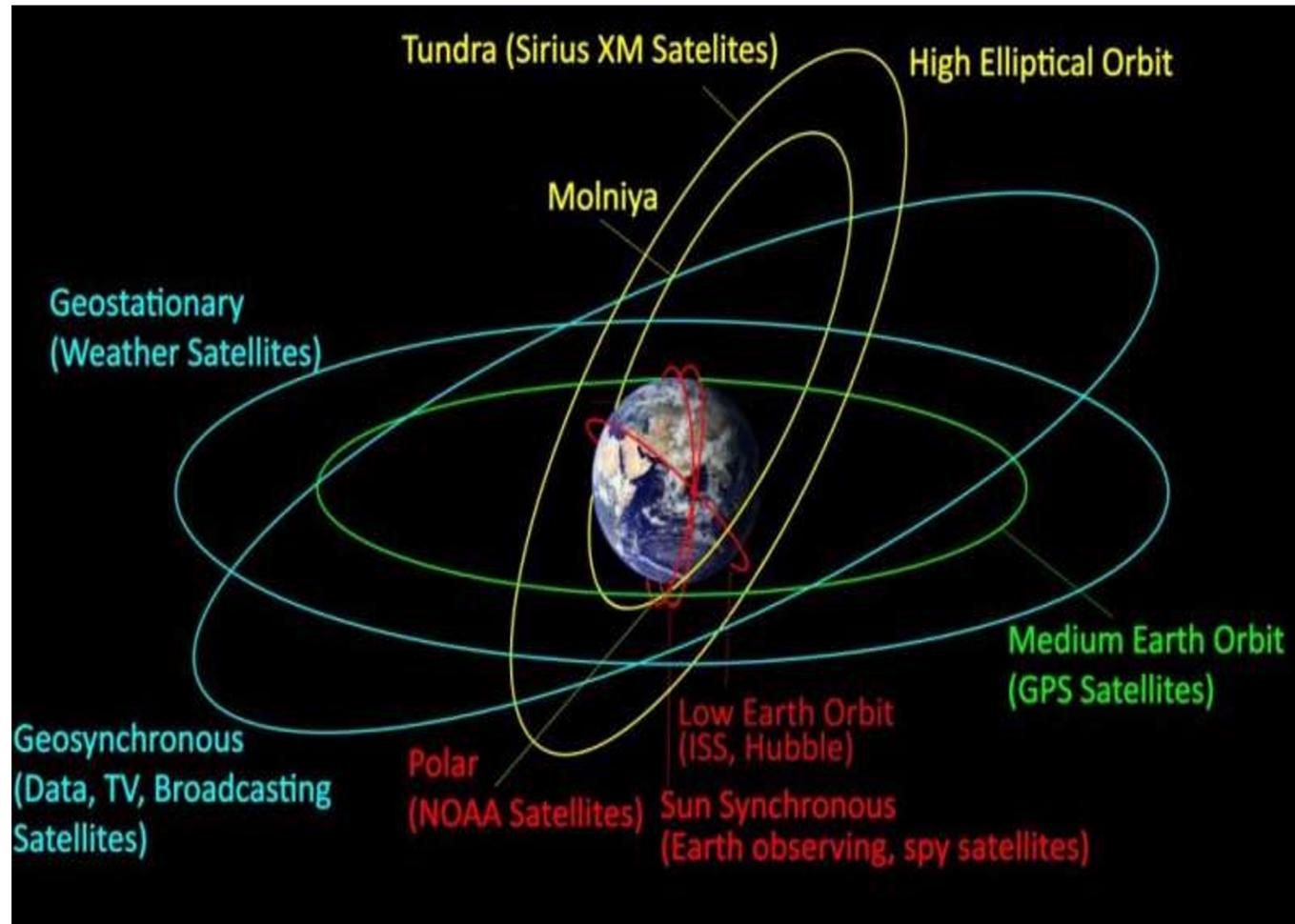


Weather Satellites and You



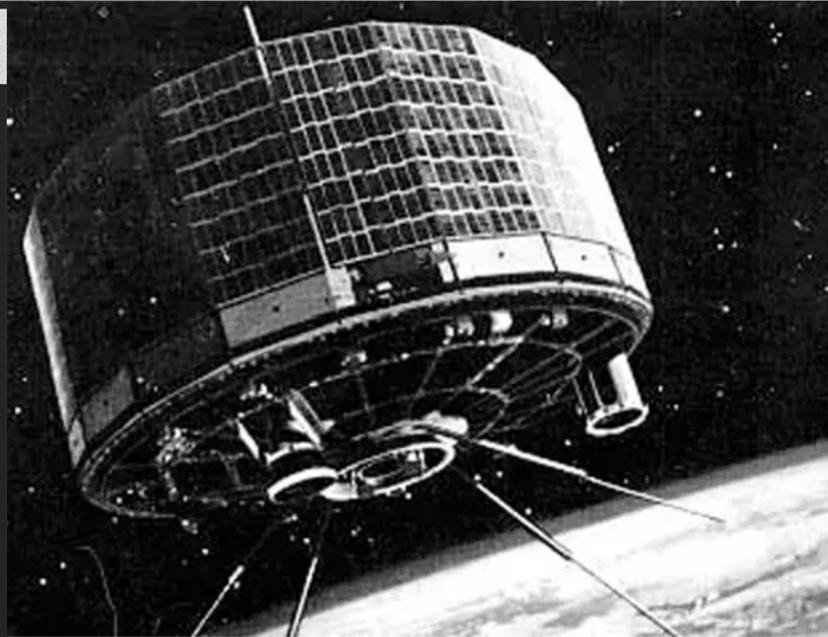
Artificial Satellite History and Orbits

- USSR launched Sputnik 1 on OCT 4 1957 becoming the first artificial vehicle to achieve orbit.
- US Responds with “Explorer 1” Jan 31 1958
- The space race begins and continues today.
- 14,904 human launched satellites are currently in various orbits.
 - Mostly Starlink



The First Weather Satellite

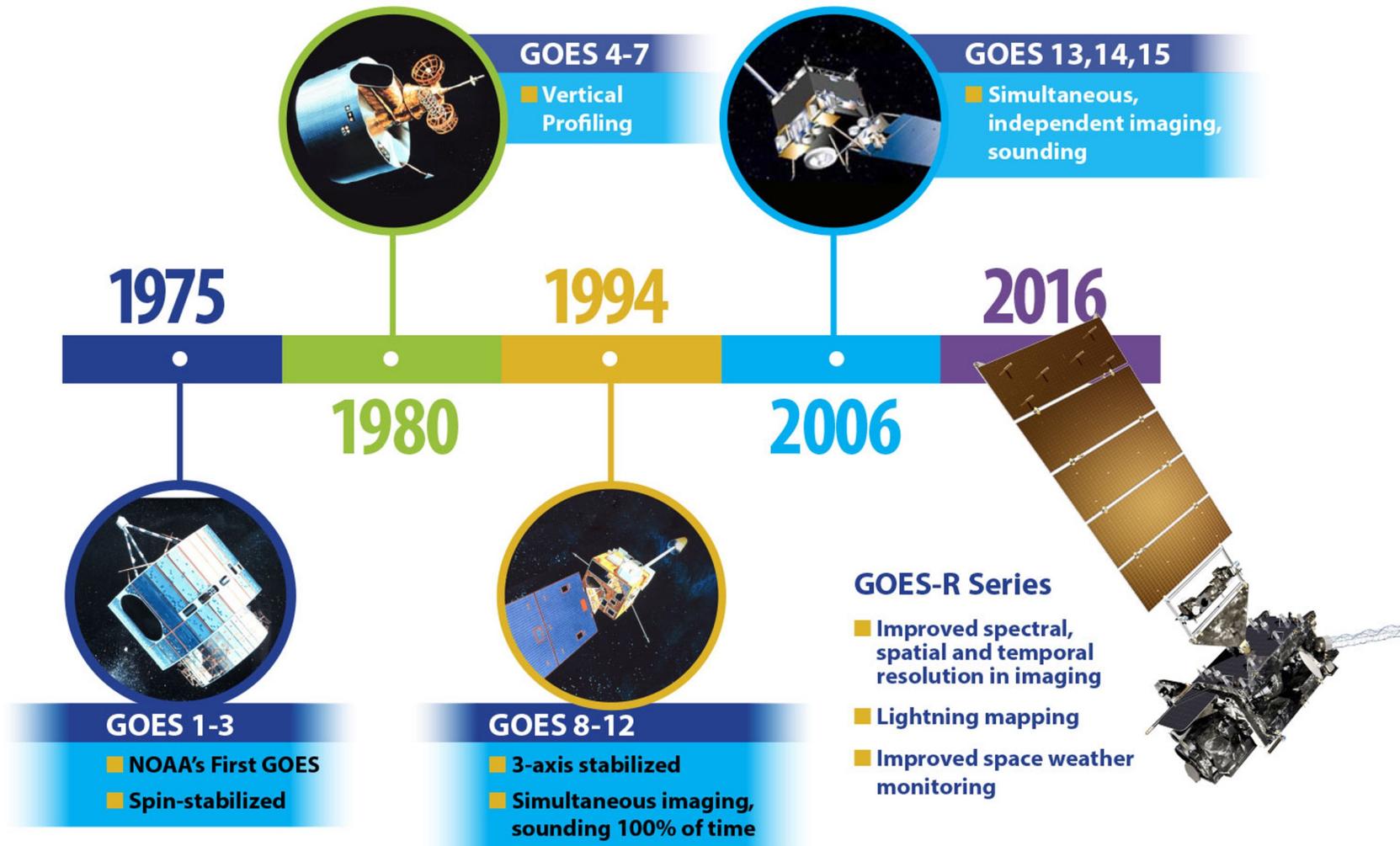
FIRST TELEVISION PICTURE FROM SPACE
TIROS I SATELLITE
APRIL 1, 1960



The TIROS-1 satellite. Credit: NASA

- TRIOS-1 Launched by NASA on April 1 1960.
- Two tape television cameras could provide 32 blurry images of clouds over the US.
- Operated for 78 Days. 450 km eccentric orbit

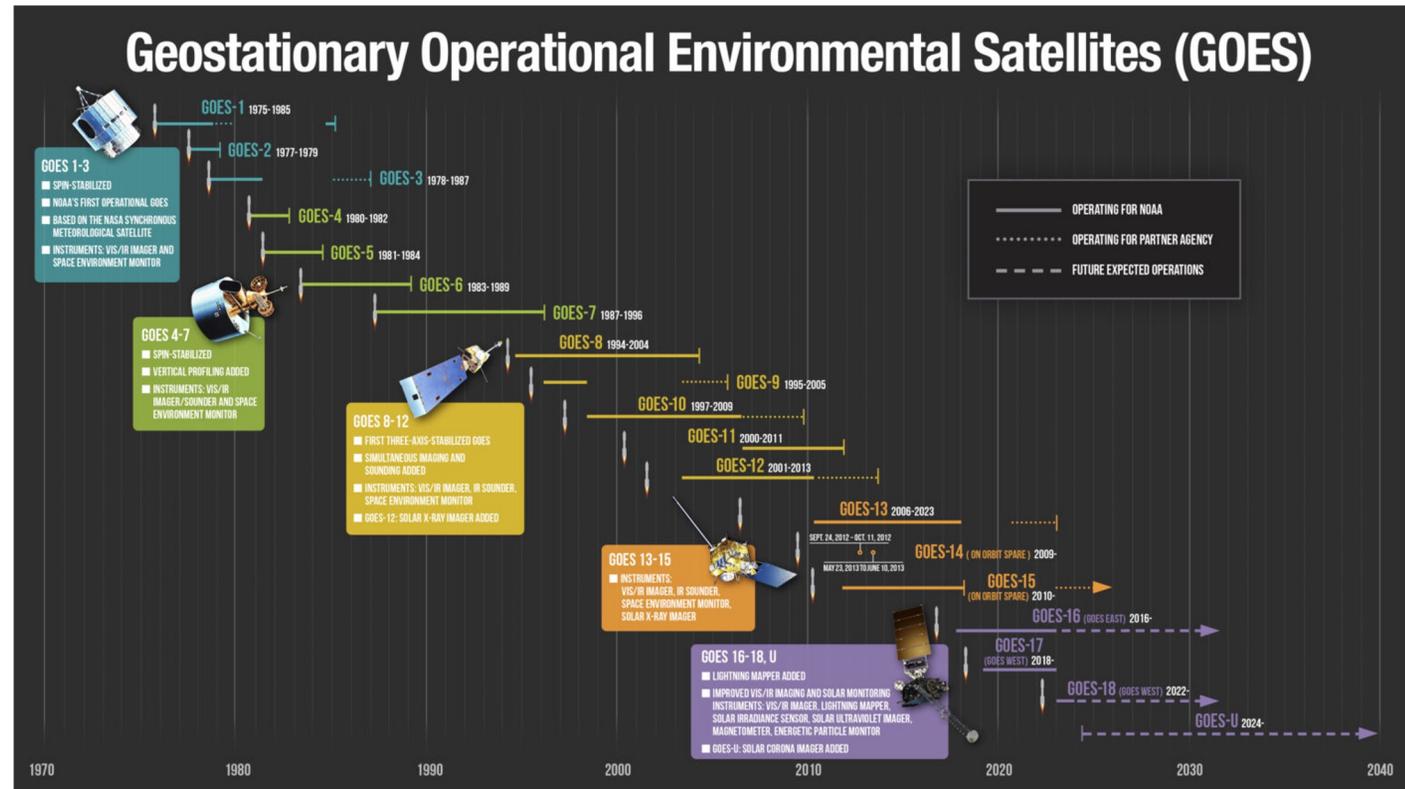
GOES (Geostationary Operational Environmental Satellites)

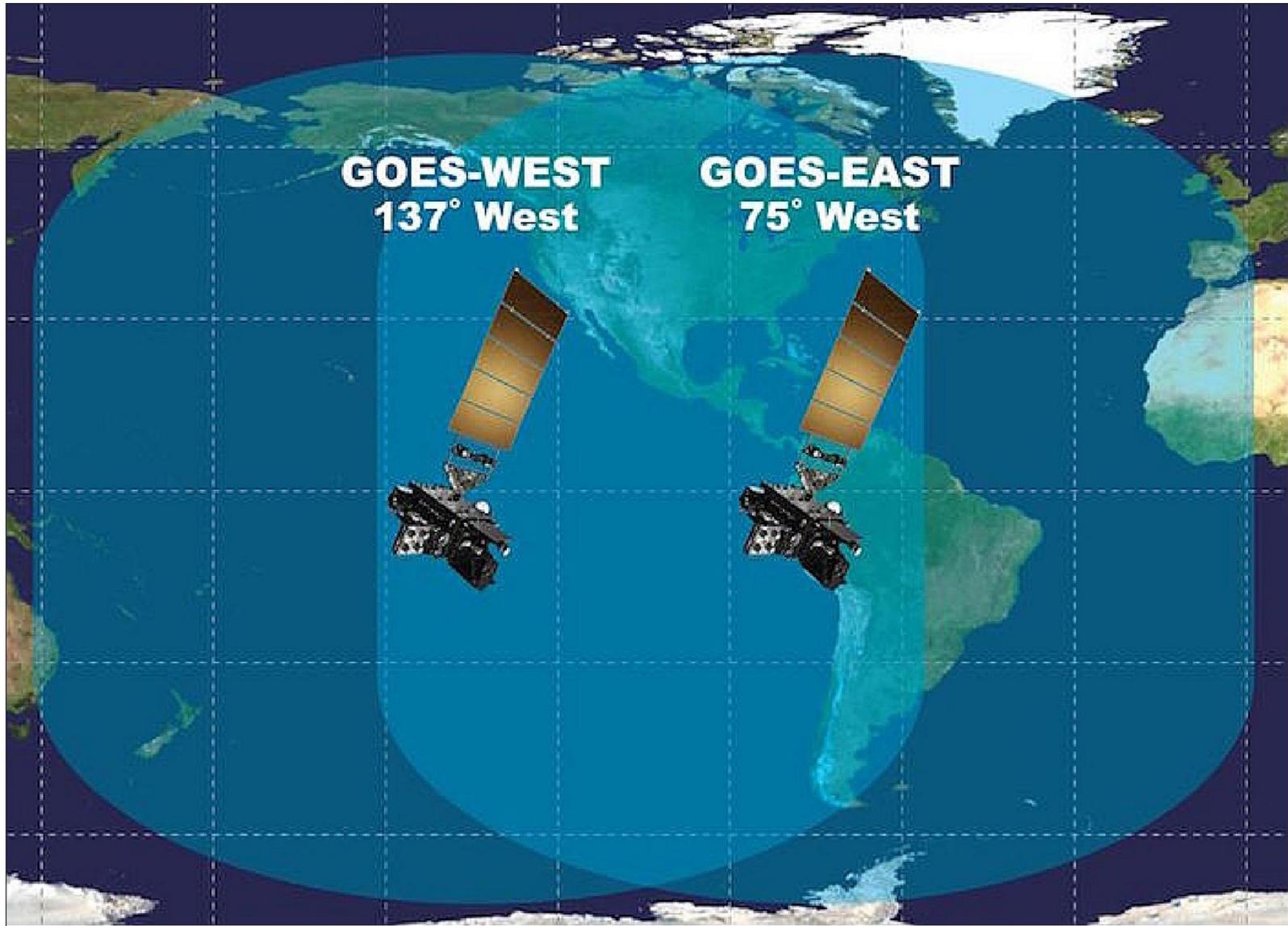


NOAA Operational Spacecraft

Current Spacecraft :

- GOES-19** Operational East
- GOES-18** Operational West
- GOES-16** On-Orbit Storage
- GOES-17** On-Orbit Storage
- GOES-14** On-Orbit Storage





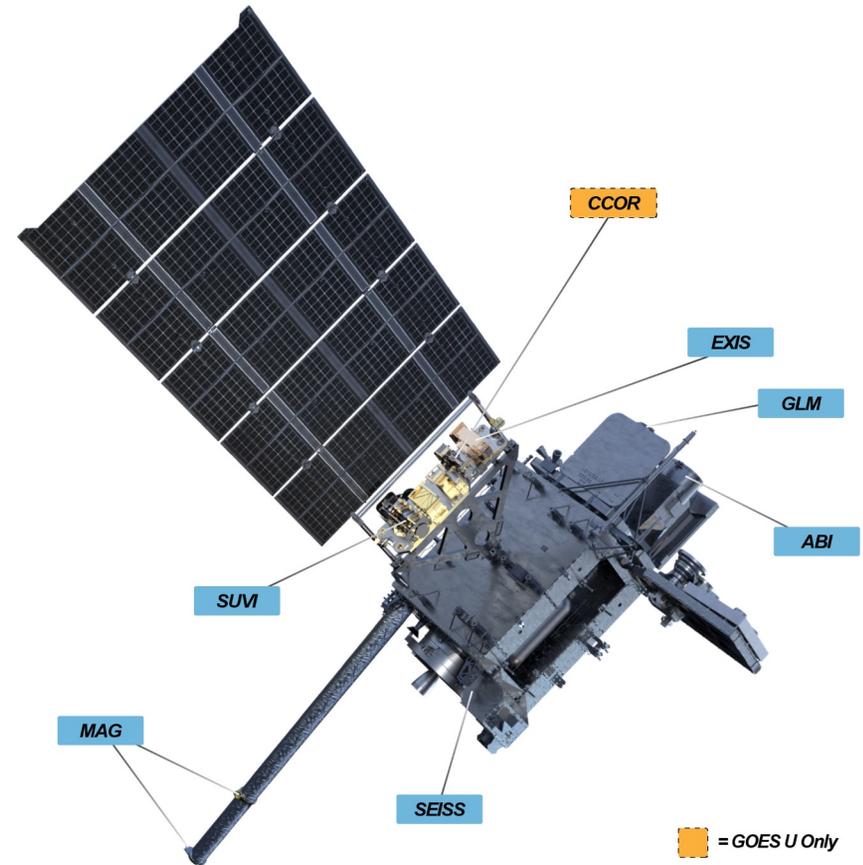
GOES-WEST
137° West

GOES-EAST
75° West

Instruments available GOES R

Instrument:

ABI	Advanced Baseline Imager
SEISS	Space Environment In-Situ Suite
SUVI	Solar Ultraviolet Imager
EXIS	Extreme Ultraviolet and X-ray Irradiance Sen
GMAG	Magnetometer
GLM	Geostationary Lightning Mapper

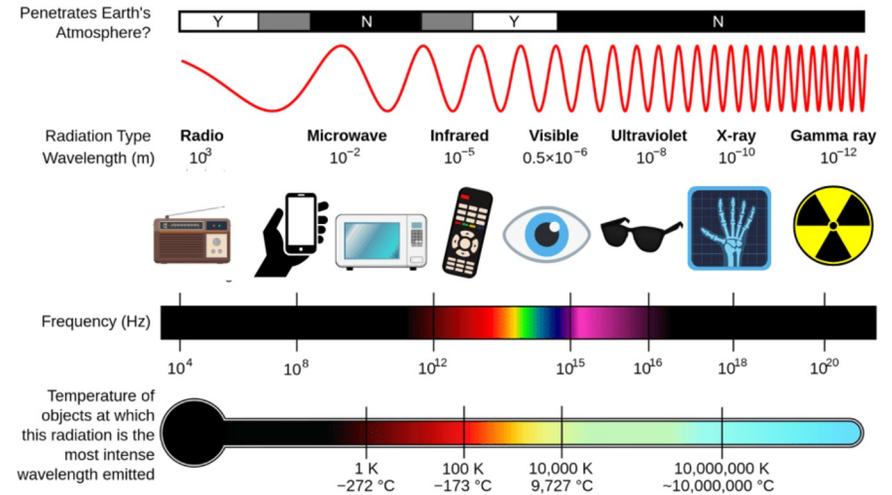


EM Spectrum and Windows

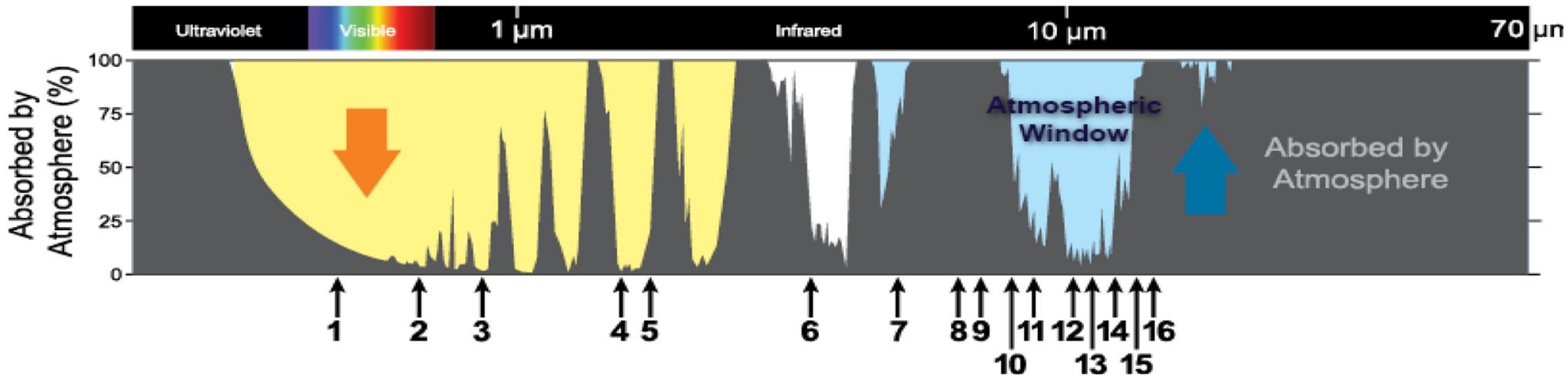
- Because of the size and temp of the Sun our eyes are “tuned” for a small portion of the EM spectrum.
- Multiple other “non-visible” portions are useful.
- Gasses absorb and reflect energy in different “windows” useful for seeing different parts of the atmosphere

Electromagnetic Spectrum

The electromagnetic spectrum is the range of all frequencies of electromagnetic radiation.



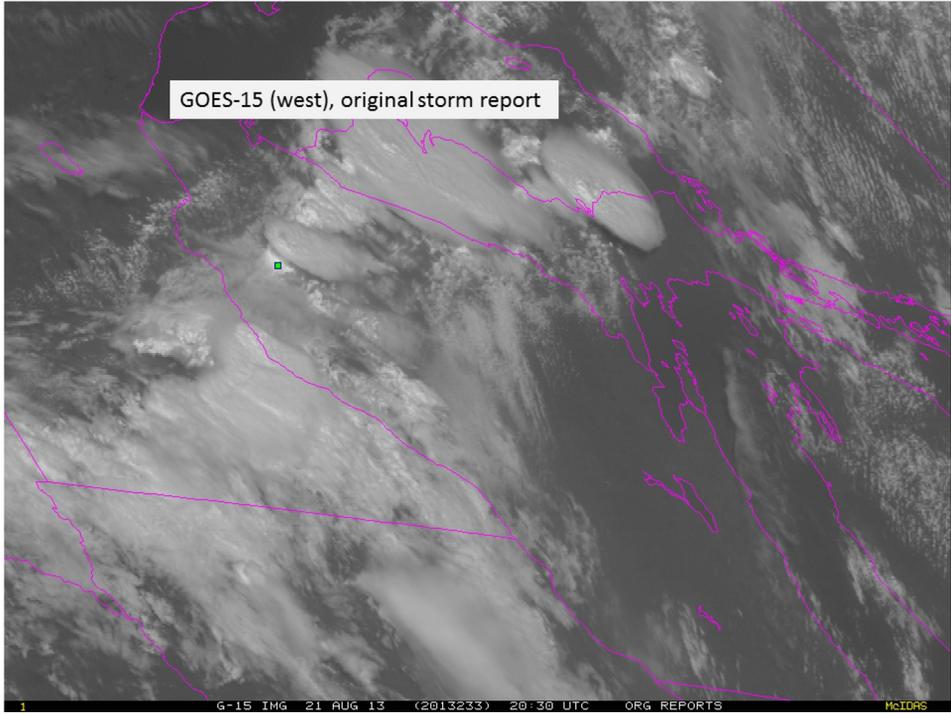
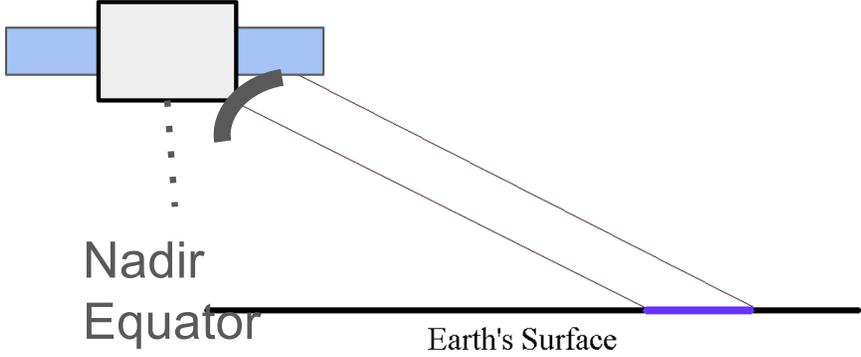
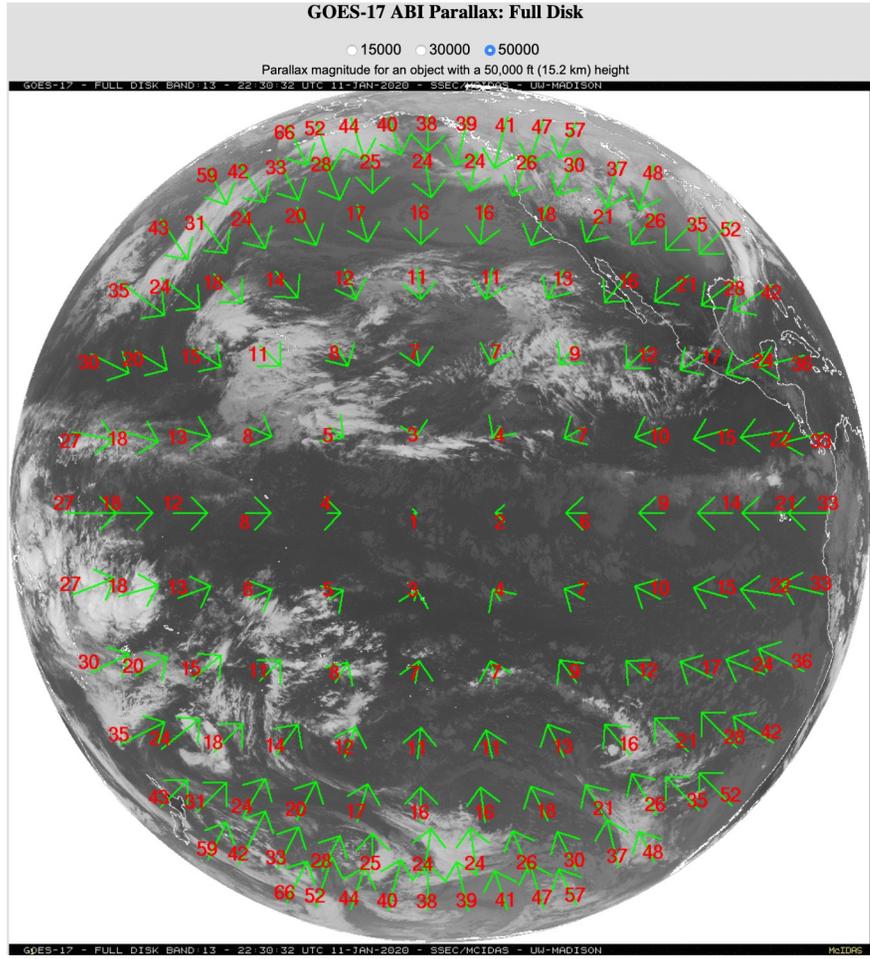
sciencenotes.org

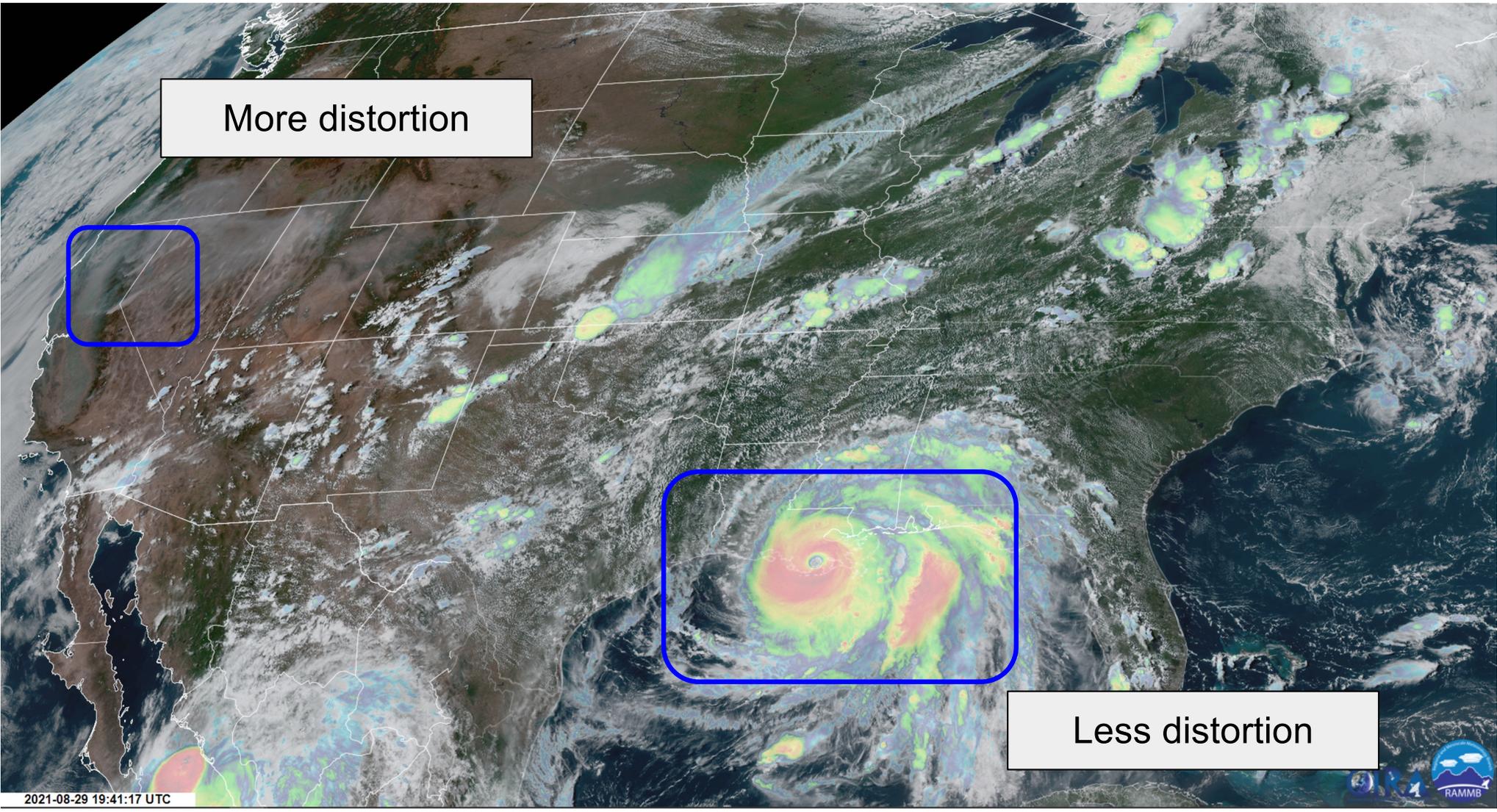


ABI Band	Central Wavelength (μm)	Type	Nickname	Best Spatial Resolution (km)
1	0.47	Visible	Blue	1
2	0.64	Visible	Red	0.5
3	0.86	Near-Infrared	Veggie	1
4	1.37	Near-Infrared	Cirrus	2
5	1.6	Near-Infrared	Snow/Ice	1
6	2.2	Near-Infrared	Cloud particle size	2
7	3.9	Infrared	Shortwave window	2
8	6.2	Infrared	Upper-level water vapor	2
9	6.9	Infrared	Mid-level water vapor	2
10	7.3	Infrared	Lower-level water vapor	2
11	8.4	Infrared	Cloud-top phase	2
12	9.6	Infrared	Ozone	2
13	10.3	Infrared	"Clean" longwave window	2
14	11.2	Infrared	Longwave window	2
15	12.3	Infrared	"Dirty" longwave window	2
16	13.3	Infrared	CO ₂ longwave	2

ABI Band	Central Wavelength (μm)	Type	Nickname	Best Spatial Resolution (km)
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8	6.2	Infrared	Upper-level water vapor	2
9	6.9	Infrared	Mid-level water vapor	2
10	7.3	Infrared	Lower-level water vapor	2
11	8.4	Infrared	Cloud-top phase	2
12	9.6	Infrared	Ozone	2
13	10.3	Infrared	"Clean" longwave window	2
14	11.2	Infrared	Longwave window	2
15	12.3	Infrared	"Dirty" longwave window	2
16	13.3	Infrared	CO ₂ longwave	2

Parallax





More distortion



Less distortion

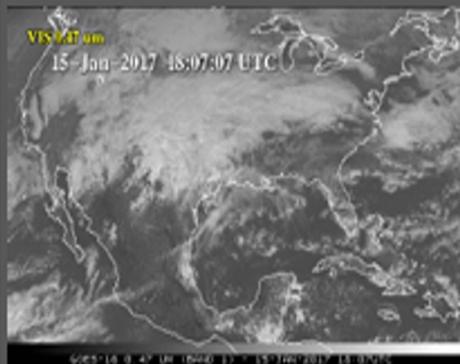
2021-08-29 19:41:17 UTC



Bands (Visible)

GOES-16 Band Reference Guide

Patrick.Ayd@noaa.gov



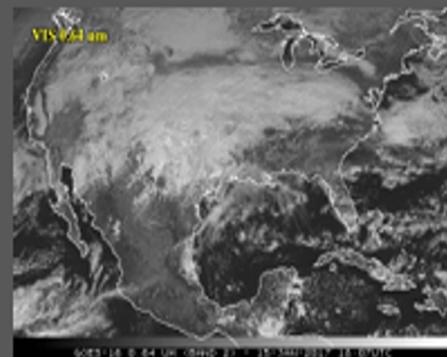
ABI Band #1

0.47 microns

Visible (“Blue Band”)

Primary Uses:

- Monitoring aerosols (smoke, haze, dust)
- Air quality monitoring through measurements of aerosol optical depth



ABI Band #2

0.64 microns

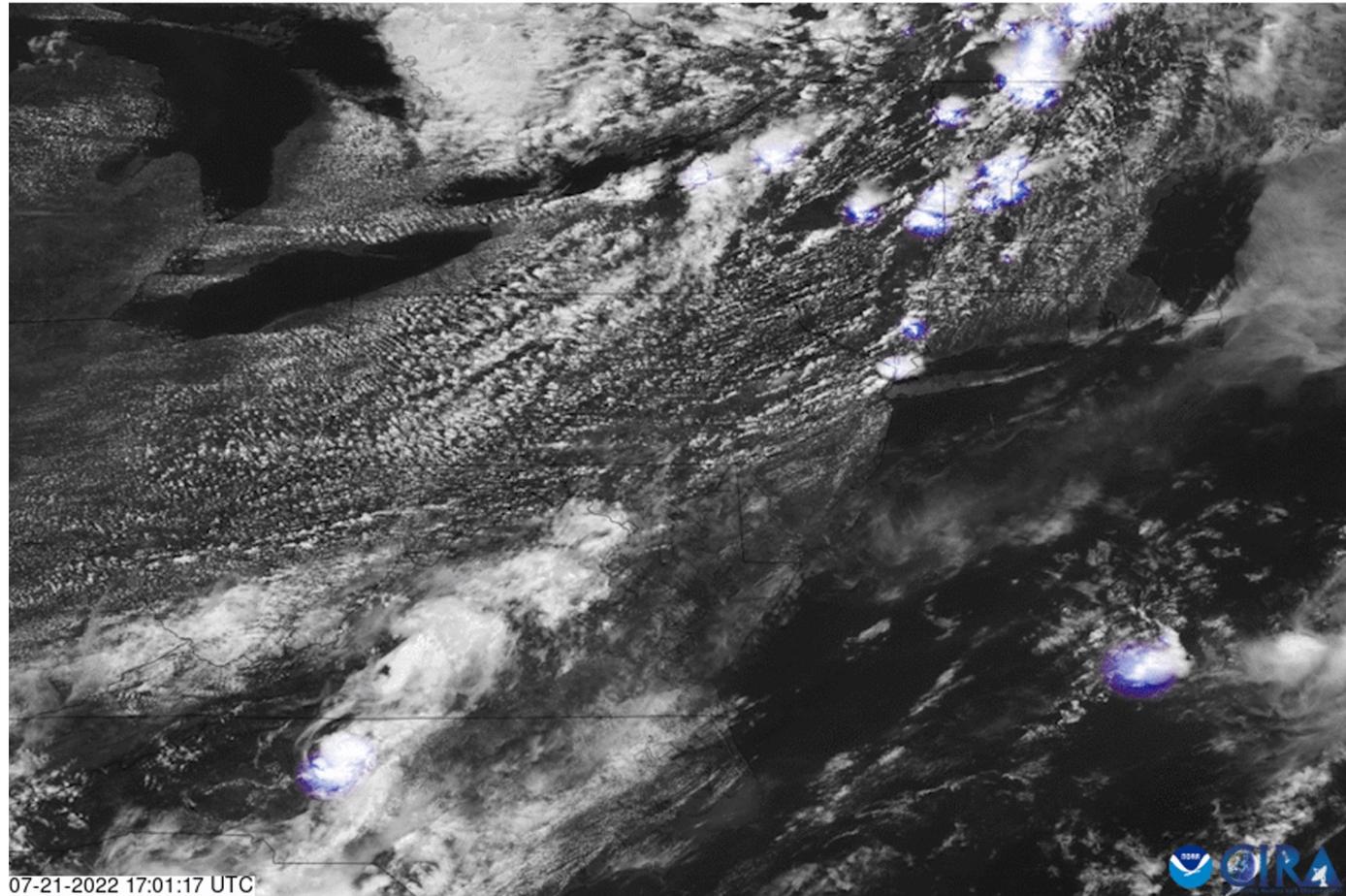
Visible (“Red Band”)

Primary Uses:

- Daytime monitoring of clouds (0.5-km spatial resolution)
- Volcanic ash monitoring

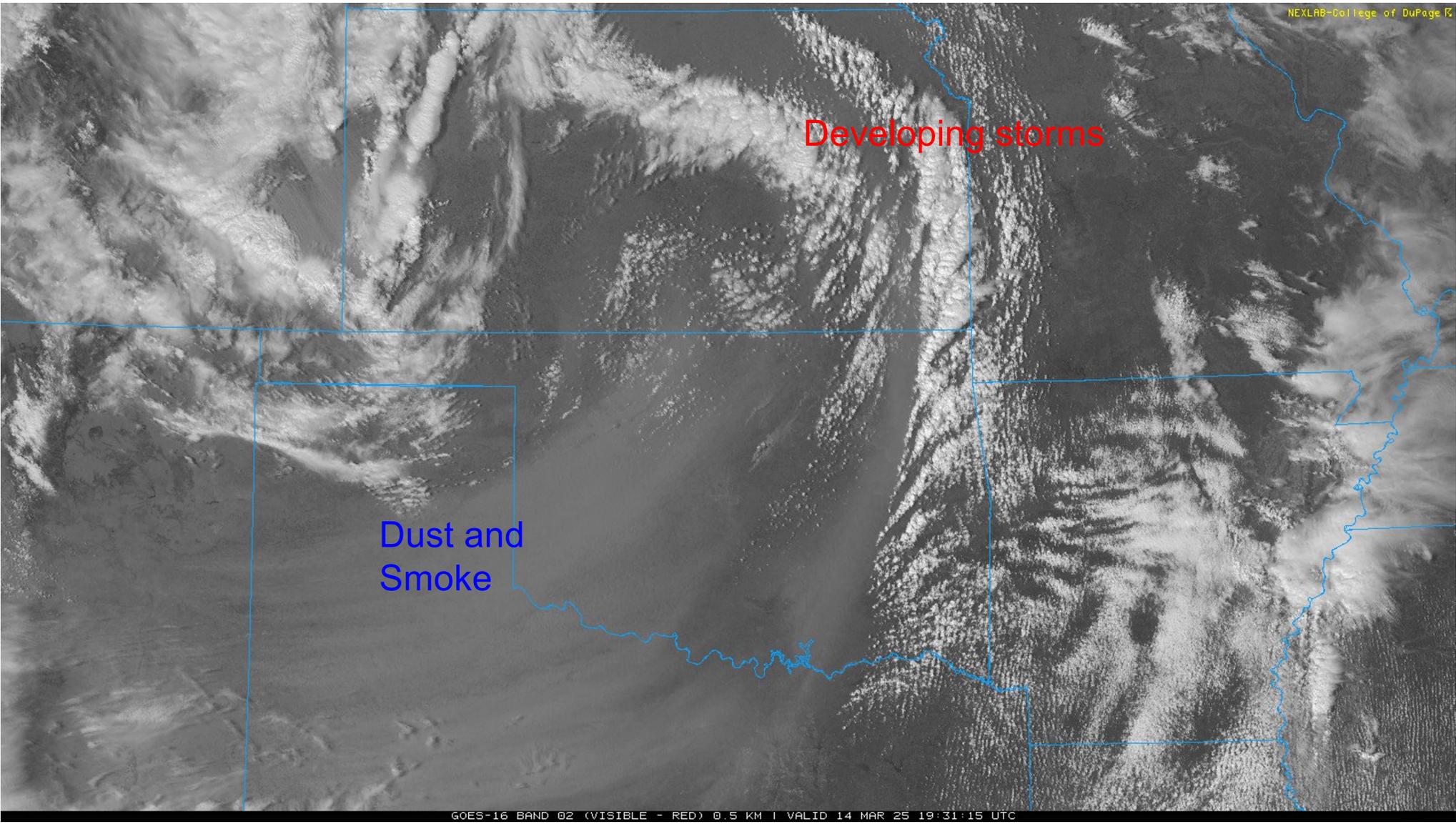
Visible

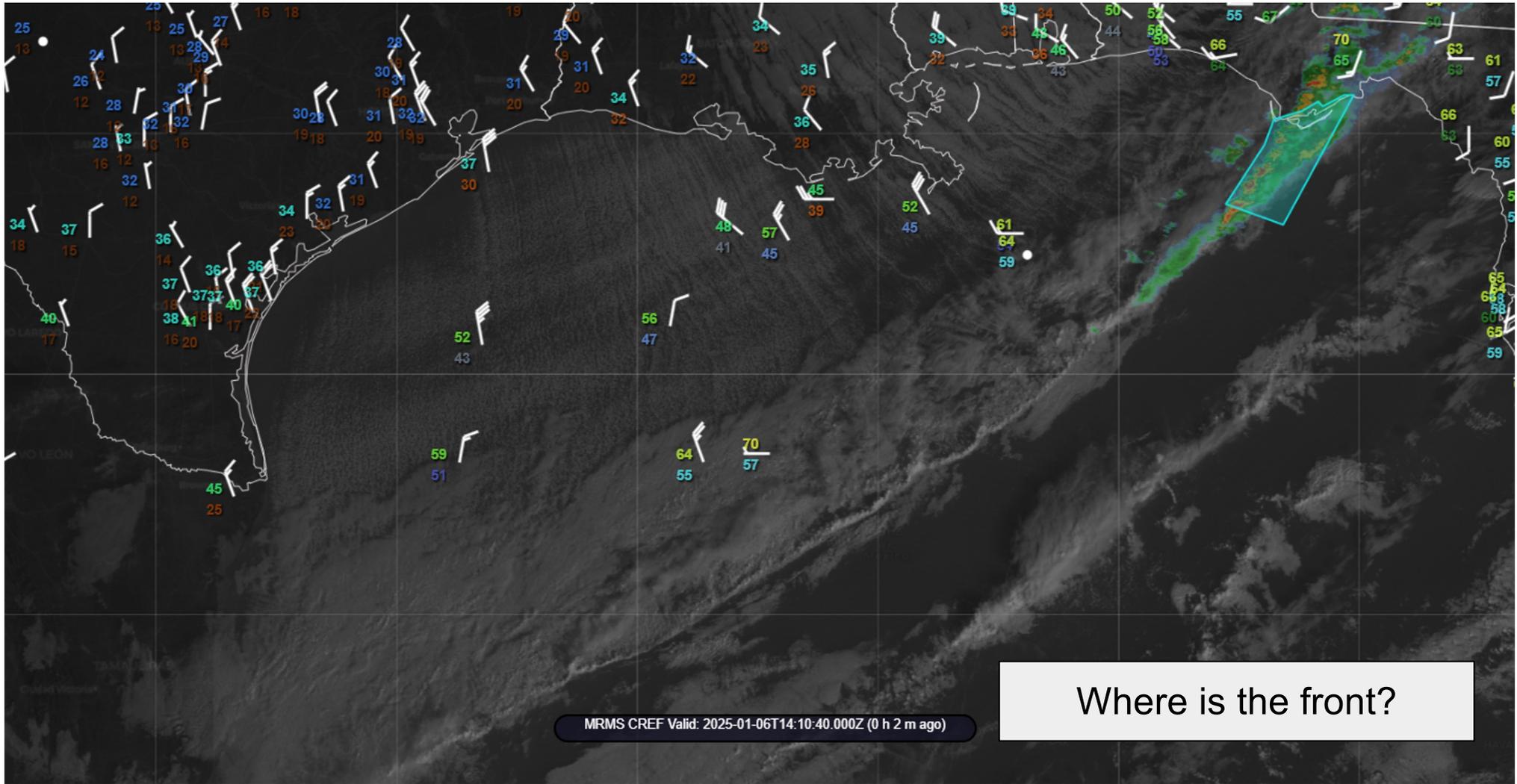
- Most used satellite band for monitoring of all weather types
 - Convection
 - Fire/Smoke
 - TCs
- Limited to daytime only
- High spatial resolution is incredibly useful for cloud monitoring in real time.

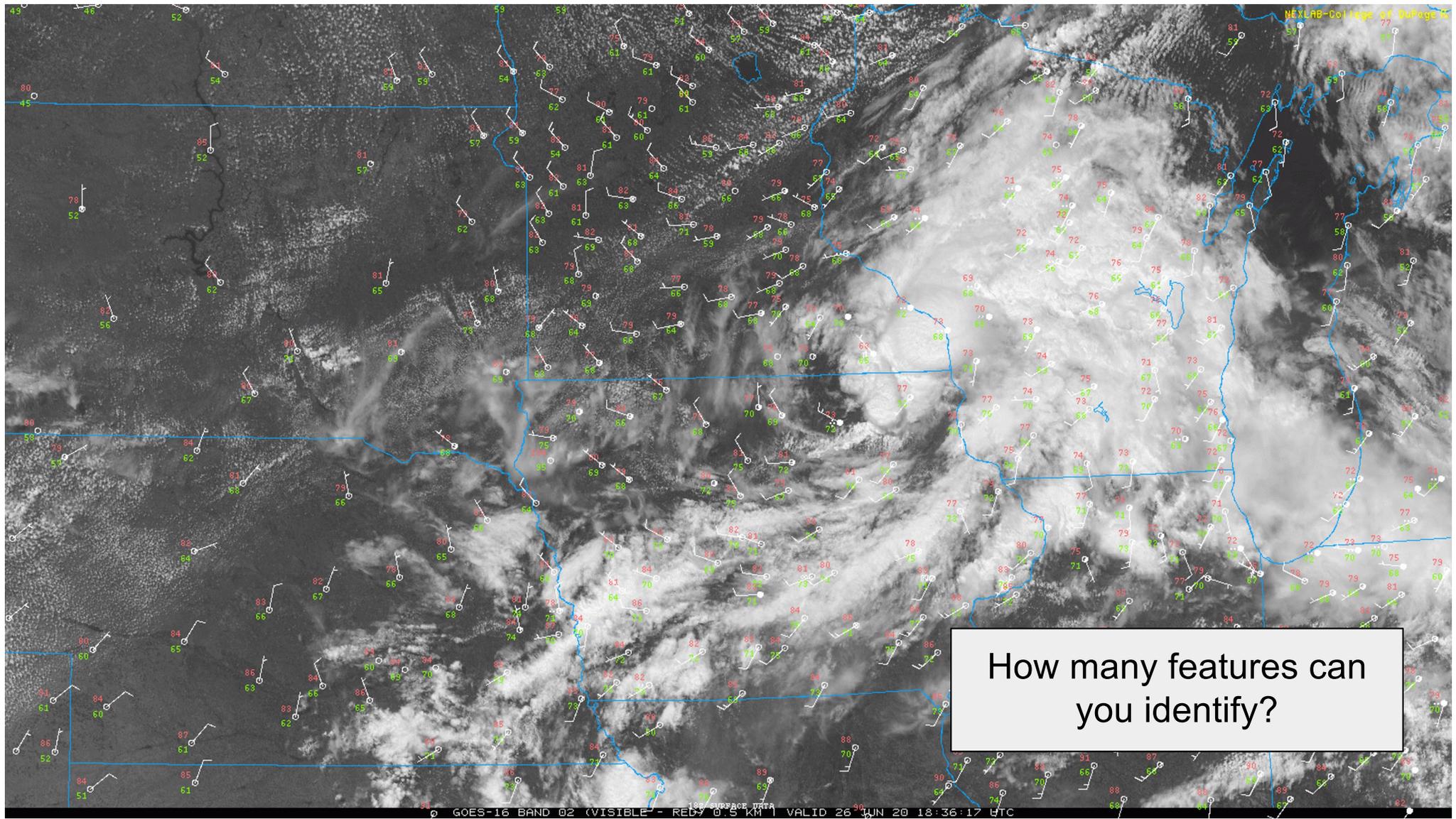


Developing storms

Dust and
Smoke

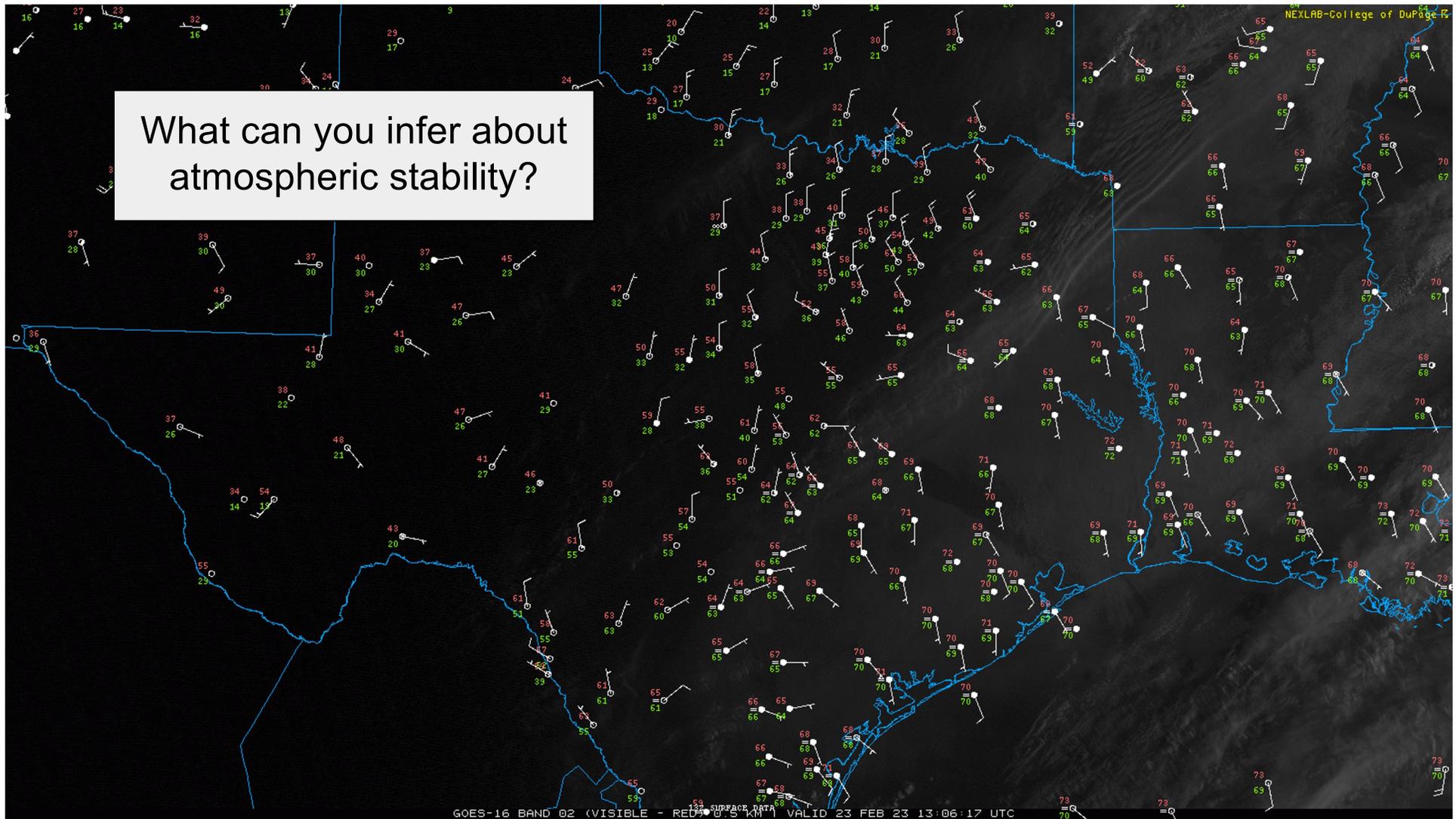




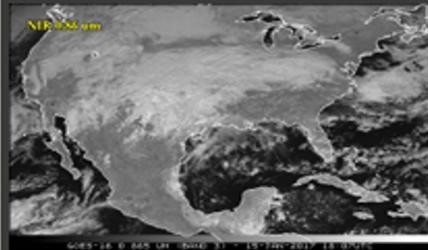


How many features can you identify?

What can you infer about atmospheric stability?



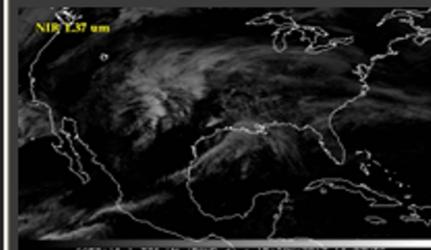
Bands (Near IR)



ABI Band #3
0.86 microns
Near-IR (“Veggie Band”)

Primary Uses:

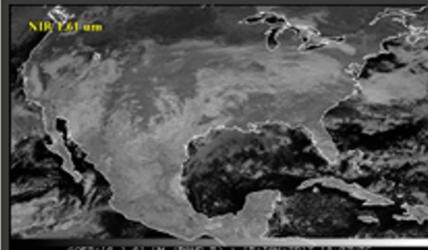
- High contrast between water and land
- Assess land characteristics including flooding impacts, burn scars, and hail swath damage



ABI Band #4
1.37 microns
Near-IR (“Cirrus Band”)

Primary Uses:

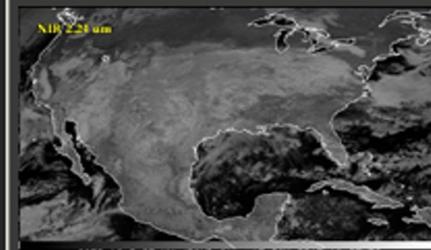
- Thin cirrus detection during the day as the lower troposphere is not routinely sensed
- Volcanic ash monitoring



ABI Band #5
1.6 microns
Near-IR (“Snow/Ice Band”)

Primary Uses:

- Daytime snow, ice, and cloud discrimination (Snow/Ice dark compared to liquid water clouds)
- Input to “Snow/Ice vs. Cloud” RGB



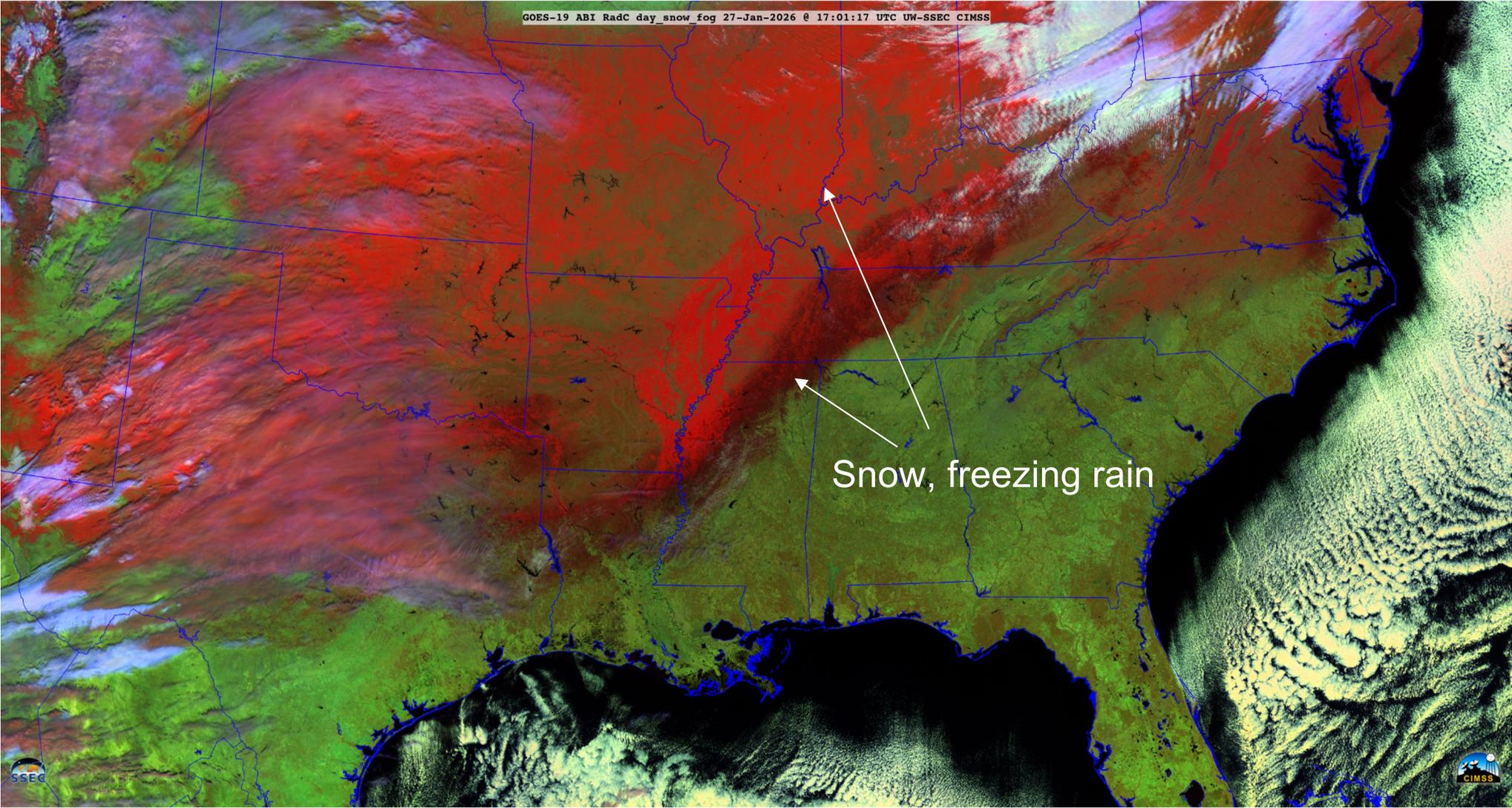
ABI Band #6
2.24 microns
Near-IR (“Cloud Particle Size Band”)

Primary Uses:

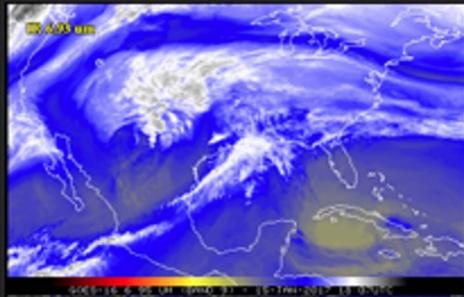
- Cloud particle size, snow, and cloud phase
- Hot spot detection at emission temperatures of greater than 600K

GOES-19 ABI RadC day_snow_fog 27-Jan-2026 @ 17:01:17 UTC UW-SSEC CIMSS

Snow, freezing rain



Bands (Water Vapor)



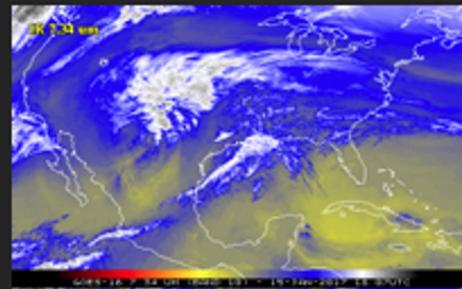
ABI Band #9

6.9 microns

IR (“Mid-Level Troposphere WV Band”)

In a standard US atmosphere the weighting function peaks around 440 mb. **** NOTE: The sensed radiation is from a layer, not just the peak pressure level which itself varies from the standard value**

Primary Uses: Mid-level feature detection



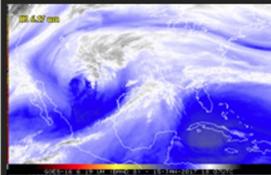
ABI Band #10

7.3 microns

IR (“Low-Level Troposphere WV Band”)

In a standard US atmosphere the weighting function peaks around 615 mb. **** NOTE: The sensed radiation is from a layer, not just the peak pressure level which itself varies from the standard value**

Primary Uses: Low-level feature detection (EML, fronts)



ABI Band #8

6.2 microns

IR (“Upper-Troposphere WV”)

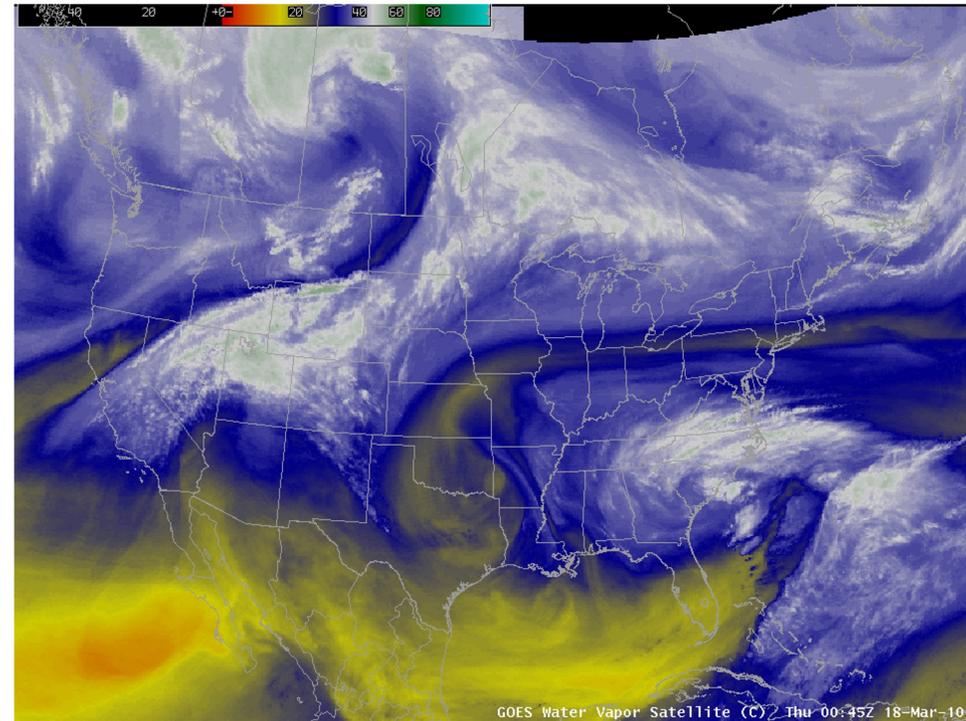
In a standard US atmosphere the weighting function peaks around 340 mb. ****NOTE: The sensed radiation is from a layer, not just the peak pressure level which itself varies from the standard value**

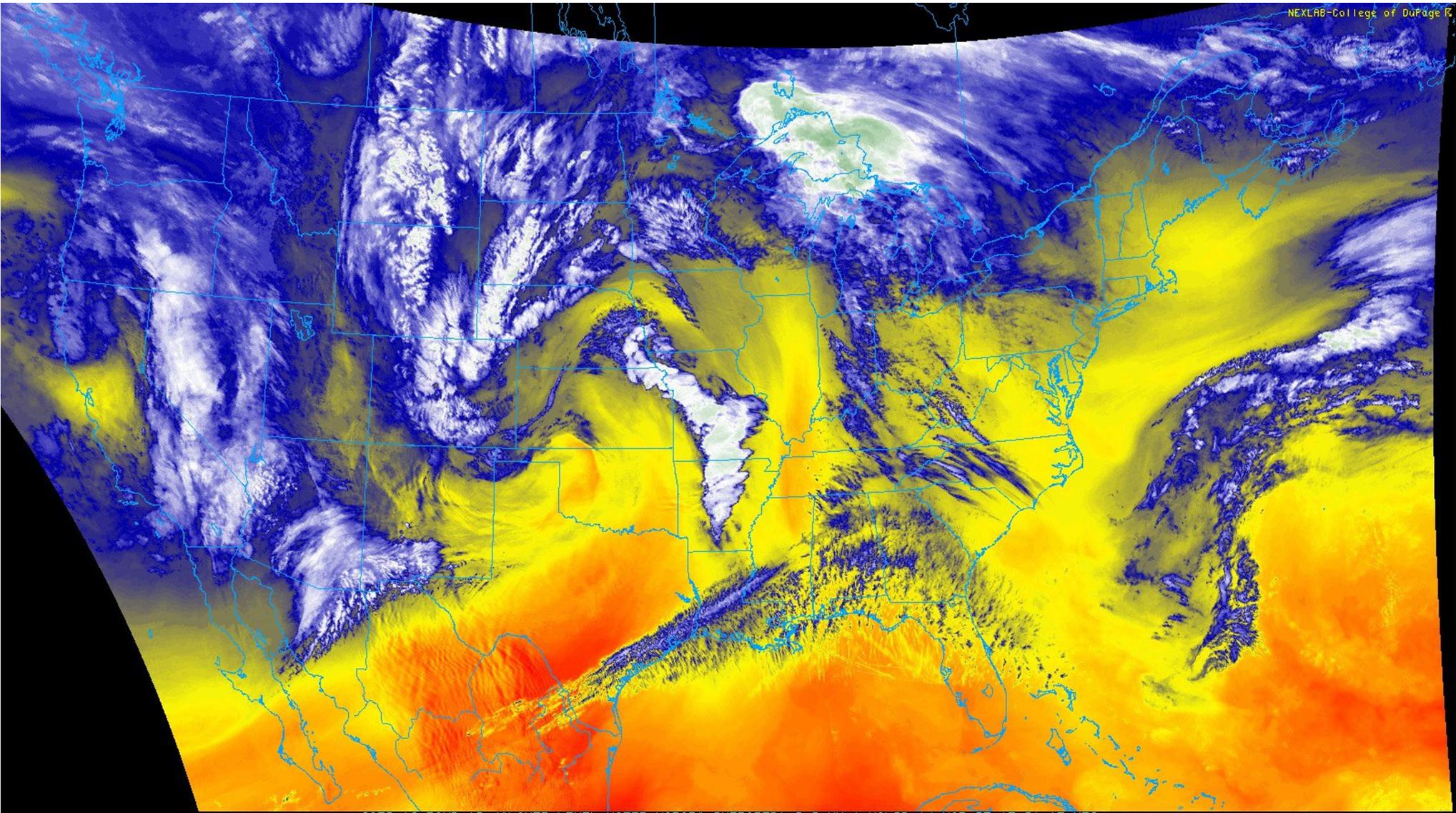
Primary Uses:

- Upper-level feature detection (jet stream, waves, etc.)

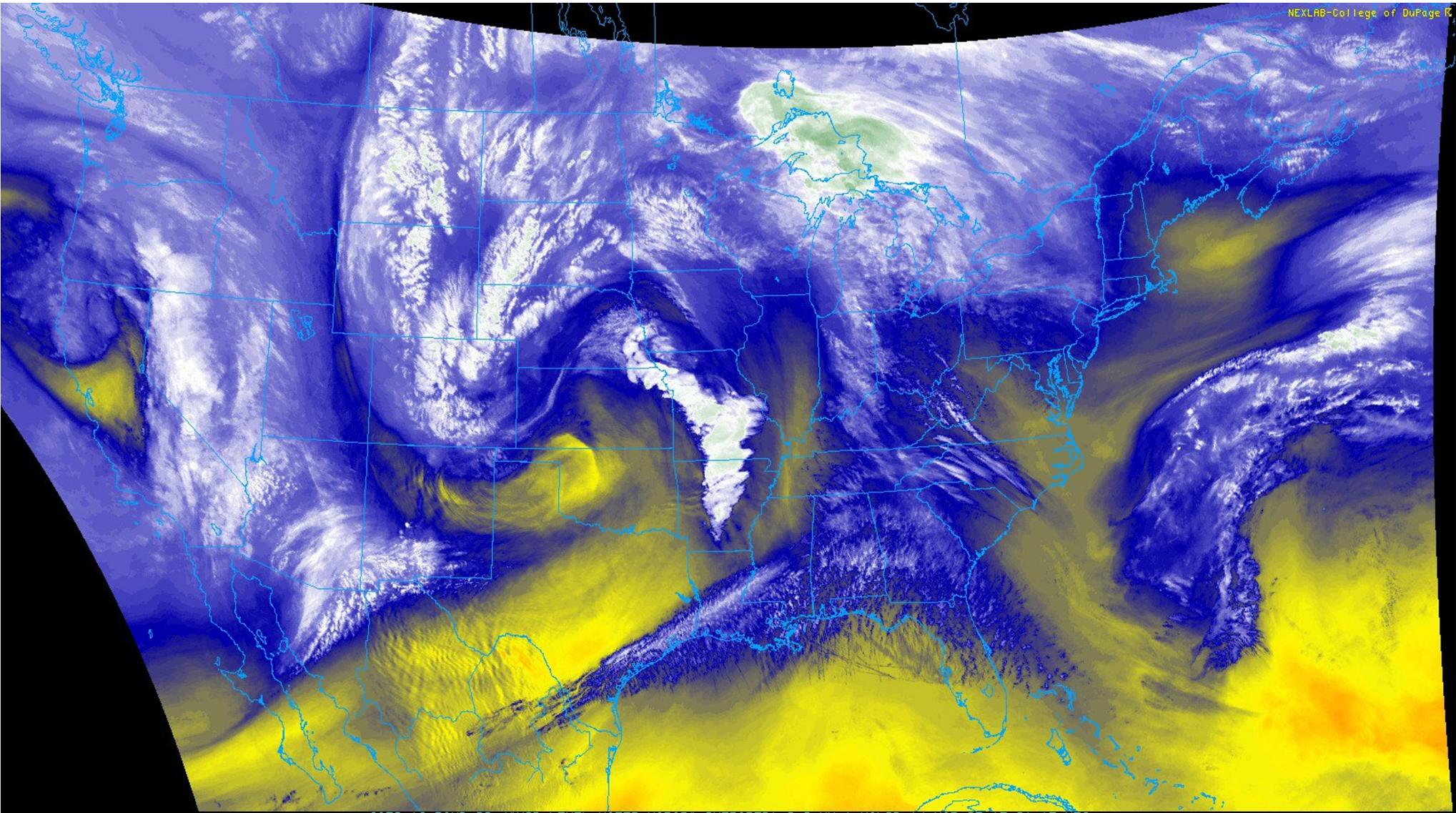
Bands (Water Vapor)

- Main Synoptic feature bands.
- Allow tracking of troughs, ridges, jets, fronts lapse rate plumes and atmospheric rivers.
- Detection is by infrared imagery.
 - Brightness temperature is affected by the water vapor content.
 - Dry air allows more thermal energy to pass appearing brighter.
- Best used in looping images to detect small details.
- **One of the most important bands for detecting shortwave troughs that could trigger convection on severe days!**

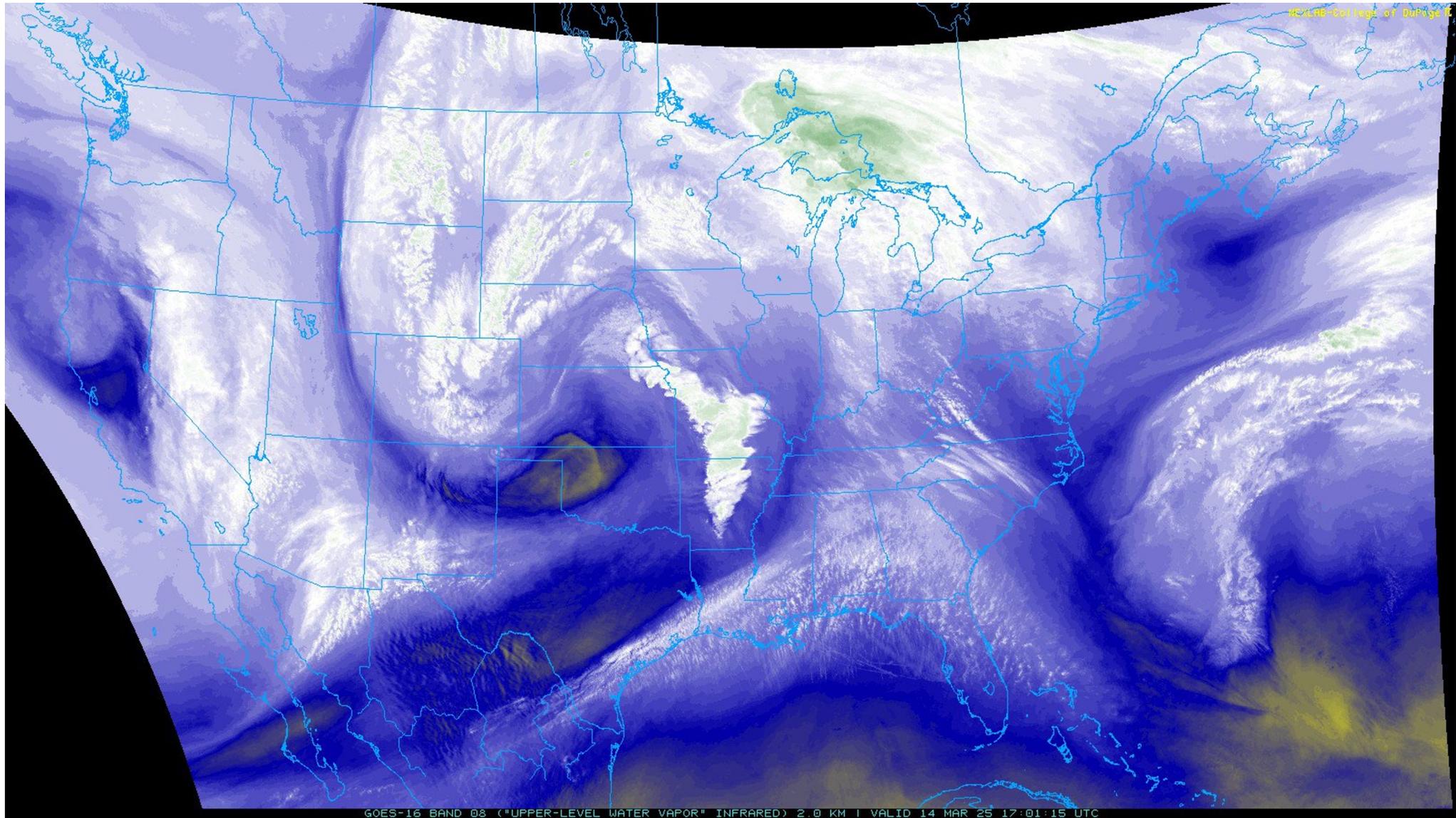




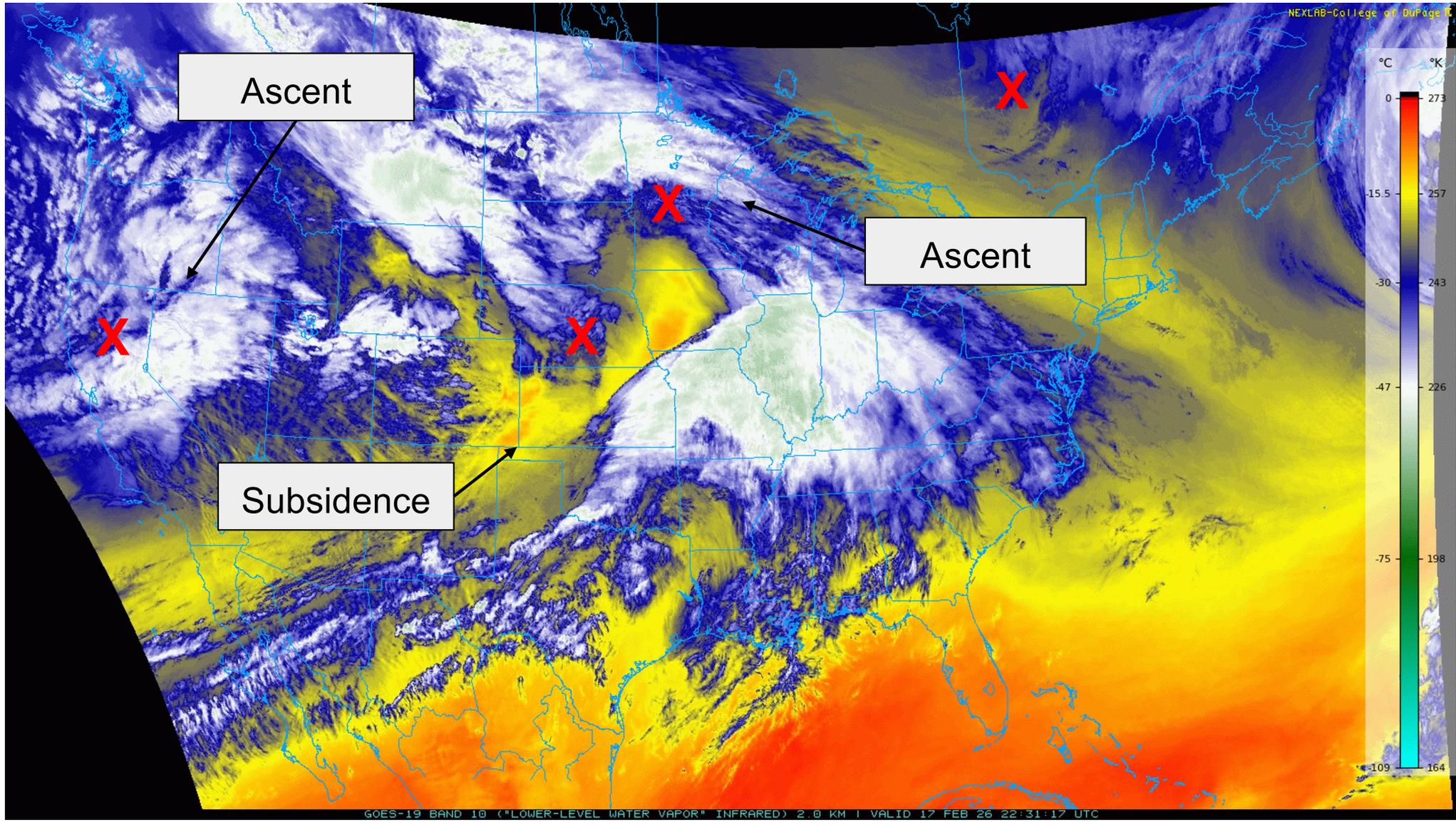
GOES-16 BAND 10 ("LOWER-LEVEL WATER VAPOR" INFRARED) 2.0 KM | VALID 14 MAR 25 17:01:15 UTC



GOES-16 BAND 09 ("MID-LEVEL WATER VAPOR" INFRARED) 2.0 KM | VALID 14 MAR 25 17:01:15 UTC



GOES-16 BAND 03 ("UPPER-LEVEL WATER VAPOR" INFRARED) 2.0 KM | VALID 14 MAR 25 17:01:15 UTC

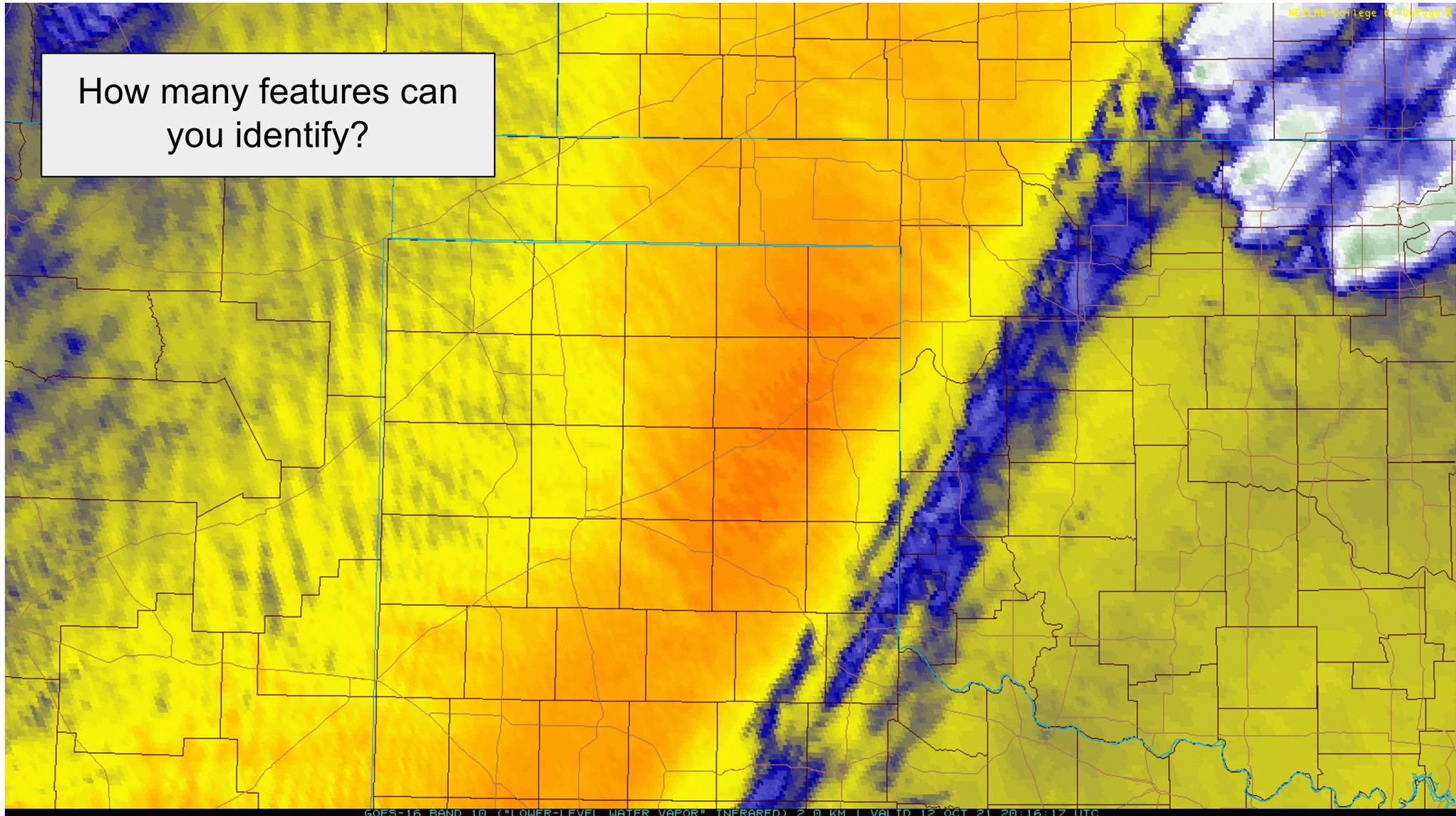


Ascent

Ascent

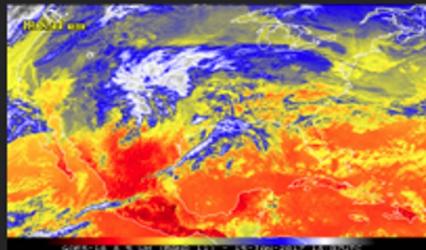
Subsidence

How many features can you identify?



GOES-16 BAND 10 (\"LOWER-LEVEL WATER VAPOR\" INFRARED) 2.0 KM | VALID 12 OCT 21 20:16:17 UTC

Bands (Long Wave IR)



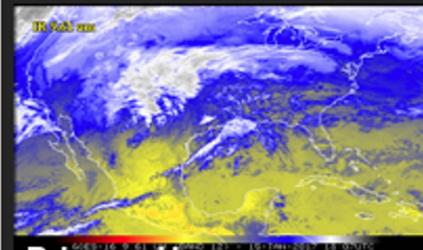
ABI Band #11

8.4 microns

IR (“Cloud-Top Phase Band”)

Primary Uses:

- Cloud-top phase and type products derived when combined with the 11.2- and 12.3- micron channels
- Volcanic ash (SO₂ detection) and dust



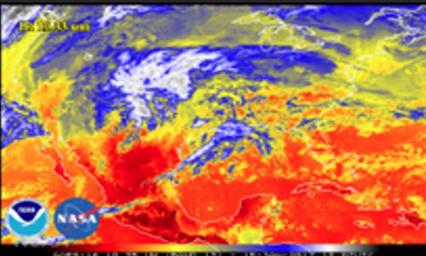
ABI Band #12

9.6 microns

IR (“Ozone Band”)

Primary Uses:

- Dynamics near the tropopause including stratospheric intrusions (high ozone) associated with cyclogenesis. PV anomaly applications
- Input to Airmass RGB

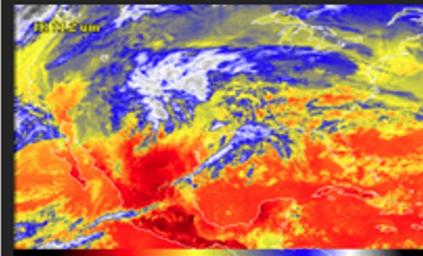


ABI Band #13

10.3 microns

IR (“Clean IR Longwave Band”)

- Less sensitive to atmospheric moisture than the other IR channels. As a result brightness temperatures are usually warmer than traditional IR as less radiation is absorbed by water vapor and re-emitted at higher altitudes



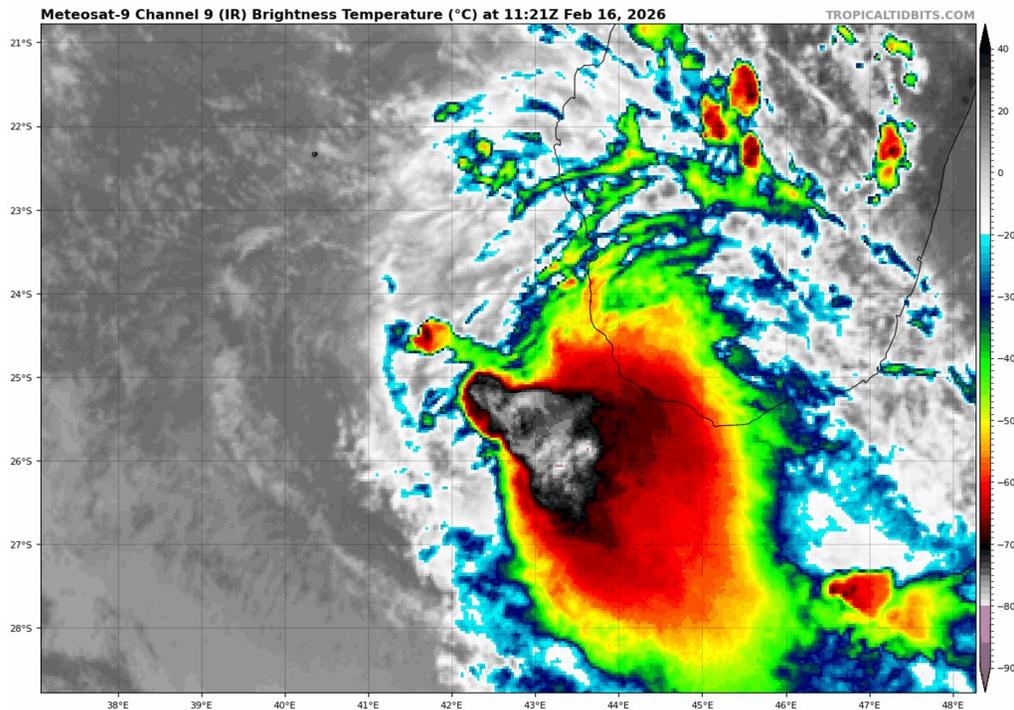
ABI Band #14

11.2 microns

IR (“IR Longwave Band”)

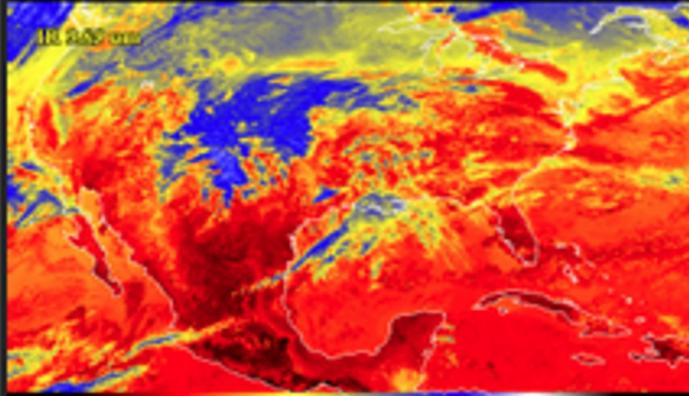
- The traditional IR window
- Differenced with the 3.9 micron near IR channel for low stratus and fog detection

Bands (Long Wave IR)



- IR imagery has a wide array of uses. Longwave IR is emitted by Earth at all times via radioisotope decay, plate tectonics, stored solar energy and other sources allowing for use during the overnight hours.
- Traditional IR imagery (11.2 micron) is used for convective monitoring, cloud top temps, TCs, low-level clouds and upper-level clouds.
- Various other combinations of bands allow for unique fog and microphysics detection.

Shortwave IR (3.9) Fire Detection.



ABI Band #7

3.9 microns

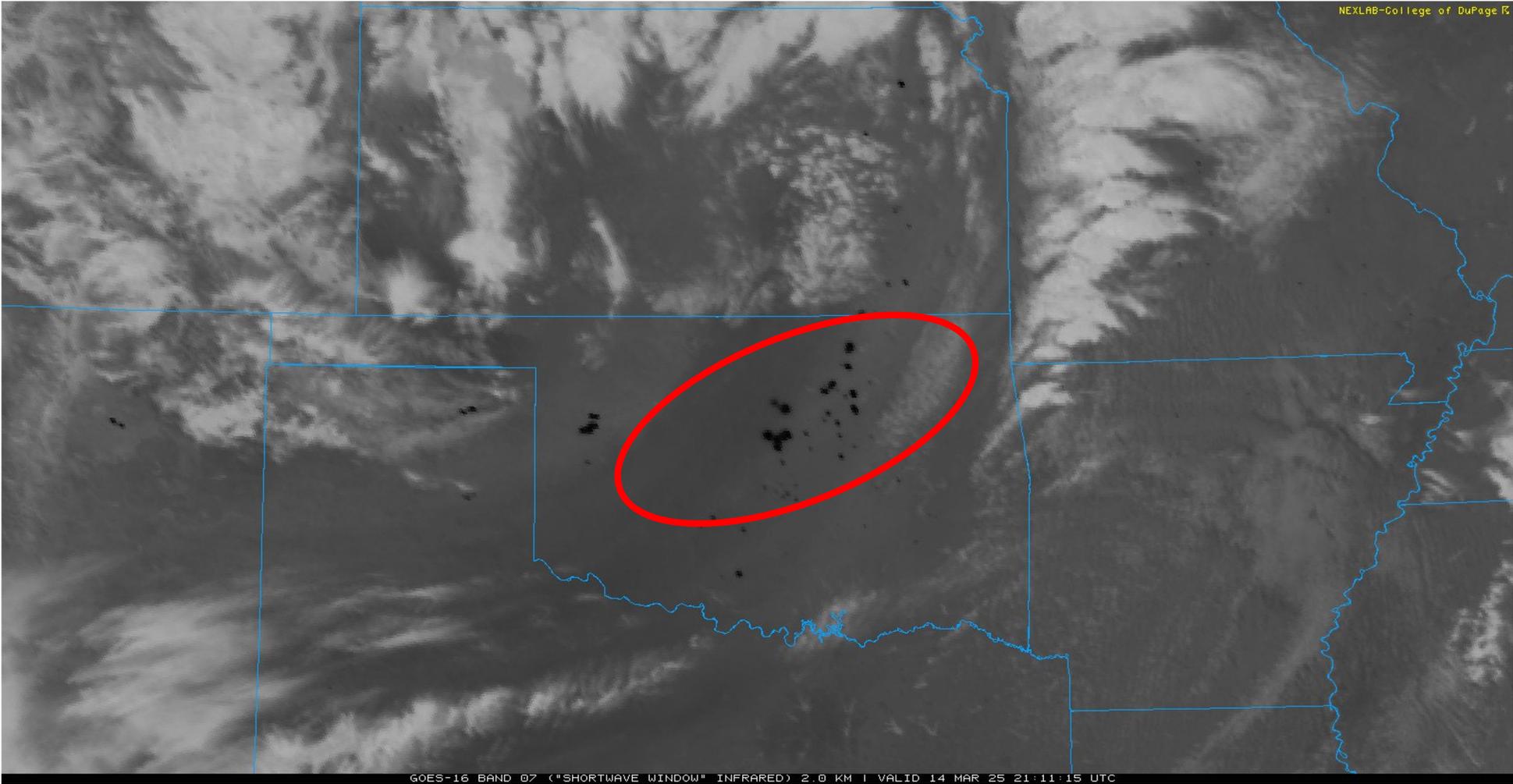
**IR (“Shortwave
Window Band”)**

Contains daytime solar reflectance component

Primary Uses:

- Low stratus and fog (especially when differenced with the 11.2-micron IR channel taking advantage of emissivity differences)
- Fire/hot spot detection and volcanic ash

Fire Band 3.9 micron 3/14/2025

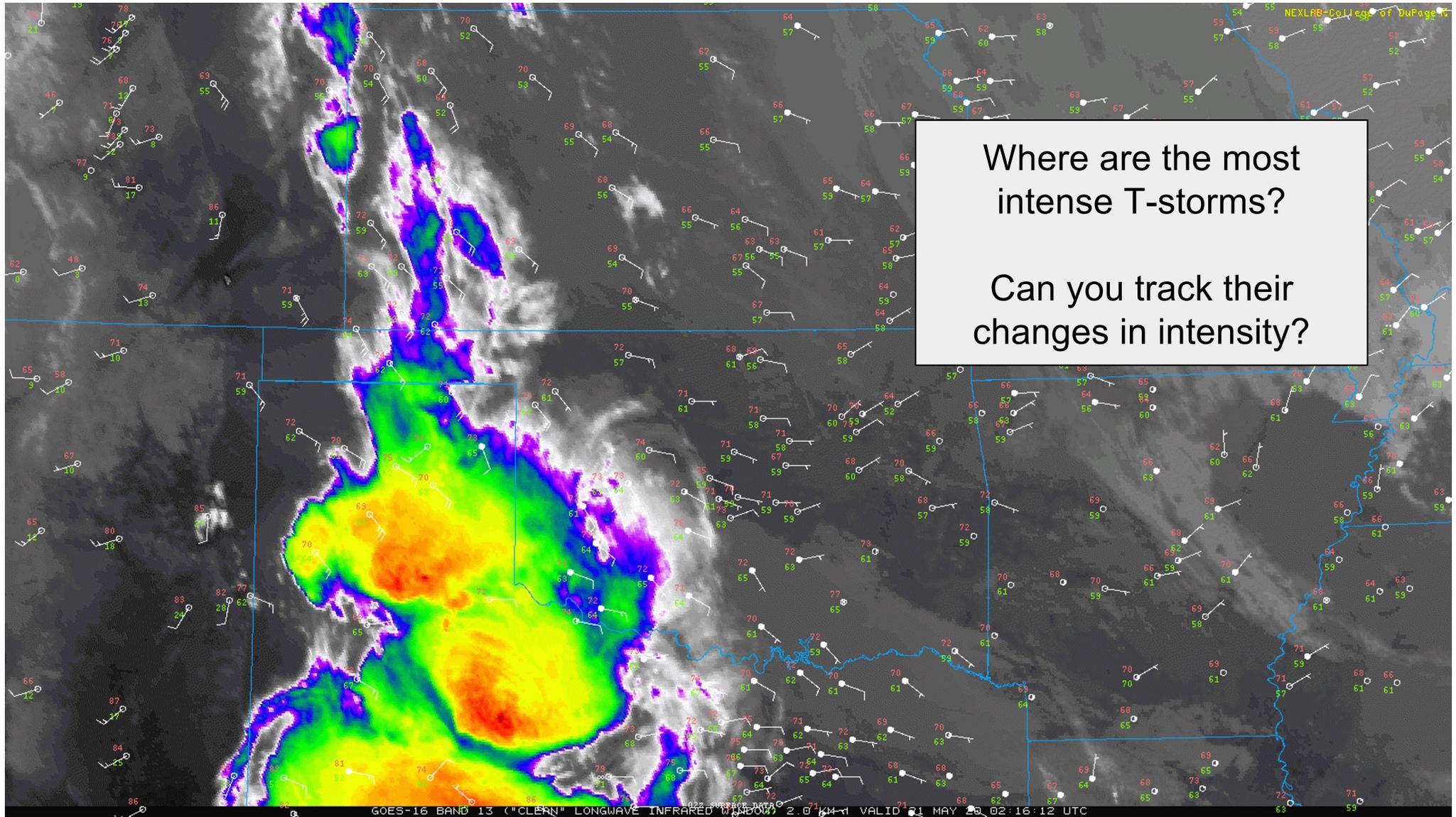


GOES-16 Satellite Captures Saturday Night's Delta-IV Rocket Launch

Both Heat and Moisture From Rocket Plume Visible on Shortwave/Water Vapor Channels

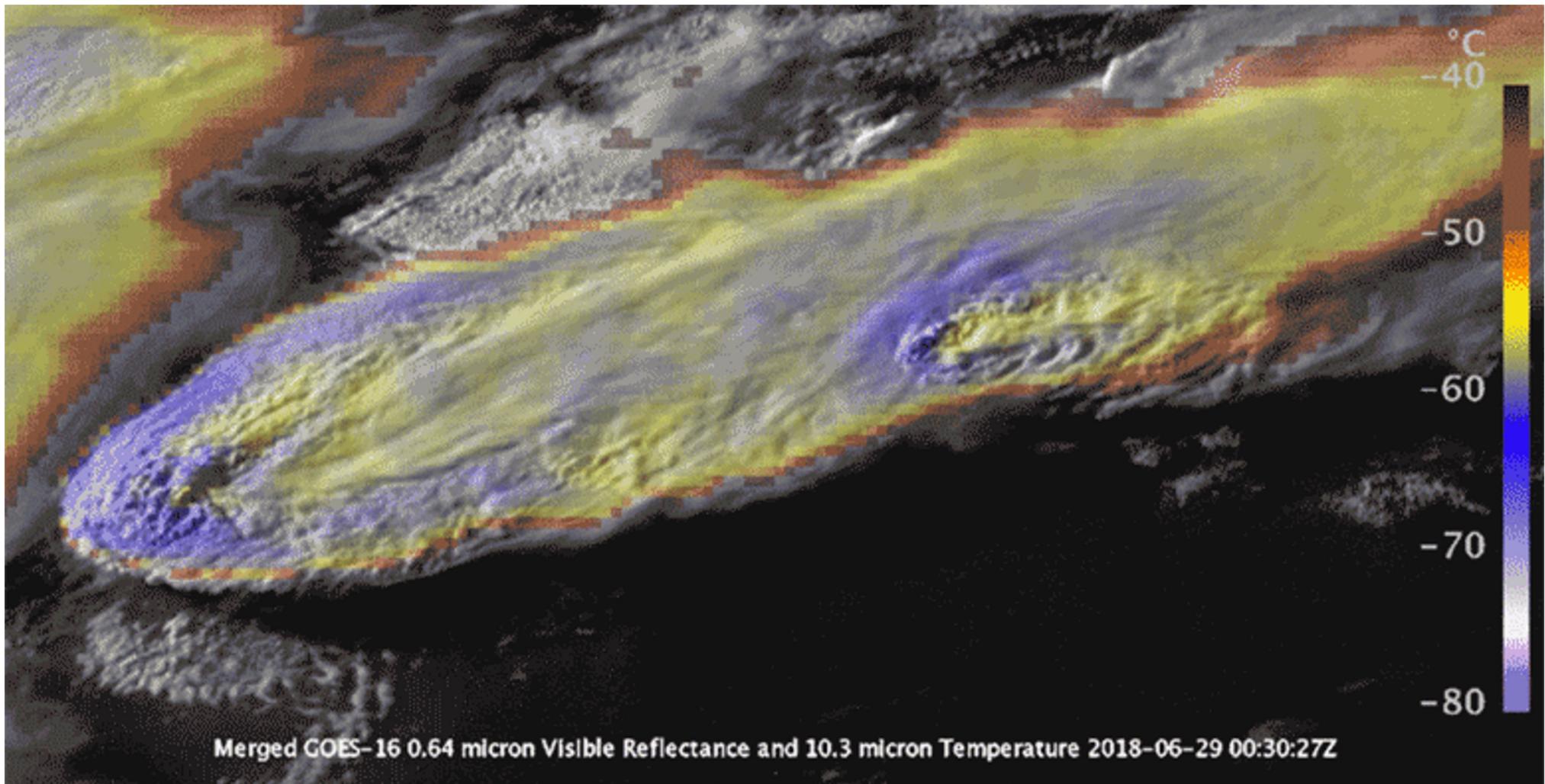


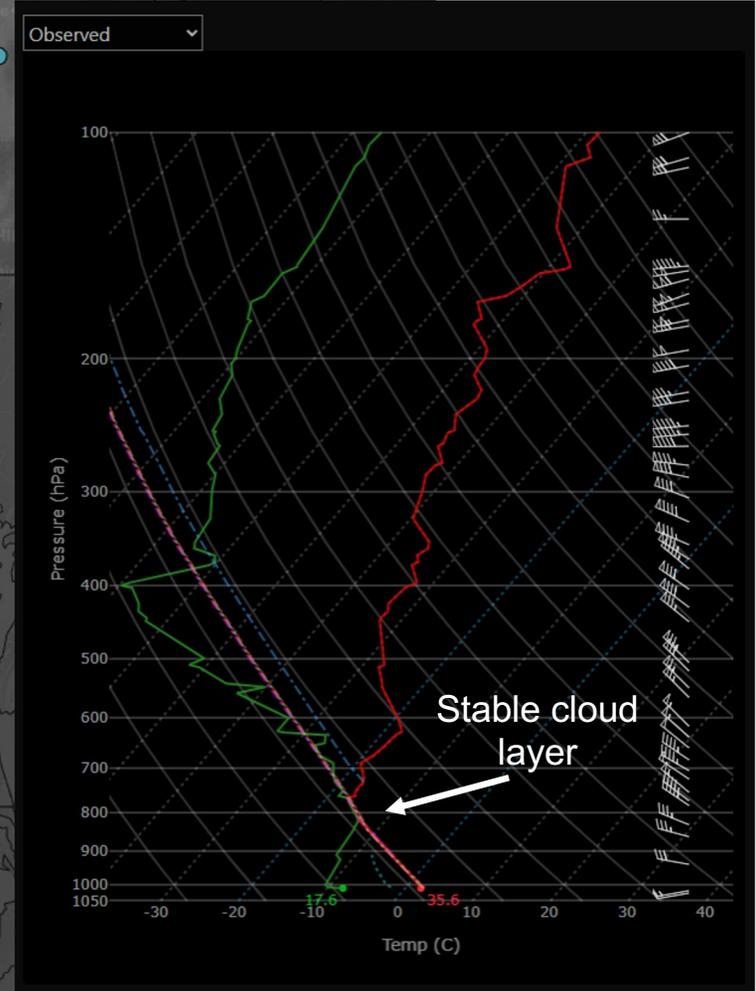
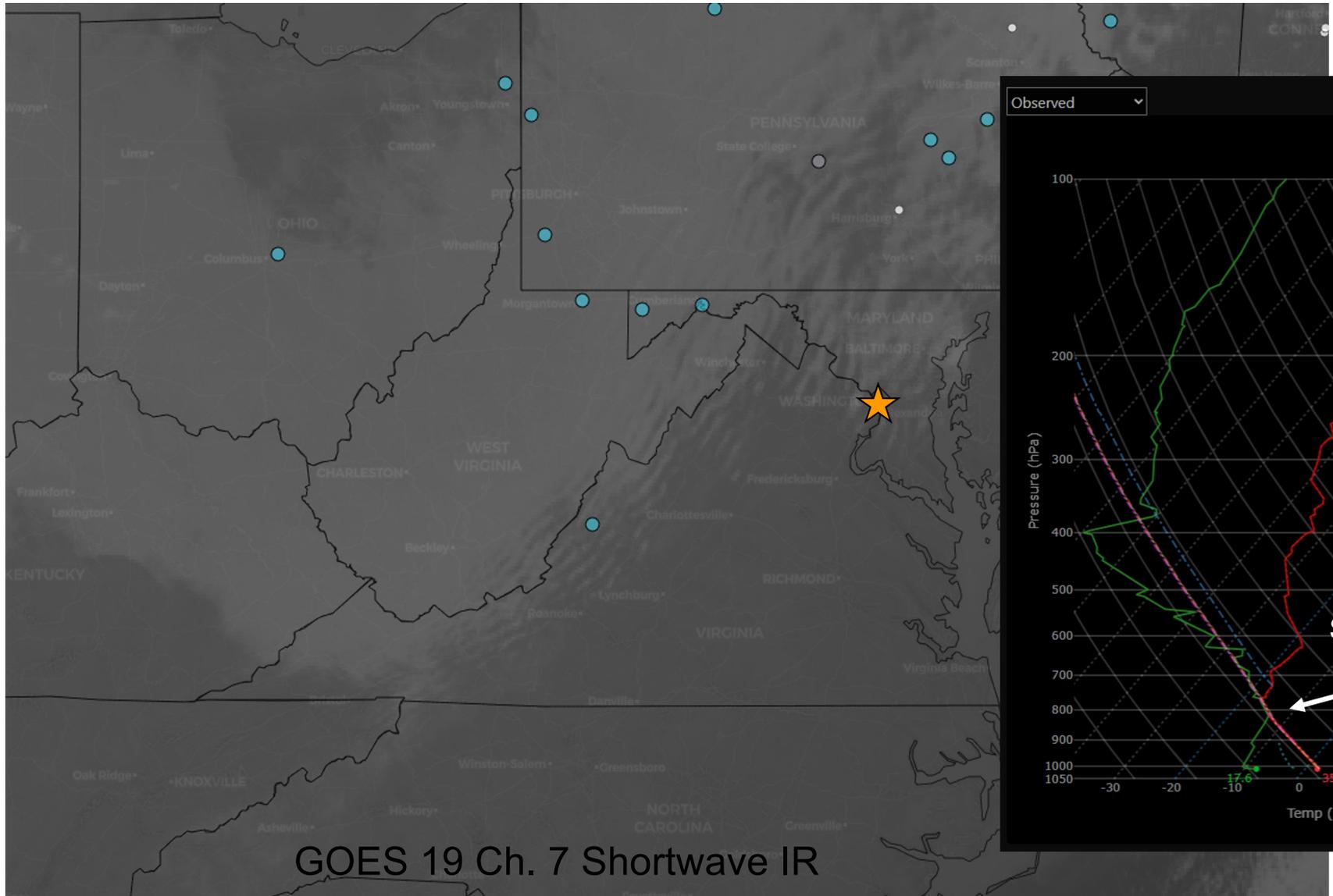
- Fun Fact!
 - Shortwave IR satellites have been flying since the 1970s.
 - The USAF used sensitive IR imagers to detect Soviet ballistic missile launches and nuclear detonations.
 - That technology is the same we use today for fire detection. It can still see rockets!



Where are the most intense T-storms?
Can you track their changes in intensity?

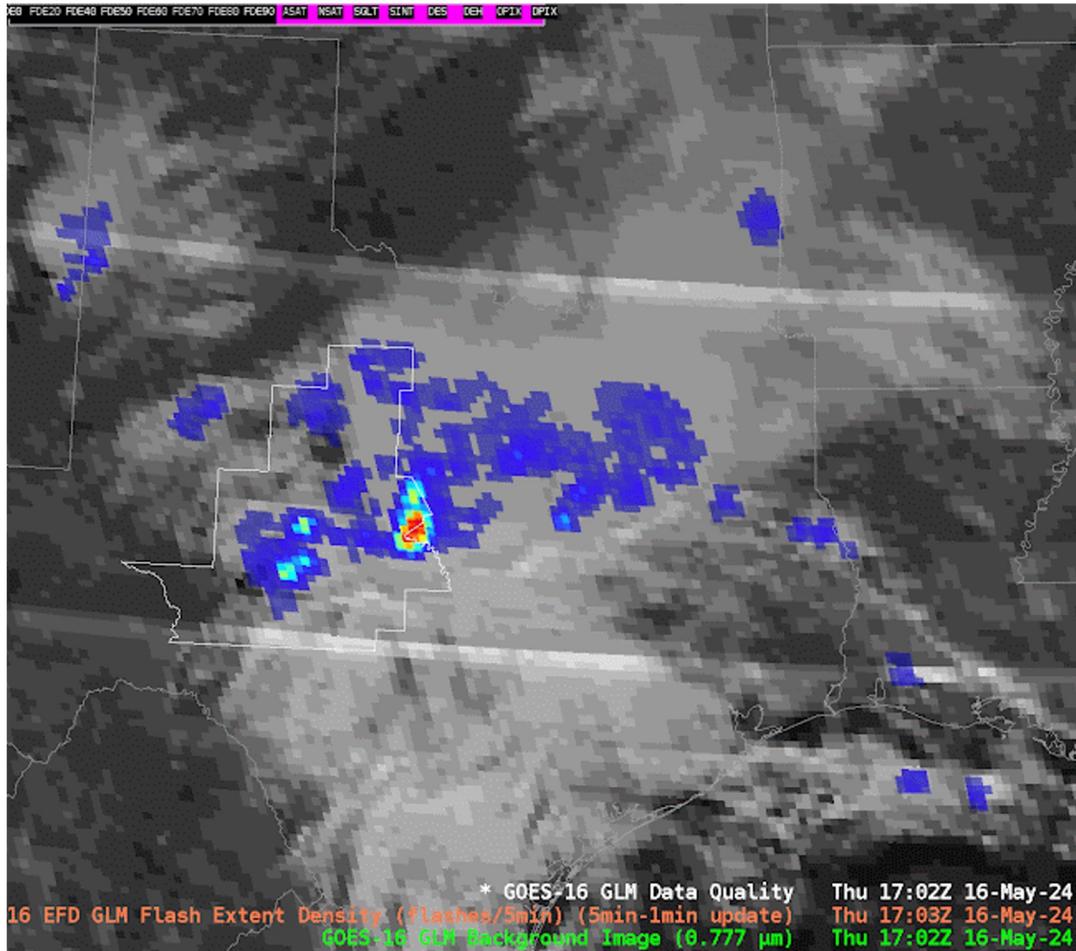
Above-Anvil Cirrus Plume - Indicator of Severe Convection





GOES 19 Ch. 7 Shortwave IR

GLM (Geospatial Lightning Mapper)



- Optical lightning detection from space!
- Looks for transient flashes.
- Measures total lightning
 - C2C
 - C2G
 - IC
- Does not detect as much as ground based RF systems.
- Still useful for initial pulses or flashes in developing convection.
- Lightning Jumps can precede strengthening of storms.

Beyond the strike: Benefits of detecting lightning from space

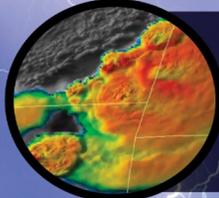
The GOES-R Series Geostationary Lightning Mapper (GLM) is the first instrument of its kind flown in geostationary orbit. It detects in-cloud, cloud-to-cloud, and cloud-to-ground lightning activity and reveals the extent of lightning flashes and the distance they travel. Rapid increases in lightning activity often precede severe and tornadic thunderstorms and can indicate a hurricane is strengthening. GLM data is critical for a number of public safety applications and contributes to long-term climate studies.



Early warning of ground strike hazards



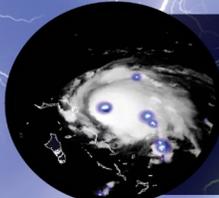
Data for aviation route planning and reducing weather-related flight delays



Early warning of severe storms and tornadoes



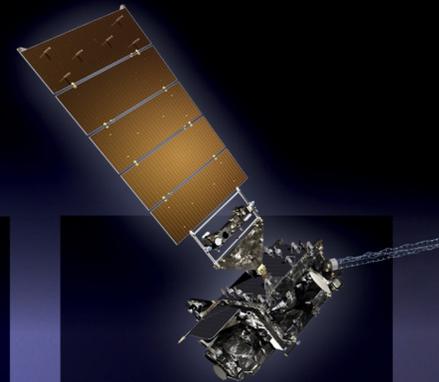
Identification of lightning strikes most likely to ignite wildfires



Prediction of hurricane rapid intensification



Improved understanding of threats posed by meteors



Lightning is an essential climate variable needed to understand and predict changes in climate. Data from GLM contributes to a long-term record tracking decadal changes in lightning activity.



GOES-R Series GLM instrument

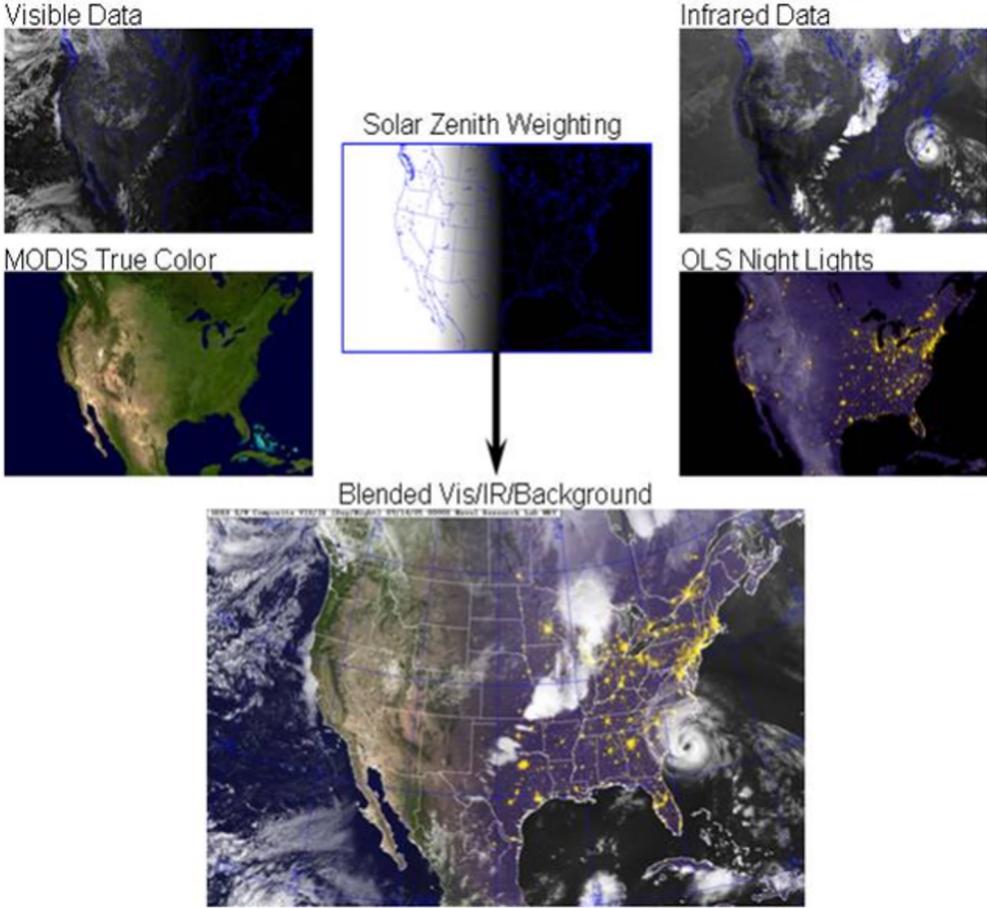
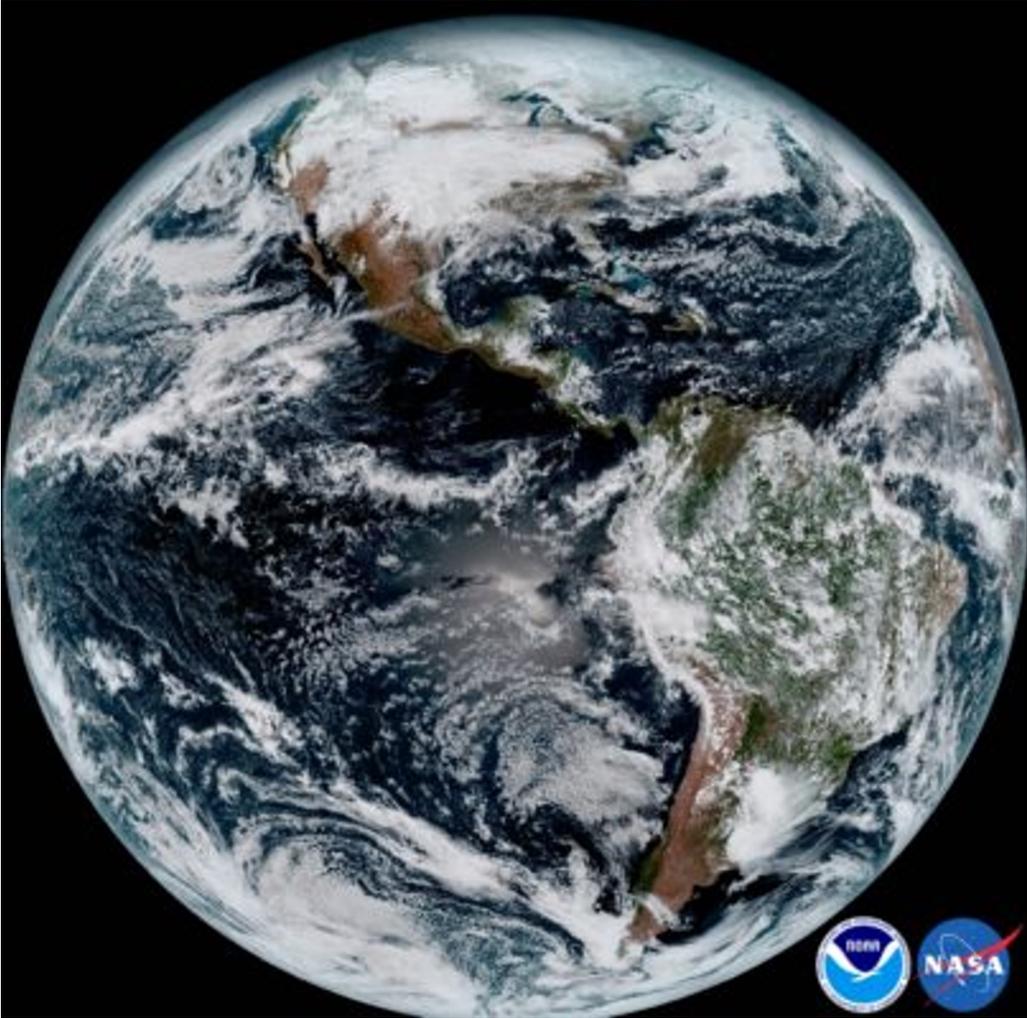
www.goes-r.gov



Combo/Derived Products

- Because of all the interesting bands and frequencies we can mix and match things!
- Individual bands are limited but combining things lets us see more.
- Analogous to looking at images in RGB space
 - AKA Color but some are not always visible to our eyes.
- Various ML products have been added over the years to make forecasting easier.

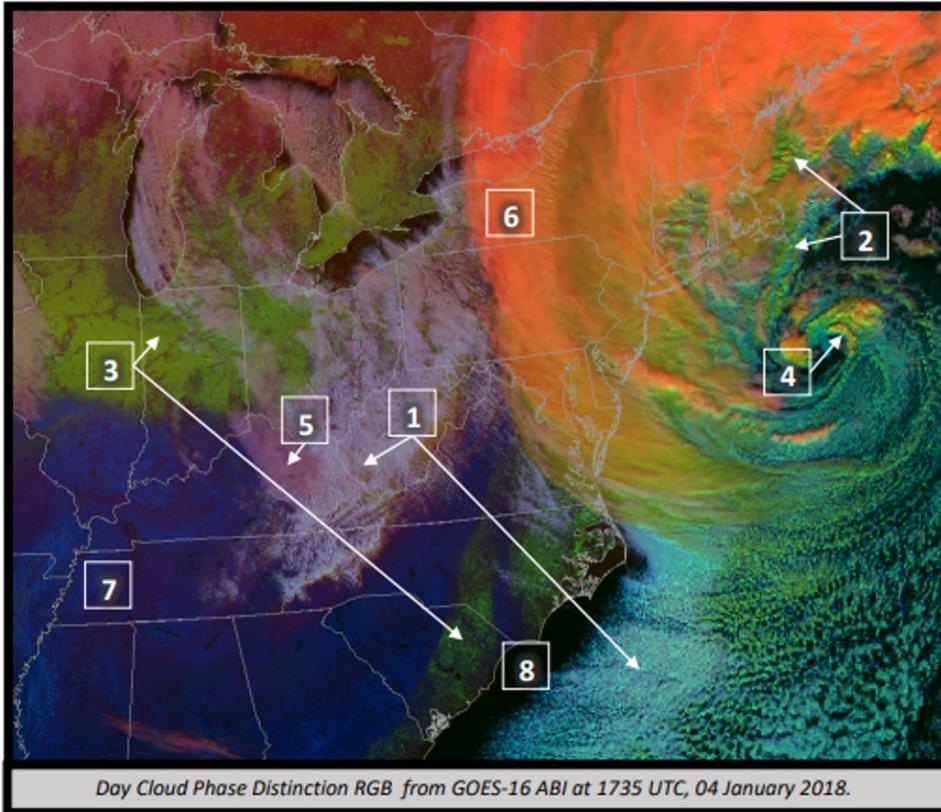
True Color



Day Cloud Phase

RGB Interpretation

- 1** Low level clouds with water droplets (cyan, lavender)
- 2** Glaciating clouds (green)
- 3** Snow (shades of green)
- 4** Thick high level clouds with ice particles (yellow)
- 5** Thin mid level clouds with water droplets (magenta)
- 6** Thin high-level clouds with ice particles (red-orange)
- 7** Land surface (shades of blue)
- 8** Water surface (black)



Note: colors may vary diurnally, seasonally, and by latitude. Since the 10.35 μm IR band is one of the RGB components, the color of a particular feature will vary seasonally, particularly for warm/cold surface temperatures and thin cloud features. The JMA developer identifies thin high level cloud as magenta whereas in the image above, a similar color cloud presents as a mid level cloud (5). In an animation, the long dark magenta colored feature in central Alabama is thin high level ice cloud (cirrus).

- Useful combination to highlight different microphysics ongoing within cloud layers.
- CI, ICE and SNOW, Mid-level features.
- Day time Only.

Day Cloud Phase Distinction RGB Recipe

Color	Band (μm)	Min to Max Gamma	Physically Relates to...	Small contribution to pixel indicates...	Large Contribution to pixel indicates...
Red	10.3 (Ch. 13)	7.5 to -53.5 °C 1	Surface or cloud top temperature	Warm: land (seasonal), ocean	Cold: land (winter), snow, high clouds
Green	0.64 (Ch. 2)	0 to 78 % albedo 1	Reflectance of clouds and surfaces	Water, vegetation, land	Cloud, snow, white sand
Blue	1.6 (Ch. 5)	1 to 59 % albedo 1	Reflectance, particle phase	Ice particles	Water particles, land surface

Impact on Operations

Primary Application

Convective initiation: Used to monitor when clouds are breaking the stable capping layer. Cumulus transitioning from light shades to bolder green and yellow shades indicates vertical development and increasing cloud ice seen with strong storms. Signs of updrafts and overshooting tops help to evaluate how a storm is evolving.



Snow squalls: Preliminary comparisons with radar indicate glaciated cloud bands are associated with heavy precipitation snow events.

Limitations

Daytime only application:

The 0.64 μm (VIS) and 1.6 μm (NIR) bands rely on reflected visible solar radiation.



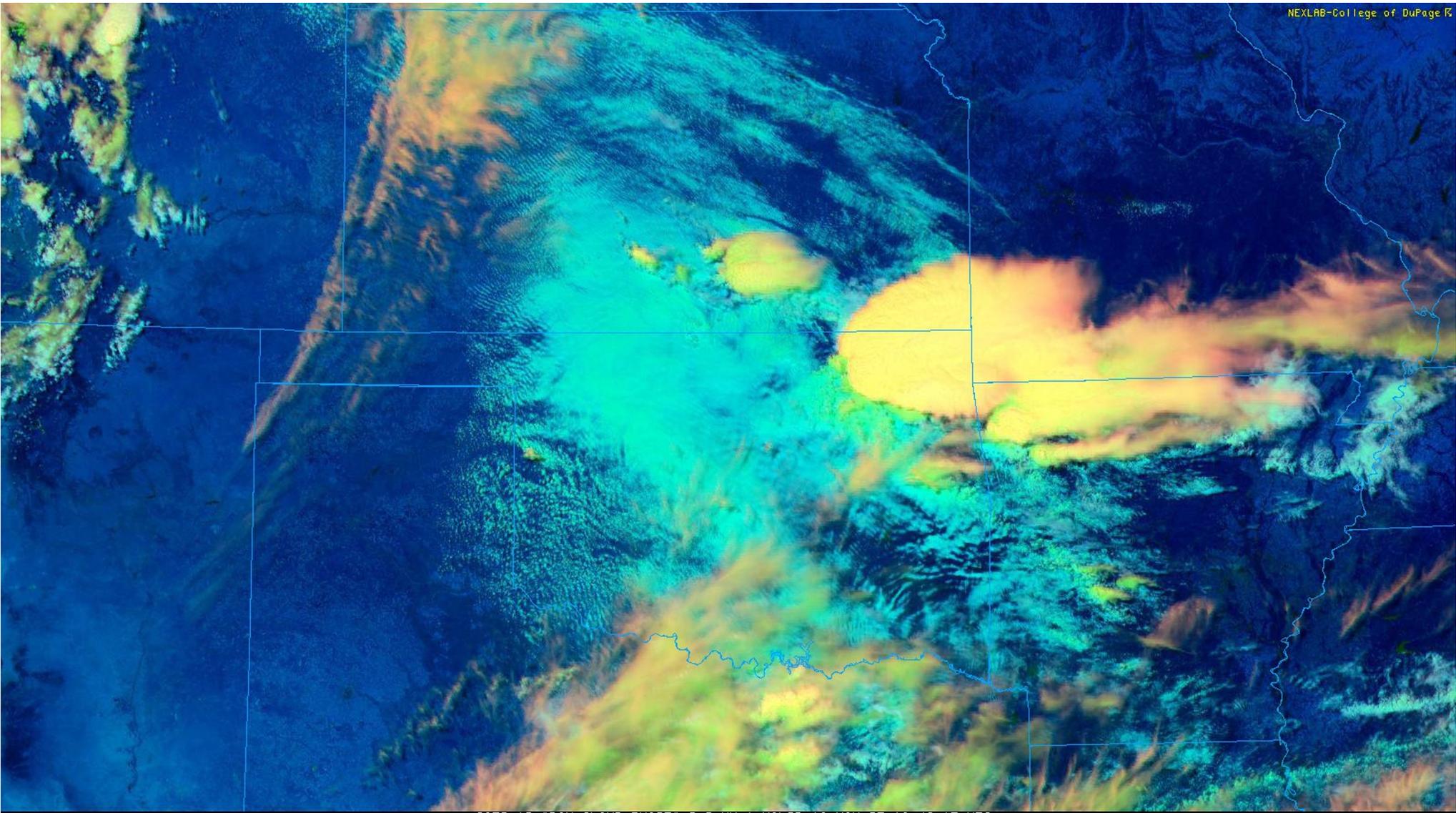
Solar angle and limb effect:

For low solar angles (i.e. sunrise and sunset, and during winter) the reflectance values of the VIS and NIR (green and blue components) are decreased. For cold winter scenes and also for viewing at high latitudes (limb cooling effect) the 10.35 μm IR (red component) is skewed towards cold temperatures. Both these effects result in a "reddish" scene.

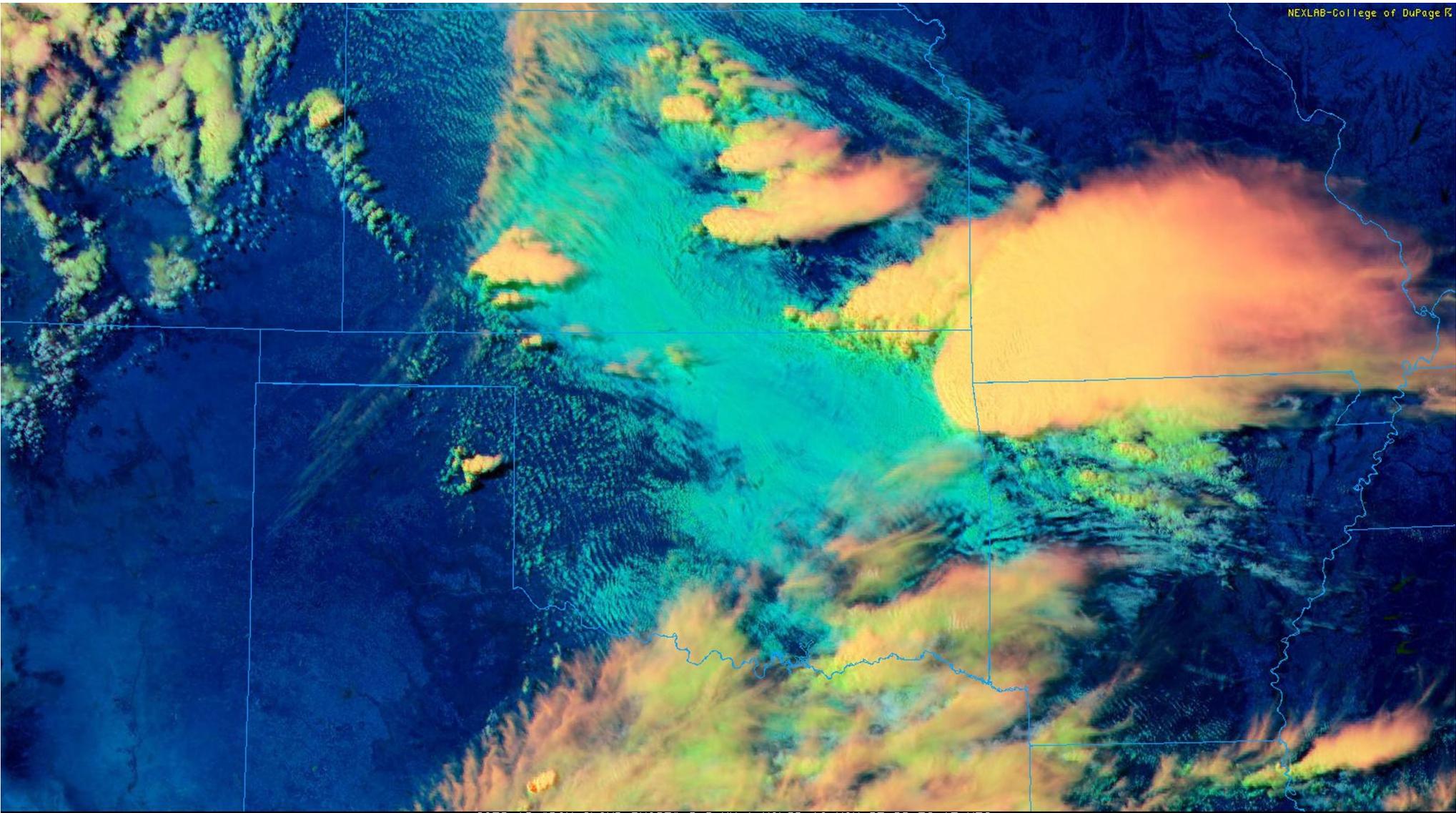
Contributors: Bernie Connell, Erin Dagg CSU/CIRA <https://www.cira.colostate.edu/>

Michael Bowlan: NOAA/NWS/SPC <http://www.spc.noaa.gov/> and OU/CIMMS <http://cimms.ou.edu/>



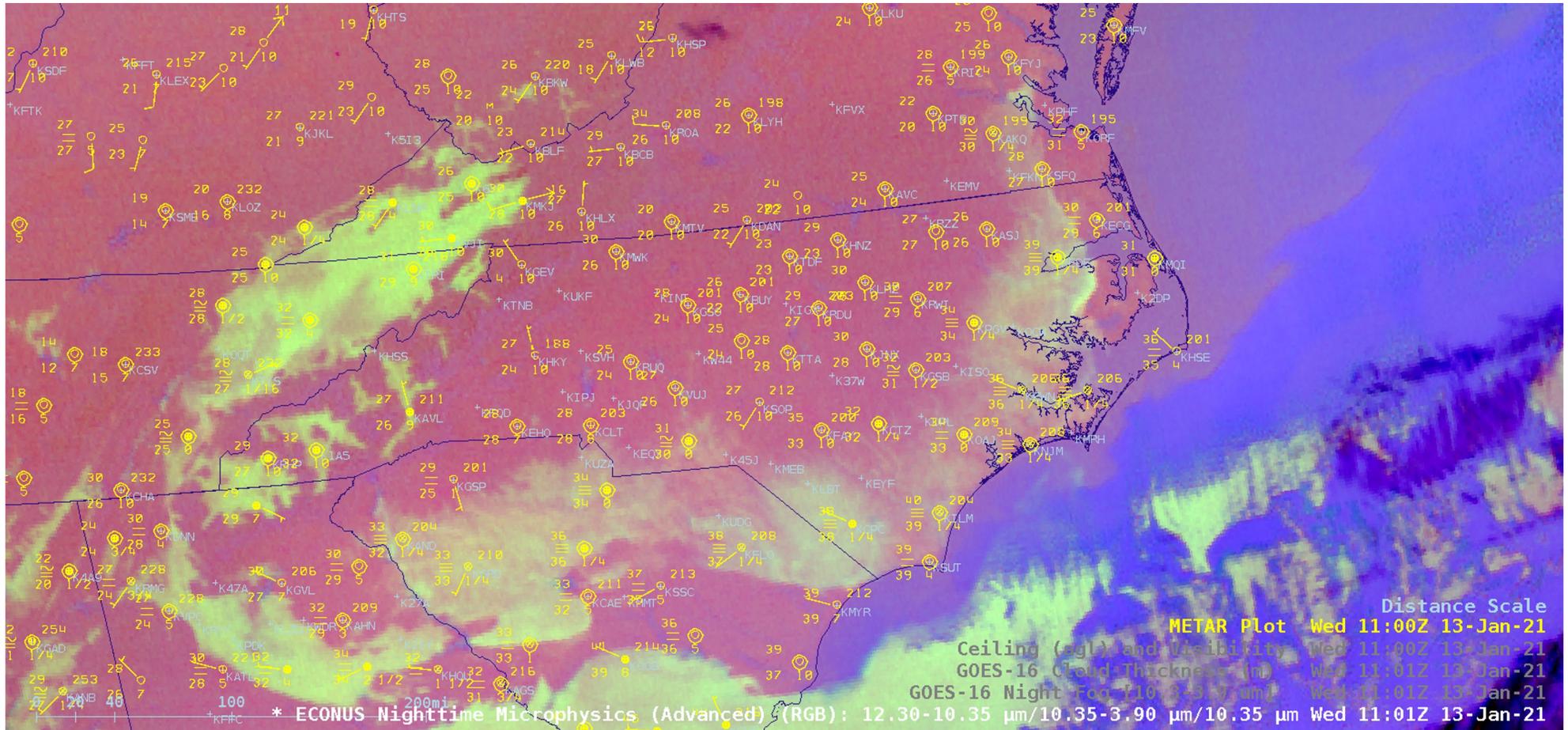


GOES-19 "DAY CLOUD PHASE" 2.0 KM | VALID 18 MAY 25 18:46:17 UTC

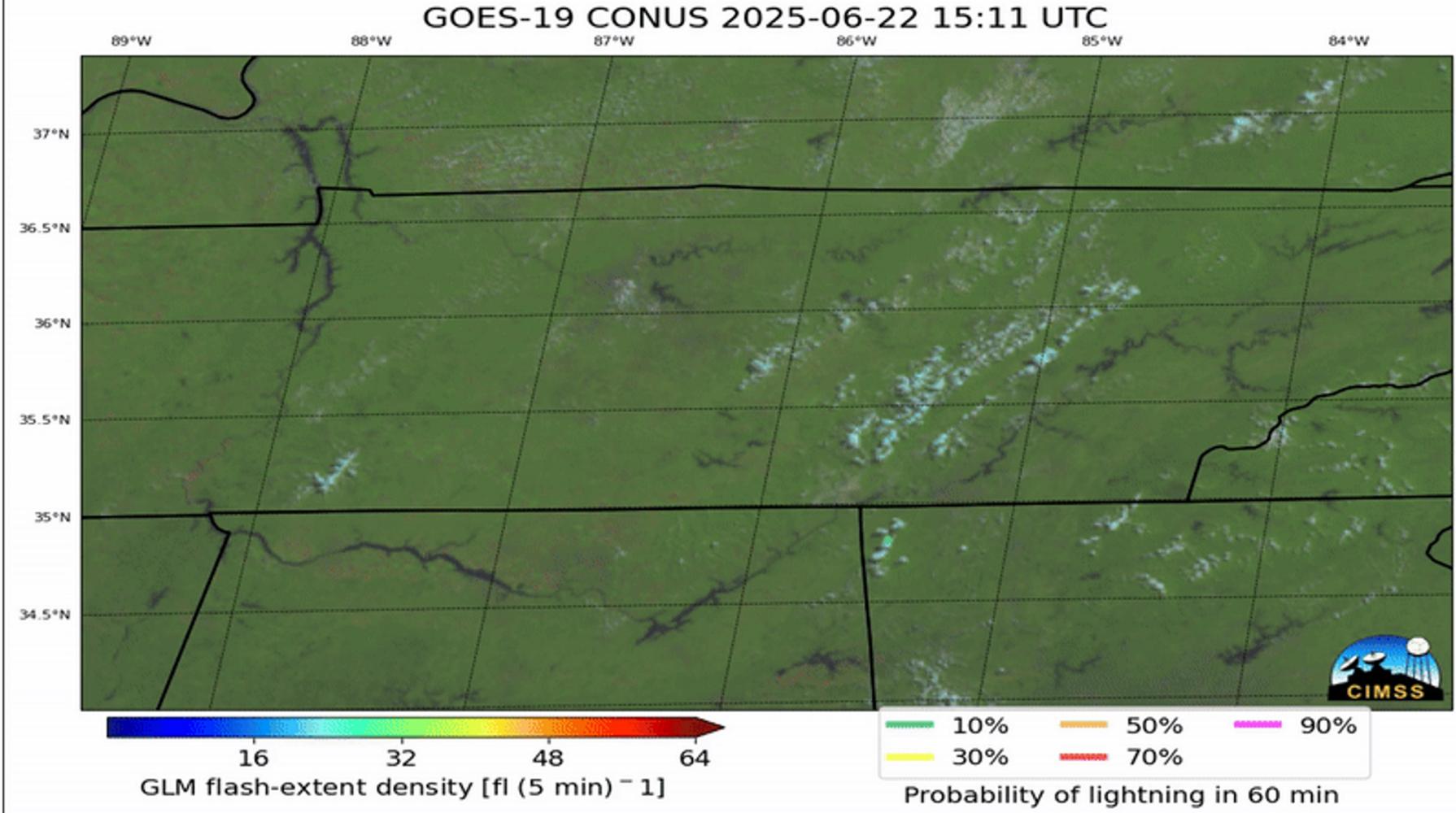


GOES-19 "DAY CLOUD PHASE" 2.0 KM 1 VALID 18 MAY 25 20:56:17 UTC

Nighttime Microphysics - freezing fog



Lightning Cast and Prob Severe



Lightning Cast and Prob Severe

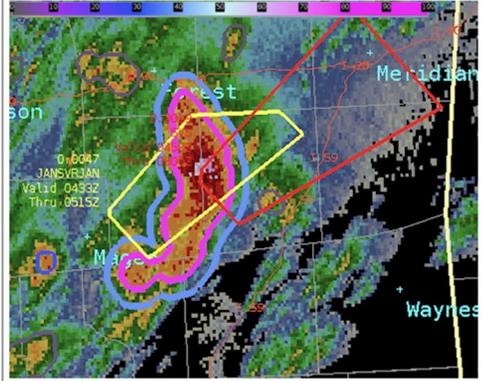
- ML-based tool that uses various cloud bands to predict when lightning strikes will occur.
- Prob severe includes satellite data and radar info to estimate the severity of a storm using ML techniques.
- Powerful combination of detecting increased CI and storm strengthening.
- https://mrms.ncep.noaa.gov/ProbSevere/PROBSEVERE/MRMS_PROBSEVERE_20260215_140037.json
- Free to use!

 **Quick Guide**

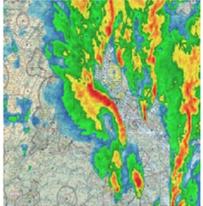
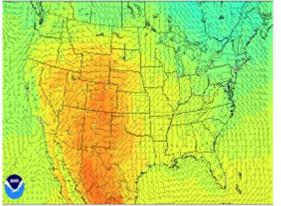
ProbSevere tracks storms in radar and satellite imagery across the contiguous U.S. It extracts and computes storm attributes from remotely sensed meteorological observations and environmental data to compute *storm-centric, next-hour probabilities of severe weather*:

1. **Probability of hail ≥ 1 in diameter**
2. **Probability of wind gust ≥ 58 mph**
3. **Probability of tornado**
4. **Probability of any of the above**

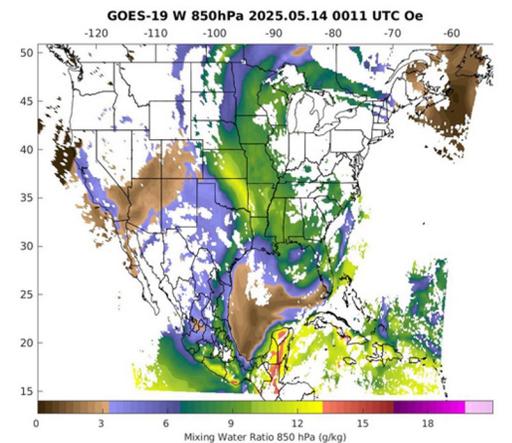
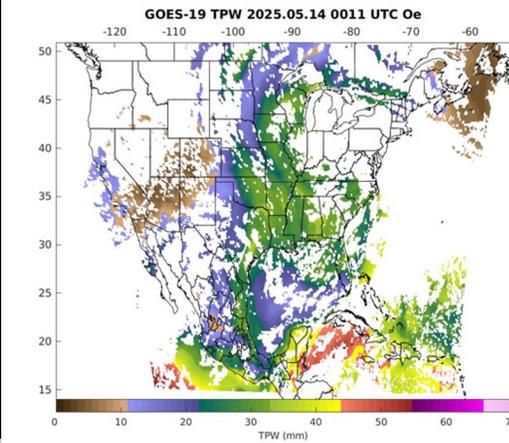
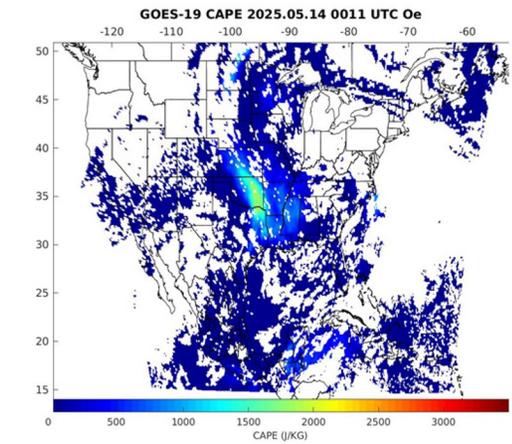
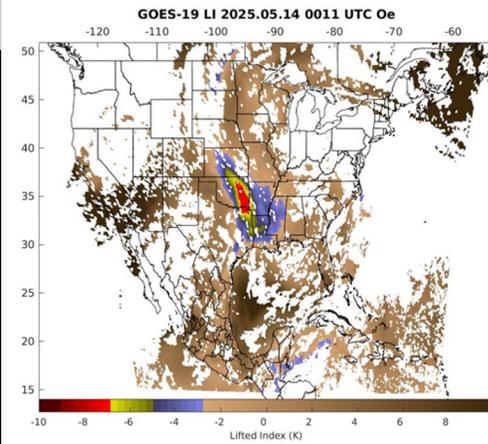
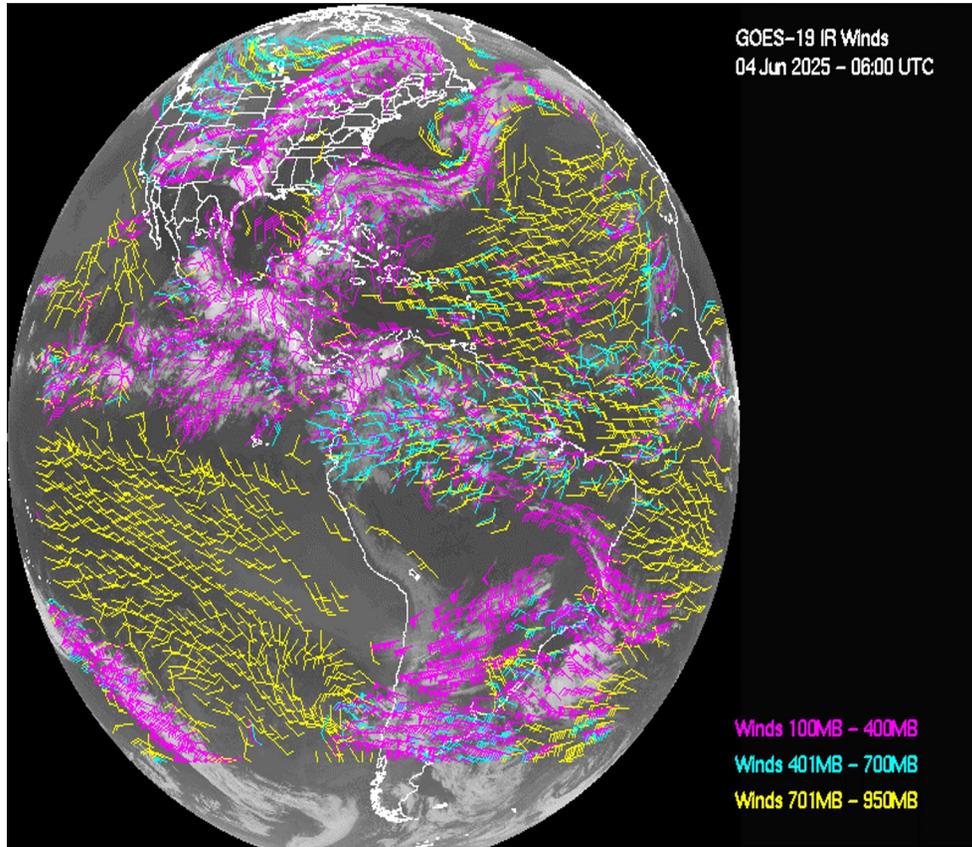
The machine-learning models are gradient-boosted decision trees.



Input sources

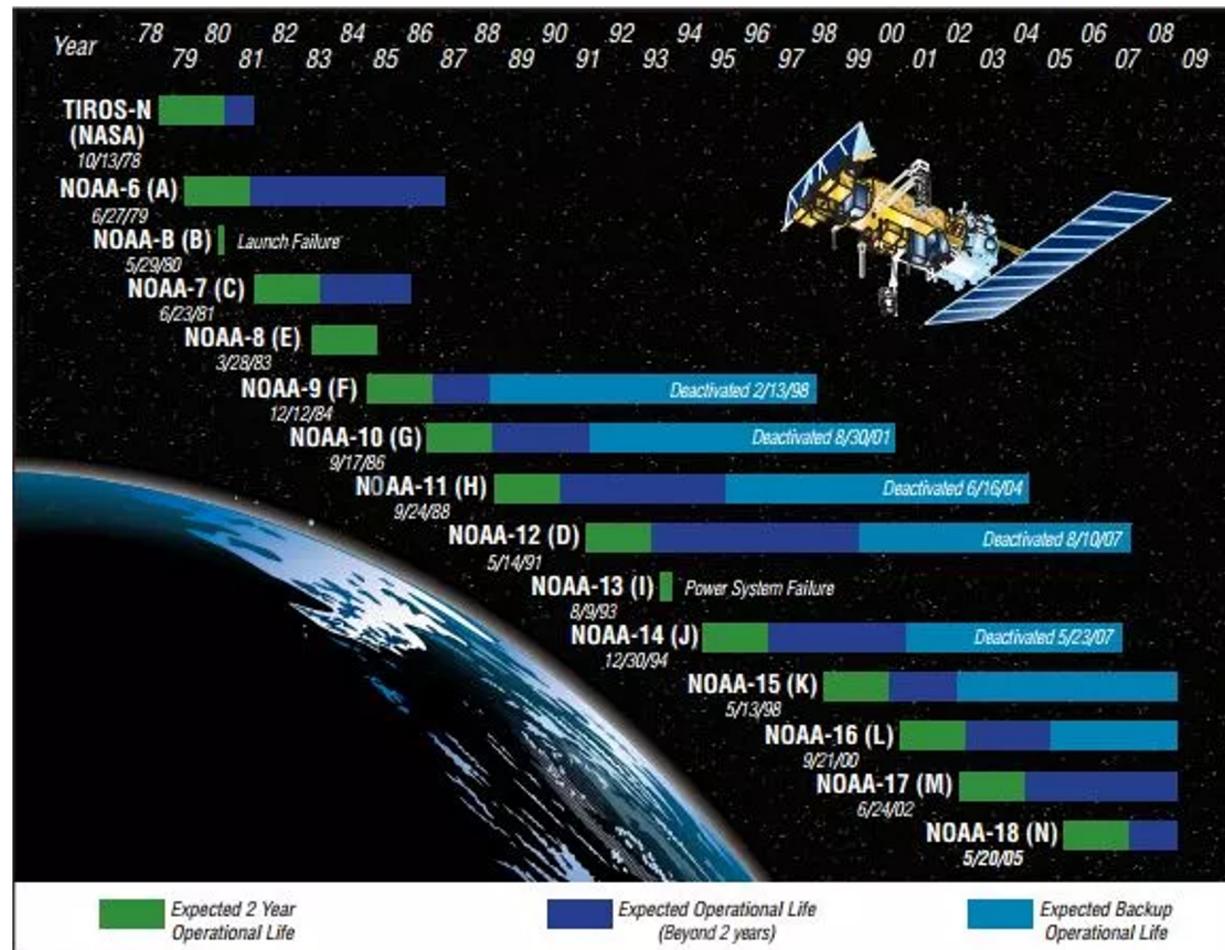
			
Multi-Radar Multi-Sensor	GOES-R ABI and GLM	ENI Lightning network	High-Resolution Rapid Refresh

Derived Motion Winds and Profiles.

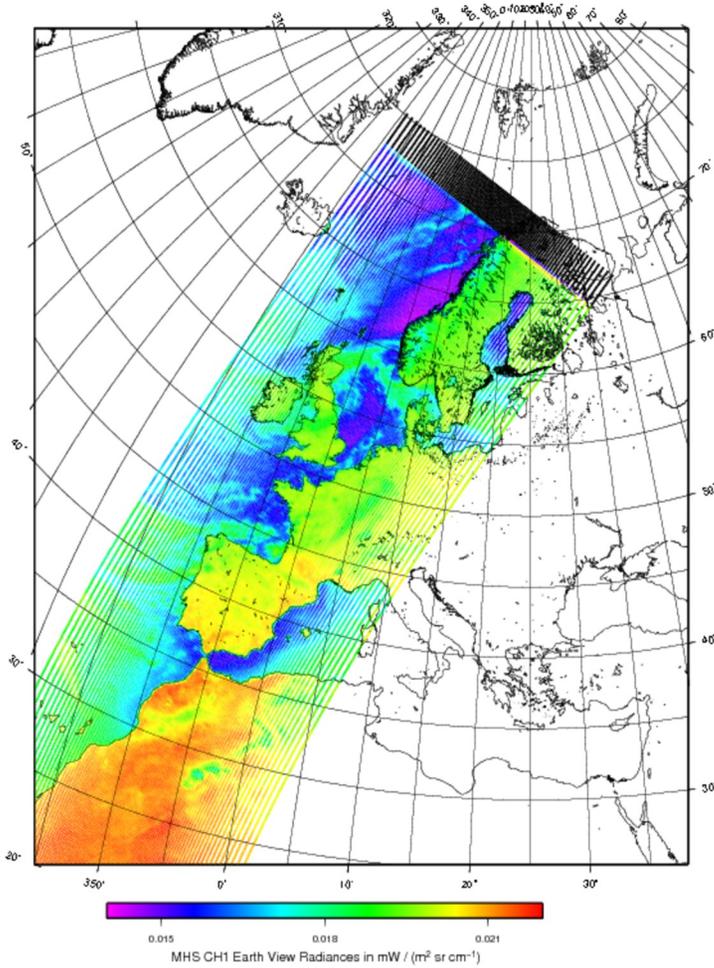


POES (Polar orbiters)

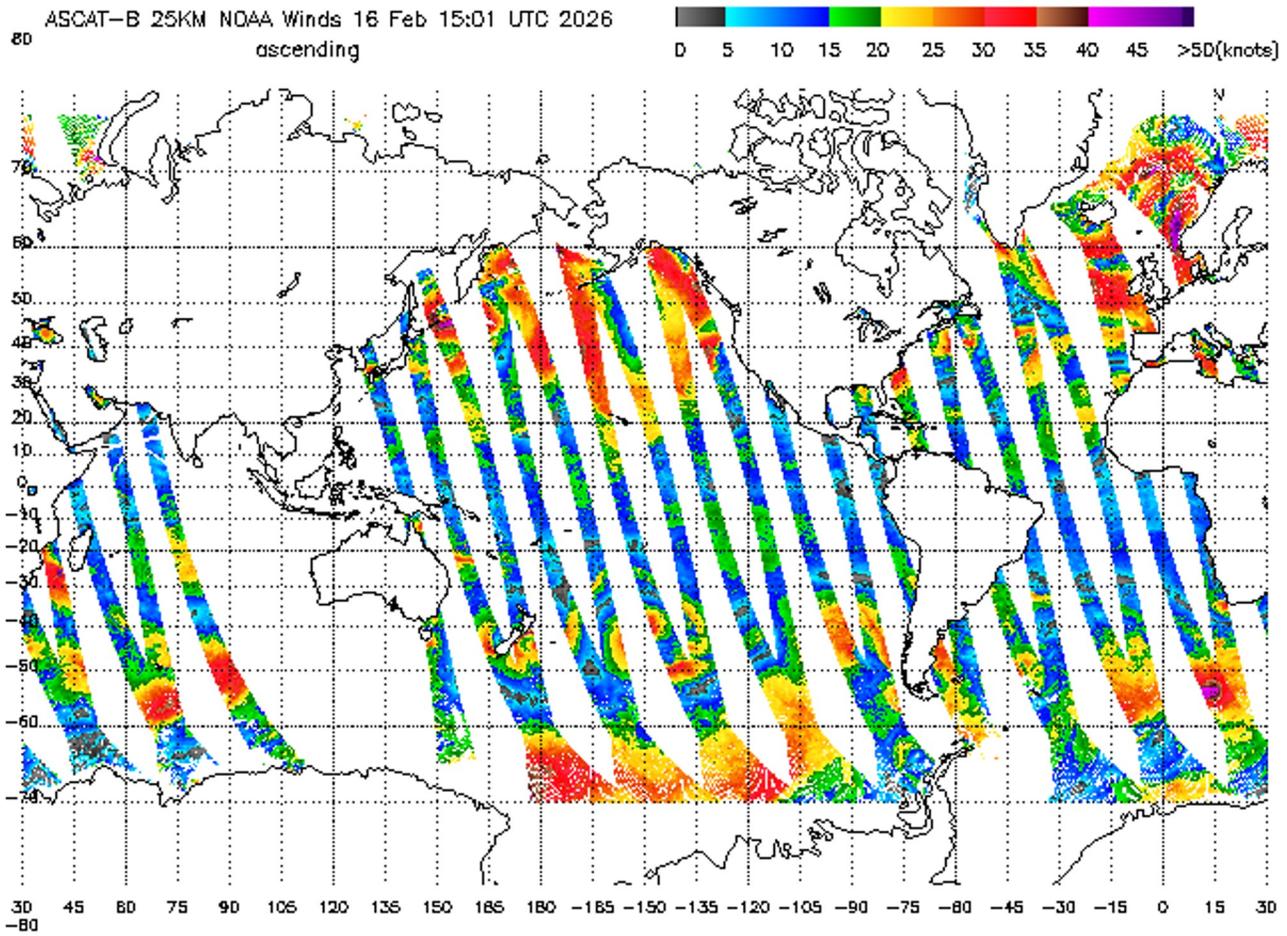
- Polar sats can provide real-time hi-res imagery of large swaths of Earth's surface.
- They “move” relative to the ground and are not limited to a fixed viewing location.
 - 14 orbits per day!
- They can see the entire planet multiple times per day.
- Visible, IR, sounders scatterometry LIDAR and synthetic aperture radar measurements.



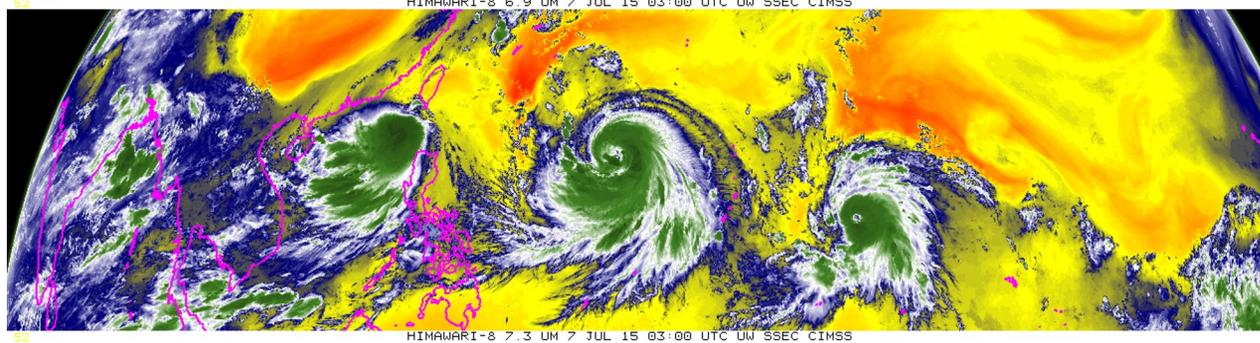
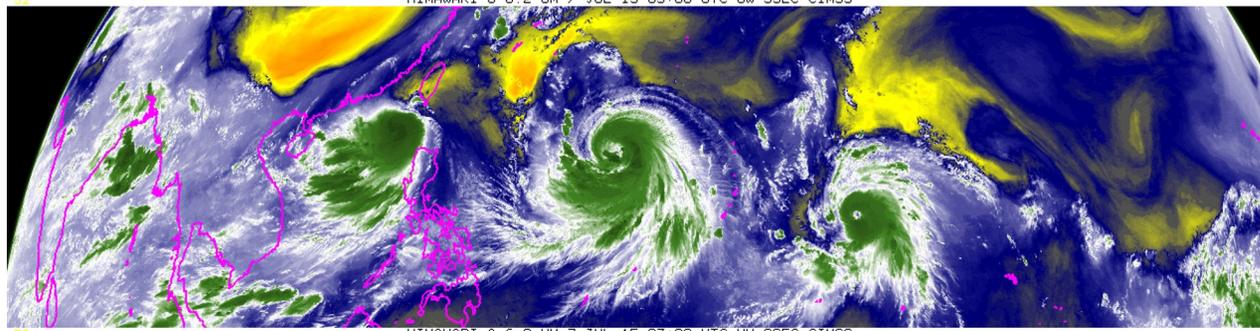
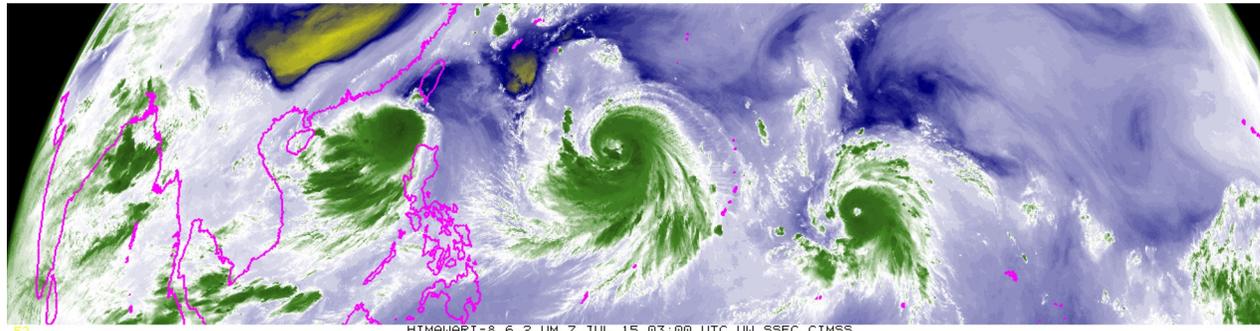
Metop-B MHS, Orbit 110, 25/09/12 10:06:51 to 10:24:51



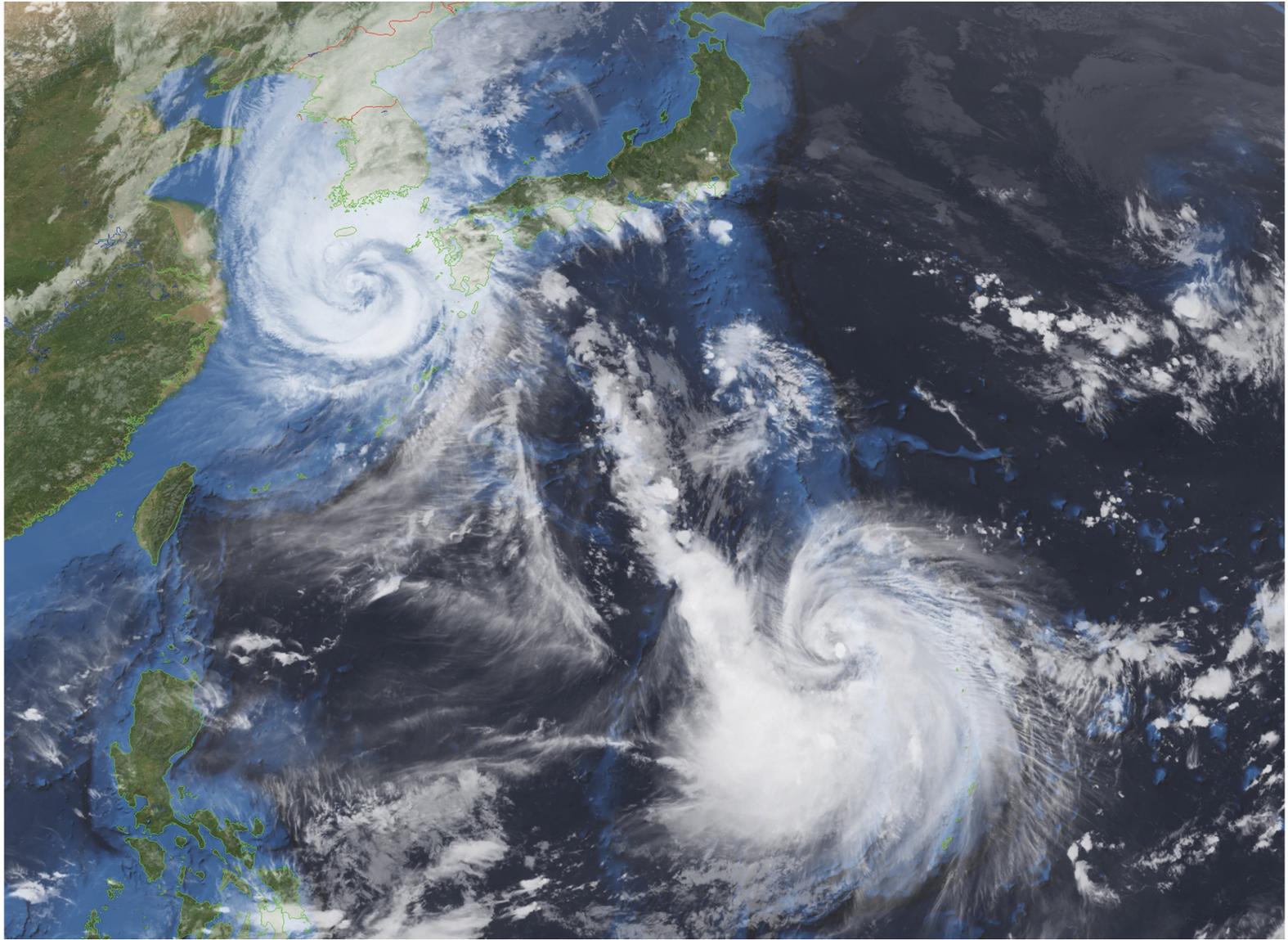
ASCAT-B 25KM NOAA Winds 16 Feb 15:01 UTC 2026
80 ascending



Other Weather Sats



- HIMAWARI 8/10
 - Very similar to GOES with the same ABI
 - Japan Meteorological Agency
- Geo-Kompo GK-2a
 - South Korean weather agency.
 - Countries first geostationary weather sat.
- Meteo Sat Series
 - 1st-3rd Gen (1977-present)
 - Joint European Agency



Source

https://www.weather.gov/media/zhu/GOES_16_Guides_FINALBIS.pdf

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