Validation of the WorldView-2 Absolute Radiometric Calibration

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Outline of Discussion

• Approach to absolute radiometric calibration
• Development of in-house capabilities
• Comparison to independent resources
• Presentation of WorldView-2 2013 calibration season
• Low reflectance regime – nonlinearity characterization
• Plans for 2014
  - Launch of WorldView-3
  - DigitalGlobe Fleet radiometric performance
  - Cross-calibration to Landsat archive
A thorough approach to absolute radiometric calibration is employed

• Combination of pre-launch and on-orbit methods
  - Vicarious deployments
  - Multiple targets
  - Include more of dynamic range
  - Attention to nonlinearity, BRDF and other items that affect uncertainty
• Implement best practices and international recommended procedures
  - Committee on Earth Observation Satellites
  - NIST traceability
• Partnership and independent validation
  - South Dakota State University (WorldView-2 & WorldView-3)
  - University of Arizona (WorldView-3)
In-house vicarious calibration capabilities

- DigitalGlobe has invested > $250K
  - Full Range Field Spectrometer (VNIR – SWIR)
  - Specialized calibration targets
  - Shadowband radiometer (Local AERONET Station)
  - Weather station
  - Handheld GPS
  - Ancillary Equipment

- Program in place with Colorado Space Grant Consortium
- A full shake-out of the new instrumentation was performed
  - Results comparable to South Dakota State University & a NASA JPL effort in 2010
2013 Calibration Season summary

- July - November
- Eleven “good” deploys in Longmont, CO, USA
  - Calibration Tarps (10 days)
  - Sandstone Ranch (grass site)
- Six collects over Libya-4
- Two collects over Brookings vegetated site
- Early part of season suffered from “wet” atmosphere in Longmont and wildfires in Brookings
Knowledge of BRDF of targets is critical

- The nimbleness of the DigitalGlobe Fleet allows for highly varying view angles
- Solar angles are also a part of the equation
It is essential to understand the BRDF behavior of calibration targets

- Even the most spectrally and physically uniform of tarps have BRDF effects

- Approach:
  - In-situ measurements always!
  - Empirical model under development
  - Frequent measurements of tarp samples outside
  - Continued throughout the year will add solar geometry to the model
  - University of Arizona lab measurements
A look at the Longmont Results
2013 Longmont, CO: Coastal Band

\[ y = 0.8488x + 6.6668 \]
\[ R^2 = 0.9885 \]

\[ y = 0.8992x \]
\[ R^2 = 0.9832 \]

Deep space looks used

Grass

48% Tarp

3% Tarp

(Thuillier 2010 Solar Curve Used)
2013 Longmont, CO: Blue Band

\[ y = 0.9649x + 4.8534 \]
\[ R^2 = 0.9958 \]

\[ y = 0.9945x \]
\[ R^2 = 0.9942 \]

(Thuillier 2010 Solar Curve Used)
2013 Longmont, CO: Green Band

\[ y = 1.0151x + 2.8854 \quad R^2 = 0.9973 \]

\[ y = 1.0342x \quad R^2 = 0.9966 \]

Ground Based Measurement Propagated to TOA by MODTRAN 5 (W \( \mu \text{m}^{-1} \text{m}^{-2} \text{sr}^{-1} \))

(Thuillier 2010 Solar Curve Used)
2013 Longmont, CO: Yellow Band

\[ y = 1.0082x + 2.4333 \]
\[ R^2 = 0.9966 \]

\[ y = 1.0254x \]
\[ R^2 = 0.996 \]

Ground Based Measurement Propagated to TOA by MODTRAN 5 (W \(\mu\text{m}^{-1}\text{m}^2\text{sr}^{-1}\))

(Thuillier 2010 Solar Curve Used)
2013 Longmont, CO: RedEdge Band

\[ y = 0.9799x + 3.2477 \]
\[ R^2 = 0.9951 \]

\[ y = 1.0072x \]
\[ R^2 = 0.9936 \]

Ground Based Measurement Propagated to TOA by MODTRAN 5 (W \( \mu m^{-1} m^{-2} sr^{-1} \))

(Thuillier 2010 Solar Curve Used)
2013 Longmont, CO: NIR1 Band

\[
y = 1.0031x + 2.6252 \\
R^2 = 0.995
\]

\[
y = 1.0272x \\
R^2 = 0.9938
\]

Satellite Radiance (W μm⁻¹m⁻²sr⁻¹)

Ground Based Measurement Propagated to TOA by MODTRAN 5 (W μm⁻¹m⁻²sr⁻¹)

(Thuillier 2010 Solar Curve Used)
Comparison to other groups

- Frenchman Flat, Nevada, USA
- Libya-4, Saharan Desert

Graph showing % difference for various regression models compared to MODTRAN for different wavelength bands of WorldView-2.
SDSU empirical absolute calibration model using Pseudo Invariant Calibration Sites (PICS):

- PICS typically used for radiometric stability
- Potential exists for **absolute** calibration
- In particular, Libya-4 Saharan Desert Site
- Promising results, some thoughts
  - Blue band sensitive to AOD
  - RedEdge and NIR2 sensitive to Water Vapor
  - Low signal in NIR2 creates higher uncertainties
  - Surface absorption features in NIR2
  - Even a small bias or offset difference in NIR2 would cause a greater uncertainty than in other bands
- Advantages:
  - Independent verification of vicarious method
  - Data can be collected year round
  - Allows for stability observations over time
- DigitalGlobe fleet observations in 2014 will add to the view angle BRDF model AND view azimuth
Effects amplified in low reflectance regime

- Atmospheric noise (esp @ high ONA)
- More sensitive uncertainties in AOD and water vapor
- Adjacency
- Uncertainties in ground instruments and protocols
- Nonlinear response
- Offset drift
- Grass targets & 3% tarp will help develop understanding of these effects on the entire dynamic range
Nonlinear Response in Low Reflectance Pixels

- WorldView-2 is well behaved
- However, science that uses darker pixels (e.g. deep water applications) may require a more rigorous approach
- Pre-launch test data used to create nonlinearity factors
  - Exponential fit to residual nonlinearity in low radiance regime
  - (These results can be made available to interested scientists)

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<td>N2</td>
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* Approximate average threshold for each band over TDI 6 - 24
Radiometric Calibration is an ongoing mission

- Preliminary WorldView-2 results show agreement with independent sources
- Continued study of low-reflectance regime
- Improvements for 2014
  - Evolve the BRDF model for tarps
  - In-situ reflectance measurements at every tarp deployment
  - Aerosol and water vapor measurements directly over site (Shadowband install)
  - Focus on high ONA collects
  - We have a full season and should be able to get more data!
  - Fingers crossed for more cooperative skies in 2014
- Validation of entire fleet
  - Continue to refine the WorldView-2
  - GeoEye-1, QuickBird, IKONOS and WorldView-2 & WorldView-3
Ongoing efforts for 2014 include the calibration of three new sensors

- WorldView-3 check-out includes a rigorous absolute calibration effort
- Local tarp deployments in Longmont, CO, USA
- South Dakota State University vegetated site in Brookings, SD, USA
- Side-by-side vicarious campaign with University of Arizona at Lunar Lake/Railroad Valley, NV, USA
  - Effort to validate WorldView-3 coefficients AND DigitalGlobe vicarious approach
- Cross-calibration of DigitalGlobe Fleet with Landsat archive