GODDARD SPACE FLIGHT CENTER

Uncertainties for Pre- And Post-Launch Radiometric Calibration of Imaging Spectrometers for Multi-Sensor Applications

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Challenge

Develop methods to combine data products from multiple sensors and do this with no noticeable sensor-related effects

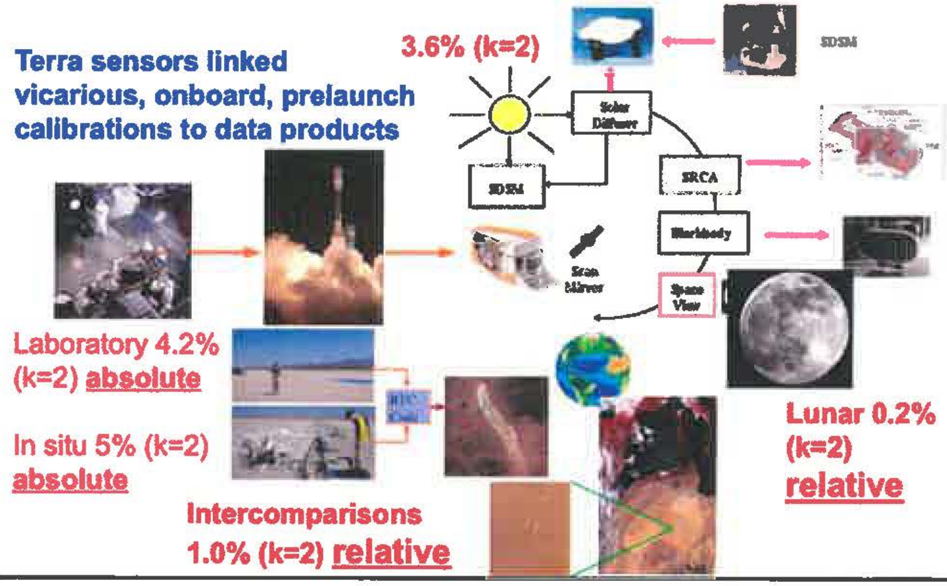
Problem more difficult with increase in smallsat and constellations use and variety of sensor designs, calibrations, and traceability

Variety of algorithms for data production adds further complications

Current methods for absolute and relative radiometric calibration

Terra MODIS calibration example showing multiple pathways to on-orbit calibration with uncertainties

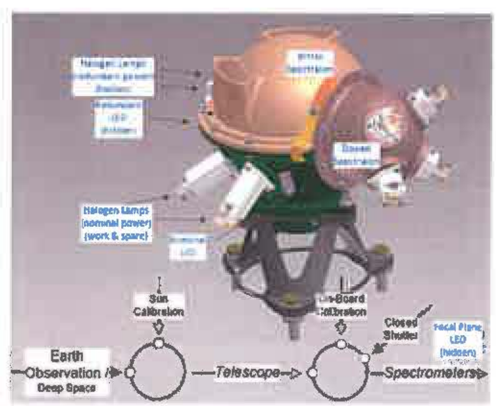
- How do we combine results from multiple sensors using multiple calibration approaches?
- What will be the uncertainty in the combined product?



EnMap example

Imaging spectrometer calibration approaches follow similar methods as those for other sensor types

- EnMap calibration approach will provide an absolute radiometric calibration with uncertainty <5% (k=1)
  - Relative radiometric stability ± 2.5% (between two consecutive calibrations)
  - Spectral calibration: 0.5 nm VNIR; 1 nm SWIR
  - Spectral stability < 0.5 nm
- Absolute radiometric calibration through onboard solar diffuser
- Conversion to physical units through an assumed solar spectral irradiance model combined with the diffuser's measured BRDF



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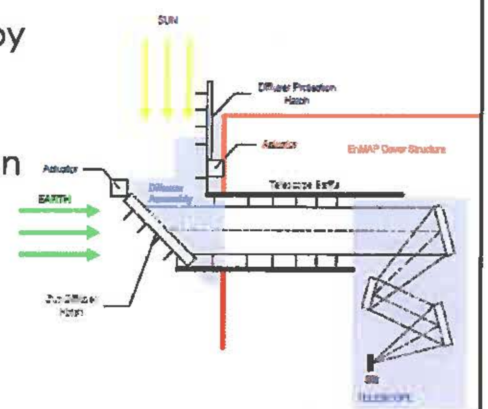
EnMap example

Prelaunch radiometric calibration of EnMap concentrates on determining diffuser BRDF

- Traceability to reflectance standards and the solar spectral irradiance
- Laboratory calibration / characterization done by OHB, including the national lab PTB for traceability, and supported by DLR
- Data product (by DLR GS) uncertainties based on simulated data by GFZ and OHB
- Diffuser mounted to mechanism that rotates panel in front of telescope covering the full optical path
- Conversion to physical units is through spectral irradiance model combined and diffuser BRDF



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Detector-based absolute calibrations reduce uncertainties

Source-based radiance calibration - Lowest absolute uncertainty (RSS, k =2) at 650 nm is 1.5% dominated by lamp irradiance and panel BRF

FEL lamp [1 kW quartz halogen lamp]

NIST calibrated 10'' Spectralon panel illuminated at 50 cm

Detector-based radiance calibration- Absolute uncertainty (RSS, k =2) is 0.6%

Detector-based calibration is traceable to optical Watt via the detector calibration

Source-based follows similar traceability but relies on the stablity of the lamp source

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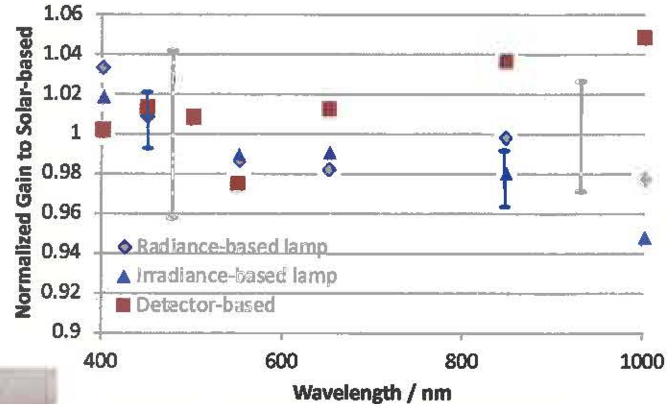
Uncertainties also being reduced via independent comparisons



Results shown here are based on four separate traceability paths

All traceability paths are based on US national lab (NIST) standards

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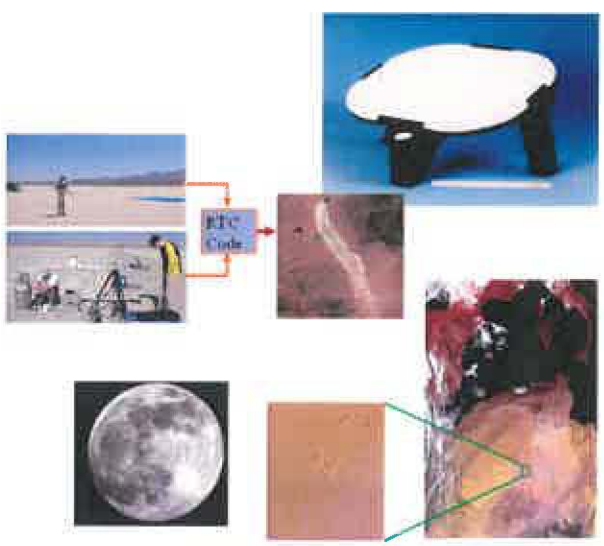
Post-launch calibration approaches

Methods range from onboard sources, lunar views, and vicarious methods

- Onboard sources include lamps and solar diffusers
- Vicarious methods rely on in situ data collections, modeled test sites, and sensor intercomparisons
- All of the methods provide both absolute and relative calibrations
- Specific methods and approaches depend on
  - Spatial resolution
  - Swath width
  - Pointing capability



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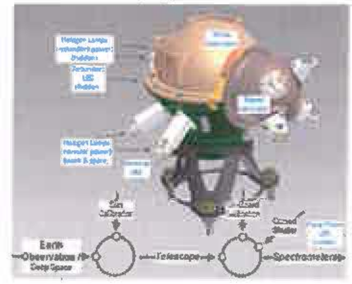
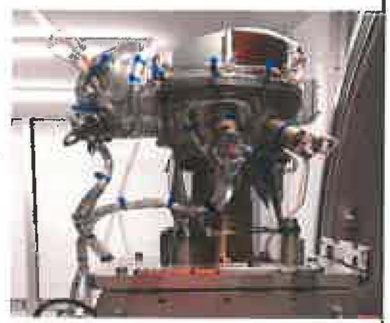
Post-launch calibration approaches for imaging spectroscopy

Recent and upcoming Imaging spectrometer sensors include traditional vicarious and onboard calibration methods



- Philosophy is to use multiple methods for specific instrument evaluations
- Also use multiple methods to decouple sensor effects from other effects
- EnMap demonstrates these ideas
  - Ground segment covers instrument monitoring, data quality assessments as well as the in-orbit calibration using the OnBoard Calibration Assembly
  - "Product validation" will rely on combination of vicarious and scene-based methods



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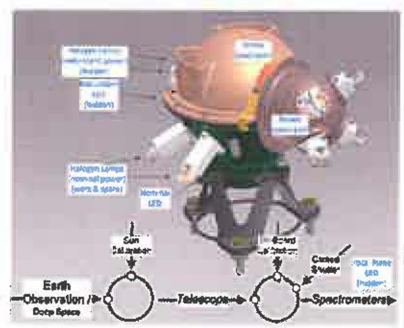
Post-launch calibration approaches for imaging spectroscopy

- EnMap relies on multiple methods to provide insight for specific sensor behavior
  - Full aperture solar diffuser for absolute radiometric
  - Integrating sphere for relative radiometric
  - Doped integrating sphere for absolute spectral
  - LEDs at Focal Plane for linearity
  - Deep Space & closed shutter for dark reference measurements
  - Vicarious methods for geometric calibration (boresight angles)



- EnMap relies on multiple methods to decouple sensor effects from other effects
  - Independent validations with international partners
  - Diffuser design to limit premature degradation from added ultraviolet exposure and avoid stray light reflections

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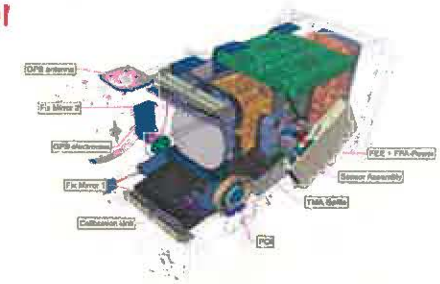
DESIS (DLR Earth Sensing Imaging Spectrometer) example

Part of Teledyne's MUSES (Multi-User System for Earth Sensing) package operating oı

- DESIS is, in part, a commercial data buy
- Teledyne follows a similar calibration path as the research instruments
  - Teledyne's requirements for absolute radiometric calibration are limited
  - Pre-launch characterization took place at DLR Berlin labs
  - In-orbit calibration is a joint activity with DLR
    - Spectral & radiometric calibration baseline with on-board calibration unit (2 LED banks)
    - Vicarious calibration and validation using RadCalNet, CEOS PICS, Pinnacles (CSIRO), cross-validation with S-2 & L-8
  - Independent validation by I2R on behalf of Teledyne



Source: KRUTZ et al. (2019), MDPI SENSORS

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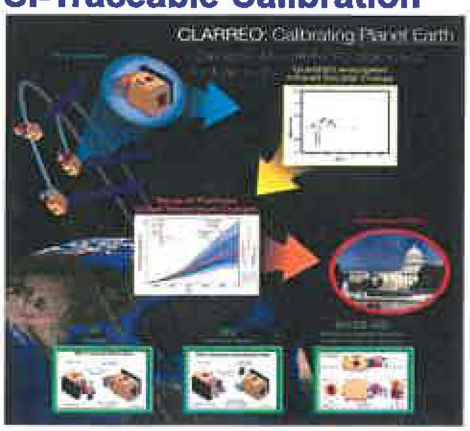
CLARREO Pathfinder imaging spectrometer approach is unique

- Determine at-sensor reflectance through direct solar views
- One goal of Pathfinder is to demonstrate the ability to reduce reflectance uncertainty by > 4 times currently available sensors

CLARREO Pathfinder is directed mission through the NASA Science Mission Directorate – Earth Science Division

Demonstrate high accuracy SI-Traceable Calibration



Launch planned for late CY2022 – early CY2023 to International Space Station for one-year mission

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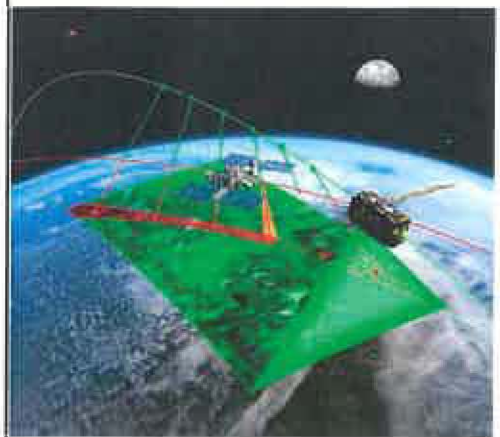
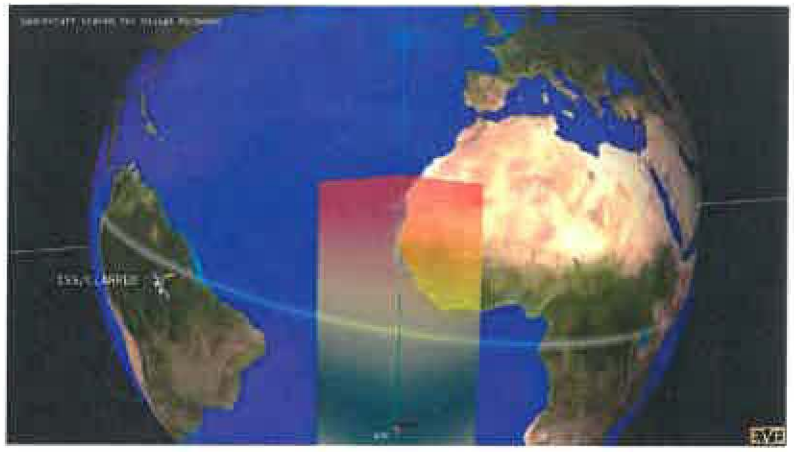
CLARREO Pathfinder will demonstrate Inter-Calibration Capabilities





Use the improved accuracy to serve as an in orbit reference spectrometer for advanced inter-calibration of other key satellite sensors across the reflected solar spectrum

Demonstrate that the inter-calibration can be done with better than 0.3% uncertainty

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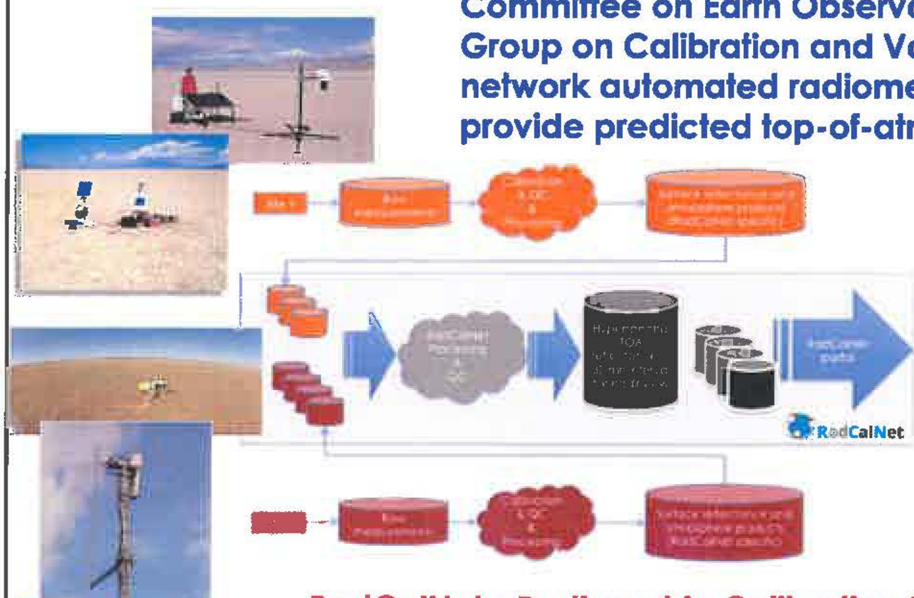
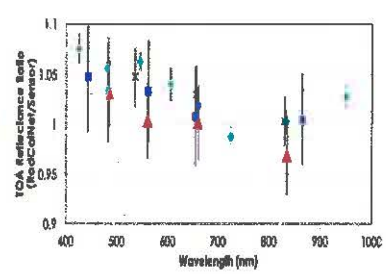
RadCalNet

Committee on Earth Observation Satellites Working Group on Calibration and Validation is working to network automated radiometric calibration sites to provide predicted top-of-atmosphere reflectance





RadCalNet - Radiometric Calibration Network

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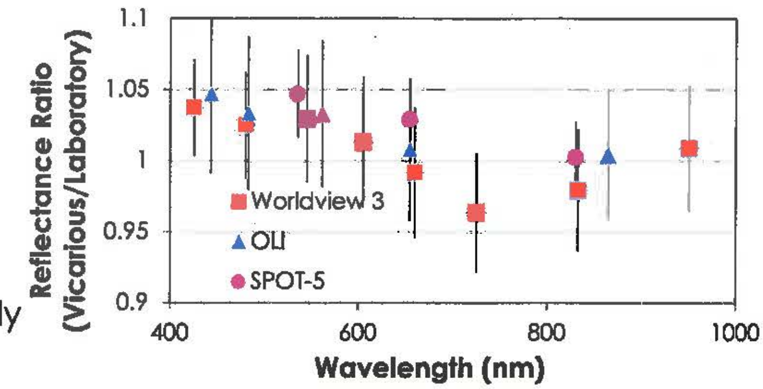
RadCalNet Inter-calibration example

All three sensors meet their absolute radiometric uncertainty are harmonised

- **Users see noticeable differences!!!**
- Some differences are physically based
  - Atmospheric absorption effects
  - View geometries
  - Collection times
  - Spatial resolutions



Objective of calibration process is to verify requirements

Objective for some users is to eliminate all sensor related effects for seamless comparisons

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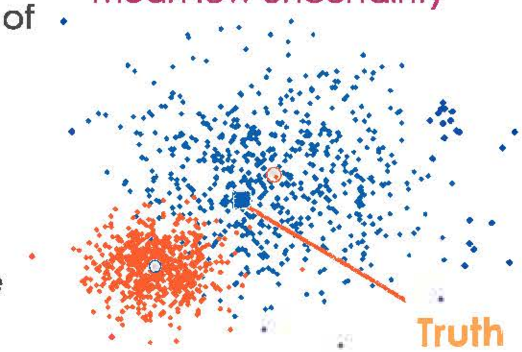
Traceability, Uncertainties, Truth

Illustrate with two sets of measurements with systematic and random uncertainties and the Truth

- Random uncertainty based on a Gaussian distribution variance
- Systematic is represented by the mean of the Gaussian
- Which is the better measurement?
- What's the best way to combine the measurement sets to develop an estimate of the "truth"
- What is the best way to harmonise if we do not know "truth"
- Is harmonising to one of the data sets sufficient given that the result may be biased to "truth"

SI-traceability does **NOT** mean low uncertainty



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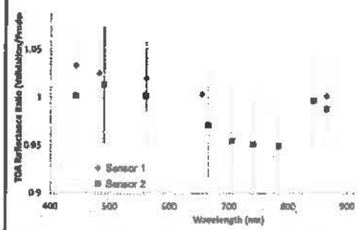
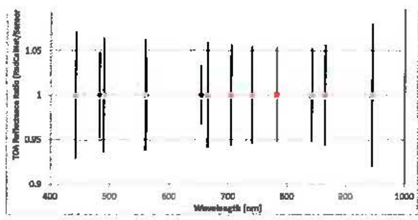
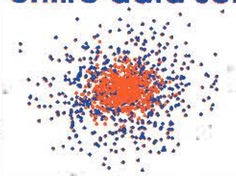
How to harmonise? And what are the uncertainties?

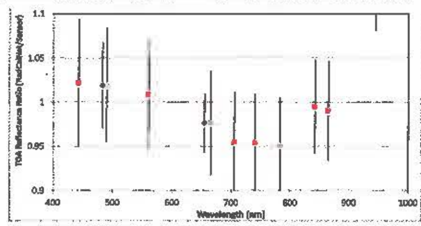


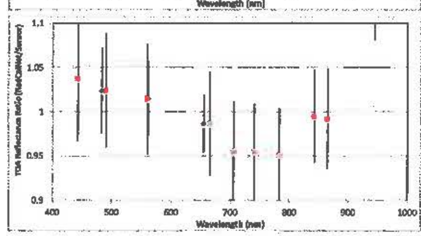


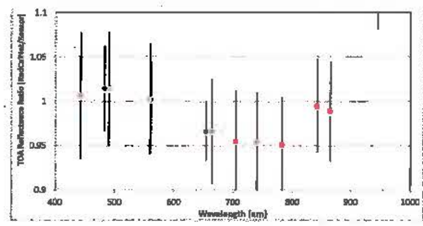
- Scale all to unity assuming RadCalNet is the reference
- Scale to average difference
- Scale one sensor to the other based on
  - Higher SNR
  - Better spatial resolution
  - Larger number of bands
  - Absolute uncertainty
  - Traceability path

Should also consider how to incorporate new sensors and whether the community wants to periodically rescale entire data sets









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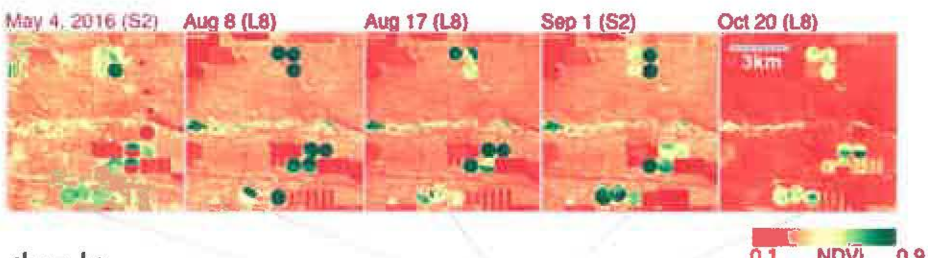
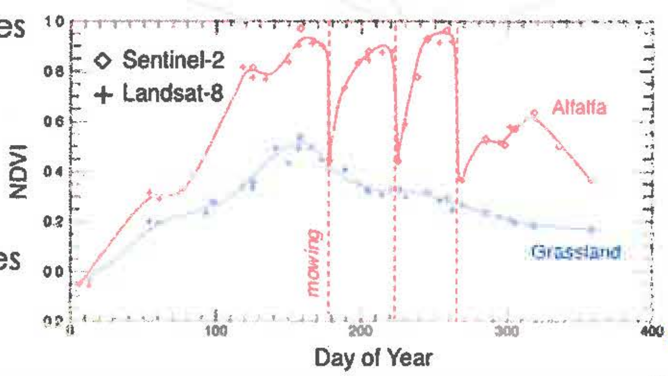
At what processing level should data products be harmonised?

Harmonised Landsat/Sentinel-2 NDVI Products - Laramie County, Wyoming, USA courtesy J. Masek, NASA/GSFC



Noise in plot can be due to
- Intercalibration differences
- Residual spectral effects
- BRDF effects
- Residual atmospheric impacts

Some users want differences to be forced to zero



Seasonal phenology (greening) for natural grassland (blue line) and irrigated alfalfa fields (red line) near Cheyenne Wyoming observed from Harmonized Landsat/ Sentinel-2 data products. The high temporal density of observations allows individual mowing events to be detected within alfalfa fields. HLS Products available from https://hls.gsfc.nasa.gov

Summary

Harmonisation is necessary to maximize the use of satellite-based data to improve temporal, spatial, and spectral sampling

- Harmonising to an absolute radiometric scale will not lead to data uniformity
  - Users are looking for <<0.5% effects in their studies
  - Climate quality reference sensors will not provide desired uniformity for the user communities
- Harmonising in a relative sense is not bad
  - Need to recognize it is being done
  - Need to understand that it works better with overlap in sensor operation to succeed (but not necessarily coincident views)
- Uniformity destroys real differences between sensors
  - Will not be an issue for true biophysical products
  - More of an issue at lower level products (radiance, reflectance, temperature)

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