GOES-R Series Virtual Course – Multispectral (RGB) Composites

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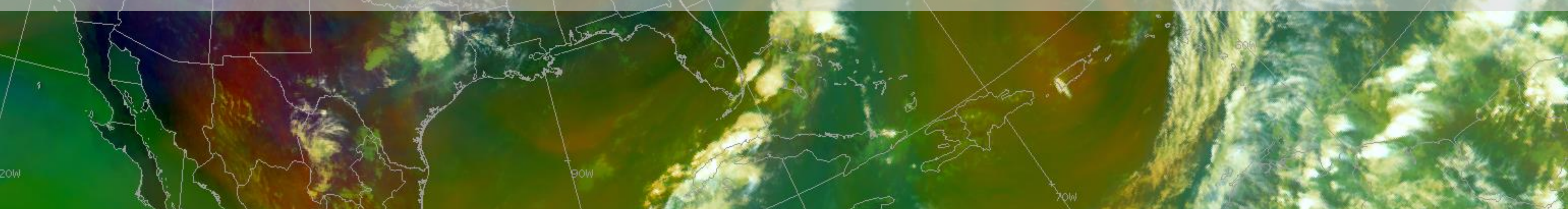
University of Maryland, ESSIC, CICS

November 1, 2017



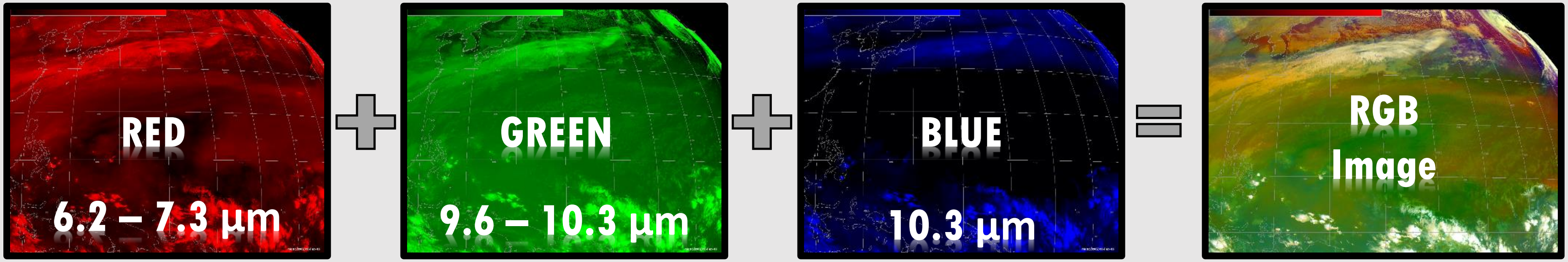
Lesson Objectives

- **Introduce** the concept of RGB imagery
  - What is RGB imagery
  - How is RGB imagery created
  - RGBs and Next Generation Imagers
  - RGBs in the GOES-R Proving Ground

- GOES-16 ABI RGB application **Examples**
  - Dust RGB
  - Night-time Microphysics RGB
  - Air Mass RGB

- Provide a list of **Resources** and papers to learn more about RGB imagery

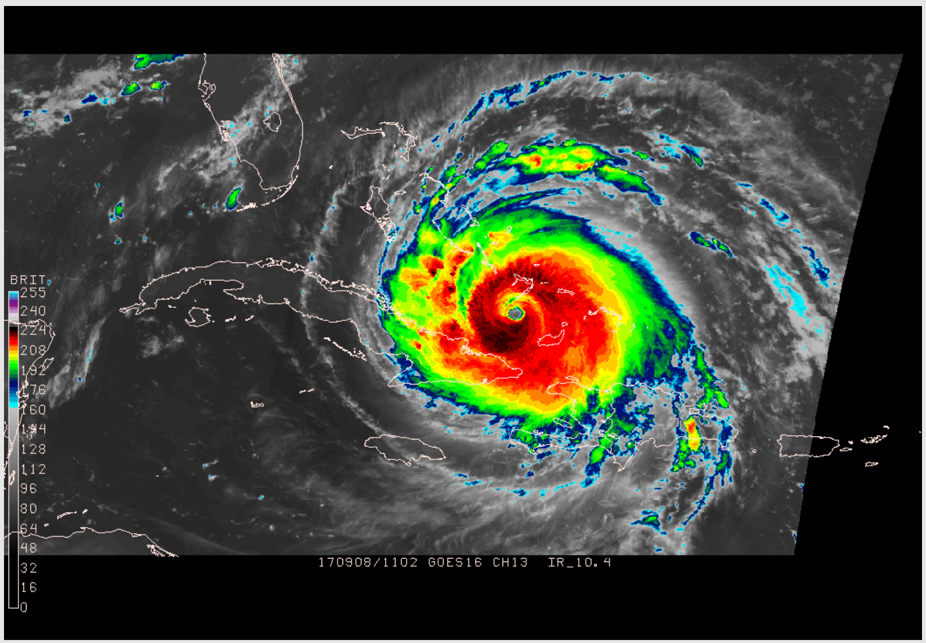
What is an RGB?



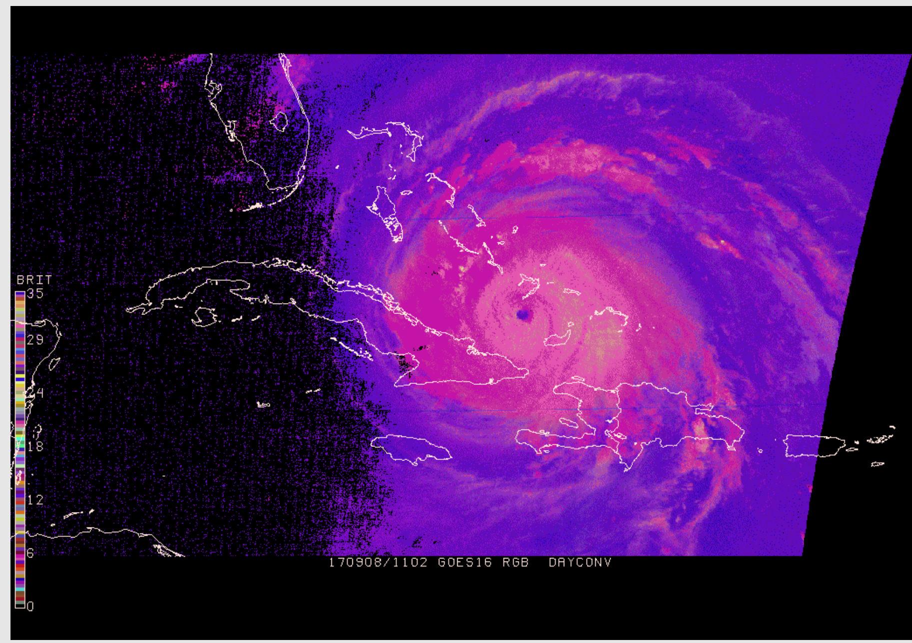
- Multispectral or Red-Green-Blue (i.e. RGB) Composites are qualitative, false color images designed to enhance a specific feature
    - Low clouds and fog
    - Dust
    - Convection
    - Air Mass characteristics
    - Fire Hot Spots
    - Snow/Ice
    - Cloud Phase
    - Volcanic Ash
- The 24-bit false color image is created by combining band or band differences into each of the Red, Green, and Blue components with a defined recipe
- The advantage of RGB products is the ability to look at a single image to identify a feature instead of analyzing multiple single channels

Day Convection RGB: Hurricane Irma (‘17)

GOES-16 10.3µm “Clean” Infrared

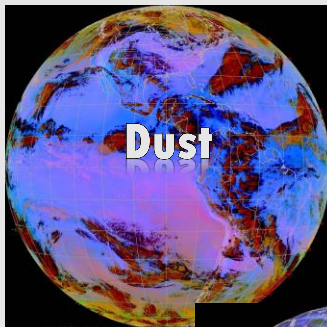


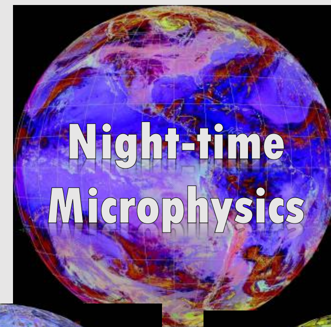
GOES-16 Day Convection RGB

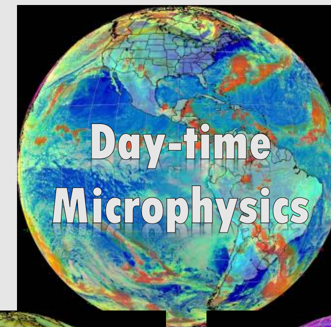


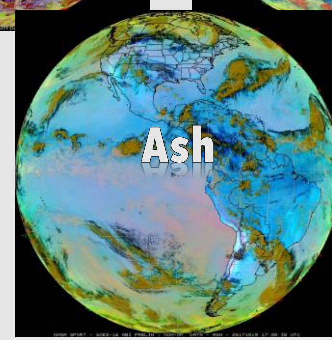
How are RGBs Created?

- In the early 2000s, EUMETSAT developed a set of RGB recipes or best practices following the launch of Meteosat Second Generation with the SEVIRI instrument aboard.







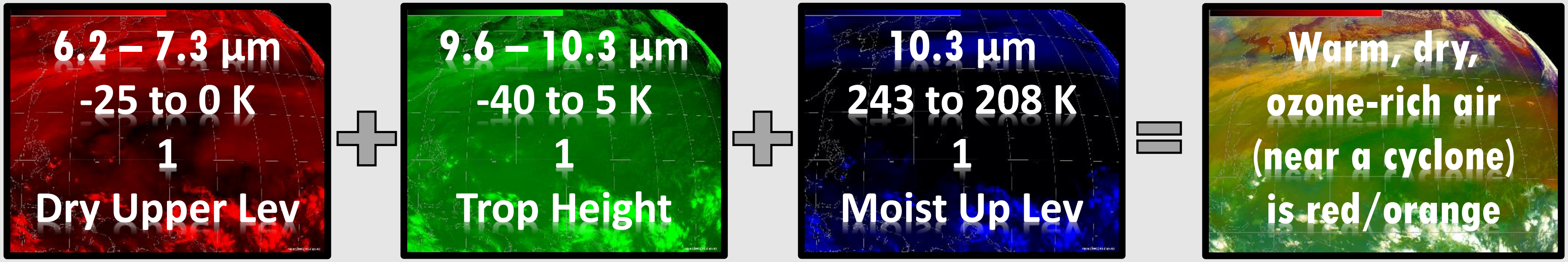


- This equation is used for the byte value conversion to store color intensity for each component over 8 bits (values of 0-255)

$$(R,G,B) = 255 * \left[\frac{(TB, \Delta TB, R, \Delta R) - MIN}{MAX - MIN}\right]^{\left(\frac{1}{\gamma R,G,B}\right)}$$

TB = Brightness Temperature
ΔTB = Brightness Temperature Difference
R = Reflectance
ΔR – Reflectance Difference
γ = Gamma Enhancement

Air Mass RGB Example



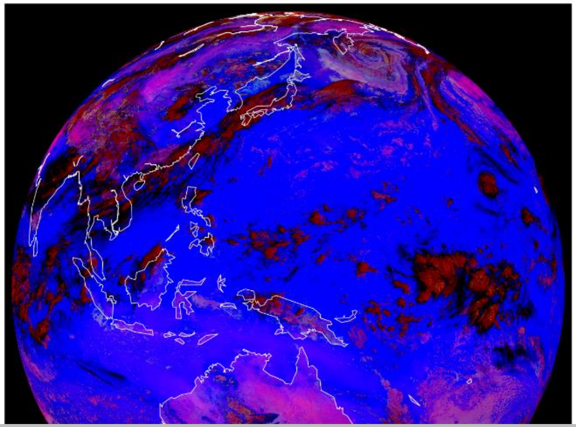
- The minimum/maximum thresholds and gamma stretching are used to focus on and enhance the color of features of interest.

- Most RGBs have a gamma=1 meaning there is linear spreading of values and constant contrast between the min/max.
  - Gamma > 1 enhances lower portion of the range
  - Gamma < 1 enhances upper portion of the range

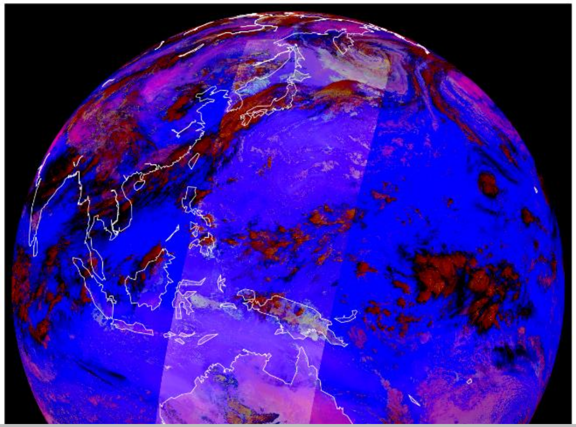
- The component can be inverted, meaning the features with cold brightness temperatures or lower reflectance have more color intensity instead of less.

RGBs and Next-Generation Imagers

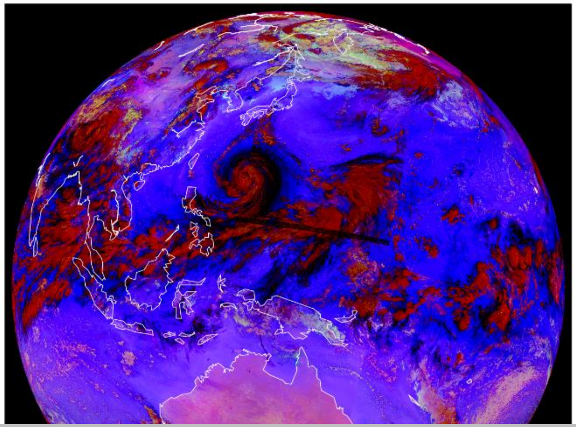
- Can I directly apply EUMETSAT recipes to Himawari-8 AHI or GOES-16 ABI?
- Recipes need to be adjusted to retain legacy coloring due to differing spectral characteristics between SEVIRI and AHI/ABI



Night-time Microphysics EUMETSAT Recipe No Adjustment



Night-time Microphysics EUMETSAT Recipe + VIIRS as SEVIRI Proxy



Night-time Microphysics Adjusted Recipe + VIIRS as SEVIRI Proxy

Berndt, E. B., N. J. Elmer, L. A. Schultz, and A. L. Molthan, 2017: A Methodology to Determine Recipe Adjustments for Multispectral Composites Derived from Next-Generation Advanced Satellite Imagers, *Journal of Atmos. And Oceanic Technology, in revision.*

Shimizu, A., 2015: Introduction of JMA VLab Support Site on RGB Composite Imagery and tentative RGBs. The 6th Asia/Oceania Meteorological Satellite Users' Conference, Tokyo, Japan, 9-13 November. [Available online at http://www.data.jma.go.jp/mscweb/en/aomsuc6_data/presentations.html].

Poll Question #1

Multispectral or Red-Green-Blue (i.e. RGB) Composites are quantitative, false color images designed to enhance a specific feature or meteorological phenomena

A. True

B. False

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A. True

B. False

Multispectral or Red-Green-Blue (i.e. RGB) Composites are **qualitative**, false color images designed to enhance a specific feature or meteorological phenomena

RGBs in the GOES-16 Proving Ground

- SPoRT has worked with the GOES-R/JPSS Proving Grounds to prepare forecasters for the GOES-R era by creating RGB products with instruments onboard polar-orbiting and geostationary satellites

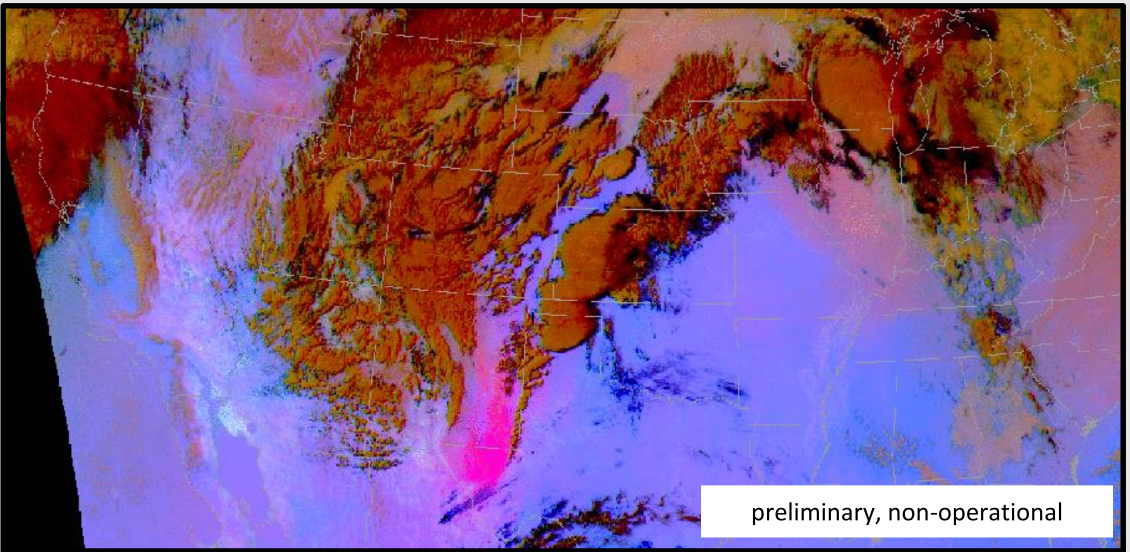
- RGBs have been successfully integrated into operations in numerous WFOs and National Centers before the launch of GOES-16

- Forecasters have expressed they are prepared to use the Dust, Air Mass, and Night-time Microphysics on Day 1!

- A subset of GOSE-16 RGBs available to NOAA NWS forecasters will be presented

Dust RGB

- **Primary Application:** Identification of dust both day/night
- **Secondary Applications:**
  - Moisture boundaries
  - Volcanic ash
  - Cloud height/type analysis



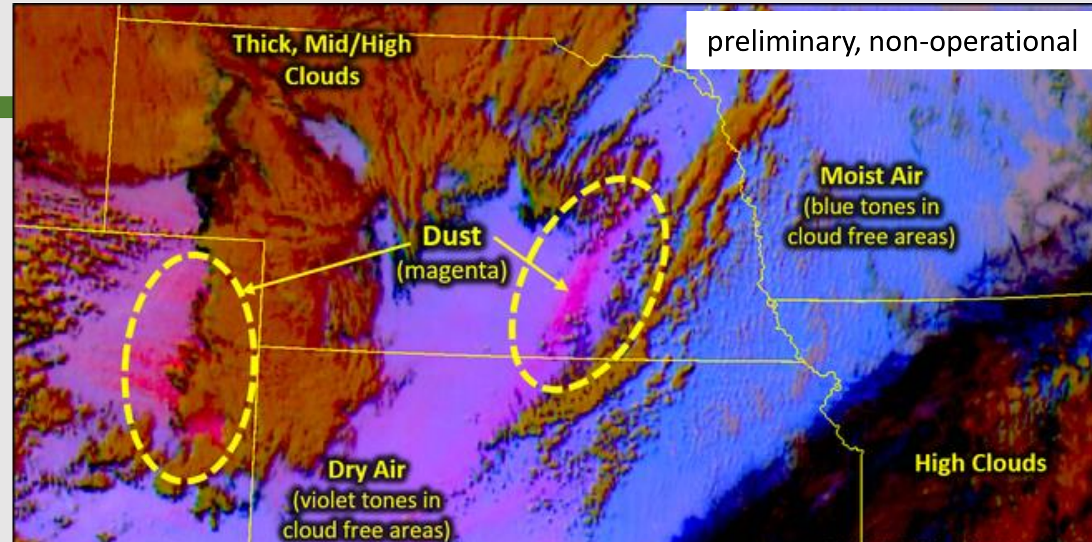
Dust RGB Imagery from 0002 to 0357 UTC, 23 March 2017 centered over western Texas. Blowing dust is colored in magenta.

- Dust RGB derived from MODIS/VIIRS has been extensively used at the Albuquerque WFO to prepare for GOES-16
  - Increased confidence in tracking dust day to night
  - Policy changes to allow blowing dust to impact TAF ceiling conditions
  - Now issue stand-alone blowing dust advisories and dust storm warnings
  - Improved decision support services to state officials to forewarn the public
  - Forecasters are ready for and prepared for RGBs in the GOES-R era

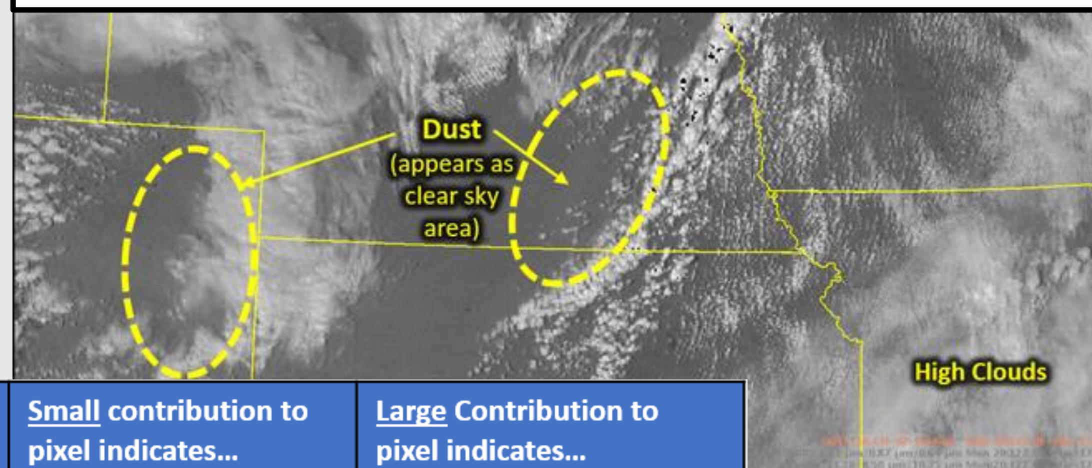
Fuell, K. K., B. J. Guyer, D. Kann, A. L. Molthan, and N. Elmer, 2016: Next generation satellite RGB dust imagery leads to operational changes at NWS Albuquerque. *J. Operational Meteor.*, **4**(6), 75–91.

Dust RGB

- Dust appears magenta
- Easy to distinguish from cloud and surface features
- Added value to single channel analysis

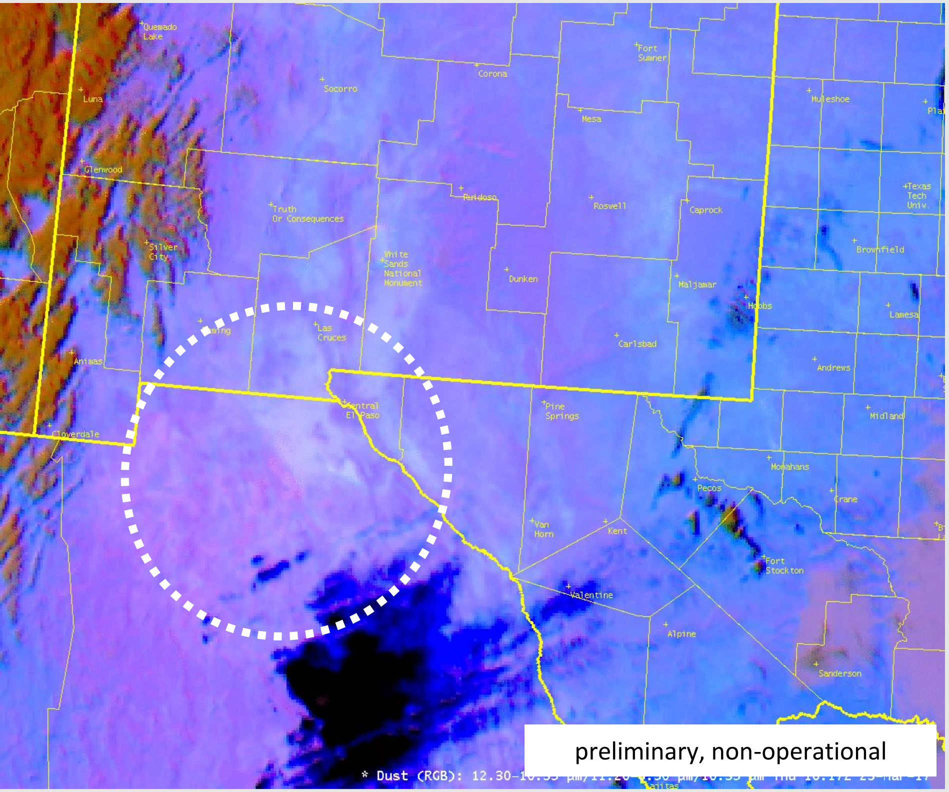


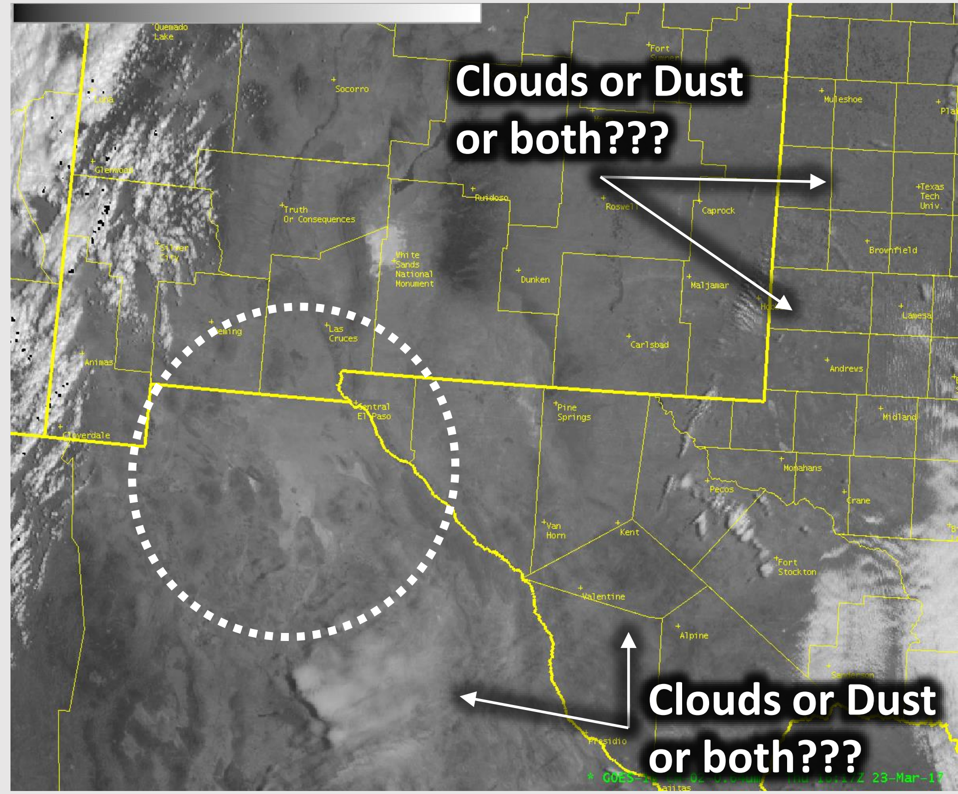
Dust RGB (above) and 0.64 µm imagery (below) from GOES-16 at 2012 UTC, 6 March 2017.



Color	Band / Band Diff. (µm)	Physically Relates to…	Small contribution to pixel indicates…	Large Contribution to pixel indicates…
Red	12.3-10.3	Optical depth as proxy to cloud thickness	Thin clouds	Thick clouds or dust
Green	11.2-8.4	Particle phase	Ice and particles of uniform shape (dust)	Water particles or thin cirrus over deserts
Blue	10.3	Surface temperature	Cold surface	Warm surface

Dust RGB: comparison to visible



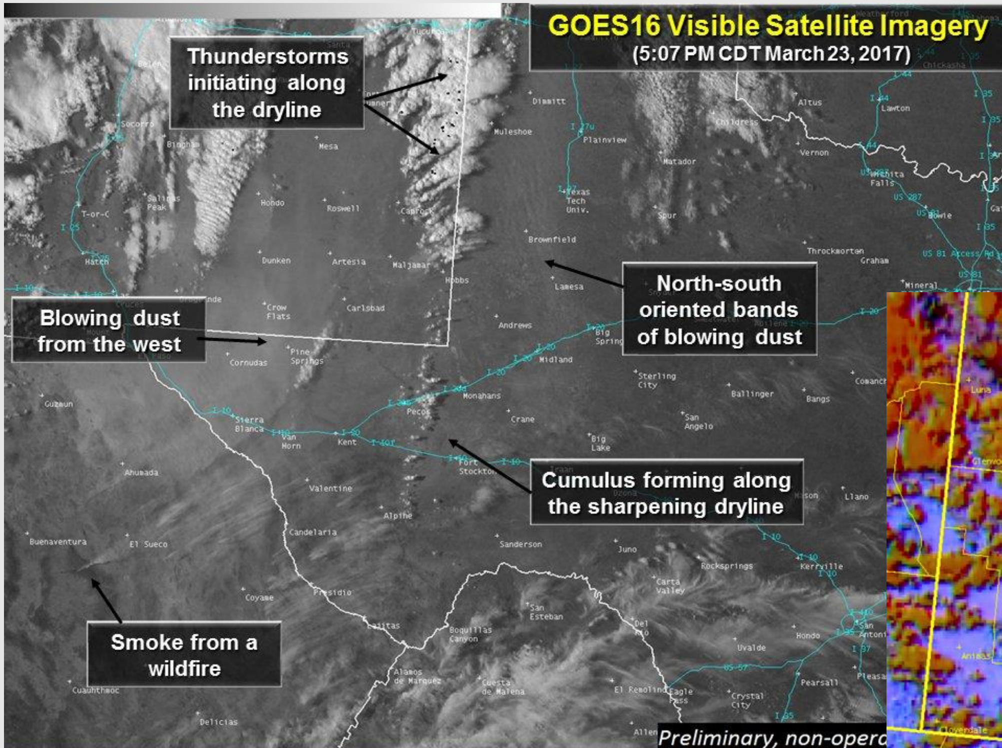


- Dust is readily apparent (dotted circles), early in loop of RGB, however the dust is much harder to observe in the visible imagery, even at end of loop
  IMPACT: RGB provides early detection/spatial extent of blowing dust

- Thin clouds have a similar appearance to dust, but RGB shows cloud types
  IMPACT: RGB differentiates thin clouds from dust for efficient analysis

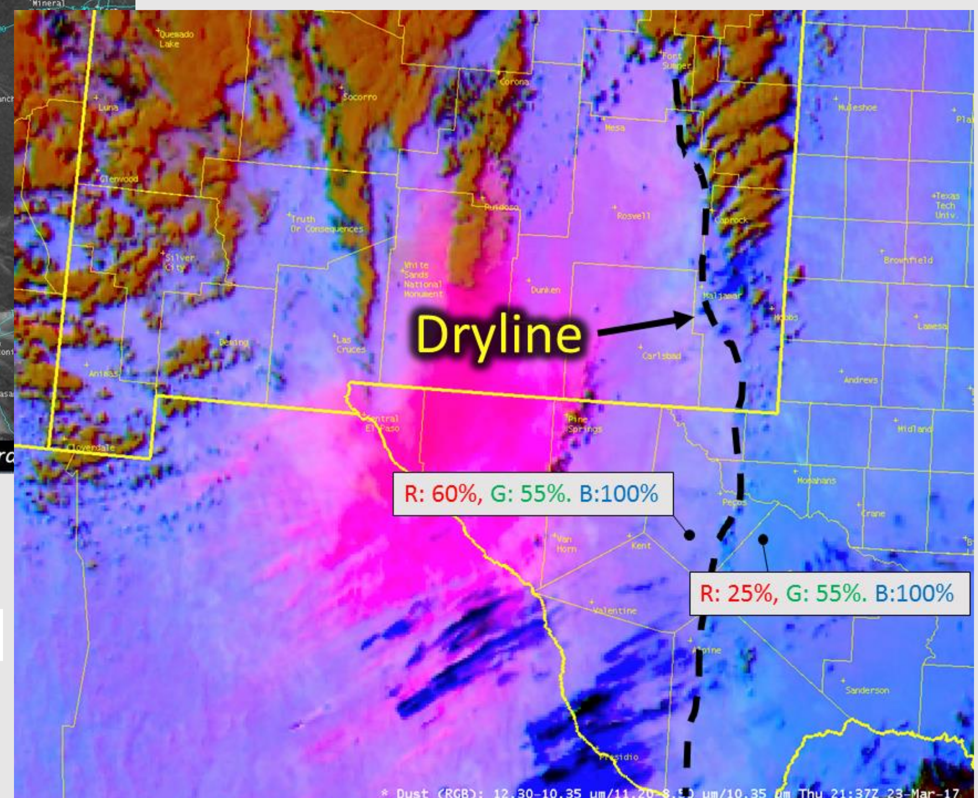
Dust RGB does more than dust!

- Identification of cloud types
- Analysis of dryline in cloud-free areas via influence of moisture on 12-10 µm difference used in red component.



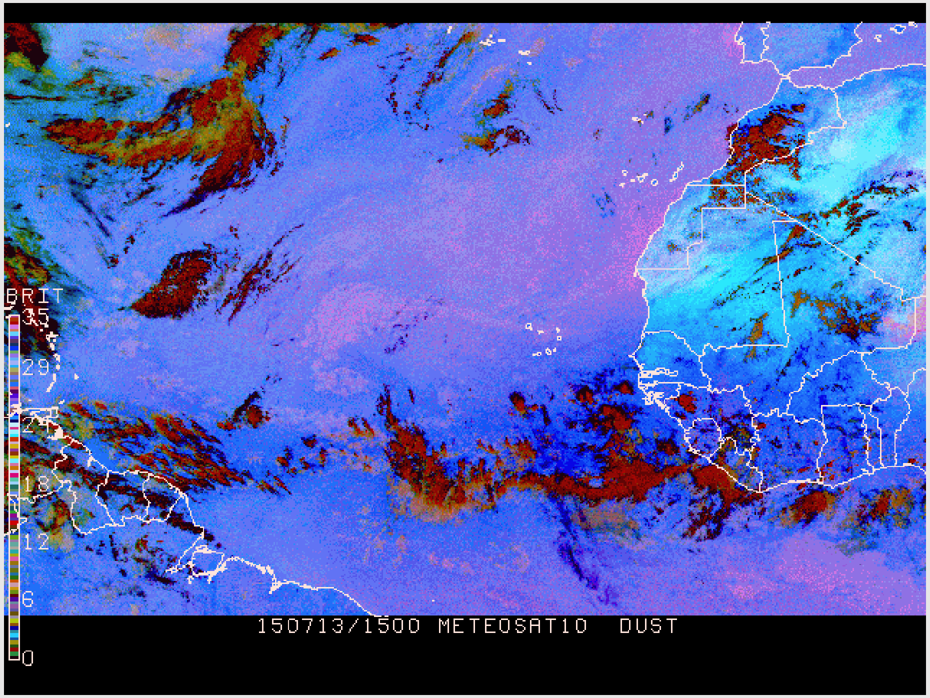
Midland WFO Twitter Image of Annotated Visible Imagery

preliminary, non-operational

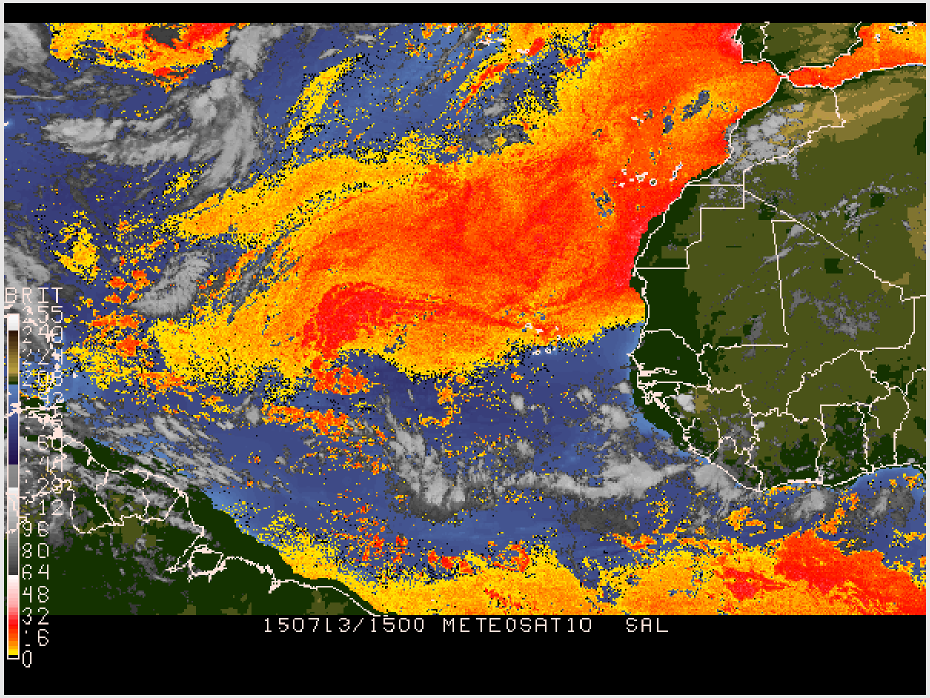


Dust RGB: Saharan Air Layer (July 2015)

Meteosat-10 Dust RGB



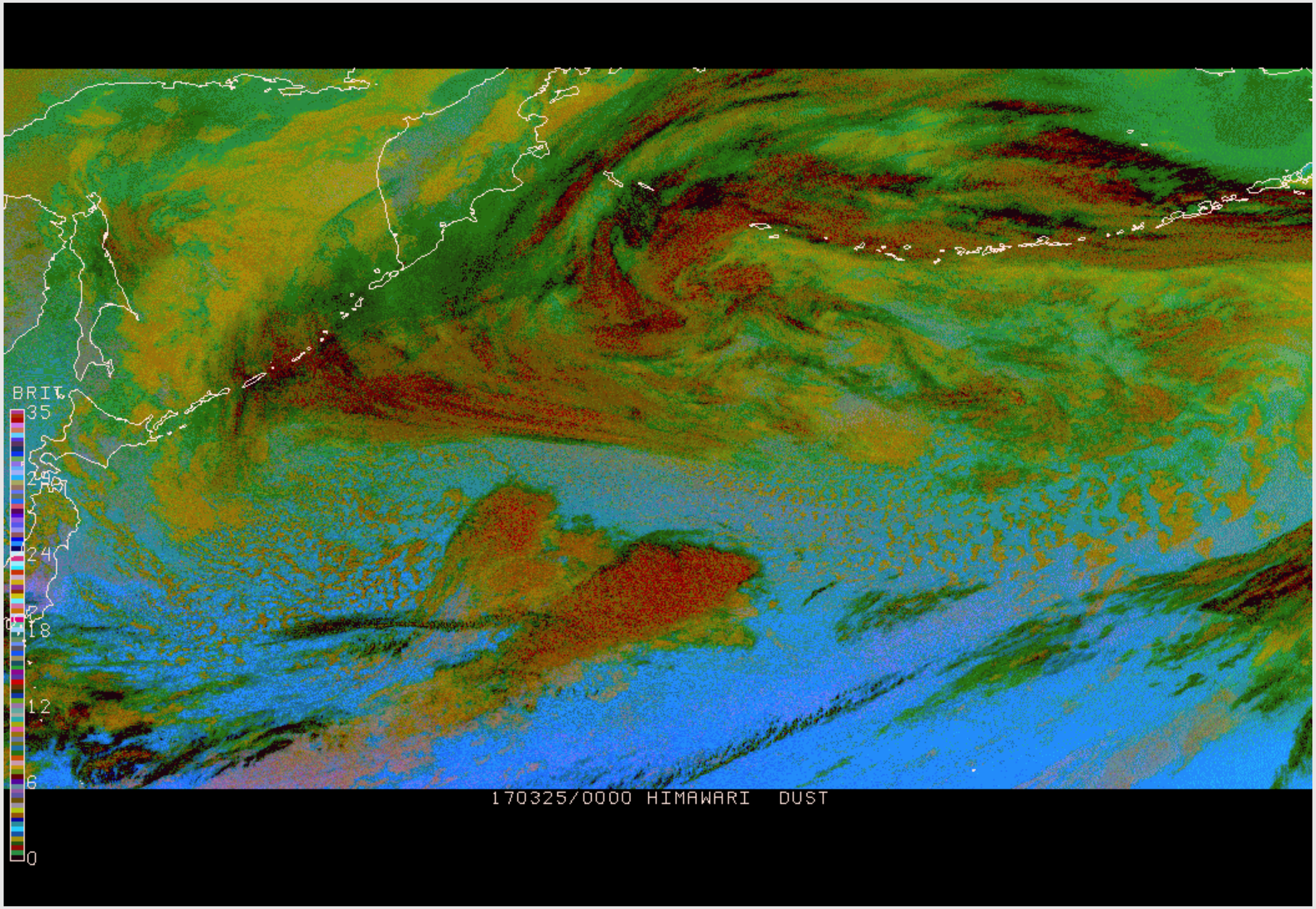
Meteosat-10
SAL Split-Window



Dust RGB: Volcanic Eruption

Himawari-8 Dust RGB

Kambalny Eruption (March 2017)



Poll Question #2

In the Dust RGB, dust is ___ color since the red component distinguishes dust from cirrus and the blue component identifies warm features. *(choose one)*

A. Mauve

B. Red

C. Magenta

D. Green

E. Blue

Poll Question #2

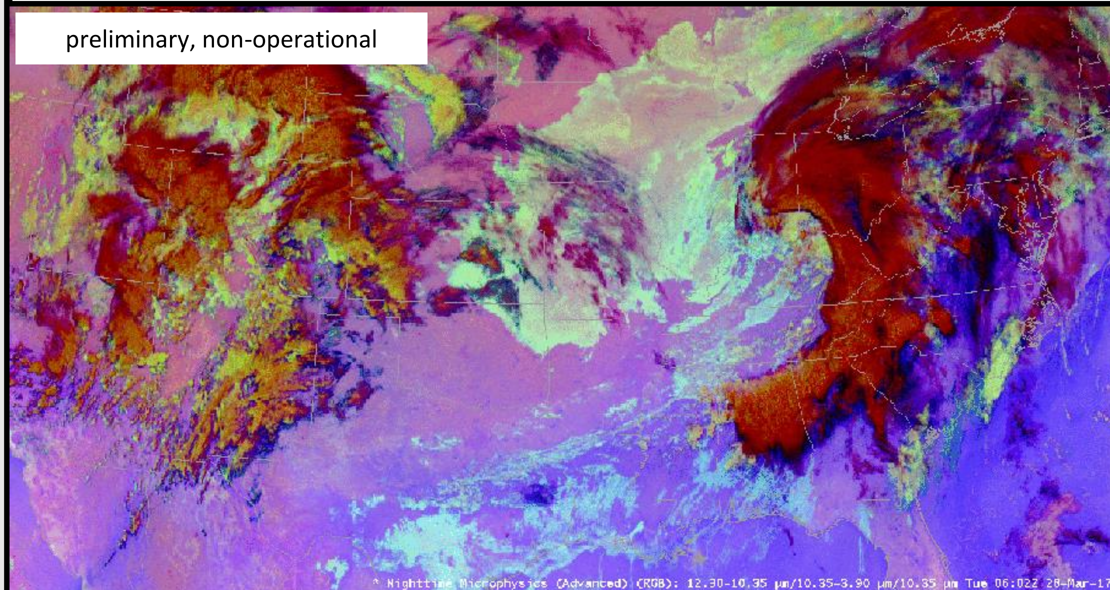
In the Dust RGB, dust is ___ color since the red component distinguishes dust from cirrus and the blue component identifies warm features. *(choose one)*

A. Mauve
B. Red
C. Magenta
D. Green
E. Blue

Night-time Microphysics RGB

- **Primary Application:** Low cloud and fog analysis
- **Secondary Applications:**
  - Cloud height/phase analysis
  - Moisture boundaries
  - Fire hot spots

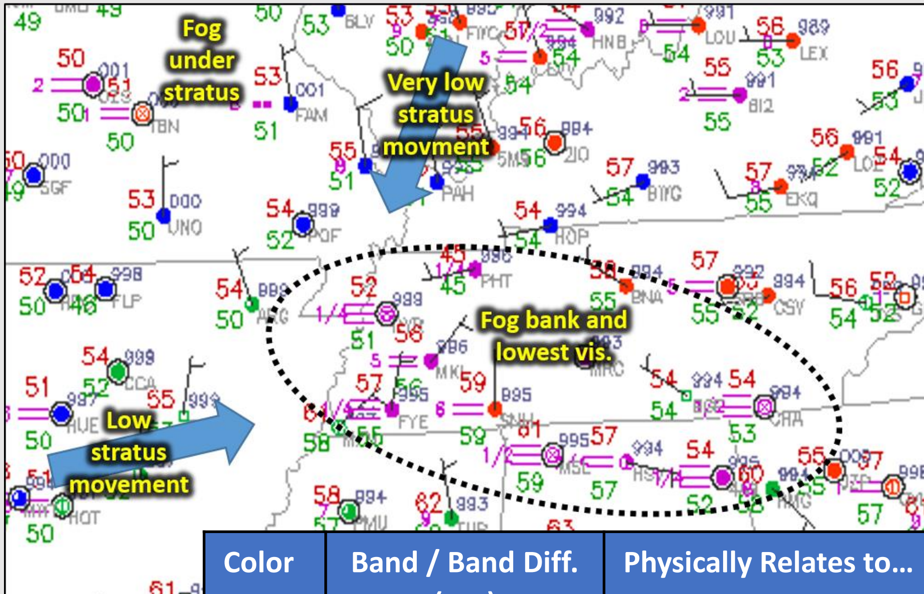
NtMicro RGB Imagery from GOES-16 at 0602 to 0957 UTC, 28 March 2017.

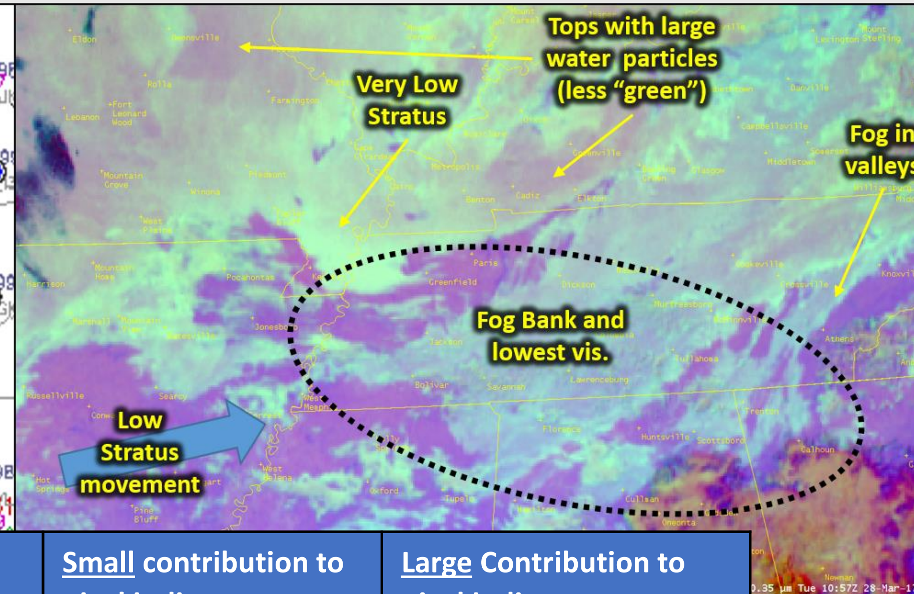


- NtMicro RGB derived from MODIS/VIIRS has been extensively evaluated and used at WFOs across the CONUS (and Alaska) to prepare for RGBs derived from GOES-16 ABI

“Raleigh, NC (RAH): “…the RGB product provided a much easier way to identify the location of the stratus vs. the traditional 11-3.9 product and based upon the shading it was apparent the clouds were high bases. Very Handy!”

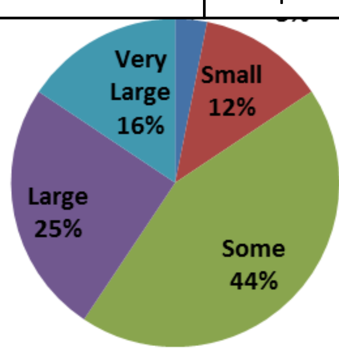
NtMicro RGB: Fog vs Low Clouds





Color	Band / Band Diff. (µm)	Physically Relates to…	Small contribution to pixel indicates…	Large Contribution to pixel indicates…
Red	12.4 – 10.4	Optical Depth	Thin clouds	Thick clouds
Green	10.4 – 3.9	Particle Phase and Size	Ice particles; surface (cloud free)	Water clouds with small particles
Blue	10.4	Temperature of surface	Cold Surface	Warm surface

preliminary, non-operational

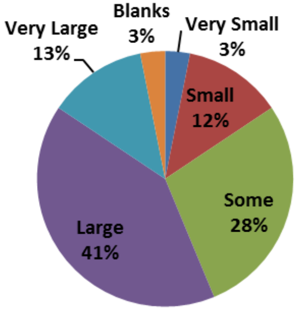


85% said some to very large impact to differentiate fog from low cloud

Forecaster feedback from VIIRS and MODIS Multispectral Imagery for Aviation Weather and Cloud Analysis at High Latitudes Assessment in 2014

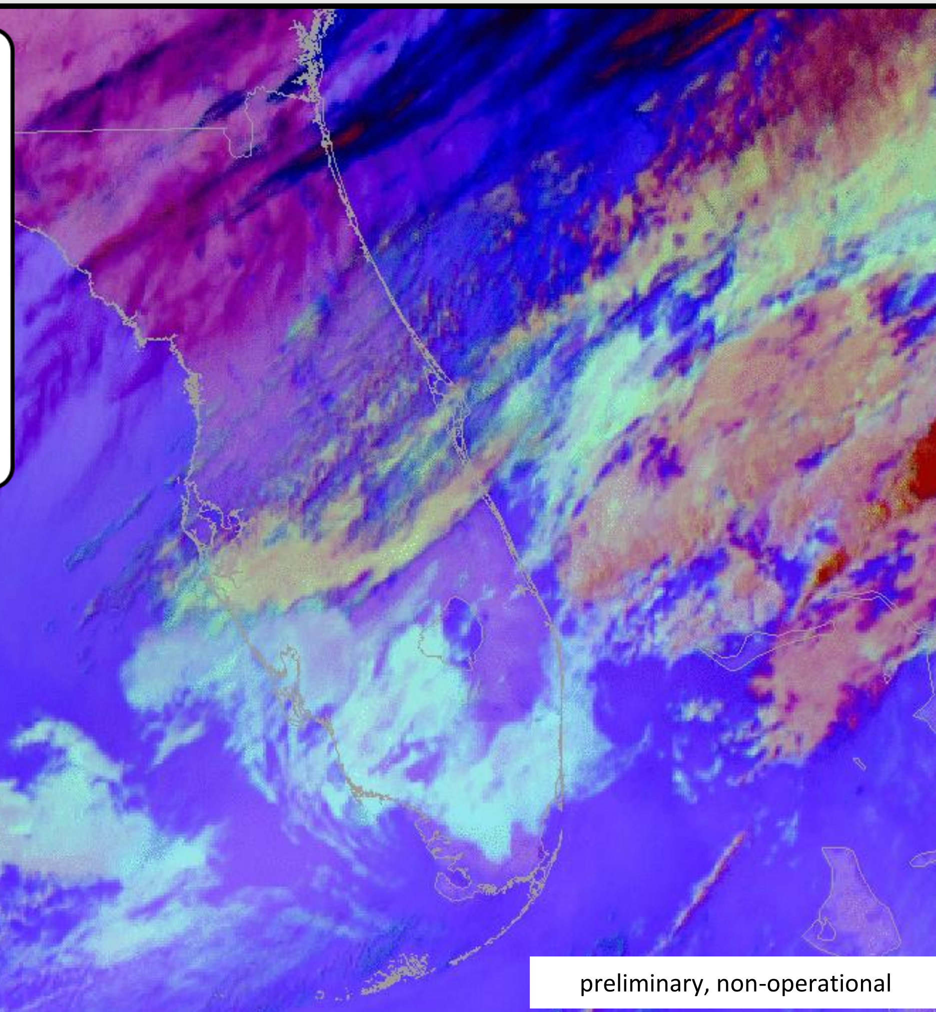
NtMicro RGB: Aviation Forecasts

Impact of NTmicro RGB to Aviation Forecast Issues (in general)



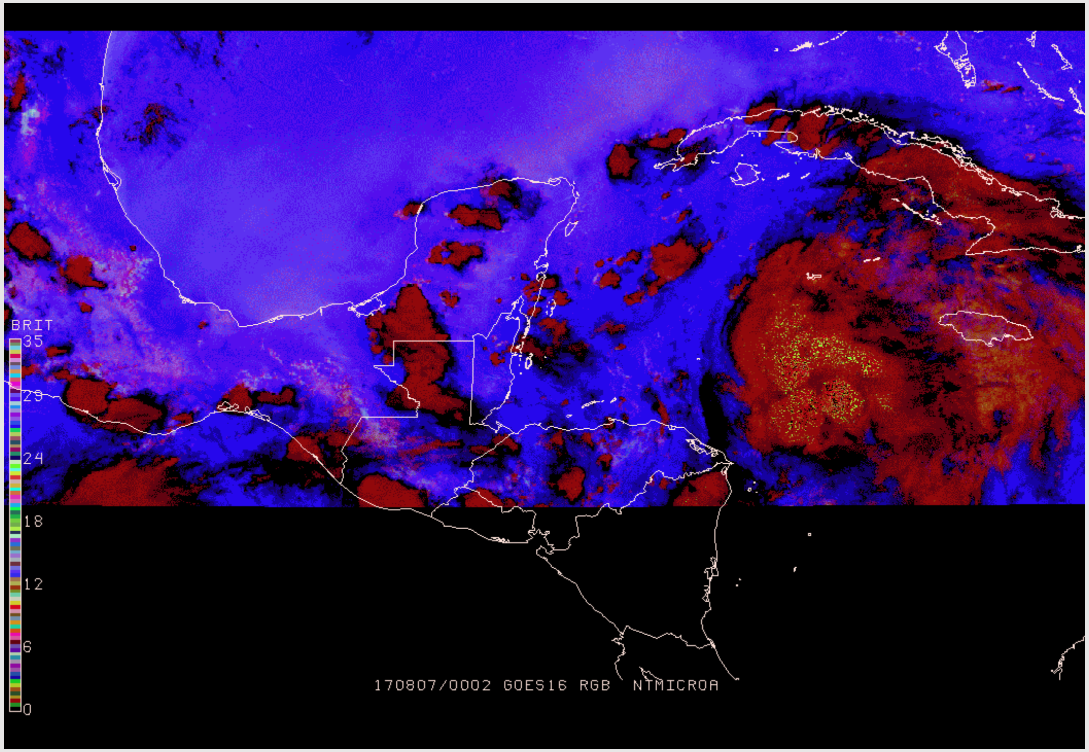
82% said some to very large impact

Forecaster feedback from VIIRS and MODIS Multispectral Imagery for Aviation Weather and Cloud Analysis at High Latitudes Assessment in 2014



Nighttime Microphysics RGB over Florida from GOES-16 0701 UTC to 1156 UTC on 3 March 2017. Aqua colored clouds depicting impacts to TAF sites experiencing MVFR ceilings.

NtMicro RGB: Hurricane Franklin (2017)



WTNT42 KNHC 070849
TCDAT2

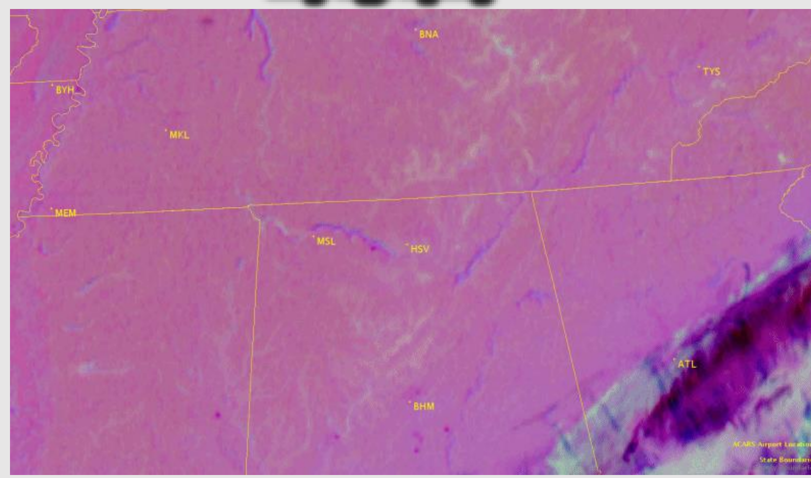
Tropical Storm Franklin Discussion Number 3
NWS National Hurricane Center Miami FL AL072017
500 AM EDT Mon Aug 07 2017

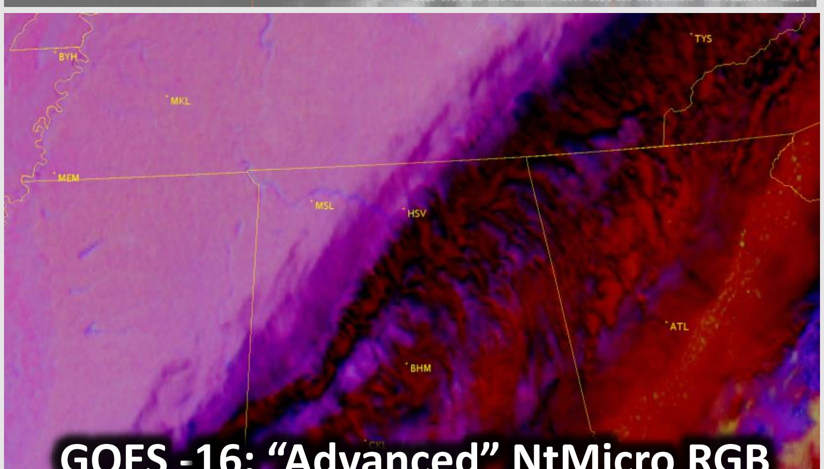
Deep convection associated with Franklin has been steadily increasing in both coverage and vertical depth since the previous advisory. ***Wind data from a late-arriving 0231Z ASCAT-A pass suggest that Franklin might not have had a closed surface circulation at that time. However, the new GOES-16 nighttime microphysics imagery clearly shows low clouds moving from west to east on the south side of the alleged center, which is suggestive of a closed low-level circulation.***

NtMicro RGB: Radiational Cooling/Fog

GOES -15: 11-3.9 um Difference 0800 – 1300 UTC

Alternating NtMicro RGB and Topography





GOES -16: "Advanced" NtMicro RGB 0702 – 1207 UTC

GOES -16: Visible Imagery 1402 UTC

preliminary, non-operational

Poll Question #3

Use of both the split window difference (12.4 – 10.4 µm) and spectral difference (10.3 – 3.9 µm) in the Night-time Microphysics RGB means _____. *(choose all that apply)*

A. Efficient cloud analysis (heights/phase) can be inferred
B. Low clouds can only be distinguished from high clouds
C. Low clouds can only be distinguished from mid-clouds
D. Fog can be distinguished from low clouds
E. Fog can't be distinguished from low clouds

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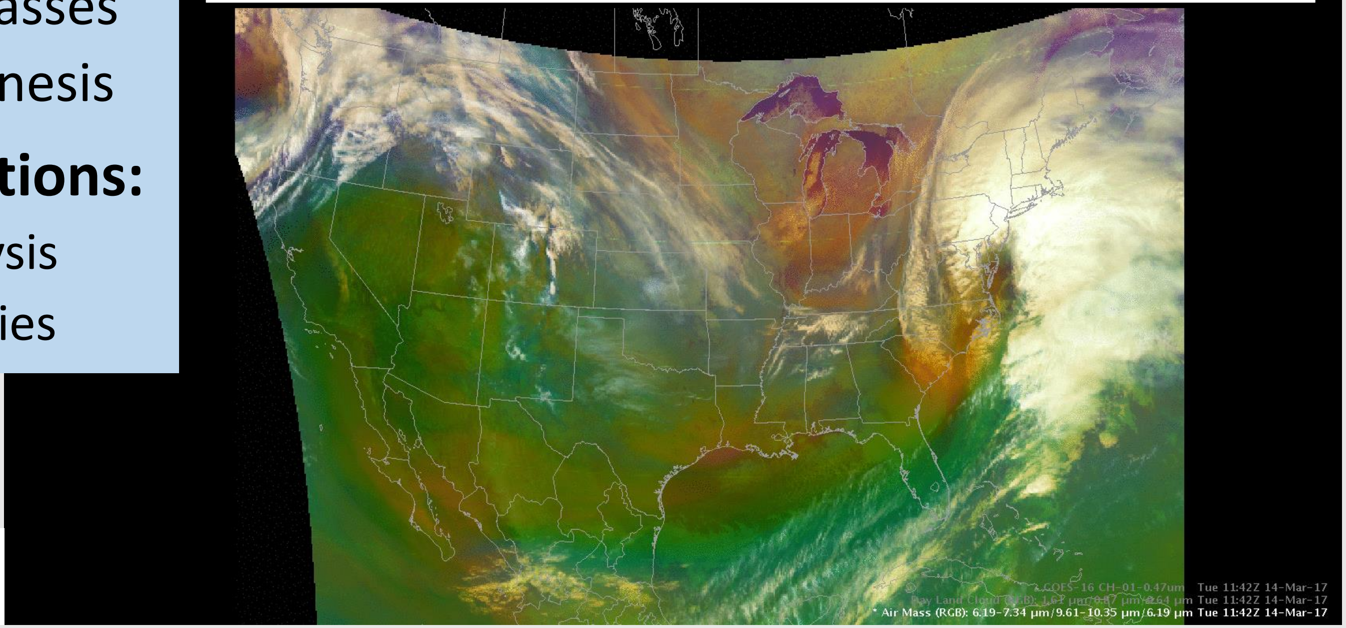
C. Low clouds can only be distinguished from mid-clouds
D. **Fog can be distinguished from low clouds**
E. Fog can't be distinguished from low clouds

Air Mass RGB

- **Primary Application:**
  - Identifying air masses
  - Inferring cyclogenesis
- **Secondary Applications:**
  - Cloud height analysis
  - Moisture boundaries

Air Mass RGB Imagery from GOES-16 at 1142 to 1422 UTC, 14 March 2017.

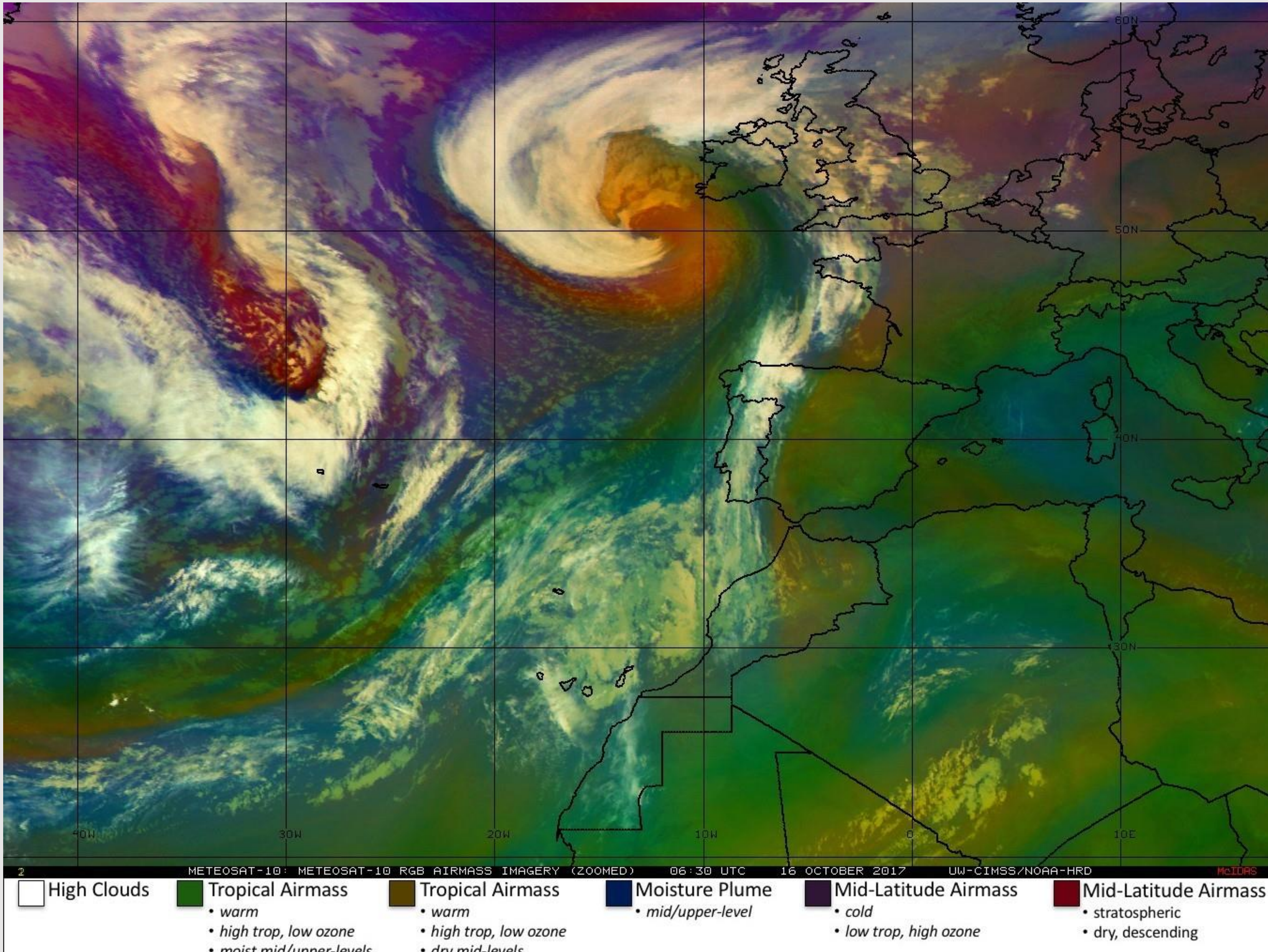


preliminary, non-operational

- Air Mass RGB derived from SEVIRI, MODIS, and AHI has been extensively used at National Centers to prepare for GOES-16
  - Regular use in operations at OPC along with Social Media posts
  - AWC has investigated used for turbulence
  - NHC uses for extratropical transition

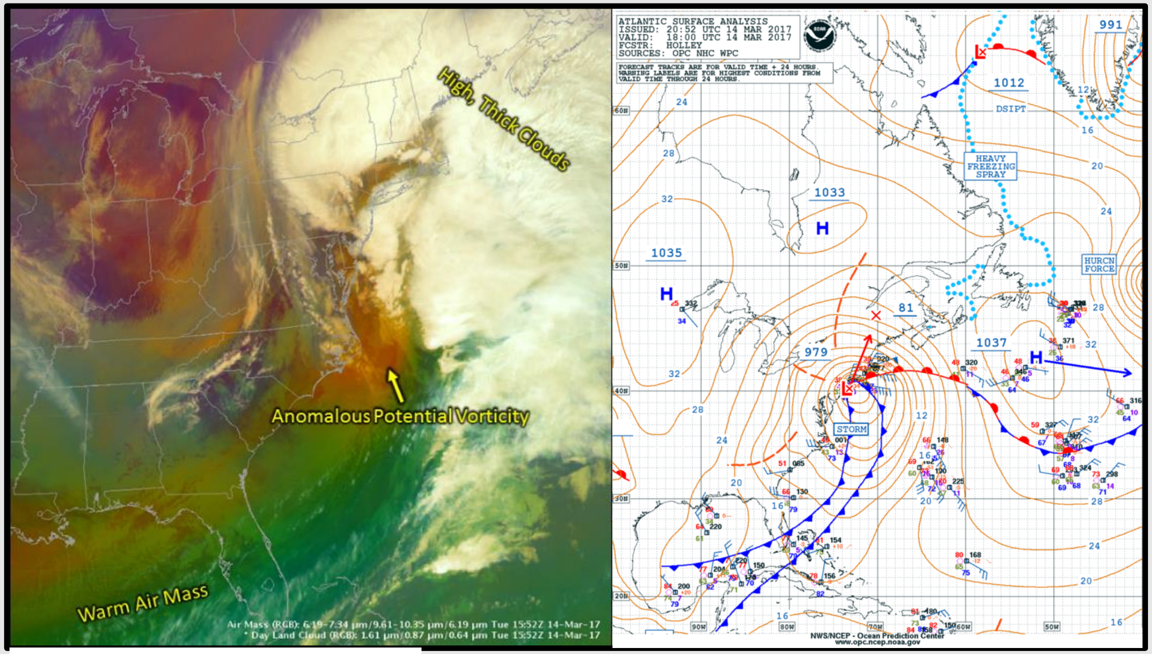
See Zavodsky et al. (2013), Berndt et al. (2016), and Elmer et al. (2016)

Air Mass RGB: Air Masses & Clouds



Extratropical Ophelia viewed by SEVIRI, image from Jason Dunion

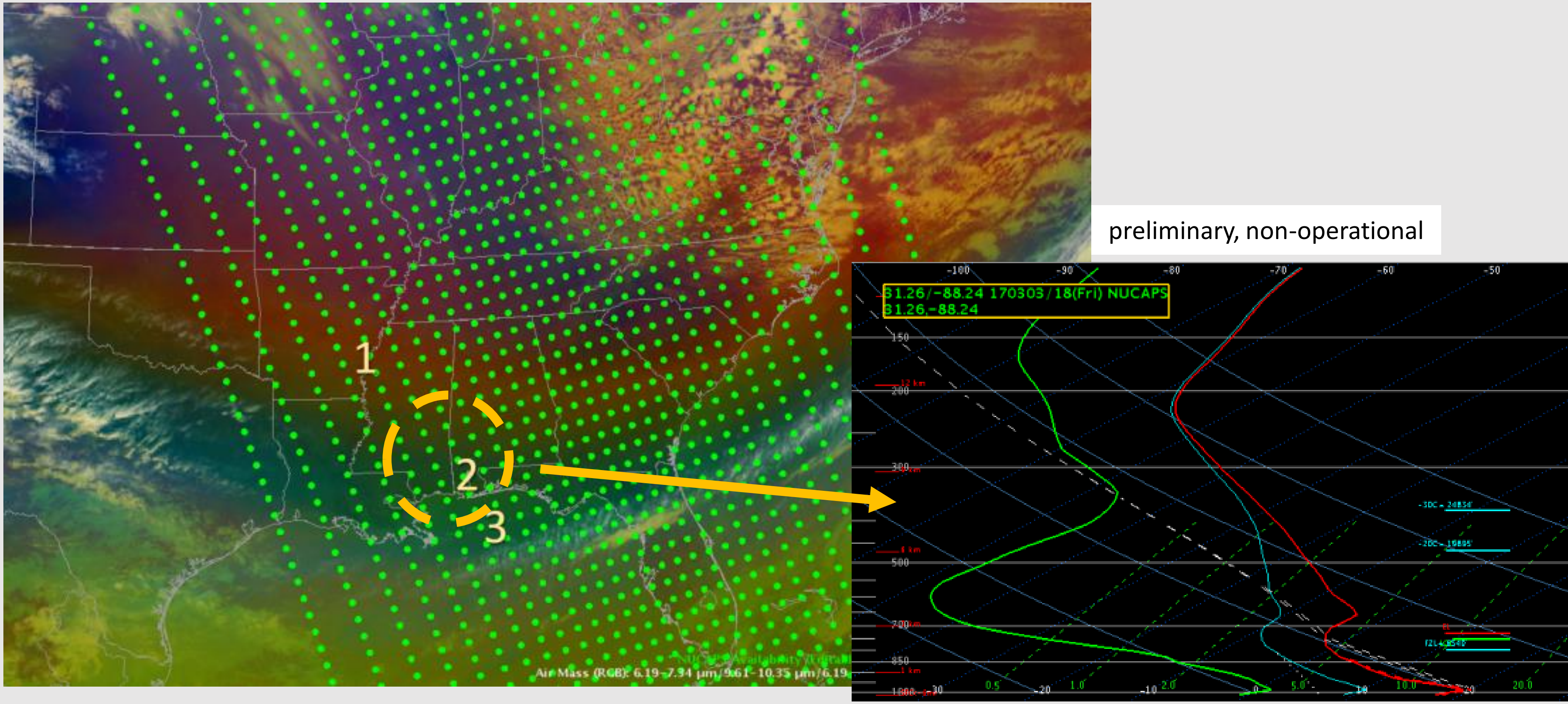
Air Mass RGB: Cyclogenesis



preliminary, non-operational

Color	Band / Band Diff. (µm)	Physically Relates to…	<u>Small</u> contribution to pixel indicates…	<u>Large</u> contribution to pixel indicates…
Red	**6.2 – 7.3**	Vertical water vapor difference	Moist upper levels	**Dry upper levels**
Green	**9.6 – 10.4**	Tropopause height based on ozone	Low tropopause and high ozone	**High tropopause and low ozone**
Blue	**6.2**	Water vapor in ~200-500 mb layer	Dry upper levels or warm brightness temperatures	**Moist upper levels or cold brightness temperatures**

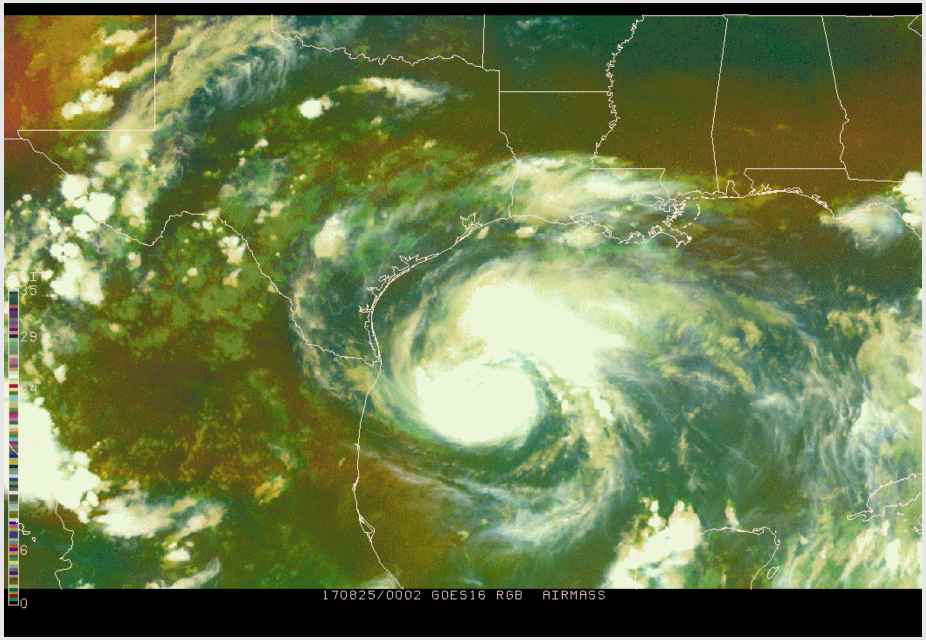
Air Mass RGB and NUCAPS Soundings



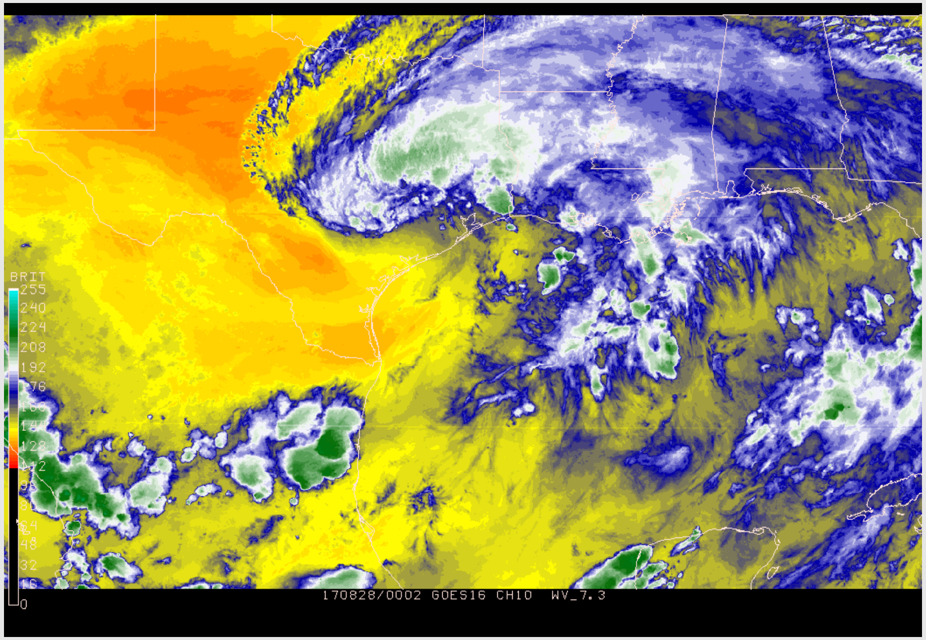
- CrIS/ATMS NUCAPS are in AWIPS and complement the Air Mass RGB
    - Identification of height of moist/dry layers
    - Identification of stratospheric intrusions and tropopause folding
    - Rapid cyclogenesis and hurricane-force wind events
    - Hurricane rapid intensification and extratropical transition

Air Mass RGB: Hurricane Harvey (2017)

GOES-16 Air Mass RGB



GOES-16 7.3µm
“Low-Level” Water Vapor

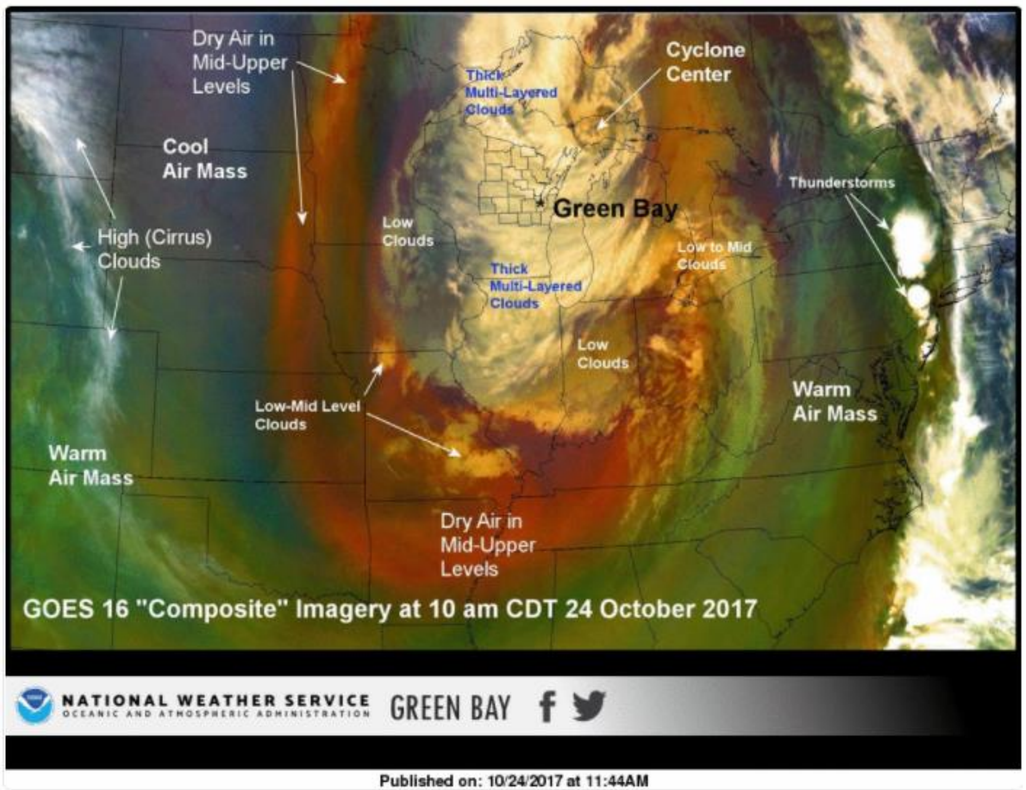


Air Mass RGB: In Operations

NWS Green Bay @NWSGreenBay

Follow

GOES16 satellite image of strong cyclone over Great Lakes. This composite distinguishes different cloud heights as well as air mass types.



9:44 AM - 24 Oct 2017

preliminary, non-operational

Poll Question #4

The advantage of the Air Mass RGB compared to single channel water vapor analysis is ____. *(choose all that apply)*

A. A colorful enhancement of dry air masses
B. Ability to identify warm, dry, ozone rich air masses
C. Fog can be distinguished from low clouds
D. Ability to distinguish low-, mid-, and high clouds

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D. Ability to distinguish low-, mid-, and high clouds

Summary

- Multispectral or Red-Green-Blue (i.e. RGB) Composites are qualitative, false color images designed to enhance specific features such as low clouds and fog, dust, air mass characteristics, convection…
- A set of defined recipes were first introduced by EUMETSAT with the advent of the SEVIRI instrument onboard Meteosat Second Generation
- SPoRT has worked with the GOES-R/JPSS Proving Grounds to prepare forecasters for the GOES-R era by creating RGB products with instruments onboard polar-orbiting and geostationary satellites
- RGBs have been successfully integrated into operations in numerous WFOs and National Centers before the launch of GOES-16
- Through SPoRT's GOES-R/JPSS Proving Ground efforts, select NWS forecasters are prepared for RGB imagery on Day 1 of operations

Resources

COMET:
“Multispectral Satellite Applications: RGB PRODUCTS EXPLAINED”

EUMETSAT User Service Division:
“Best practices for RGB compositing of multi-spectral imagery”

SPoRT:
Applications Library, Real-time RGB imagery, The Wide World of SPoRT Blog
Static & Interactive Quick Guides

GOES-R & JPSS:
Satellite Liaison Blog

EUMETRAIN:
RGB Colour Interpretation Guide

EUMETSAT: Real-time Imagery

Australian BOM: Melbourne Vlab Centre of Excellence, RGB Product Resources

JMA: Himawari RGB Training Library

Papers

Berndt, E. B., B. T. Zavodsky and M. J. Folmer, 2016: "Development and Application of Atmospheric Infrared Sounder Ozone Retrieval Products for Operational Meteorology," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 54, no. 2, pp. 958-967.

Berndt, E.B., A. L. Molthan, W. W. Vaughan, and K. K. Fuell, 2017: Transforming Satellite Data into Weather Forecasts, *AGU EOS, 98*, https://doi.org/10.1029/2017EO064449.

Berndt, E. B., N. J. Elmer, L. A. Schultz, and A. L. Molthan, 2017: A Methodology to Determine Recipe Adjustments for Multispectral Composites Derived from Next-Generation Advanced Satellite Imagers, *Journal of Atmos. And Oceanic Technology, in revision.*

Elmer, N., E. Berndt, G. J. Jedlovec, 2016: Limb Correction of MODIS and VIIRS Infrared Channels for the Improved Interpretation of RGB Composites, *Journal of Atmos. And Oceanic Technology,* vol. 33, no. 5, pp. 1073-1087.

Fuell, K. K., B. J. Guyer, D. Kann, A. L. Molthan, and N. Elmer, 2016: Next generation satellite RGB dust imagery leads to operational changes at NWS Albuquerque. *J. Operational Meteor.*, **4**(6), 75–91.

Lensky, I. M. and D. Rosenfeld, 2008. Clouds-Aerosols-Precipitation Satellite Analysis Tool (CAPSAT). *Atmos. Chem. Phys.*, **8**, 6739-6753, doi: 10.5194/acp-8-6739-2008.

Rosenfeld, D. and I. M. Lensky, 1998: Satellite-Based Insights into Precipitation Formation Processes in Continental and Maritime Convective Clouds. *Bull. Amer. Meteor. Soc.*, vol. **79** (11), 2457-2476.

World Meteorological Organization, 2007: RGB Composite Satellite Imagery Workshop Final Report. RGB Composite Satellite Imagery Workshop 5-6 June 2007, Boulder, Colorado. [Available online at http://www.wmo.int/pages/prog/sat/documents/RGB-1_Final-Report.pdf].

World Meteorological Organization, 2012: WMO/EUMETSAT Workshop on RGB Satellite Products Final Report. WMO/EUMETSAT Workshop on RGB Satellite Products, 17-19 September 2012, Seeheim, Germany. [Available online at http://www.wmo.int/pages/prog/sat/documents/RGB-WS-2012_FinalReport.pdf].

Zavodsky, B. T., A. L. Molthan, and M. J. Folmer, 2013: Multispectral imagery for detecting stratospheric air intrusions associated with mid-latitude cyclones. *J. Operational Meteor.*, **1**(7), 71–83.