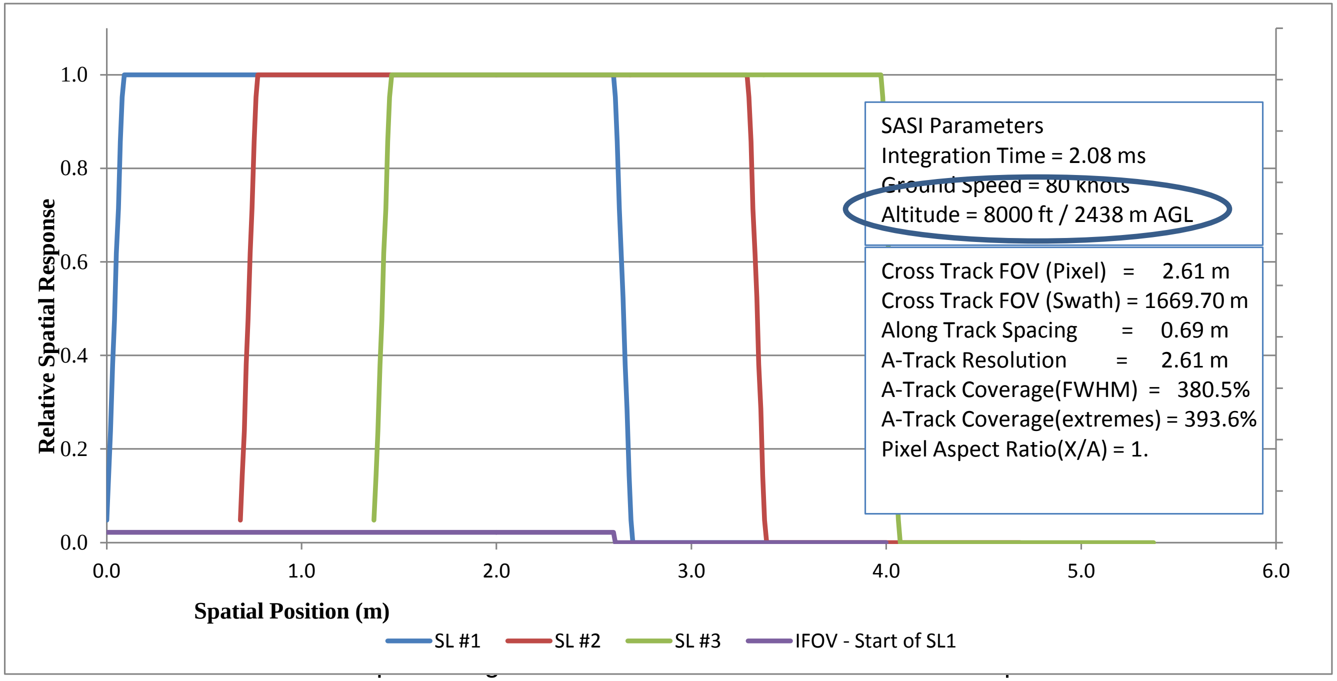
I.T. ≠ Frame Time

CASI 1500 80 knots / 120 knots IT = 30 ms		
	Along Track Pixel Spacing (m)	Along Track Pixel Resolution (m)
1000 ft 305 m	1.24 / 1.85	1.31 / 1.93
2000 ft 610 m	1.24 / 1.85	1.39 / 2.00
4000 ft 1220 m	1.24 / 1.85	1.54 / 2.16
8000 ft 2440 m	1.24 / 1.85	1.84 / 2.46

SASI Along Track Geometry

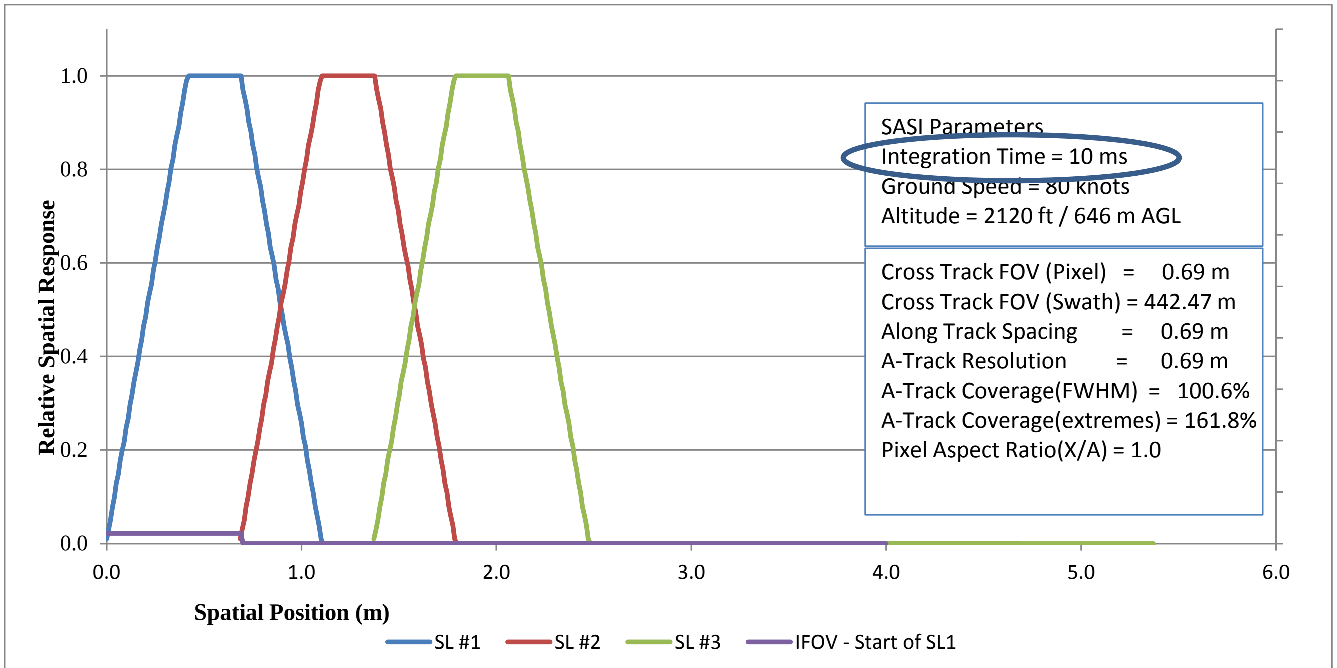


SASI Scan Line (Along Track) Sampling Considerations Effect of Altitude



NRC·CNRC

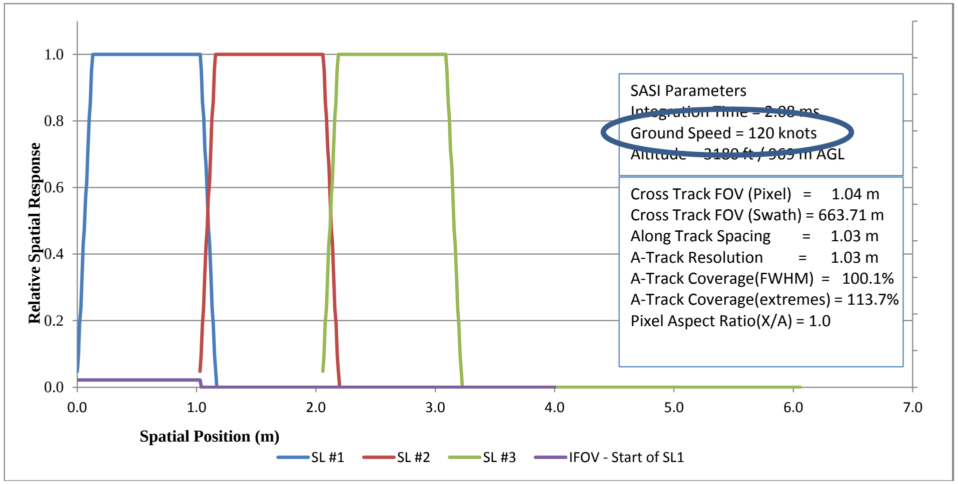
SASI Scan Line (Along Track) Sampling Considerations Effect of I.T.



Long I.T. – unequal contributions from each location on the surface
- large amount of overlap

NRC·CNRC

SASI Scan Line (Along Track) Sampling Considerations
Effect of Ground Speed



Increase Ground Speed – Spread pixel out

NRC·CNRC

Solar Zenith/Azimuth Angle considerations during data acquisition

- Normal procedure
  - Look at Solar Zenith Angle (SZA) as function of Time of Day (ToD) for given date of operation.
  - Discuss acceptable ToD for Image acquisition with client/collaborator.

    i.e. SZA ≥ 60° → Solar Noon ± 2.5 hours

    Lower sun angles → lower radiance levels
  - Monitor forecast (systems, atmospheric pressure, relative humidity, probability of convective cloud development).
  - Development of daytime convective clouds frequently eliminates opportunities for image acquisition during the later part of the previously identified image acquisition window.

Other technical challenges of significance that are in the process of being addressed but are not discussed here

- Atmospheric Correction
  - Visibility derived from:
    - Ground based sun photometer (Microtops II, Cimel)
    - MODIS
    - Model derived (ATCOR 4)
  - Blue end calibration
- Vicarious Calibration
- Use of DEM with Geocorrection process
- Processing logistics (NRC Hyperspectral Database)

Questions?

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