Advanced Himawari Imager (AHI) Design and Operational Flexibility

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AHI – Paradigm Shift in Geostationary Weather Imaging

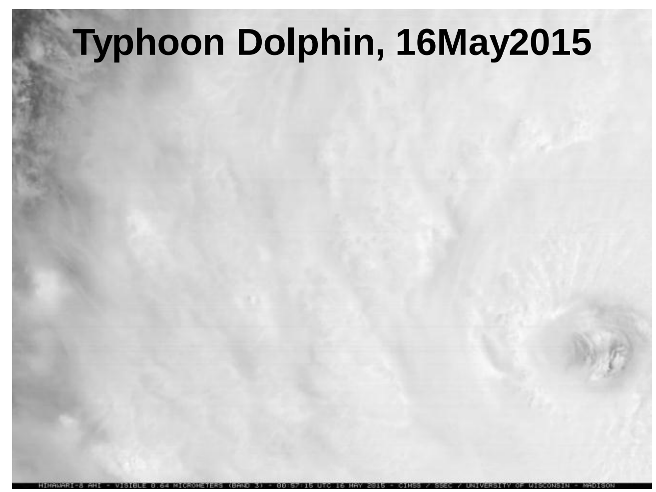
Better spectral, spatial, and temporal resolution improves quality and number of critical data products

Improved calibration targets yields more accurate images

Interleaved scene collection provides operational flexibility

- Himawari-8: Full Disk, Japan, and rapid scan interleaved
- Himawari-7 (MTSAT-2): interrupt Full Disk for rapid scan of storms
- **One instrument** – multiple scenes of different sizes, locations, and repetitions seamlessly interleaved

AHI-8 lunar image courtesy of JMA



Data from JMA, Video courtesy of UW/SSEC, CIMSS

Agenda

AHI Design

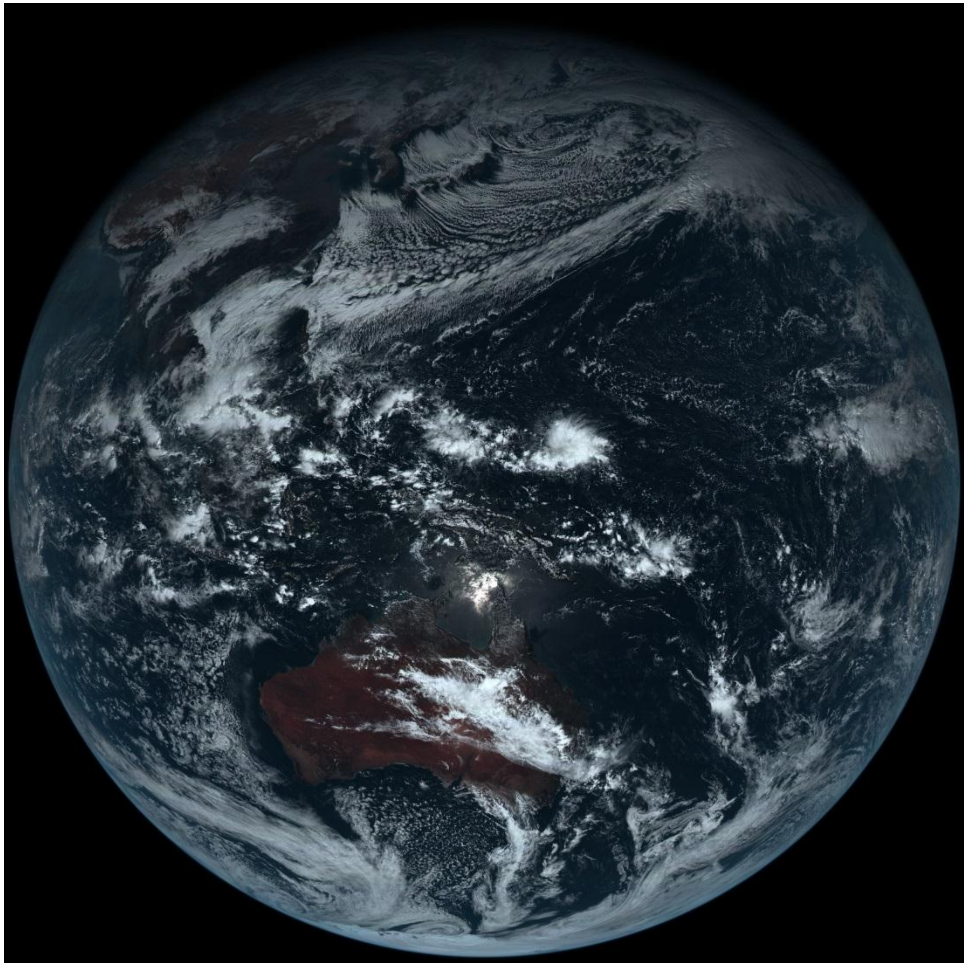
Calibration Targets

Operational Flexibility

Resampling

Summary

AHI-8 (photo by Harris)



Himawari-8 True Color (RGB) Image courtesy of JMA

AHI-8: First Next Generation Geostationary Imager On Orbit

ABI imagers supporting three missions:

- GOES-R (ABI), Himawari (AHI), GEO-KOMPSAT-2A (AMI)

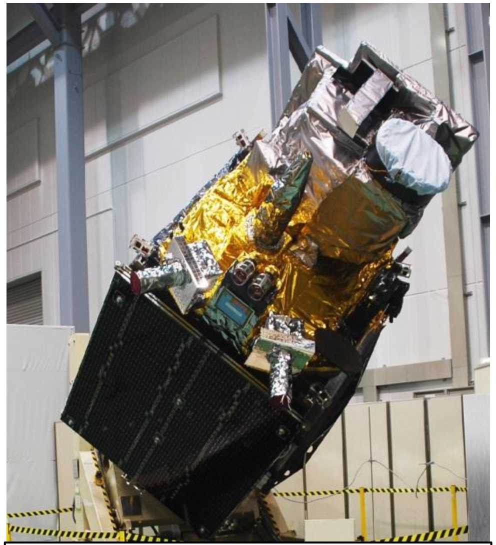
Four flight models delivered

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

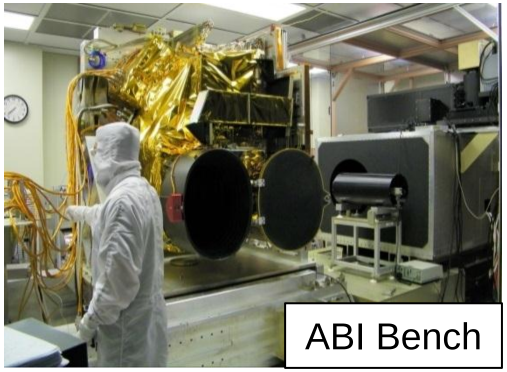
Three more in production at Harris

- ABI FM3, ABI FM4, AMI

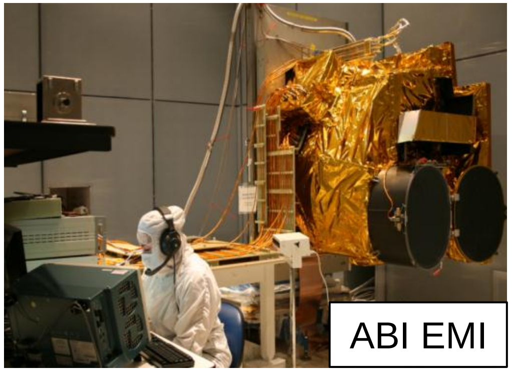
Himawari 8



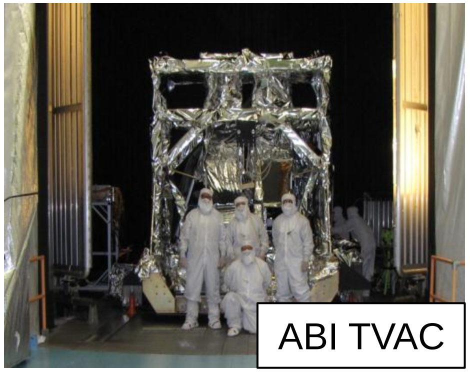
Courtesy of Mitsubishi Electric Corporation



ABI Bench



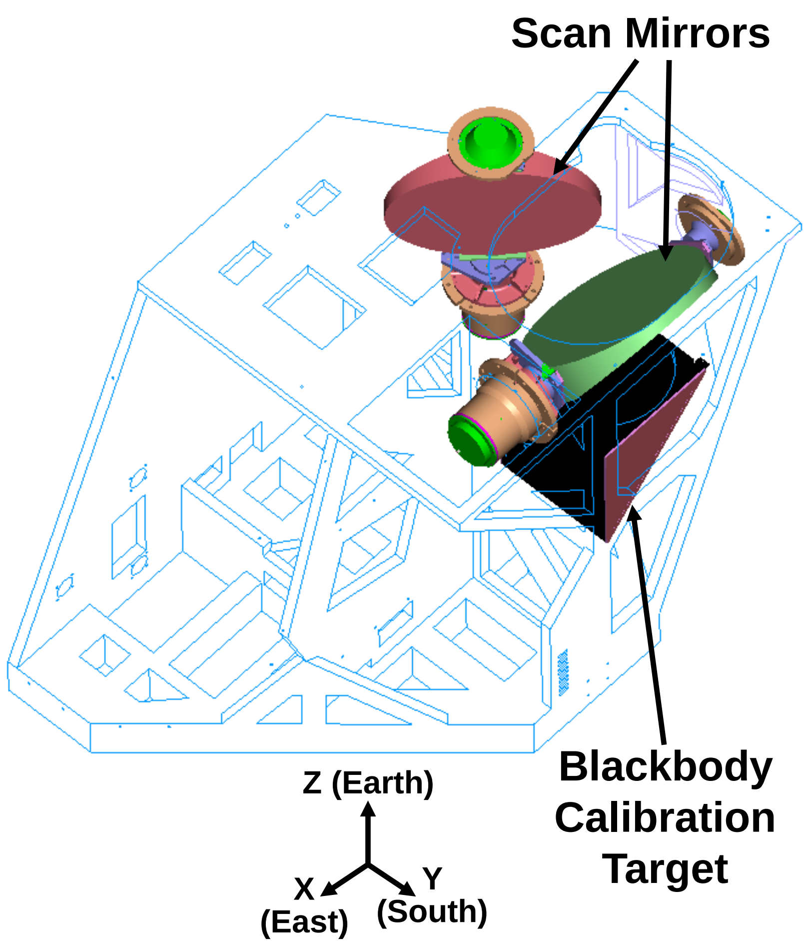
ABI EMI



ABI TVAC

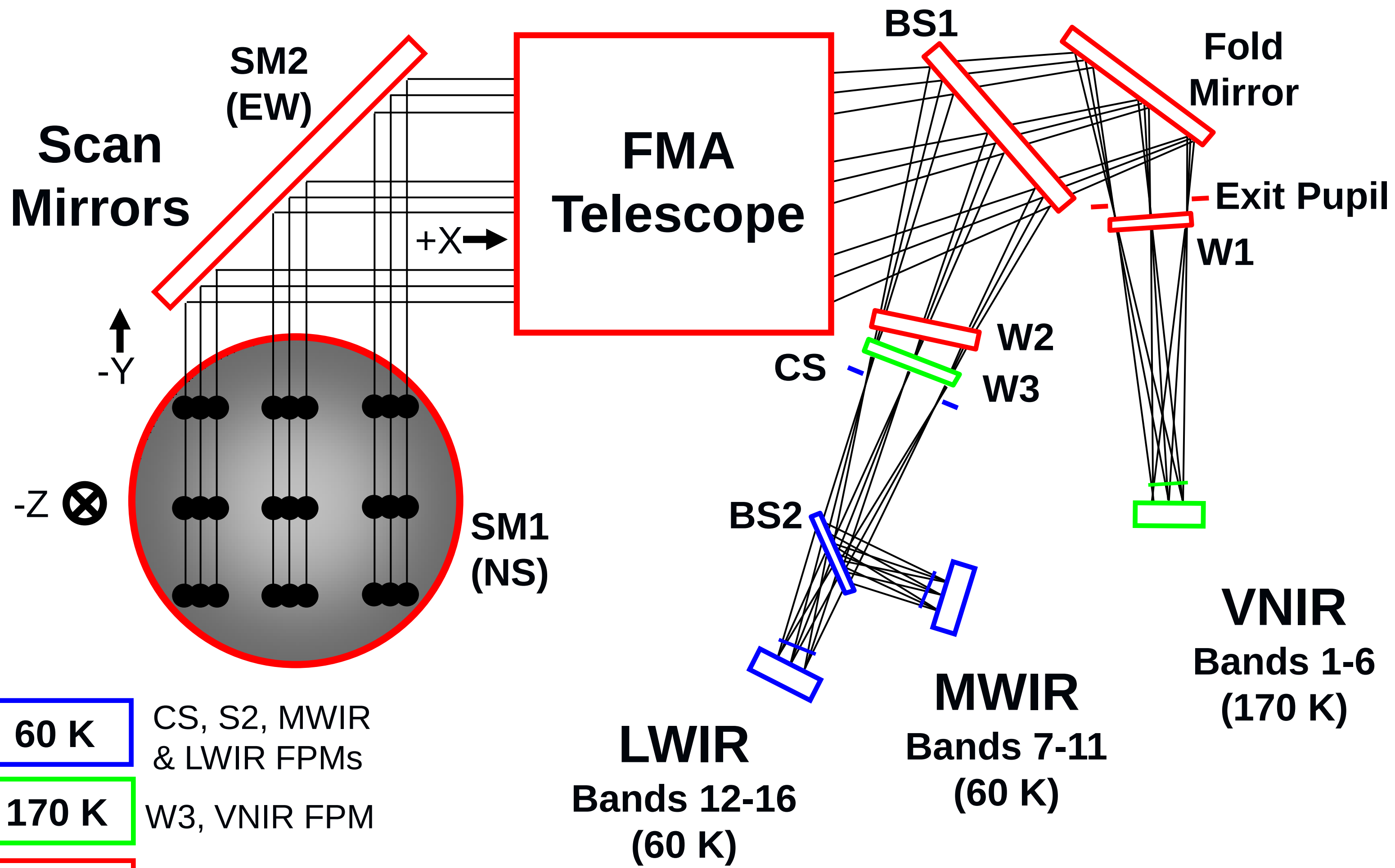
AHI's 2-Mirror Scanner Key to Operational Flexibility

- 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

AHI Optical Architecture: Simple Solution to Mission Needs



60 K	CS, S2, MWIR & LWIR FPMs
170 K	W3, VNIR FPM
300 K	Remaining structure

AHI Channels Optimized for JMA's Mission

FPM	FPA	Resolution (km)	AHI Band #	Nominal Wavelength (µm)		
				ABI	AHI	AMI
VNIR	A047	1	1	0.47	0.47	0.47
	A086	1	2	0.86	0.51	0.51
	A064	0.5	3	0.64	0.64	0.64
	A161	1	4	1.61	0.86	0.86
	A138	2	5	1.38	1.61	1.38
	A225	2	6	2.25	2.26	1.61
MWIR	A390	2	7	3.9	3.9	3.9
	A618	2	8	6.185	6.185	6.185
	A695	2	9	6.95	6.95	6.95
	A734	2	10	7.34	7.34	7.34
	A850	2	11	8.5	8.5	8.5
LWIR	A961	2	12	9.61	9.61	9.61
	A1035	2	13	10.35	10.35	10.35
	A1120	2	14	11.2	11.2	11.2
	A1230	2	15	12.3	12.3	12.3
	A1330	2	16	13.3	13.3	13.3

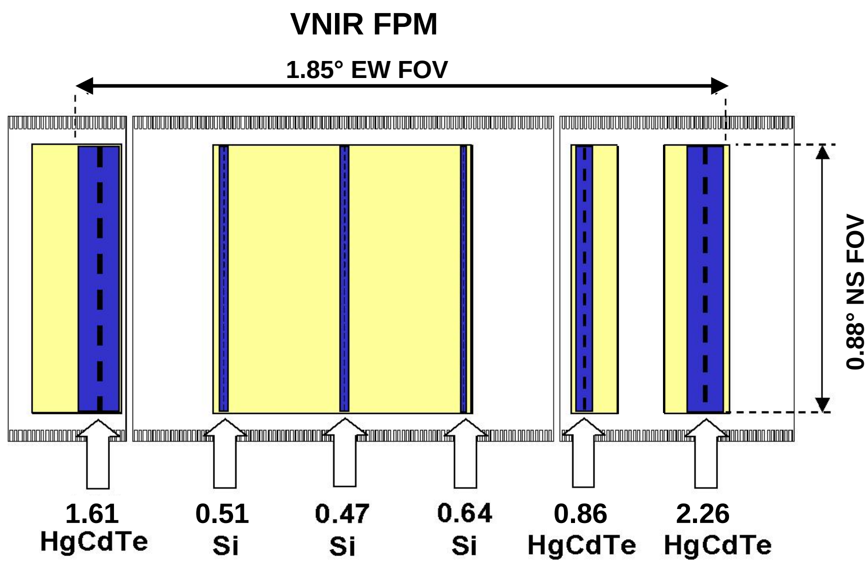
- AHI & AMI added 1-km 0.51 µm channel (green)
  - True 3-color visible images
  - Improved ocean images
- Retained 1-km 0.865 µm channel
  - Shifted to HgCdTe detector array
- Changed 1.61 µm channel to 2-km
- Eliminated one NIR channel
  - AHI: 1.378 µm
  - AMI: 2.25 µm

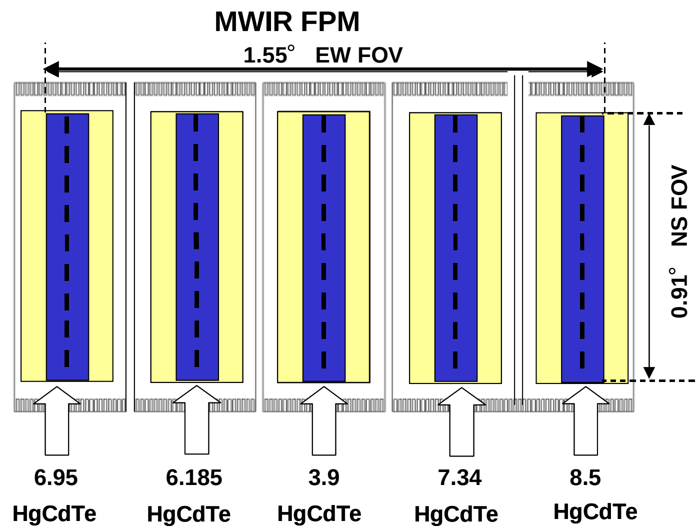
Color Key:

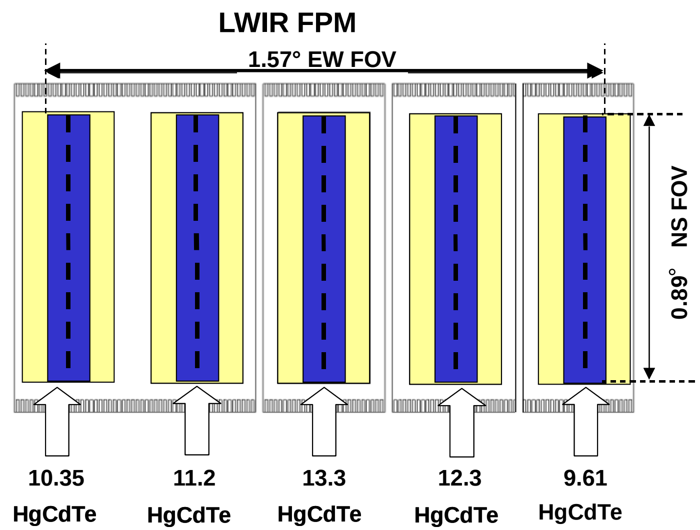
Not in ABI
Different FPA

Focal Plane Modules Spatially Separate Channels in Scan Direction

HARRIS







Acronyms:

- FPM = Focal Plane Module
  - VNIR = Visible and Near-Infrared
  - MWIR = Midwave Infrared
  - LWIR = Longwave Infrared
- FPA = Focal Plane Array
- FOV = Field of View

Focal Plane Module Field-of-View (FOV)

FOV (degrees)	Nominal		Maximum†		Minimum†	
	NS	EW	NS	EW	NS	EW
VNIR FPM	0.88°	1.85°	0.90°	1.91°	0.85°	1.79°
MWIR FPM	0.91°	1.55°	0.93°	1.60°	0.88°	1.50°
LWIR FPM	0.89°	1.57°	0.92°	1.62°	0.86°	1.52°

†Possible range of build-to-build variation

0.64 µm channel defines swath height

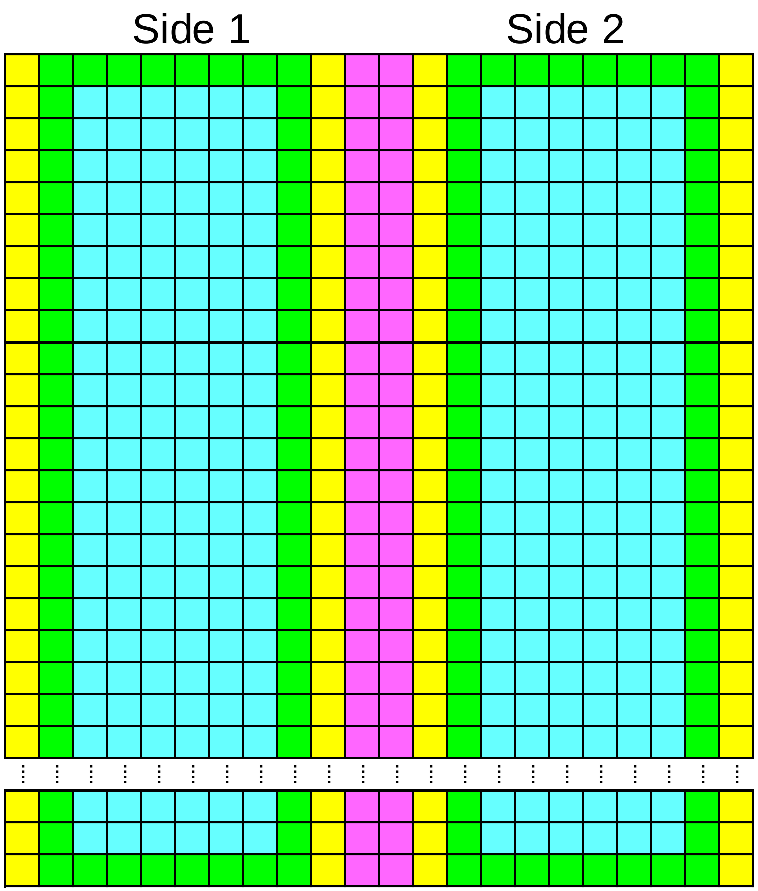
- All other FPAs have larger NS FOV; aligned to envelope 0.64 µm

VNIR FPM EW FOV defines scene over-scanning

- MWIR and LWIR EW FOVs aligned to lie within VNIR EW FOV

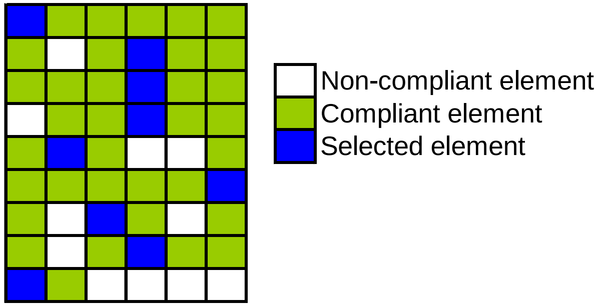
Maximum FPM EW FOV = 0.033203 radians

Detector Selection Capability Provides Operational Redundancy and Optimization



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

Best Detector Select (BDS) Map Can Be Updated In Orbit

All detector elements characterized using on-board targets, spacelooks, and/or stable vicarious calibration targets

- Zero radiance and “typical” radiance scenes
- Performed for all detector elements in each column

“Best” detector element in each row selected

- Operable – i.e. responds to light
- Median quantum efficiency
- Low noise – but not unrealistically low
- No popcorn noise
- Minimal long term drift

Updated BDS map uploaded to instrument

Detector Elements: IFOV, Rows, Columns

Channels (wavelengths in µm)	Resolution (km)	IFOV (µrad)		Rows	Columns
		NS	EW		
0.64	0.5	10.5	12.4	1460	3
0.47, 0.51, 0.86	1	22.9	22.9	676	6
1.61, 2.26	2	42	51.5	372	6
3.9, 6.18, 6.95, 7.34, 8.5, 9.61	2	47.7	51.5	332	6
10.35, 11.2, 12.3, 13.3	2	38.1	34.3	408	6

Resolution = pixel spacing of final image after resampling

- 1 km = 28 µrad

77,400 detector elements total; 7,856 downlinked

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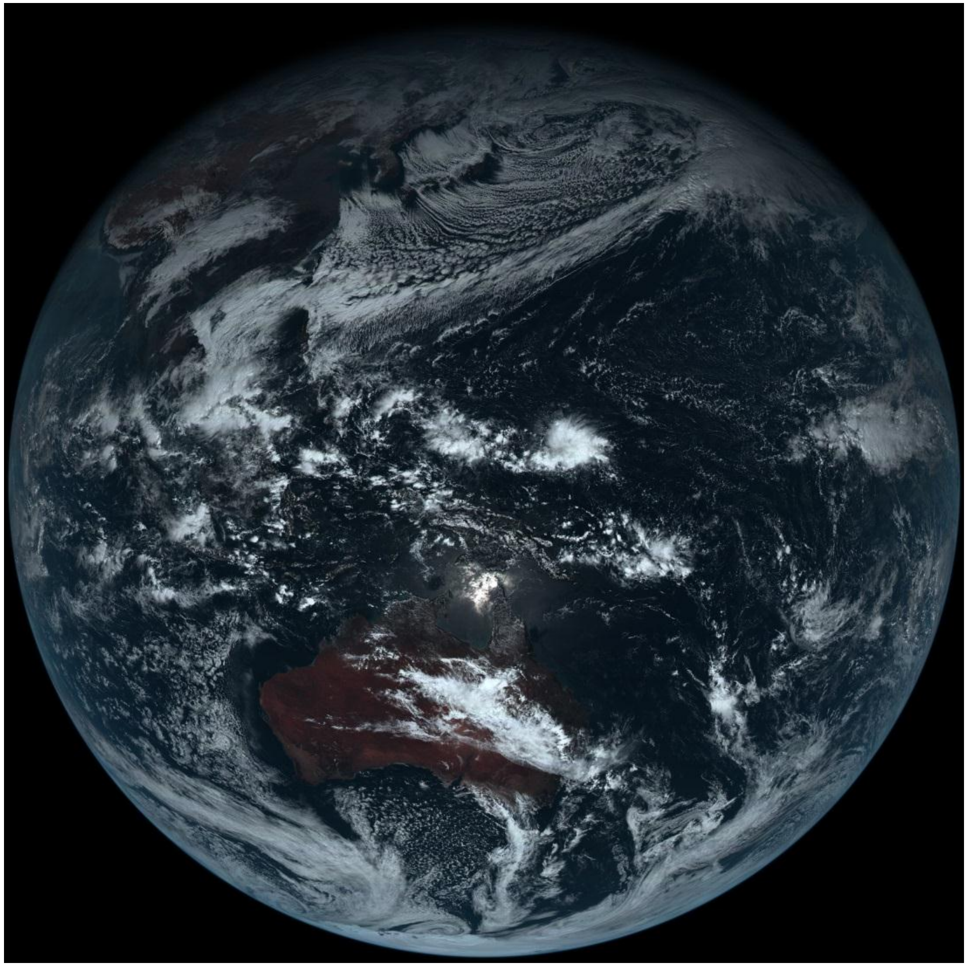
AHI-8 (photo by Harris)



Himawari-8 True Color (RGB) Image courtesy of JMA

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

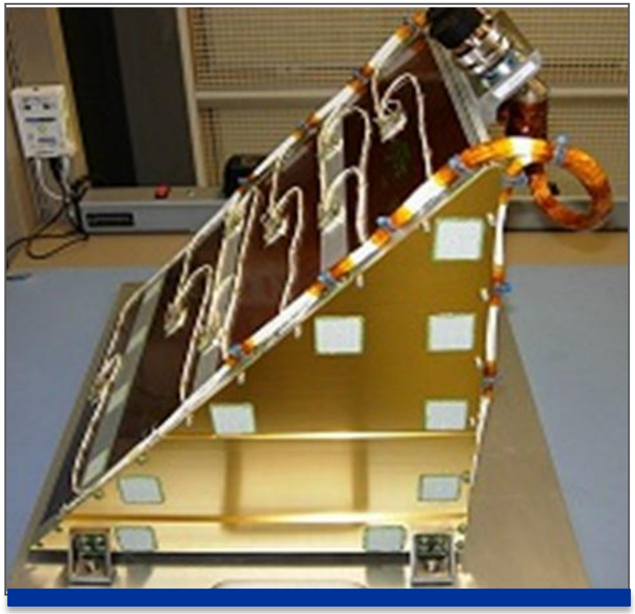
Greater calibration accuracy expectations

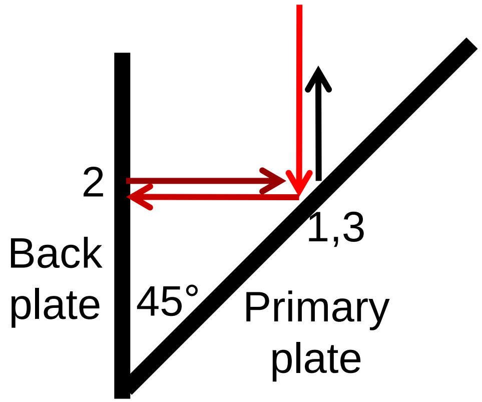
Parameter	Units	Himawari-7	AHI	Ratio
Channels		5	16	3.2
Detector Elements: total		24	77,400	3225
Detector Elements: downlinked		16	7,856	491
NS FOV: max channel	μrad	274	16,311	60
EW FOV: max FPM	μrad	140	33,203	237

Harris' ABI-class imager provides calibration solutions

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

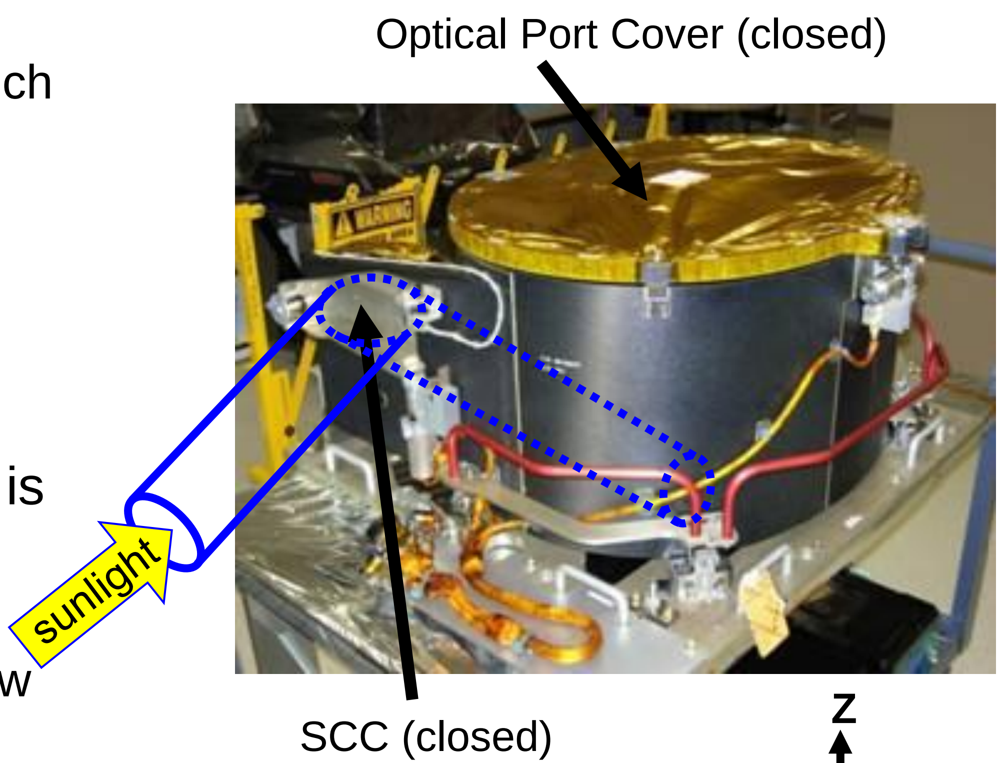

ABI PFM 3-bounce blackbody



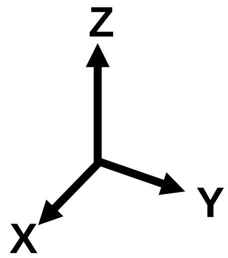
Full aperture,
end-to-end calibration

Solar Calibration Assembly Delivers On-Orbit Calibration Over Mission Life

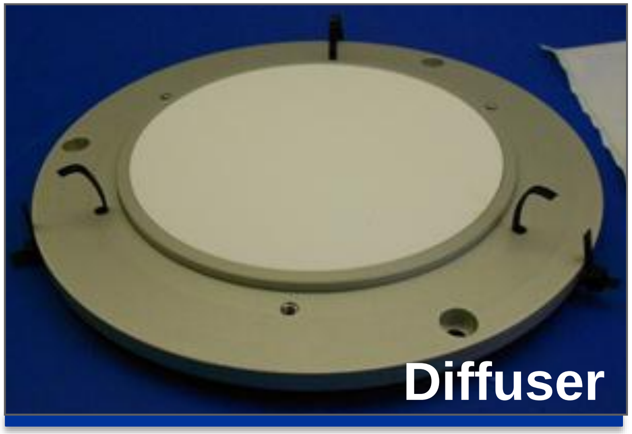
- Optical Port Cover:
  - One time deployable
  - Keeps payload clean during launch and outgassing
- Solar Cal Cover (SCC):
  - Open only when calibrating
  - Closed rest of time to preserve cleanliness
- Solar Calibration Target (SCT) is Spectralon™ diffuser
  - Calibration can occur any day of year 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 (bands 1-6) when viewing SCT
  - Nominal SCT observation performed with integration factor of 10x
- Second set typically used for λ > 5 μm (bands 8-16) when viewing ICT
- Third set typically used for λ = 3.9 μm (band 7) when viewing ICT

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

Operational Calibration Routinely Performed

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
- Explicitly scheduled in timeline as needed

Blackbody (ICT) observed at start of each timeline

- Hence, collected every 10 minutes
- Ensures all imagery collected during timeline can be radiometrically calibrated

Solar calibration scheduled when needed

- Primary cause of VNIR calibration drift is throughput loss due to molecular contamination and radiation

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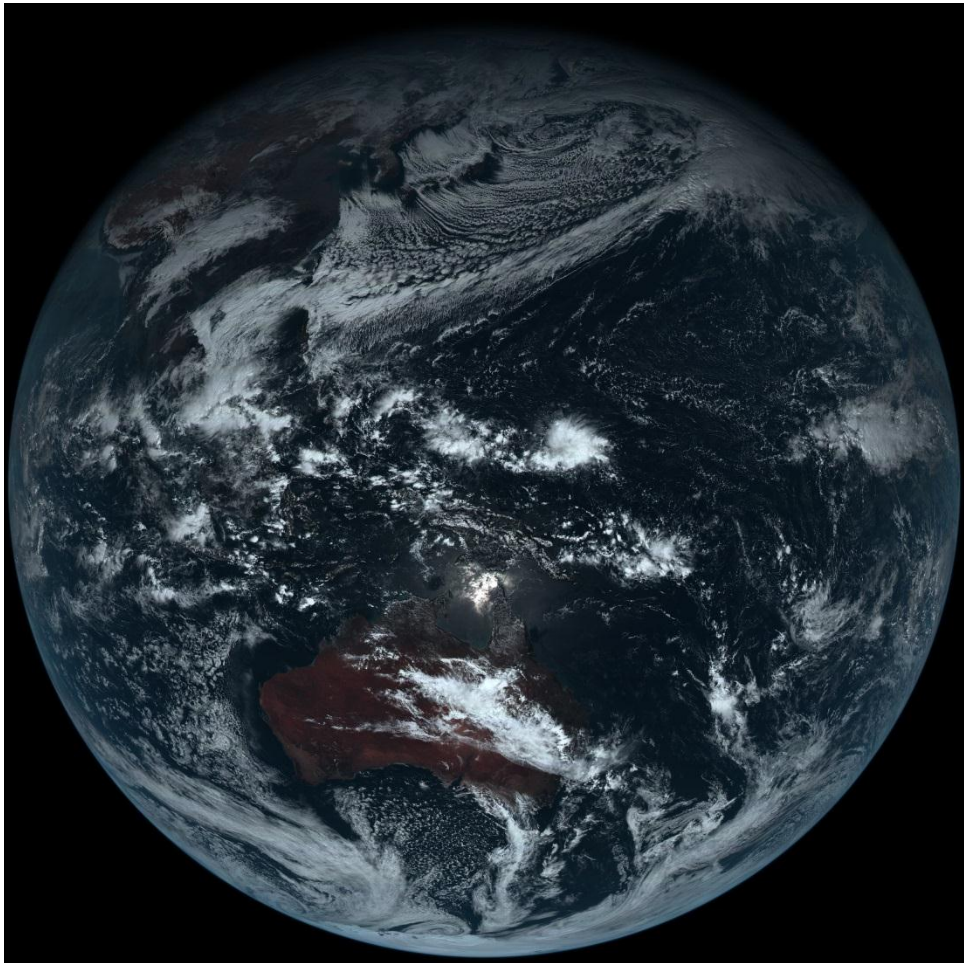
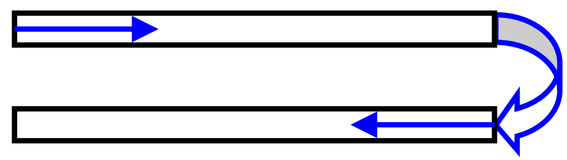


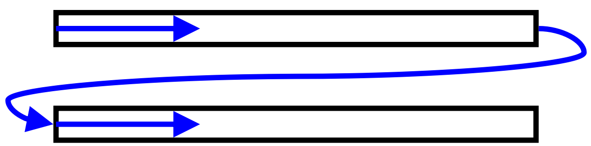
Himawari-8 True Color (RGB) Image courtesy of JMA

On-Orbit Operations: Raster Scan vs. Boustrophedonic

Himawari-7 Imager
Boustrophedonic
("as the ox plows")



AHI
Default = Raster Scan
Capable of boustrophedonic



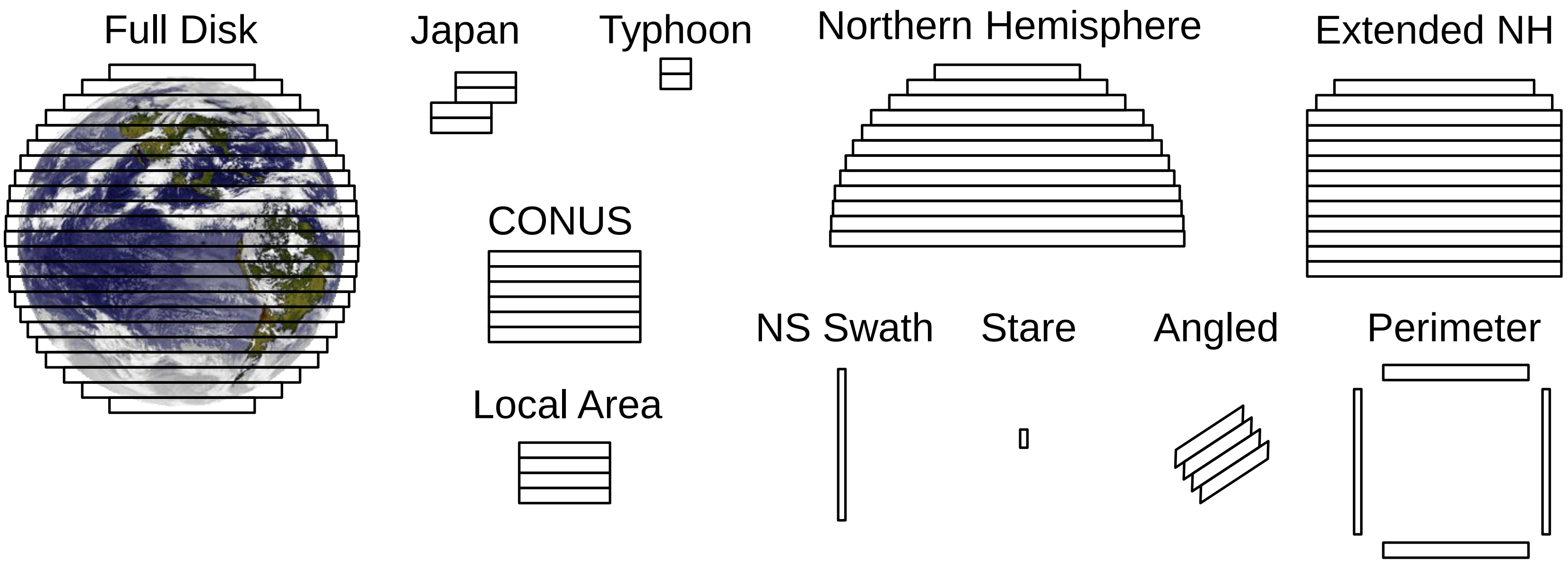
Raster scan results in higher quality images

- Constant time interval across swath boundary

Only possible because of Harris' advanced scanner

- Smooth, fast slews at low power with little spacecraft disturbance

Harris' ABI-Class Imagers Offer Unique Scan Flexibility



NS swath & stare support vicarious calibration for GSICS

Angled swaths can compensate for spacecraft yaw

- FPM is not rotated; hence coverage decreases as tilt increases

All scenes and timelines can be updated in orbit

AHI Image Collection Paradigm Shift: Swath-based, not Image-based

HARRIS

Pixel Image: calibrated, geolocated, resampled image

- Desired image; serves as start of scene definition process

Scene: commanded area to be observed (e.g. CONUS)

- Ordered set of swaths; need not be contiguous

Swath: sub-area of scene collected in a single scan

- Defined by start and end coordinates
- Straight line at <u>any</u> angle (usually west-to-east, parallel to equator)

Scan: scan maneuver during a swath; constant velocity

Stare: swath with same start and end coordinates

Slew: scan maneuver between swaths

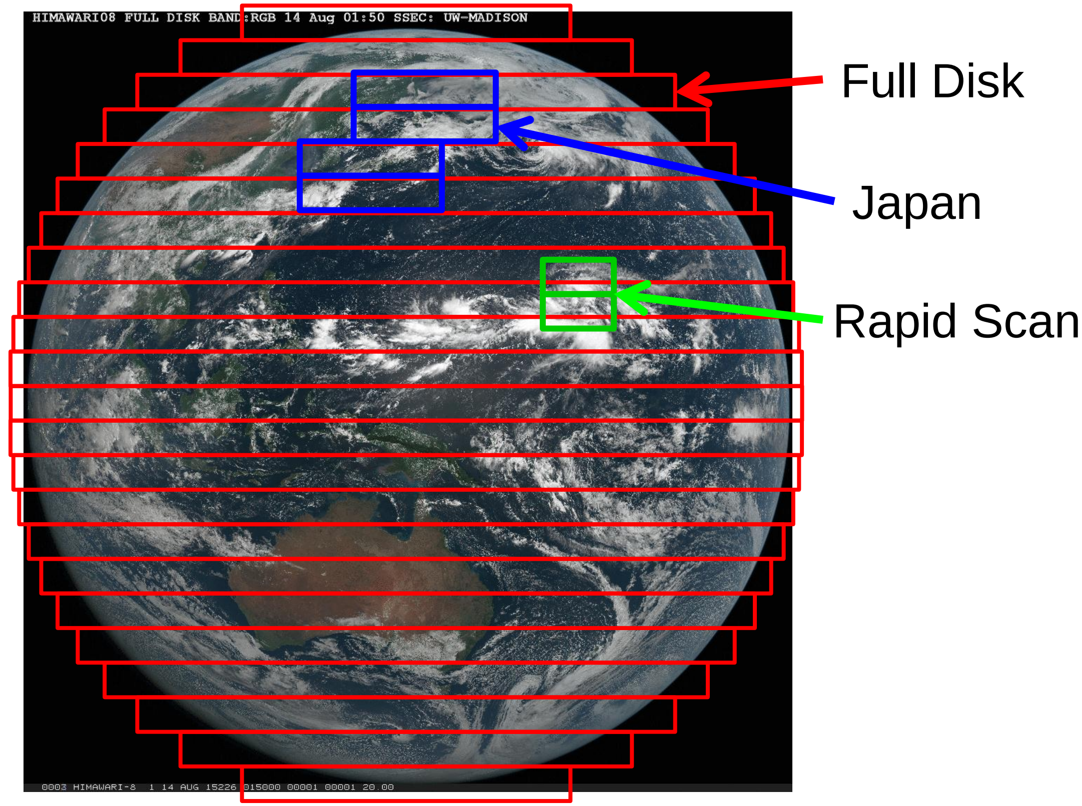
- NS and EW scanners maneuver simultaneously

Timeline: defines what to observe when

- Time sequenced set of scene swaths and durations

AHI Unique Interleaved Scene Collection Delivers Full Disk and Regional Scenes

- Himawari Observation Timeline
  - Full Disk: every 10 minutes
  - Japan: every 2.5 minutes
  - Rapid Scan (RO3): every 2.5 minutes
    - Typhoons, calibration, etc.
- Himawari Housekeeping with Solar Calibration Timeline
  - Solar Calibration
  - Japan: every 2.5 minutes
  - Rapid Scan: every 2.5 minutes
- Blackbody, spacelooks, & landmarks included in all timelines for radiometric calibration and navigation



AHI-8 data from JMA, Image courtesy of UW/SSEC CIMSS

User can design and load any desired scenario, even on orbit

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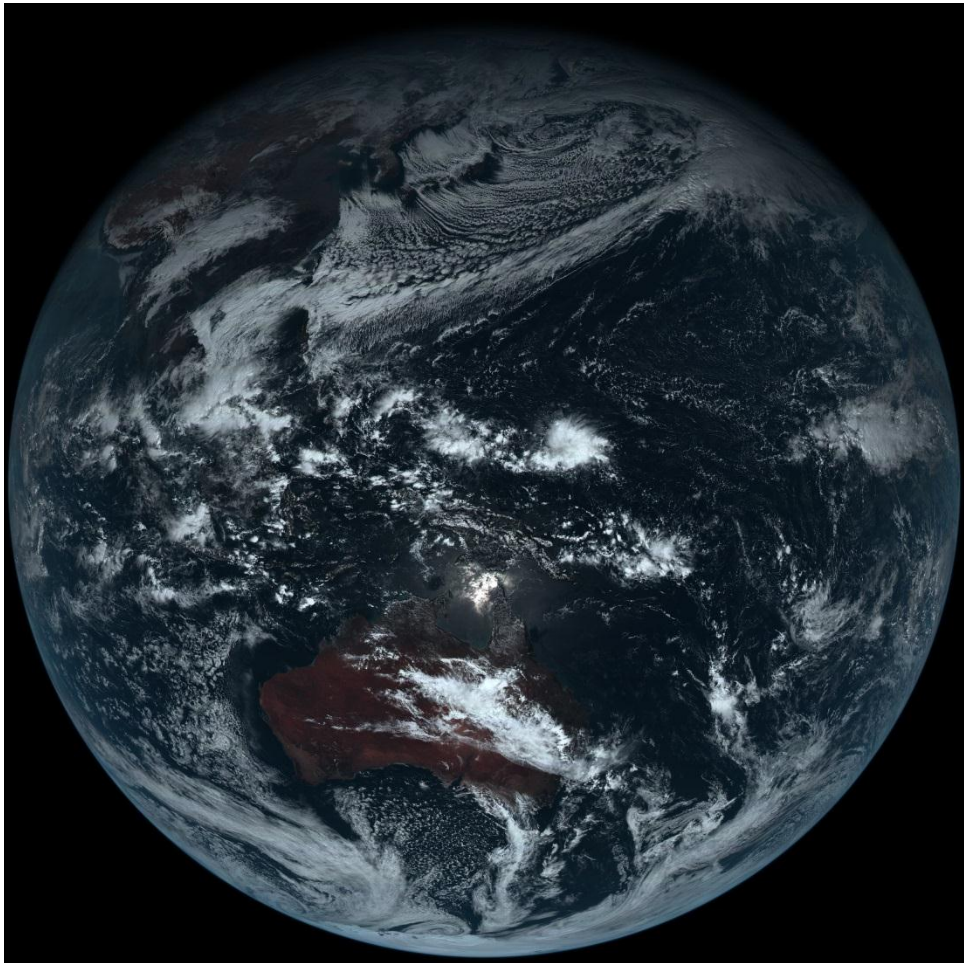
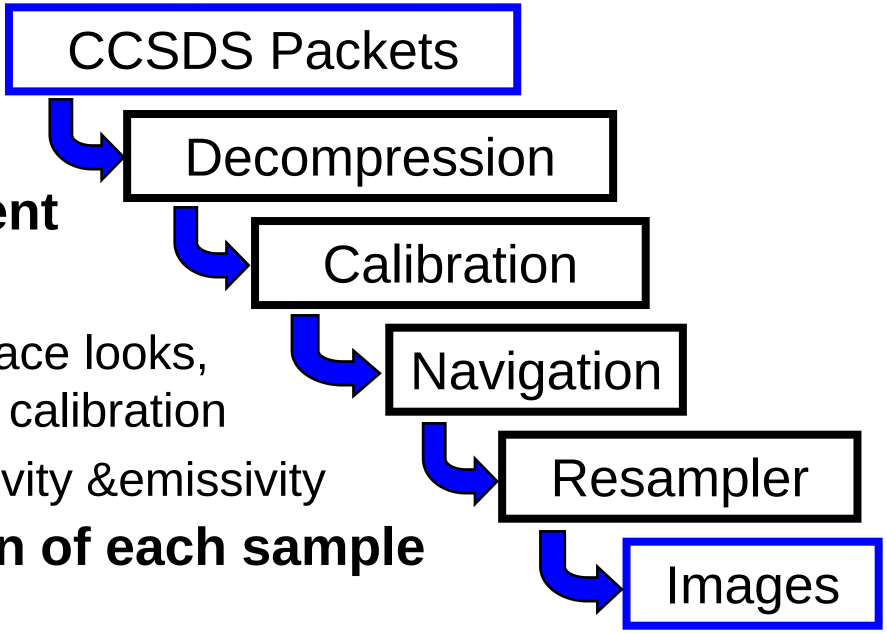


Himawari-8 True Color (RGB) Image courtesy of JMA

Ground Processing Algorithms Key to Quality Images and Data Products



Decompression

- Rice algorithm (lossless)

Calibration: Element-by-element

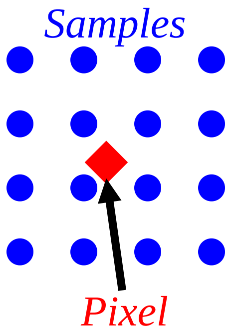
- JMA algorithm
- Detector gain and offset from space looks, blackbody calibration, and solar calibration
- Correction for scan angle reflectivity &emissivity

Navigation: Determine location of each sample

- JMA algorithm

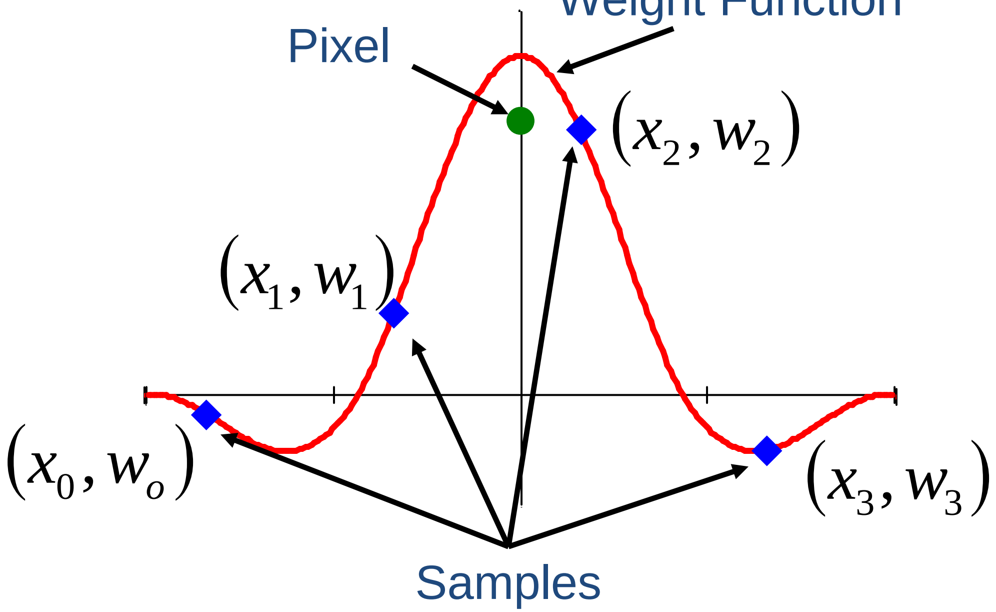
Resampling: Calculate pixels on fixed grid

- JMA's implementation of Harris' resampler algorithm
- 4x4 kernel
- Custom weighting function supplied by Harris for each instrument
  - – Optimized spatial response across all bands



AHI Resampler uses 4x4 Kernel Separable EW & NS

One-dimensional example



Ideal relationships

$$x_{n+1} - x_n = ASD$$

$$\sum_i w_i = 1$$

Actual formula

$$P = \frac{\sum_{i=1}^{4}\sum_{j=1}^{4} w_i w_j S_{i,j}}{\sum_{i=1}^{4}\sum_{j=1}^{4} w_i w_j}$$

ASD = angular sample distance

All samples used come from the same swath

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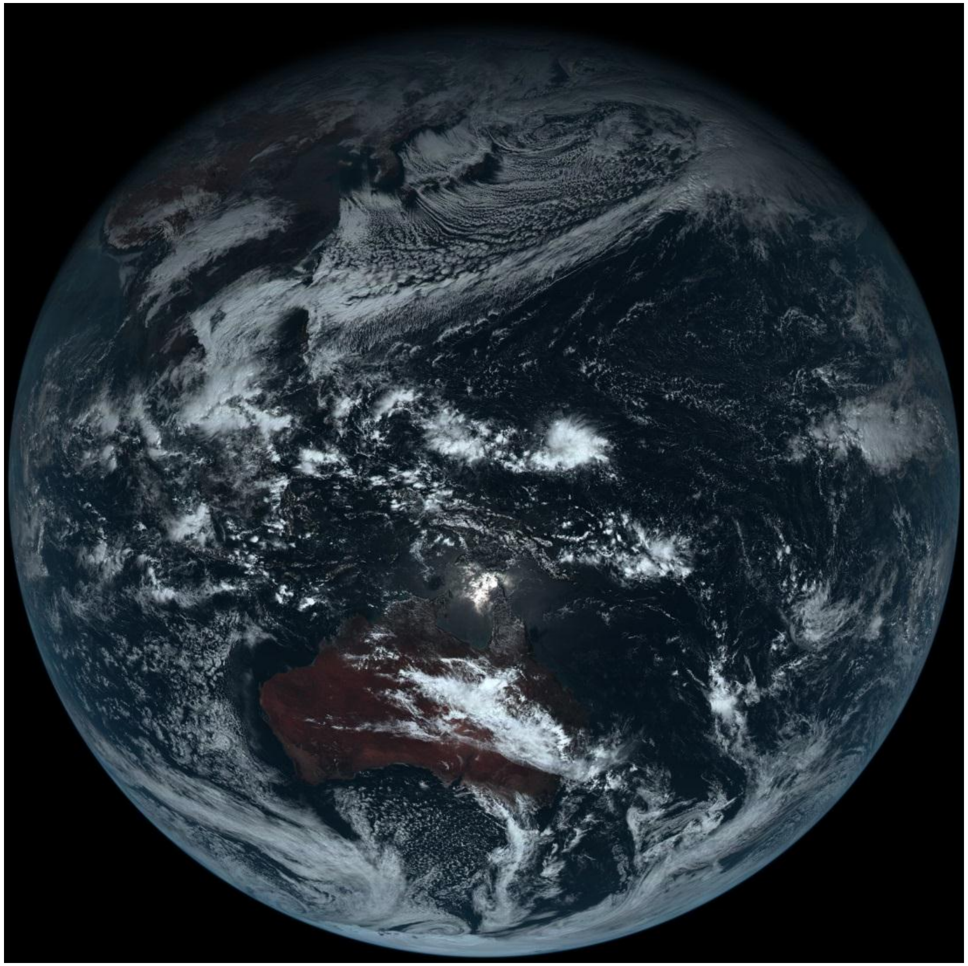

Himawari-8 True Color (RGB) Image courtesy of JMA

Summary

AHI-8 is the first of the next generation geostationary weather imagers in operation

Provides improved spectral, spatial and temporal resolution

New on-board targets improve radiometric calibration

Paradigm shift in image collection delivers regional and rapid scan images without impacting Full Disk cadence

- Due to scanner performance and innovative scan algorithm

Operational flexibility provides unique vicarious calibration capability

AHI-8: The Future is Now!

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Appreciation to NOAA, JMA, MELCO, and UW/SSEC CIMSS