

Japanese Advanced Meteorological Imager: A Next Generation GEO Imager for MTSAT-1R

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ABSTRACT

The Japanese Advanced Meteorological Imager (JAMI) introduces next generation technology geosynchronous earth orbit (GEO) imagers for operational meteorological remote sensing. Raytheon Santa Barbara Remote Sensing is building JAMI for Space Systems/Loral as the imager subsystem for Japan's MTSAT-1R system. JAMI represents the best balance between heritage and newer space-qualified technology and meets all Japan Ministry of Transport MTSAT requirements from beginning to end of life with considerable margin, using a simple, inherently low risk design. The advanced technology built into this imager benefits operational meteorological imaging for Japan, East Asia and Australia by enabling significantly better radiometric sensitivity and absolute accuracy, higher spatial resolution and faster full disk coverage times than available from current GEO imagers. JAMI is on schedule for an on time or early delivery to Space Systems/Loral.

Keywords: remote sensing, advanced technology, meteorological imaging, geosynchronous orbit

1. INTRODUCTION

Raytheon Santa Barbara Remote Sensing is building the Japanese Advanced Meteorological Imager (JAMI) for Space Systems/Loral as the Imager Subsystem for Japan's MTSAT-1R multifunctional satellite system, which combines meteorological imaging with air traffic control functions. JAMI is based on advanced imager technologies that have already been space qualified and flown in Raytheon-built hardware. Raytheon expertise developed in US programs enables JAMI's pioneering use of an active cooler in GEO. JAMI meets all MTSAT-1R requirements with margin in a package that's smaller than current GEO imagers. It covers the 0.55 μm to 12.5 μm spectral region using the required 4 infrared bands and 1 visible wavelength band. JAMI's thermal IR bands have fully redundant 84 element 1-d arrays that sample Earth with 2 km ground-projected IFOV at nadir. The visible band has 336 element 1-d arrays that sample Earth with 0.5 km ground-projected IFOV at nadir. These large format arrays enable faster full disk coverage rate with slower scan rate than current systems. Benefits of slower scan rate include better system MTF and a longer life scanner. JAMI's off-axis TMA telescope helps avoid solar intrusion problems. JAMI covers the full earth disk, including all required pointing verification and calibration scans, in <24 min. An onboard calibration system for all bands is built into the imager.

2. DESCRIPTION

Figure 1 shows an isometric view of the imager. Key features and associated benefits of this imager are described in Table 1. Table 2 compares a few of the general characteristics of JAMI with MTSAT-1R requirements.

The imager provides a 21.4 deg (N-S) by 23.6 deg (E-W) full frame scan area that is centered at the projection of spacecraft nadir on Earth (Figure 2). After launch in 2003, JAMI will be stationed at the 140 E longitude orbital slot that has traditionally been reserved for operational weather imaging for Japan, East

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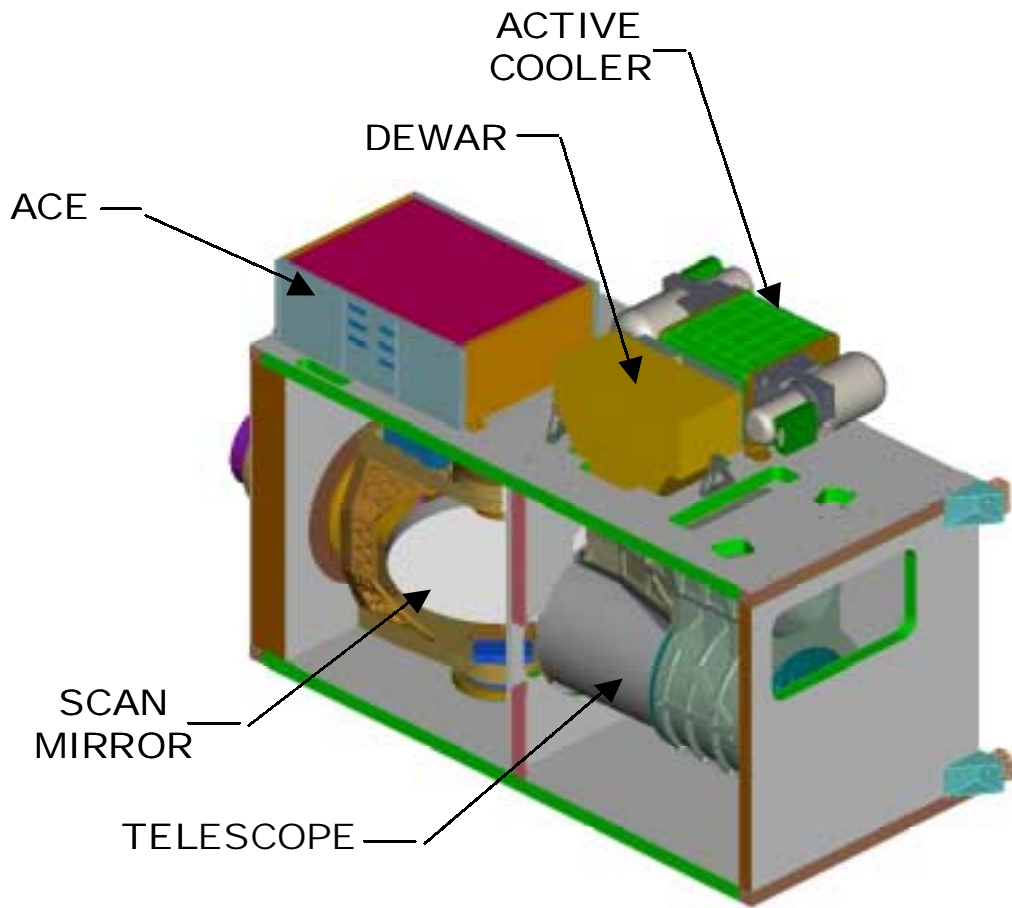


Figure 1. This advanced GEO imager provides data with unprecedented detail and fidelity and is optimized for the multifunctional MTSAT-IR platform.

Asia and Australia. JAMI's full frame includes a complete view of Earth as well as views of cold space for calibration and star sensing.

A gimballed two-axis scan mirror relays input scene radiance to an off axis focal telescope. The scanner can be commanded to point outside this full frame scan area and provide views of onboard blackbody and albedo monitoring sources. The scan function for this imager is completely flexible. For example, regions of any size within the imager frame may be scanned. Scan mirror pointing can be adjusted during each scan by commands from the spacecraft that correct for pointing errors resulting from spacecraft attitude variations. Full disk coverage time for this imager, including all pointing verification and calibration source observations, is less than 24 min.

This design addresses and mitigates limitations of existing operational GEO imagers with respect to solar intrusion by using an off-axis telescope with a sunshade. The telescope design offers advantages of less susceptibility to solar intrusion and better MTF performance because of the absence of the central spider present in current operational imagers. In addition, the simple, efficient optical design enabled by this telescope provides better throughput and an easier to build instrument without the complexity and band-to-band registration problems of current operational imagers. Additional thermal and optical design features of this imager enable it to function during solar intrusion and meet all MTSAT requirements after the intrusion ends. Furthermore, our standard approach of using deployable covers for the scanner aperture window minimizes likelihood of contamination affecting instrument performance.

A focal three-mirror off axis reflective telescope collects and focuses input radiance onto two focal planes which spatially sample Earth at the Nyquist rate for 4 km IR ground resolution and 1 km visible ground

resolution. Detector arrays in both focal planes are completely redundant and contain monolithic detector arrays that use materials optimized to their spectral regions. Two rows of detectors are fabricated for each array. This provides a primary and an alternative pixel, individually selectable during focal plane subsystem integration and testing to improve producibility of 100% operable arrays. This second-generation Raytheon technology, already flight-proven on MODIS, MTI and other programs provides excellent sensitivity, low noise, very low power and simple electrical and mechanical interfaces.

The double focal plane offers significant advantages with respect to other design approaches. These include separation of visible and infrared arrays to improve cooling performance of the infrared arrays and a much simpler and easier to build optical layout than current operational imagers.

Each focal plane contains one set of arrays for each spectral band in that plane with individualized spectral filters over the arrays. The visible array is uncooled and uses technology already proven in a number of Raytheon programs, including EO-1. The infrared bands are contained in two sensor chip assemblies (SCAs), a design approach already proven on TRMM/VIRS, MODIS and MTI. The infrared focal plane is cooled by an active cooler that is based on more than 10 years of flight heritage.

The manufacturing alignment tolerances of these arrays built with semiconductor device lithographic techniques provide deviations in relative pixel locations that are far superior to misalignments associated with manual assembly processes. For this MTSAT imager, pixel-to-pixel misalignments are a very small fraction of the infrared band ground resolution.

Signal processing and data handling electronics convert the Nyquist-sampled focal plane output to digital form, process and format the raw data for transmission to the JAMI Ground Processor. The JAMI Ground Processor transforms JAMI data from its Tapered Elevation Scan native format into a GOES-like fixed grid in scan angle space and then transmits that data to the MTSAT Image Data Acquisition and Control System (IDACS).

Calibration is provided through several mechanisms that are designed to work together to supply accurate, stable performance: space view and V-groove blackbody source (already flight-proven on TRMM/VIRS and MODIS) for the infrared bands and a reflective solar albedo monitor for the visible band. The albedo monitor design is derived from heritage approaches developed over decades of onboard visible wavelength calibration work with Landsat, TRMM/VIRS, SeaWiFS and MODIS.

A mechanical cooler, with more than 10 years of flight heritage to the original Oxford design and incorporating lessons learned from many years of ground and flight-testing at Raytheon and elsewhere, enables a cryogenic detector operating temperature and exceptional reliability and lifetime. The superior operating temperature performance of JAMI with respect to current operational imagers enables use of PV HgCdTe detector technology in MTSAT, which eliminates 1/f noise, calibration and radiometric sensitivity problems of current operational imagers.

3. ADVANTAGES OF JAMI FOR OPERATIONAL WEATHER IMAGING

This advanced MTSAT imager represents the best balance between heritage and newer space-qualified technology. Use of proven second-generation focal plane technology from MODIS, MTI and other Raytheon programs improves radiometric and calibration performance, eliminates 1/f noise striping problems of current operational imagers while simplifying and reducing risk in instrument integration and test. The active cooler enables exceptional radiometric sensitivity performance over a long life using an approach with direct heritage to the Oxford designs first developed in the mid 1980s. The optical configuration and scan approach provide spatial resolution and MTF performance that is superior to current operational imagers, while also eliminating well documented solar intrusion problems of these systems. Built-in modularity simplifies imager system integration and facilitates selection and insertion of alternative subassemblies or component elements as dictated by cost, performance and schedule issues.

Table 1. The features of this instrument provide significant benefits for operational weather imaging of Japan, East Asia and Australia compared with current imagers.

Key Feature	Benefits
Heritage from more than 70 space-based instrument developments including ATS-3, GOES, GMS, Landsat, TRMM/VIRS, MODIS, MTI and other programs	High confidence in maturity, performance and long life of imager
Modular cooler design that is compatible with active or passive cooling	Enables use of high performance PV HgCdTe detectors for infrared bands and leads to much better detector operating performance than current operational imagers
PV HgCdTe detectors for infrared bands	10-100x better linearity, 1.4x higher BLIP D* and much reduced 1/f noise performance with respect to PC detectors used in existing operational imagers
Simple optical design that uses off axis focal telescope with two focal planes	Improved optical throughput, easier-to-build instrument without the complexity and band-to-band registration problems of current operational imagers, less susceptible than current operational imagers to thermal problems associated with solar intrusion
Large format infrared and visible detector arrays	Enable more efficient full frame coverage leading to reduced scan rate which improves MTF performance, reduces telescope size and minimizes impact of scan motion on spacecraft
Nyquist spatial frequency sampling of earth scene	Ensures radiometric accuracy of resampled and registered data, provides capability to implement landmark collection mode to improve nighttime IR landmarking and better determine non-static co-registration errors
Programmable scan configurations	Enable fully flexible data collections including rapidly updateable special region scans, space scans for improved calibration and adjustable overlap between adjacent scanlines

Table 2. JAMI meets MTSAT-1R performance requirements with significant margin in all areas.

Parameter	MTSAT-1R Requirement	JAMI Design Value
Spectral Channels	Visible: 0.55 μm to 0.75 - 0.90 μm IR1: 10.3 μm to 11.3 μm IR2: 11.5 μm to 12.5 μm IR3: 6.5 μm to 7.0 μm IR4: 3.5 - 3.8 μm to 4.0 μm	Visible: 0.55 μm to 0.90 μm IR1: 10.3 μm to 11.3 μm IR2: 11.5 μm to 12.5 μm IR3: 6.5 μm to 7.0 μm IR4: 3.5 μm to 4.0 μm
Collected Image Data Ground Resolution	Design Dependent	0.5 km (visible), 2 km (infrared)
Observation Data Ground Resolution	1.25 km (visible), 5.0 km (infrared)	1.0 km (visible), 4.0 km (infrared)
MTF (Visible) at 20000 rad-1 at Digitizer	>0.30	0.60
Field of View	Design Dependent	0.269 deg per swath
Image Frame	17.6 deg (N-S) by 17.6 deg (E-W)	21.4 deg (N-S) by 23.6 deg (E-W)
Detector Array Lengths	Design Dependent	336 (visible), 84 (infrared)
Detector Operating Temperatures	Design Dependent	Ambient (visible), 75 K (IR)
Full Disk Coverage Time	<30 min	<24 min
Calibration Accuracy (One Observation)	2.5% (visible) 0.21 K (IR at 300 K) 0.10 (IR at 220 K)	2.5% (visible) 0.08 - 0.16 K (IR at 300 K) 0.08 - 0.10 K (IR at 220 K)

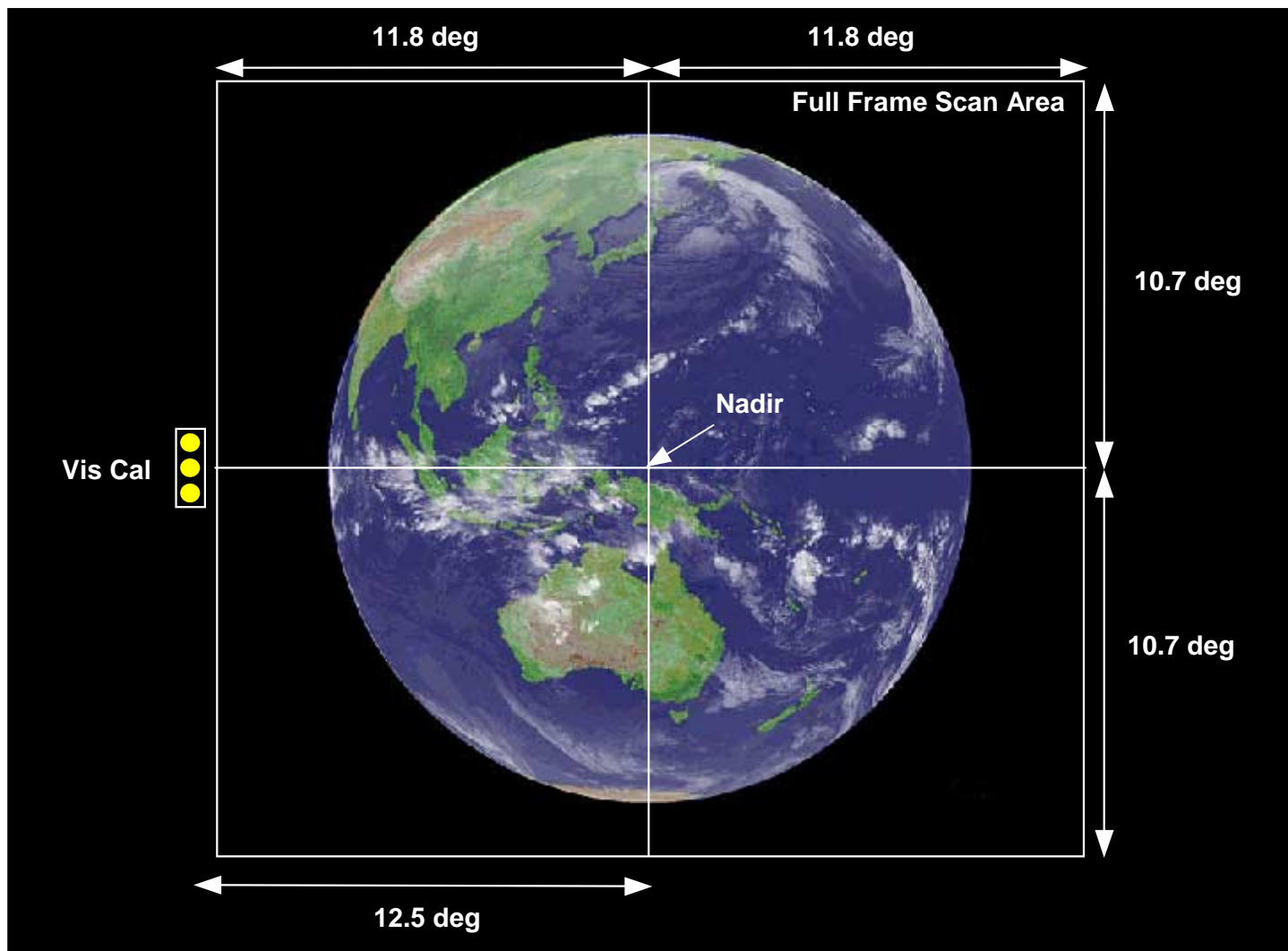


Figure 2. JAMI's full frame scan area exceeds MTSAT-1R requirements.

Solar Intrusion Mitigation. JAMI avoids solar intrusion problems, by design. Consequently, JAMI provides high quality data throughout the day, including close to local midnight when sunlight can directly illuminate the entrance aperture.

JAMI's focal plane subsystem design eliminates residual solar intrusion effects by using a spaceflight-proven detector electronics design. Electronics recovery time is within one frame time. Thus, if JAMI should point at the sun momentarily, recovery of the instrument is almost immediate.

Since solar intrusion is a demanding and critical issue for a geosynchronous imager, our JAMI design incorporates many well-engineered features, to limit deleterious effects. The thermal control systems are designed to minimize their drain on system resources such as power, weight and volume. The thermal control systems are also essentially simple, involving no complex servos, no exotic materials and no unusual manufacturing tolerances or processes. The approach is efficient and effective, exceeds the requirements, and does not include any expensive or risky features.

Operational capabilities beyond MTSAT-1R requirements. The JAMI design has built-in capability to provide data of much higher ground resolution and fidelity than the minimum required for MTSAT-1R. Built-in additional capabilities include 2 km infrared and 0.5 km visible wavelength ground sampling and 12 bit linear data in all channels.

JAMI transmits 2-km infrared data in normal operating modes and can provide 0.5-km visible band data with minor changes in manufacturing. Advantages of higher spatial resolution are illustrated in Figure 3. Higher spatial resolution data improves cloud edge detection and tracking, which results in more accurate wind drift information, better capability to describe and forecast behavior of rapidly evolving weather systems and better typhoon tracking. Furthermore, JAMI will enable identification of smaller scale phenomena such as fog, cloud-top thermal gradients and outflow boundaries that are unresolved by current systems.

The better spatial sampling provided by JAMI improves data quality compared with existing systems. JAMI's Nyquist spatial sampling improves radiometric accuracy of resampled and registered data compared with current operational systems that undersample the Earth scene.

JAMI will enable improved image navigation and registration by providing better daytime and nighttime landmarking and better capability to determine non-static visible-infrared co-registration errors by viewing landmarks at high resolution.

Making use of the 12 bit dynamic range built into the imager offers additional advantages to the MTSAT meteorological mission. For instance, operating the visible band at the full 12 bit dynamic range enables its use for low light level missions. This low light level capability could also be used to improve image navigation performance at night and provide forecasters with better data to discern fog and severe weather outflow boundaries earlier in the morning as well as later at night.

Superior performance enabled by advanced technology. Operational weather imaging benefits from advanced imager technologies built into JAMI that have already been space qualified and flown in Raytheon-built hardware. JAMI and its subassemblies are low risk because all subsystems have direct spaceflight history. This subsystem heritage combined with Raytheon's proven system analysis and development skills, as evidenced by a 100% success record with >70 sensors built for spaceflight over >30 years, ensures a low risk, long life and high performance JAMI.

Key subsystem technologies and their associated heritage include:

- Two-axis gimballed scan mirror with qualified optical and mechanical elements that have direct heritage to MODIS, GMS, Landsat, TRMM/VIRS, SBIRS-Low and many other Raytheon programs with demanding requirements for spaceflight operation

- Compact, off-axis three mirror anastigmat telescope with direct relevant spaceflight experience with multi-mirror systems in SeaWiFS, MODIS, THEMIS and numerous other programs
- Focal plane subsystem that incorporates qualified designs with direct flight experience in TRMM/VIRS, MTI, EO-1 and MODIS
- Active cooler design with flight heritage perfected over more than 15 years
- Processing hardware already used in numerous spaceflight programs including Globalstar and Mars Pathfinder and incorporating processing algorithms already proven on Landsat, Hubble Space Telescope and many other spaceflight programs
- Onboard blackbody calibrator that has already been qualified and spaceflight proven on TRMM/VIRS and MODIS

The telescope, focal plane subsystem, active cooler, onboard processor, V-groove onboard blackbody calibrator and design redundancy are examples of technologies that have not only passed the test for performance and reliability in space, but also give JAMI substantial performance advantages over current operational imagers in terms of radiometric sensitivity, full disk coverage rate, spatial resolution and data quality.

4. Project Status

As of late February 2002, JAMI remains on schedule for an on time or early delivery to Space Systems/Loral. All system elements have been built by Raytheon or received from suppliers and system integration and testing is underway.

Figure 4 shows a few of the most important JAMI flight system elements. The JAMI focal plane arrays achieved 100% operability in all channels, even without implementing detector-level redundancy built into each array. The excellent performance of these arrays enables roughly a factor of two or better margin in radiometric sensitivity in all channels. The telescope meets all requirements with margin. The telescope manufacturer, Axsys, believes the JAMI telescope is the best ever built by their organization. The JAMI ground processor was developed by Raytheon C3I in Aurora, Colorado and is complete. Flight electronics are ready for system integration.

5. Summary

The Raytheon-built JAMI introduces the next generation of GEO meteorological imager. The advanced technology built into JAMI benefits operational meteorological remote sensing by enabling much improved spatial, radiometric, Earth coverage and 24-hour observation capability compared with current operational GEO imagers. JAMI will be delivered to Space Systems/Loral on time for integration into the MTSAT-1R system.

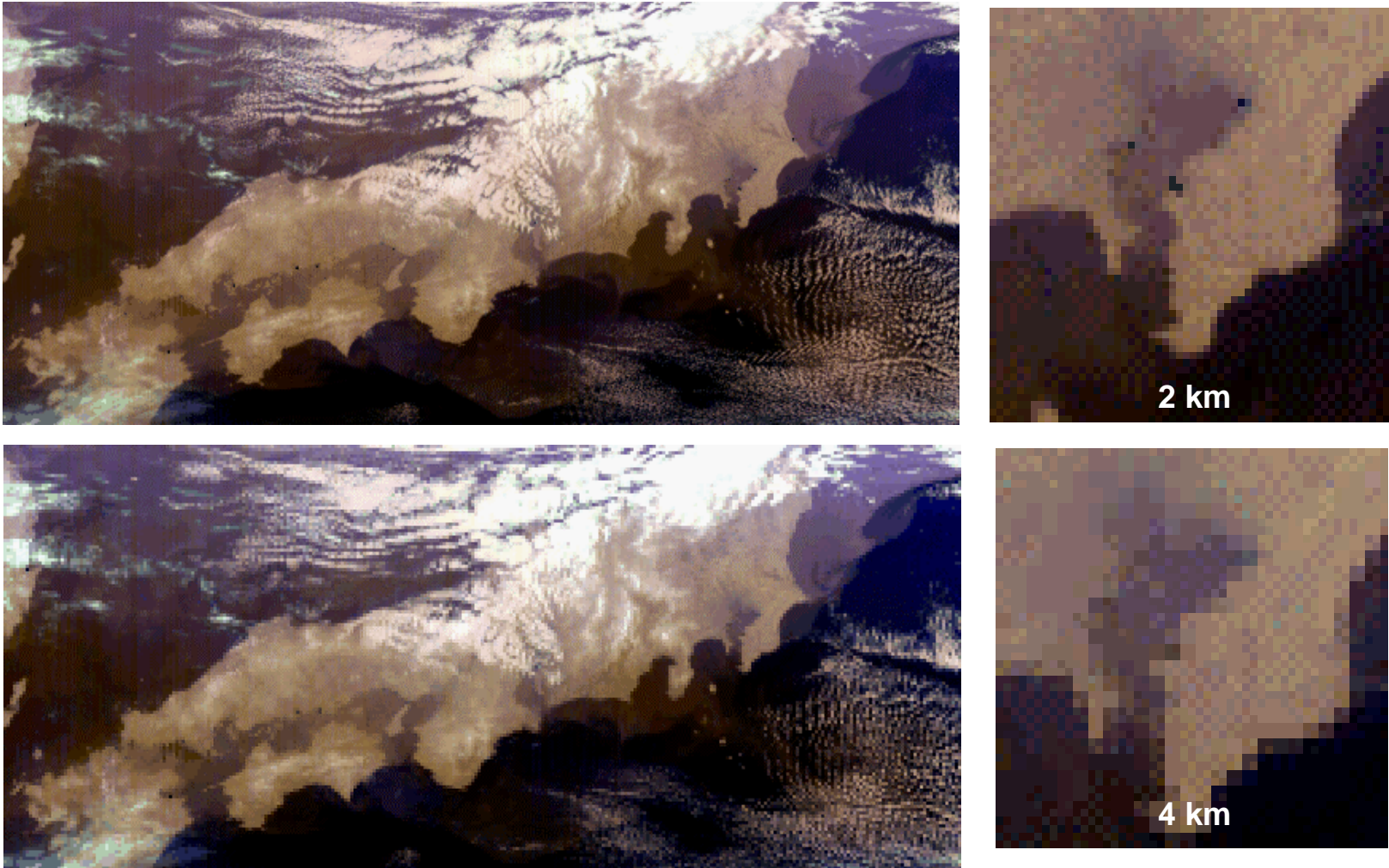


Figure 3. 2x better spatial resolution built into JAMI can directly improve ability to monitor and forecast rapidly evolving weather systems.



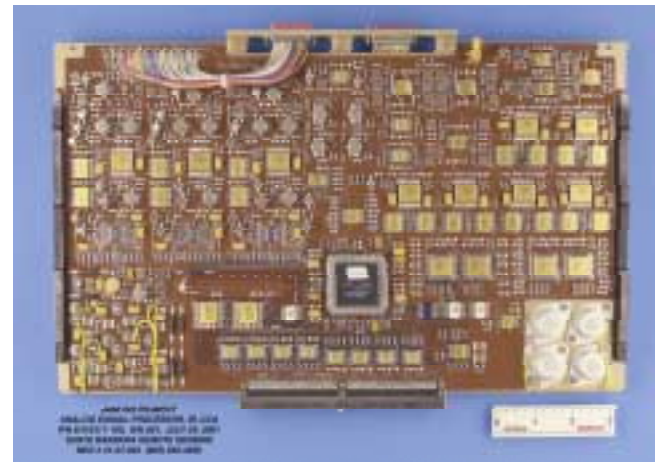
FPA module achieved 100% operability in all channels



Flight Telescope “best Axsys has ever built”



JAMI Ground Processor has been delivered



Flight Electronics ready for full system integration

Figure 4. These major JAMI system elements have been completed and are being integrated into the system, as of late February 2002.