Role of imaging spectrometer data for model-based cross-calibration of imaging sensors

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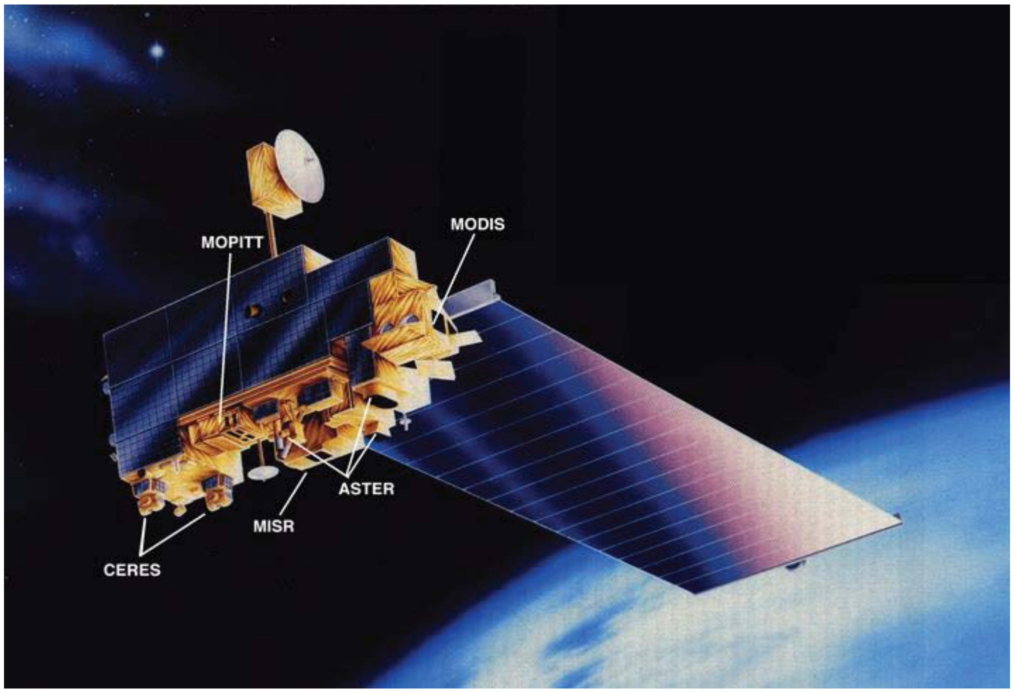
Need for cross-calibration

Climate-system modeling will rely on a wide array of current and future systems

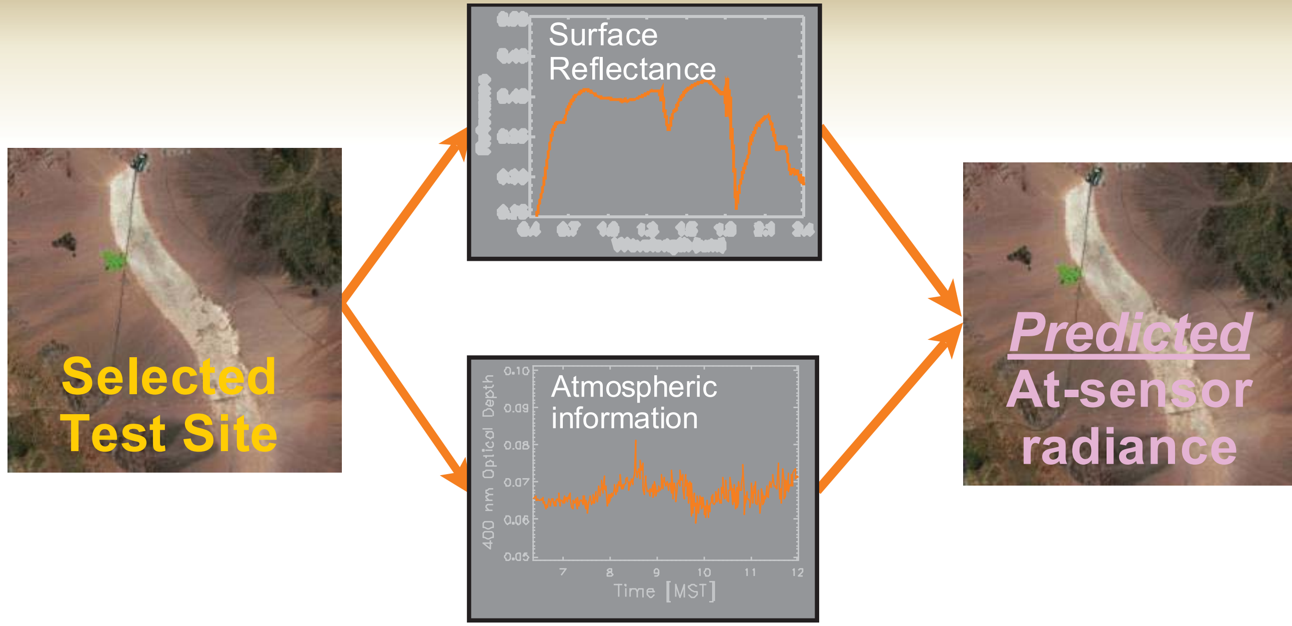


Terra platform synergy of multiple sensors has been key to the mission's success

- Research-quality systems (OLI and MSI)
- Operational weather systems (VIIRS and OLCI)
- Requires consistently calibrated and validated data sets
  - Intercalibration to a few high-quality sensors
  - Valid across time and multiple countries

Talk overview

Discuss SI-traceable cross-calibration approach relying on test site characterization

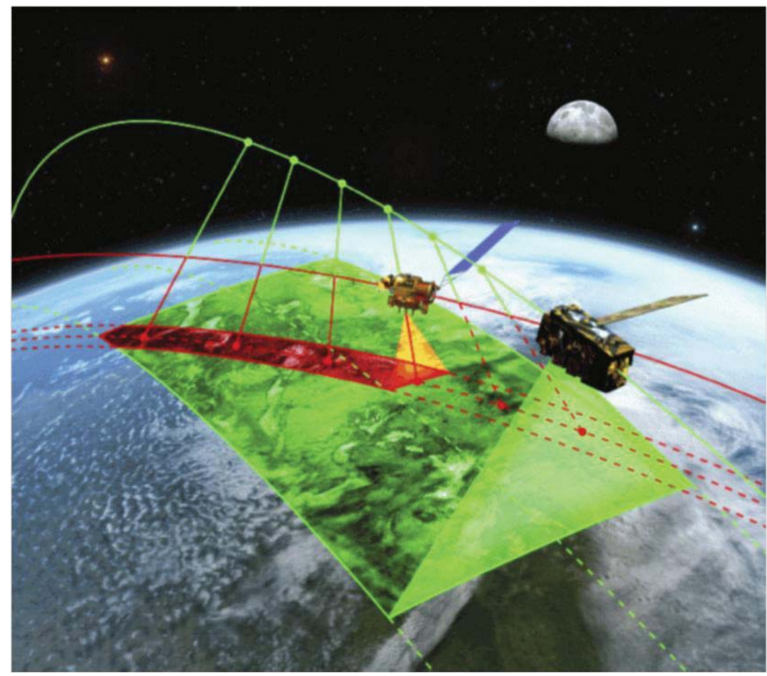


- Site characterization benefits from imaging spectrometry to determine spectral bi-directional reflectance of a well-understood surface
- Outline
    - Cross calibration approaches
    - Uncertainties
    - Role of imaging spectrometry
    - Model-based site characterization
    - Application to product validation

On-orbit cross calibration

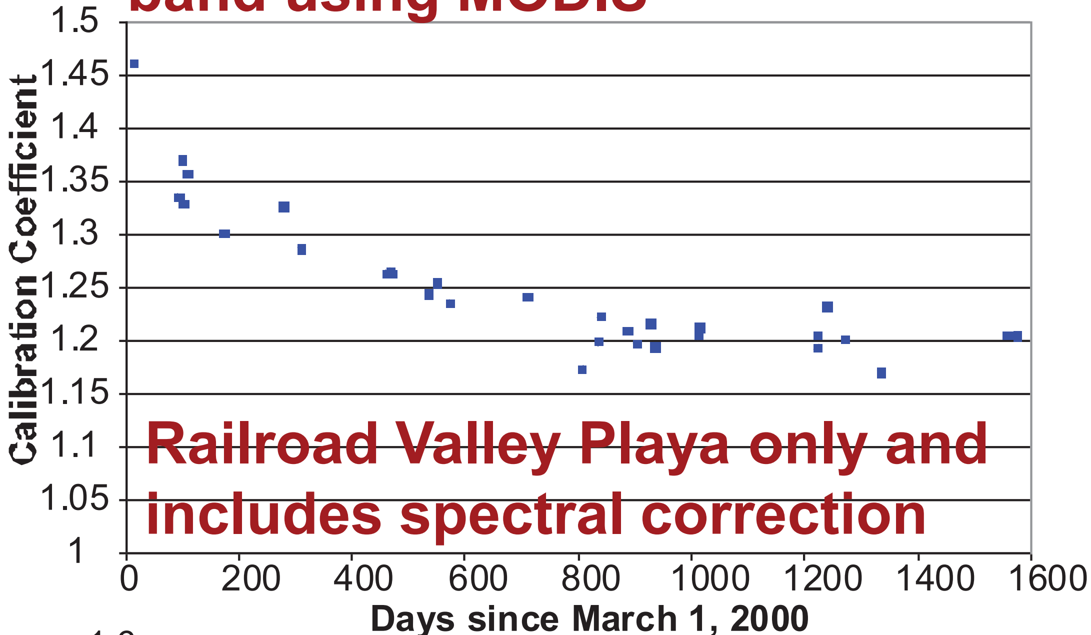
Recent years have seen great advancements in approaches for cross-calibration

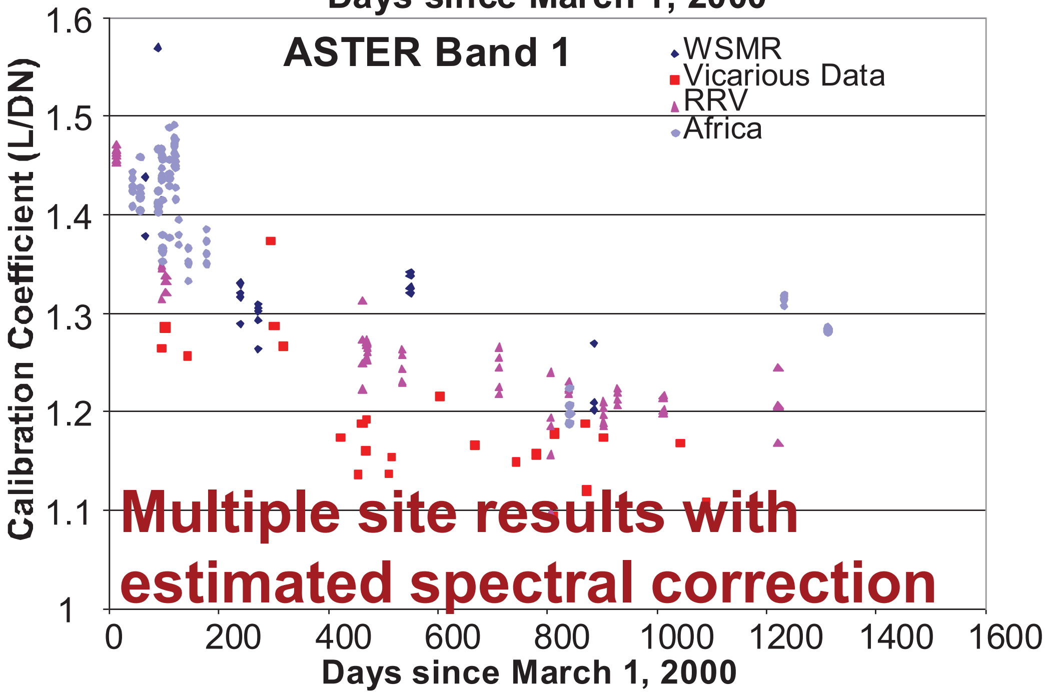
- Typically near-coincident views
  - Simultaneous Nadir Overpasses at Arctic sites
  - Chance coincidence at mid-latitude sites
- More recent work has emphasized methods that do not require simultaneous data collections
  - Invariant scene approaches
  - In-situ ground measurement methods
- **Methods with SI traceability do not require sensor data to overlap in time**



Scatter in coincident view cross-calibration

Calibration for ASTER green band using MODIS



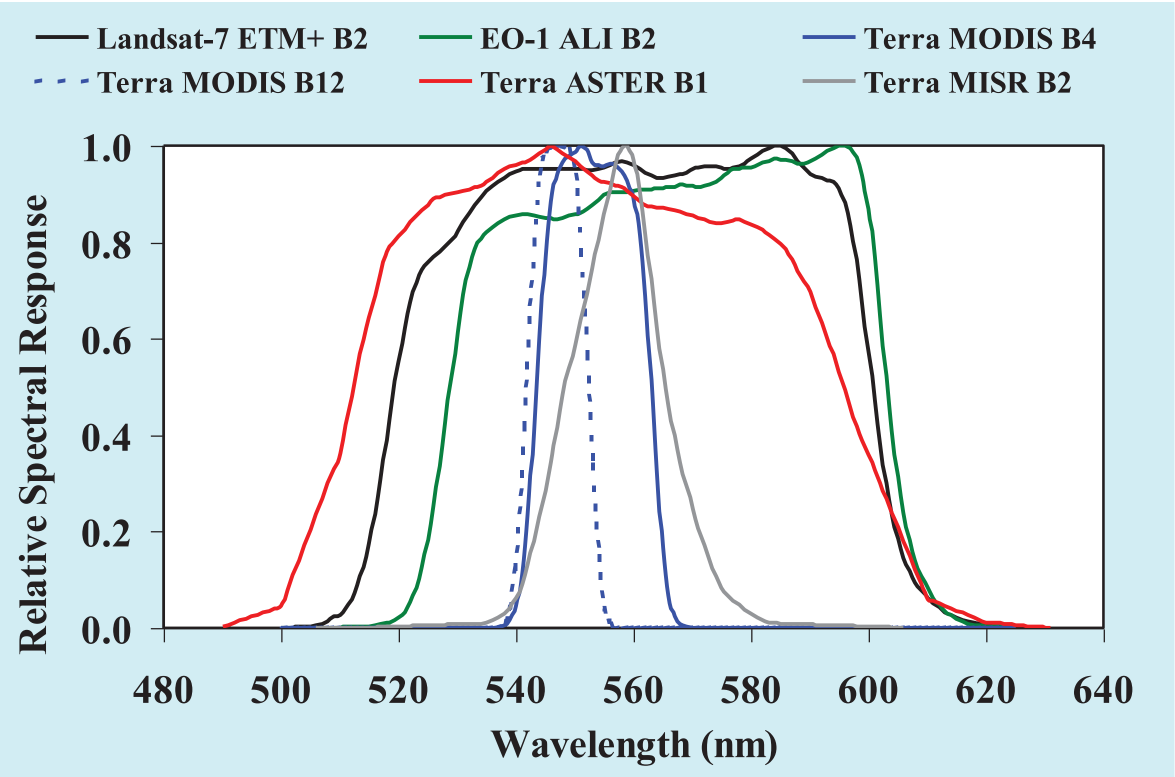


MODIS and ASTER "easiest" case

- Same platform, coincident views, similar bands
- ASTER Band 1 (green band) results using MODIS
- Scatter caused by
  - Spectral band differences
  - Registration effects

Spectral band differences – We know this already

ETM+ Band 2 Analogs	A	B	C	D	E	F
A: Landsat-7 ETM+ B2	1	0.996	1.005	0.990	0.988	0.989
B: EO-1 ALI B2		1	1.009	0.994	0.992	0.993
C: Terra ASTER B1			1	0.985	0.983	0.984
D: Terra MODIS B4				1	0.998	0.999
E: Terra MODIS B12					1	1.001
F: Terra MISR B2						1



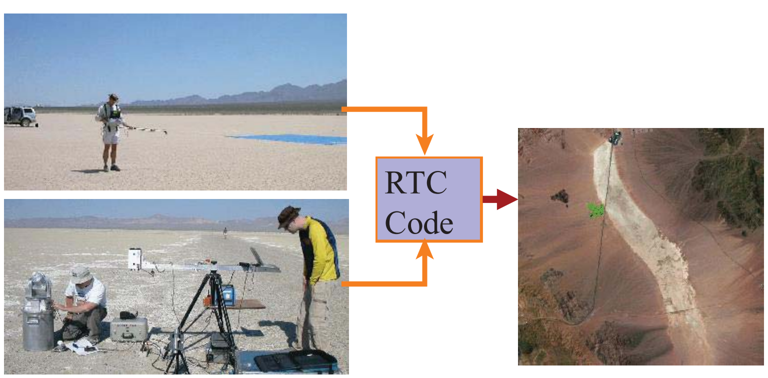
Uncertainty due to spectral differences decrease as **hyperspectral** data of sites are accumulated

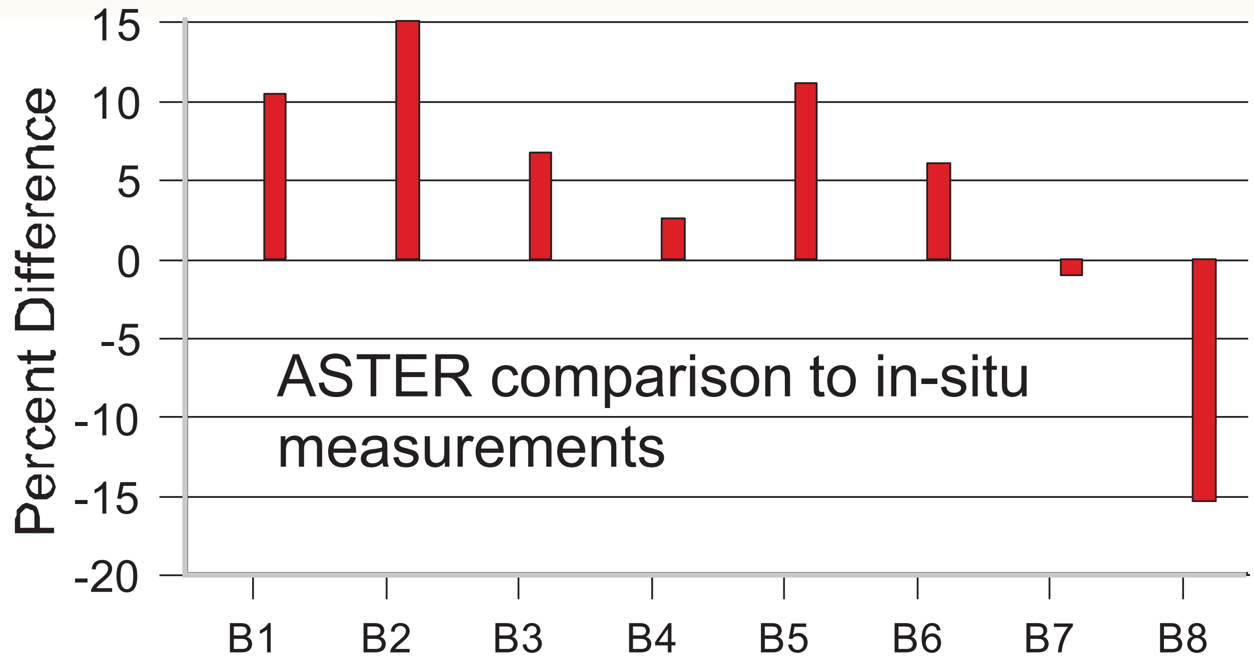
Ground data, Hyperion, SCIAMACHY

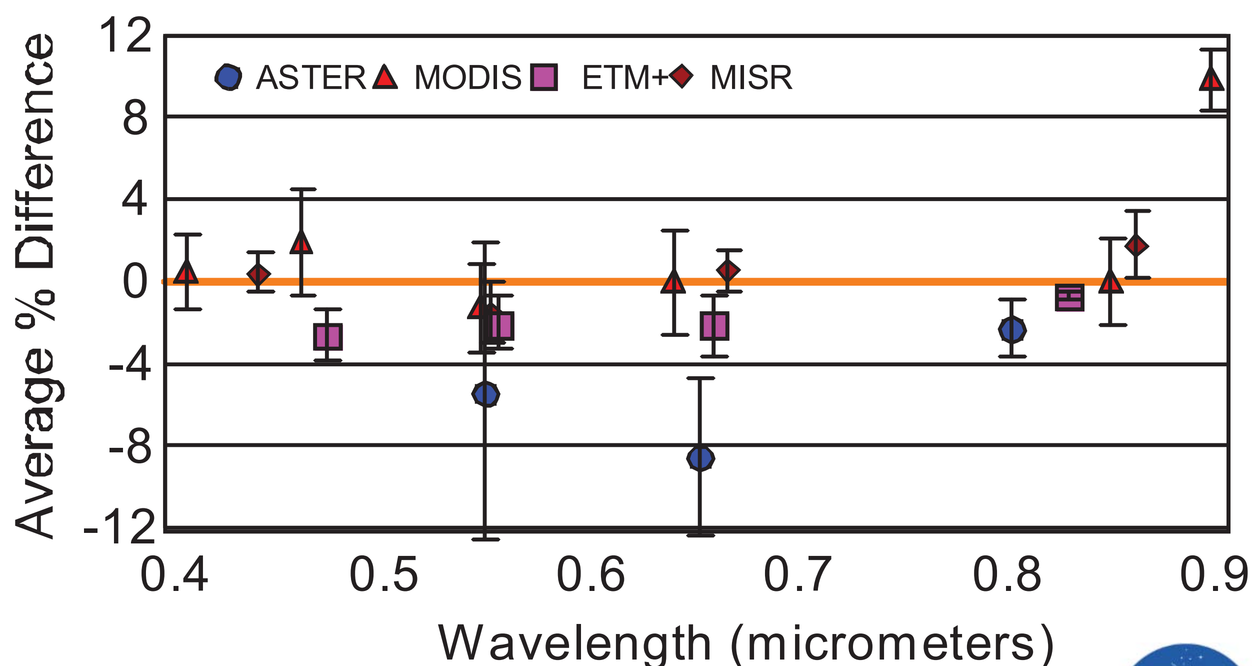
Calibration relative to in-situ

Calibration to SI-traceable, ground-based measurements

- Cross-calibration relative to in-situ data
- Requires sensors at ground site at overpass time

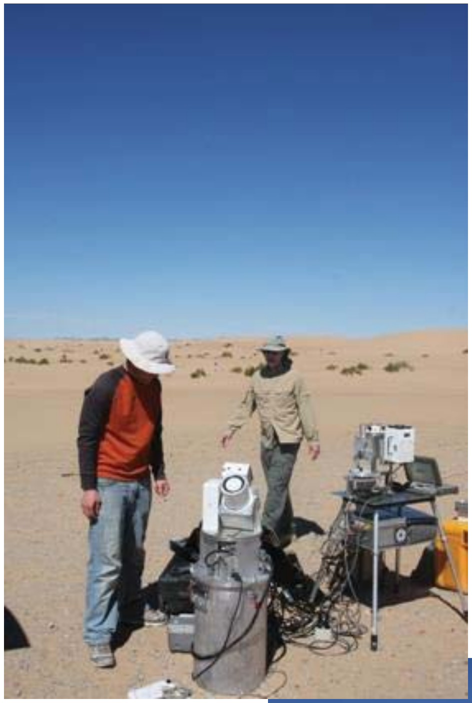






Best of both worlds

Combine philosophy of in-situ measurements with invariant site approaches

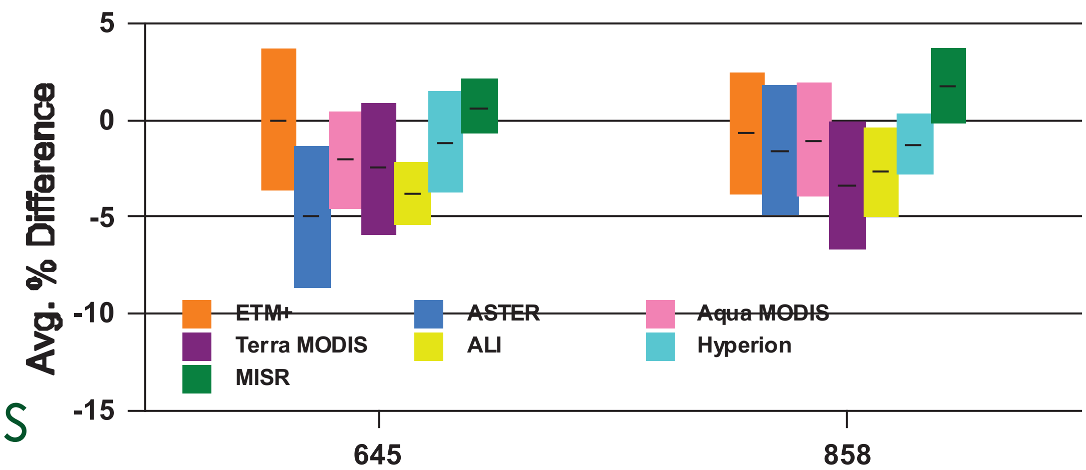


- Site measurements become basis for a physically-based model
  - Atmospheric
  - Surface
- Goal is SI-traceable result
- **Requires innovative measurement approaches**

Cause of scatter

Multidimensionality of the at-sensor radiance and non-identical sensors cause scatter

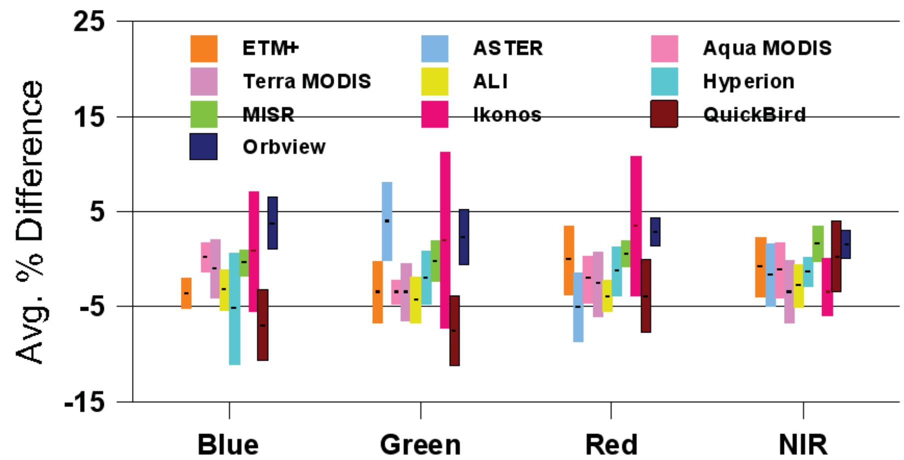
- View/solar geometry differences
  - Surface reflectance changes (BRDF)
  - Atmospheric effects
- Temporal differences
  - Solar angle
  - Surface reflectance
  - Atmospheric changes



- Spatial differences and registration effects
- Spectral differences
- Sensor effects
- All successful methods attempt to account for these effects or minimize the sensitivity

Site characterization

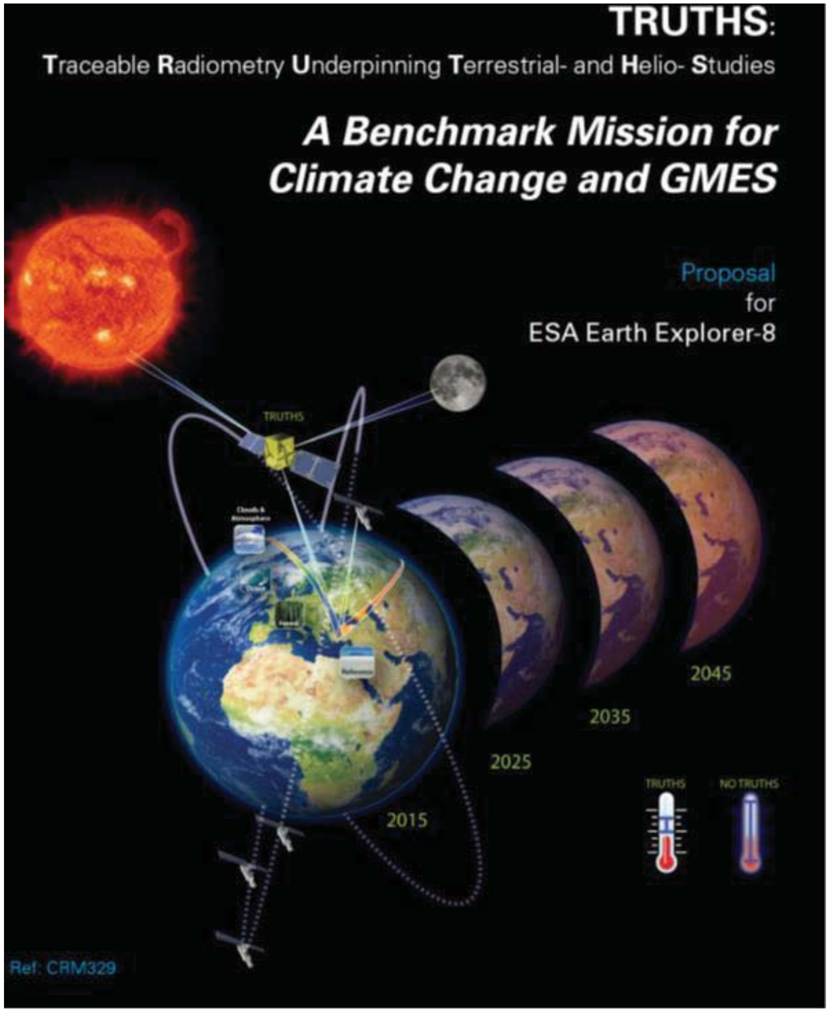
High-accuracy, imaging spectrometry would provide necessary understanding of test sites

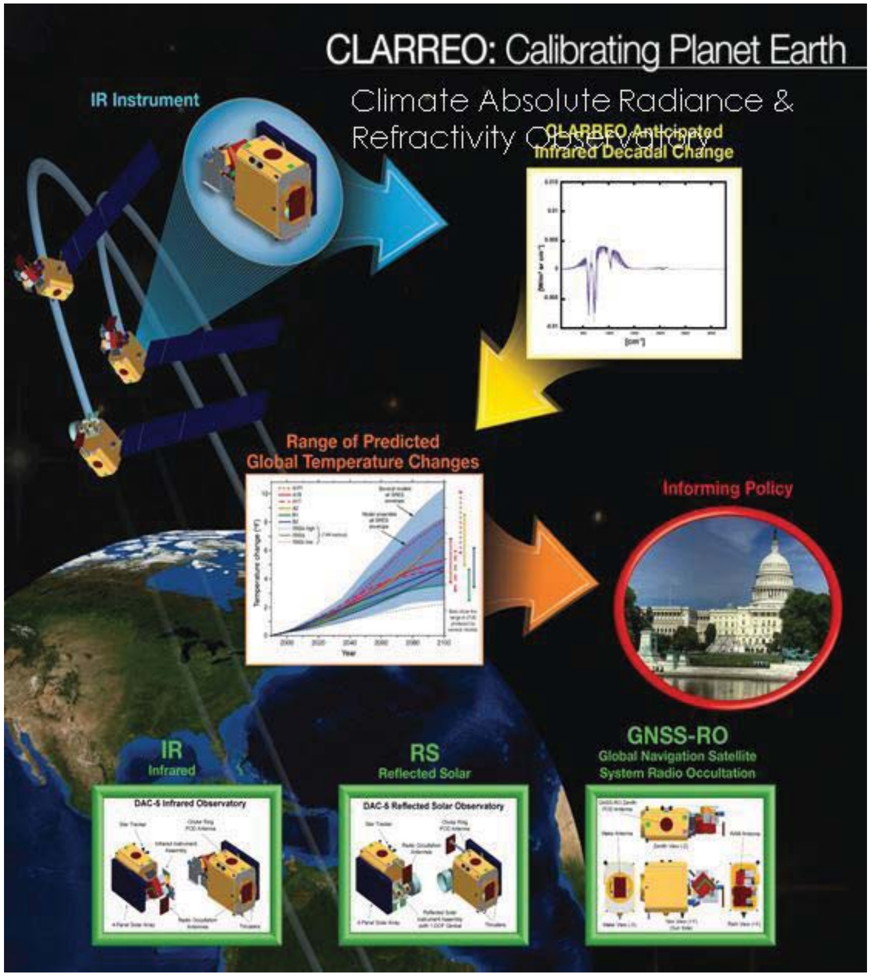


- Cannot decouple
  - On-orbit sensor effects
  - Atmospheric variability
  - Surface variability
- Past results indicate that all three play a role
  - Note that the comparison of sensors improves in the NIR
  - Bands with highest SNR for on-orbit and ground-based sensors
  - Atmospheric effects are not as dominant
- Sensors to do this need to be improved

Site characterization

Well-characterized imaging spectrometers such as CLARREO or TRUTHS or HyspIRI can provide site characterizations for SI-traceable cross calibrations





CLARREO and TRUTHS

SI-traceable sensors for climate model evaluations

- Traceable Radiometry Underpinning Terrestrial- and Helio- Studies
- Climate Absolute Radiance and Refractivity Observatory
- Spectrometer resolution
- Unprecedented uncertaities
  - Earth reflected solar radiance < 0.3% (k=2)
  - Earth emitted infrared (IR) radiances < 0.1 K (k=3)
- Rely on both
  - Direct climate benchmark
  - Improving other sensors to provide independent climate benchmarks

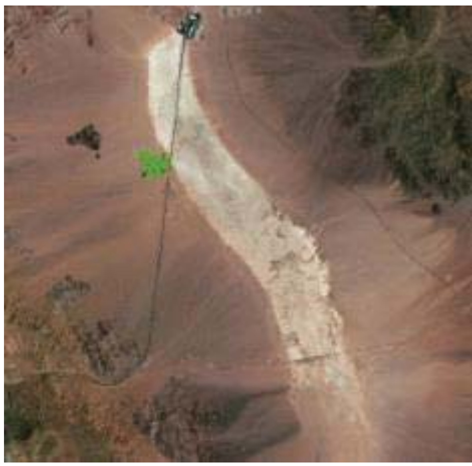
Current scatter due to instruments?

First question asked in cross-calibration is which instrument is better calibrated

- CLARREO and TRUTH-like accuracies would remove that issue
- Absolute uncertainties <0.3% in band-integrated albedo allows separation of surface effects from atmospheric effects permitting the development of the needed models for the at-sensor radiance prediction
- Similarly well-calibrated and characterized ground-based instrumentation and airborne sensors are likewise needed to improve site assessments

Basic approach

Selected Test Site



Ground-based Measurements

Satellite-based Measurements

Airborne-based Measurements

Model-based “Measurements”

Predicted At-sensor radiance

Emphasizes the source radiance

Moves away from one-to-one cross calibrations and empirical only

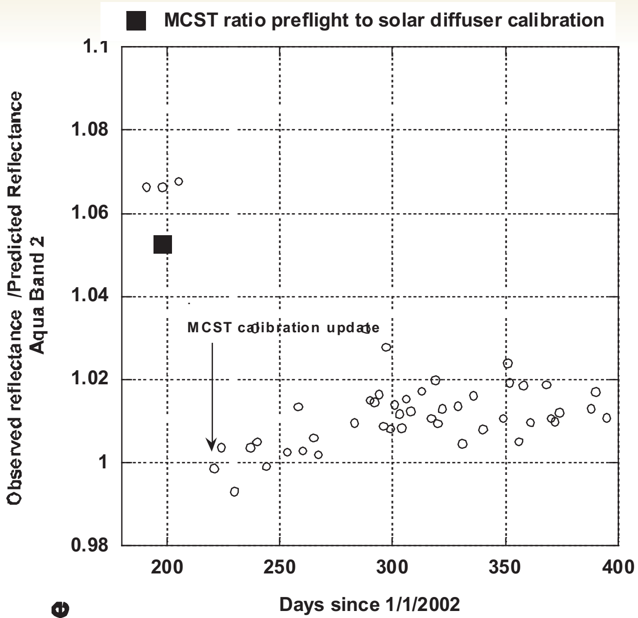
Radiance is for arbitrary
1) Time
2) View angle
3) Sun angle

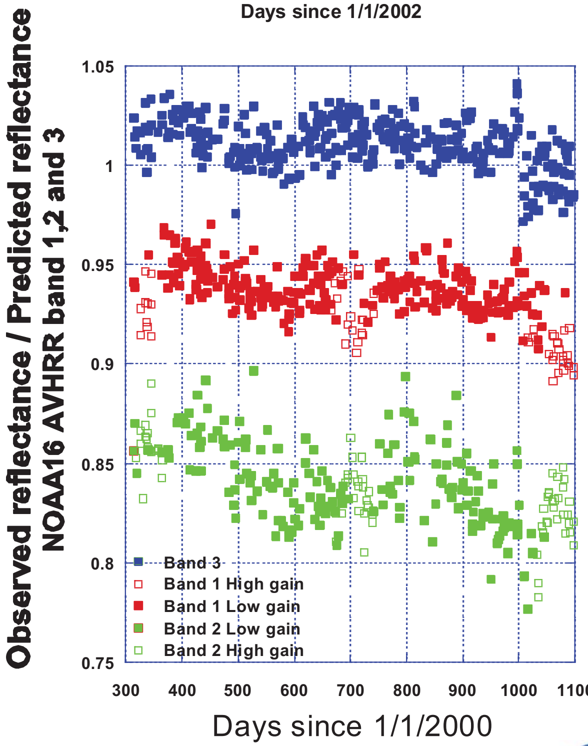
SI-Traceable with documented error budget and uncertainty

Model-based measurements

Others have used a similar pathway

- Dome C empirical corrections for BRDF and atmospheric effects
- Inclusion of BRDF models in desert site work for MODIS, AVHRR, MSG
  - Surface BRDF model corrected by Terra MODIS or POLDER
  - Includes atmospheric corrections based on climatological values
- Coupling automated data with surface models
- Deep convective cloud calculations in radiance

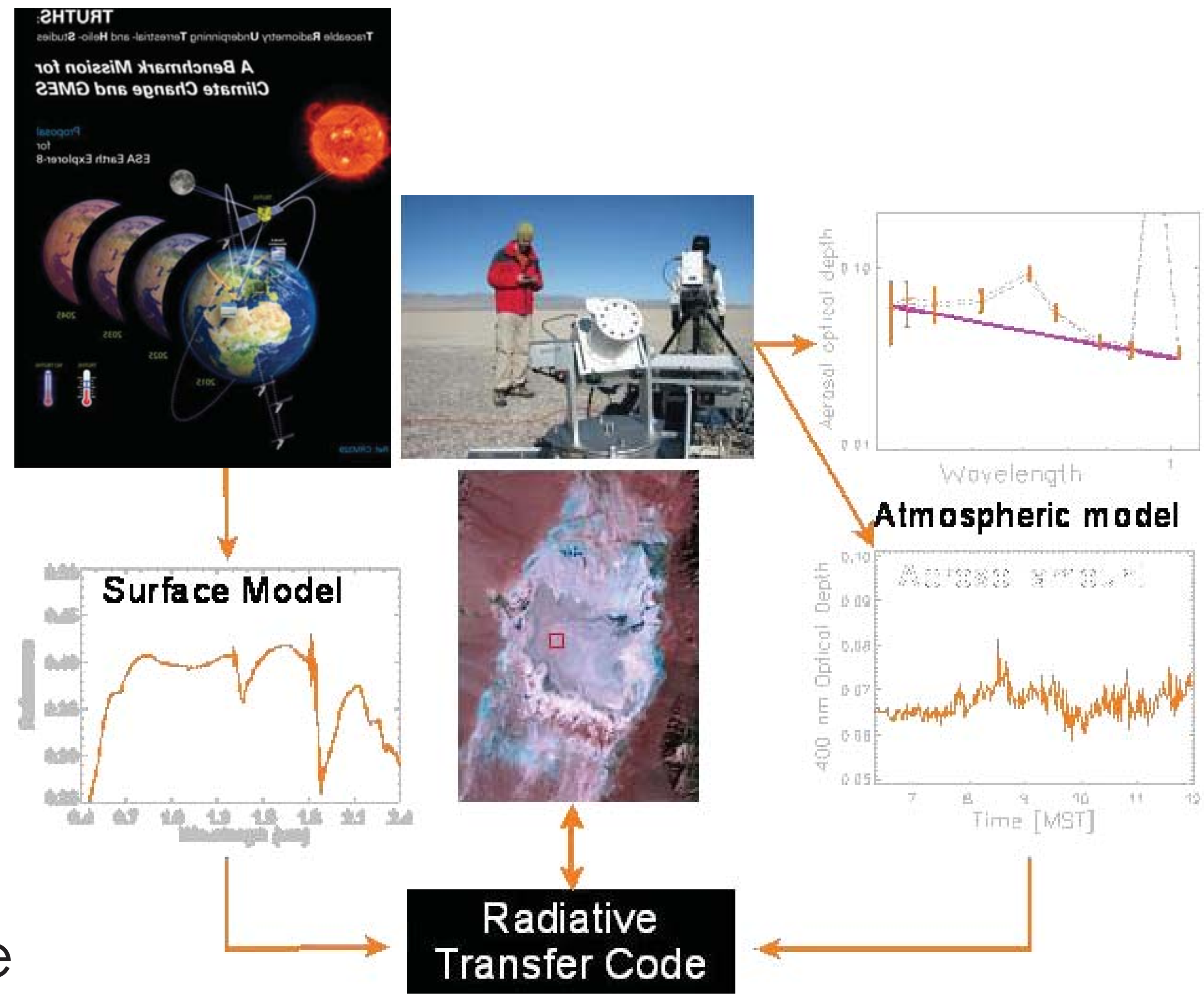




Key measurements

Spectral and directional reflectance of surfaces are highest priority

- Temporal sampling
  - directional reflectance (or at least validation)
  - Site stability
- Imaging provides spatial information
- Spectral samples aggregated to simulate bands
- Imaging spectrometry can lead to knowledge of surface morphology



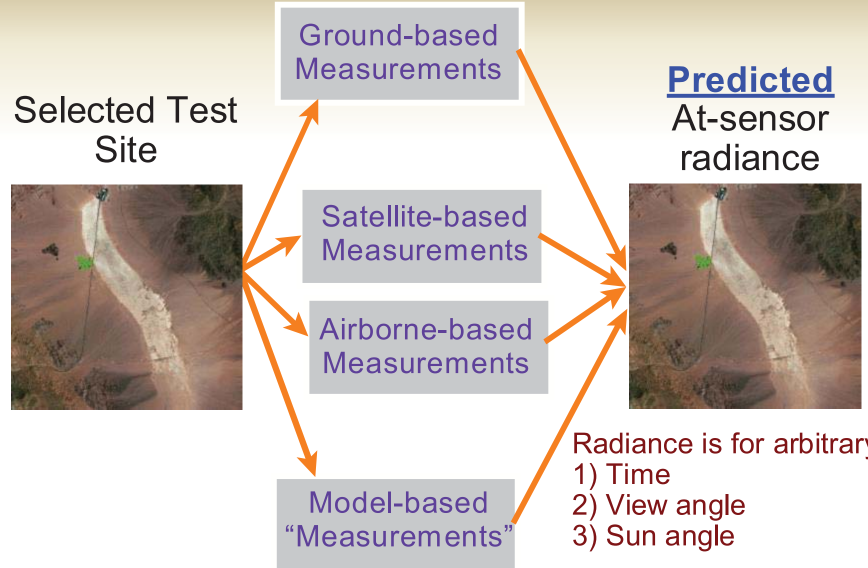
Climate-quality data products

Level 2 data products would also benefit from TRUTHS and CLARREO

- Same basic methods as the sensor calibration
- Much of the efforts rely on
  - On-orbit comparisons
  - Airborne systems
  - Ground-based
- Goal is to understand the biophysical processes and impacts from scaling
- Current systems limited by the sensors
  - Implementing CLARREO-like calibration approaches will
  - Consider if Hyperion has been higher SNR and better accuracy

Summary

Switch from sensor-centric to SI-traceable source-centric mentality is key



Radiance is for arbitrary
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SI-Traceable with documented error budget and uncertainty

- One-by-one empirical comparisons between sensors have been successful but have limits
- Combination of physically-based modeling and empirical data is not be trivial
- Inclusion of highly-accurate, imaging sensors is necessary to develop the physical models
- Method will provide improved relative calibration precision and absolute calibration that has the capability of matching current methods