Enabling Consistent Calibration of Multispectral Solar Reflective Imager Data for Climate Data Record Development Using the Moon

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Outline

- Project Description
- Production and QA Approach
- Applications
- Schedule & Issues

Project Description

- Project: An independent evaluation of calibration of visible channel imagers on meteorological satellites using the Moon as a reference source
- Goals: consistent calibration to a common scale, long-term calibration stability with high precision
- Apply established technique of lunar calibration to succession of satellites using archived image data
  - The Moon is an ultra-stable, but non-uniform, solar diffuser
  - To utilize the Moon requires a lunar model to normalize its varying brightness – USGS lunar irradiance model used here
  - Lunar calibration analysis provides sensor temporal response trending/correction and cross-comparison with sub-percent precision
- A utility for CDR development using satellite data

Project Description

CDR(s) (Validated Outputs)	Period of Record	Spatial Resolution; Projection information	Time Step	Data format	Inputs	Uncertainty Estimates (in percent or error)	Collateral Products (unofficial and/or unvalidated)
Calibration assessment for meteor-ological satellite visible channel imagers	June 1983 to present	Instrument native spatial resolution	any	ASCII	• Image data containing the Moon • Satellite orbital elements • Sensor spectral response	1-2% relative radiometric calibration and inter-instrument bias; ~5% absolute radiometric calibration; $<0.1\%$ per year calibration stability	Comparison with other vicarious calibration methods

Production Approach

Lunar calibration: comparison of lunar irradiance measurements taken by sensors against the reference standard provided the USGS lunar model

- Inputs: images of the Moon
  - Captured by chance – coincidence of Moon position with routine imaging schedule; predicted by orbit and ephemeris
  - Dedicated Moon observations – begun in 2005; GOES-10 on
- Irradiance measurements from images
  - Spatial integration:
  - Pixel conversion to radiance – using constant (pre-launch) calibration coefficients reveals temporal trends
  - Selection of pixels on the Moon disk

$$I = \Omega_{\mathrm{p}} \sum_{i=1}^{N_{\mathrm{p}}} L_i$$

L_i = pixel radiance
Ω_{p} = pixel solid angle
N_{p} = # of pixels on Moon

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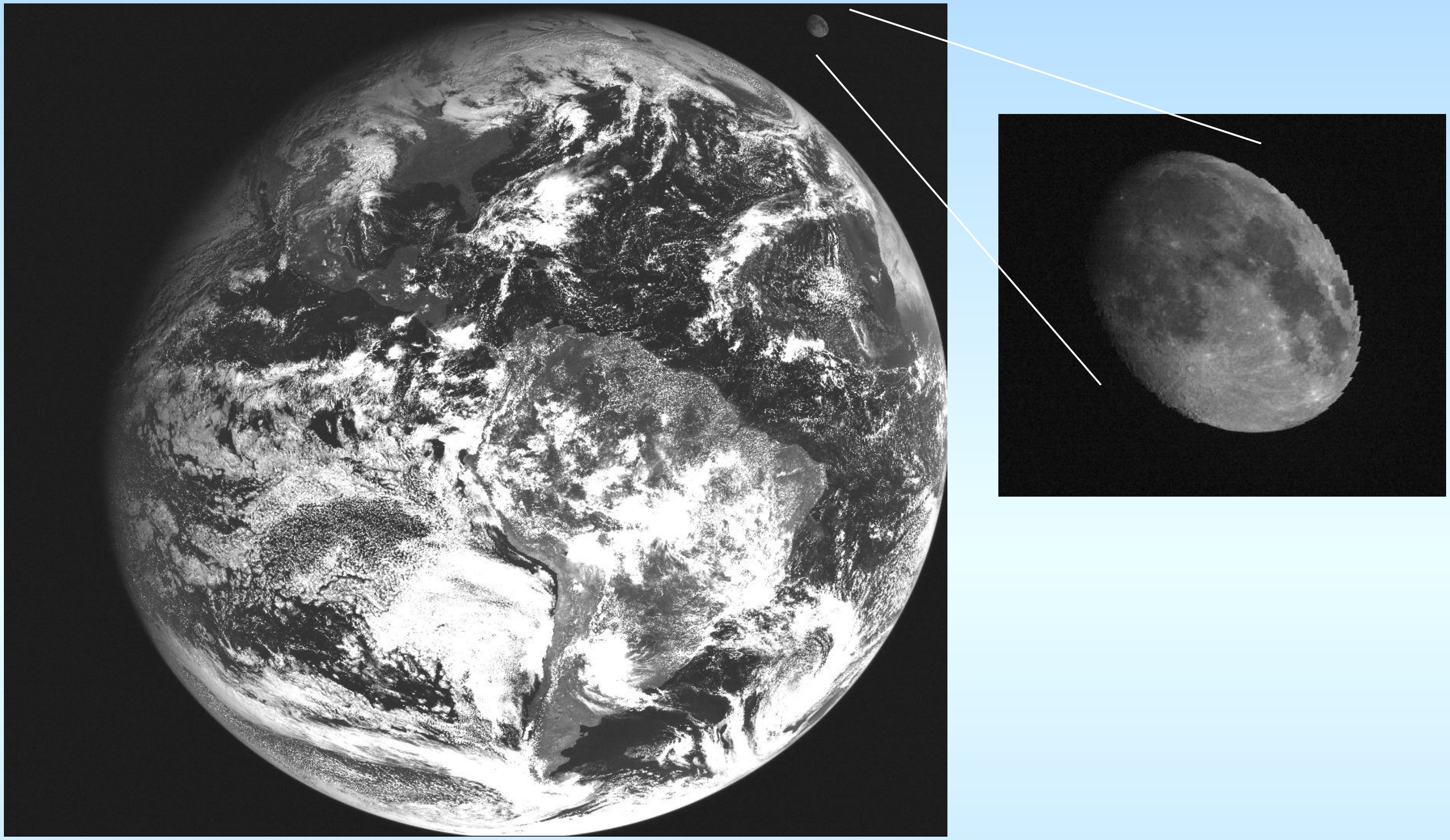
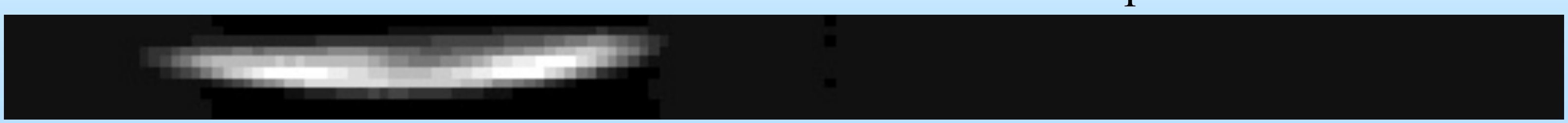
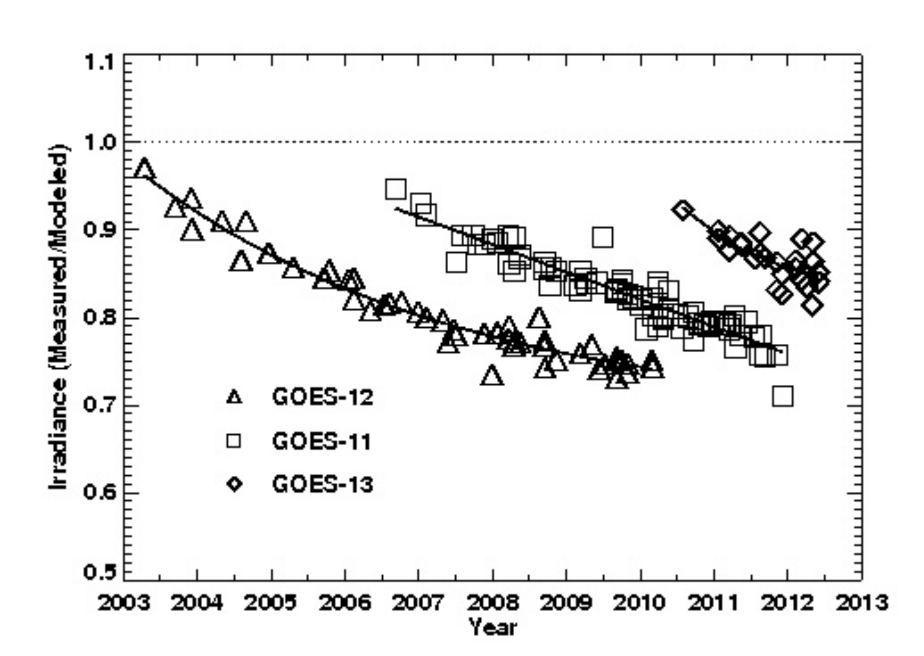


NOAA−16 AVHRR 2002-12-12 16:37 Ch.2 Space-view



Production Approach

- Model-generated irradiance
  - Analytic model form, accommodates any view geometry
  - Model inputs: observation time, and instrument (satellite) location @ time; sensor spectral response
  - Model outputs adjusted for instrument spectral bands, image acquisition (e.g. oversampling), actual distances
  - Results are directly comparable to measured values
- Measured/model irradiance comparisons
  - Normalizes lunar brightness variations (primarily w/phase)
  - Time-series of comparisons reveal sensor response changes
  - Temporal changes are quantified to develop calibration corrections, directly applicable to radiance data products
  - Applying corrections stabilizes sensor response, allows cross-comparison and inter-satellite bias evaluations

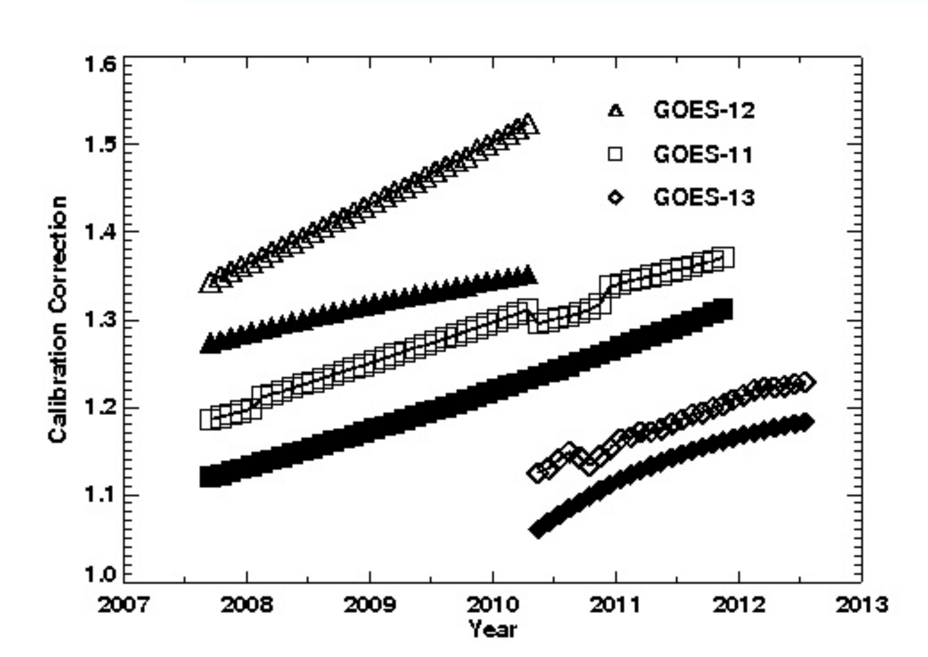


GOES imager sensor response trends, from lunar calibration analysis

- measured/model ratio of lunar irradiance
- each series fitted with temporal degradation function, typically a form of exponential decay

GOES calibration corrections

- open symbols: NOAA operational post-launch calibration, from cross-calibration with MODIS
- filled symbols: derived from lunar calibration analysis



Production Approach

- Specific challenges still to be addressed: AVHRR Moon images in space-view
  - AVHRR uses space-view to set dark level offset – clamping
  - Increased radiance of the Moon perturbs this automated system, drives the offset low (damages Earth-view data)
  - Dark level must be evaluated to measure lunar irradiance from images; achieving high accuracy is a major challenge

NOAA-16 AVHRR 2002-12-12 16:37 Ch.2 Space-view

time ⟶

- stretch applied to show background level behavior

Quality Assurance Approach

- Uncertainty in measurements from images
  - Radiance calibration – pre-launch coefficients used; leads to systematic errors for each instrument; revealed by analysis, corrected with inter-satellite bias evaluations
  - Lunar disk pixel selection method/parameters – errors evaluated with sensitivity studies
  - Instrument specifications, e.g. IFOV, image oversampling factor, lead to systematic errors for each instrument
  - Short-term sensor response variations – topic under study
- Uncertainty in model-generated lunar irradiance
  - Model relative error for phase differences over obs. series is under 1% – evaluated from fit residuals at development
  - Model spectral dependence – similar wide bands of GEO visible channel imagers contribute minimal relative errors
  - Geometric parameters, e.g. computed lunar ephemeris, satellite position errors (hundreds of km) lead to negligible differences in input geometries and model results

Quality Assurance Approach

- Measurement/model errors applied to time series
  - Uncertainty in fitted parameters for sensor response trend functions derived from least-squares fit covariance
  - Directly gives uncertainty in calibration corrections
  - Propagated to inter-satellite bias evaluations

- Detailed study and quantitative evaluation of uncertainties is project year-2 focus

Applications

- Project outcome is a quantitative calibration assess-ment for succession of visible-channel met. imagers
  - Intended users are CDR developers
  - Applicable to radiance data products of the instruments in this study
  - Provides consistent and stable calibration, capability to enhance data quality and inter-operability of datasets across satellite platforms
- Precision achievable can meet sensor calibration requirements for detecting climate change
  - On-orbit calibration against a stable external reference provides the only assured means for tracking degradation of optical systems operating in the space environment
  - Future operational imaging missions plan to use the Moon, e.g. GOES−R ABI, Meteosat Third Gen. FCI, LDCM OLI

Applications

- Radiance data products (visible wavelengths) potentially gaining enhanced QA for CDR development:
  - Global albedo – particularly cloud amount and optical properties
  - Land cover; snow and ice cover
  - Ocean color – >90% of the radiance received by satellite instruments in blue/green wavelengths originates from atmospheric scattering, thus tightly constrained calibration requirements; SeaWiFS has achieved <0.1% per year calibration stability using the Moon and USGS system
  - Aerosols – e.g. optical depth, scattering properties
  - Vegetation indices – typically differential spectral measurements

Schedule & Issues

- Relatively small project — 0.3 FTE, two years duration
- Accomplished in first year:
  - Moon appearance predictions for GEO satellites, Full Disk and sector coverages, dedicated Moon looks (from 2005, GOES-10 and later)
  - obtaining and selecting image data for GOES-8 through 13, Meteosat–8 and 9, NOAA-16
  - image processing to lunar irradiance measurements
  - generating lunar model results and developing time series comparisons
  - fitting sensor temporal trends and developing calibration corrections; comparing these to published NOAA operational post-launch calibration
  - initial analysis of NOAA-16 AVHRR lunar images, space clamp response
- Planned for second year:
  - continue study of AVHRR space-view lunar images
  - develop inter-instrument bias evaluations
  - conduct detailed uncertainty analysis
  - prepare and deliver to NOAA a technical report, to include a prescription for applying the results of this calibration analysis to radiance data products from the instruments used here

Schedule & Issues

- Risks/Concerns:
  - to fully utilize AVHRR lunar images acquired in space-view requires quantitative evaluation of the clamping system response to intrusion of the Moon. Specifying this behavior analytically will likely exceed available resources, and may ultimately not be successful.

- How can the CDR Program better assist you?
  - additional direction regarding program expectations/requirements would be welcome