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11.2 ABI’s Unique Calibration and Validation Capabilities

Dr. Paul C. Griffith

12th Annual Symposium on New Generation Operational Environmental Satellite Systems
AMS Annual Meeting, 11-14 January 2016

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ABI’s Unique Calibration and Validation Capabilities

Accurate radiometric calibration essential for reliable weather data products

Advanced imagers provide improved imagery but pose calibration challenges

Harris’ ABI-class imagers provide calibration solutions

• Better on-board targets
• Unprecedented operational flexibility permitting improved on-orbit radiometric calibration utilizing external sources
  – e.g. Earth, Moon, …
• Significantly more calibration opportunities
  – Ability to perform most calibrations without interrupting routine Full Disk and regional observation collections

ABI: Designed for calibration
Agenda

ABI-Class Imager Description
On-board Radiometric Calibration Targets
Operational Calibration
Additional Capabilities for Calibration & Validation
Summary

AHI-8 True Color (RGB) Image 3Dec2015 12:00 JST
(Data from JMA, Processing by Harris)
ABI-Class Imager is a Mature Product Line

Supporting three missions:
- GOES-R (ABI), Himawari (AHI), GEO-KOMPSAT-2A (AMI)

Four flight models delivered
- ABI PFM: Integrated on GOES-R spacecraft
- AHI-8: Operating on orbit (Himawari-8)
- ABI FM2: Delivered
- AHI-9: Integrated on Himawari-9 spacecraft

Three more in production at Harris
- ABI FM3, ABI FM4, AMI
ABI’s 2-Mirror Scanner Key to Improved Calibration Capability

- Scans parallel to equator without rotating image
  - 100% scan coverage efficiency
- Lowest inertia and power
- 2x EW and NS mechanical-to-optical motion
- Inherently polarization compensating
  - At nadir, polarization introduced by reflection off NS scanner is canceled by reflection off of EW scanner
  - Blackbody located anti-nadir, so same observing geometry applies

Delivers fast slews and accurate slow scans with minimal disturbance
ABI-class Imagers Provide 16 Channels, Optimized for Customer’s Mission

• AHI & AMI added 1-km 0.51 μm channel (green)
  – Silicon detector array
  – Improved ocean images

• Retained 1-km 0.865 μm channel
  – Shifted to HgCdTe detector array

• Changed 1.61 μm channel to 2-km

• Eliminated one NIR channel
  – AHI: 1.378 μm
  – AMI: 2.25 μm

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**Color Key:**
- Not in ABI
- Different FPA
Focal Plane Modules Spatially Separate Channels in Scan Direction

VNIR FPM

1.9° EW FOV

0.9° NS FOV

Scan Direction

1.38 HgCdTe
0.86 Si
0.47 Si
0.64 Si
1.61 HgCdTe
2.25 HgCdTe

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Detector Selection Capability Provides Operational Redundancy

Externally: Line array
Internally: 2D array

Select best element in each row

Color Key:
- Non-compliant element
- Compliant element
- Selected element

Ground
Guard
Active Detector Element
Separation

Requirement: one operational element per downlinked row per side
# ABI ASD, IFOV, and Aperture

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**ASD = angular sample distance**
- EW interval at which samples are collected at standard scan rate

**NS ASD = NS IFOV (100% fill factor)**
- NS interval at which samples are collected

**Resolution = pixel spacing of final image after resampling**
- 1 km = 28 µrad

*77,400 detector elements total; 7,856 downlinked*
Advanced Imagers Pose Calibration Challenges

Large number of detector elements
- Much more to be calibrated
- Increased risk of striping

Large FOV
- Much larger than traditional vicarious calibration scenes

Greater calibration accuracy expectations

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<th>GOES-R ABI</th>
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<td>NS FOV: max channel</td>
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<td>EW FOV: max FPM</td>
<td>μrad</td>
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Harris’ ABI-class imager provides calibration solutions
Agenda

ABI-Class Imager Description

On-board Radiometric Calibration Targets

Operational Calibration

Additional Capabilities for Calibration & Validation

Summary

AHI-8 True Color (RGB) Image 3Dec2015 12:00 JST
(Data from JMA, Processing by Harris)
Internal Calibration Target (ICT) Accurately Calibrates Emissive Channels On-orbit

- 3-bounce blackbody based on patented 5-bounce Harris design
  - Trap configuration and specular black paint guarantees very high emissivity (>0.995)
  - Robust against stray light and contamination
  - NIST-traceable
- Built, tested, and demonstrated

Full aperture, end-to-end calibration

ABI PFM 3-bounce blackbody
Solar Calibration Assembly Delivers On-Orbit Calibration Over Mission Life

- **Optical Port Cover:**
  - One time deployable
  - Keeps payload clean during launch and outgassing

- **Solar Cal Cover (SCC):**
  - Open only when calibrating
  - Closed rest of time to preserve cleanliness

- **Solar Calibration Target (SCT) is Spectralon™ diffuser**
  - Calibration can occur any day of year at 6:00 a.m. (6:00 p.m. if yaw flipped)
  - Collected with 10x integration time to obtain ~100% albedo signal with sub-aperture target
Solar Calibration Subsystem Built, Tested, and Qualified for ABI

Design optimized for minimum calibration uncertainty

Diffuser

Optical Port Sunshield Assembly
Stray Light Baffles

Solar Calibration Port
Electronic Calibration (ECAL) Verifies Linearity Throughout Mission

End-to-end test collects radiance from on-board targets (ICT & SCT) while varying integration time multiplicative factor
- 0.5x to 16.5x in 33 steps of 0.5x
- 0.0625x to 2x in 32 steps of 0.0625x (1/16th)
- 1x to 22x in 22 steps of 1x

Integration time proportional to integrated photons
- More easily controlled than injected voltage levels and tests much more of analog-to-digital signal processing chain

All integration times collected with all targets and all channels
- First set typically used for $\lambda < 3 \, \mu m$ when viewing SCT
  - Nominal SCT observation performed with integration factor of 10x
- Second set typically used for $\lambda > 5 \, \mu m$ when viewing ICT
- Third set typically used for $\lambda = 3.9 \, \mu m$ when viewing ICT

ECAL can also be used when observing space or any other external scene
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Operational Calibration Utilizes Space and On-Board Targets

**Spacelook collected at least every 30 s**
- First data collected in every operational timeline
- Automatically collected as part of every Full Disk swath
  - Either at start or end, depending upon scan direction and location of sun
  - Can be autonomously collected on side opposite the sun

**Blackbody (ICT) observed at start of each timeline**
- Hence, collected at least every 15 minutes
- Ensures all imagery collected during timeline can be radiometrically calibrated

**Solar calibration scheduled when needed**
- Frequency a function of throughput loss
  - Twice a week at start of mission, once a quarter by end of mission
- ABI: Interrupts operational image collection (uses macro)
- AHI: Special timeline without Full Disk (collects Japan and RO3)
Radiometric Calibration Utilizes Quadratic Equation

Spacelook subtracted to obtain relative counts
Linear coefficient (M) obtained from on-board target observation
Quadratic coefficient (Q) based on pre-launch testing

- Quite small and could probably be ignored because detectors are inherently linear

\[
\langle L_{\text{sample}} \rangle = \frac{M \cdot \Delta x_{\text{sample}} + Q \cdot \Delta x_{\text{sample}}^2 - \Delta L_{\text{EW @ sample}}^{\text{eff}} - \Delta L_{\text{NS @ sample}}^{\text{eff}}}{\rho_{\text{EW @ sample}} \cdot \rho_{\text{NS @ sample}}}
\]

- \( \Delta x_{\text{sample}} \) = scene sample minus spacelook
- \( \Delta L_{\text{EW @ sample}}^{\text{eff}}, \Delta L_{\text{NS @ sample}}^{\text{eff}} \) = contribution from scan mirrors
- \( \rho_{\text{EW @ sample}} \cdot \rho_{\text{NS @ sample}} \) = reflectance of scan mirrors
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On-Orbit Operations: Raster Scan vs. Boustrophedonic

**GOES N Imager**
Boustrophedonic  
(“as the ox plows”)

**GOES-R ABI**
Default = Raster Scan  
Capable of boustrophedonic

Raster scan results in higher quality images
- Constant time interval across swath boundary

Only possible because of Harris’ advanced scanner
- Smooth, fast slews at low power with little spacecraft disturbance

**ABI baseline scan rate = 0.024434 rad/s (1.4 degree/s)**
- Scan rate can be increased or decreased if different EW ASD is desired
Harris’ ABI Offers Unique Scan Flexibility

NS swath & stare support vicarious calibration for GSICS
Angled swaths can compensate for spacecraft yaw
  • Utilized by OMC (orbit motion compensation)
  • FPM is not rotated; hence coverage decreases as tilt increases

All scenes and timelines can be updated in orbit
ABI’s Scan Flexibility Offers Improved Vicarious Calibration Options

Standard calibration scenes easier to observe with ABI

Unique collections possible
  • Significantly increases types of collections for independent assessments of calibration accuracy

Calibration interleaved with standard scenes
  • Greatly increases opportunities for calibration
  • Calibration collections should be routine rather than special events

Six examples will be discussed:
  1. North-South (NS) scan
  2. Moon scan
  3. Fine scale raster scan
  4. Perimeter scans or stares of space
  5. Simultaneous collections with under-flying payloads
  6. Simultaneous collections with other ABI-class imagers
1. Purely North-South Scan

Purely NS scan permits every detector element of a single channel to observe same scene

Stable uniform scene provides accurate relative calibration within each channel
  • Absolute calibration if source radiance well known

Requires 16 swaths (one per channel)

Swaths tailored to each instrument
  • Start and stop match south and north detector line-of-sight
  • Swath tilt compensates for FPA rotation
  • Duration based on NS IFOV so samples collected at same NS location

Vicarious calibration scene much smaller than NS FOV
  • Size based on detector element NS IFOV & FPA EW IFOV, plus pointing uncertainties

Spacecraft yaw compensated by OMC

Collections of different scenes and locations permit effects of scan angles and spectral content to be assessed
North-South Scan Collection Time: 18.99 s

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Minimum scene (NS x EW): 312 x 577 µrad = 11.1 x 20.6 km
2. Moon Scan

Moon observations used by many instruments for absolute calibration

ABI provides very detailed moon image
- 332 to 1460 rows per FPA
- Moon fills ~60% of ABI NS FOV

Total moon radiance can provide absolute scale for relative calibration obtained from NS scans
- Use relative response to compute weighted total counts for moon image
- Divide into total radiance

Can collect moon as part of timeline
- Interleaved with Full Disk and CONUS
- Meso time allocation permits two Moon swaths

AHI-8 Band 3 (0.64 μm)
2 Aug 2015

AHI-8 image courtesy of JMA
3. Fine Scale Raster Scan

Calibration accuracy can be affected by scan angle and variation of angle of incidence over the length of the FPA

- ABI’s calibration algorithm includes adjustment for scan mirror angle
- ABI calibrates angle of incidence effects by end-to-end calibration of entire FPA in single observation of on-board calibration target

Effectiveness of on-board target calibration can be validated via a fine raster scan of a stable scene

- Scanning same scene with slight changes in NS swath location
  - E.g., each swath could step south by 280 μrad (10 km), providing 50 swaths for 500 km scene
  - 3 seconds per swath; can be interleaved with Full Disk and CONUS collections

Provides 3rd assessment method of FOV and scan angle effects

- Compare to result of on-board targets and NS scan results
4. Perimeter Scans Or Stares Of Space

Emissivity of scan mirrors varies with angle of incidence
Causes variation in self emission background radiance between spacelook and Earth scene
Component-level measurement of emissivity vs. angle of incidence used as part of on-orbit calibration of scene data
Observing space (zero radiance) at different scan mirror angles provides independent assessment over life of mission
Baseline is to collect data at 8 locations around perimeter of Earth
  • Could also do piecewise linear scans
5. Simultaneous Collections With Under-flying Payloads

Comparing images of same scene taken by multiple space-based payloads provides cross-calibration
ABI provides much greater ability to implement this technique

- More opportunities
  - Collection interleaved with baseline Full Disk and CONUS collections rather than interrupting them
  - Meso opportunity every 30 s in Scan Mode 3 timeline, permitting multiple collections within a single underpass

- Better temporal correlation
  - Meso can be positioned to directly overlap under-flying payload, resulting in simultaneous collections

- Better spectral correlation
  - Sixteen bands to chose between rather than just five
6. Simultaneous Collections With Other ABI-class Imagers

- Significant coverage overlap
  - Cross-calibration opportunities
- PCW would further enhance calibration
  - Cross-calibrate with all geostationary imagers

PCW = Canada’s proposed Polar Communication and Weather mission
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ABI-class imagers are designed for improved calibration
Scan flexibility provides significantly more calibration opportunities and unique methods, including:

1. North-South (NS) scan
2. Moon scan
3. Fine scale raster scan
4. Perimeter scans or stares of space
5. Simultaneous collections with under-flying payloads
6. Simultaneous collections with other ABI-class imagers

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