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**

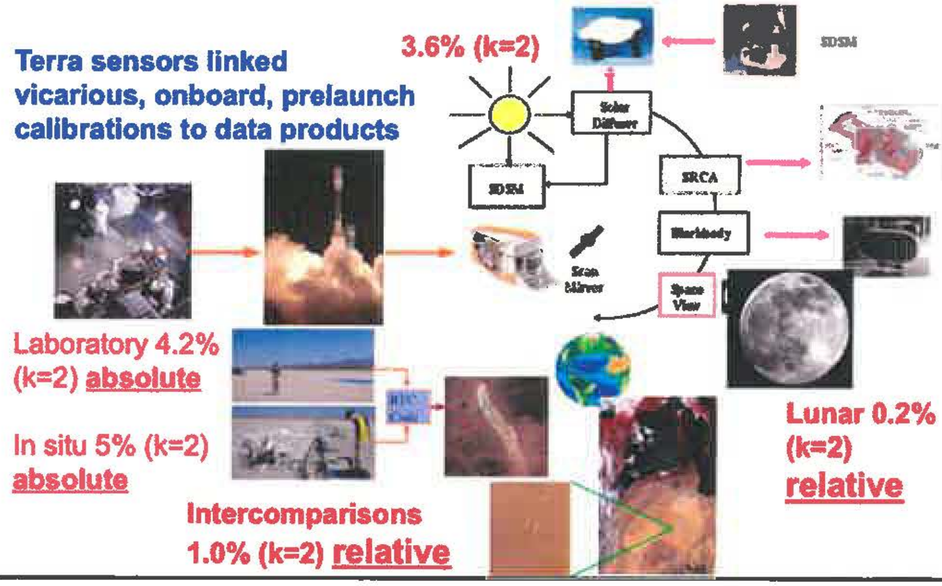
Problem more difficult with increase in smallsat and constellations use and variety of sensor designs, calibrations, and traceability

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

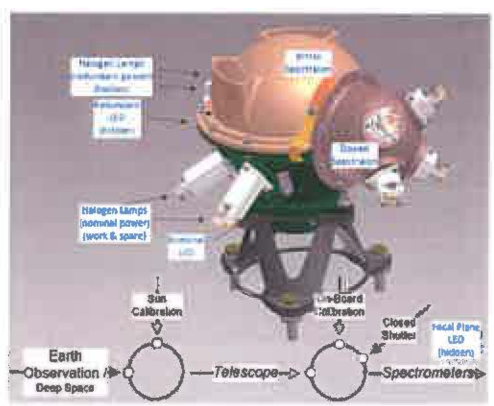
- How do we combine results from multiple sensors using multiple calibration approaches?
- What will be the uncertainty in the combined product?




## 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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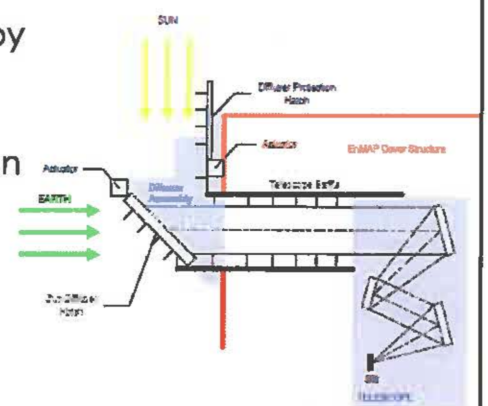
## EnMap example

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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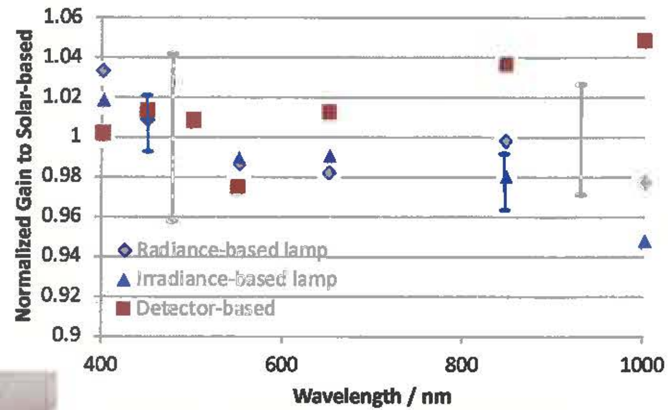
## Uncertainties also being reduced via independent comparisons




**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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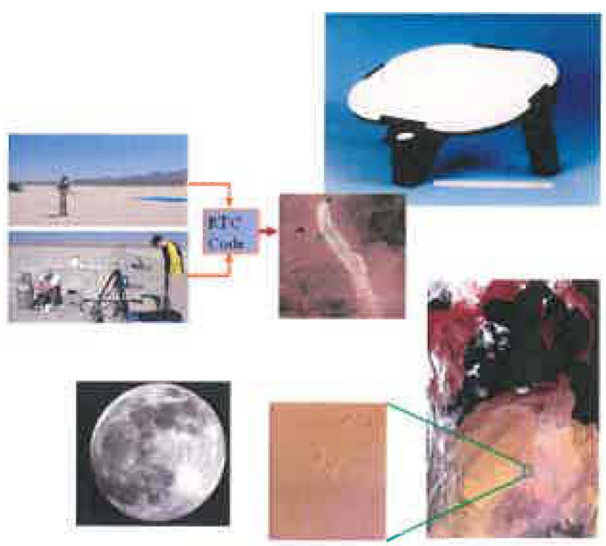
## Post-launch calibration approaches

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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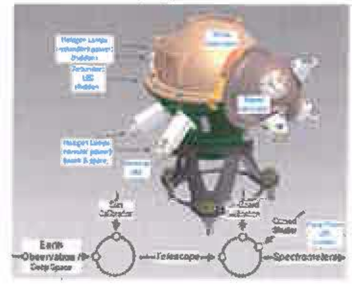
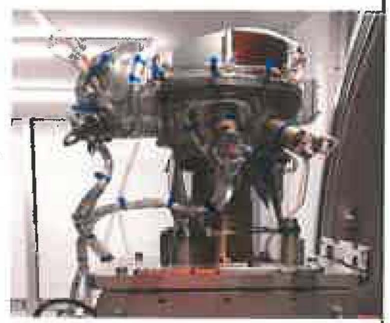
## Post-launch calibration approaches for imaging spectroscopy

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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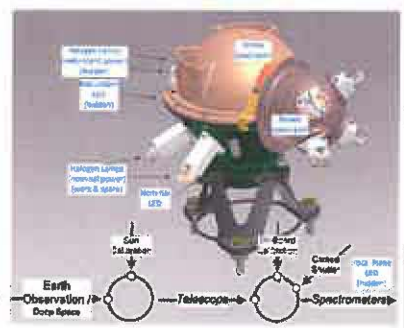
## Post-launch calibration approaches for imaging spectroscopy

- 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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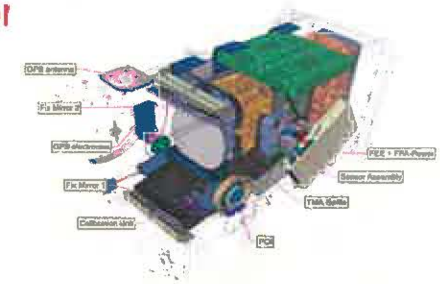
## DESIS (DLR Earth Sensing Imaging Spectrometer) example

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

- 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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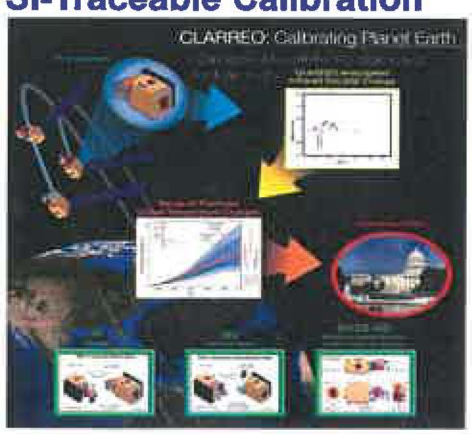
## CLARREO Pathfinder imaging spectrometer approach is unique

- 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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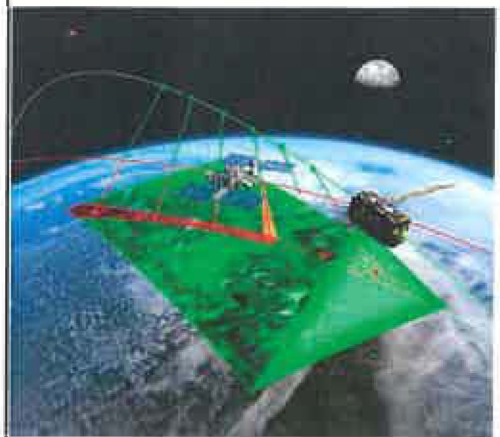
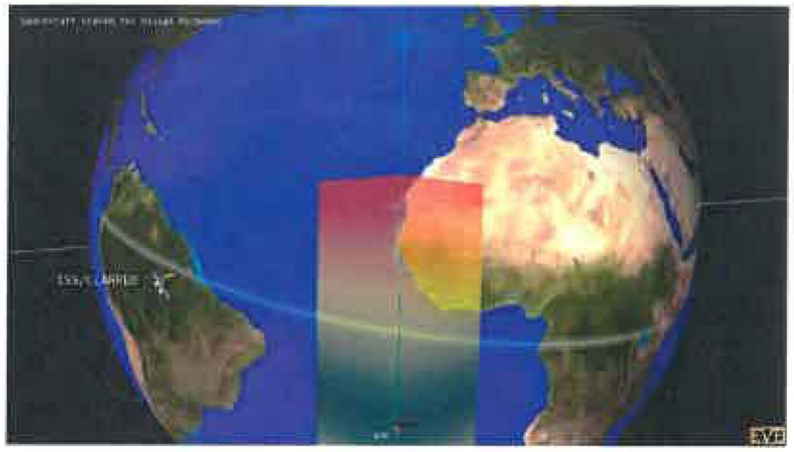
## CLARREO Pathfinder will demonstrate Inter-Calibration Capabilities





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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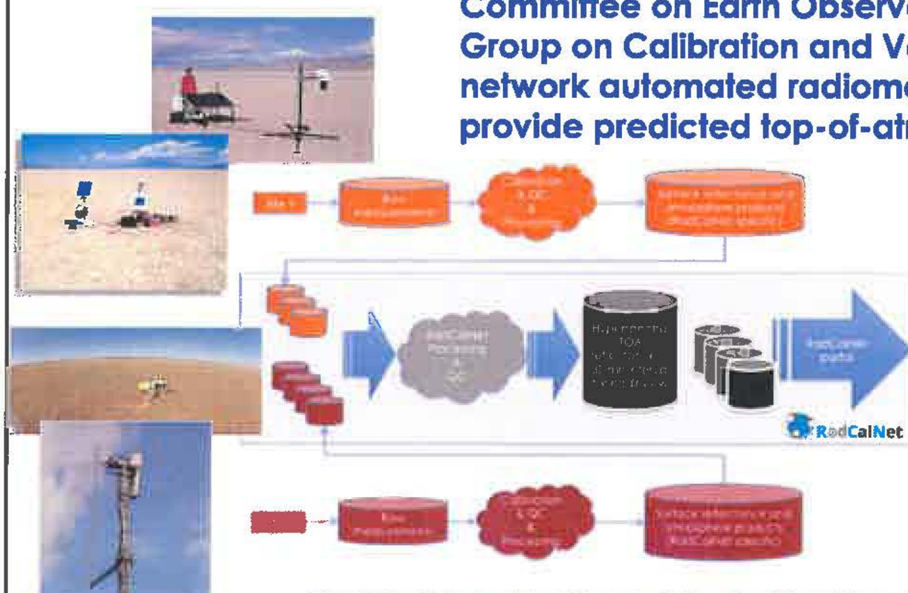
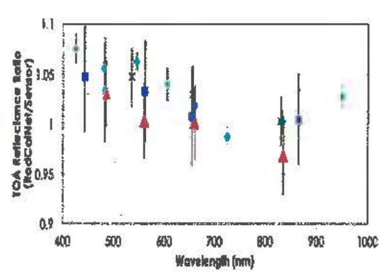
## RadCalNet

**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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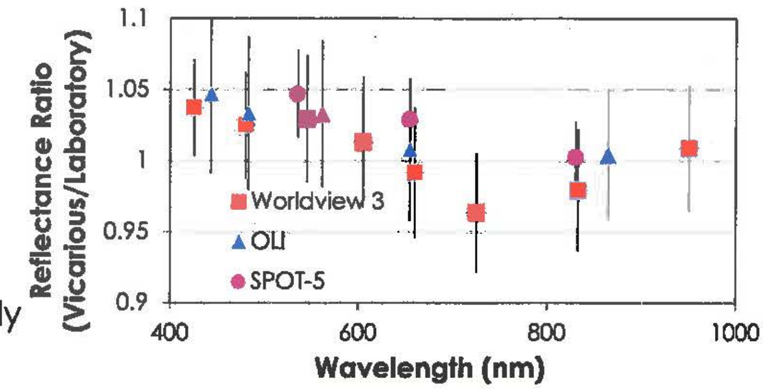
## RadCalNet Inter-calibration example

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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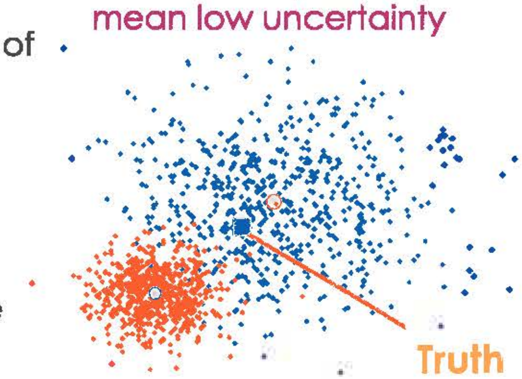
## Traceability, Uncertainties, Truth

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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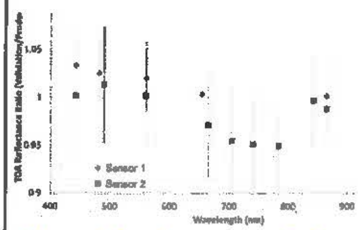
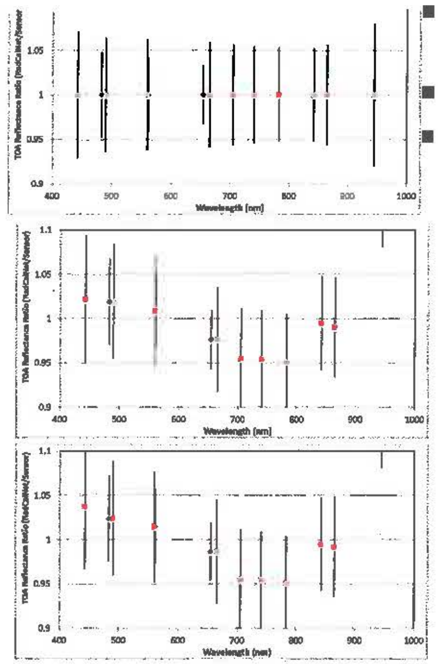
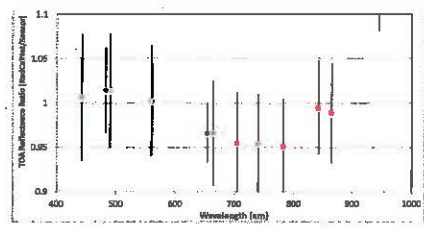
## How to harmonise? And what are the uncertainties?



- 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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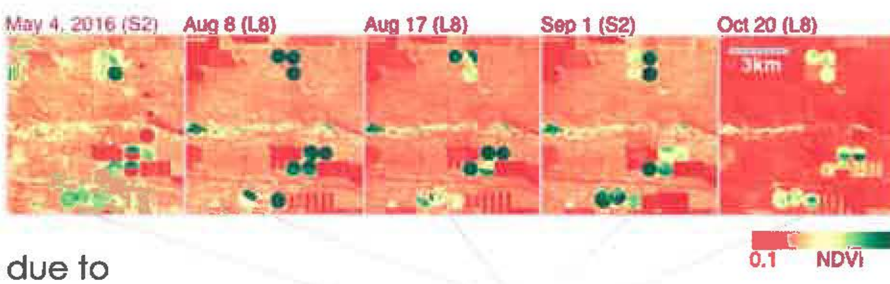
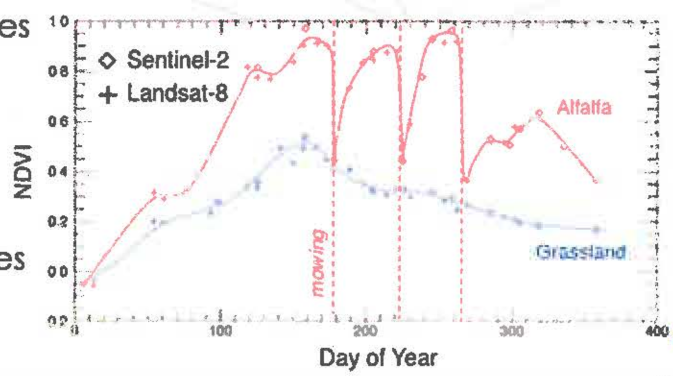
## At what processing level should data products be harmonised?

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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