Post Launch Calibration and Testing of The Advanced Baseline Imager on the GOES-R Satellite

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Overview

• Geostationary Operational Environmental Satellite R (GOES-R)
  – Next generation NOAA satellite
  – Advanced Baseline Imager (ABI) multi-channel radiometer

• Initial on-orbit calibration and performance characterization of ABI
  – Post Launch Tests (PLT’s) to establish baseline for post launch performance
  – Unique challenges due to large number of detectors for sixteen channels
  – Six month PLT period

• Presentation of planned PLT’s
  – Motivation
  – Details

Advanced Baseline Imager (ABI)
(http://www.goes-r.gov/spacesegment/abi.html)
PLT Introduction

• Health and safety
  – Solar avoidance
  – Detector screening
  – Scanner and scan encoder performance tracking

• Radiometric testing
  – Basic calibration and trending
  – Calibration stability
  – Noise performance
  – Dynamic range
  – Repeatability
  – Desert scene observation

• Final tests
  – Image navigation and registration (INR)
  – Image quality
Health and Safety PLT’s
Solar Avoidance

- Motivation: Confirm solar avoidance algorithm prior to Optical Port Cover opening
- Demonstrate avoidance of exclusion zone
  - 0.5 degree margin for FOV reaching edge of sun
  - Demonstrate truncated scan with cover closed with two sun locations
Detector Screening

• ABI channels consist of line Focal Plane Arrays (FPA’s) with multiple columns of detectors for redundancy
  – Best Detector Selection (BDS) used to choose detectors for each row
  – BDS choices may change with cool-down cycles

• Motivation: Screening process for performance on-orbit
  – Image collections
    • Solar Calibration Target (SCT) diffuser
    • On-board thermal reference – Internal Calibration Target (ICT)
    • Space look
    • Ground scene

• Four-step procedure
  – Visual/Near Infrared (VNIR) channel images of SCT
  – Emissive channel images of ICT while adjusting bias voltages on FPA’s
  – 30-second stare at ICT
  – 2.4-second stare at Earth target (large, time-stable area)

• Evaluation
  – Gain and stability, offset and stability, and noise

Typical layout of optimized set of detectors (Padula 2015)
Scan Encoder Fine Track Error Trending

• Motivation: Track changes in commanded versus executed scan mirror position
  – Depends on encoder calibration coefficients and on environmental/aging factors

• Pre-defined pointing scenarios

• Results in telemetry
  – Trended over time

ABI Scan Mirror (Mandt 2009)
Radiometric PLT’s
IR Radiometric Calibration Stability

15-minute Mode 3 timeline with 3 CONUS images and ICT look (Gerth 2014)

- **Motivation**: Demonstrate channel-to-channel repeatability
  - Requirement for thermal channels < 0.2

- **Mode 3 timeline**
  - 15 minute duration
  - 3 Continental United States (CONUS) images and ICT look

- **Comparison of Mode 3 timelines over 24 hours**
  - Spatial average of CONUS images before and after ICT look
  - Difference tracked as effective delta temperature
  - Determine drift in calibration coefficients needed for 0.2 K specification failure
Alignment Assessment

Footprint of Landsat-8 data for Sonoran Desert/Gulf of California coastline (USGS 2016)

- **Motivation:** Determine and correct for misalignment between ABI and S/C attitude determination system
  - Ties navigated LOS to S/C attitude determination
  - No star positions for this PLT (later PLT will refine using stars)

- **Comparison between Landsat and ABI**
  - Landsat Ground Control Point (GCP) residuals
  - 3-axis navigation offsets
  - Diurnal profiles
  - Line of site motion compensation (LMC) coefficients
IR NEdT and Dynamic Range Characterization

- Motivation: Establish beginning-of-life (BOL) performance
  - Noise Equivalent delta Temperature (NEdT)
  - Dynamic Range (DR)
  - Quantization Step Size (QSS)
- Long-duration (2-second) ICT and space looks
  - NEdT at single ICT temperature compared to ground test
  - 2-scene measurement extrapolated to saturation for DR
  - QSS calculated assuming linearity based on ground test
System Linearity

Measurement of linearity using digital counts versus integration time for Landsat thermal IR sensor, TIRS (Montanaro 2014)

- **Motivation:** Demonstrating linearity over operational DR
- **Changing integration time while starting at target**
  - SCT for VNIR channels and ICT for emissive channels
  - Constant increments except for 3.9 micron channel (different step size for higher sensitivity)
  - To demonstrate < 1% nonlinearity

Unlike Landsat TIRS, ABI is expected to behave linearly over operational DR
Motivation: Measure repeatability of adjacent pixels and between swaths/channels/images

- Specifications are < NEDT difference
- Typical operational use would be CONUS (every 5 minutes) or full disk images (every 15 minutes)

Synthetic images using ICT looks

- Pixel to pixel: local RMS row deviation from mean of 3 R x 10 C sub-images
- Swath to swath: boundaries of swaths in CONUS images (comparison of neighboring rows from two swaths)
- Channel to channel: Successive CONUS images in two channels; average temperature difference
- Image to image: Successive CONUS images; average temperature differences

ABI scan patterns (Griffith 2016) simulated by ICT stares
VNIR Radiometric Calibration Trending

• Motivation: Baseline trending measurements and calibration stability
• Frequent solar calibrations during PLT phase to establish baseline
  – Two-point (solar diffuser and space) calibration
  – BDS detectors for each row of VNIR channels
  – Comparison to ground test
  – Long-term trending and information on appropriate decrease in solar calibration frequency post-PLT
Desert VNIR Monitoring

Desert validation target for routine PLT north/south scan (NSS) collections

• **Motivation:** Vicarious ground-truth validation of on-board calibration
  – Trending of detector performance
  – Alternative calibration methodology in case of SCT failure

• **NSS over three targets**
  – Sonoran Desert, White Sands Missile Range, Uyuni Salt Flats, Bolivia
  – Six NSS – one for each VNIR channel
  – ~ 200 km ground track; collected within +/- 7.5 minutes local solar noon
Image Quality and Image Navigation and Registration (INR) PLT’s
Coherent Noise

Landsat-8 Band 3 coherent noise off coast of Gulf of Panama (USGS)

- **Motivation:** Compare coherent noise performance with ground measurement
  - Identifying spatial frequencies > 25% NEdN
  - Looking for in-family performance
- **Synthetic full disk images using ICT and space observations**
  - Timeline to mimic full disk collection
  - 2D Fourier transforms

Coherent noise structures such as these can be identified as spatial frequencies
Spatial Uniformity Characterization over Field of Regard

• Motivation: Measure BOL spatial variation in response over Field Of Regard (FOR)
  – Confirm validity of scan mirror emissivity/reflectivity coefficients
  – Check against required 0.3% uniformity

• Characterized using space looks
  – ICT calibration, followed by eight locations equally spaced around Earth
  – Long duration looks (25 seconds)
  – Repeated every four hours for a total of 24 hours
  – Run Spatial Uniformity Calibration PLT if needed
LOS Estimation Filter Performance Characterization and Tuning

- **Motivation:** Orbital measurements for Line-of-Sight (LOS) estimation filter
  - Characterize performance
  - Characterize LOS diurnal profile for use in computing tuning parameters

- **Star measurements**
  - Navigated to fixed grid with current INR parameters
  - Navigation errors and measurement noise parameters extracted to use in LOS filter

ABI Image Navigation and Registration (INR) Process (Ellis 2008)
Co-registration Characterization Analysis (MWIR/LWIR offset)

- Motivation: Measure co-registration error between Mid-Wave IR (MWIR) and Long-Wave IR (LWIR) channels
  - Difference in navigation between spectral channels for a given pixel in the same frame
  - Check against required limit of 11.2 microradians

- Star measurements
  - MWIR 3.9 micron channel compared to an LWIR channel (TBD)
  - Offset extracted using star measurement residuals

False detection of fog on GOES-13 due to ~1 pixel misalignment between 10.7 um and 3.9 um bands (Grotenhuis 2013)
INR Earth Pointing Platform Deployment Assessment

- Motivation: Assess INR performance before and after EPP launch locks are released
- INR assessments using Landsat comparison
  - Landsat GCP’s and image-to-image tie-points from Level 1B ABI imagery
  - Navigation assessment (comparison with GCP)
  - Within frame (distance between pairs of control points in image with GCP’s)
  - Frame-to-frame, swath-to-swath, and channel-to-channel (distances between GPC’s or tie-points in each)
Spatial Resolution Characterization

- **Motivation**: Measure BOL Modulation Transfer Function (MTF) performance
  - Check if within family of ground performance baseline
  - Determine if ABI focus adjustment is needed

- **Lunar edge as on-orbit target for East/West (E/W) and North/South (N/S) MTF**
  - Sharp edge with large brightness contrast
  - Sub-pixel Edge Spread Function (ESF) assembled from one or a concatenation of images
  - Spatial derivative (ESF) $\rightarrow$ Line Spread Function (LSF); Norm. mag. Fourier Transform (LSF) $\rightarrow$ MTF
  - E/W MTF at full scan and 1/10 scan rates & N/S MTF at 1/10 scan rates to compare to ground test

Edge sampling in early AHI-8 lunar images (courtesy of Japan Meteorological Agency, JMA) used to demonstrate that AHI-8 met or exceeded ABI requirements
Lunar Trending for Performance

Lunar image from AHI-8 (Takahashi 2015)

• Motivation: VNIR calibration target
  – VNIR calibration trending
  – Relative spectral response of scan mirrors across FOR

• Lunar imagery when moon in FOR but outside Earth limb
  – Two images per month (one per Earth side)
  – At least one set of images of Moon transiting through North or South end of FOR to evaluate scan mirror spectral response
3.9 Channel Stray Light Characterization

GOES-R proxy data created from 2004 MODIS data (Gurka 2014)

- **Motivation:** Characterize and quantify stray light due to known sneak path
  - Hardware approach developed to mitigate sneak path past field stop and scattering off beam splitter
  - Strongest on 390 channel, but may be detectable throughout VNIR
  - Present for solar incidence angles between 10 and 15 deg. south of nadir Line of Sight (LOS)
  - Verify accuracy of stray light modeling predictions

- **Full disk images at appropriate times and beta angles**
  - S/C local midnight +/- 1 hour (every five minutes)
  - Beta angles between -14.44 deg and -7.5 deg (sun position from 19 deg south to 10 deg south)
  - Image differencing to suppress Earth radiance and identify stray light
Summary

• Large and varied assortment of PLT’s planned
• Health and safety
• Quantify and characterize performance
  – Radiometric
  – Image quality
  – Navigation
  – Comparison to ground test
• Tune and trend performance
  – Optimize selected parameters
  – Trending to confirm performance or need for changes in parameters
• Goal is a well-characterized, optimized, state-of-the-art instrument

Advanced Baseline Imager (ABI)
http://www.goes-r.gov/mission/images/overview/ABII.jpg
References


www.goes-r.gov.


Padula, Francis, Steve Goodman, Changyong Cao, and Xiangqian Wu. 2015. GOES-R Field Campaign: Addressing the Validation Challenges of Geostationary Satellite Observations. CALCON.


Japan Meteorological Agency (JMA); image courtesy of Mr. Masaya Takahashi, Scientific Officer at JMA.


U.S. Geological Survey (USGS) Products; data available from the U.S. Geological Survey