11.2 ABI's Unique Calibration and Validation Capabilities

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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

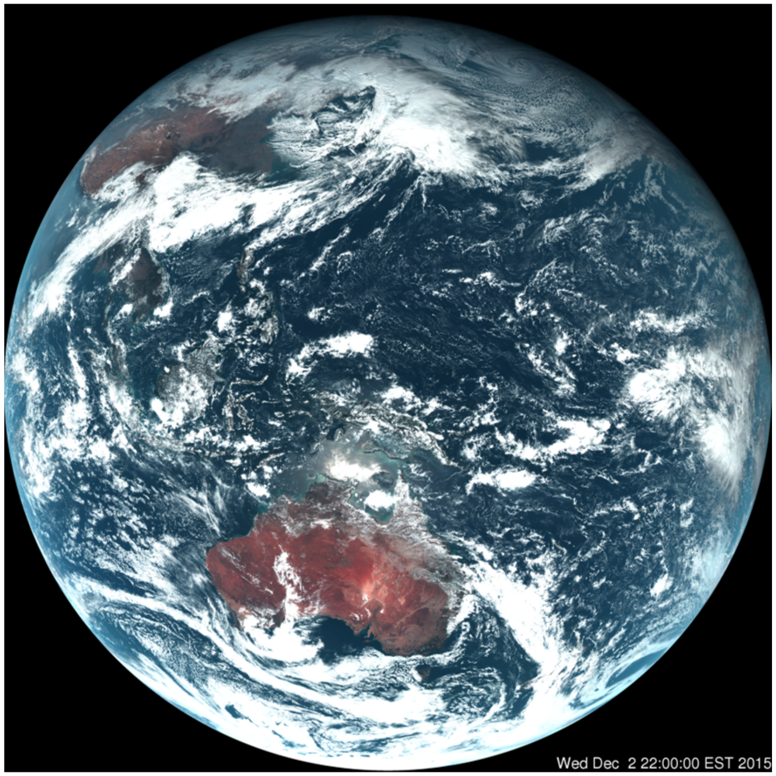
ABI-Class Imager Description

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

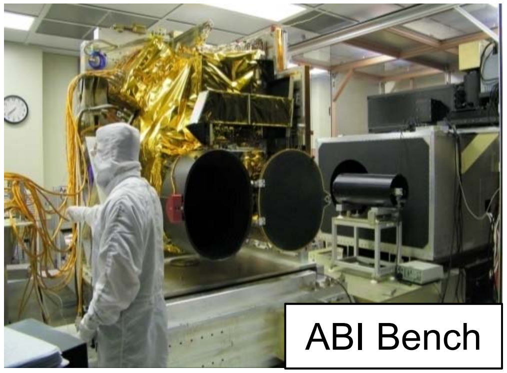
- ABI PFM: Integrated on GOES-R spacecraft
- **AHI-8: Operating on orbit (Himawari-8)**
- ABI FM2: Delivered
- AHI-9: Integrated on Himawari-9 spacecraft

Three more in production at Harris

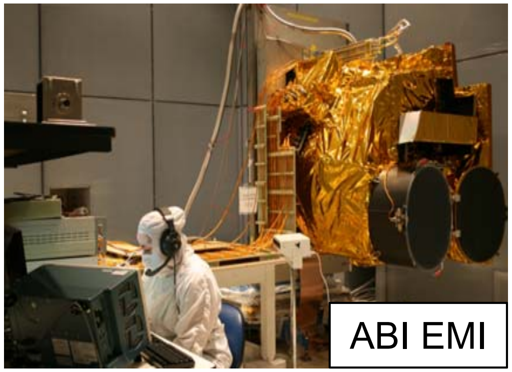
- ABI FM3, ABI FM4, AMI

Himawari 8

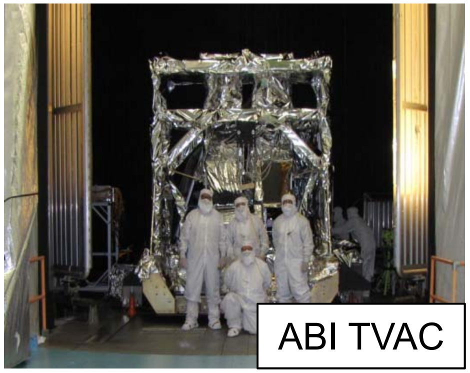
Mitsubishi Electric Corporation



ABI Bench



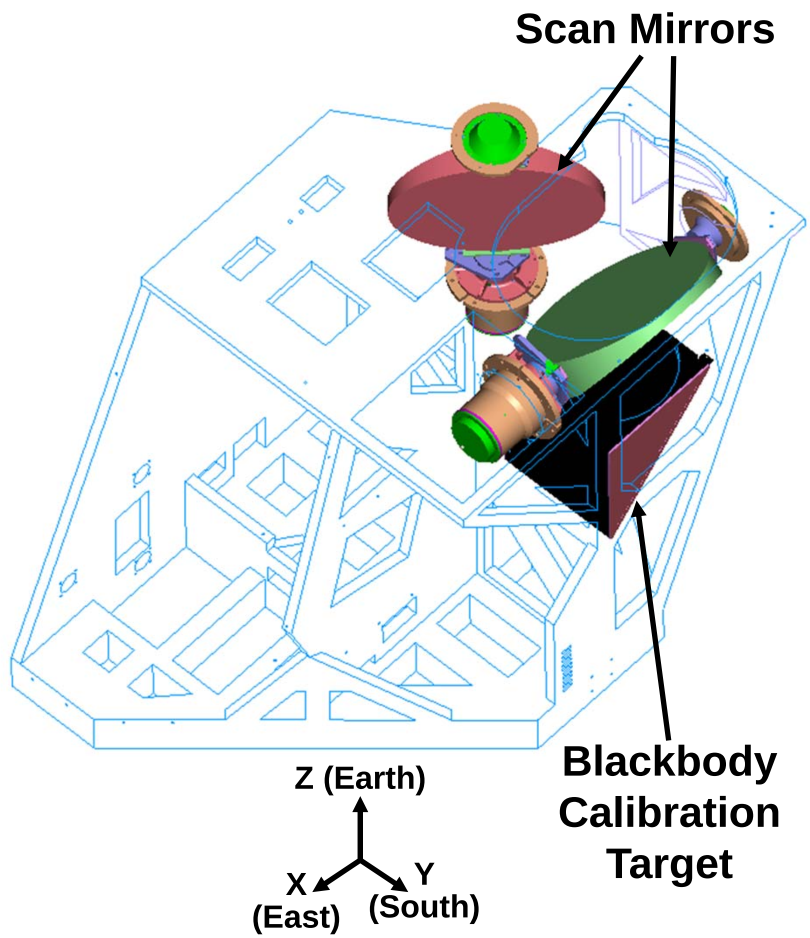
ABI EMI



ABI TVAC

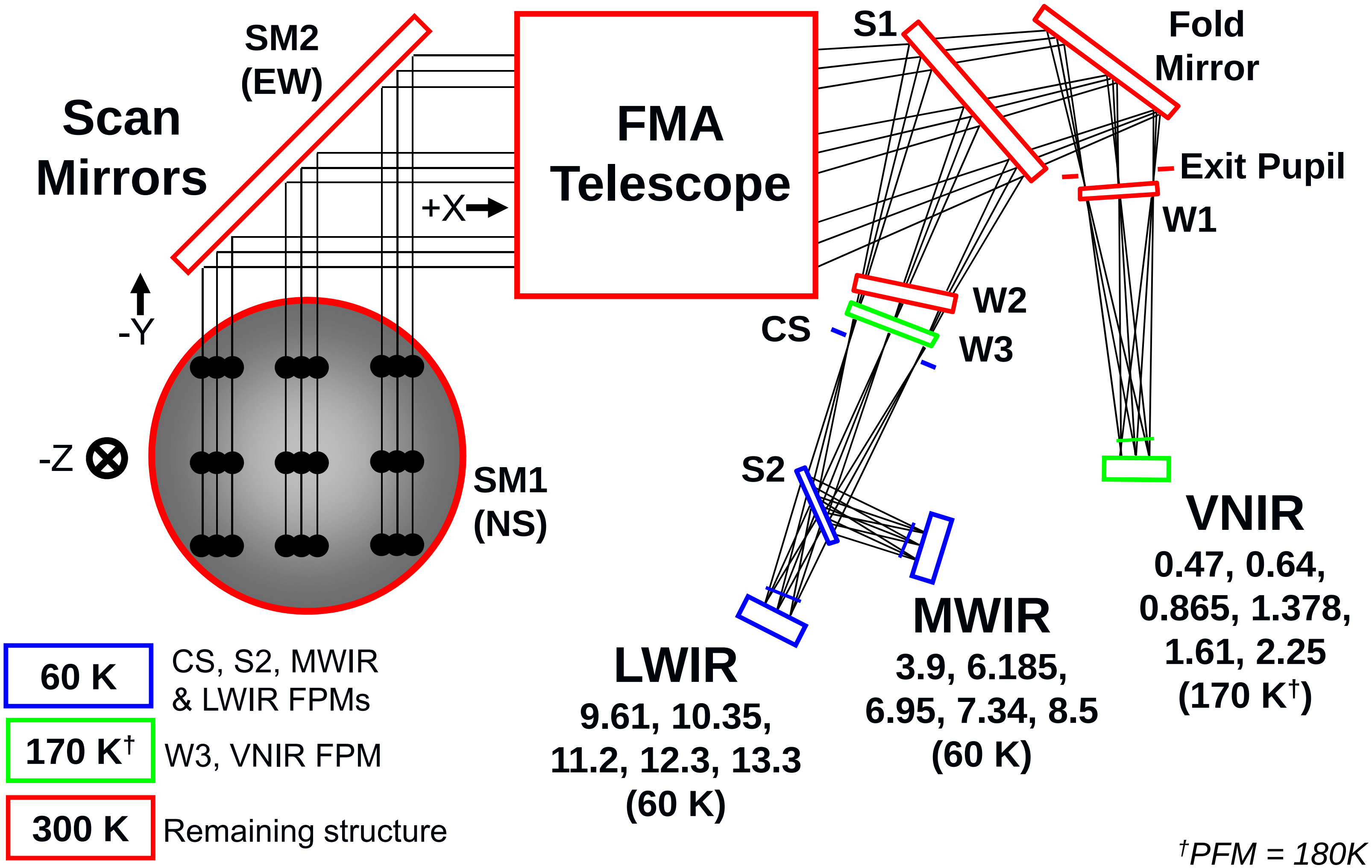
ABI's 2-Mirror Scanner Key to Improved Calibration Capability

- Scans parallel to equator without rotating image
  - 100% scan coverage efficiency
- Lowest inertia and power
- 2x EW <u>and</u> 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 Optical Architecture: Simple Solution to Mission Needs



†PFM = 180K

ABI-class Imagers Provide 16 Channels, Optimized for Customer's Mission

HARRIS

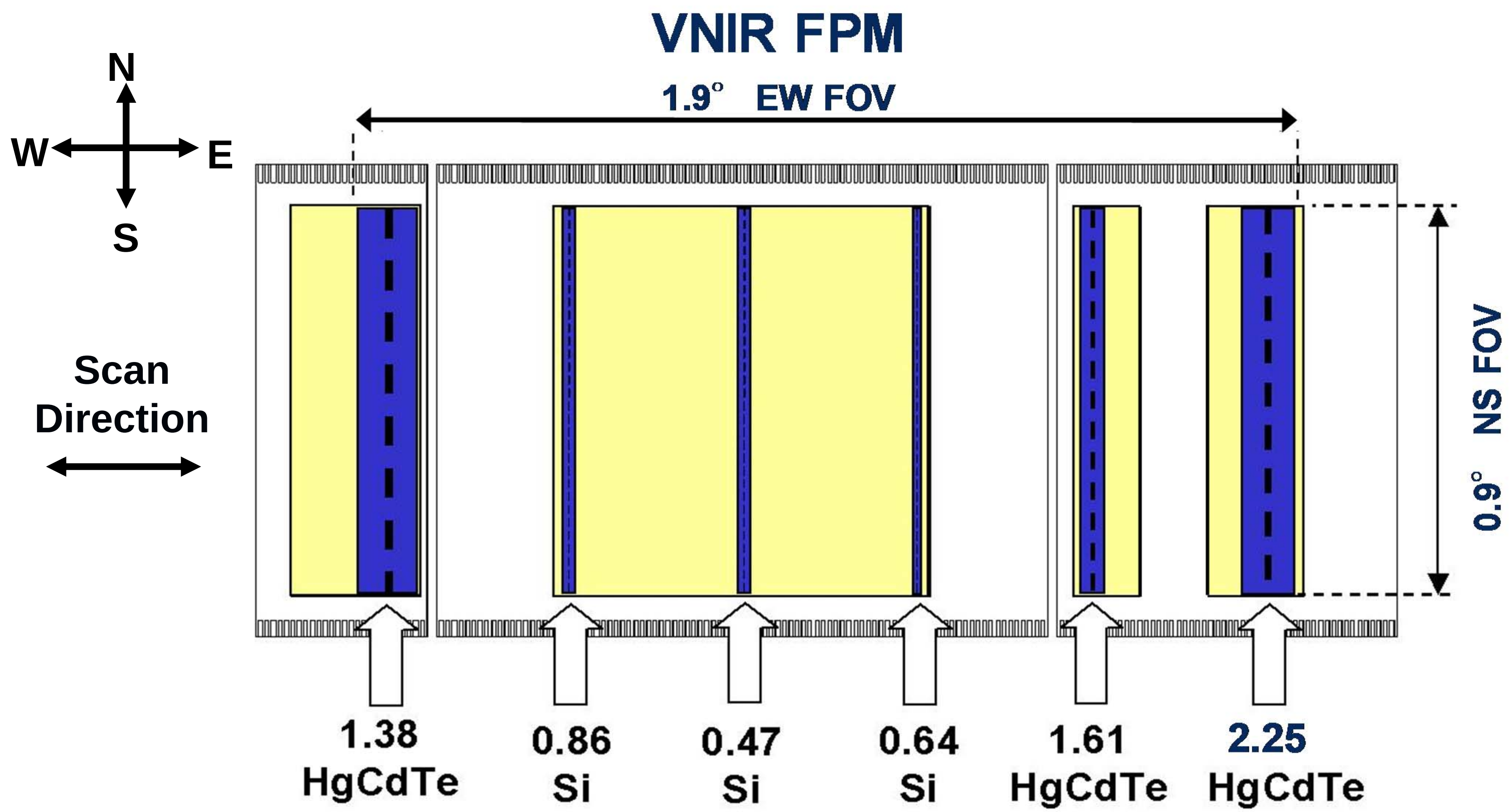
FPM	FPA	Resolution (km)	Center wavelength (μm)		
			ABI	AHI	AMI
VNIR	A047	1	0.47	0.47	0.47
	A064	0.5	0.64	0.64	0.64
	A086	1	0.865	0.51	0.51
	A138	2	1.378	1.61	1.378
	A161	1	1.61	0.865	0.865
	A225	2	2.25	2.25	1.61
MWIR	A390	2	3.9	3.9	3.9
	A618	2	6.185	6.185	6.185
	A695	2	6.95	6.95	6.95
	A734	2	7.34	7.34	7.34
	A850	2	8.5	8.5	8.5
LWIR	A961	2	9.61	9.61	9.61
	A1035	2	10.35	10.35	10.35
	A1120	2	11.2	11.2	11.2
	A1230	2	12.3	12.3	12.3
	A1330	2	13.3	13.3	13.3

- 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

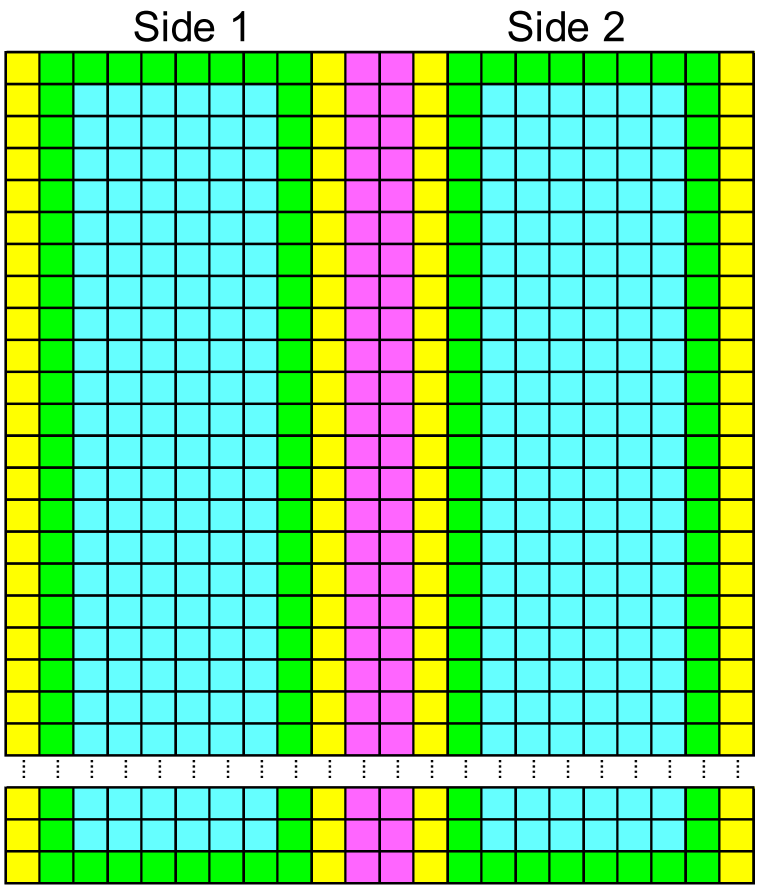
Color Key:

Not in ABI
Different FPA

Focal Plane Modules Spatially Separate Channels in Scan Direction

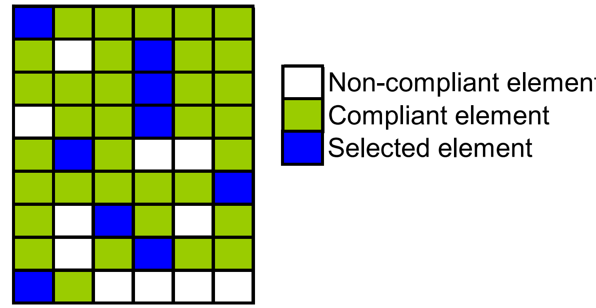


Detector Selection Capability Provides Operational Redundancy



Externally: Line array
Internally: 2D array

Select best element in each row



Color Key:
- Ground
- Guard
- Active Detector Element
- Separation

Requirement: one operational element per downlinked row per side

ABI ASD, IFOV, and Aperture

Channels (wavelengths in μm)	Resolution (km)	EW ASD (μrad)	IFOV (μrad)		Rows	Columns
			NS	EW		
0.64	0.5	11	10.5	12.4	1460	3
0.47, 0.86	1	22	22.9	22.9	676	3
1.61	1	22	22.9	22.9	676	6
1.38, 2.25	2	44	42	51.5	372	6
3.9, 6.18, 6.95, 7.34, 8.5, 9.61	2	44	47.7	51.5	332	6
10.35, 11.2, 12.3, 13.3	2	44	38.1	34.3	408	6

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

Parameter	Units	GOES-O Imager	GOES-R ABI	Ratio
Channels		5	16	3.2
Detector Elements: total		24	77,400	3225
Detector Elements: downlinked		16	7,856	491
NS FOV: max channel	µrad	274	16,311	60
EW FOV: max FPM	µrad	140	33,203	237

Harris' ABI-class imager provides calibration solutions

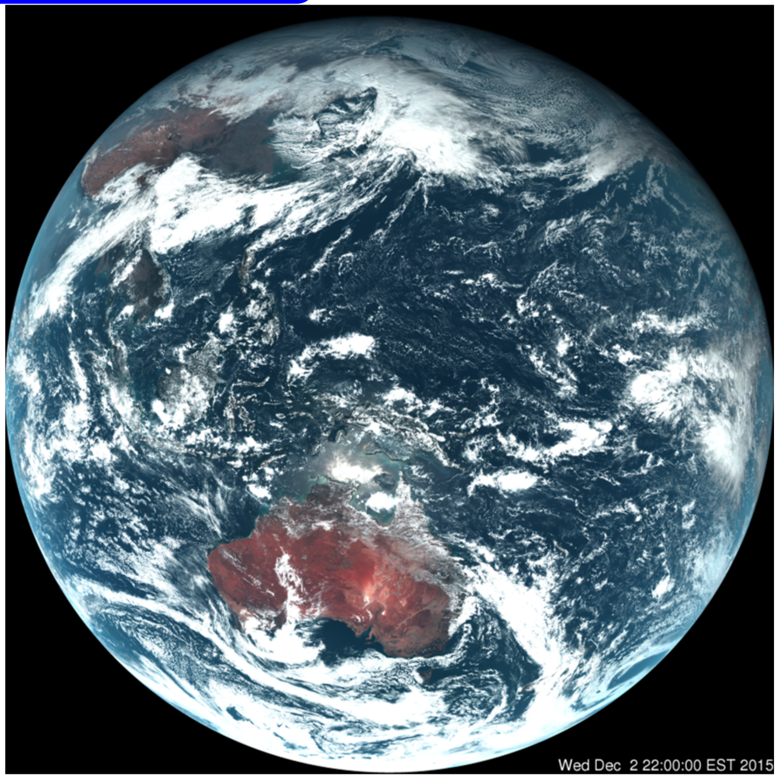
ABI-Class Imager Description

On-board Radiometric Calibration Targets

Operational Calibration

Additional Capabilities for Calibration & Validation

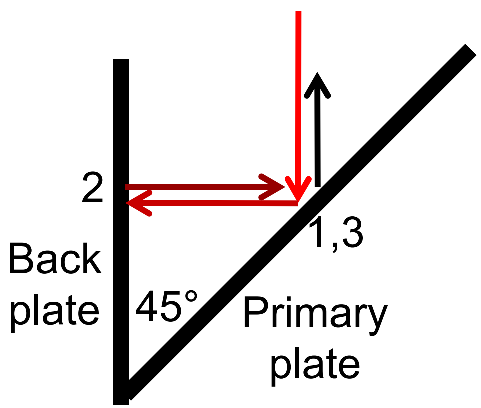
Summary

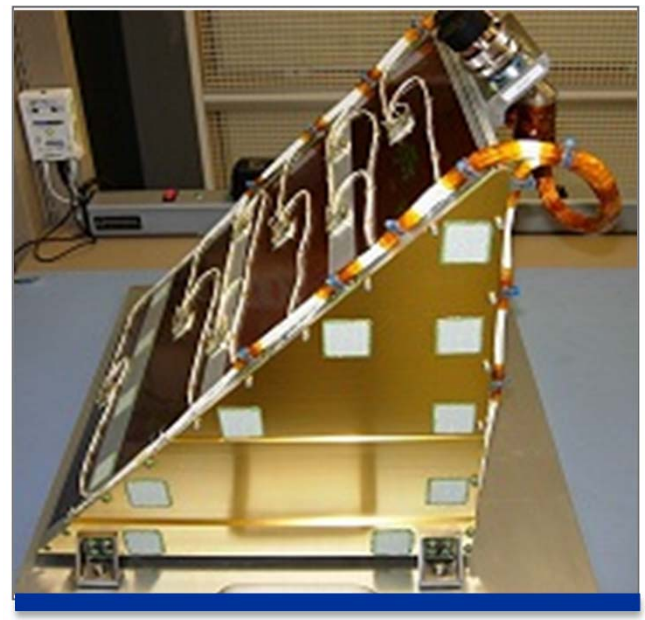


AHI-8 True Color (RGB) Image 3Dec2015 12:00 JST
(Data from JMA, Processing by Harris)

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



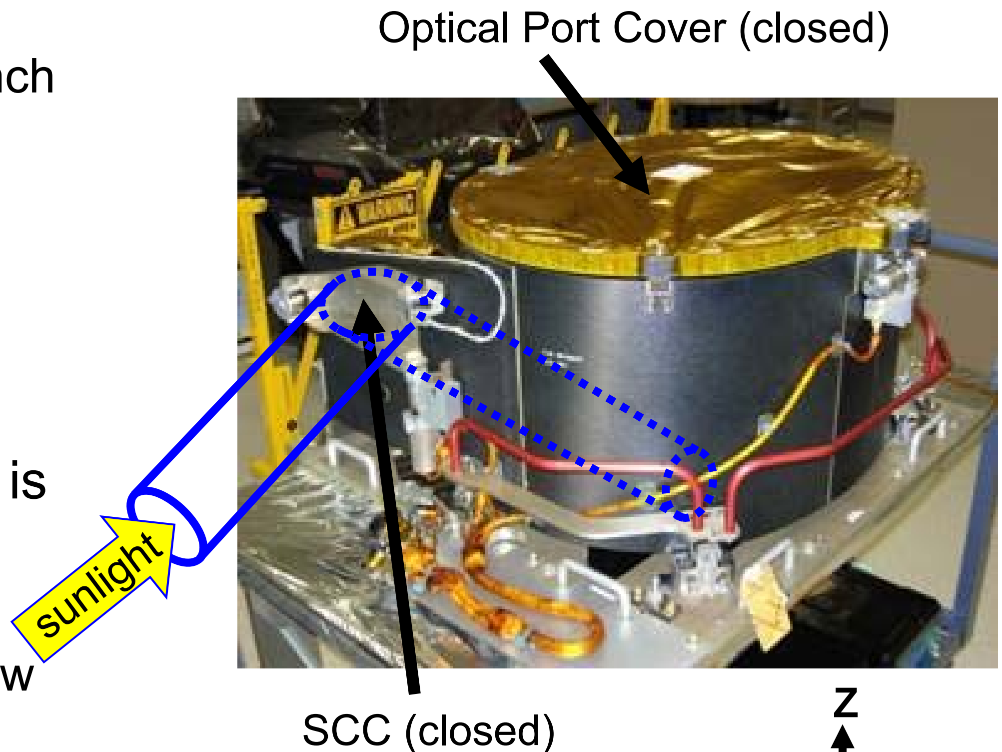


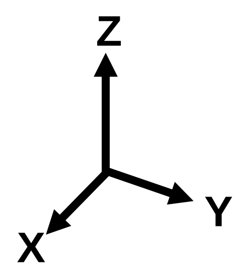
ABI PFM 3-bounce blackbody

Full aperture,
end-to-end calibration

Solar Calibration Assembly Delivers On-Orbit Calibration Over Mission Life

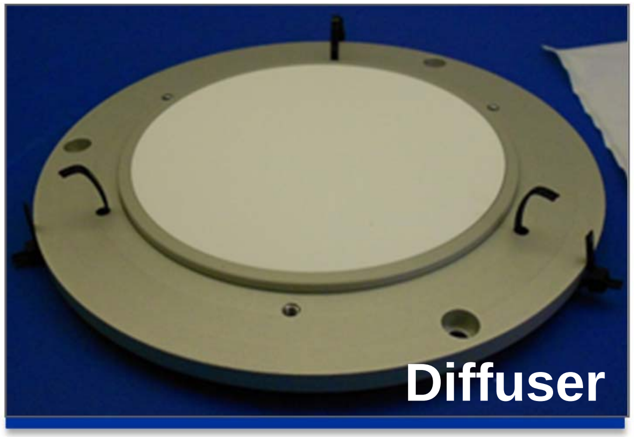
- Optical Port Cover:
  - One time deployable
  - Keeps payload clean during launch and outgassing
- Solar Cal Cover (SCC):
  - Open only when calibrating
  - Closed rest of time to preserve cleanliness
- Solar Calibration Target (SCT) is Spectralon™ diffuser
  - Calibration can occur any day of year 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





End-to-end calibration

Solar Calibration Subsystem Built, Tested, and Qualified for ABI



Design optimized
for minimum
calibration uncertainty

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 λ < 3 μm when viewing SCT
  - Nominal SCT observation performed with integration factor of 10x
- Second set typically used for λ > 5 μm when viewing ICT
- Third set typically used for λ = 3.9 μm when viewing ICT

ECAL can also be used when observing space or any other external scene

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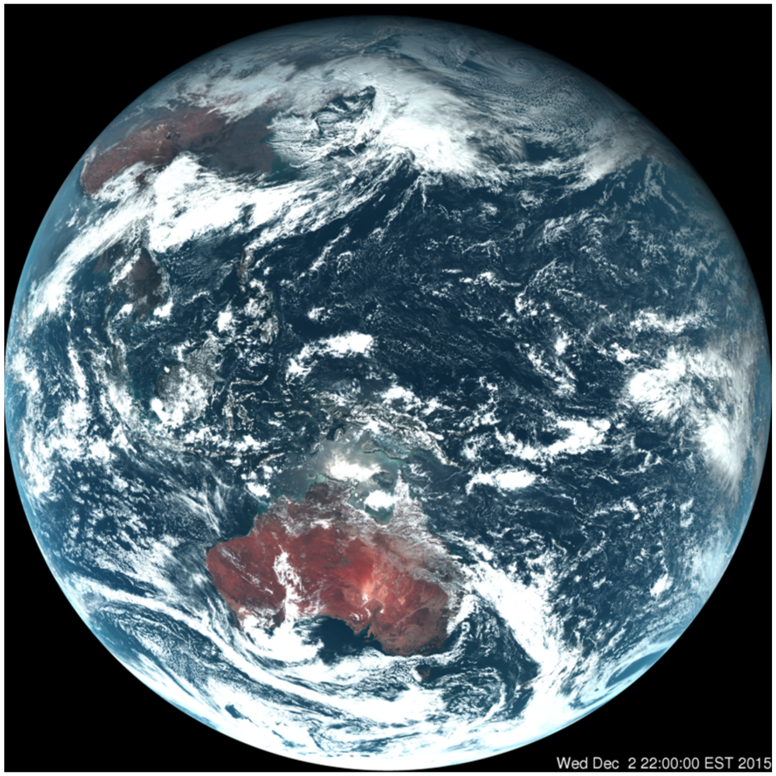

AHI-8 True Color (RGB) Image 3Dec2015 12:00 JST
(Data from JMA, Processing by Harris)

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

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

Δx_{sample} = scene sample minus spacelook

$\Delta L_{EW@sample}^{eff}, \Delta L_{NS@sample}^{eff}$ = contribution from scan mirrors

$\rho_{EW@sample}, \rho_{NS@sample}$ = reflectance of scan mirrors

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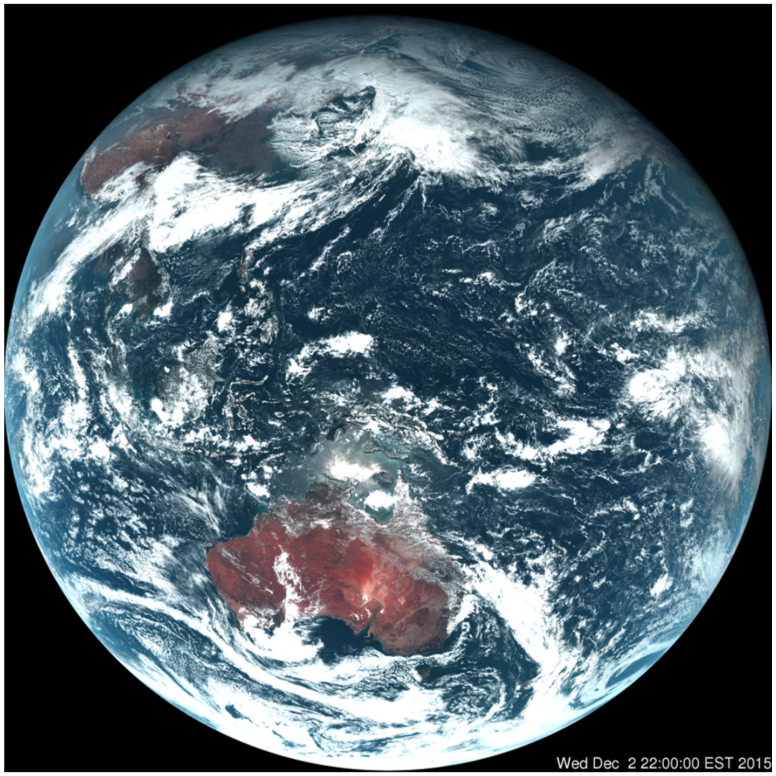

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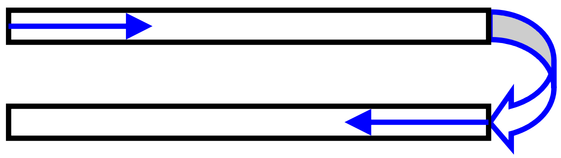
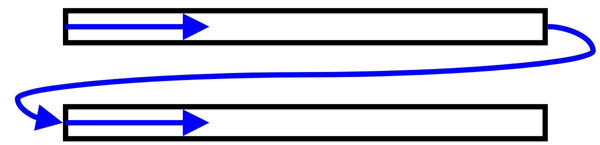
On-Orbit Operations: Raster Scan vs. Boustrophedonic

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

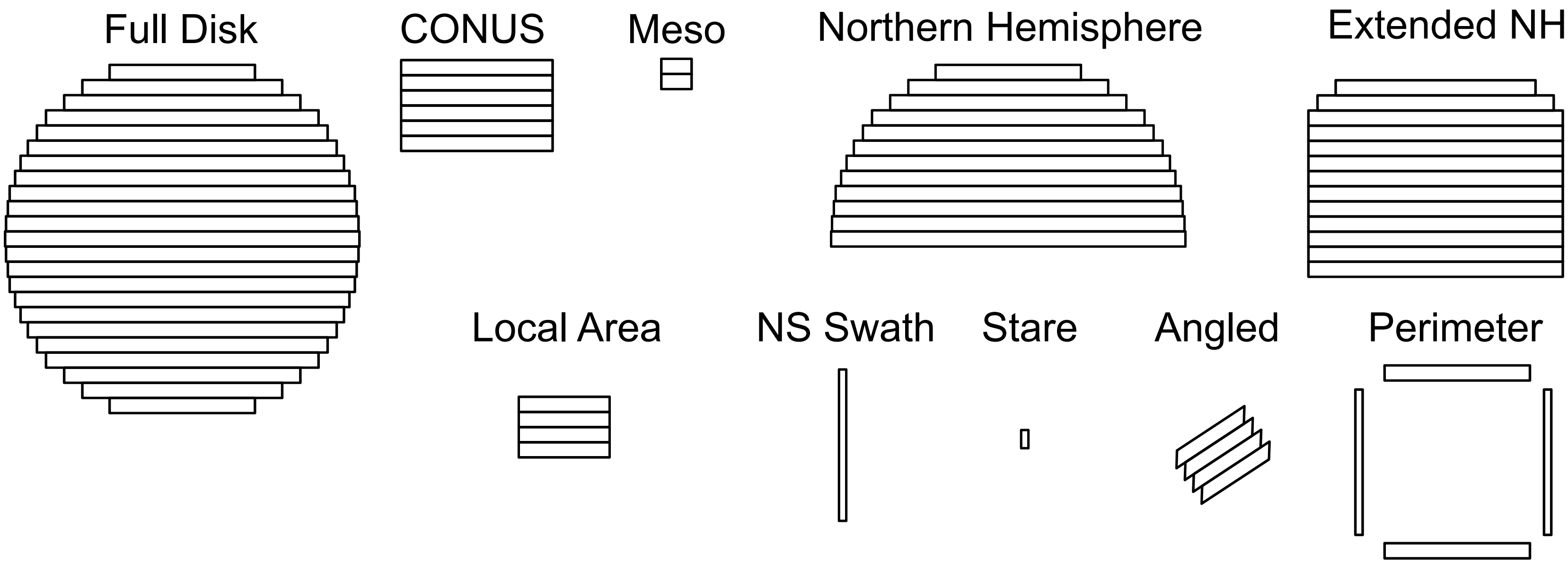
Only possible because of Harris’ advanced scanner

- 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

HARRIS

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

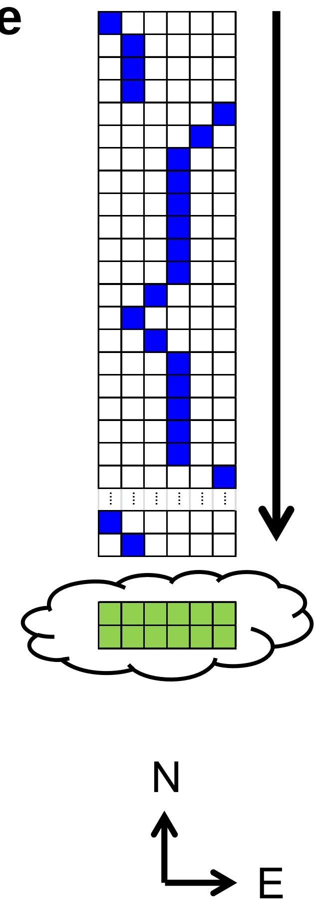
- Start and stop match south and north detector line-of-sight
- Swath tilt compensates for FPA rotation
- Duration based on NS IFOV so samples collected at same NS location

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

FPM	Wavelength (µm)	IFOV (µrad) NS	IFOV (µrad) EW	Columns	Rows	Frame Time (ms)	Duration (s)
VNIR	0.47	22.9	22.9	3	676	0.902	0.610
	0.64	10.5	12.4	3	1460	0.451	0.658
	0.865	22.9	22.9	3	676	0.902	0.610
	1.378	42.0	51.5	6	372	1.803	0.671
	1.61	22.9	22.9	6	676	0.902	0.610
	2.25	42.0	51.5	6	372	1.803	0.671
MWIR	3.9	47.7	51.5	6	332	1.803	0.599
	6.185	47.7	51.5	6	332	1.803	0.599
	6.95	47.7	51.5	6	332	1.803	0.599
	7.34	47.7	51.5	6	332	1.803	0.599
	8.5	47.7	51.5	6	332	1.803	0.599
LWIR	9.61	47.7	51.5	6	332	1.803	0.599
	10.35	38.1	34.3	6	408	1.803	0.736
	11.2	38.1	34.3	6	408	1.803	0.736
	12.3	38.1	34.3	6	408	1.803	0.736
	13.3	38.1	34.3	6	408	1.803	0.736

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)
2Aug2015

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

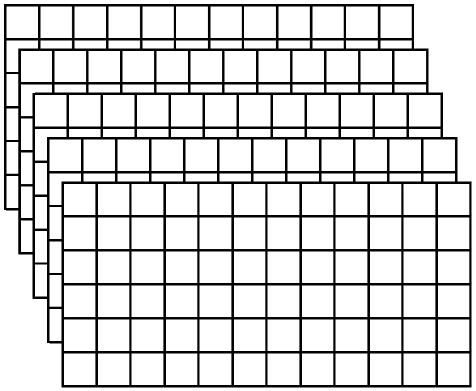
- ABI's calibration algorithm includes adjustment for scan mirror angle
- ABI calibrates angle of incidence effects by end-to-end calibration of entire FPA in single observation of on-board calibration target

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

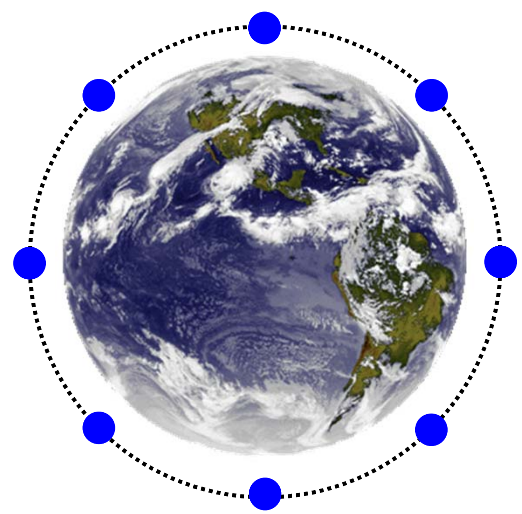
Causes variation in self emission background radiance between spacelook and Earth scene

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

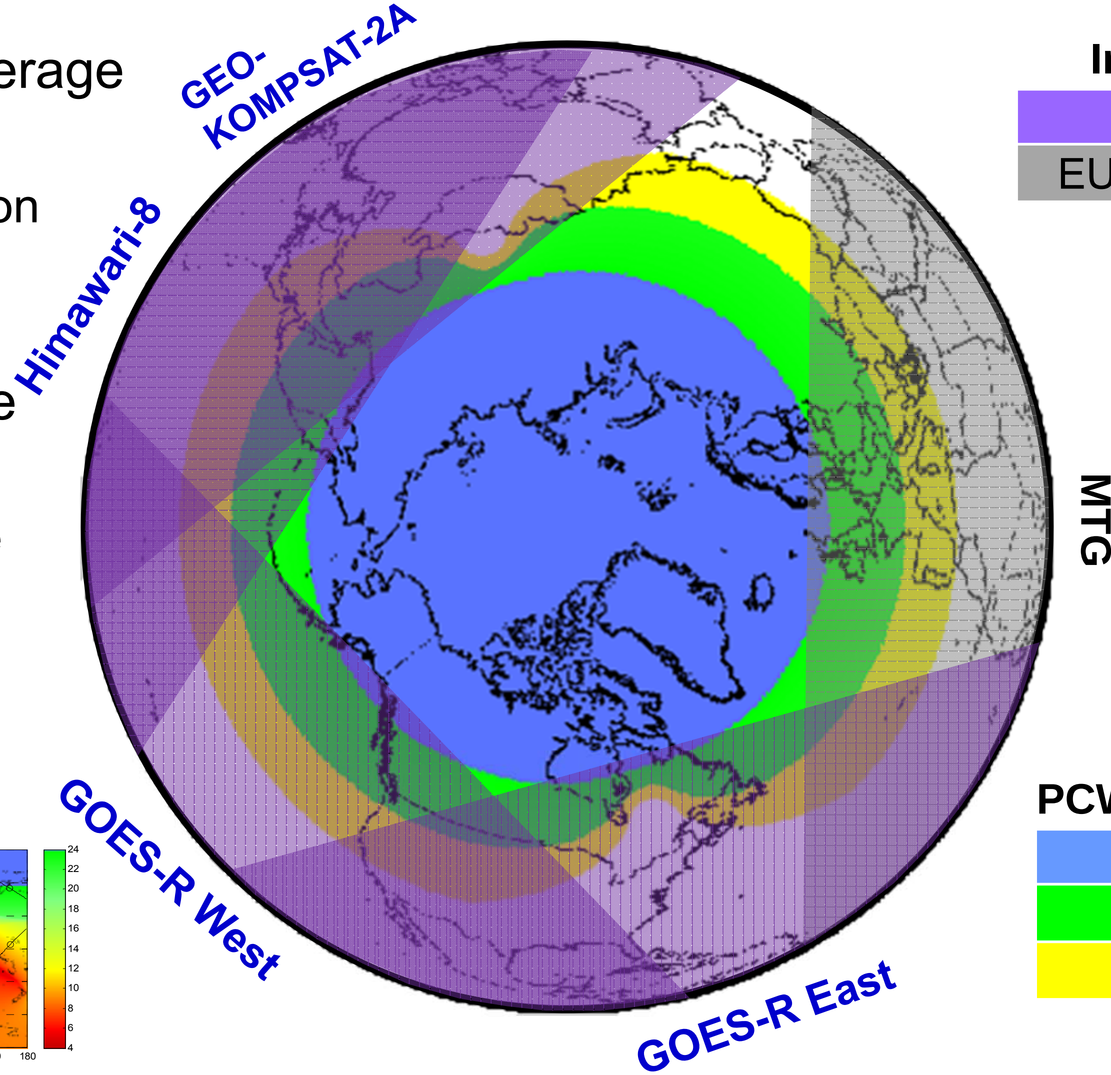
Comparing images of same scene taken by multiple space-based payloads provides cross-calibration

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



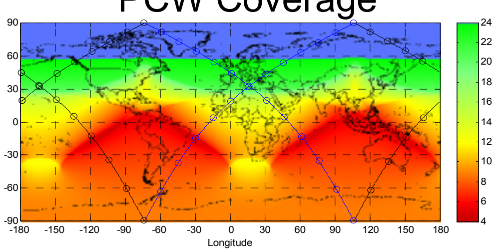
Imagers

Imagers
Harris
EUMETSAT

PCW Coverage

PCW Coverage
100%
95%
90%

PCW Coverage



PCW = Canada's proposed Polar Communication and Weather mission

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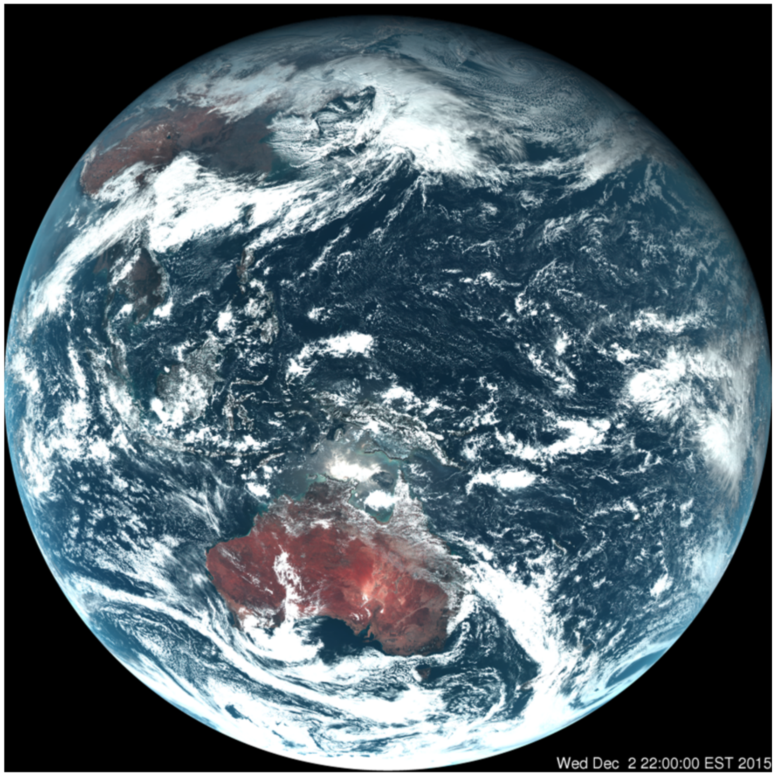

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Summary

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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Appreciation to Tim Schmit,
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and to NOAA, JMA, and UW/SSEC CIMSS