Satellites

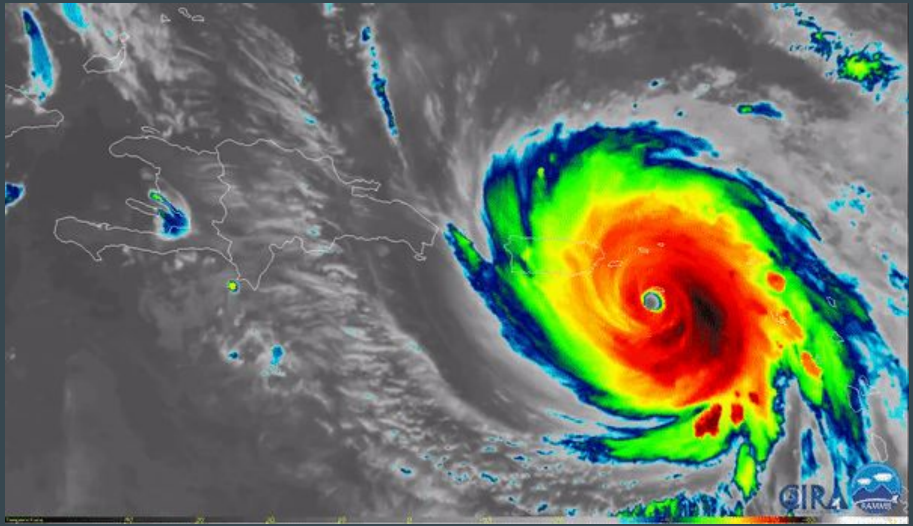
Meteorologist Caroline M. Adcock

NWS Nashville, TN


NATIONAL WEATHER SERVICE
NWS Nashville Presents
Weather 101

In this lesson

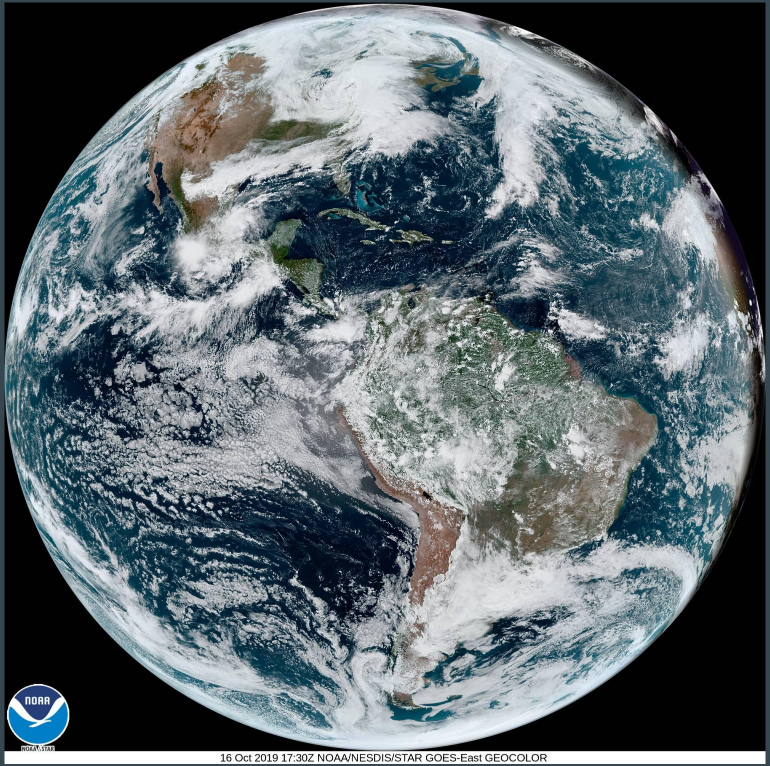
- Background and History
  - What are satellites?
  - How do they work?
  - Limitations and advantages
  - Advancements in satellite (GOES Era)
- Satellite products and applications
  - GOES 16 and 17 channels
  - Real-world applications



GOES-16 imagery of Hurricane Maria over Puerto Rico on September 20, 2017. This loop was created using band 13, one of the new spectral bands offered by ABI.
Credit: NOAA/CIRA

What are Satellites?

- The study of Earth's atmosphere (and atmospheric processes) using measurements from satellites in orbit
- These are indirect measurements
    - Also know as remote sensing
- Orbit of the satellite influences what a satellite can tell us because of:
    - How fast it travels
    - Where it orbits



Credit: NOAA/CIRA

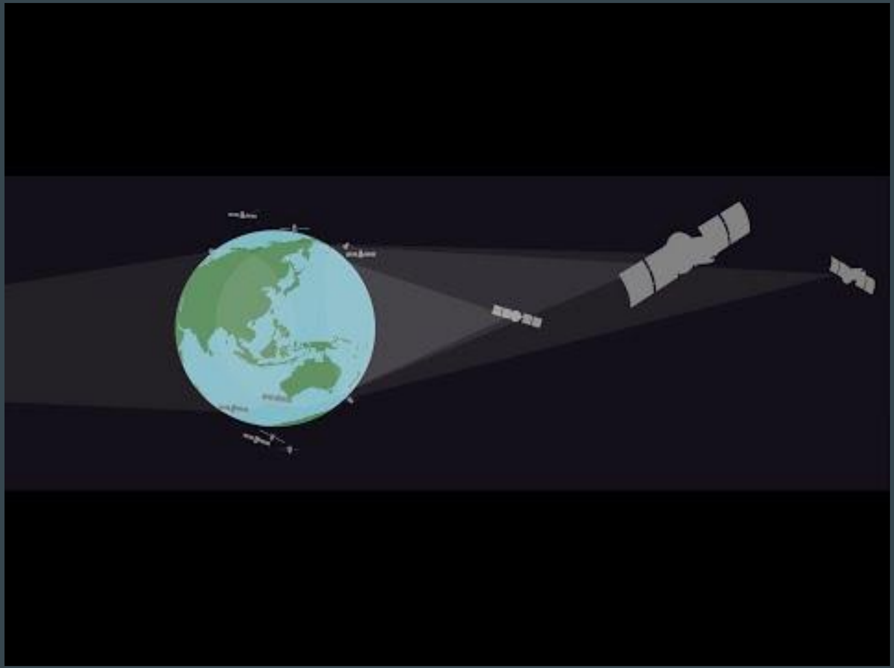
Early Timeline of Satellites

- October 4, 1957 - Sputnik 1 (USSR)
  - The first human-made object to orbit Earth
  - This triggered the space race between the USSR and United States
- November 3, 1957 - Sputnik 2 (USSR)
  - The first being to travel to outer space was a female part-Samoyed terrier called Laika
- December 6, 1957 - Vanguard 1A (USA)
  - Explosion on the launch pad resulting in an unsuccessful attempt to reach space by the U.S.
- January 31, 1958 - Explorer 1 (USA)
  - The first American satellite in space
- March 17, 1958 - Vanguard 1C (USA)
  - After two more U.S. failures from Vanguard 1B and Explorer 2, Vanguard 1C reached space. First to use solar cells to power a satellite.
  - Fun Fact: Vanguard 1C is still in space making it the oldest orbiting satellite

Early Timeline of Weather Satellites

- October 13th, 1959 - Explorer 7
  - First (successful) satellite with weather-related instruments
- April 1, 1960 - TIROS-1 (Television InfraRed Observation Satellites)
  - First dedicated meteorological satellite in orbit
- December 7, 1966 - ATS-1 (Applications Technology Satellite)
  - First geostationary satellite
  - Intended as a communications satellite, but was eventually used for weather
- October 16, 1975 - GOES-1
  - NOAA's GOES program begins

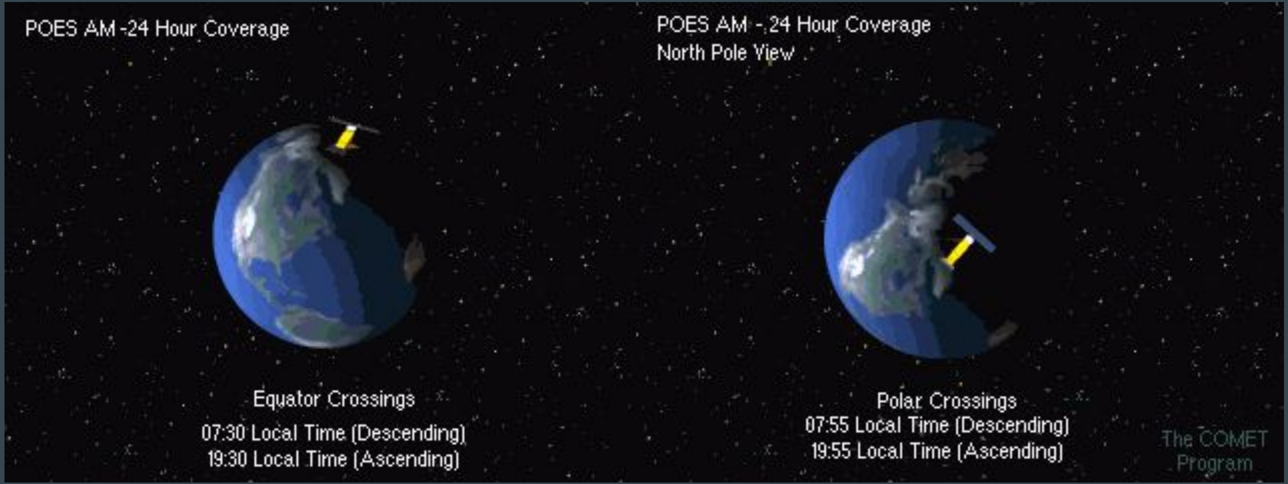
Types of Satellites



Youtube Link - https://youtu.be/oeCixBGQVMI

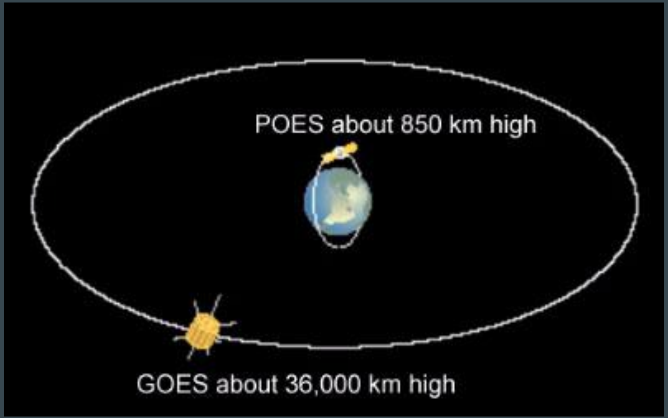
Types of Weather Satellites

- Polar-Orbiting Environmental Satellites (POES)
  - Orbit around the poles and provide high resolution snapshots
  - First satellite launched on April 1, 1960



Types of Weather Satellites

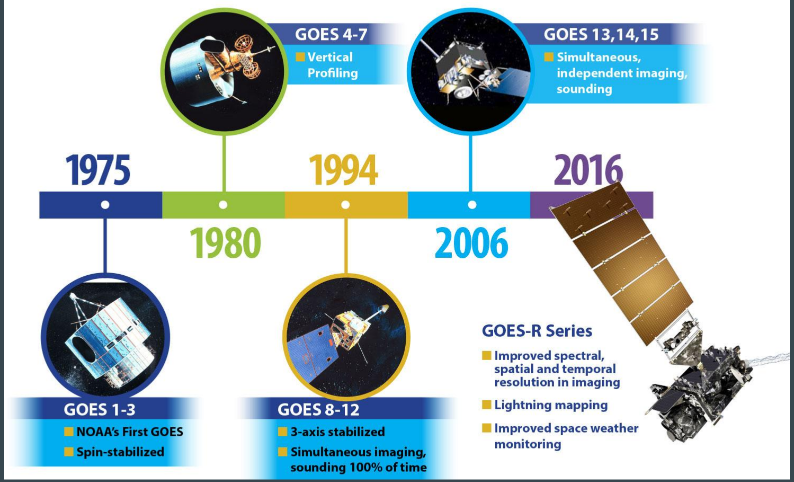
- Polar-Orbiting Environmental Satellites (POES)
  - Orbit around the poles and provide high resolution snapshots
  - First satellite launched on April 1, 1960
- Geostationary Operational Environmental Satellites (GOES)
  - Orbit the earth above the equator at the same speed as the earth rotates
  - First GOES satellite launched on October 16, 1975



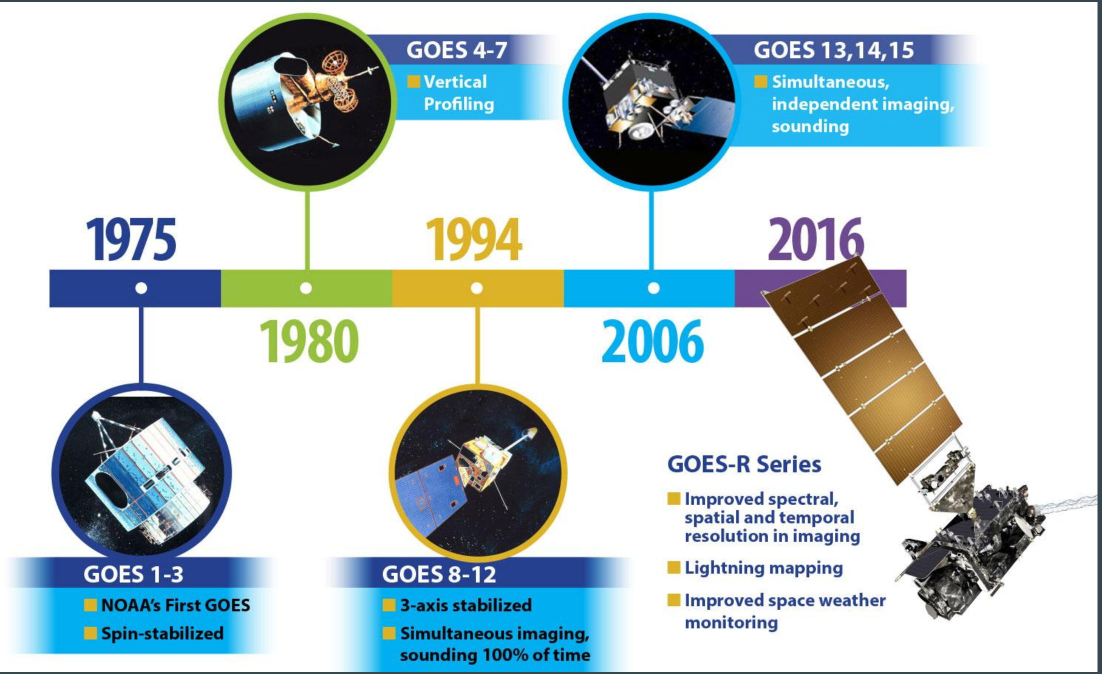
Question Time

Geostationary Operational Environmental Satellites (GOES)

- Since 1975, GOES have provided continuous imagery and data on atmospheric conditions and solar activity (space weather)
- GOES data products have led to more accurate and timely weather forecasts and better understanding of long-term climate conditions
- NASA builds and launches them while NOAA operates them



History of GOES



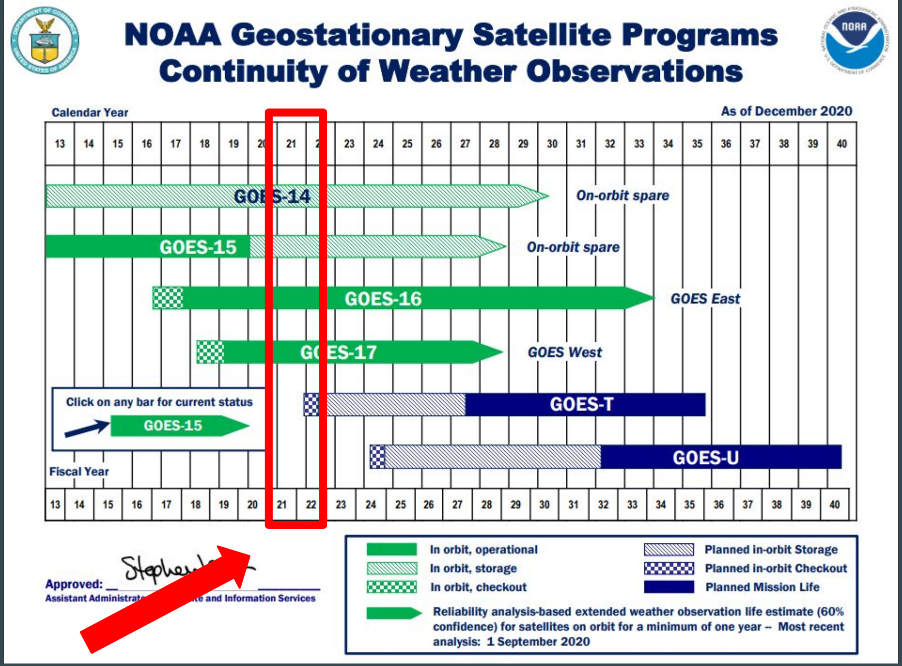
LAUNCH DESIGNATION:	OPERATIONAL DESIGNATION:	LAUNCH:	STATUS:
GOES-A	GOES-1	October 16, 1975	Decommissioned 1985
GOES-B	GOES-2	June 16, 1977	Decommissioned 1993, reactivated 1995, deactivated 2001
GOES-C	GOES-3	June 16, 1978	Decommissioned 2016
GOES-D	GOES-4	September 9, 1980	Decommissioned 1988
GOES-E	GOES-5	May 22, 1981	Decommissioned 1990
GOES-F	GOES-6	April 28, 1983	Decommissioned 1992
GOES-G	N/A	May 3, 1986	Failed to orbit
GOES-H	GOES-7	February 26, 1987	Decommissioned 2012
GOES-I	GOES-8	April 13, 1994	Decommissioned 2004
GOES-J	GOES-9	May 23, 1995	Decommissioned 2007
GOES-K	GOES-10	April 25, 1997	Decommissioned 2009
GOES-L	GOES-11	May 3, 2000	Decommissioned 2011
GOES-M	GOES-12	July 23, 2001	Decommissioned 2013
GOES-N	GOES-13	May 24, 2006	Now in service as U.S. Space Force Electro-Optical Infrared Weather System – Geostationary (EWS-G1), providing coverage over the Indian Ocean
GOES-O	GOES-14	June 27, 2009	On-orbit spare
GOES-P	GOES-15	March 4,	On-orbit storage
GOES-R	GOES-16	November 19, 2016	In operation as GOES East
GOES-S	GOES-17	March 1, 2018	In operation as GOES West
GOES-T			Scheduled for launch in December 2021
GOES-U			Launch commitment date 1Q FY 2025

Where we are now

NWS Nashville, TN

Present and Future of GOES

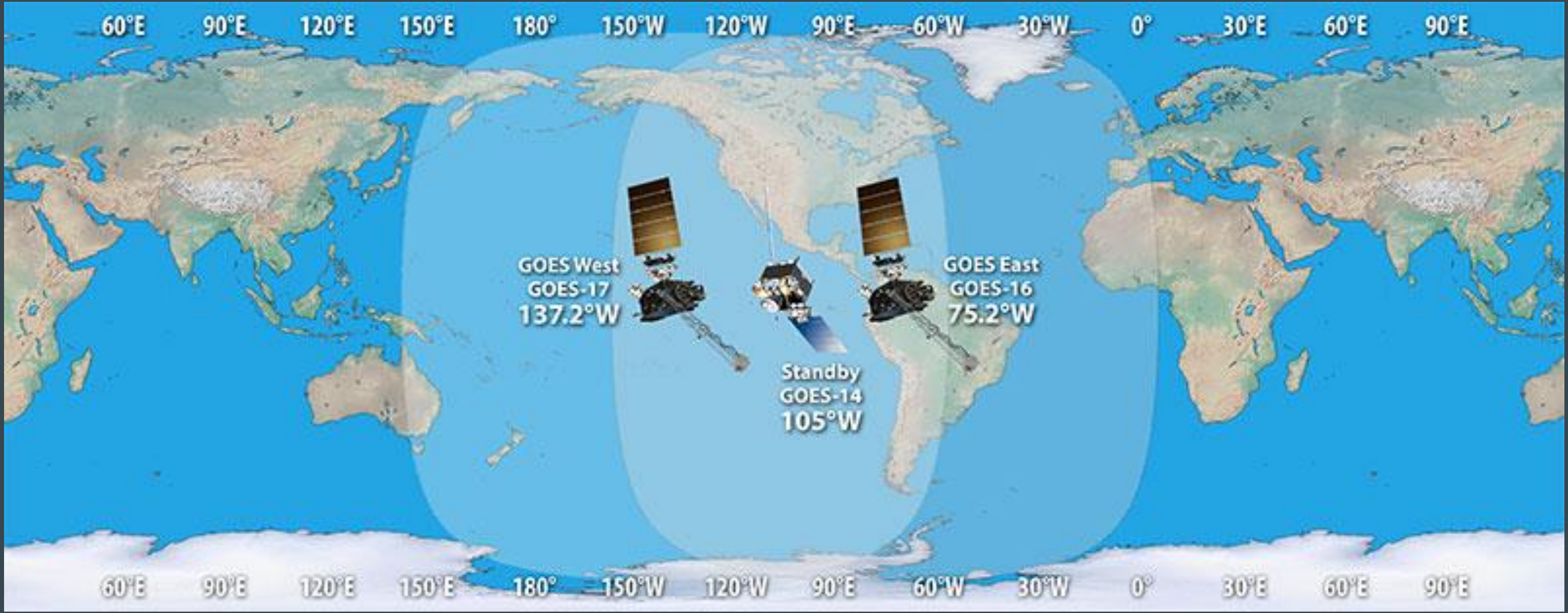
- NOAA’s latest generation and most advanced fleet of geostationary weather satellites
  - GOES-R Series is a four-satellite program including:
    - GOES-R (GOES-16/GOES East)
    - GOES-S (GOES-17/ GOES West)
    - GOES-T
    - GOES-U



Where we are now

NWS Nashville, TN

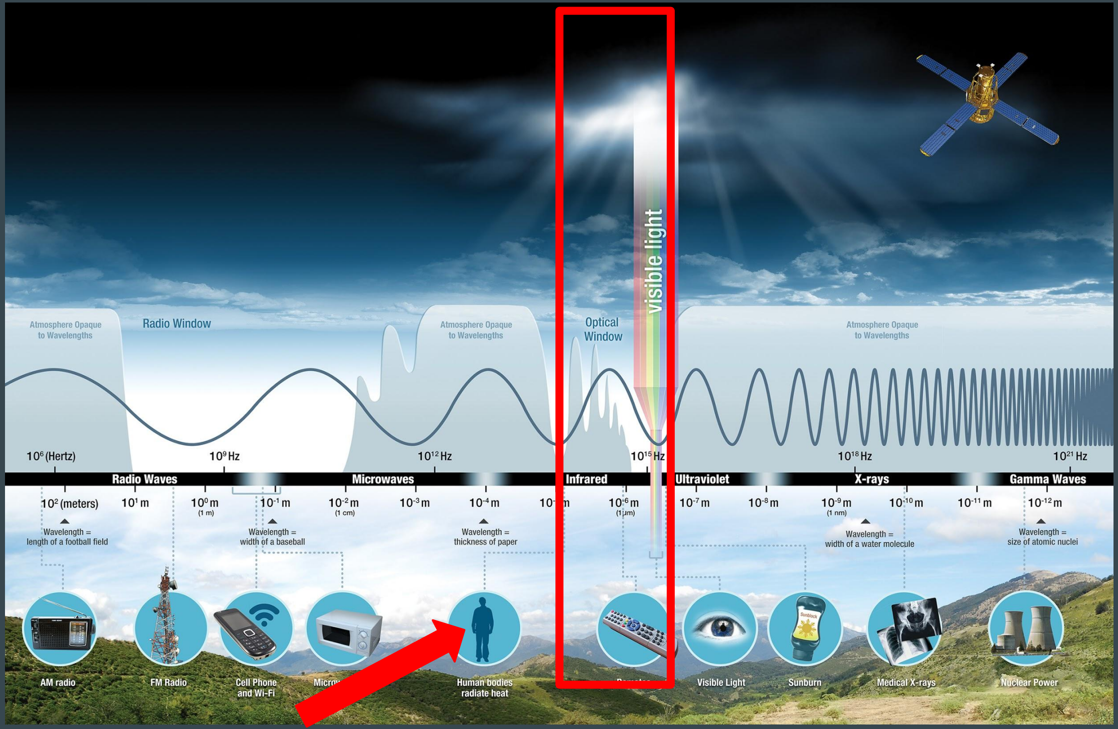
Current Operational GOES Satellites



*GOES-15 is used for on-orbit storage

NWS Nashville, TN

How do Satellites Work?

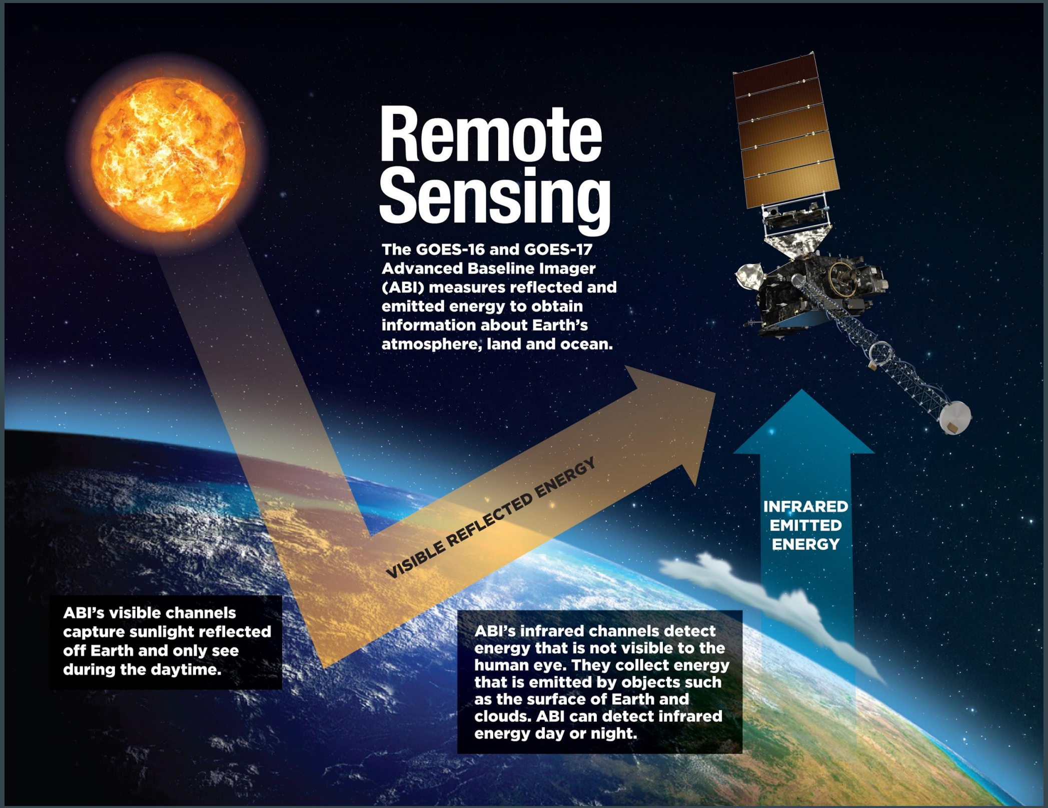


GOES satellites fall in the Infrared (IR), Near-IR, and Visible spectrum

NWS Nashville, TN

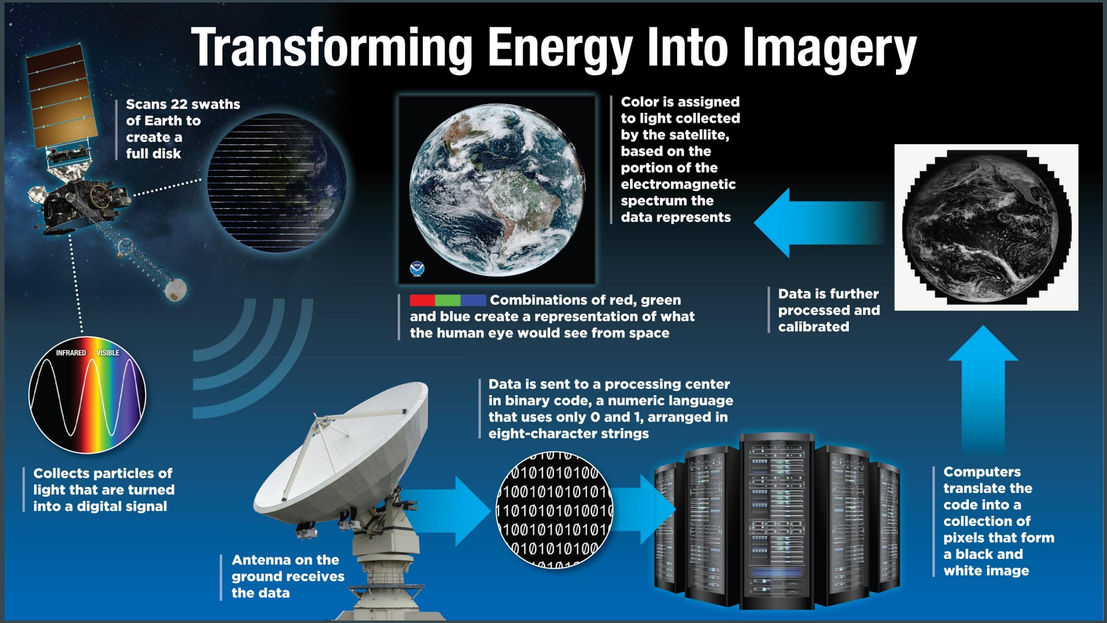
How do Satellites Work?

- Each channel measures the amount of reflected or emitted energy in a specific wavelength.
  - Reflected Energy - means these bands are only available during the daytime
  - Emitted - available during both daytime and nighttime



How do Satellites Work?

- Information is turned into radio waves and is transmitted to antennas on Earth
- Satellite imagery is made up of tiny squares called pixels, like pictures on TV



GOES-R Series - Instruments Onboard

- Earth-pointing *our focus today*:
  - Advanced Baseline Imager (ABI)
  - Geostationary Lightning Mapper (GLM)
- Sun-pointing:
  - Extreme Ultraviolet and X-ray Irradiance Sensors (EXIS)
  - Solar Ultraviolet Imager (SUVI)
- In-situ:
  - Magnetometer (MAG)
  - Space Environment In-situ Suite (SEISS)

GOES-R Series - Advanced Baseline Imager (ABI)

- ABI is a multi-channel passive imaging radiometer that images Earth's weather, oceans, environment with 16 spectral bands
  - 2 visible, 4 near-infrared, and 10 infrared channels
- Geographic coverage
  - Full Disk
    - Circular image depicting nearly full coverage of the Western hemisphere
  - CONUS/PACUS
    - Rectangular image depicting the Continental US (CONUS) (GOES-16) or the Pacific Ocean including Hawaii (PACUS) (GOES-17)
  - Mesoscale
    - Smaller rectangular image with higher temporal resolution
    - Two mesoscale domains on each satellite
    - Requests can be made to have mesoscale sector over a particular area

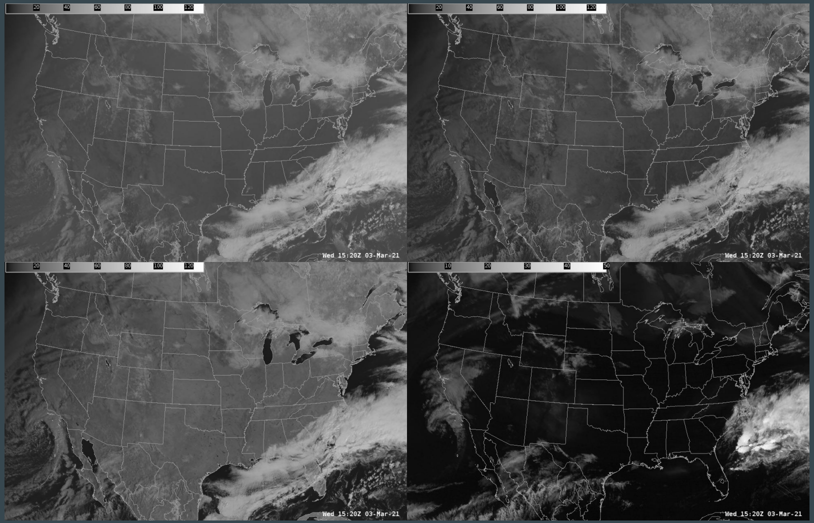
GOES-R Series - Geostationary Lightning Mapper (GLM)

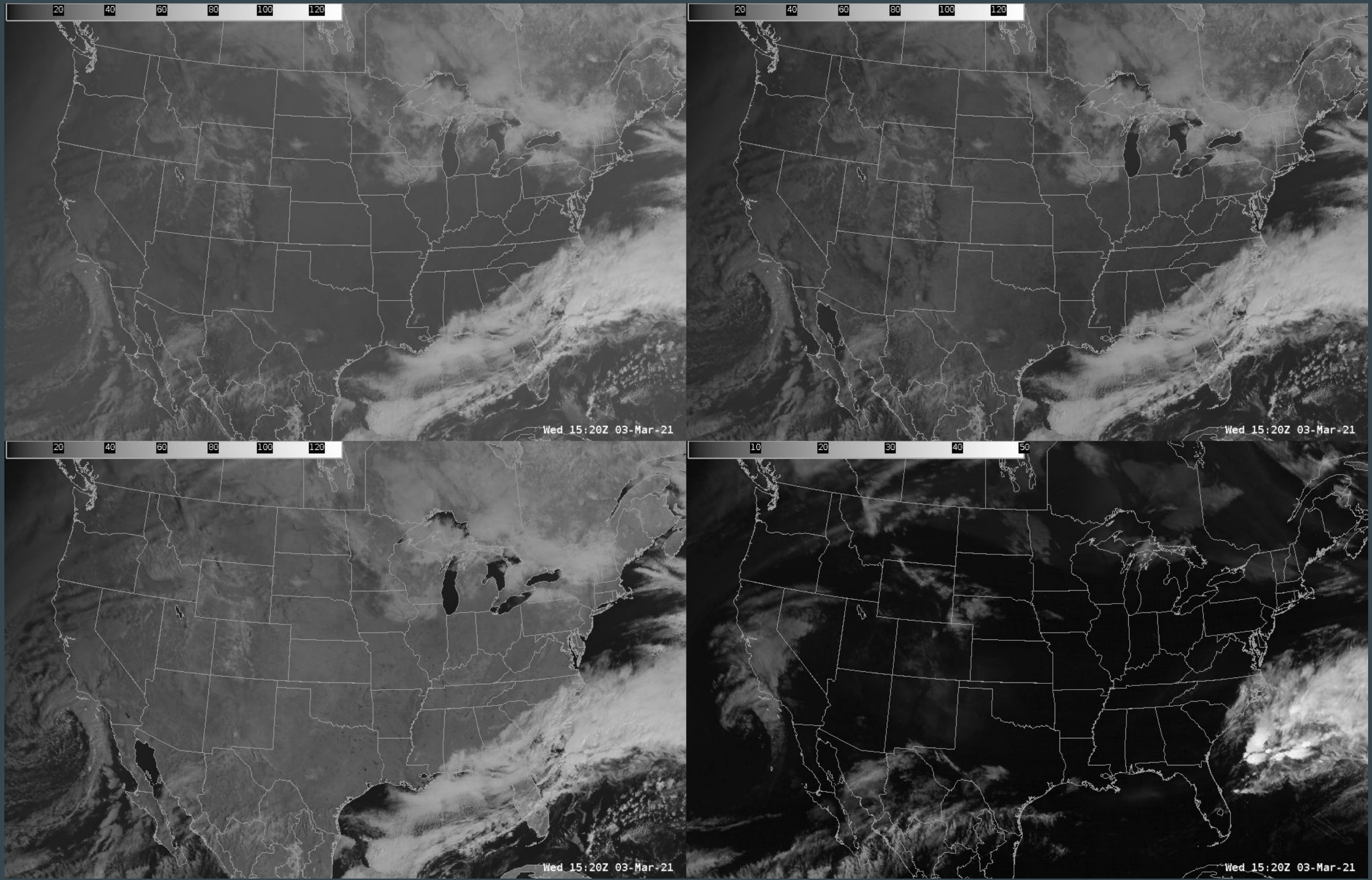
- GLM is a single-channel, near-infrared optical transient detector the captures the momentary changes in an optical scene.
  - Allows for GLM to measure a dedicated region with continuous views capable of providing lightning detection from space.
  - GLM detects all forms of lightning during both day and night, continuously, with a high spatial resolution and detection efficiency.
    - This includes in-cloud, cloud-to-cloud, and cloud-to-ground lightning.
- GLM collects information such as frequency, location, and extent of lightning discharges to identify intensifying thunderstorms and tropical cyclones.
  - Provides critical information to forecasters, allowing them to focus on developing severe storms much earlier and before these storms produce damaging winds, hail, or even tornadoes.
    - Increase tornado and other severe storm warning lead time
    - Better detection of heavy rainfall and flash flooding
    - Improved aviation route planning

Question Time

GOES-16 & 17 ABI Bands

- ABI Band 1 - “Blue” Band
  - Approximate Central Wavelength (μm) - 0.47
  - Band Type - Visible
- ABI Band 2 - “Red” Band
  - Approximate Central Wavelength (μm) - 0.64
  - Band Type - Visible
- ABI Band 3 - “Veggie” Band
  - Approximate Central Wavelength (μm) - 0.86
  - Band Type - Near-IR
- ABI Band 4 - “Cirrus” Band
  - Approximate Central Wavelength (μm) - 1.37
  - Band Type - Near-IR

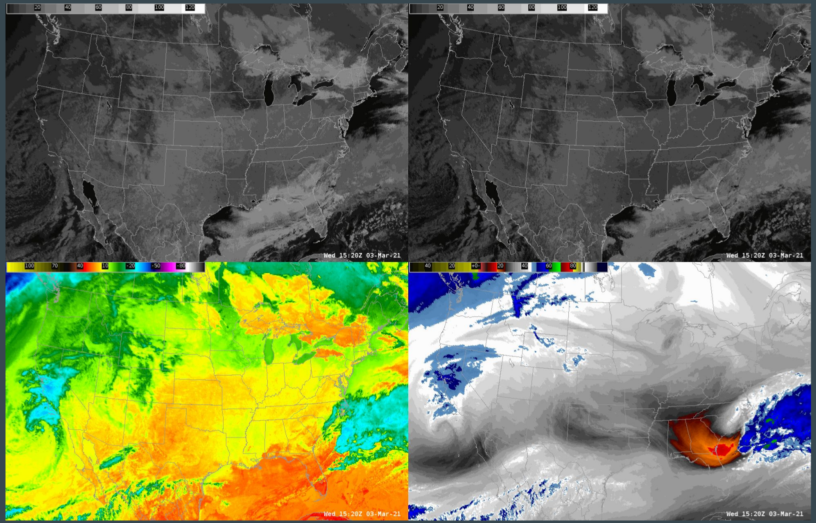


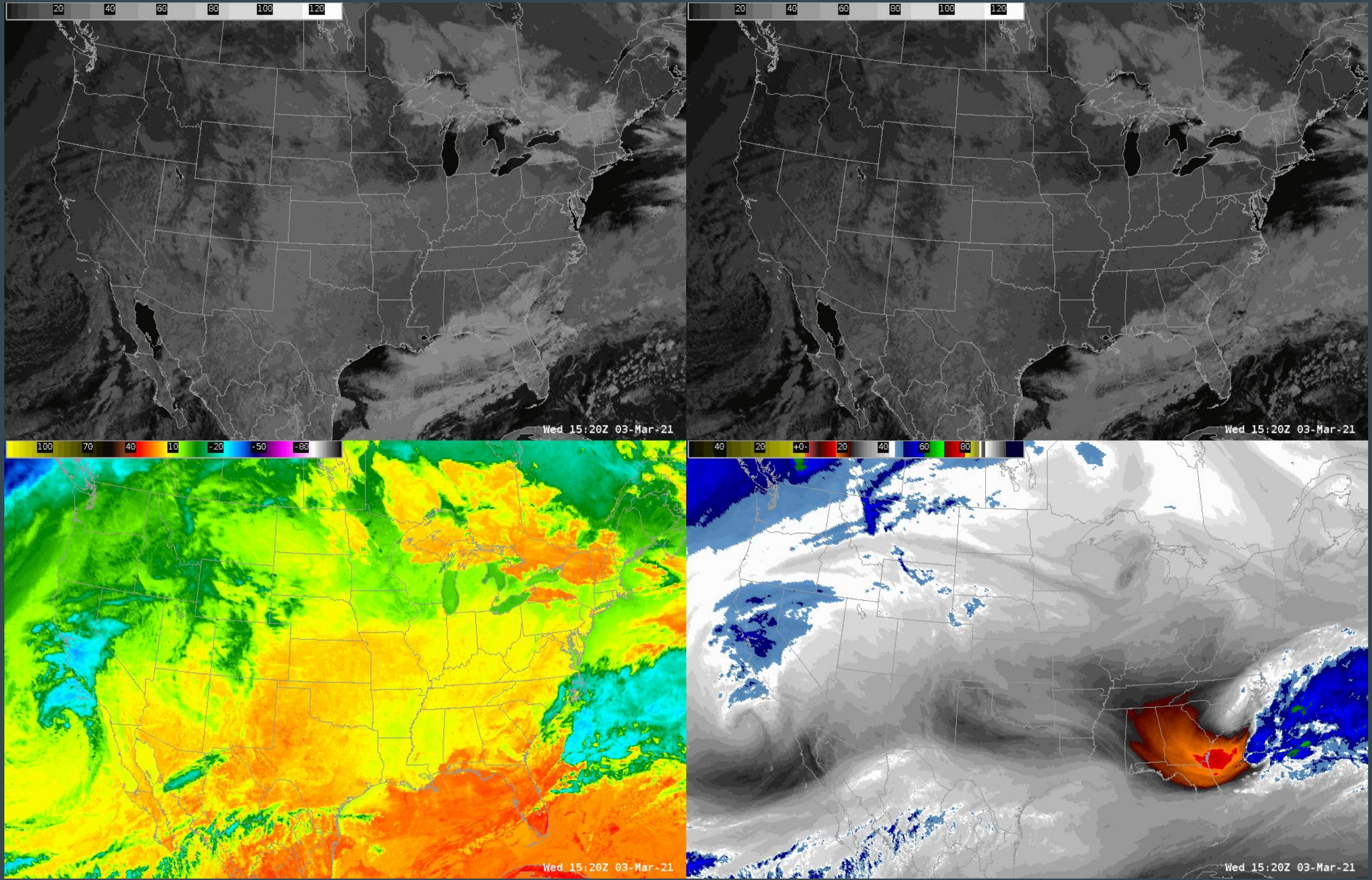


NWS Nashville, TN

GOES-16 & 17 ABI Bands

- ABI Band 5 - “Snow/Ice” Band
  - Approximate Central Wavelength (µm) - 1.6
  - Band Type - Near-IR
- ABI Band 6 - “Cloud Particle Size” Band
  - Approximate Central Wavelength (µm) - 2.2
  - Band Type - Near-IR
- ABI Band 7 - “Shortwave Window” Band
  - Approximate Central Wavelength (µm) - 3.9
  - Band Type - IR (with reflected daytime component)
- ABI Band 8 - “Upper-Level Tropospheric Water Vapor” Band
  - Approximate Central Wavelength (µm) - 6.2
  - Band Type - IR

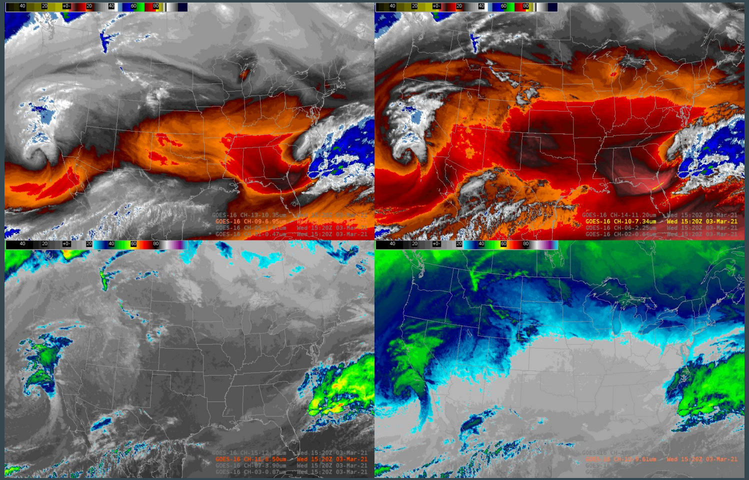




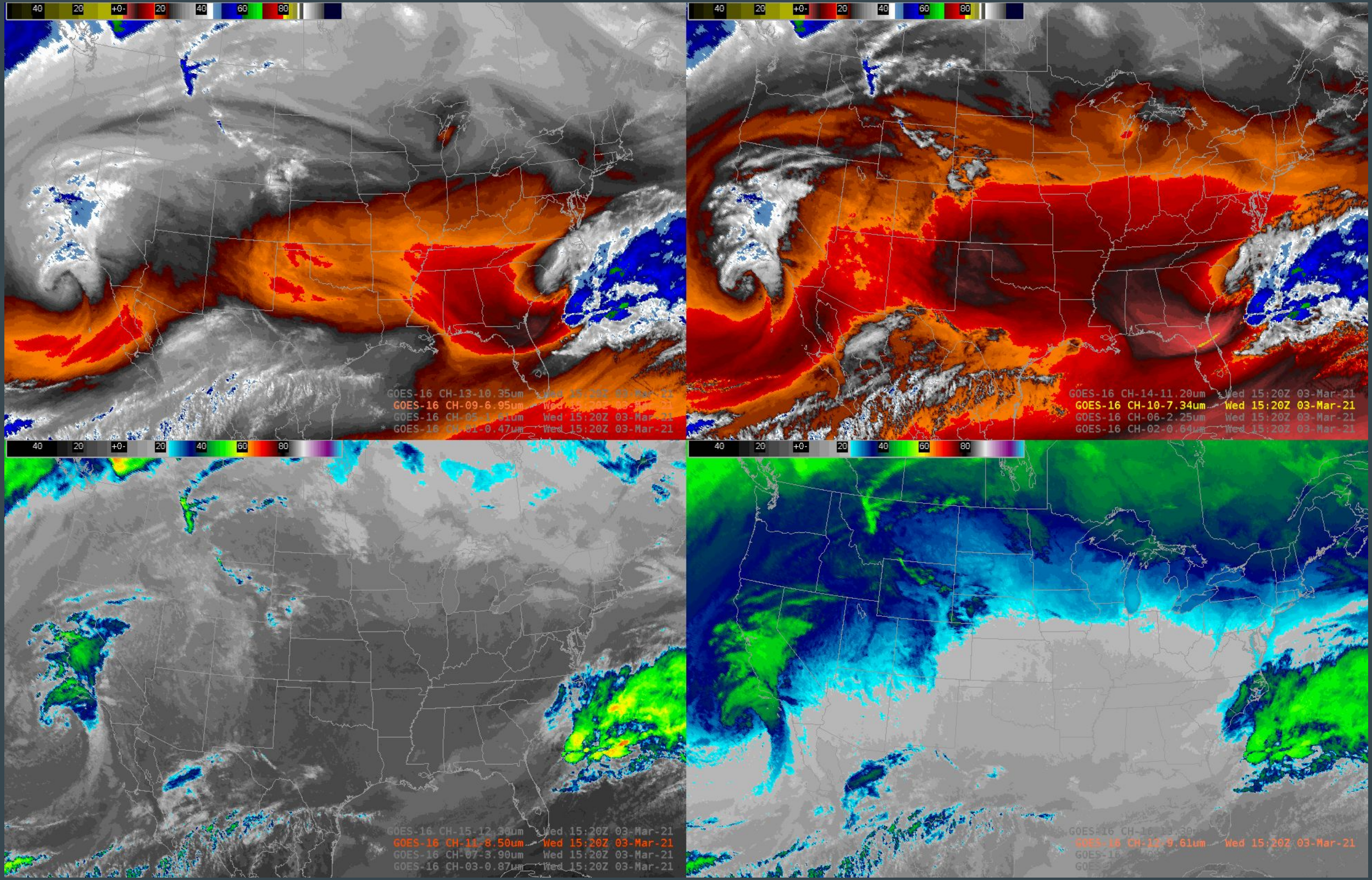
NWS Nashville, TN

GOES-16 & 17 ABI Bands

- ABI Band 9 - "Mid-Level Tropospheric Water Vapor" Band
  - Approximate Central Wavelength (μm) - 6.9
  - Band Type - Near-IR
- ABI Band 10 - "Lower-Level Water Vapor" Band
  - Approximate Central Wavelength (μm) - 7.3
  - Band Type - Near-IR
- ABI Band 11 - "Cloud-Top Phase" Band
  - Approximate Central Wavelength (μm) - 8.4
  - Band Type - IR (with reflected daytime component)
- ABI Band 12 - "Ozone Band" Band
  - Approximate Central Wavelength (μm) - 9.6
  - Band Type - IR



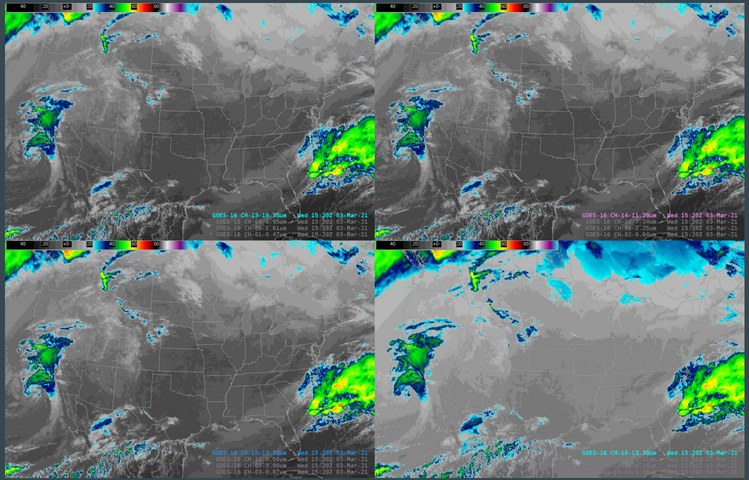
NWS Nashville, TN

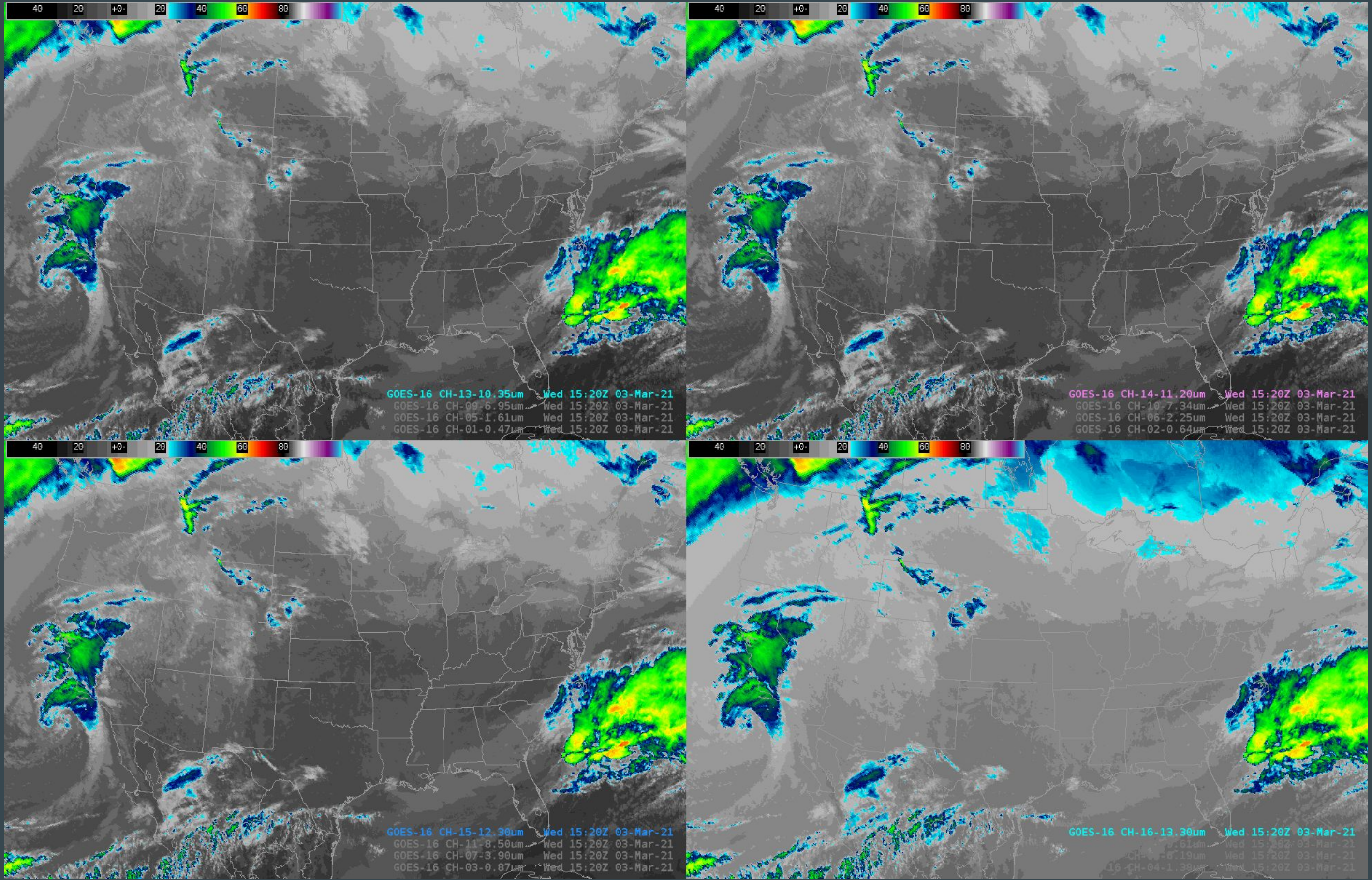


NWS Nashville, TN

GOES-16 & 17 ABI Bands

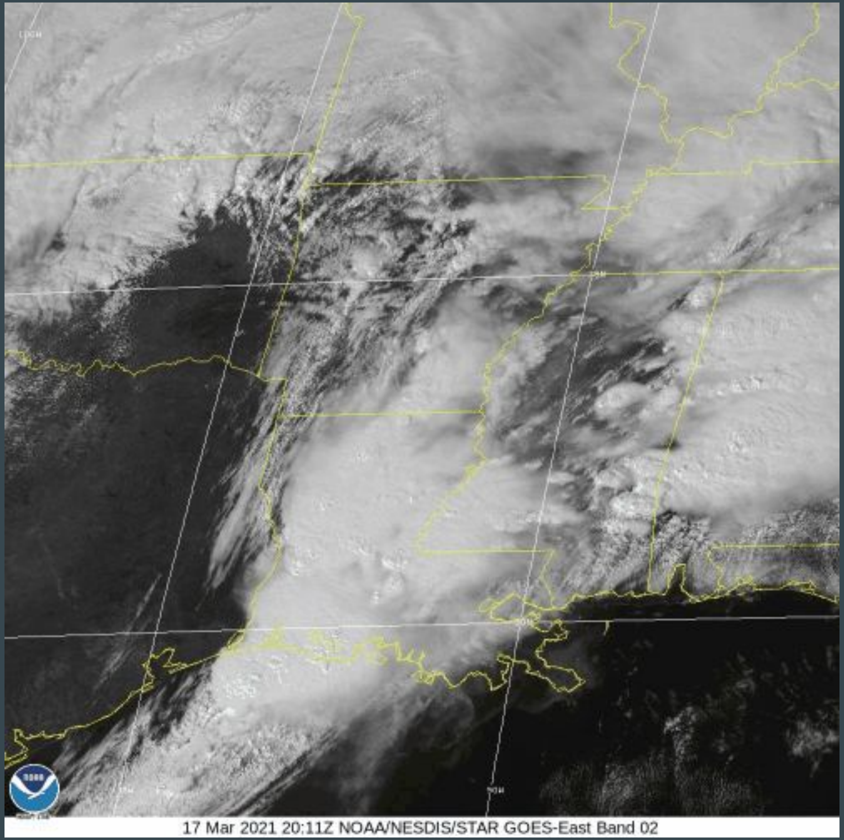
- ABI Band 13 - "Clean" IR Longwave Window Band
  - Approximate Central Wavelength (µm) - 6.9
  - Band Type - Near-IR
- ABI Band 14 - IR Longwave Window Band
  - Approximate Central Wavelength (µm) - 7.3
  - Band Type - Near-IR
- ABI Band 15 - "Dirty" Longwave Window Band
  - Approximate Central Wavelength (µm) - 8.4
  - Band Type - IR (with reflected daytime component)
- ABI Band 16 - "CO_2" Longwave Band
  - Approximate Central Wavelength (µm) - 9.6
  - Band Type - IR

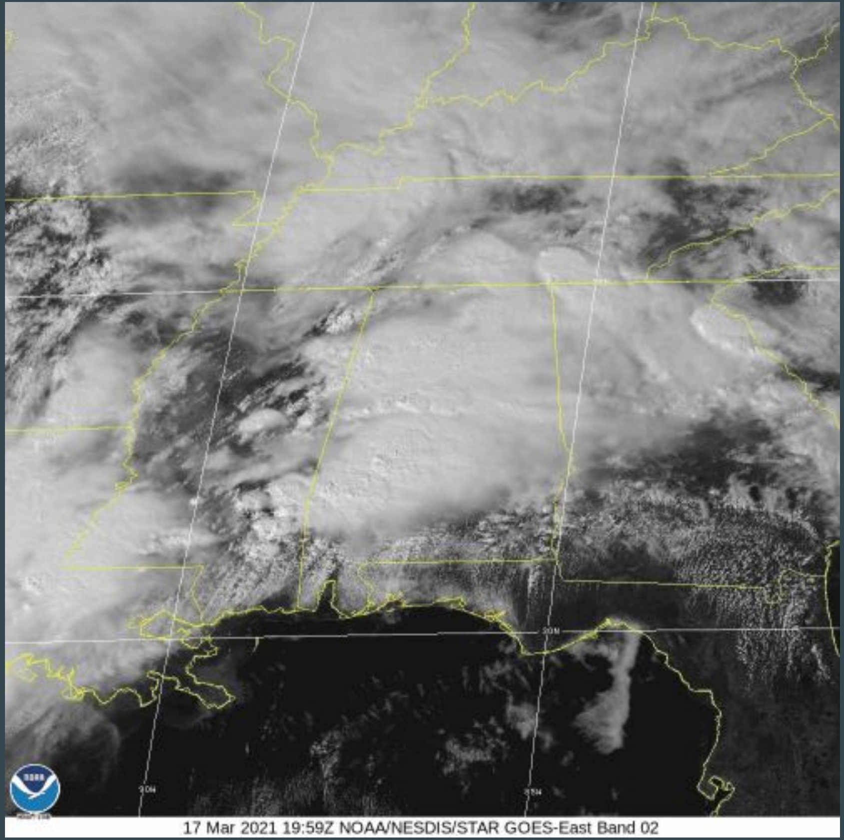




NWS Nashville, TN

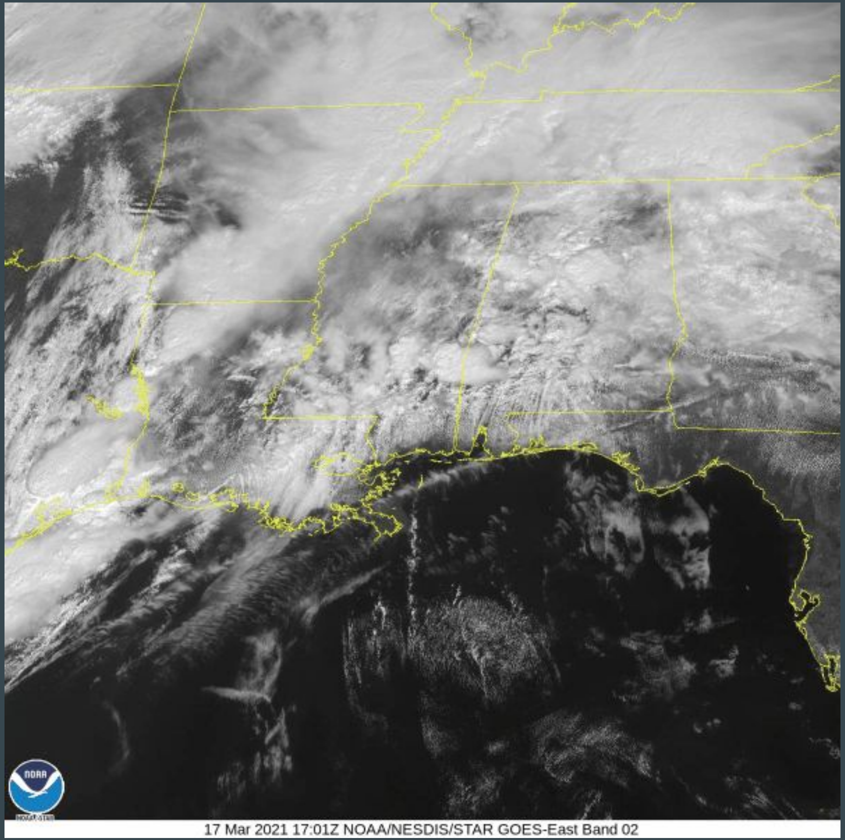
GOES-16 in action
March 17th, 2021

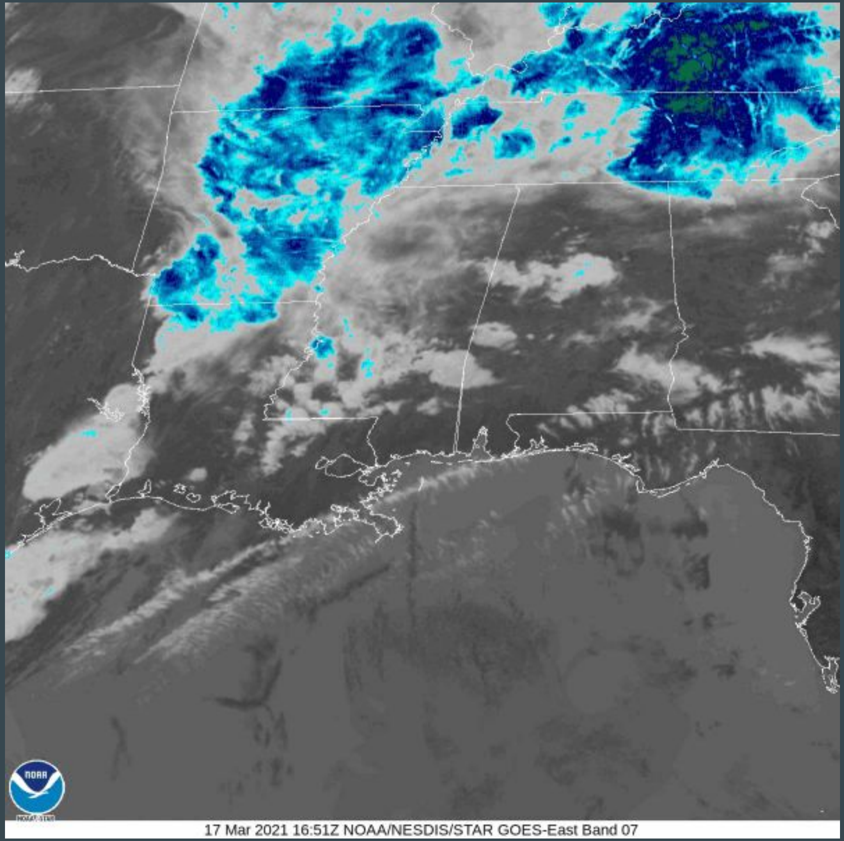




NWS Nashville, TN

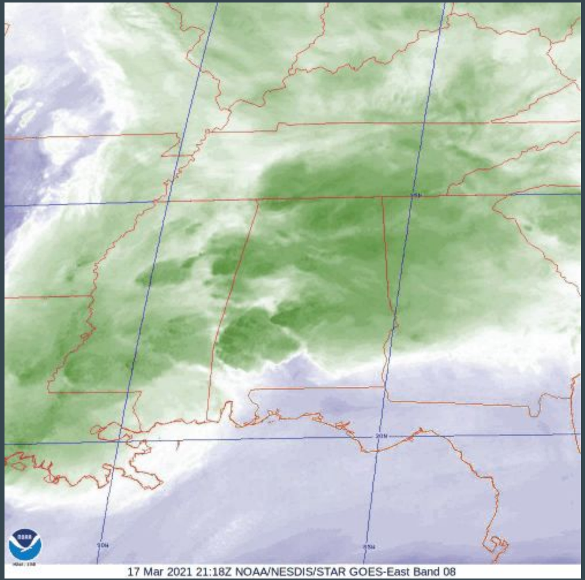
GOES-16 in action
March 17th, 2021

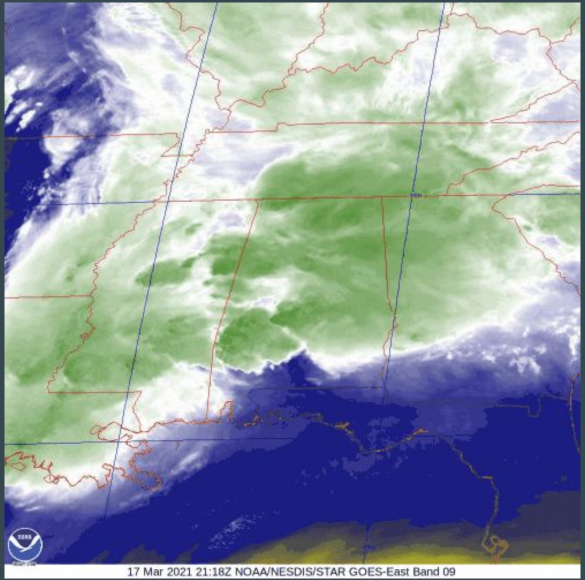


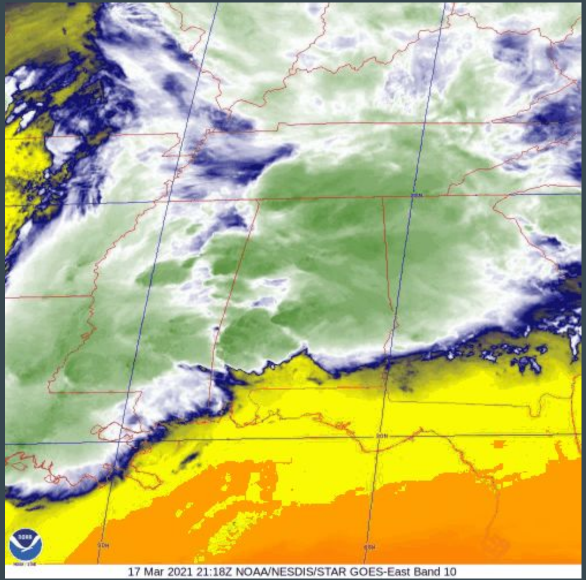


NWS Nashville, TN

GOES-16 in action
March 17th, 2021

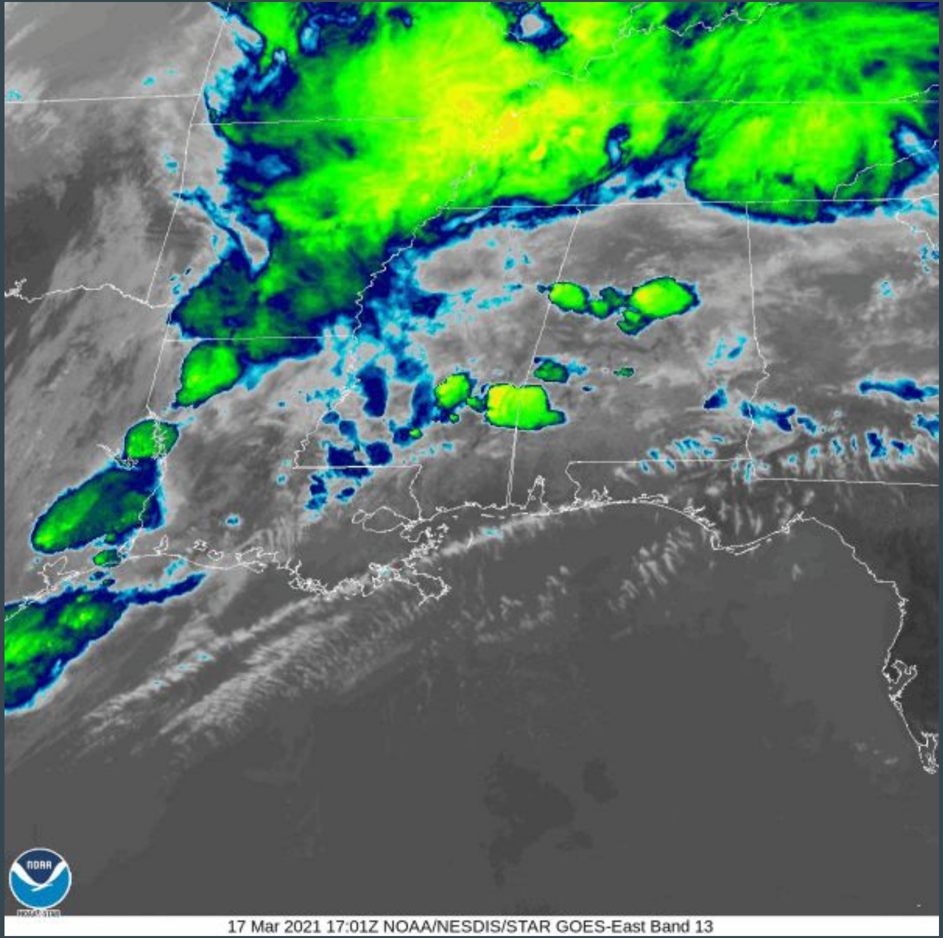






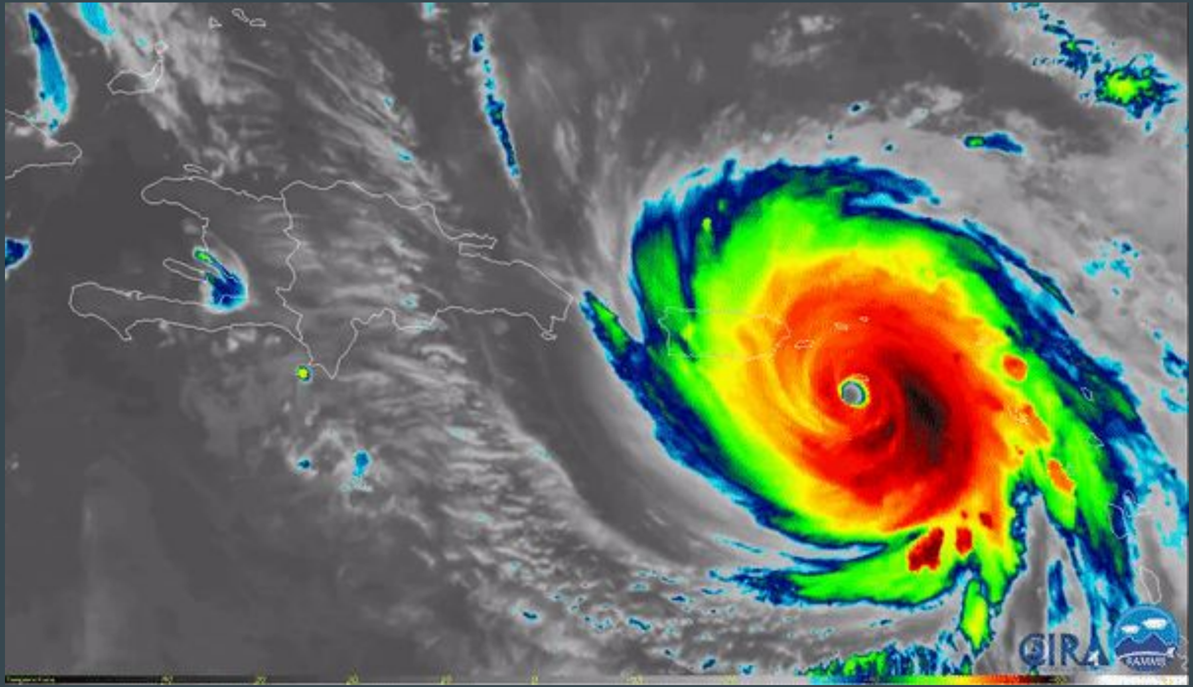
NWS Nashville, TN

GOES-16 in action
March 17th, 2021



NWS Nashville, TN

GOES-16 in action
Hurricane Maria



NWS Nashville, TN

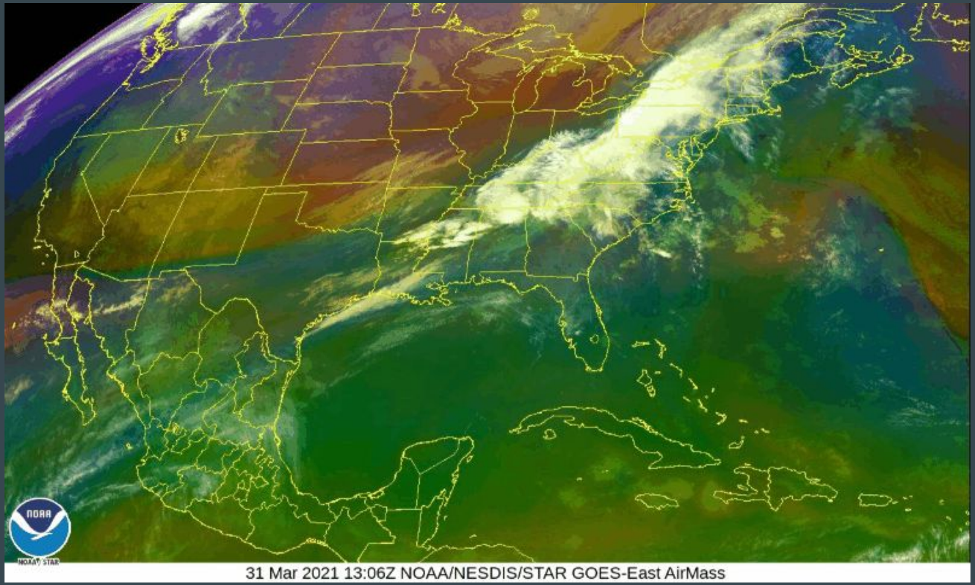
Additional GOES Features - RGB Products

- RGB - Red, Green, Blue
  - Combines different channels to highlight the presence and evolution of important meteorological phenomena including: fog, dust, fire hot spots, smoke, snow/ice, volcanic ash plumes, cloud properties, air mass temperatures, etc.
- Two or more ABI channels (or channel differences) are assigned “red”, “green”, and “blue” color properties that can be used to help distinguish features that some single-channel images can’t.

Youtube Link - https://youtu.be/JhBuHiXzsH0

Additional GOES Features - RGB Products

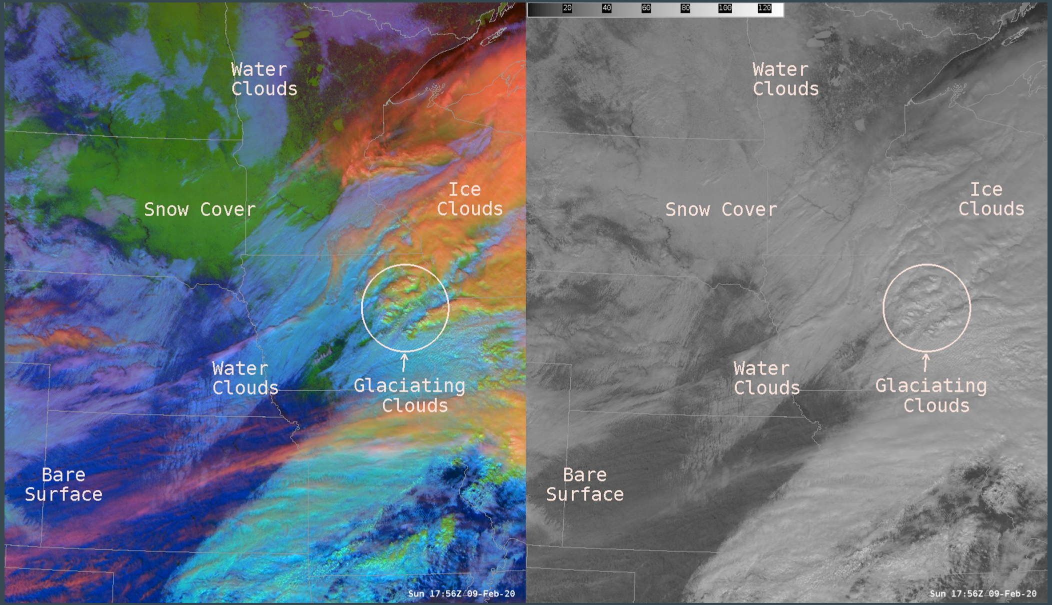
- Dust
- Air Mass
- Ash
- Fire Temperature
- Day Snow Fog
- Day Cloud Convection
- Nighttime Microphysics
- Differential Water Vapor
- SO_2
- Day Land Cloud Fire
- Day Land Cloud
- Day Convection
- Day Cloud Phase Distinction
- CIMSS Natural True Color
- Simple Water Vapor



NWS Nashville, TN

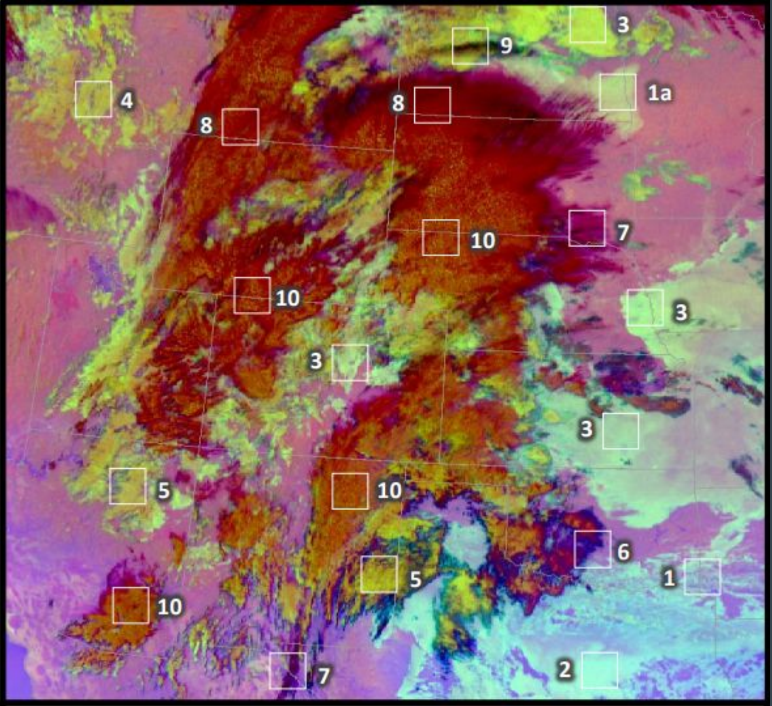
GOES Example - Day Cloud Phase Distinction RGB

- Day Cloud Phase Distinction
  - Red: Clean LWIR (Ch. 13)
  - Green: Red Visible (Ch. 2)
  - Blue: Snow/Ice (Ch. 5)
- Allows us to have a better understanding and differentiate between weather phenomenon



GOES Example - Nighttime Microphysics RGB

- Red: Dirty LWIR (Ch. 15) minus Clean LWIR (Ch. 13)
  - Optical depth
  - Thin clouds vs. thick clouds
- Green: Clean LWIR (Ch. 13) minus Shortwave IR (Ch. 7)
  - Particle phase and size
  - Ice particles vs. water clouds
- Blue: LWIR (Ch. 13)
  - Temperature of surface
  - Cold surface vs. warm surface



NtMicro RGB from GOES-16 ABI at 1127 UTC, 28 March 2017.

RGB Interpretation

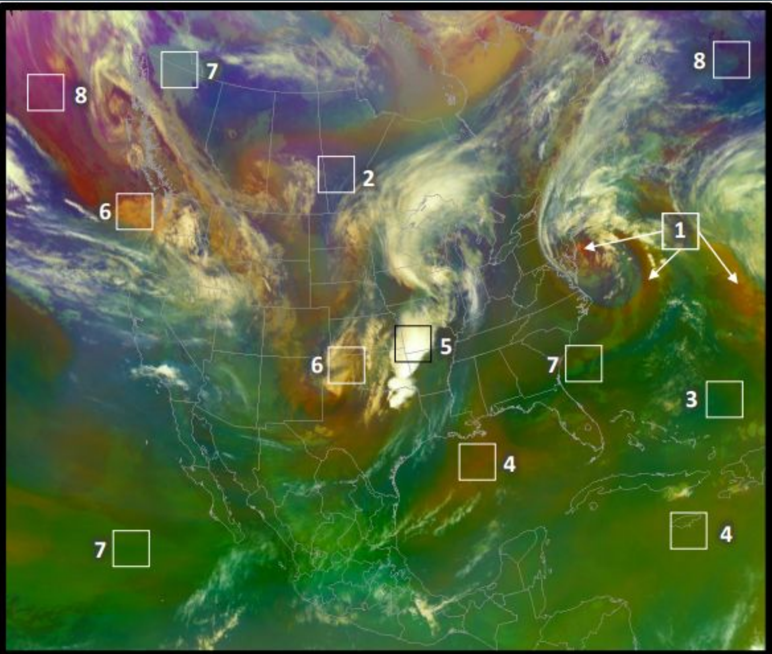
- 1 — Fog *(dull aqua to gray)*
- 1a — Fog – cold regime *(dull yellow-green to gray)*
- 2 — Very low, warm cloud *(aqua)*
- 3 — Low, cool, cloud *(bright green)*
- 4 — Mid water cloud *(light green)*
- 5 — Mid, thick, water/ ice cloud *(tan)*
- 6 — High, thin, ice cloud *(dark blue)*
- 7 — High, very thin, ice cloud *(purple)*
- 8 — High, thick cloud *(dark red)*
- 9 — High, opaque cirrus cloud *(near black)*
- 10 — High, thick, very cold cloud *(red/yellow, noisy)*

Note:, colors may vary diurnally, seasonally, and latitudinally

NWS Nashville, TN

GOES Example - Airmass RGB

- Red: Upper-Level Water Vapor (Ch. 8) minus Low-Level Water Vapor (Ch. 10)
  - Vertical water vapor difference
  - Moist or dry upper levels
- Green: Ozone (Ch. 12) minus Clean LWIR (Ch. 13)
  - Tropopause height based on ozone
  - Low tropopause and high ozone or vice versa
- Blue: Upper-Level Tropospheric Water Vapor (Ch. 8)
  - 200mb to 500mb water vapor
  - Dry or moist upper levels



Air Mass RGB from GOES-16 ABI at 1245 UTC, April 26 2017.

RGB Interpretation

1. **Jet stream / PV / deformation zones / dry upper level** *(dark red/orange)*
2. **Cold air mass** *(dark blue/purple)*
3. **Warm air mass** *(green)*
4. **Warm air mass, less moisture** *(olive/dark orange)*
5. **High thick cloud** *(white)*
6. **Mid-level cloud** *(tan/salmon)*
7. **Low-level cloud** *(green, dark blue)*
8. **Limb effects** *(purple/blue)*

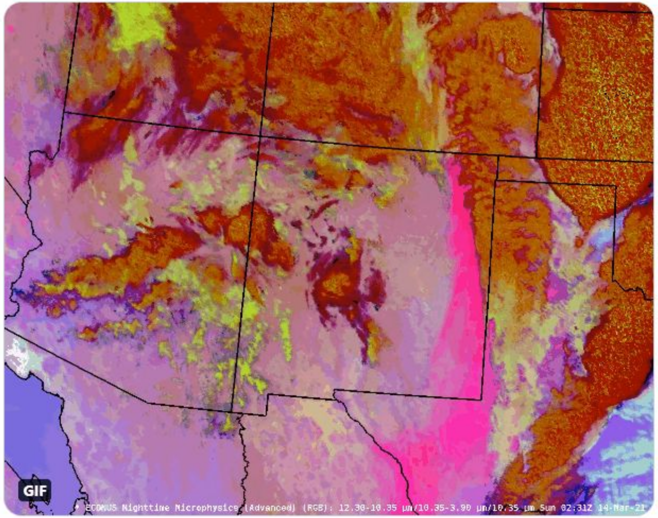
Note: colors may vary diurnally, seasonally, and latitudinally

GOES Example - Dust RGB

- Red: Dirty LWIR (Ch. 15) minus Clean LWIR (Ch. 13)
  - Optical depth
  - Thin clouds vs. thick clouds or dust
- Green: LWIR (Ch. 14) minus Cloud-Top Phase (Ch. 11)
  - Particle phase
  - Water particles vs. thin cirrus over deserts
- Blue: Clean LWIR (Ch. 13)
  - Temperature of surface
  - Cold surface vs. warm surface

NWS Albuquerque
@NWSAlbuquerque

The dust that was lofted this afternoon from the playas in Mexico (hot pink on the satellite imagery) has now been transported all the way into Colorado! Fortunately, the dust seems to be above the surface, so no restrictions to visibility in NM. #nmwx



9:48 PM · Mar 13, 2021 · TweetDeck

RGB Interpretation

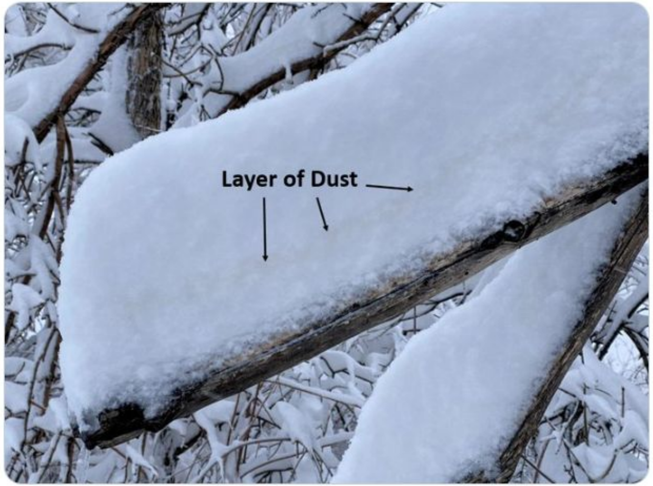
1. **Dust plume (day)** *(bright magenta, pink)*
   Note: Dust at night becomes purple shades below 3 km
2. **Low, water cloud** *(light purple, not shown)*
3. **Desert surface (day)** *(light blue, not shown)*
4. **Mid, thick clouds** *(tan shades)*
5. **Mid, thin cloud** *(green)*
6. **Cold, thick clouds** *(red)*
7. **High, thin ice clouds** *(black)*
8. **Very thin cloud (Over warm surface)** *(blue)*

Note: colors may vary diurnally, seasonally, and latitudinally

GOES Example - Dust RGB

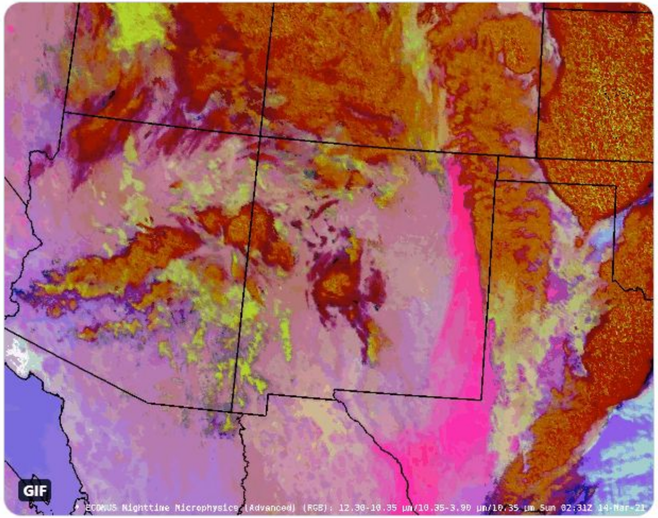
NWS Boulder
@NWSBoulder

Check it out! We received a few comments that people saw a brownish layer in the snow and we were able to capture a picture of it here at the office. This is actually a layer of dust transported from Mexico! @NWSAlbuquerque pointed it out on satellite last night. #COwx



NWS Albuquerque
@NWSAlbuquerque

The dust that was lofted this afternoon from the playas in Mexico (hot pink on the satellite imagery) has now been transported all the way into Colorado! Fortunately, the dust seems to be above the surface, so no restrictions to visibility in NM. #nmwx



9:48 PM · Mar 13, 2021 · TweetDeck

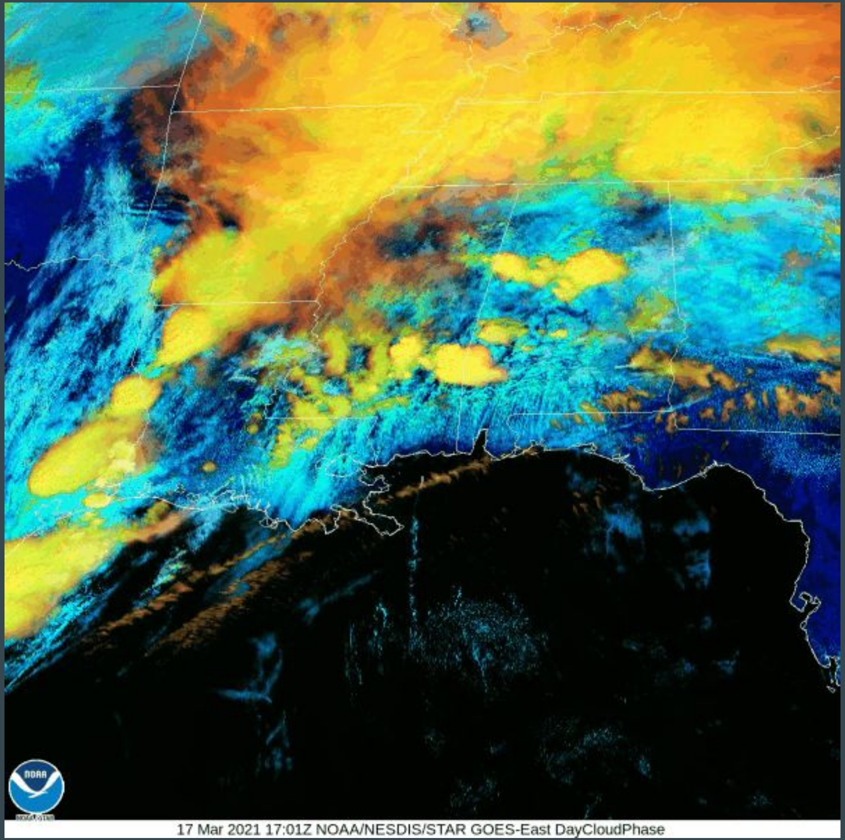
RGB Interpretation

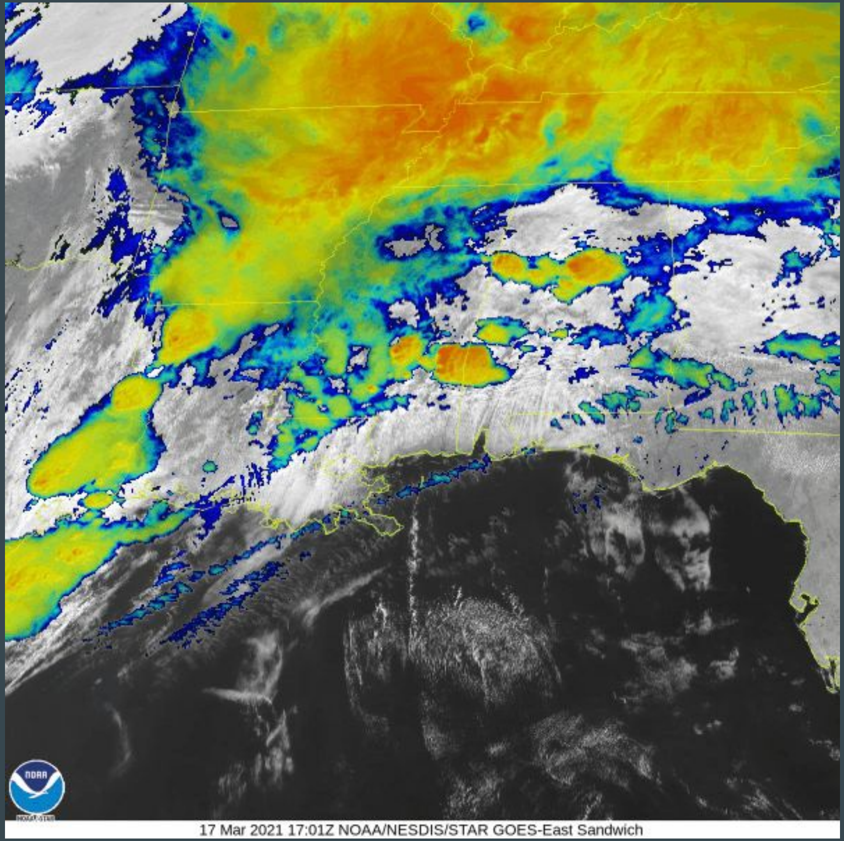
1. **Dust plume (day)** *(bright magenta, pink)*
   Note: Dust at night becomes purple shades below 3 km
2. **Low, water cloud** *(light purple, not shown)*
3. **Desert surface (day)** *(light blue, not shown)*
4. **Mid, thick clouds** *(tan shades)*
5. **Mid, thin cloud** *(green)*
6. **Cold, thick clouds** *(red)*
7. **High, thin ice clouds** *(black)*
8. **Very thin cloud (Over warm surface)** *(blue)*

Note: colors may vary diurnally, seasonally, and latitudinally

NWS Nashville, TN

GOES-16 in action
March 17th, 2021



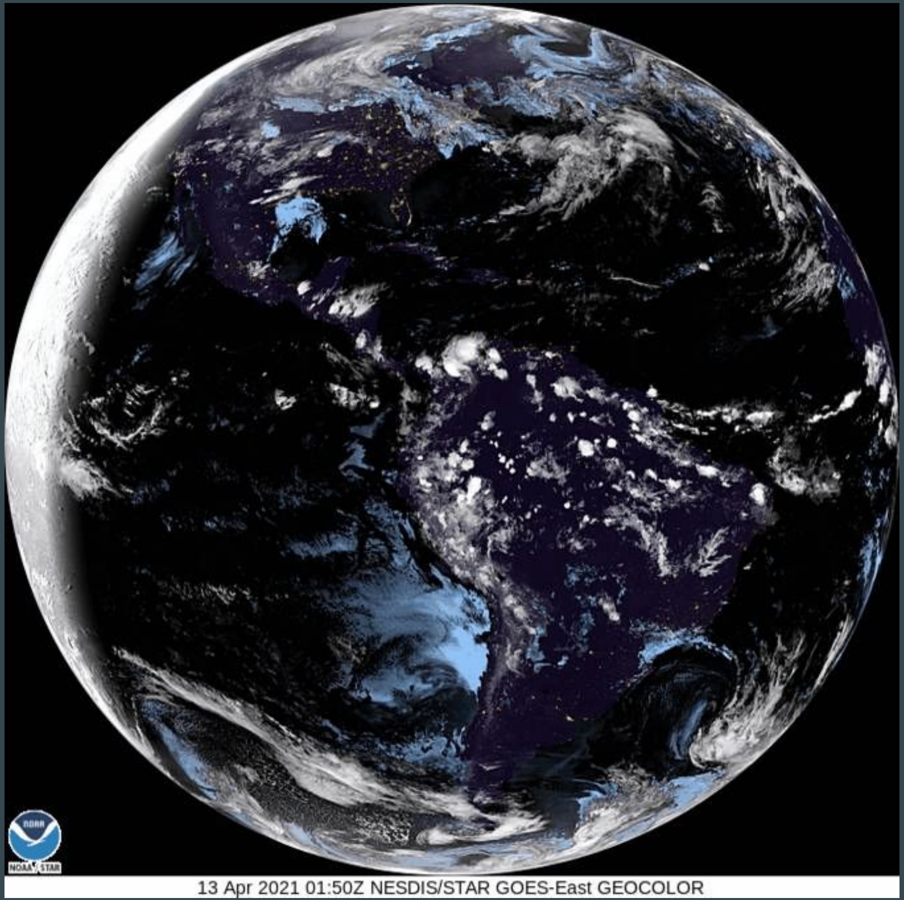


NWS Nashville, TN

GOES Example - GeoColor

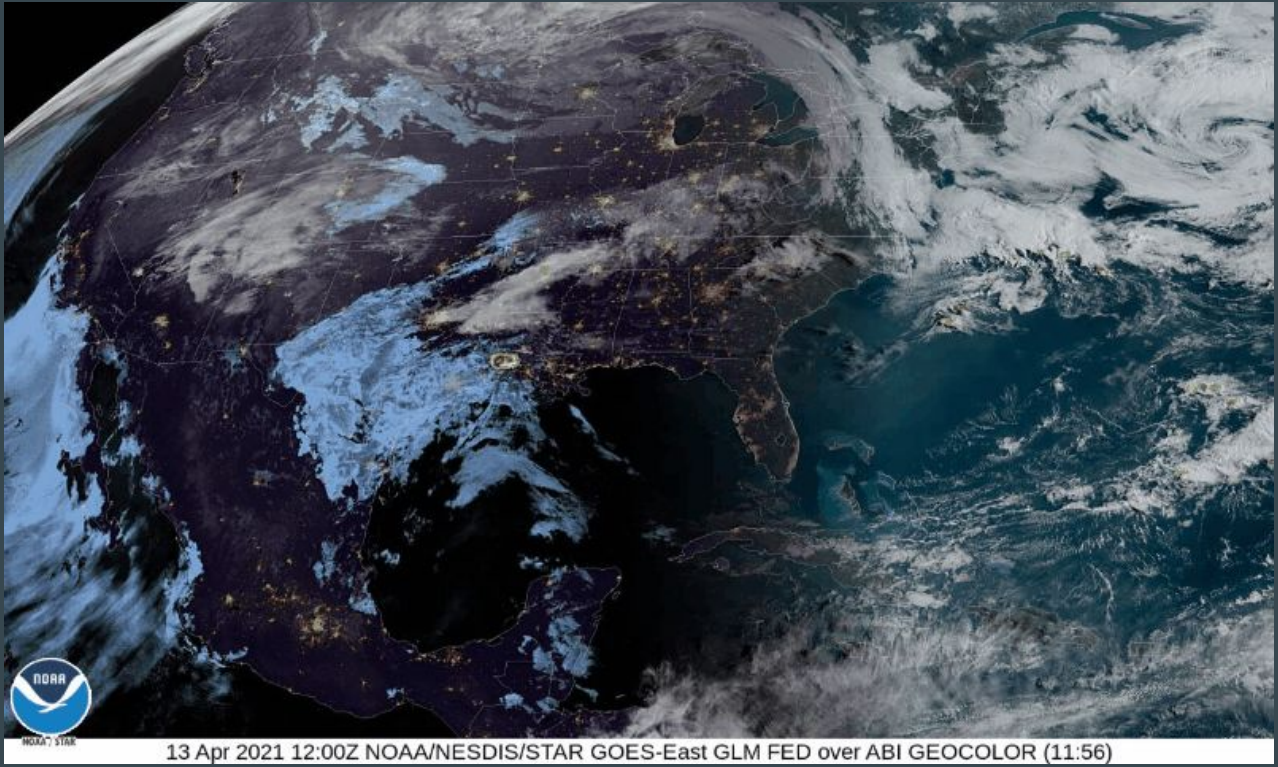
Geocolor uses a total of five channels from the GOES-R ABI.

- Daytime:
  - Combination of:
    - Channel 1 : “blue” band - 0.47 μm
    - Channel 2: “red” band - 0.64 μm
    - Channel 3: “veggie” band - 0.86 μm
  - Simulated from data using Himawari-8 AHI “green” channel (0.51 μm) (Japanese)
- Nighttime:
  - Uses a combination of channel 13 (10.3 μm “Clean IR” and a traditional fog product (10.3 μm - 3.9 μm)
    - 3.9 μm is from Channel 7



NWS Nashville, TN

GOES Example - GLM Lightning



GLM Extent Density of Lightning is the number of lightning flashes that occur within a grid cell over a given period of time, and was the first GLM product routinely available to NWS forecasters.

GOES Satellites - Benefits and Applications

- Improved hurricane track and intensity forecasts
- Increased thunderstorm and tornado warning lead time
- Earlier warning of lightning ground strike hazards
- Better detection of heavy rainfall and flash flood risks
- Better monitoring of smoke and dust
- Improved air quality warnings and alerts
- Better fire detection and intensity estimation
- Improved detection of low cloud/fog
- Improved transportation safety and aviation route planning
- Improved warning for communications and navigation disruptions and power blackouts
- More accurate monitoring of energetic particles responsible for radiation hazards

GOES Satellites - Advantages and Disadvantages

- Advantages
  - Always located in the same spot and can view the entire earth at once (one side at least)
  - High temporal resolution
    - CONUS scan every 5 minutes, mesoscale every minute
    - Very useful for severe weather and nowcasting
- Disadvantages
  - Visible channels only available during daylight hours
    - Can't use any RGB products that have visible components
  - Spatial resolution is not the best
    - Located 22,300 miles from Earth
    - Polar orbiting satellites have much higher spatial resolution
    - Views of polar regions is limited due to the earth's curvature

Question Time

Questions?

caroline.adcock@noaa.gov