Observing convection with the next generation of geostationary satellites: Himawari, GOES-R, and Meteosat Third Generation

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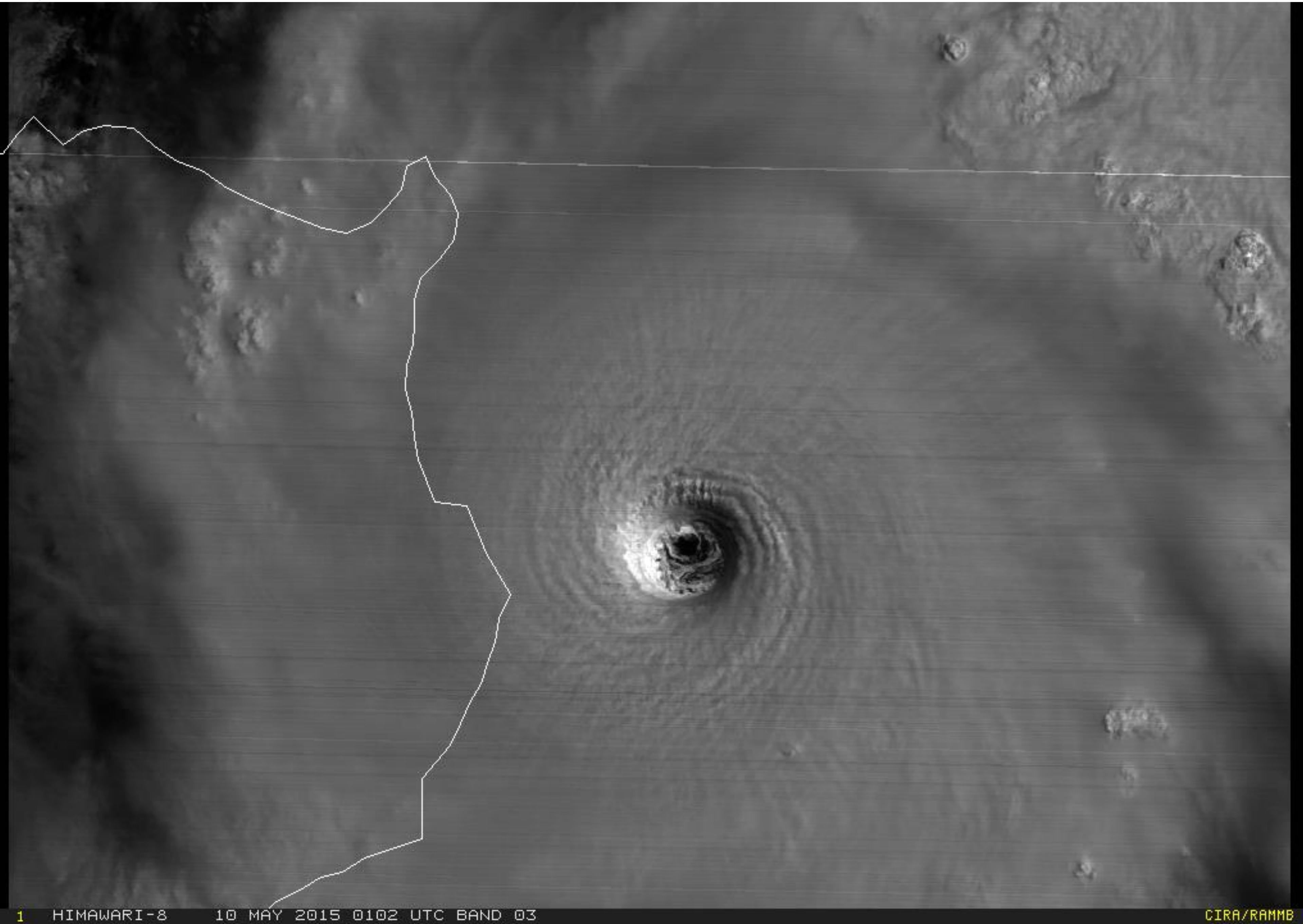
Next Generation of Geostationary Satellites

- The next generation of geostationary satellite imagers is here and more are coming
- Himawari-8 was launched by JMA in October 2014, and its Advanced Himawari Imager (AHI) has been providing amazing imagery for over a year
- GOES-R is scheduled for launch on Oct. 13, 2016 – it will carry the Advanced Baseline Imager (ABI) and a Geostationary Lightning Mapper (GLM), in addition to a few other instruments
- Meteosat Third Generation (MTG) is scheduled for launch in 2-3 years
- All three instruments have significantly improved spectral, spatial, and temporal resolution. Provided here are demonstrations of each of these improvements, focusing on the Himawari AHI since that imager is already in orbit collecting data
- This presentation will focus on *qualitative* applications of the imagery; many quantitative algorithms are also being developed (and have been discussed in detail here this week)

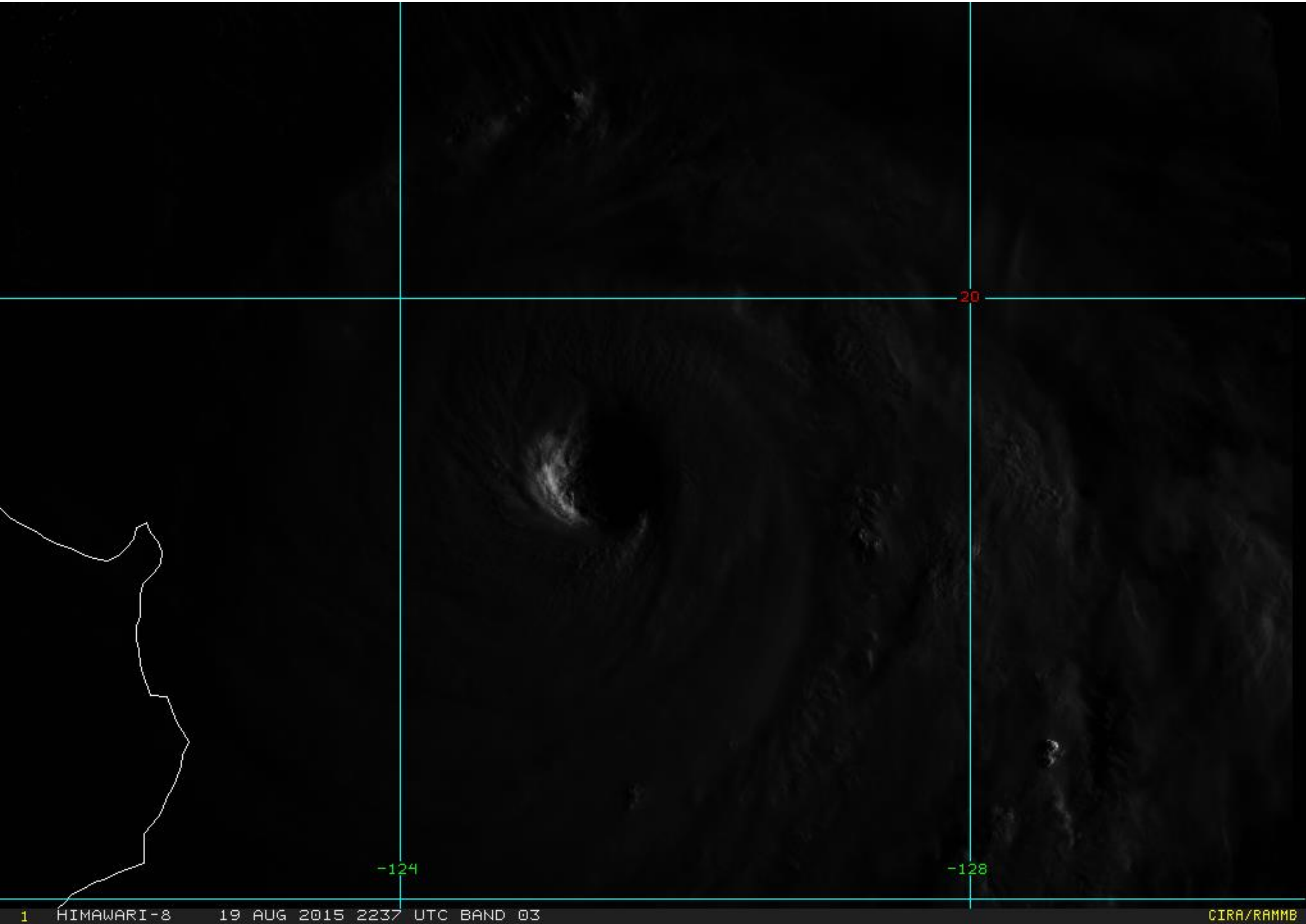
1. Improved Temporal Resolution

- Temporal resolution varies among current geostationary imagers
- Operational GOES-East and -West has ~15-minute imagery over certain sectors and 3-hourly full disk
- In “Rapid Scan Operations” it increases to 5-minute over the Continental U.S. (CONUS) domain
- For research purposes, GOES can collect “Super Rapid Scan Operations” which allows for 1-min (or 30-second) over a mesoscale domain
- GOES-R (GOES-16) will generally be operated in “Mode 3” or “Flex Mode”
    - 15-minute full disk scans
    - 5-minute CONUS scans
    - Two moveable mesoscale domains for 1-minute data
    - The National Weather Service will be able to select the locations of the domains in order to capture weather phenomena of interest (e.g., severe thunderstorms)
- Himawari-8 has four mesoscale domains over which it collects 2.5-min data

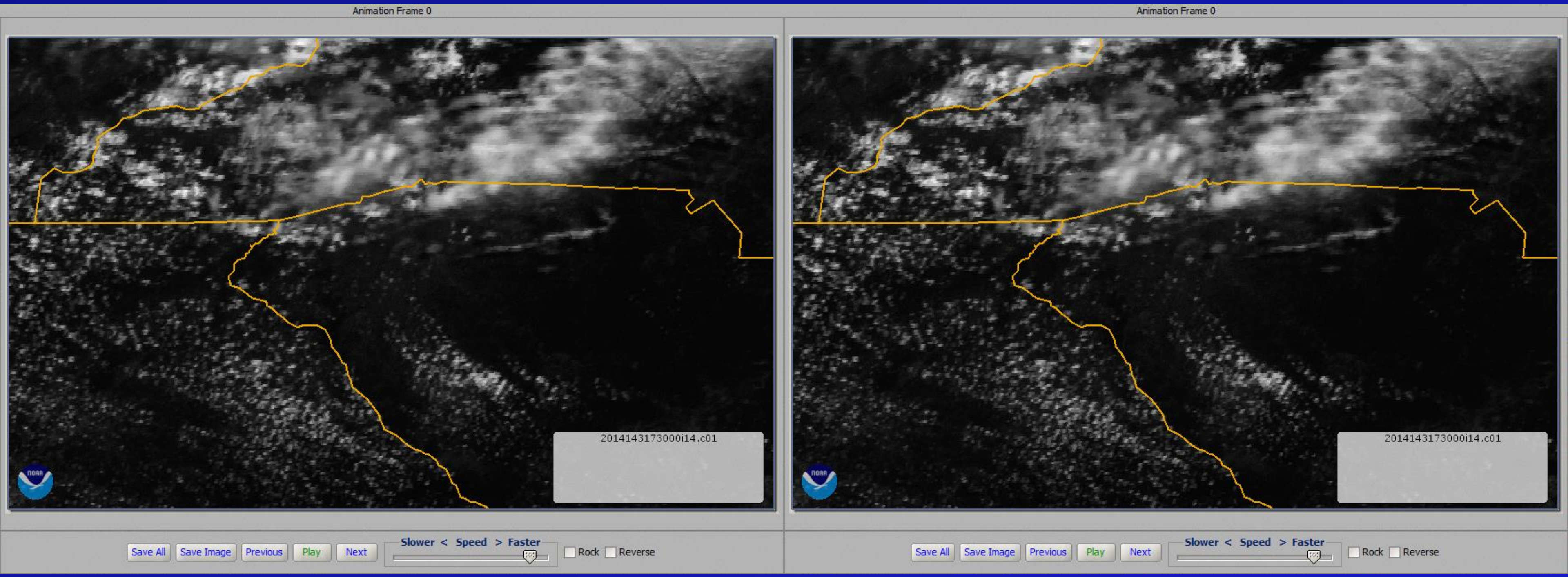
Typhoon Noul – Himawari-8, band 3 (0.5 km VIS), 2.5-min rapid scan



Typhoon Goni – Himawari-8, band 3 (0.5 km VIS), 2.5-min rapid scan

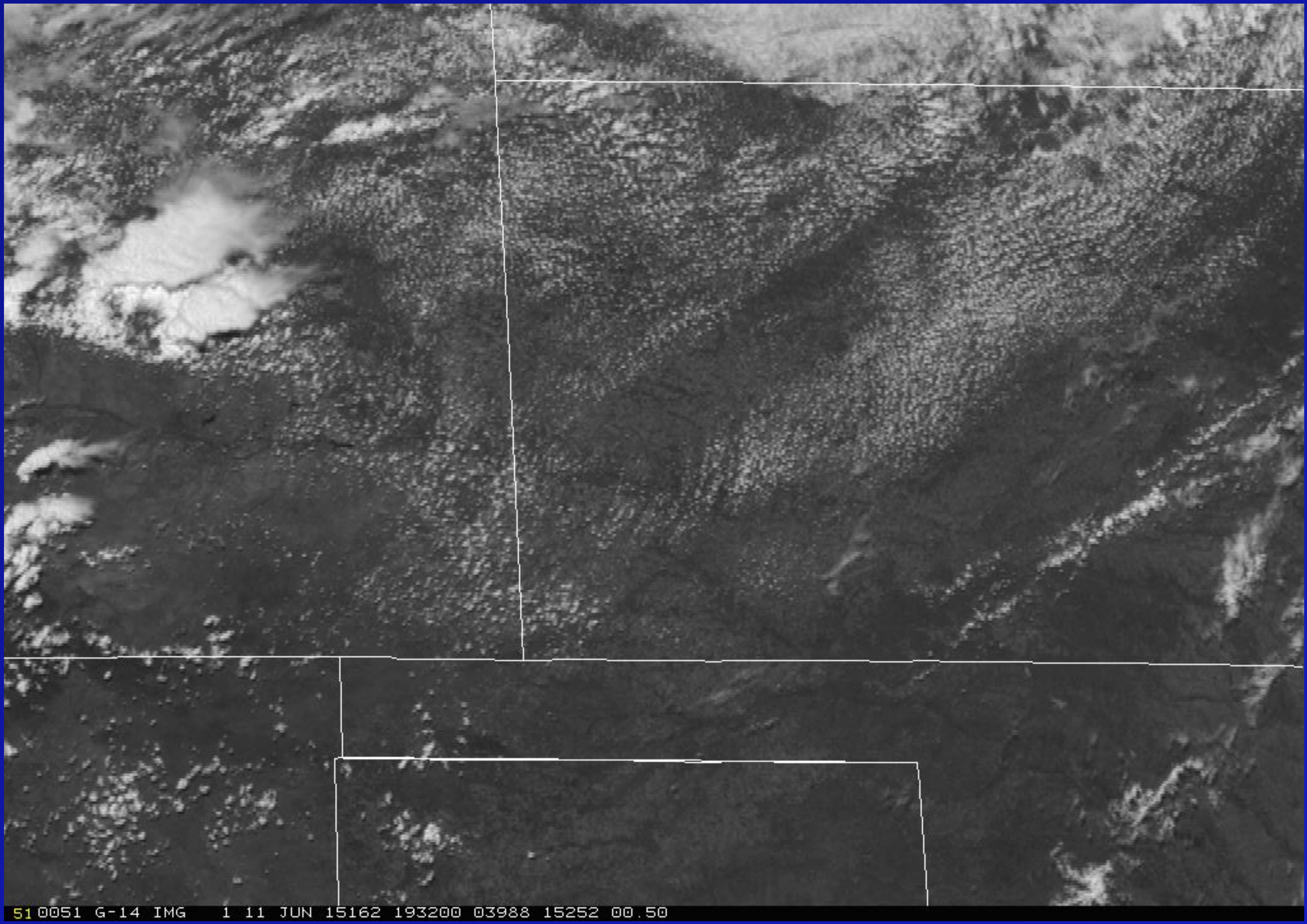


Comparison of 1-minute v/s 15-minute imagery – Georgia and South Carolina
GOES-14 – 23 May 2014

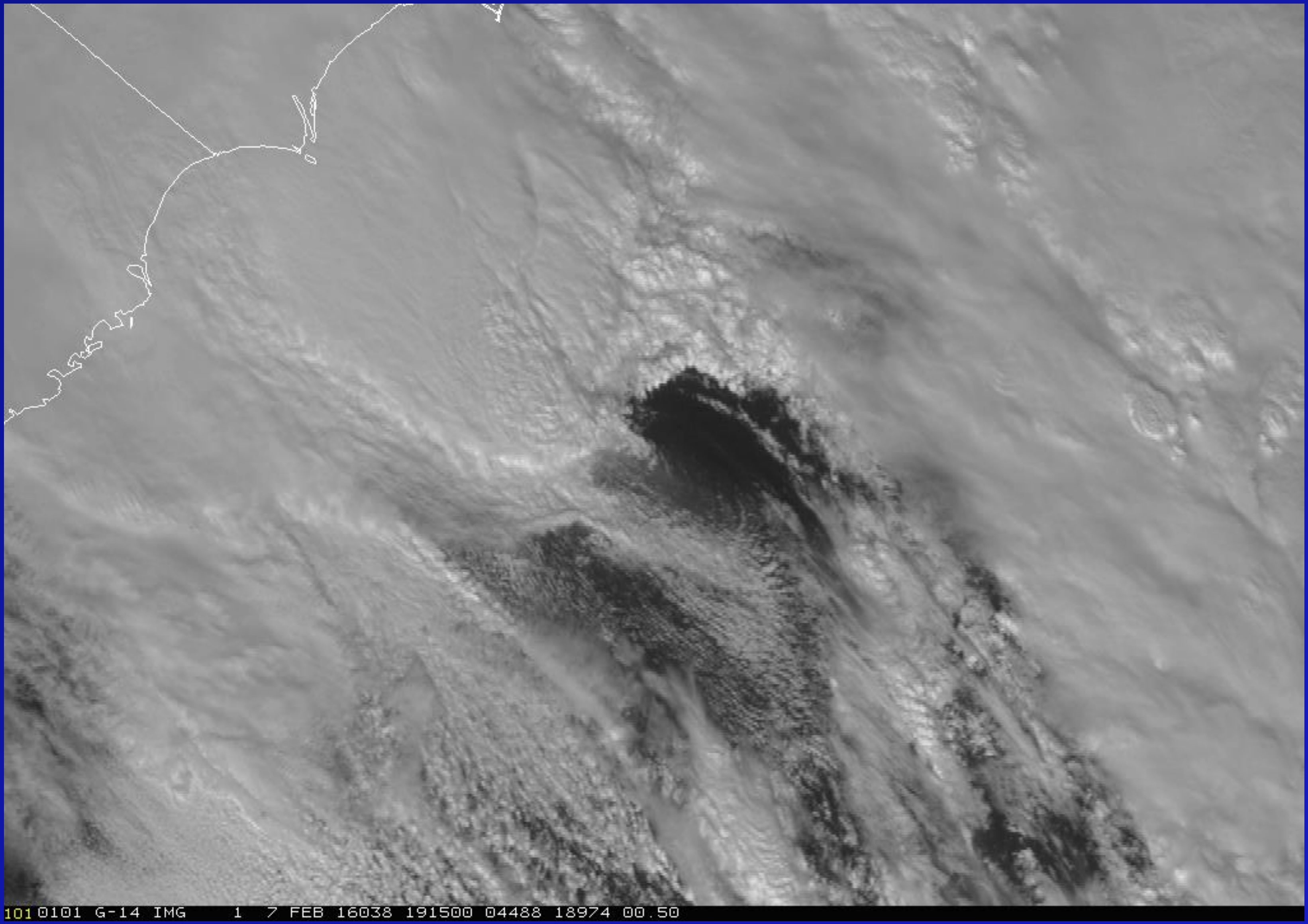


Images courtesy of Frank Alsheimer, NWS

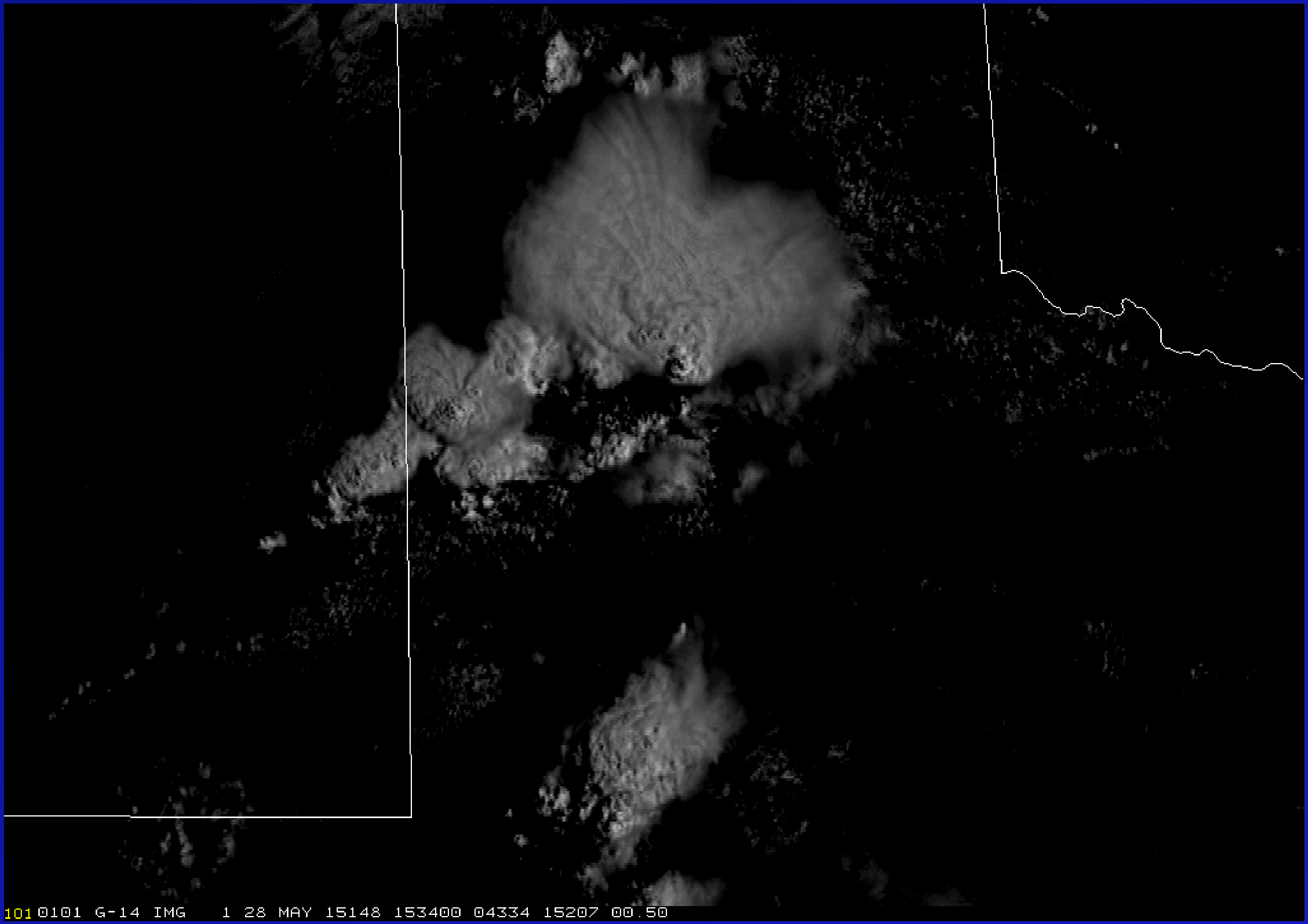
GOES-14 1-min imagery – 11 June 2015 – Colorado and Kansas



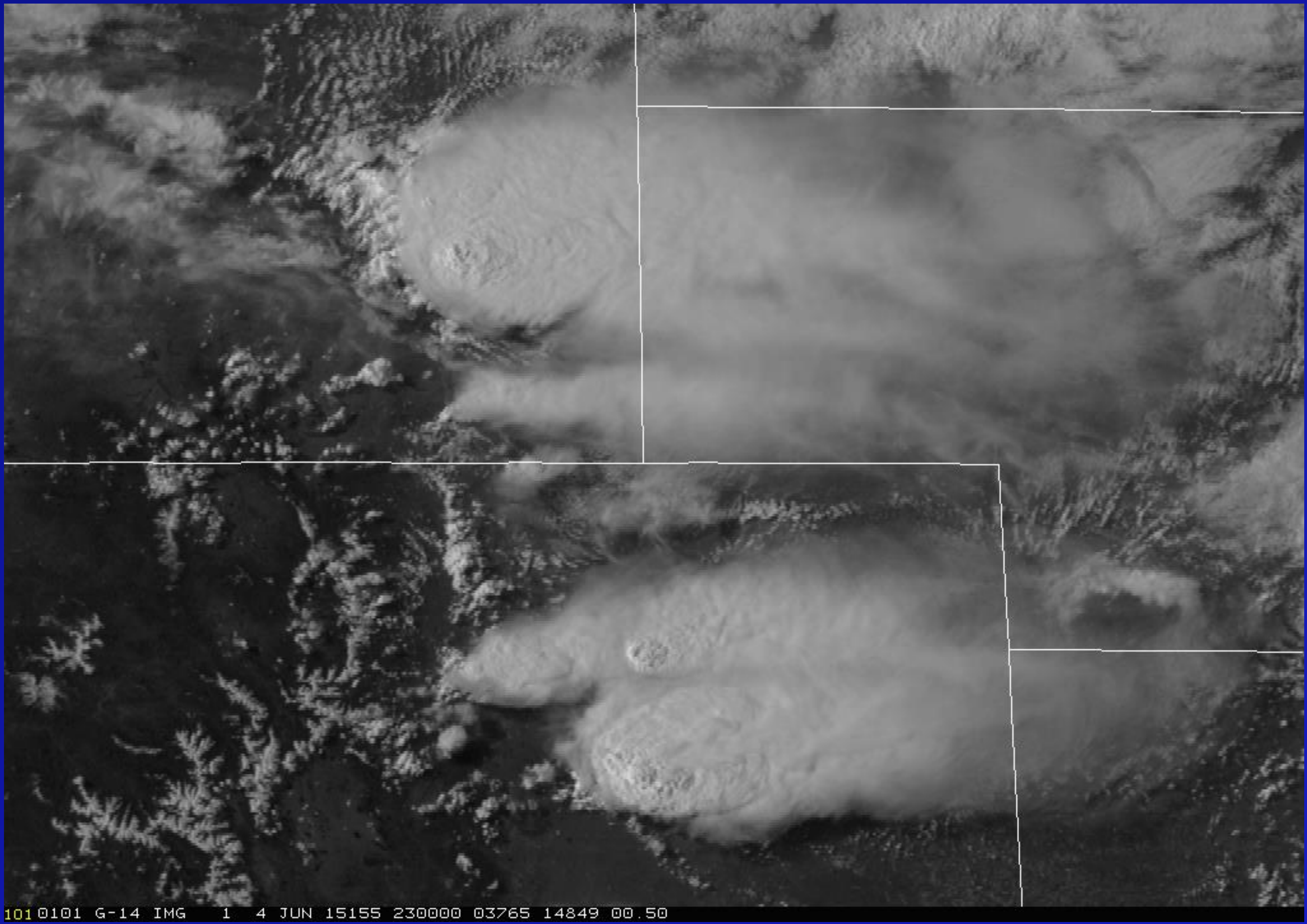
GOES-14 1-min imagery – 7 Feb. 2016 – over the Gulf Stream



GOES-14 1-min imagery – 28 May 2015 – north Texas



GOES-14 1-min imagery – 4 June 2015 – Observed tornado locations marked with yellow + symbols



Simla, Colorado, supercell – 4 June 2015

Photo courtesy of Kelly Delay and wired.com

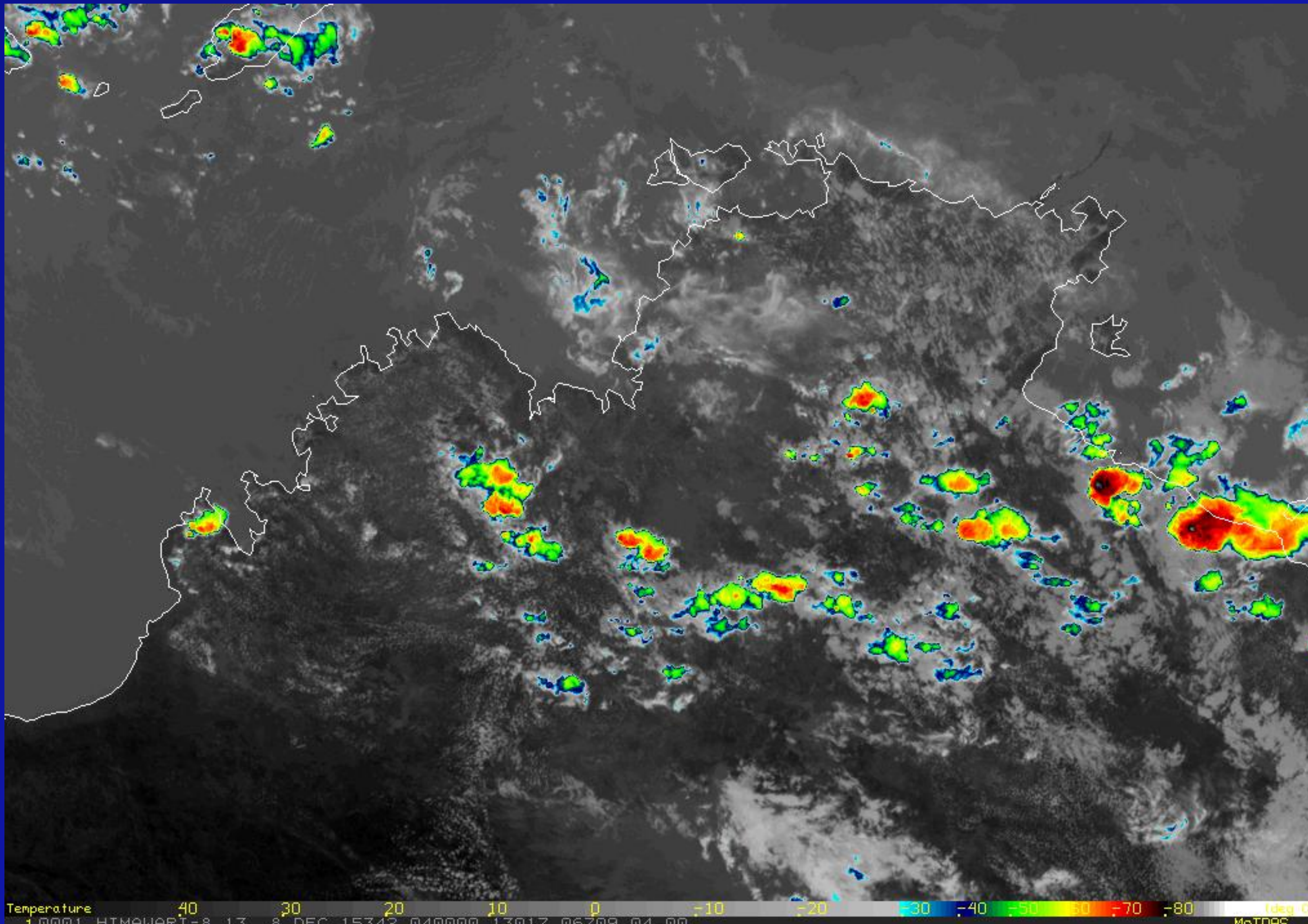
Simla, Colorado, tornado – 4 June 2015

Photo courtesy of James Stewart and National Geographic

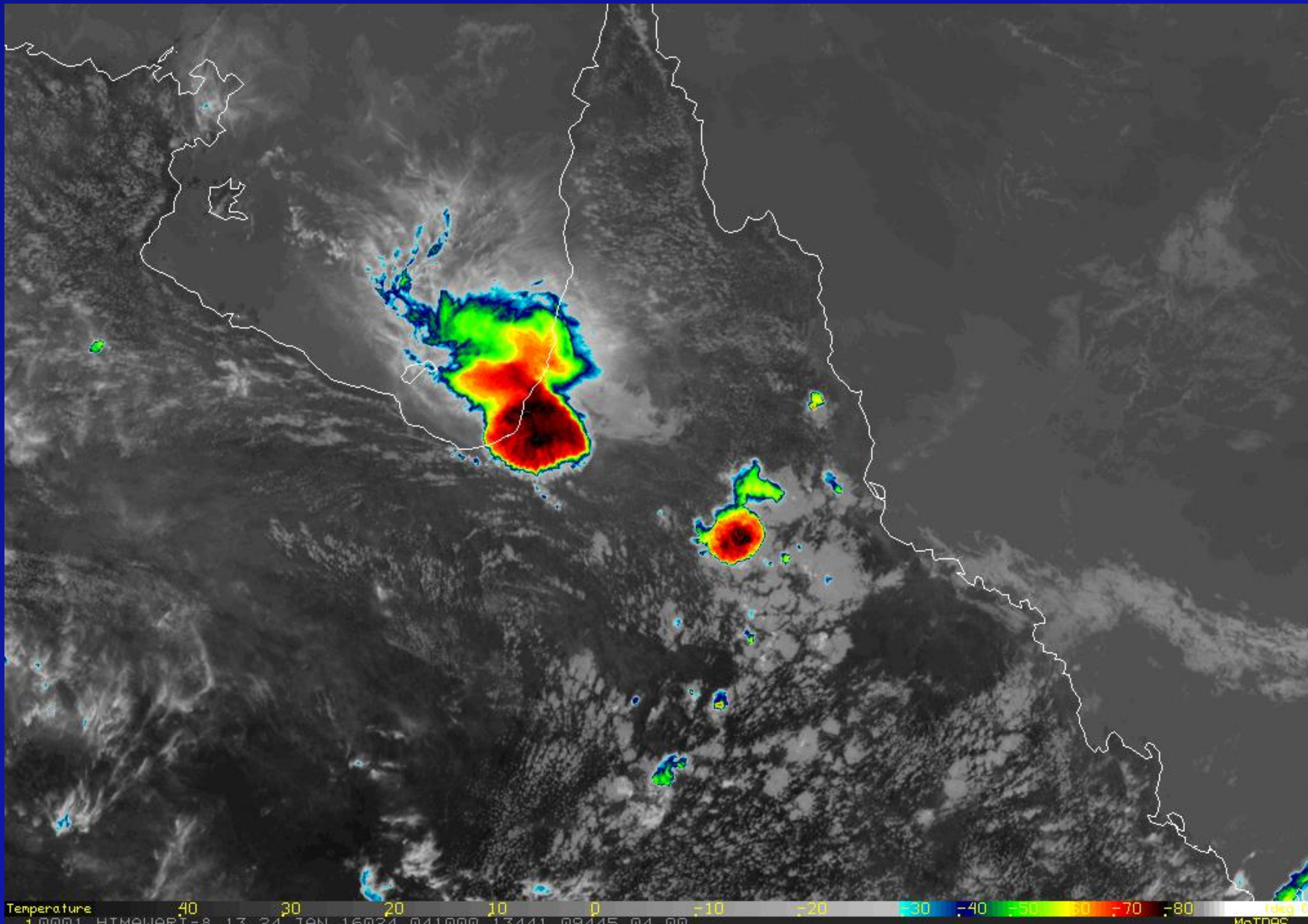
2. Improved Spatial Resolution

- Current GOES has Visible resolution of 1 km and IR resolution of 4 km at nadir
- The GOES-R ABI will have improved resolution at all wavelengths
  - Band 3 visible (0.64 µm): 500 m
  - Other visible bands: 1 km
  - Infrared bands: 2 km
- In terms of viewing convection, we now have “MODIS-like” resolutions from a geostationary orbit, allowing for the ability to track in time relatively small-scale cloud features

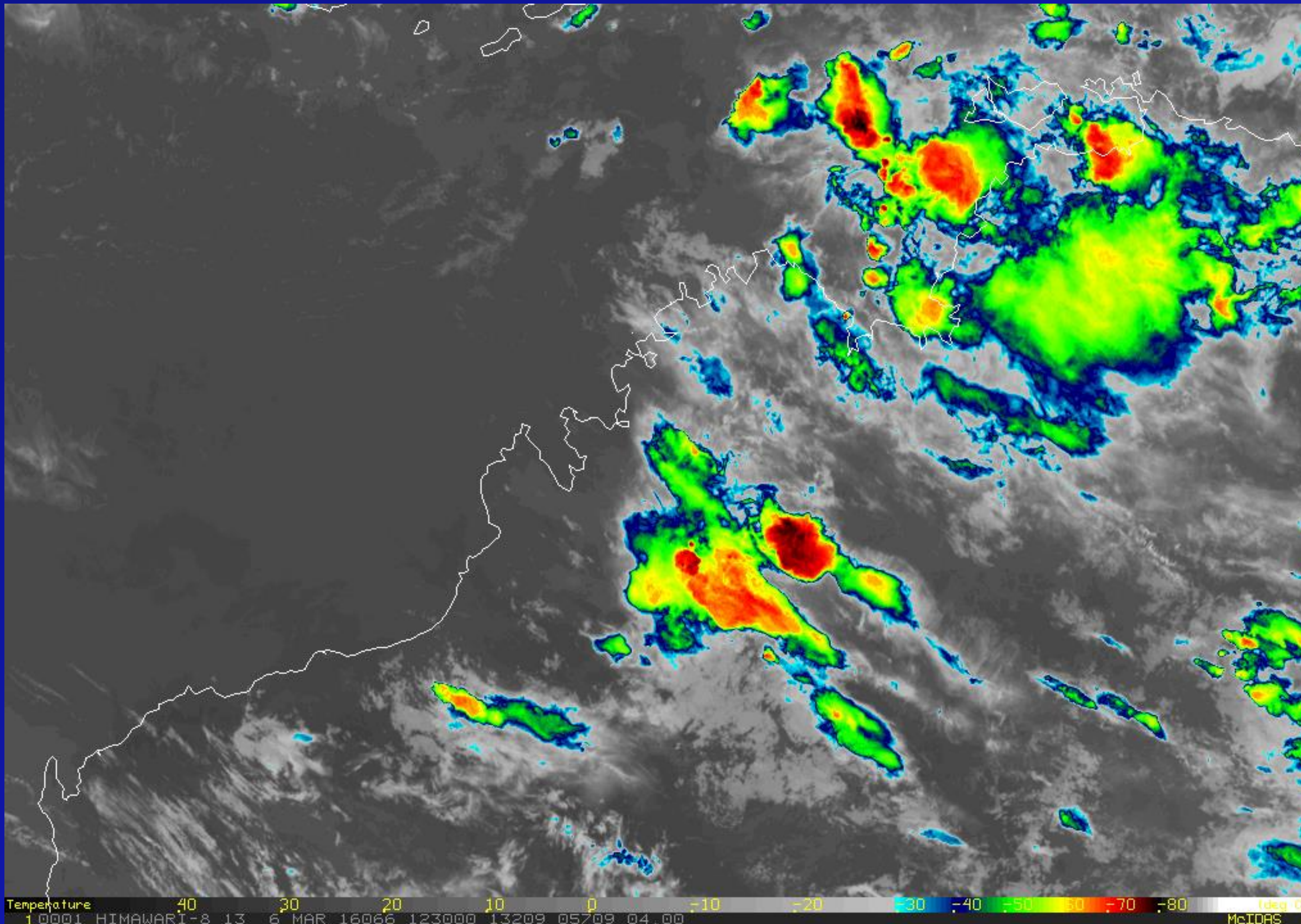
Band 13 (10.4 µm) IR over northern Australia – 8 Dec. 2015



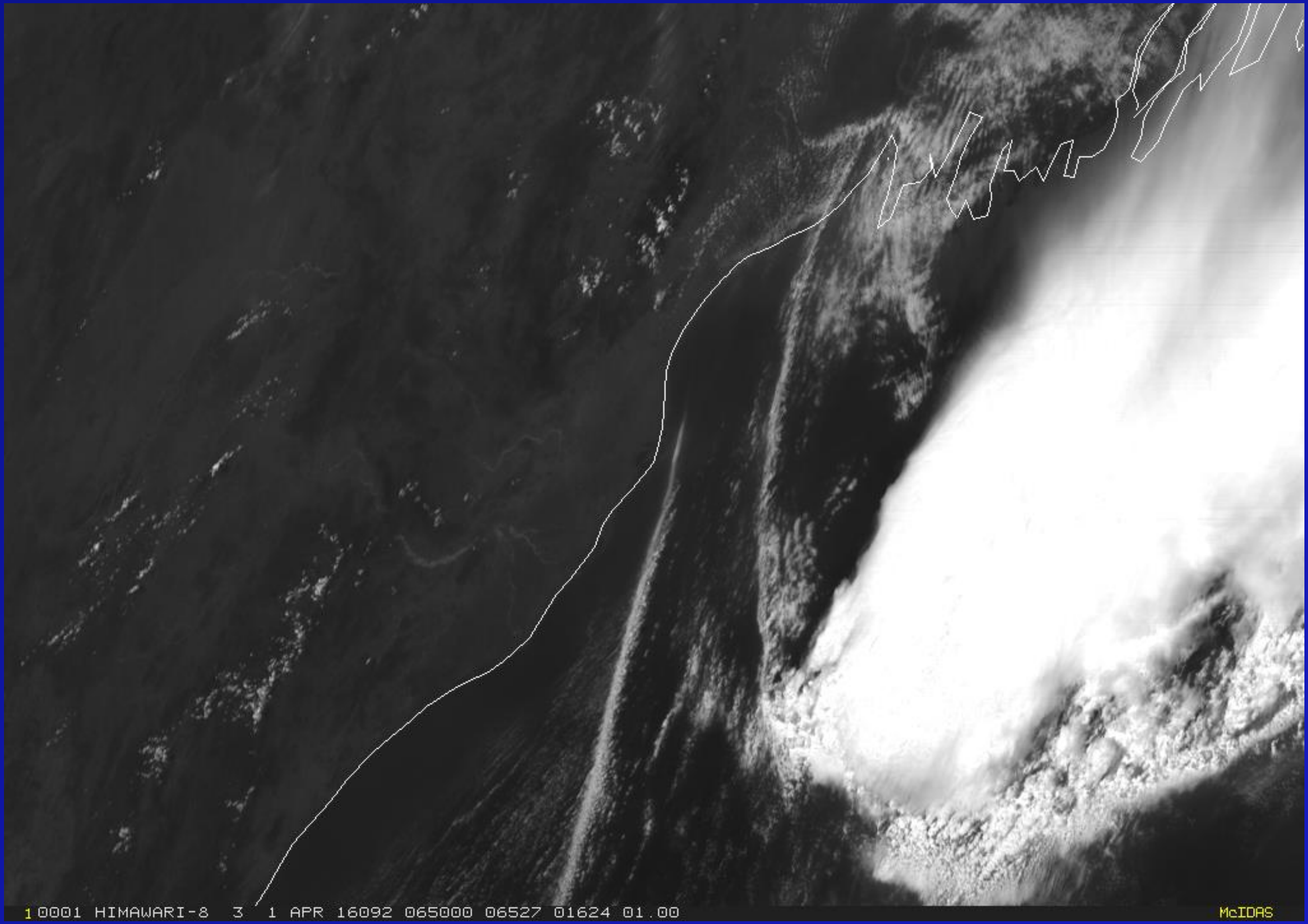
Band 13 (10.4 µm) IR over northern Australia – 24 Jan. 2016



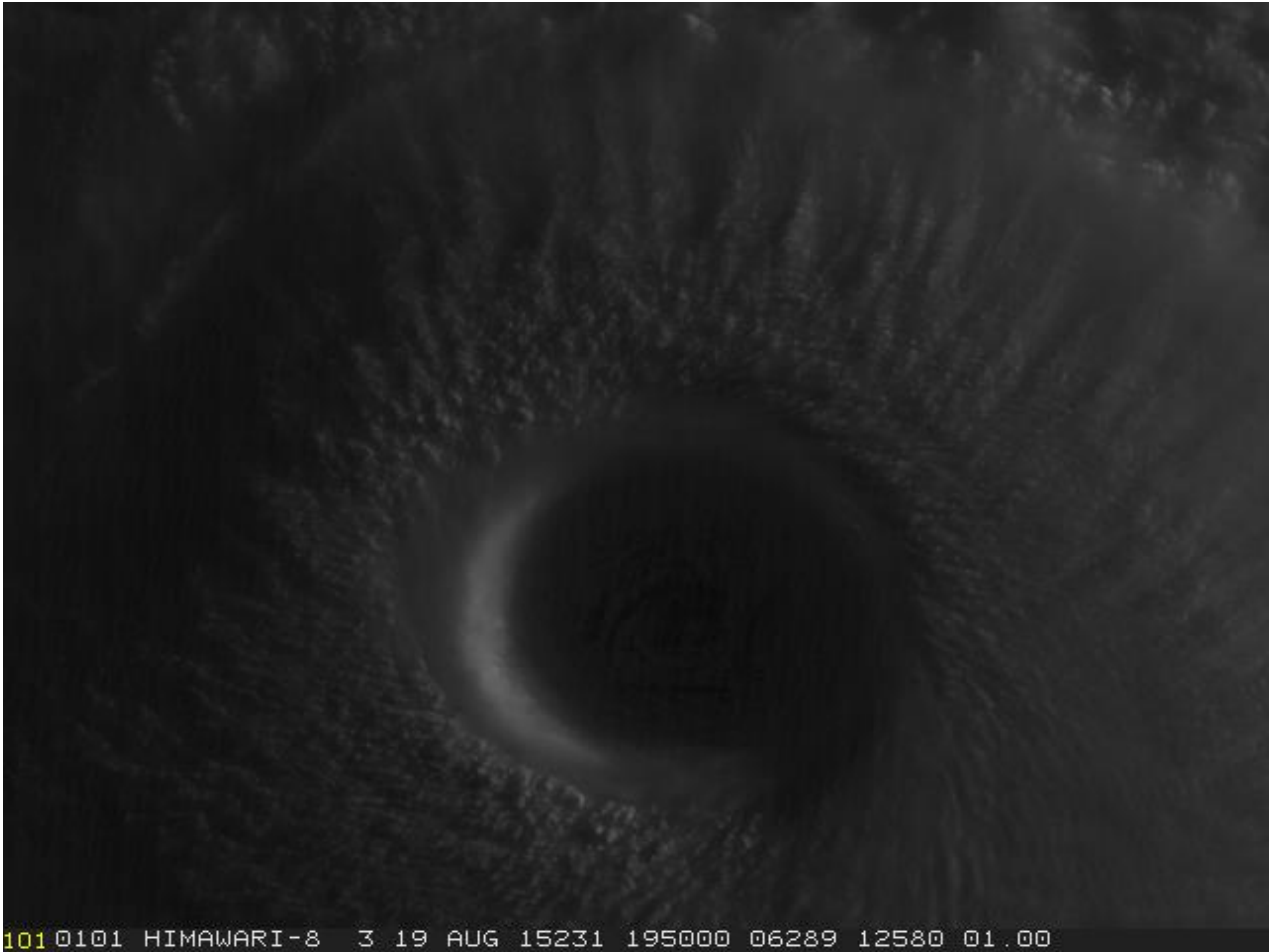
Band 13 (10.4 µm) IR over northern Australia – 6 Mar. 2016



Band 3 (0.64 µm) VIS over northeast India – 1 Apr. 2016



Typhoon Atsani – Himawari , band 3 (0.5 km VIS), 10-min time steps



Total Solar Eclipse – 8 Mar. 2016 – Band 3 Visible

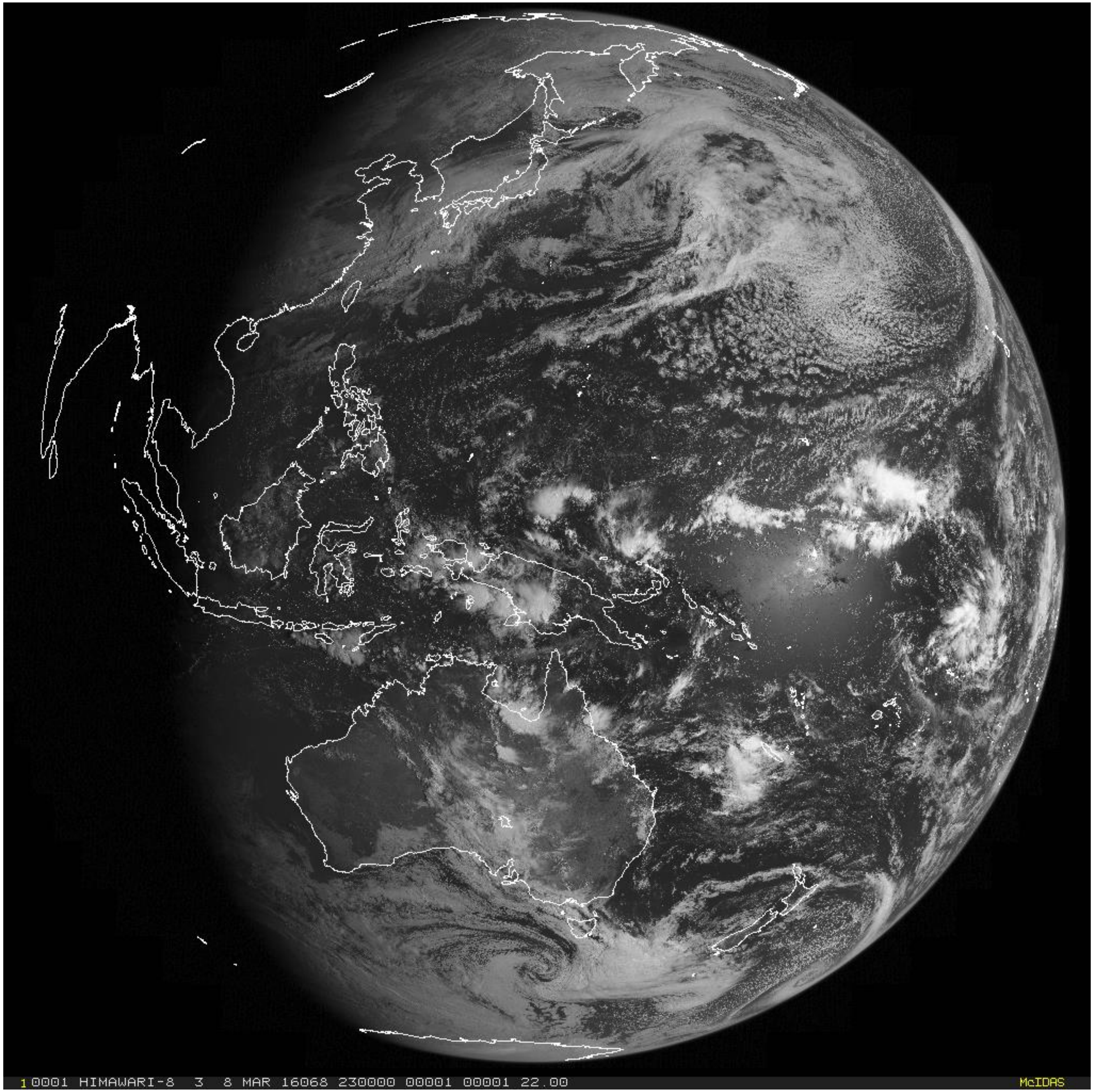


Photo of the Pavlof Eruption in Alaska – 28 Mar. 2016

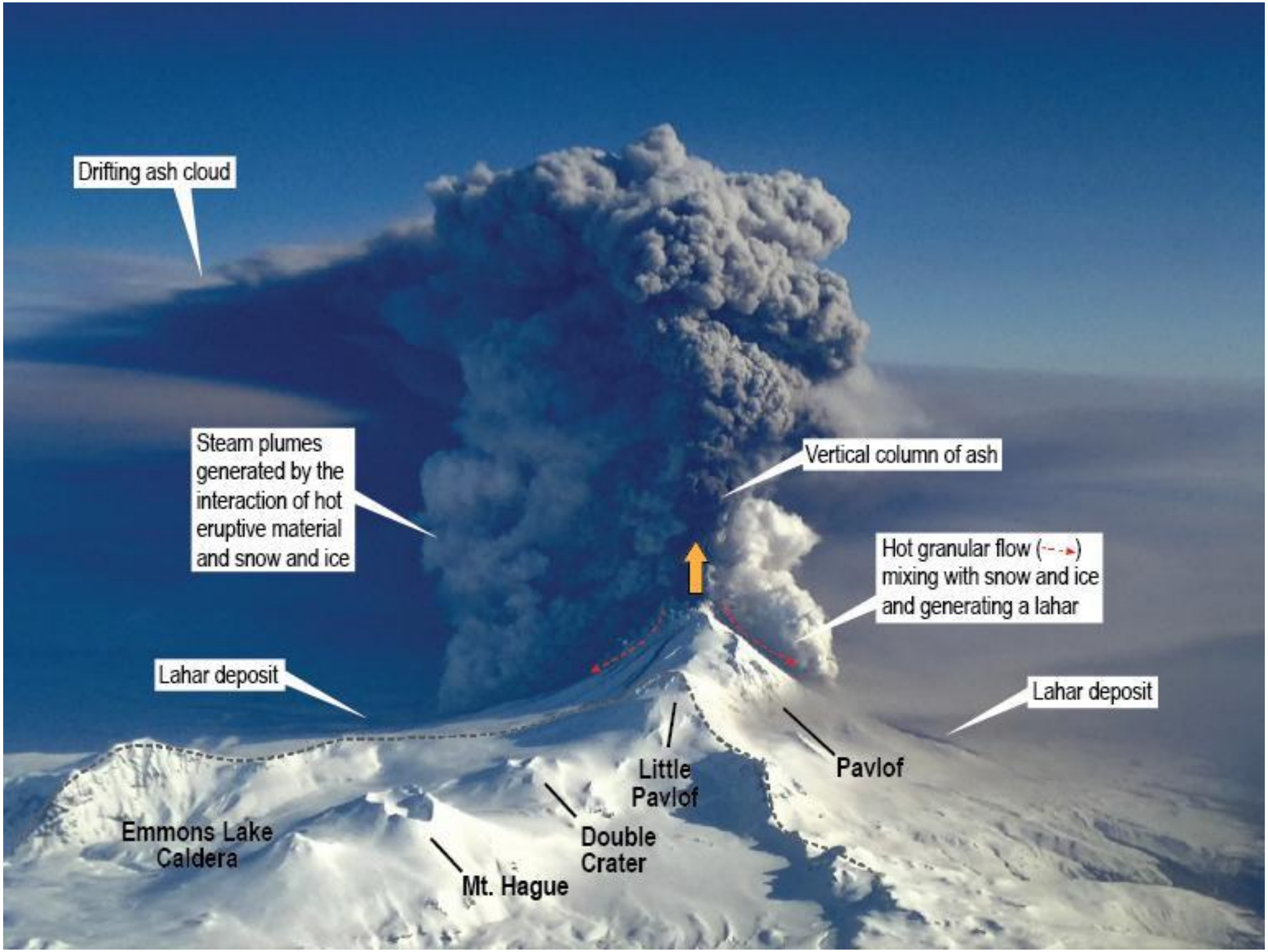
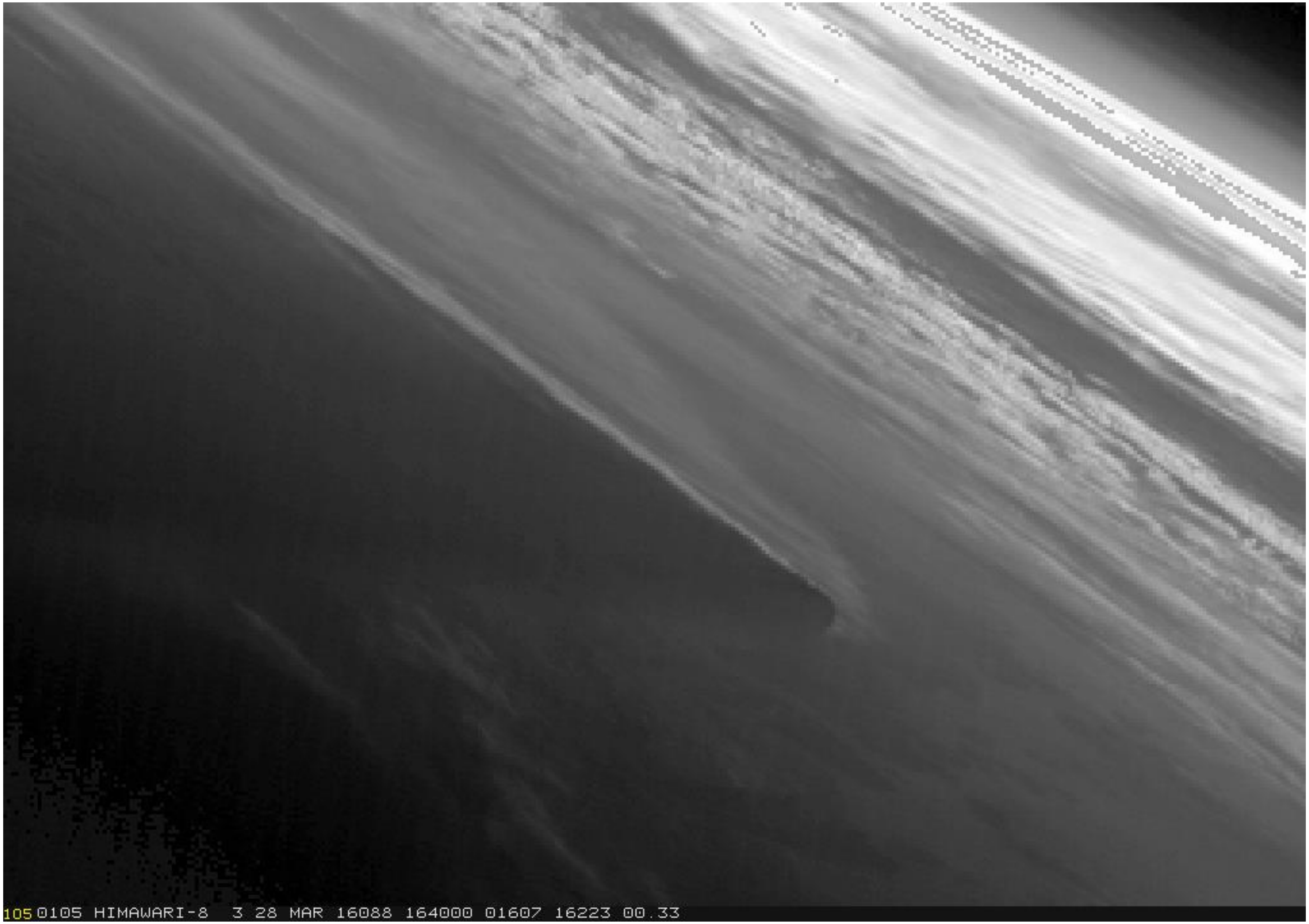


Image courtesy of the Alaska AVO

Eruption of Pavlof in the Aleutian Islands of Alaska – 28 Mar. 2016
Due to the limb view, we can see the side of the volcanic cloud, almost a vertical cross-section



3. Improved Spectral Resolution

- The new state-of-the-art imagers will have 16 spectral bands
- These additional bands have allowed a plethora of new and improved algorithms and products
- There is no time to cover all of these, so today we will focus on True Color imagery, a special case of an RGB combination

Comparison of Spectral Bands

Approx. Central Wavelength (µm)	Band Explanation	GOES-R ABI	Himawari AHI	GK-2 AMI	MTG FCI	FY-4 AGRI
		Central Wavelength (µm) [Band Number]				
0.47	Visible/reflective	0.47 [1]	0.47 [1]	0.46 [1]	0.44 [1]	0.47 [1]
0.51		None	0.51 [2]	0.51 [2]	0.51 [2]	None
0.64		0.64 [2]	0.64 [3]	0.64 [3]	0.64 [3]	0.65 [2]
0.865	Reflective	0.865 [3]	0.86 [4]	0.86 [4]	0.865 [4]	0.825 [3]
0.91		None	None	None	0.914 [5]	None
1.378	Cirrus	1.378 [4]	None	1.38 [5]	1.38 [6]	1.375 [4]
1.61	Snow/Ice	1.61 [5]	1.61 [5]	1.61 [6]	1.61 [7]	1.61 [5]
2.25	Particle size	2.25 [6]	2.25 [6]	None	2.25 [8]	2.25 [6]
3.90	Shortwave IR	3.90 [7]	3.9 [7]	3.85 [7]	3.8 [9]	3.75[2] [7,8]
6.19	Water vapor	6.19 [8]	6.2 [8]	6.24 [8]	6.3 [10]	6.25 [9]
6.95		6.95 [9]	6.9 [9]	6.95 [9]	None	7.1 [10]
7.34		7.34 [10]	7.3 [10]	7.35 [10]	7.35 [11]	None
8.5	Water vapor, SO_2	8.5 [11]	8.6 [11]	8.6 [11]	8.7 [12]	8.5 [11]
9.61	Ozone	9.61 [12]	9.6 [12]	9.63 [12]	9.66 [13]	None
10.35	Longwave IR	10.4 [13]	10.4 [13]	10.43 [13]	10.5 [14]	10.7 [12]
11.2		11.2 [14]	11.2 [14]	11.2 [14]	None	None
12.3		12.3 [15]	12.3 [15]	12.3 [15]	12.3 [15]	12.0 [13]
13.3		13.3 [16]	13.3 [16]	13.3 [16]	13.3 [16]	13.5 [14]

True-color component bands are highlighted in red, green, and blue.

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13.3		13.3 [16]	13.3 [16]	13.3 [16]	13.3 [16]	13.5 [14]

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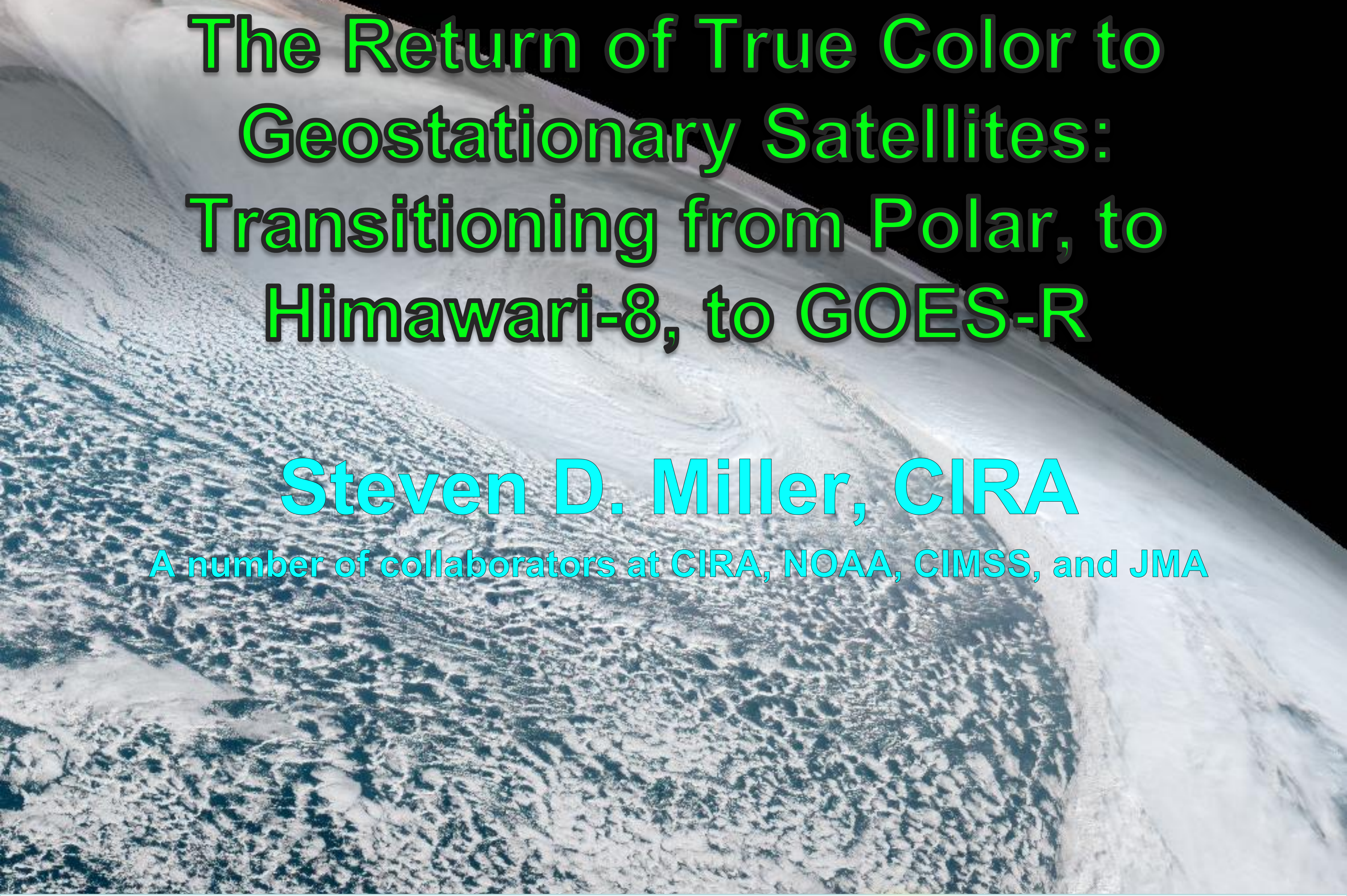


The Return of True Color to Geostationary Satellites: Transitioning from Polar, to Himawari-8, to GOES-R

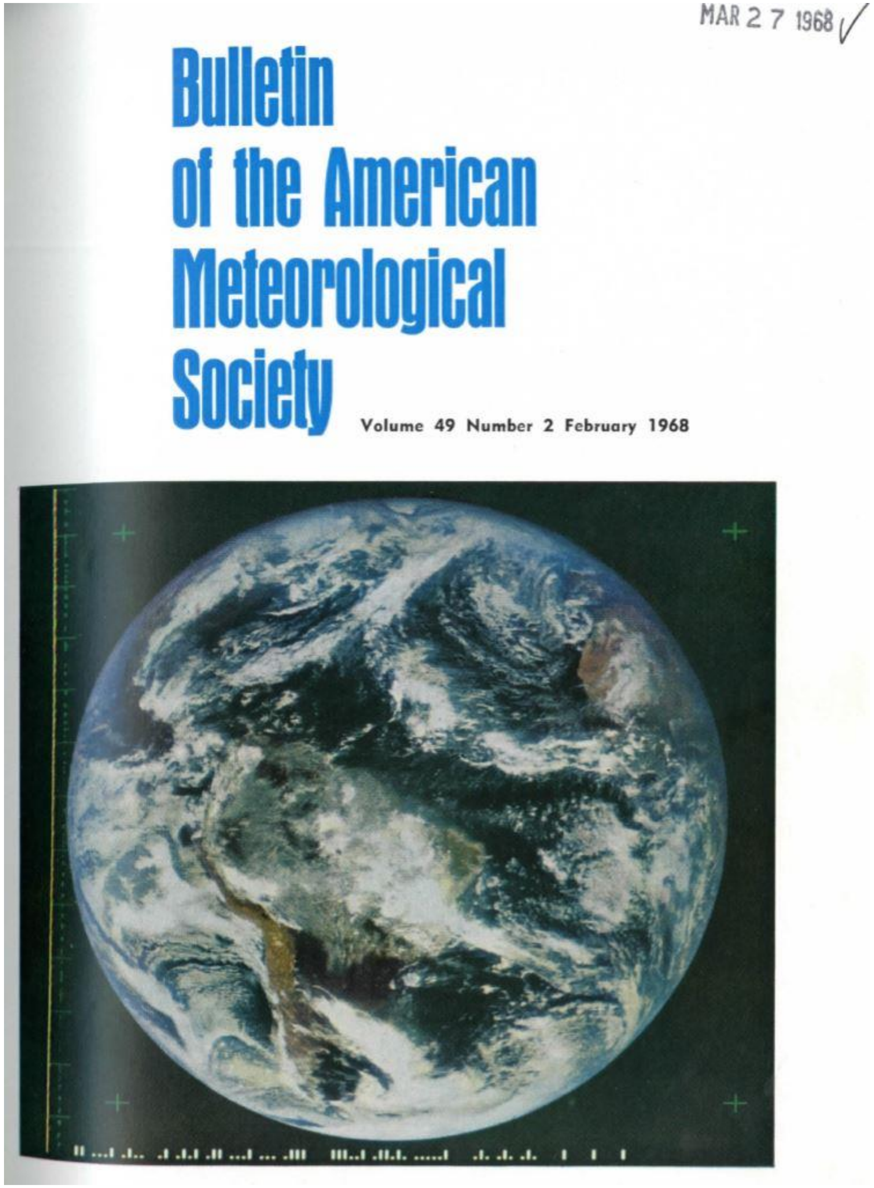
Steven D. Miller, CIRA

A number of collaborators at CIRA, NOAA, CIMSS, and JMA

Connecting Models and Observations

True Color from Geostationary Orbit

NASA ATS-3 (1967)
The last geostationary satellite to offer a true color imaging capability.


MAR 27 1968

Bulletin of the American Meteorological Society

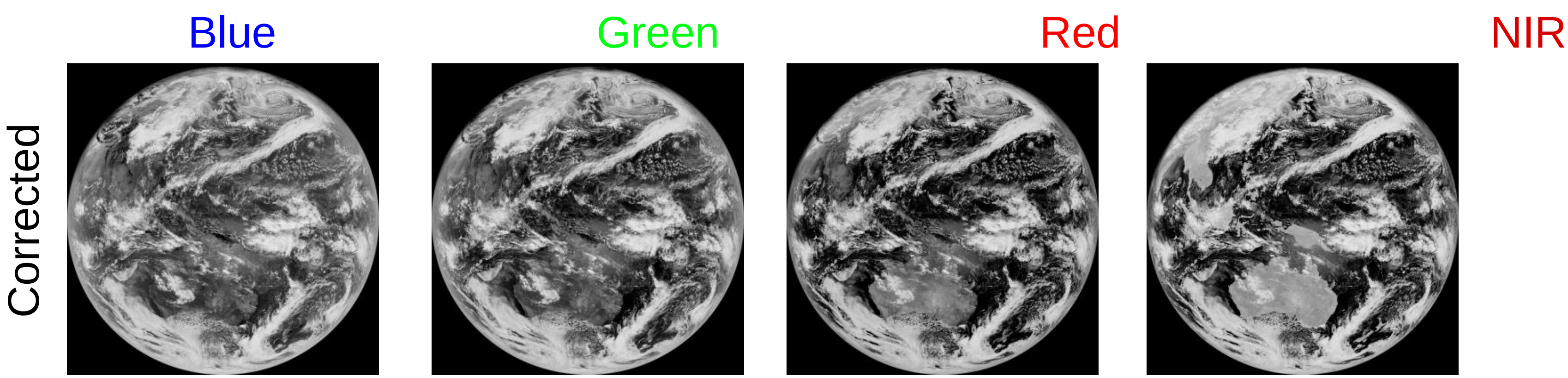
Volume 49 Number 2 February 1968

The Fundamental Value of True Color

- True Color is a special case of Red/Green/Blue (R/G/B) composite imagery.
- Visible-band reflectance data from red (0.65 µm), green (0.55 µm), and blue (0.47 µm) are loaded into the respective R/G/B color guns.
- True Color provides a visually intuitive (*Read: minimal training requirements*) form of baseline imagery for scene interpretation.
- This baseline serves as a useful reference for value-added False Color enhancements.

Rayleigh Corrections

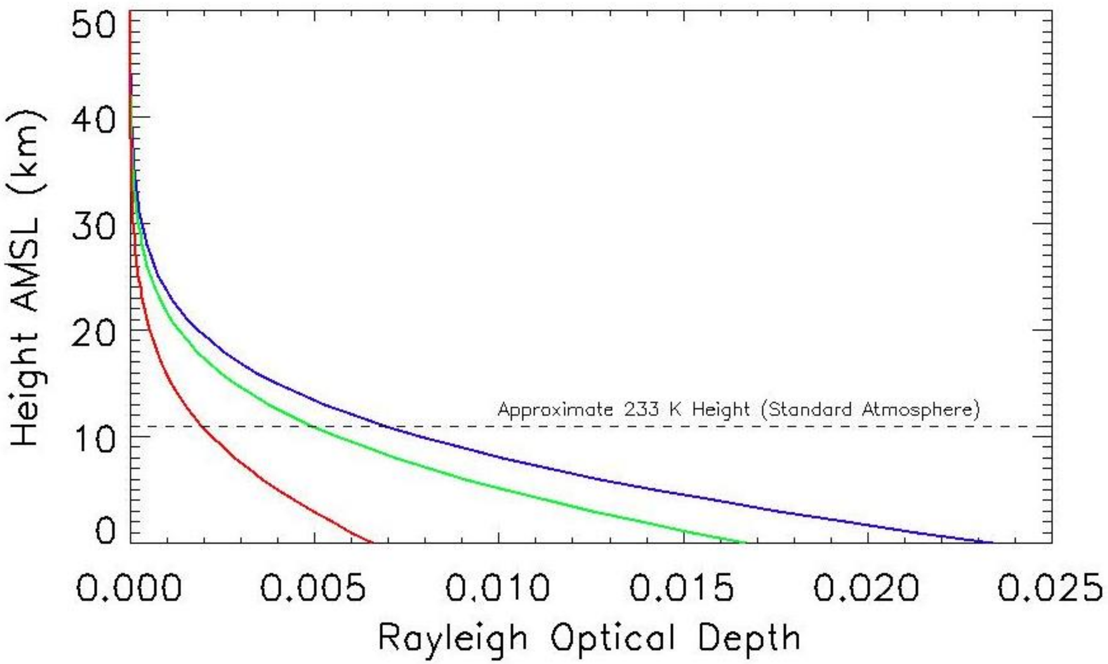
- Molecular scatter of sunlight by the gaseous atmosphere is significant, particularly in the blue-band
- Adapted atmospheric correction software, applied previously to SeaWiFS/MODIS/VIIRS sensors, to AHI bands
- Corrections are a function of solar & satellite geometry



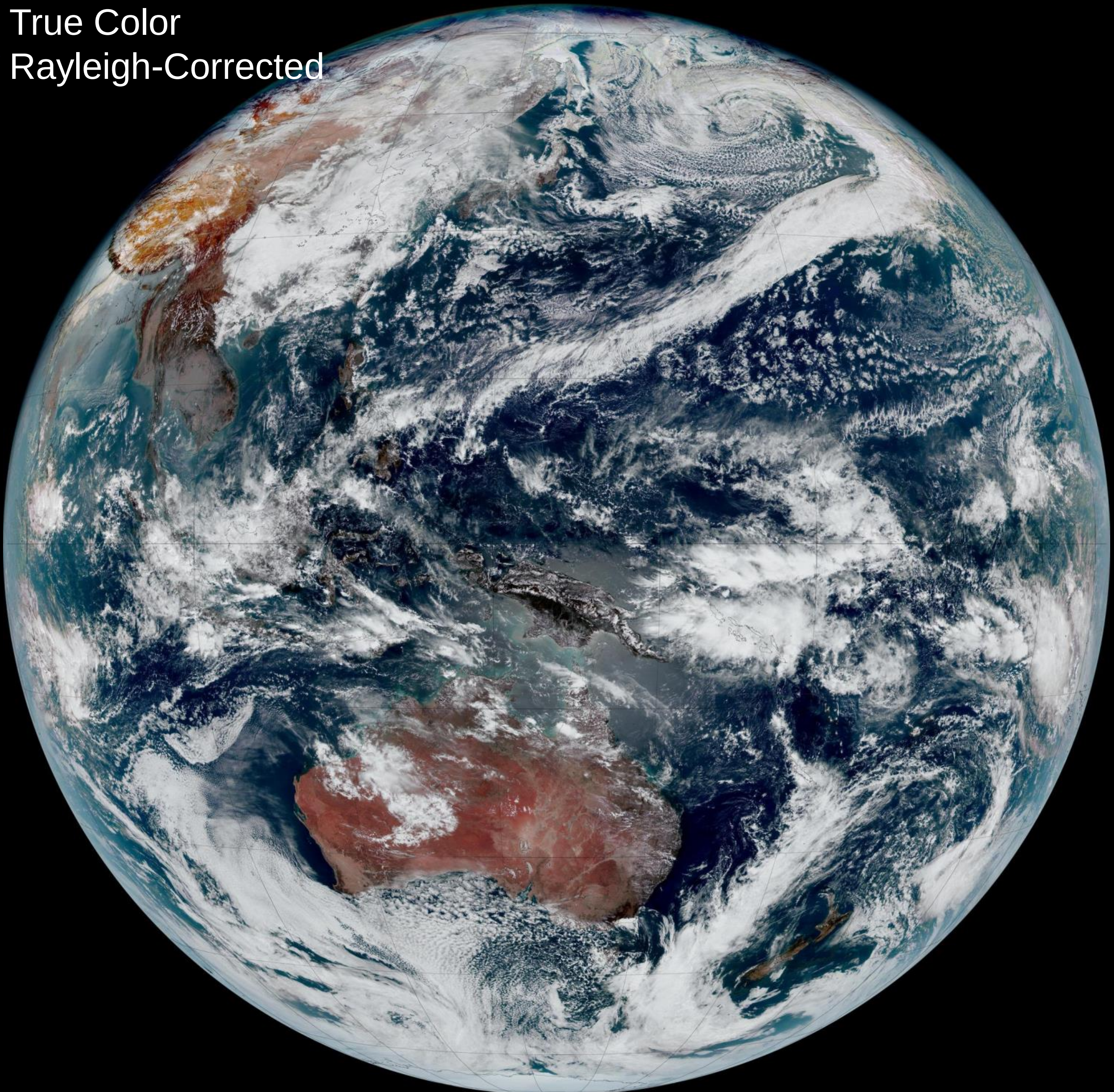
→ *These atmospheric corrections are a critical step in attaining high-quality true color imagery*

Dealing with Extreme Geometries

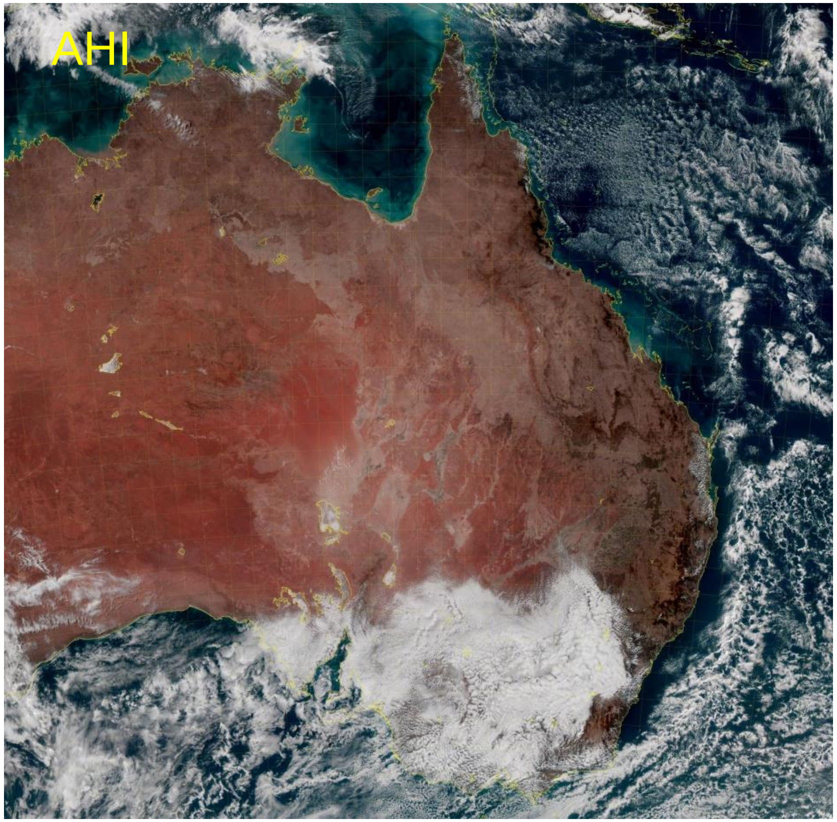
- Long optical paths correspond to larger Rayleigh atmospheric corrections.
- The errors in the corrections are amplified wherever simple assumptions are violated.
- High clouds truncate the optical path to the surface, leading to over-corrections.
  – Leads to image artifacts near Earth's limb →

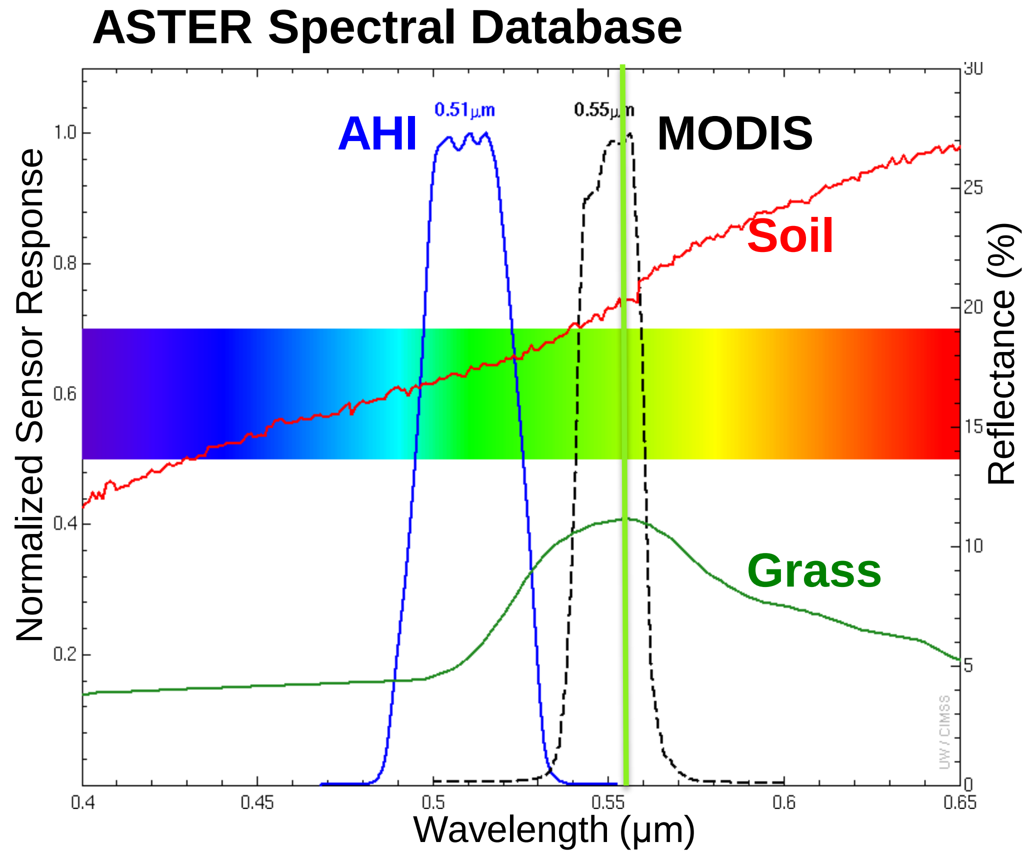


True Color
Rayleigh-Corrected



Inconsistencies with MODIS/VIIRS





- Comparisons of AHI true color imagery to VIIRS & MODIS showed vegetation too brown, deserts too red…
- The 510 nm AHI band misses the 555 nm chlorophyll signal, and mineral soils are more absorbing (MODIS & VIIRS both use 555 nm).

Proposing a '*Hybrid Green*' Band

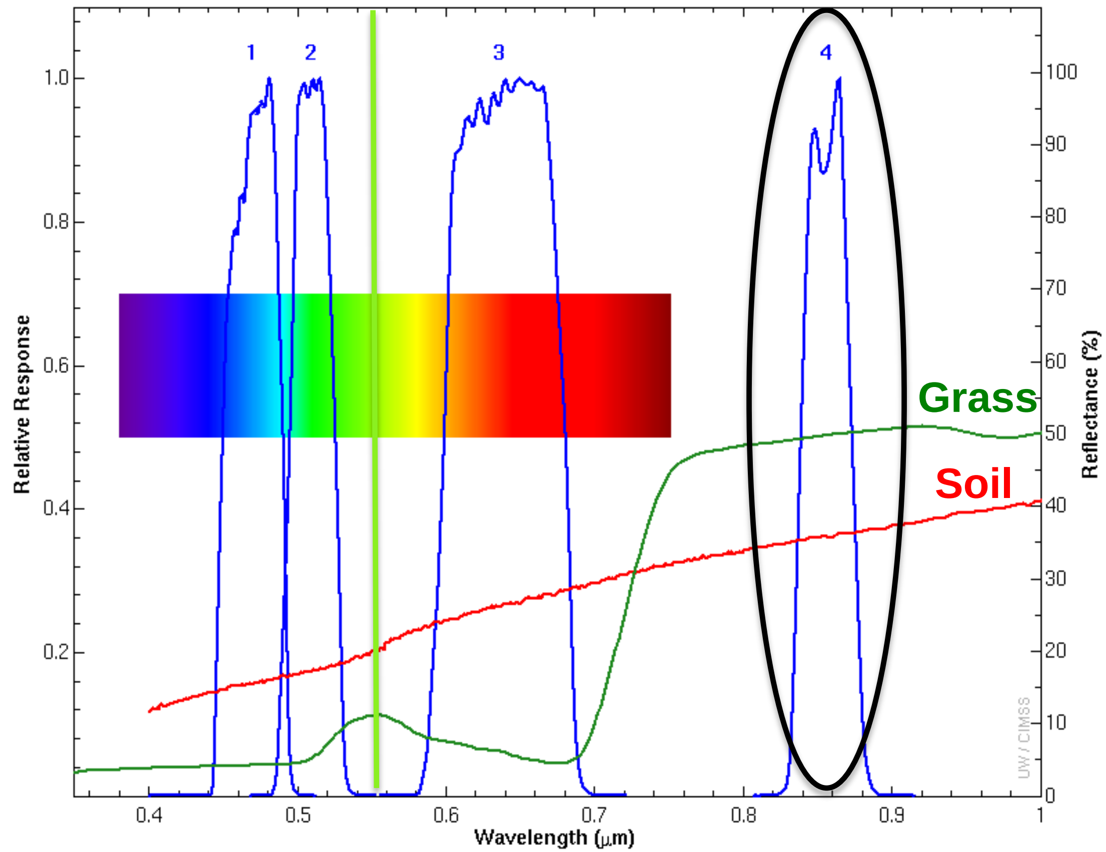
- Blend 510 nm green band with vegetation-sensitive 856 nm band to produce a 'hybrid green' band (G_H):

$$G_H = (1-F) * R\_510 + F * R\_856$$

F ~ 0.07 (experimental)

- Provides enhancement to green vegetation and to mineral soils (e.g., deserts).

- Minimal impact to other features of the scene (clouds, ocean, and shallow-water coloration)

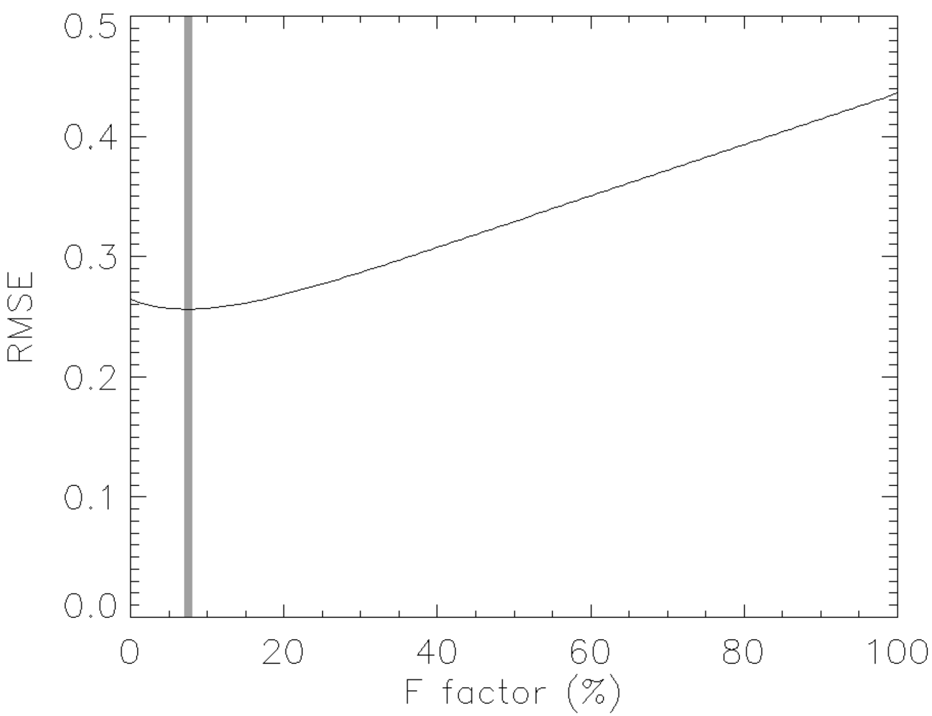


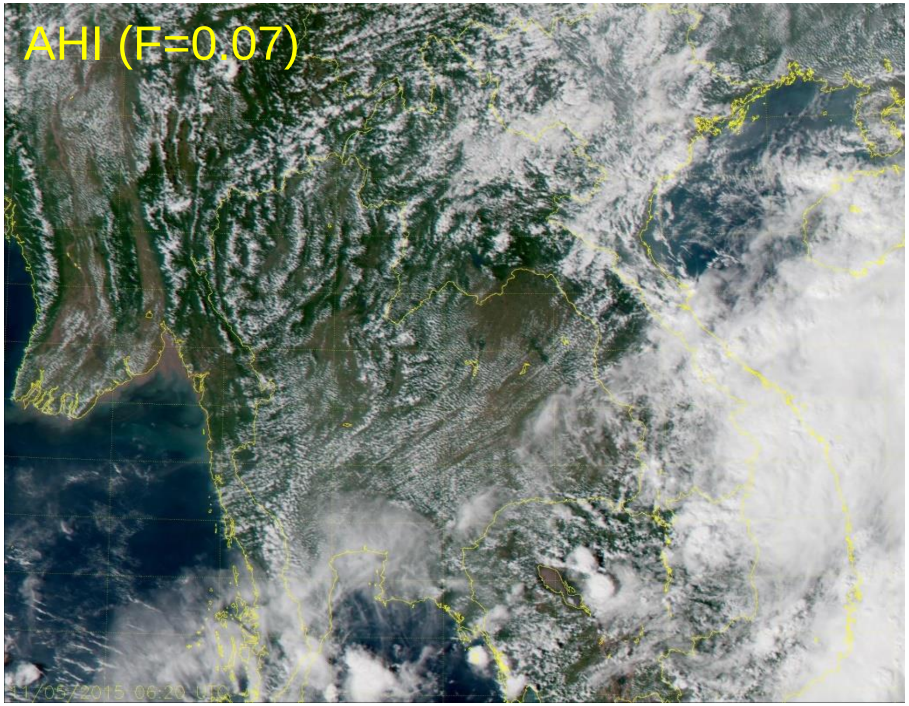
→ **AHI Band 4 (856 nm) provides a 'boost' to the 510 nm vegetation and soil reflectance…**

CIRA
Connecting Models and Observations

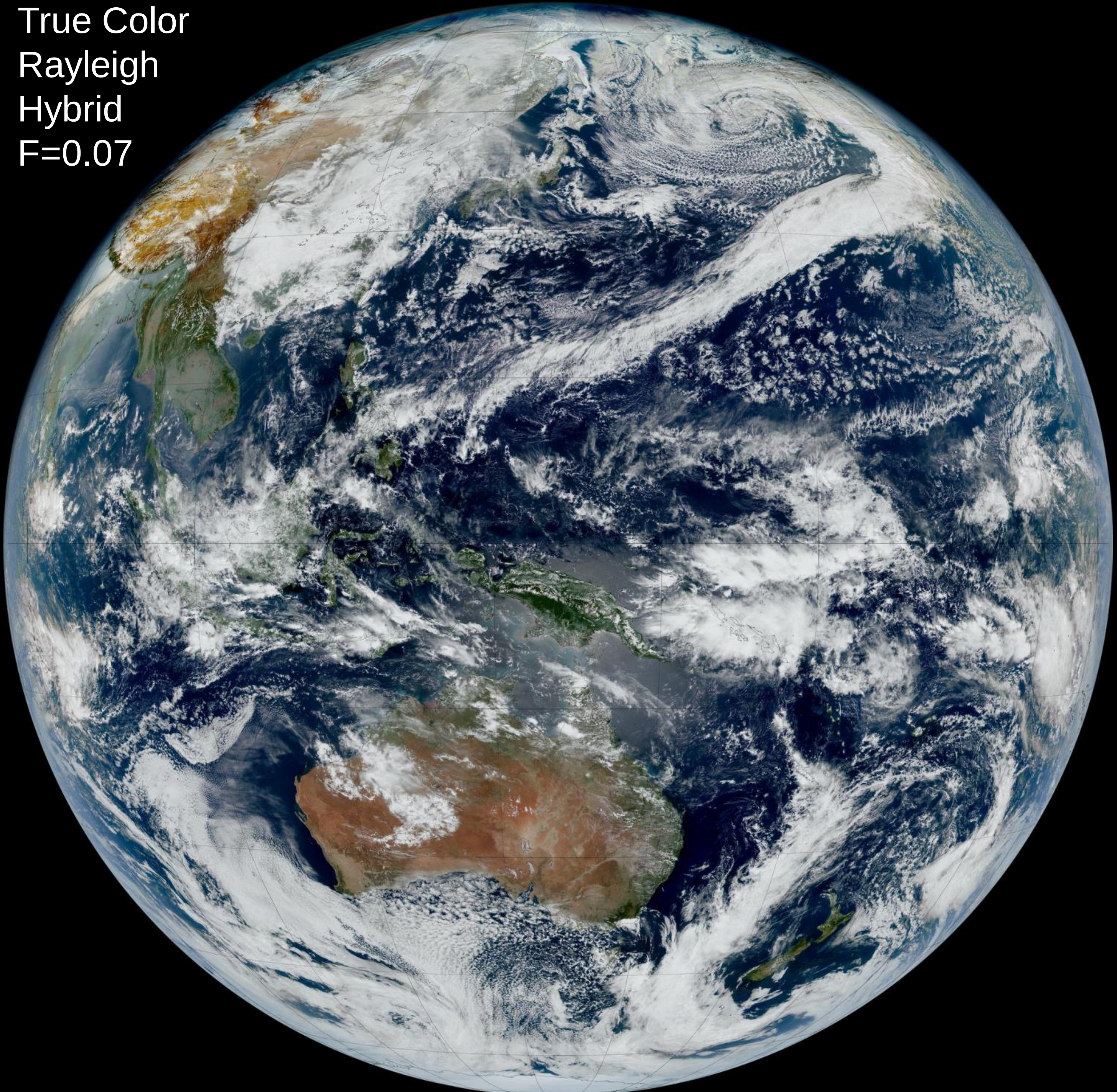
Objective Determination of ‘F’

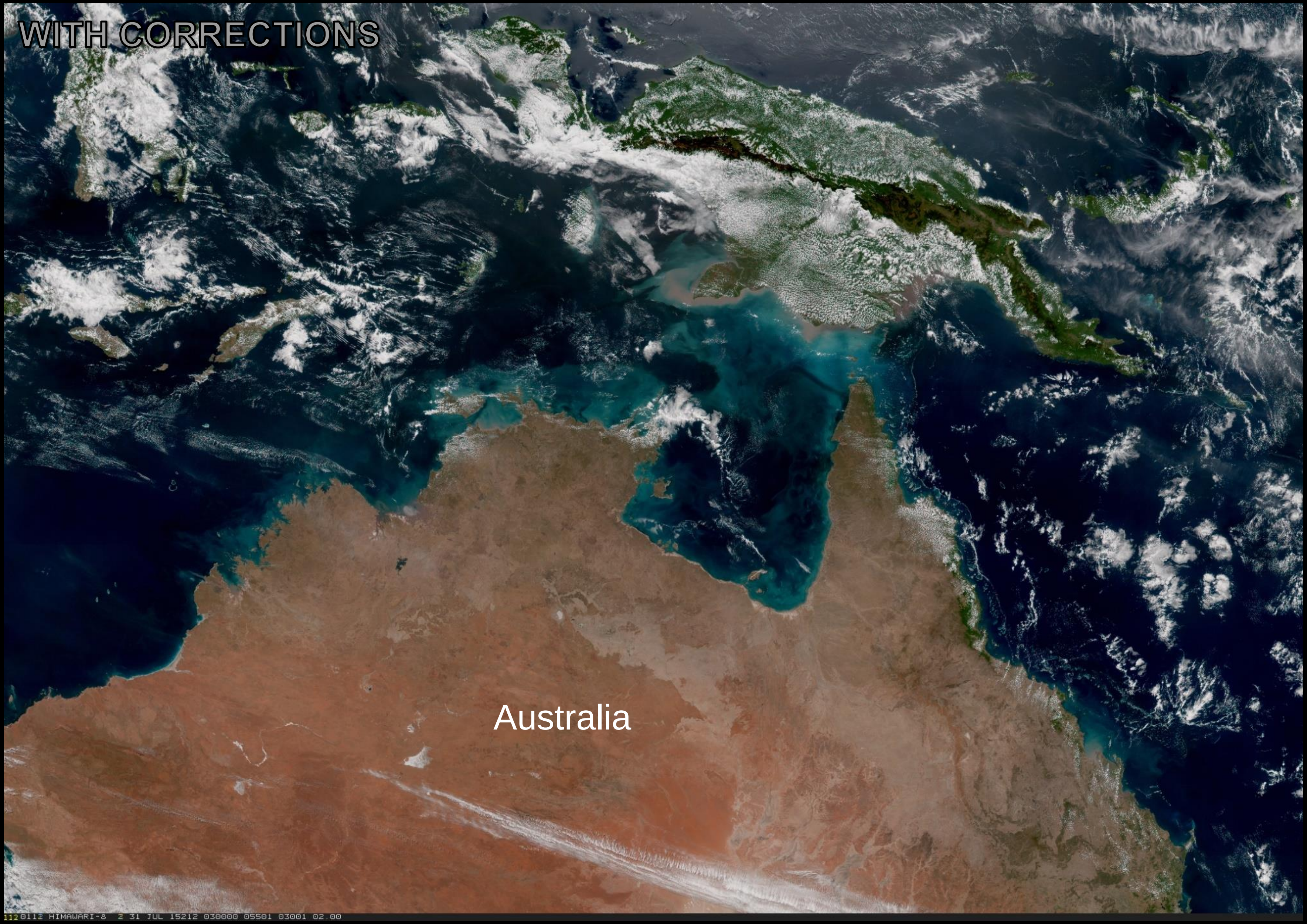
- Space/time match AHI to VIIRS for a diverse land scene.
- Adjust F to compute G_H that minimizes a scalar cost function: $$C = \frac{1}{N}\sum_{pixels}\sqrt{\left(G_{viirs} - G_{ahi,H}\right)^2}$$





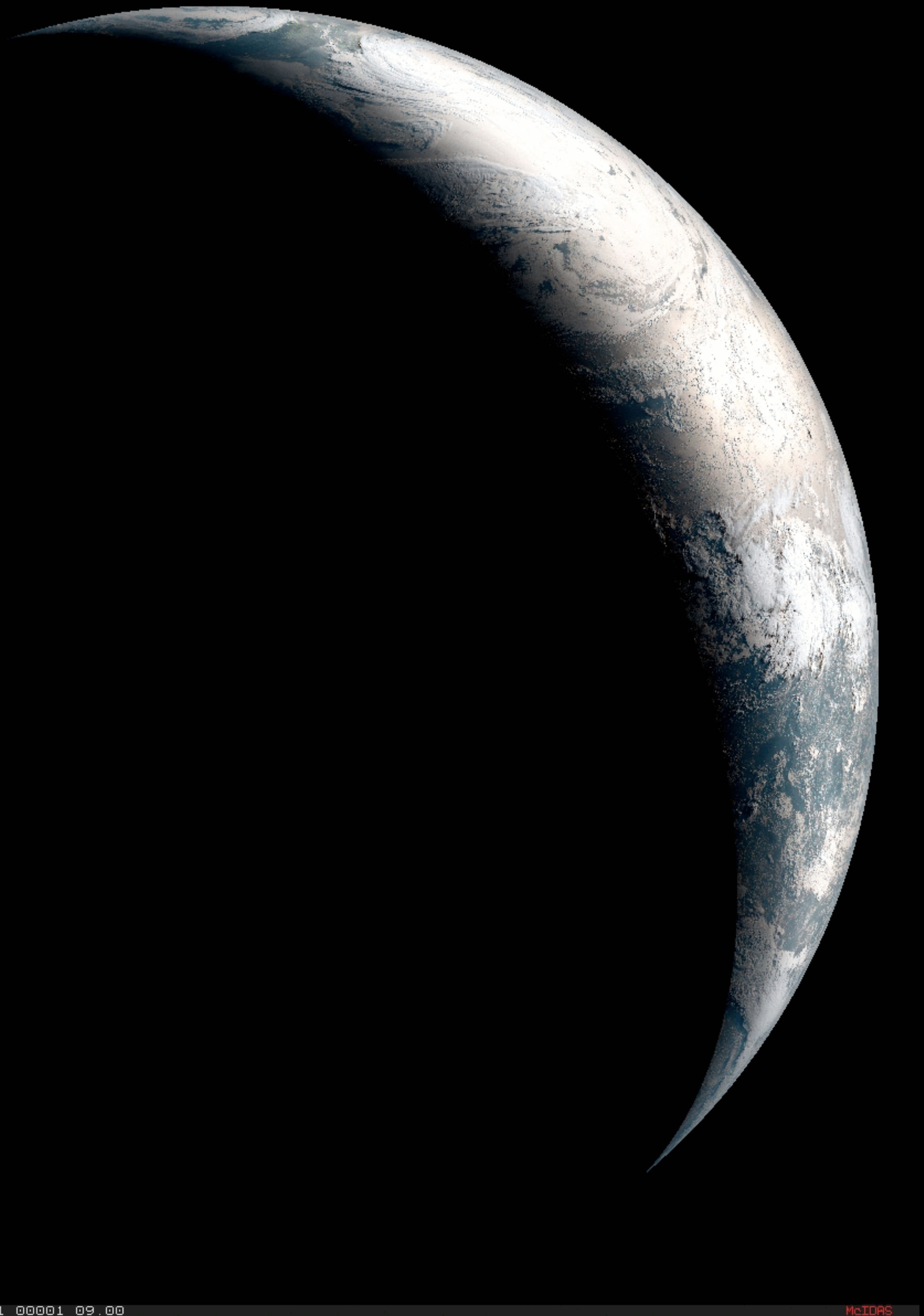
True Color
Rayleigh
Hybrid
F=0.07



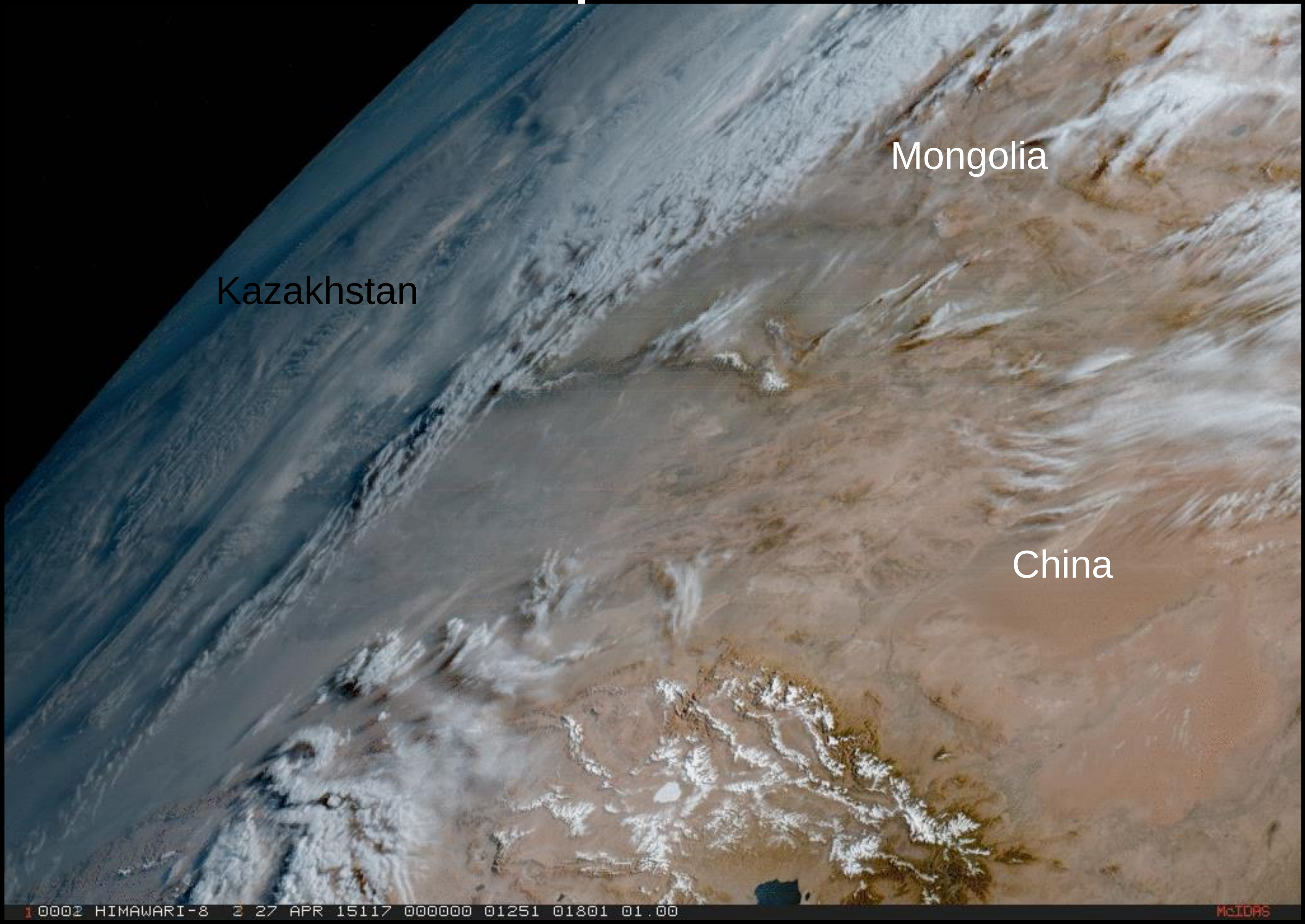


Miller, S. D., et al., 2016, *Bull. Amer. Meteorol. Soc.*, in press

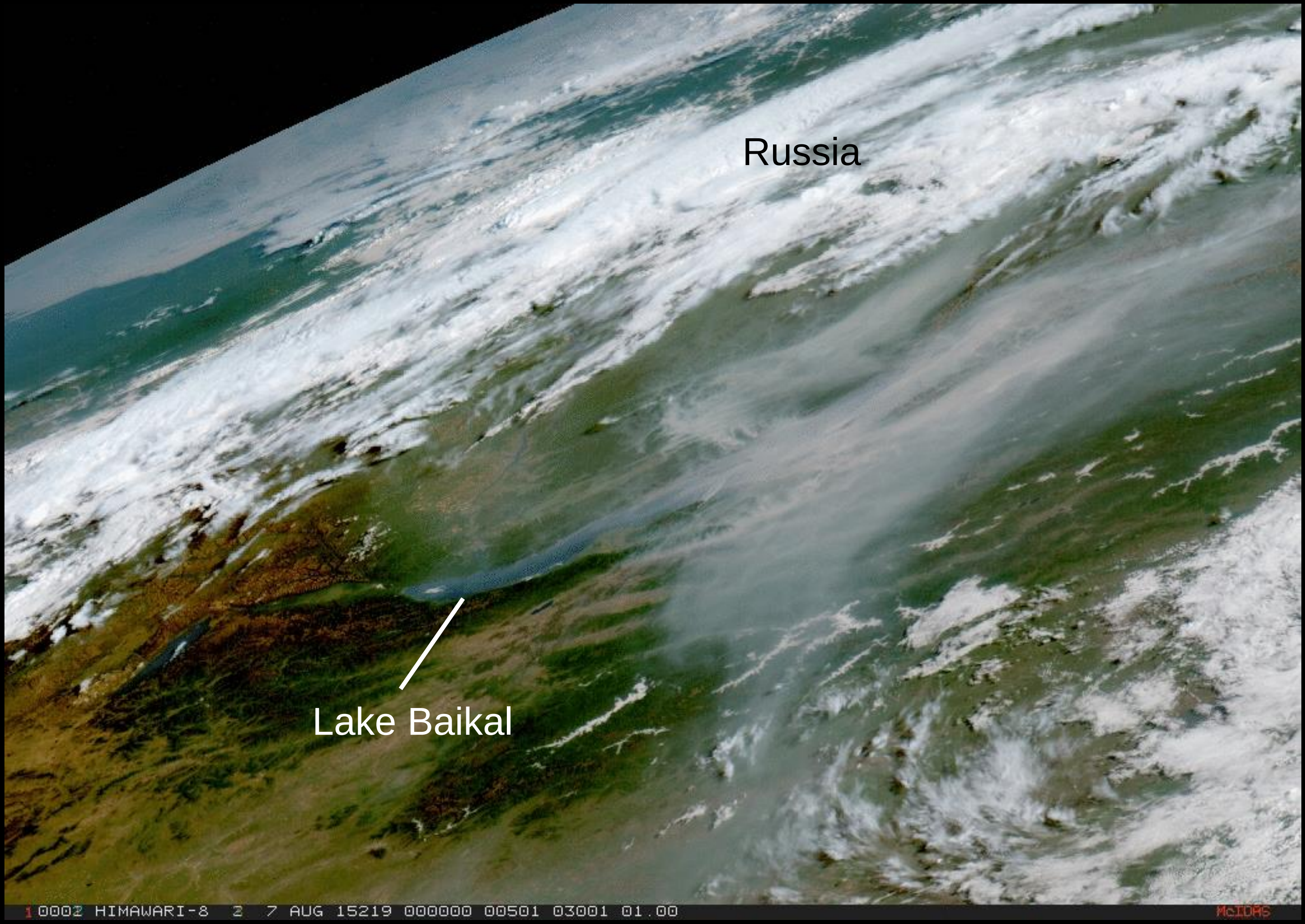
Full Disk Animation
Himawari-8 AHI
6 July 2015



Large Chinese Dust Storm
27 April 2015

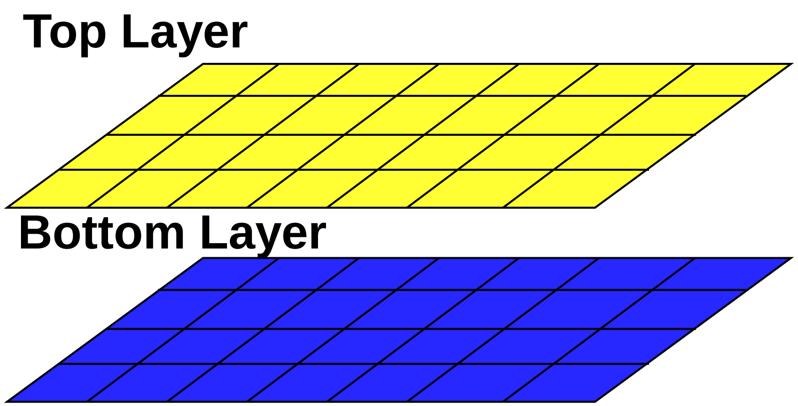


Forest Fires Near Lake Baikal, Russia
7 August 2015

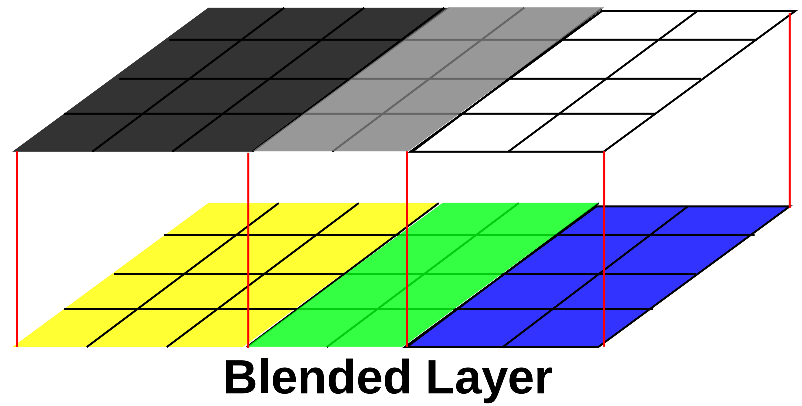


Extending into the Night: The *GeoColor* Concept

Layers of Information (2 layer example)

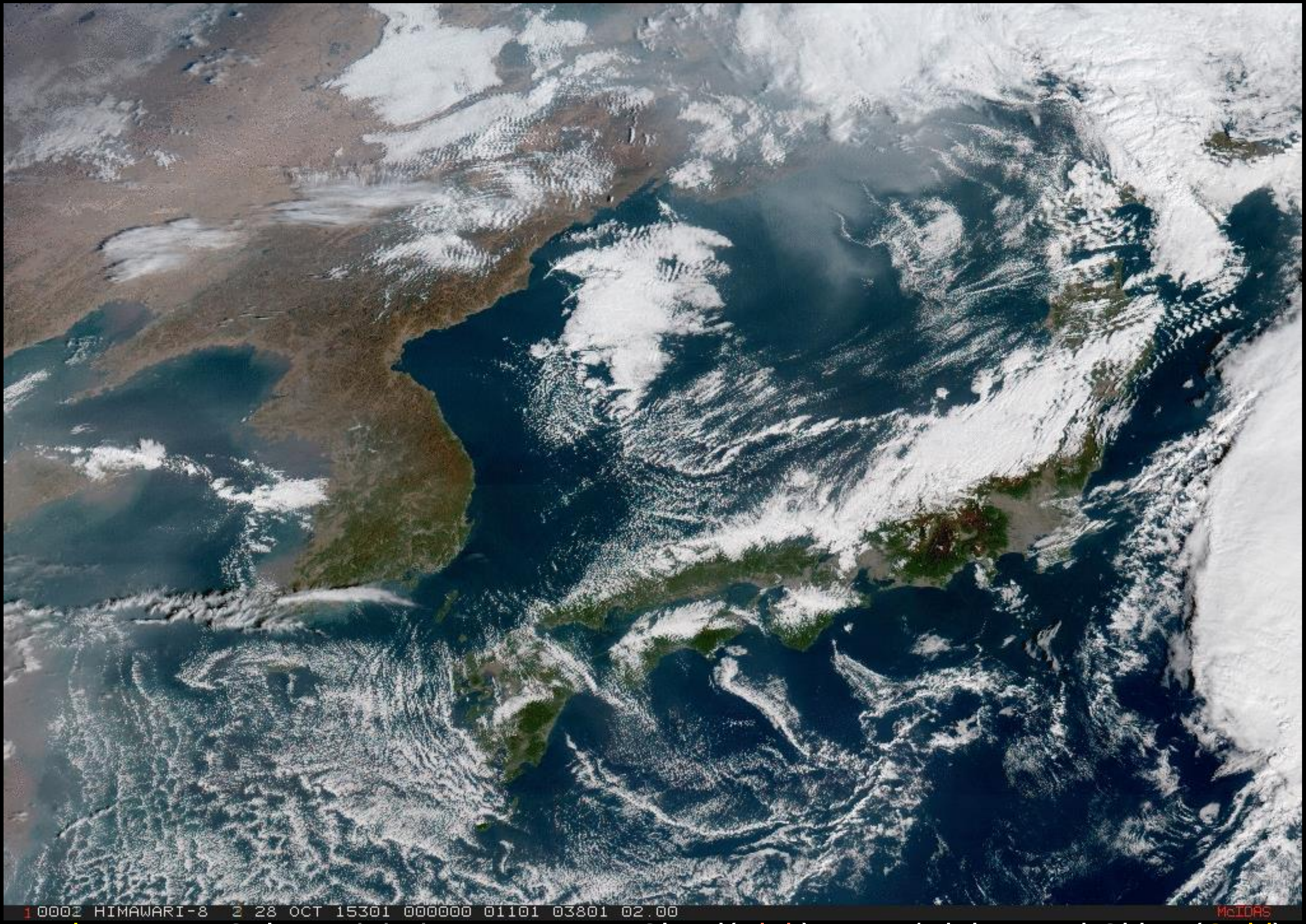


Spatial Opacity Rules for Top Layer (Black= Opaque, White=Transparent)



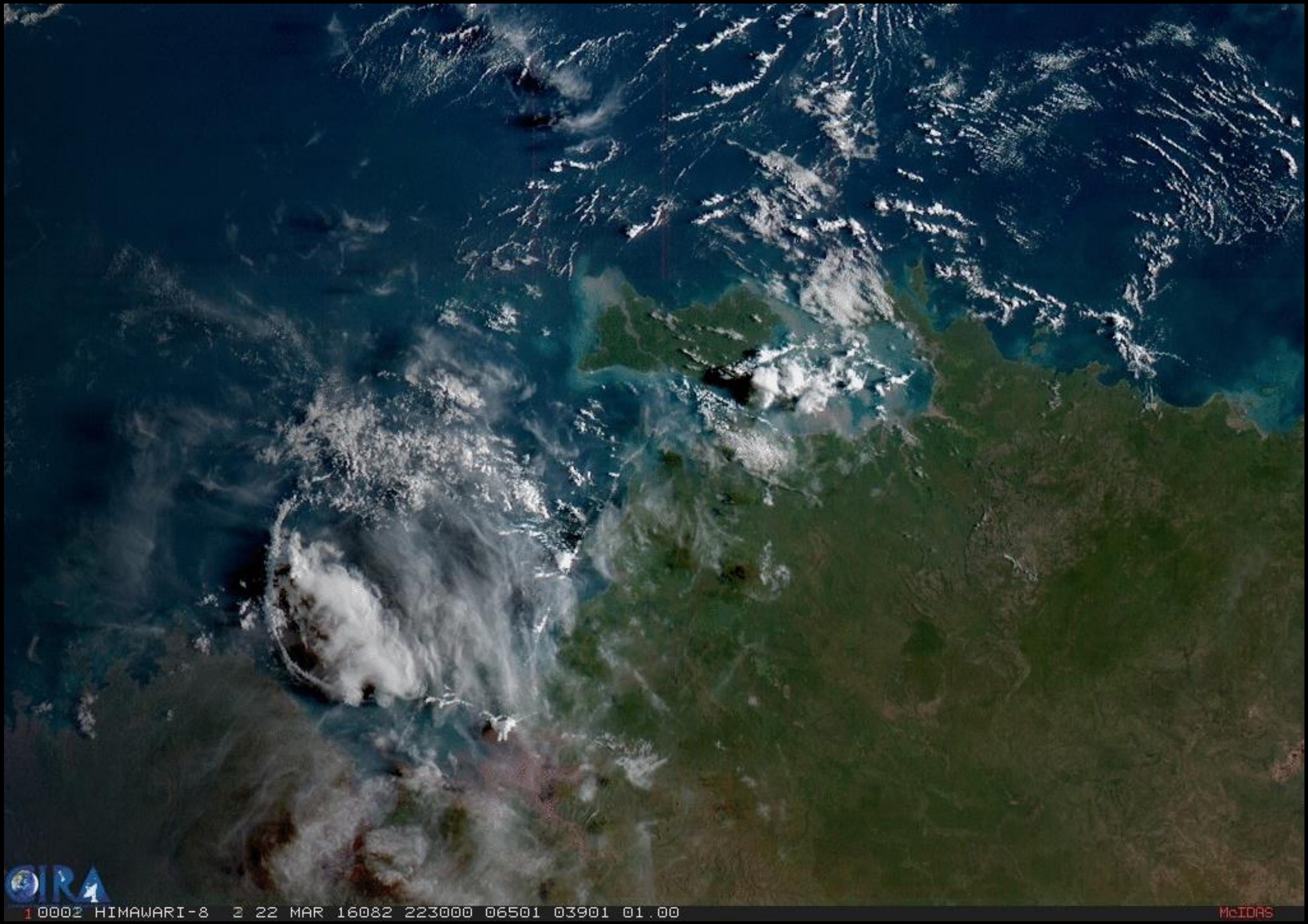
- Each layer of information has an associated opacity field that is defined at the pixel level.
- A separate blend is done for each color gun (R/G/B).
- Concept can be extended to "N-dimensions," allowing for ***simultaneous display of multiple enhancement layers***.

AHI GeoColor Imagery (Provisional)

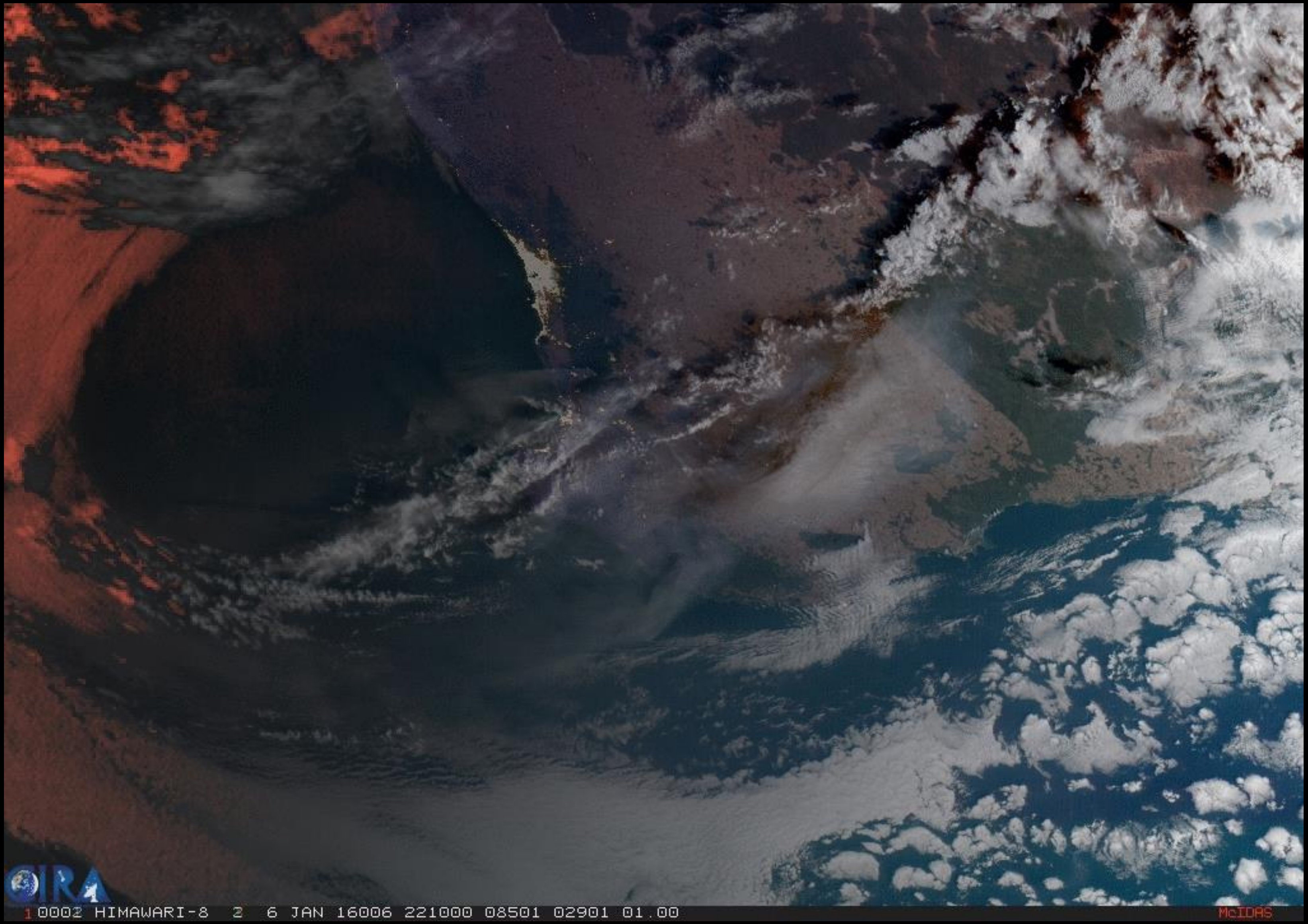


Daytime: True Color   Nighttime: IR + Low Cloud(Pink) + Day/Night Band Cities (Gold)

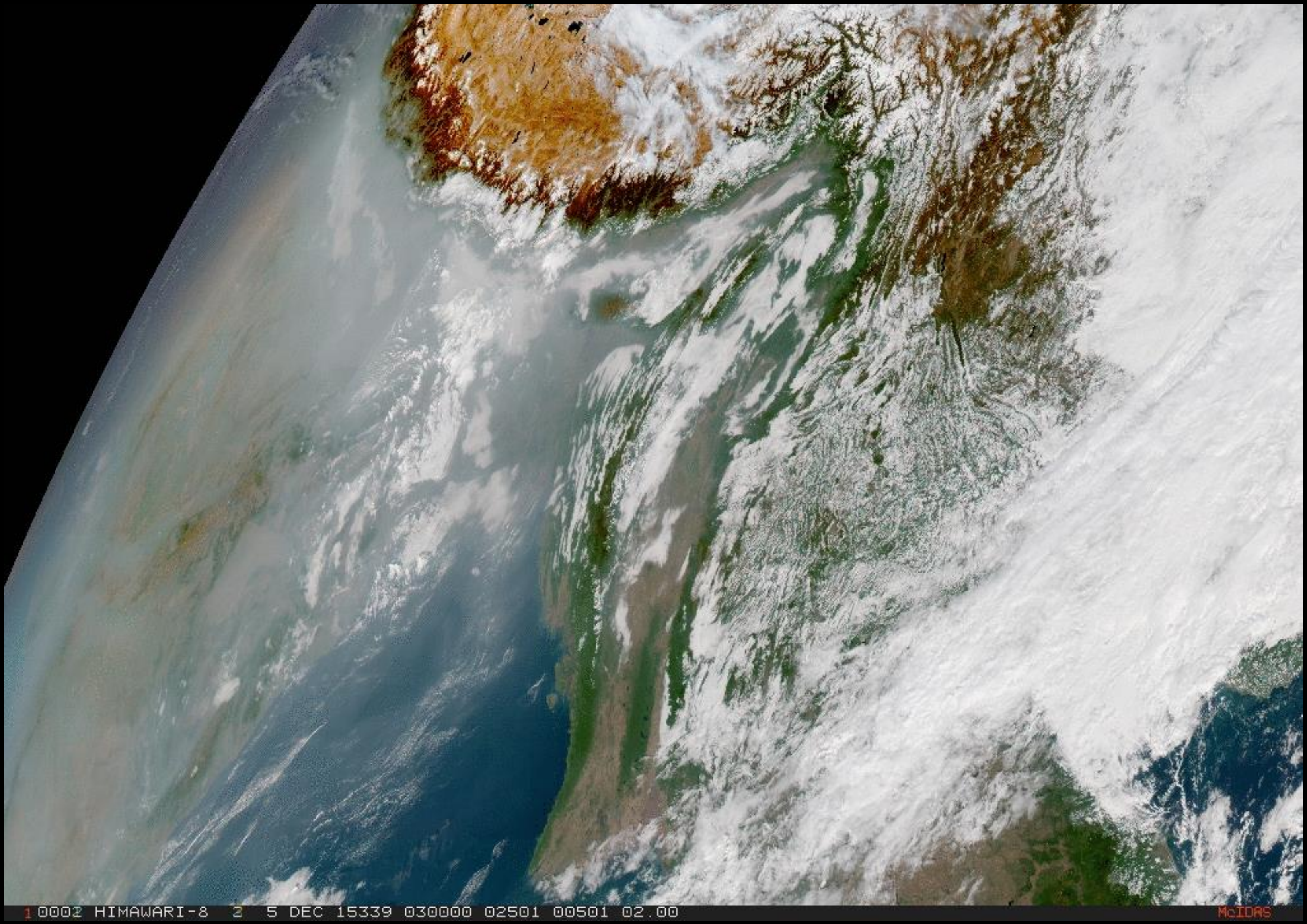
True color over northern Australia – 22 Mar. 2016



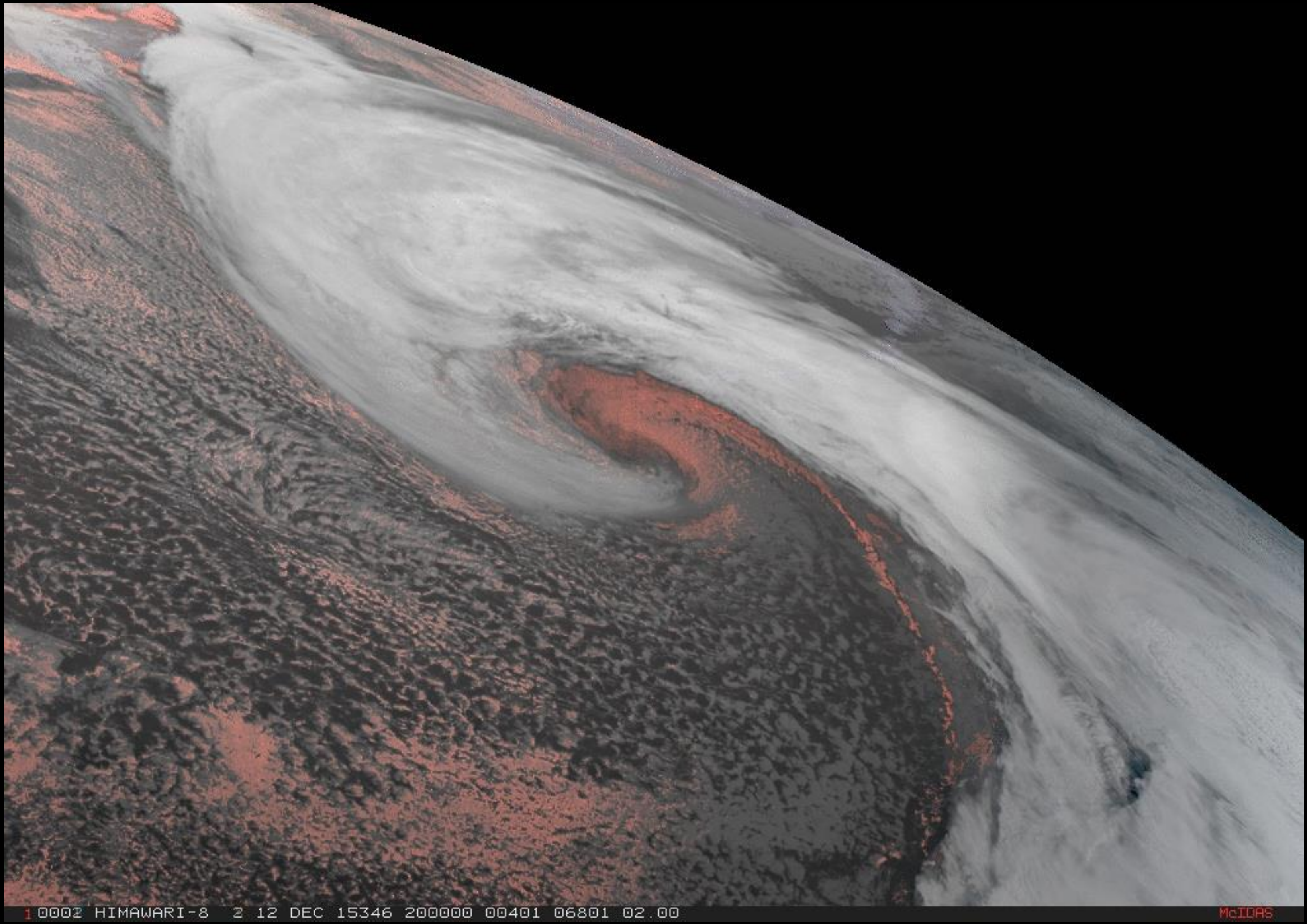
True color/Geocolor over southwestern Australia – 6 Jan. 2016



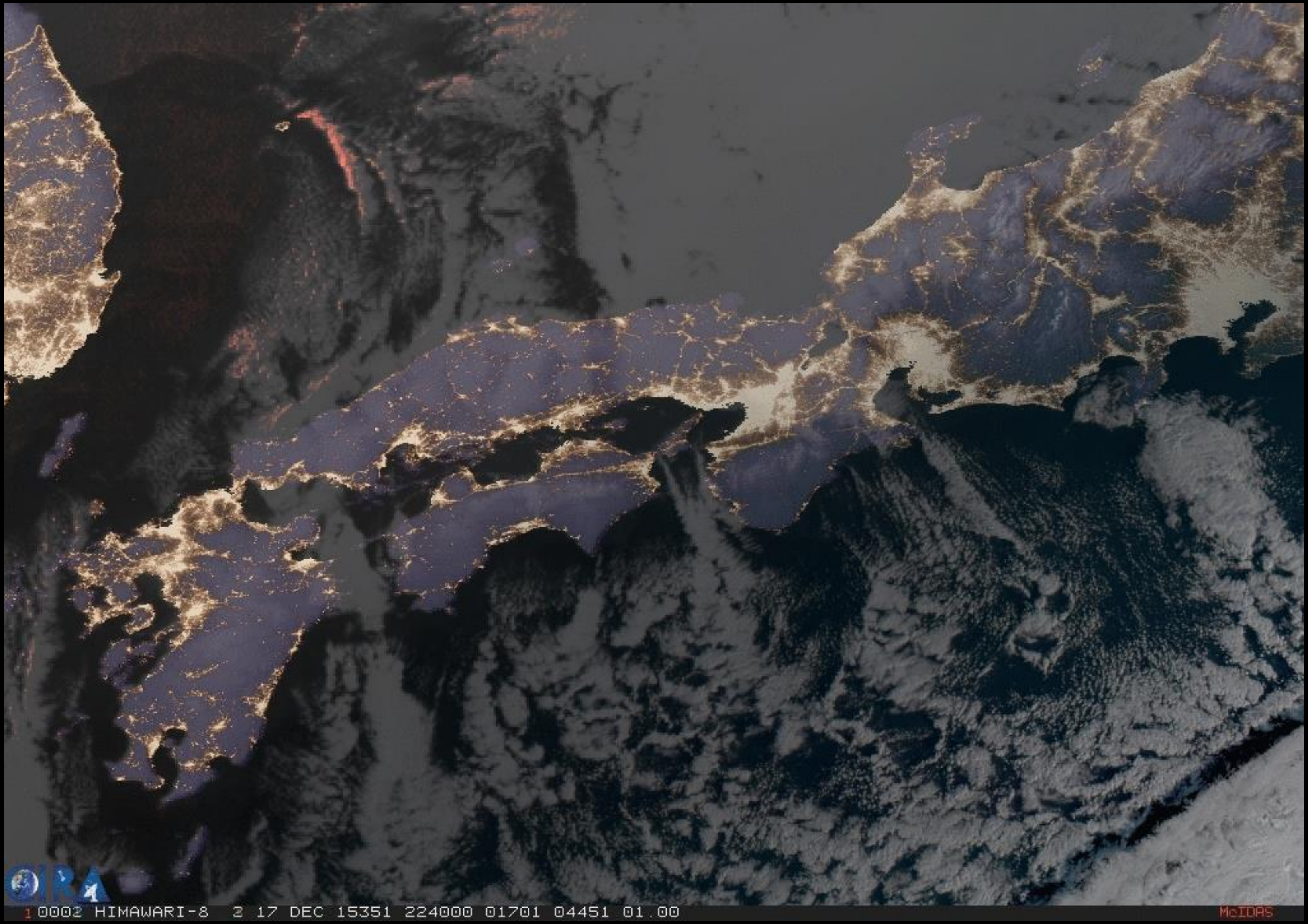
True color/Geocolor over India and southeast Asia – 5 Dec. 2015



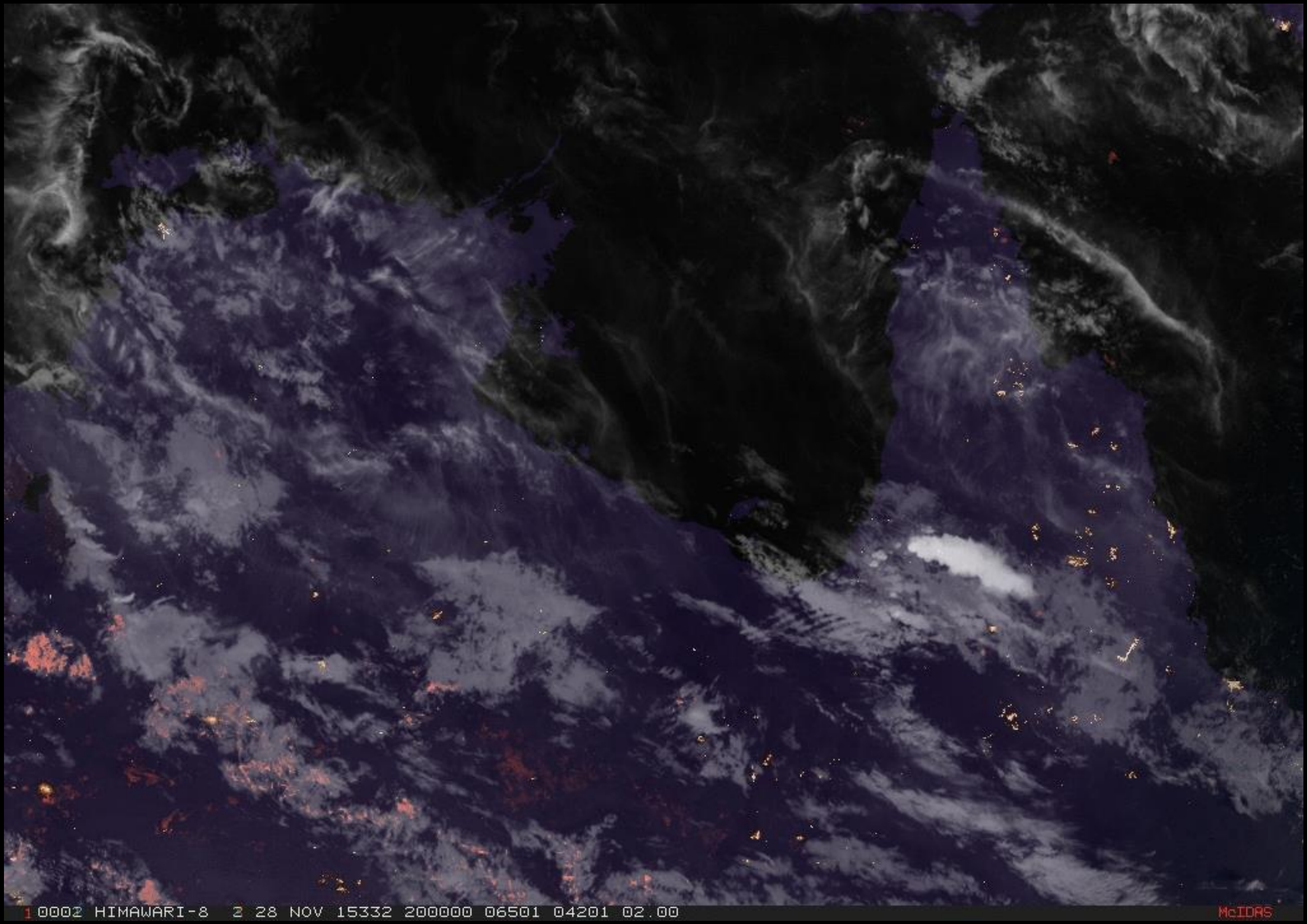
True color/Geocolor showing a 928 mb low in the north Pacific – 12 Dec. 2015



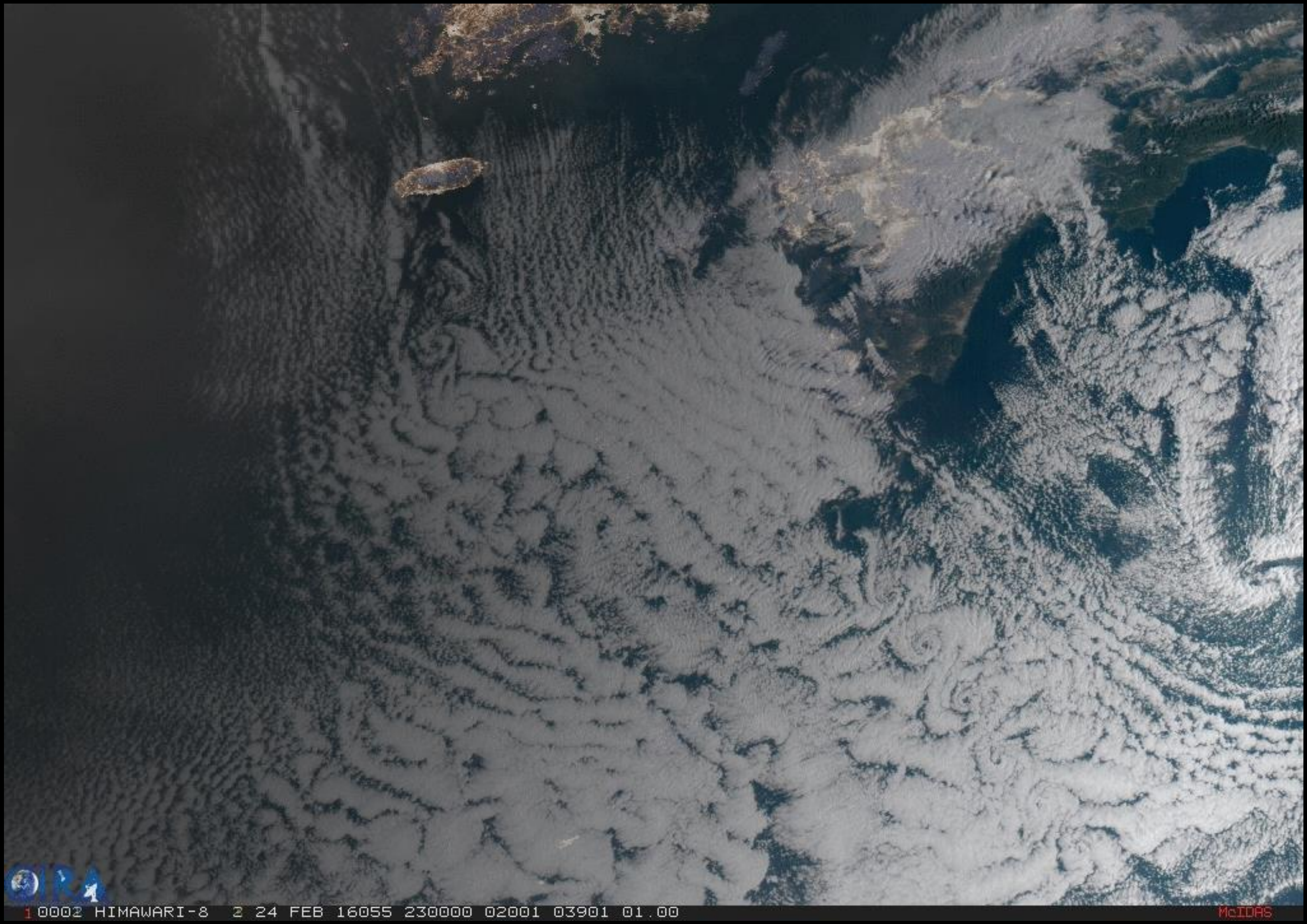
True color/Geocolor illustrating gap flow over Japan – 17 Dec. 2015



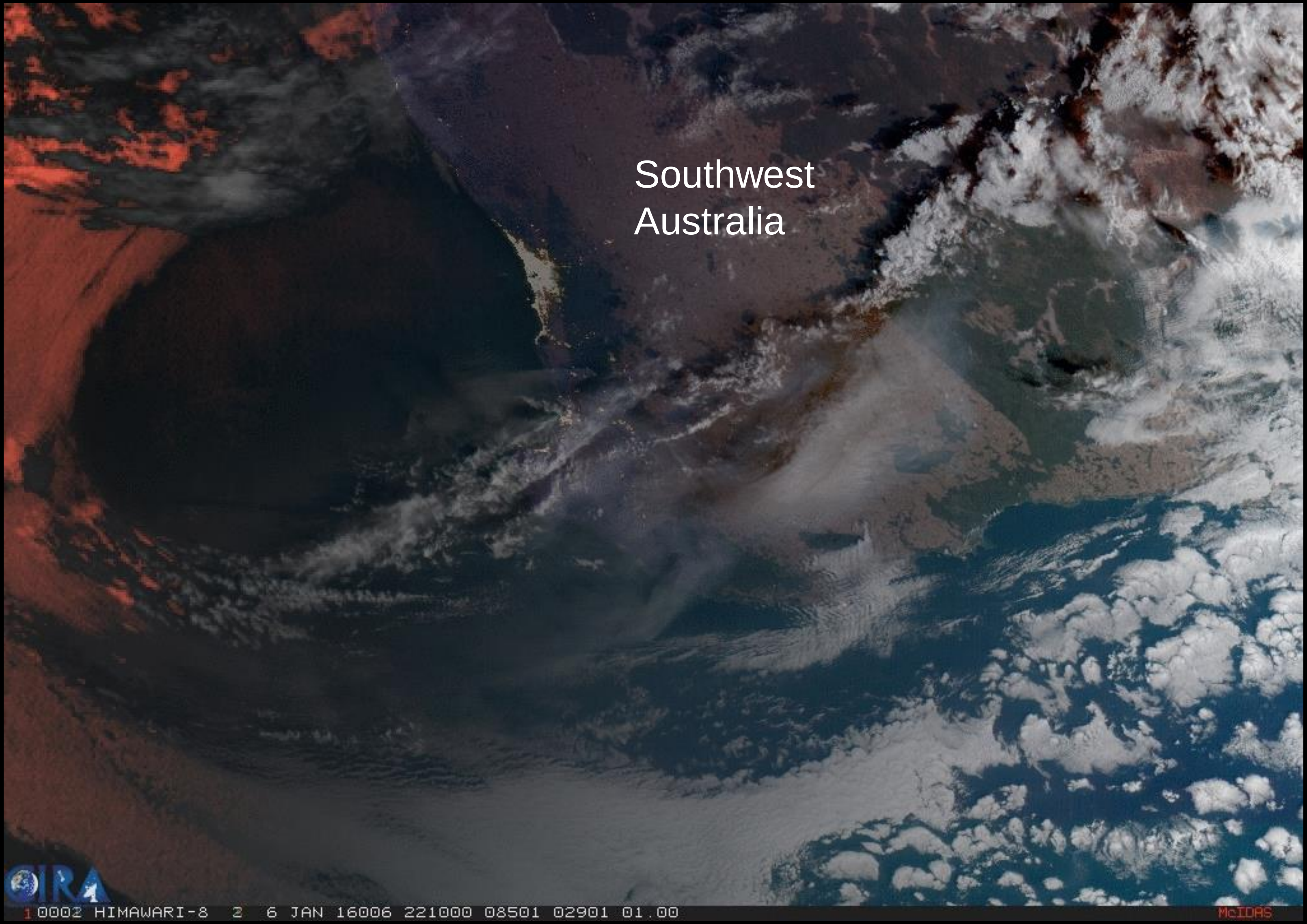
True color/Geocolor - Convection over northern Australia – 28 Nov. 2015



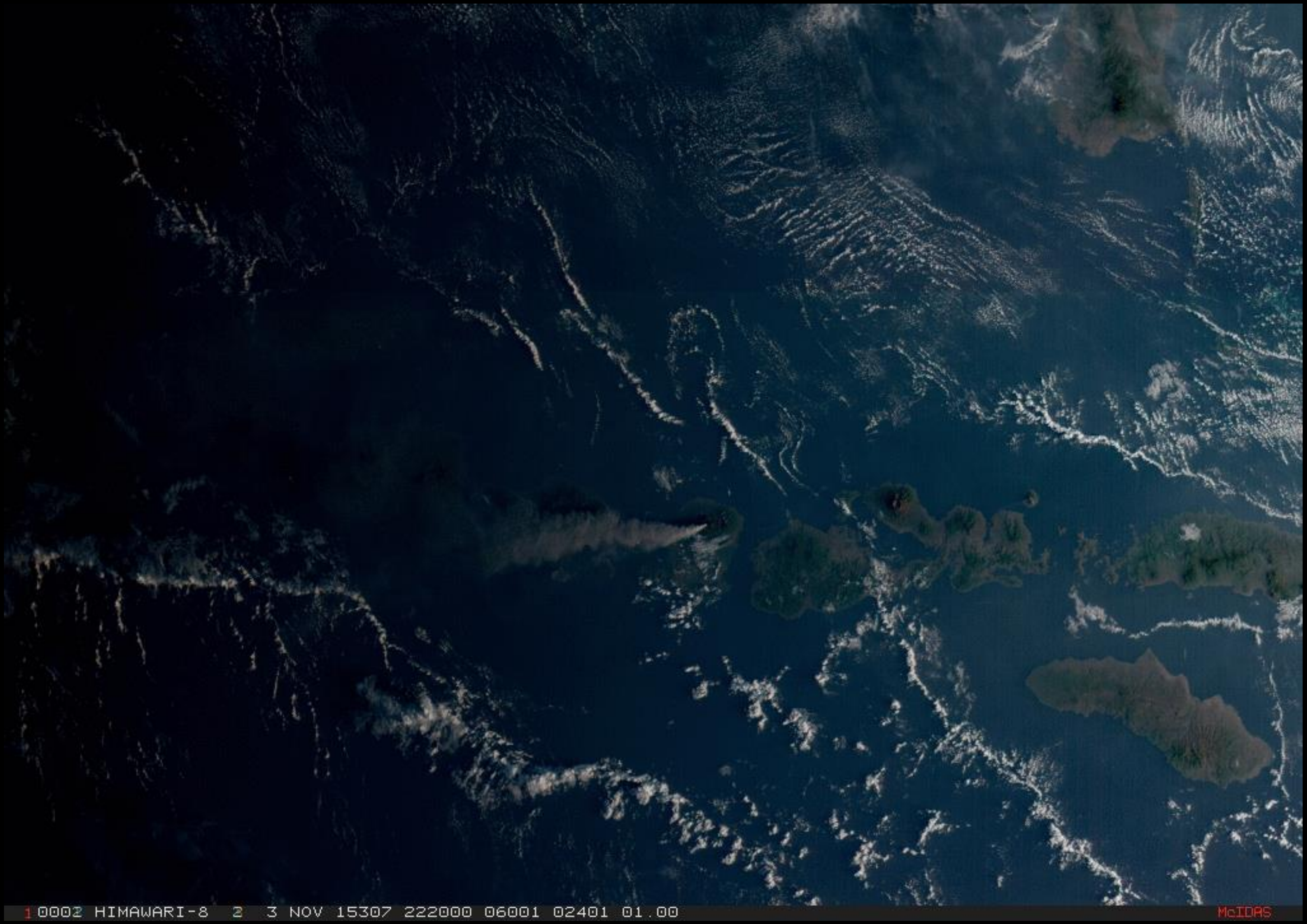
True color – Von Karman vortices south of Japan – 24 Feb. 2016



Forest Fires in Southwest Australia 6 January 2015

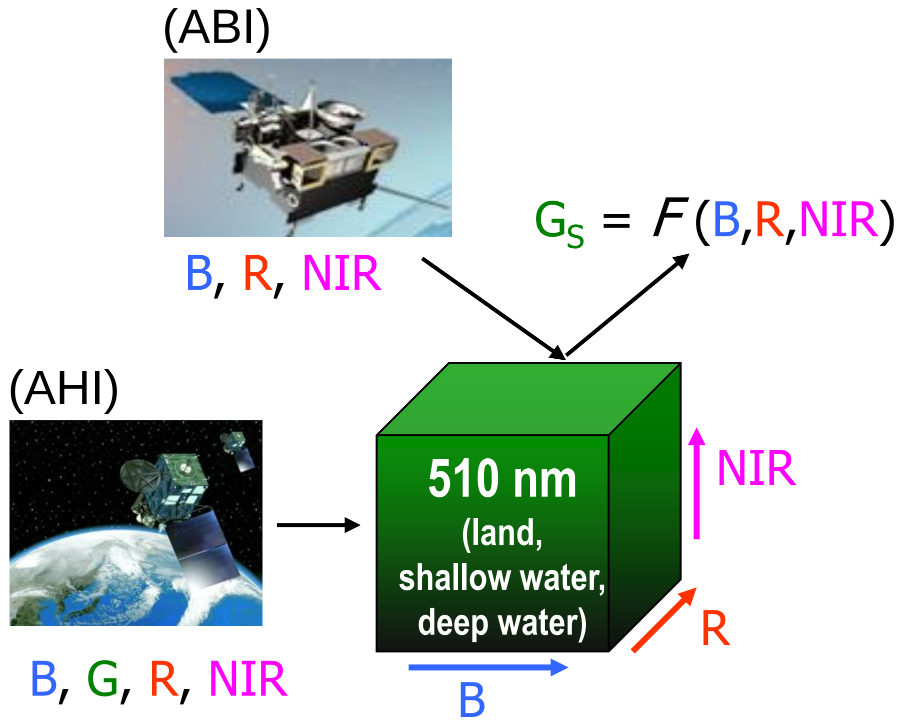


Mount Rinjani Volcano, Indonesia, 4 Nov. 2015



A Synthetic Green Solution for GOES-R

GOES-R ABI has no green band—in order to enable true color imagery, we must approximate it via correlations with other available bands. We are using Himawari-8 AHI to help define this relationship:



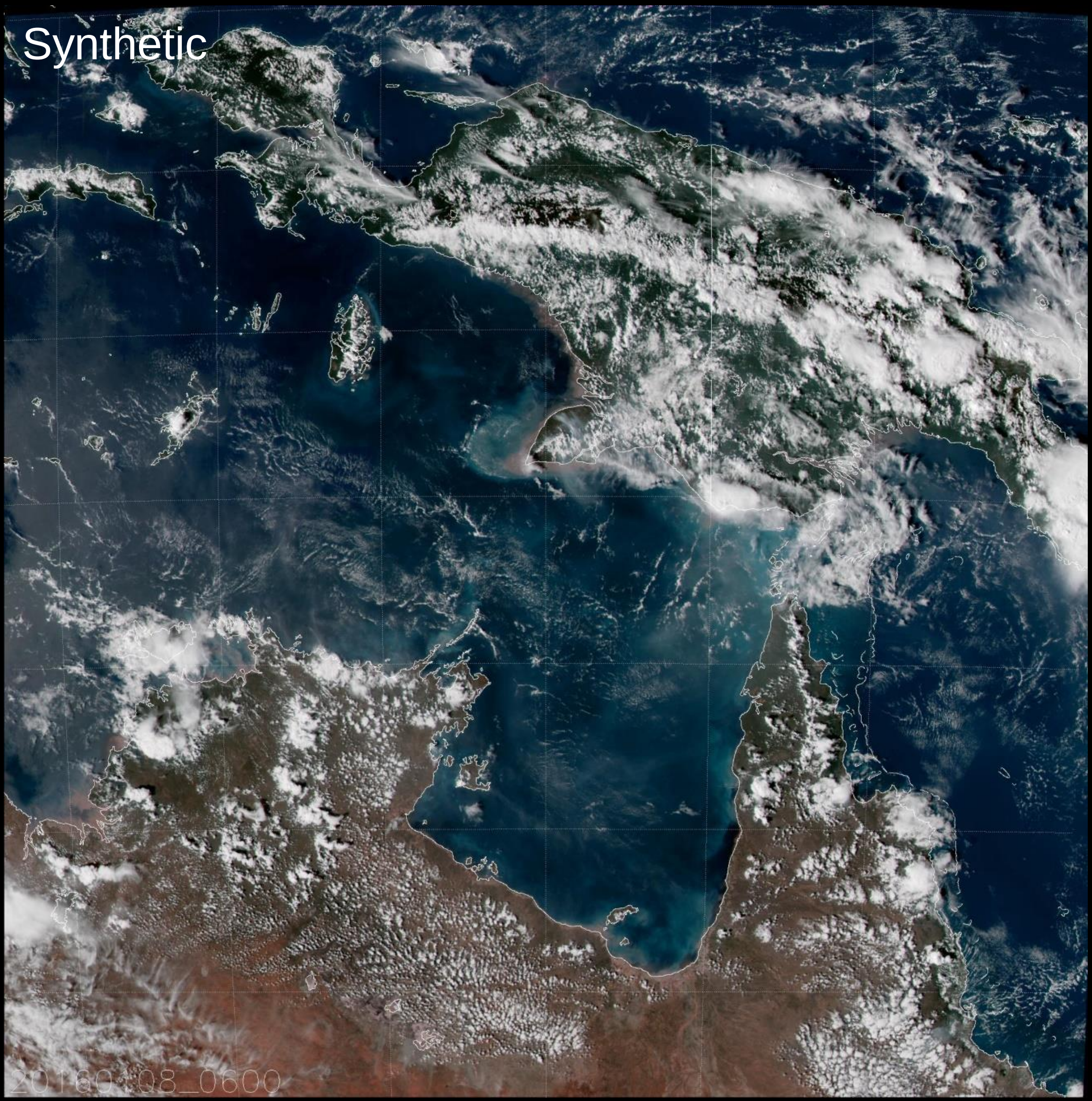
The look-up table (LUT) is built from many representative scenes. Multiple entries to a given index are averaged.

For GOES-R ABI, we will first construct G_S (510 nm), then compute $G_{H,S}$ via:

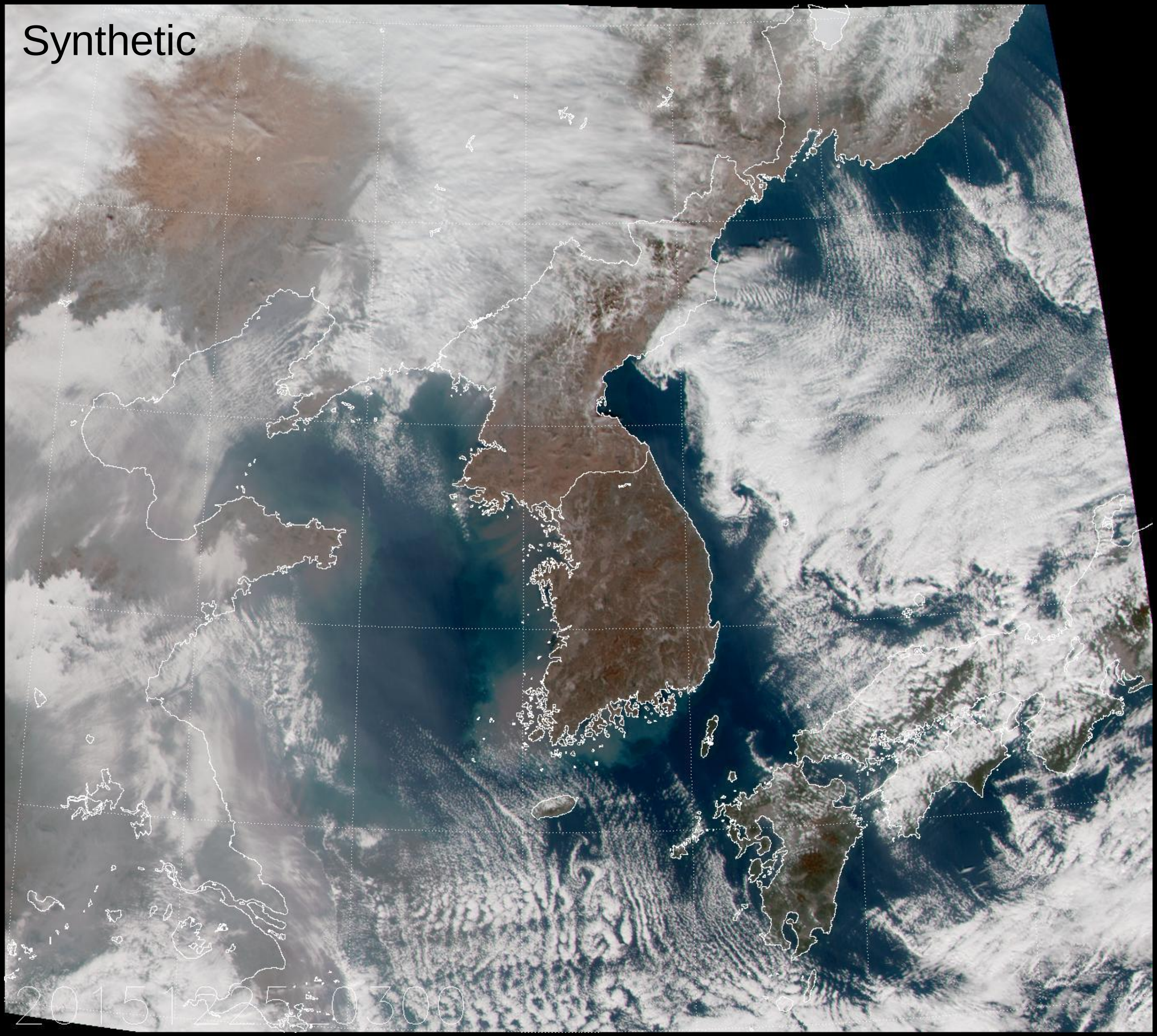
$$G_{H,S} = (1-F)*G_S + F*R_{856} \quad , F = 0.07$$

Miller, S. D., et al., 2012, *Int. J. Rem. Sens*., **33**(13), 3999-4028.

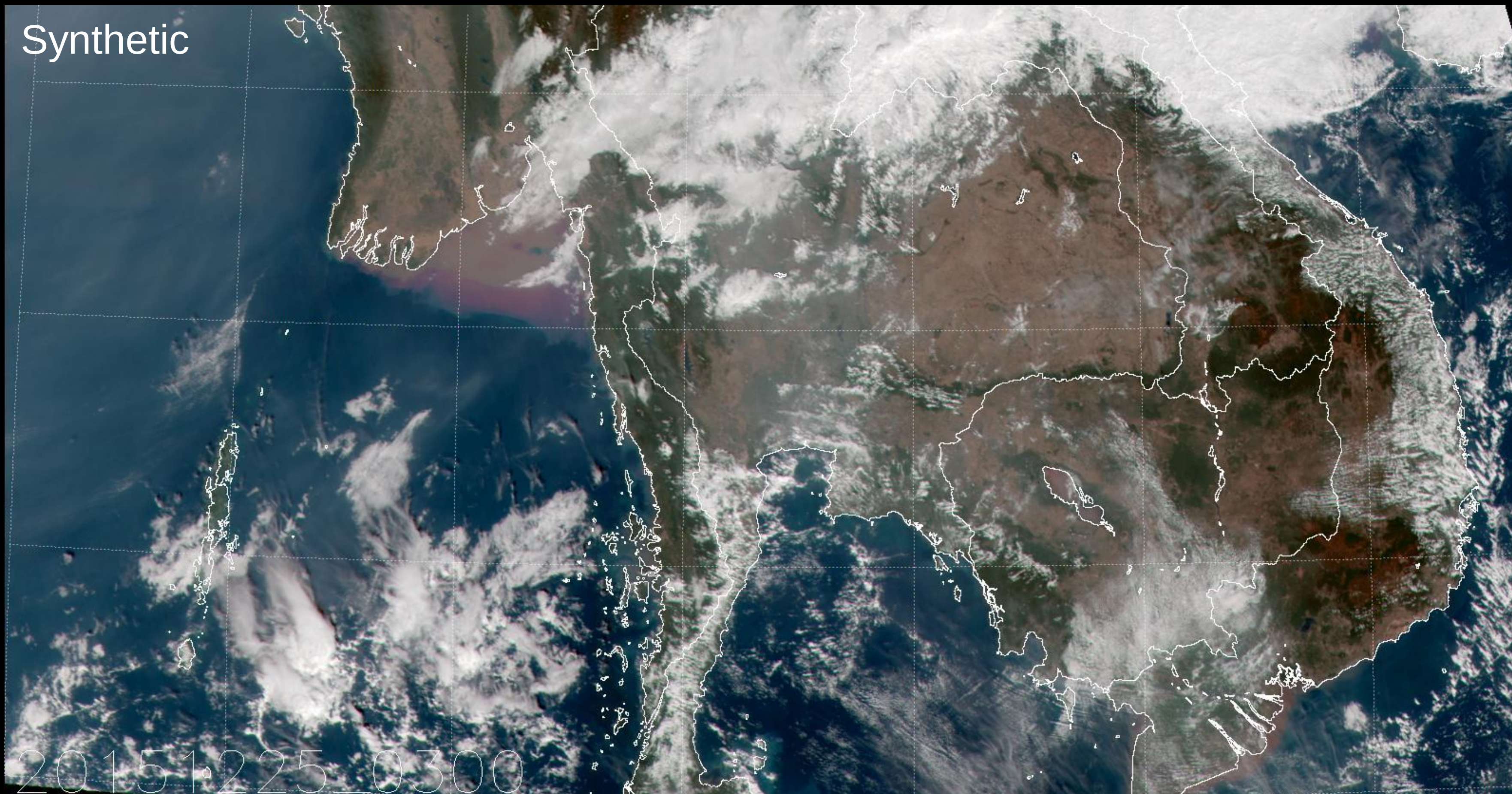
Timor Sea



Korean Peninsula



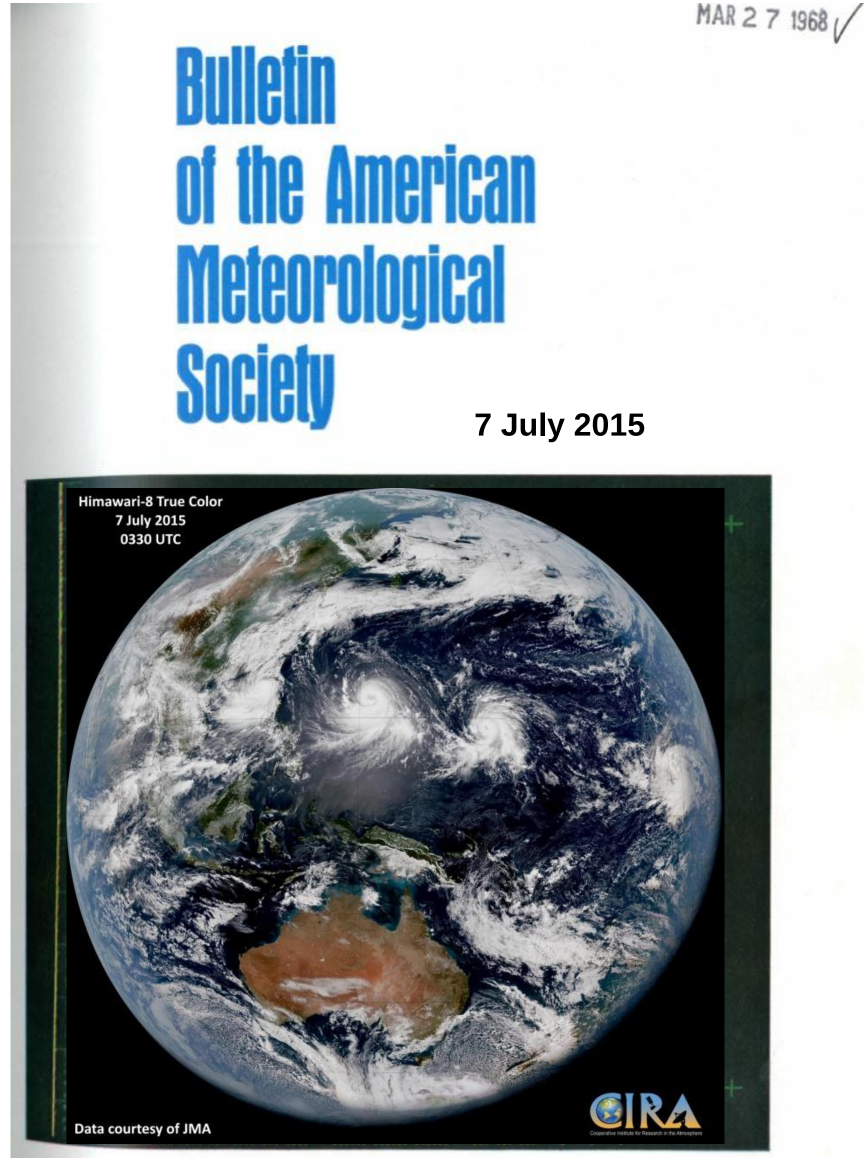
Thailand



→ 'Bright water' features present the greatest challenge. Work to refine the Synthetic Green LUT as a function of surface type, season, etc., is ongoing.

True Color Wrap-up

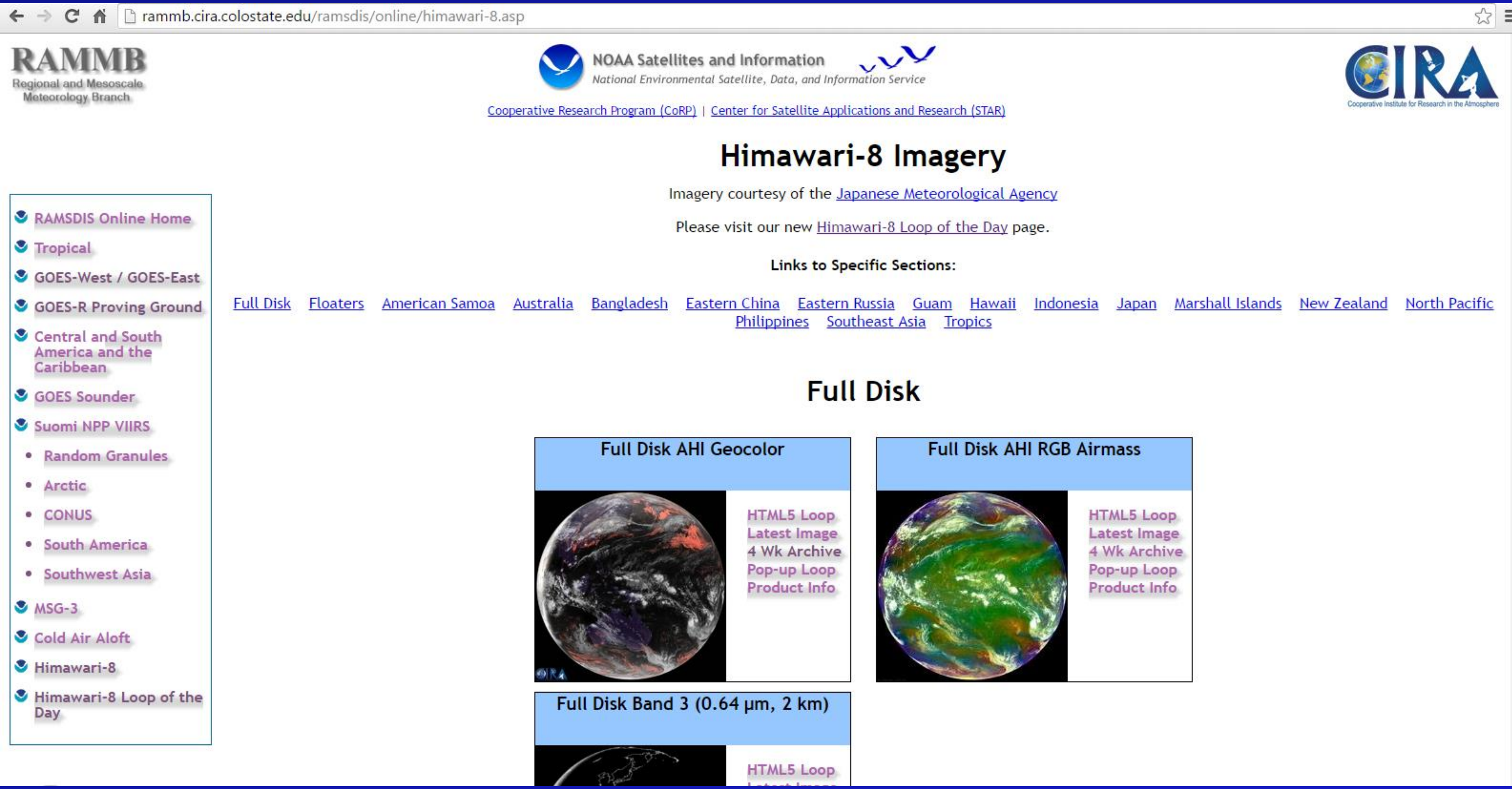
- Himawari-8 AHI provides a useful proxy to GOES-R ABI for true color development.
- The unanticipated 510 nm green band issue has been addressed via a Hybrid Green approach, enlisting the 865 nm ‘veggie band.’
- Synthesis of the 510 nm band via correlation look-up-tables shows promising early results.
- Goal is to hit the ground running with high-quality true color imagery for first-light GOES-R ABI.



Miller, S. D., et al., 2016, A Sight for Sore Eyes: the Return of True Color to Geostationary Satellites. *Bull. Amer. Meteorol. Soc.,* in press. http://journals.ametsoc.org/doi/abs/10.1175/BAMS-D-15-00154.1

Real-time Himawari Imagery

http://rammb.cira.colostate.edu/ramsdis/online/himawari-8.asp



Himawari Loop of the Day

http://rammb.cira.colostate.edu/ramsdis/online/loop_of_the_day/

rammb.cira.colostate.edu/ramsdis/online/loop_of_the_day/

RAMMB
Regional and Mesoscale Meteorology Branch

NOAA Satellites and Information
National Environmental Satellite, Data, and Information Service

Cooperative Research Program (CoRP) | Center for Satellite Applications and Research (STAR)

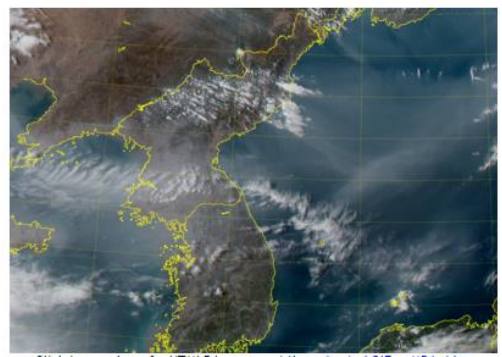
CIRA
Cooperative Institute for Research in the Atmosphere

- RAMSDIS Online Home
- Tropical
- GOES-West / GOES-East
- GOES-R Proving Ground
- Central and South America and the Caribbean
- GOES Sounder
- Suomi NPP VIIRS
  - Random Granules
  - Arctic
  - CONUS
  - South America
  - Southwest Asia
- MSG-3
- Cold Air Aloft
- Himawari-8
- Himawari-8 Loop of the Day

Himawari-8 Loop of the Day

Latest Loop

2016/04/05 - Smog over Korea - Geocolor



Click image above for HTML5 loop, or get the animated GIF or MP4 video

Archive

- 2016/04/04 - Cloud waves near Kamchatka Peninsula in Rapid Scan - Band 3 HTML5 Loop | Animated GIF | MP4 Video
- 2016/04/03 - Fires in Laos - Fire Temperature RGB HTML5 Loop | Animated GIF | MP4 Video
- 2016/04/02 - Low Clouds, Snow and Ice on the coast of Kamchatka Peninsula - Natural Color RGB HTML5 Loop | Animated GIF | MP4 Video
- 2016/04/01 - Northeast India Storms - Band 3 Visible HTML5 Loop | Animated GIF | MP4 Video
- 2016/03/31 - Strong storms in Bangladesh - Band 3 Visible HTML5 Loop | Animated GIF | MP4 Video
- 2016/03/30 - Convection over New Guinea - Geocolor HTML5 Loop | Animated GIF | MP4 Video

Conclusions/Recommendations

- Himawari-8 has provided the opportunity to work with data that is quite similar to what the GOES-R ABI will provide starting in less than 1 year
- A big thanks to JMA for providing a data feed to NOAA!
- Improved temporal, spatial, and spectral resolution allows for significant improvements in the detection and monitoring of many phenomena, including convection
- True color imagery provides more operational value than just “pretty pictures”
- It helps with the intuitive detection and tracking of features that have unique colors, such as blowing dust, smoke, and volcanic ash
- Rayleigh correction significant improves the clarity of the visible bands, and is highly recommend for other satellite sensors (e.g., MTG’s imager)
- Perhaps these corrections might improve some quantitative products that make use of the reflective bands