Observing the Earth With Satellites

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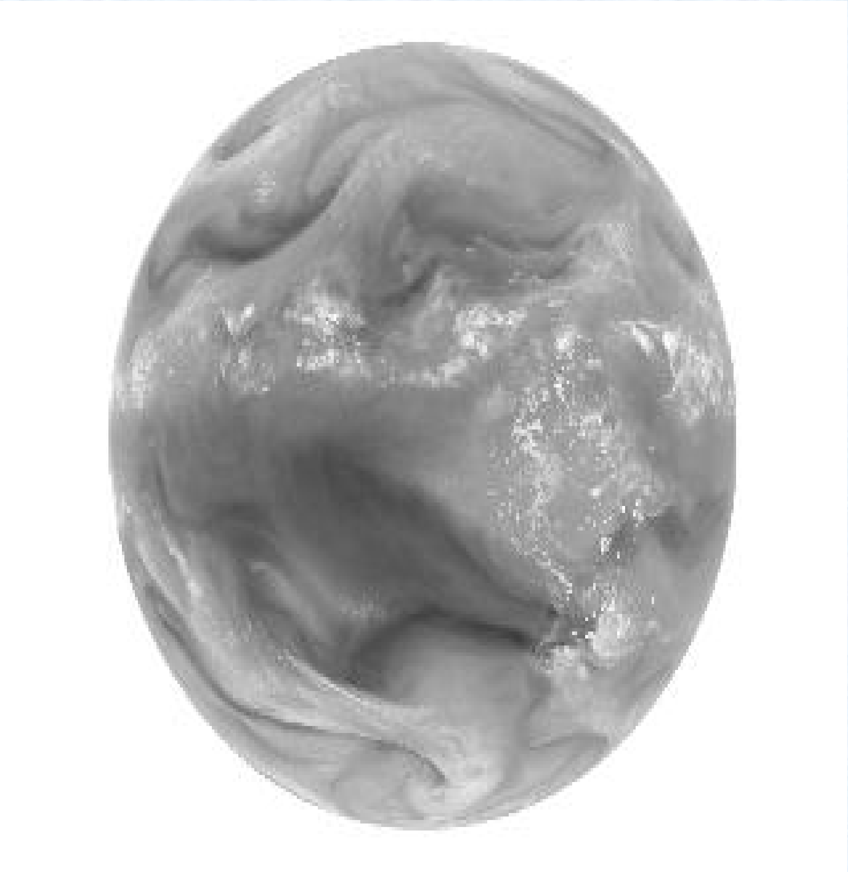
Overview

- Images from geostationary satellites (GOES) can be applied to detect and monitor Earth surface characteristics, changes, and hazards including:
- Atmosphere and clouds
- Snow and ice cover
- Water vs. land
- Volcanic eruptions

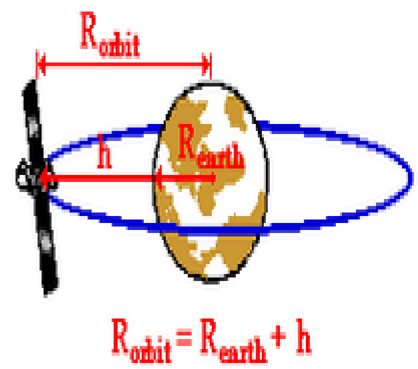
What is a geostationary satellite?

- Located 36,000 km above the earth, the GOES (Geostationary Operational Environmental Satellite) continuously observes the same region (the western hemisphere).
- Why 36,000 km?



Physics of Geotationary Orbit

The unknown in this problem is the height (h) of the satellite above the surface of the earth. Yet there is no equation with the variable h. The solution then involves first finding the radius of orbit and using this R value and the R of the earth to find the height of the satellite above the earth. As shown in the diagram at the right, the radius of orbit for a satellite is equal to the sum of the earth's radius and the height above the earth. The radius of orbit can be found using the following equation:



$$\frac{T^2}{R^3} = \frac{4 * \pi^2}{G * M_{central}}$$

The equation can be rearranged to the following form

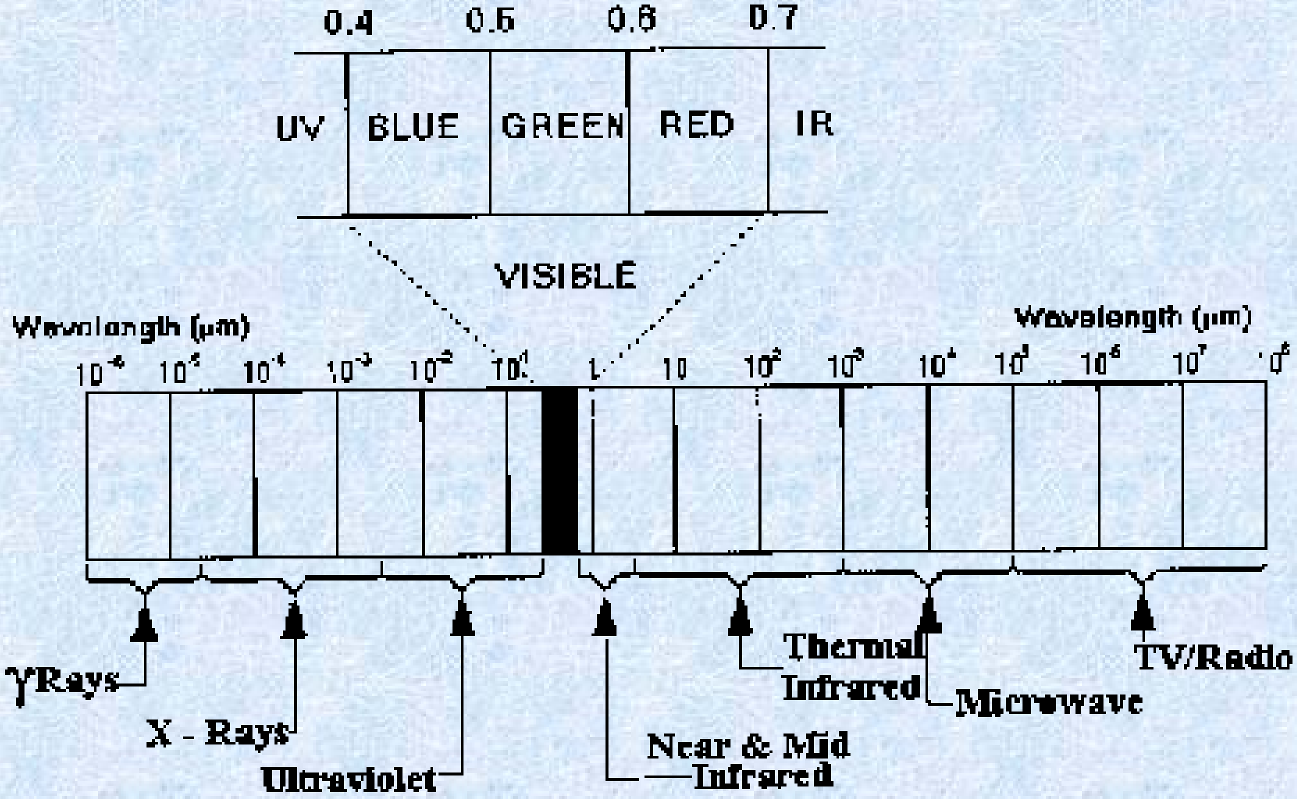
$$R^3 = [(T^2 * G * M_{central}) / (4 * pi^2)]$$

Courtesy of the Physics Classroom: http://www.physicsclassroom.com/class/circles/u6l4c.cfm

GOES Earth Observing

- The GOES imagery for earth observing is based on energy measured in different wavelength bands:
  - formulas that add or subtract satellite measured temperatures to show regions of land cover change and hazards.
- Albedo (reflectance)= $\frac{\text{reflected energy}}{\text{incident energy}} \times 100$

Electromagnetic Spectrum



Visible vs. Infrared (Thermal) Images

- Visible satellite imagery:
  - Brightness is based on the albedo (reflectance) of sunlight against the Earth's surface and objects on the surface.
  - Energy (radiance) comes from sunlight that is reflected off the Earth's surface.

- Infrared satellite imagery:
  - Brightness is based on the temperature sensed on the Earth's surface and objects on the surface.
  - Radiance (energy) comes from the Earth's surface. Sensed at wavelengths where the atmosphere is non-absorbing (windows).

Current GOES Channels

Band	Wavelength (µm)	Use
1 (Visible)	0.52-0.77	Cloud detection and identification
2 (Shortwave IR)	3.76-4.03	Fog identification, water vs. ice clouds
3 (Water Vapor)	5.77-7.33	Moisture content
4 (Longwave IR)	10.2-11.2	Cloud top temperature
5 (Longwave IR, G-11)	11.5-12.5	Low-level moisture
6 (Longwave IR)	12.96-13.72	Cloud characteristics

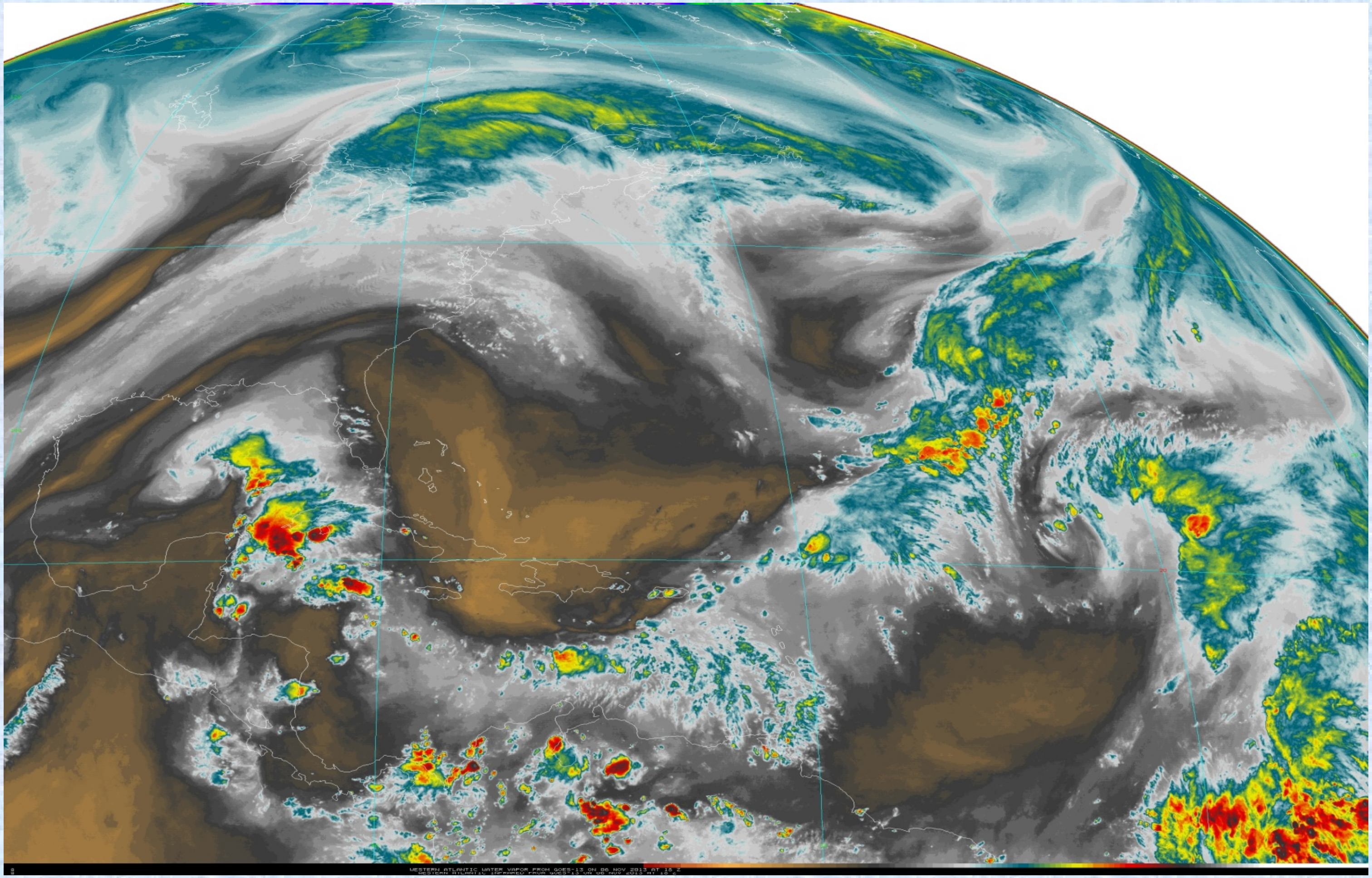
Next Generation: GOES-R

	ABI	Current GOES Imager
Spectral Coverage	16 bands	5 bands
Spatial Resolution		
0.64 μm Visible	0.5 km	~ 1 km
Other visible/near-IR	1.0 km	n/a
Bands (>2 μm)	2 km	~ 4 km
Spatial Coverage		
Full Disk	4 per hour	Scheduled (3 hrly)
CONUS	12 per hour	~4 per hour
Mesoscale	Every 30 sec	n/a
Visible (reflective bands)		
On-orbit calibration	Yes	No

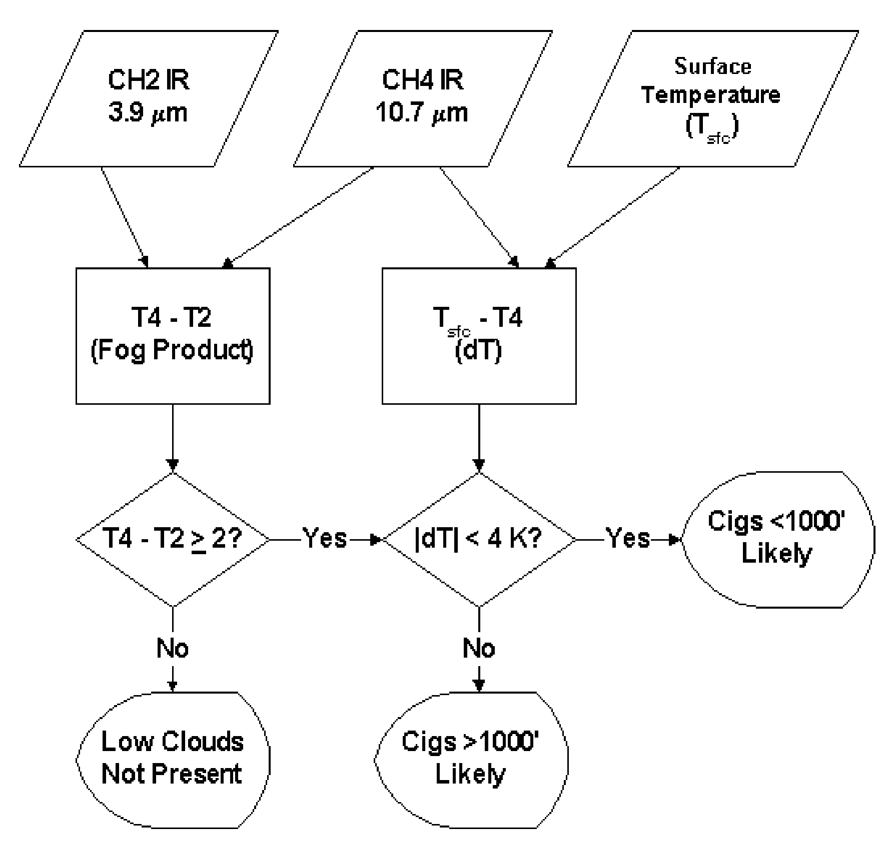
TABLE 1. Summary of the wavelengths, resolution, and sample use and heritage instrument(s) of the ABI bands. The minimum and maximum wavelength range represent the full width at half maximum (FWHM or 50%) points. [The Instantaneous Geometric Field Of View (IGFOV).]

Future GOES imager (ABI) band	Wavelength range (μm)	Central wavelength (μm)	Nominal subsatellite IGFOV (km)	Sample use	Heritage instrument(s)
1	0.45–0.49	0.47	1	Daytime aerosol over land, coastal water mapping	MODIS
2	0.59–0.69	0.64	0.5	Daytime clouds fog, insolation, winds	Current GOES imager/sounder
3	0.846–0.885	0.865	1	Daytime vegetation/burn scar and aerosol over water, winds	VIIRS, spectrally modified AVHRR
4	1.371–1.386	1.378	2	Daytime cirrus cloud	VIIRS, MODIS
5	1.58–1.64	1.61	1	Daytime cloud-top phase and particle size, snow	VIIRS, spectrally modified AVHRR
6	2.225–2.275	2.25	2	Daytime land/cloud properties, particle size, vegetation, snow	VIIRS, similar to MODIS
7	3.80–4.00	3.90	2	Surface and cloud, fog at night, fire, winds	Current GOES imager
8	5.77–6.6	6.19	2	High-level atmospheric water vapor, winds, rainfall	Current GOES imager
9	6.75–7.15	6.95	2	Midlevel atmospheric water vapor, winds, rainfall	Current GOES sounder
10	7.24–7.44	7.34	2	Lower-level water vapor, winds, and SO_2	Spectrally modified current GOES sounder
11	8.3–8.7	8.5	2	Total water for stability, cloud phase, dust, SO_2 rainfall	MAS
12	9.42–9.8	9.61	2	Total ozone, turbulence, and winds	Spectrally modified current sounder
13	10.1–10.6	10.35	2	Surface and cloud	MAS
14	10.8–11.6	11.2	2	Imagery, SST, clouds, rainfall	Current GOES sounder
15	11.8–12.8	12.3	2	Total water, ash, and SST	Current GOES sounder
16	13.0–13.6	13.3	2	Air temperature, cloud heights and amounts	Current GOES sounder/*GOES-12+* imager

GOES Infrared Imagery

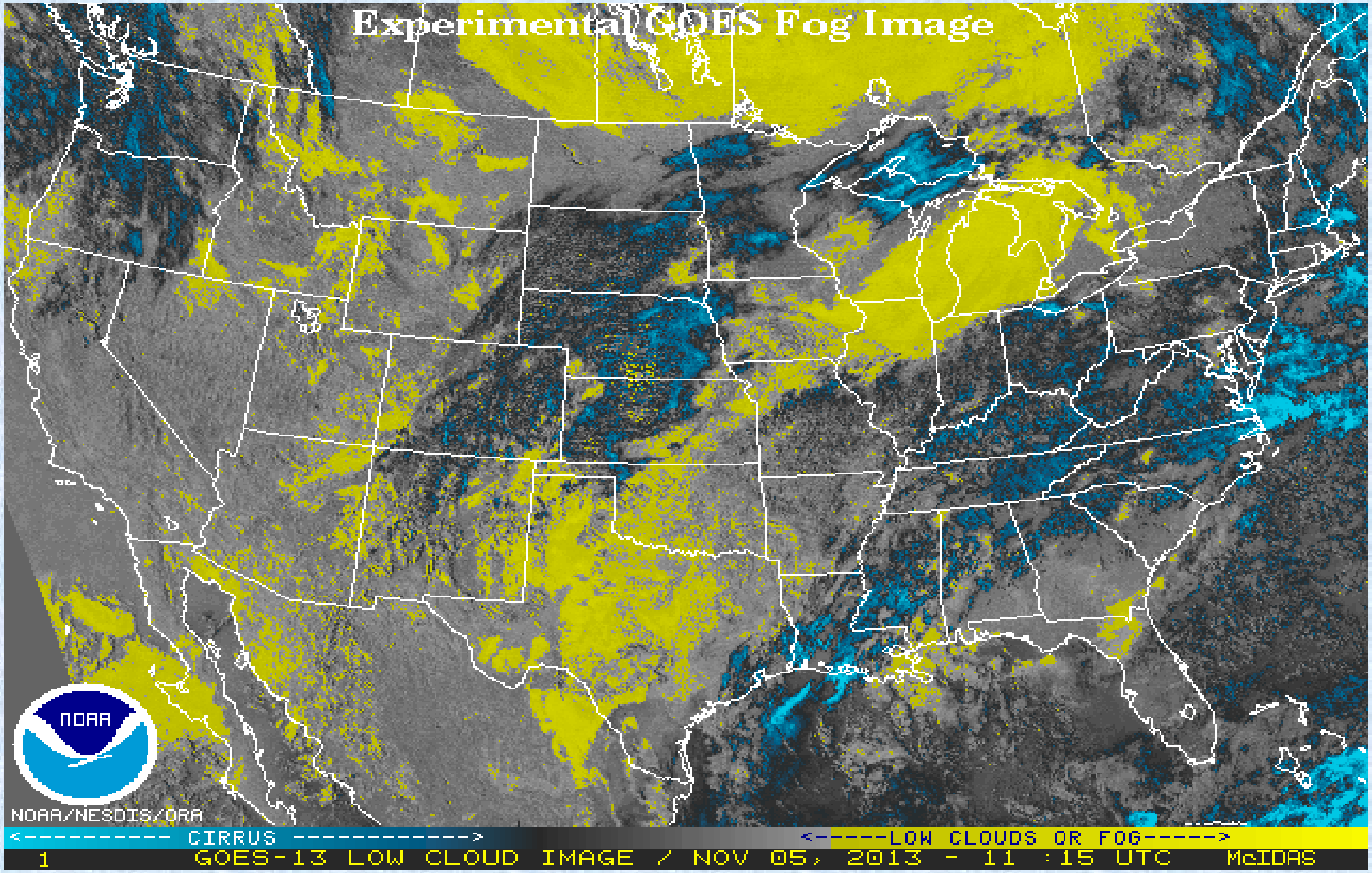


Fog vs. Low Cloud Detection with GOES



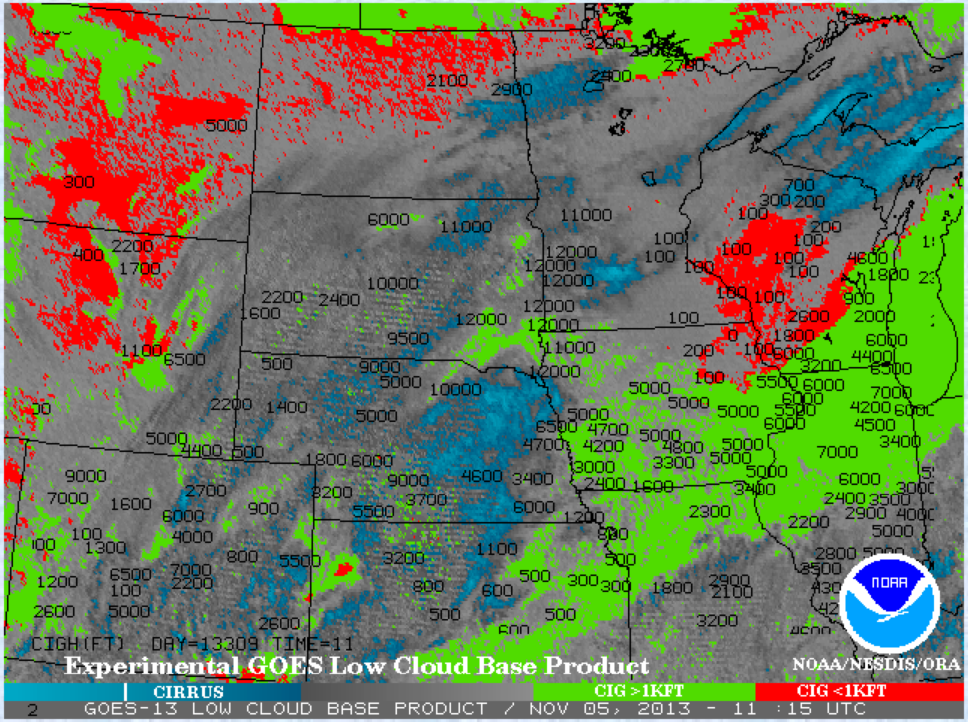
- Surface temperatures are obtained from METARs and ship reports
- Surface temperature grid is generated using a Barnes interpolation technique and then calibrated to ch. 4 IR image.
- Barnes parameter: smoothing factor for the conversion of point data to grids; a larger number results in a data point influencing a greater number of grid points, and the generation of a smoother grid.

GOES Fog Detection



GOES Low Cloud Base Product

- Based on difference of two IR channels (11 µm-3.9 µm) and surface minus cloud top temp.
- Unable to observe low clouds covered by cirrus or middle clouds
- Green shading indicates MVFR or VFR ceilings of any height associated with liquid water clouds.

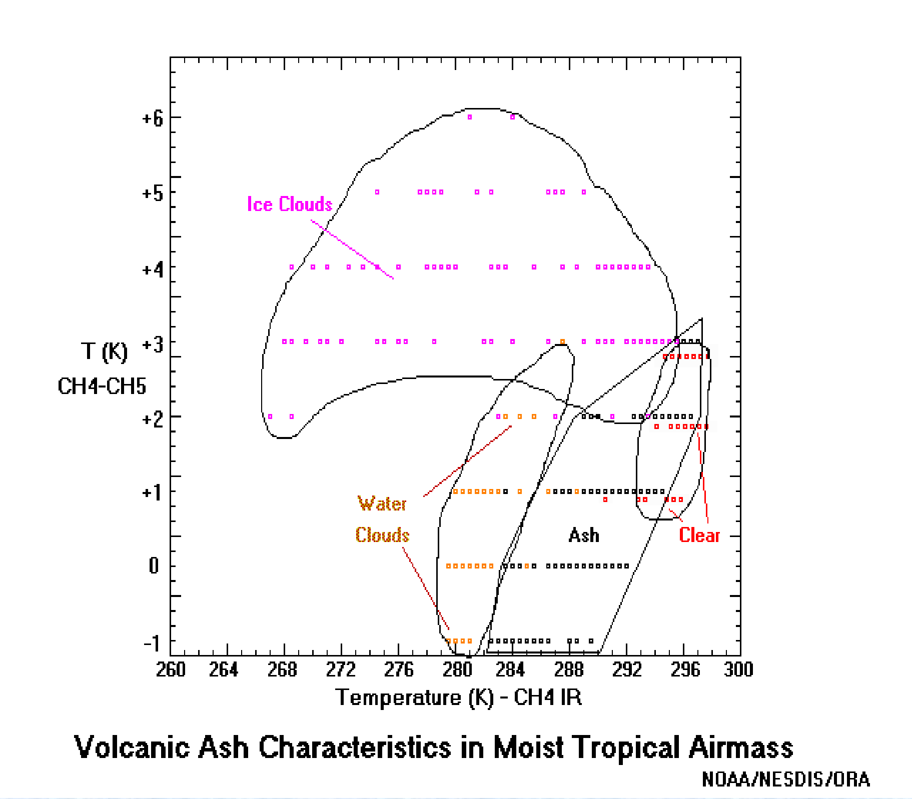


Red areas show where cloud bases <1000 ft (IFR) are likely, green areas > 1000 ft (MVFR), blue are cirrus clouds.

Satellite Volcanic Ash Detection

VAP = 3 X (T2 – T4) + 10 X (T5 – T4)

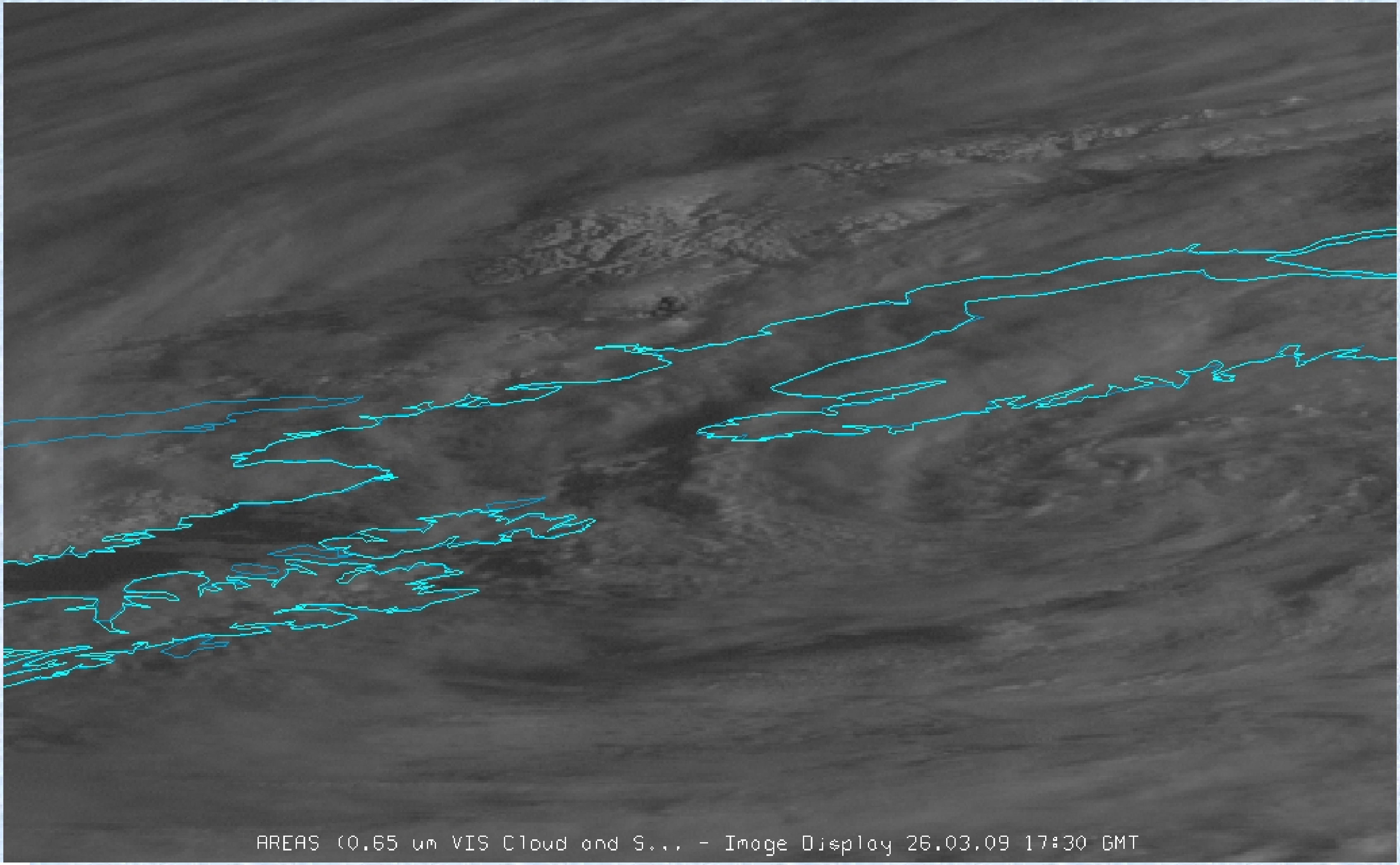
- Combine information from the shortwave IR (CH 2), with two longwave IR channels (4 and 5).
- Temperature differences in Bands 4 and 5 can help identify areas of volcanic ash due to unique energy properties.



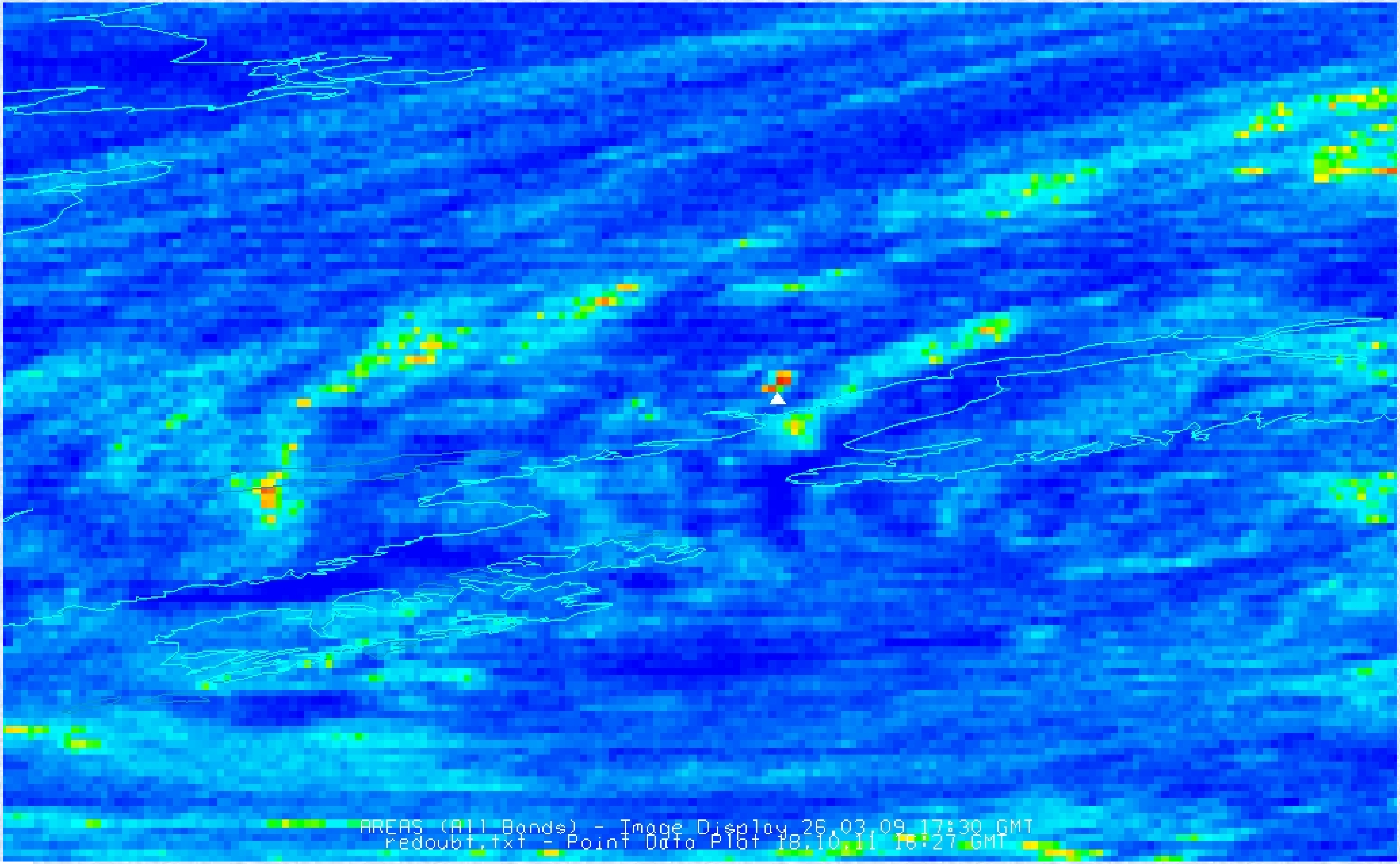
Mount Redoubt, AK
Eruption 26 March 2009

- Explosive eruptions at 8:34 and 9:34 AM ADT.
- First ash cloud rose to 30,000 ft. ASL, second ash cloud rose to 65,000 feet ASL.
- Volcanic ash material was composed of andesite rock.
- Ashfall at Homer and Anchorage.

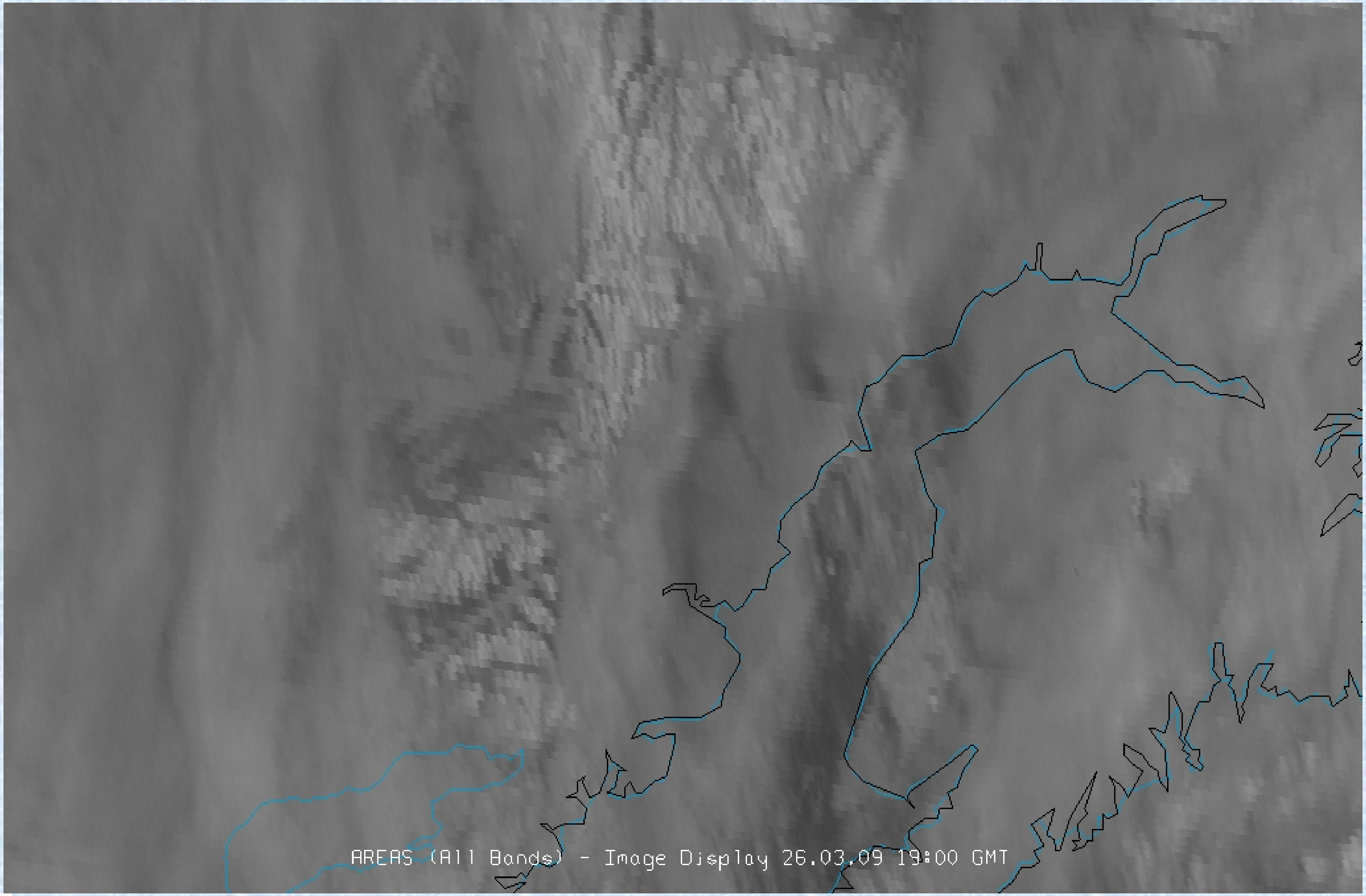
Satellite Volcanic Ash Detection



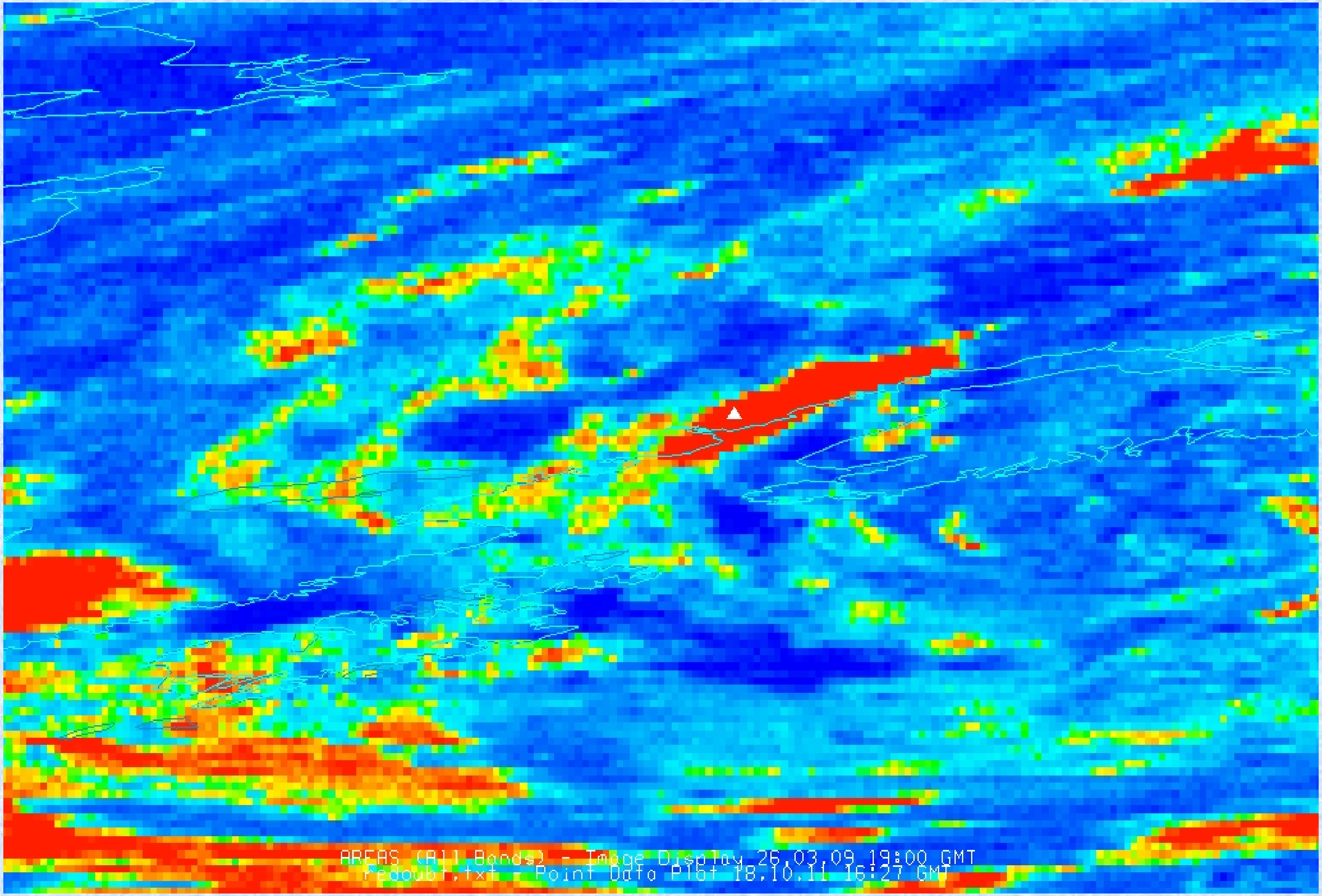
Satellite Volcanic Ash Detection



Satellite Volcanic Ash Detection



Satellite Volcanic Ash Detection



Mount Redoubt, AK
Eruption 26 March 2009

Turbulence

Turbulence

- Definition:
  - Irregular motion in the atmosphere, can be observed as gusts and lulls in the wind.
- Causes:
  - Vertical wind shear
  - Convection

Causes of Turbulence

Clear-air Turbulence (CAT)

Mountain wave Turbulence (MWT)

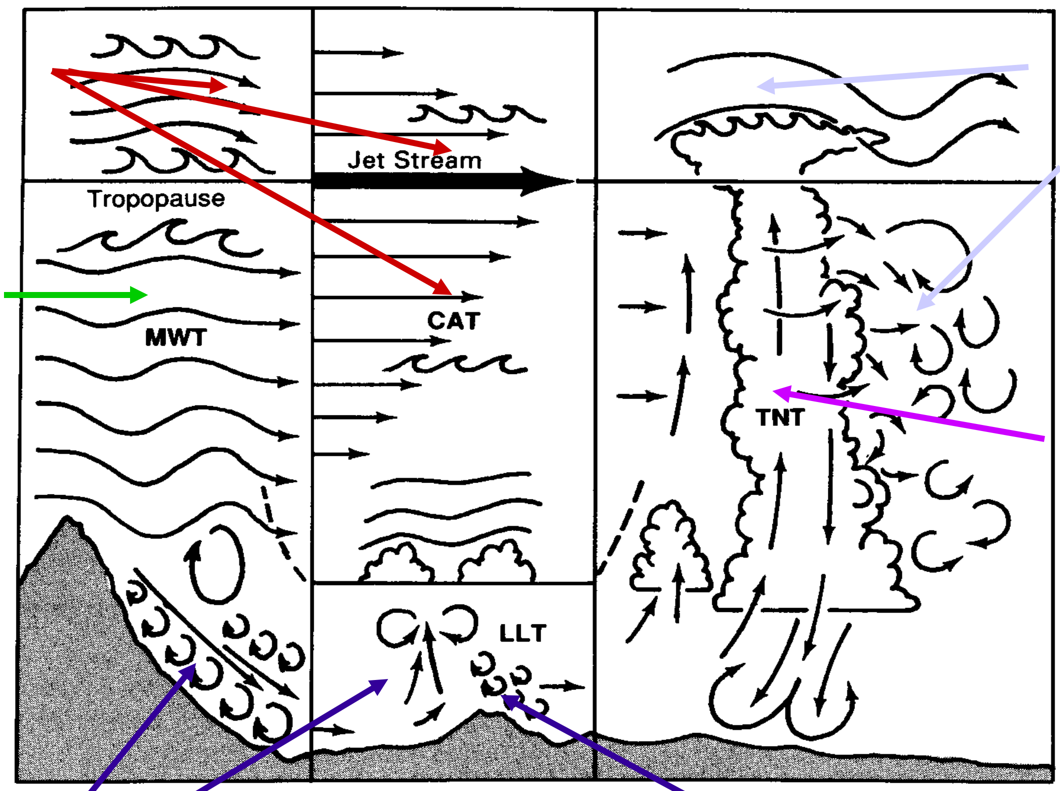


Figure 1-16. Aviation turbulence classifications. This figure is a pictorial summary of the turbulence-producing phenomena that may occur in each turbulence classification.

Cloud-induced or Convectively-induced Turbulence (CIT)

In-cloud turbulence

Low level Terrain-induced Turbulence (LLT)

Convective boundary Layer turbulence

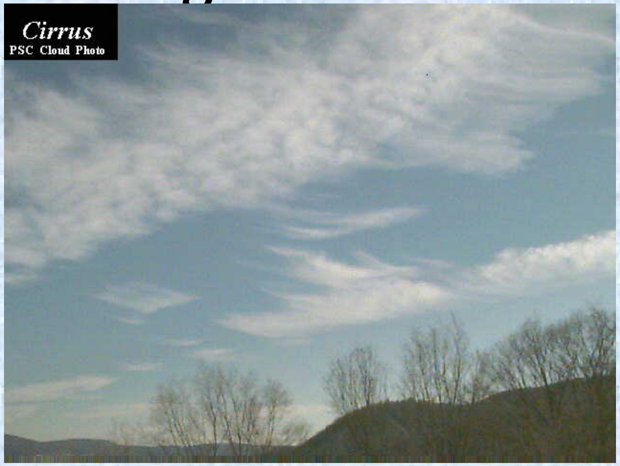
Source: P. Lester, "Turbulence – A new perspective for pilots," Jeppesen, 1994

Aviation Products

Cloud Classification

- Height
- Shape
- Vertical Development

High Cloud- Cirrus



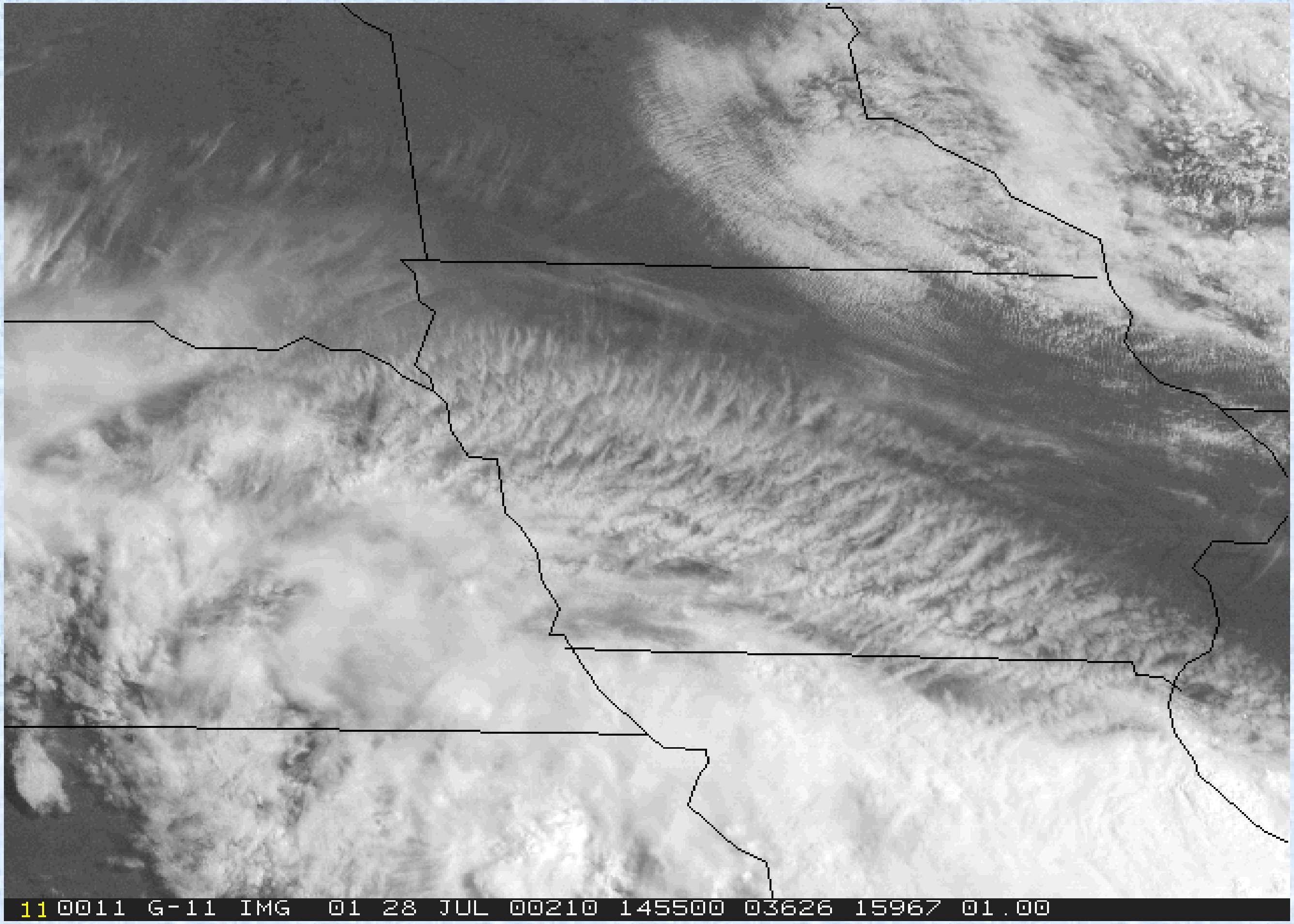
Cumulus

Low Cloud- Stratus

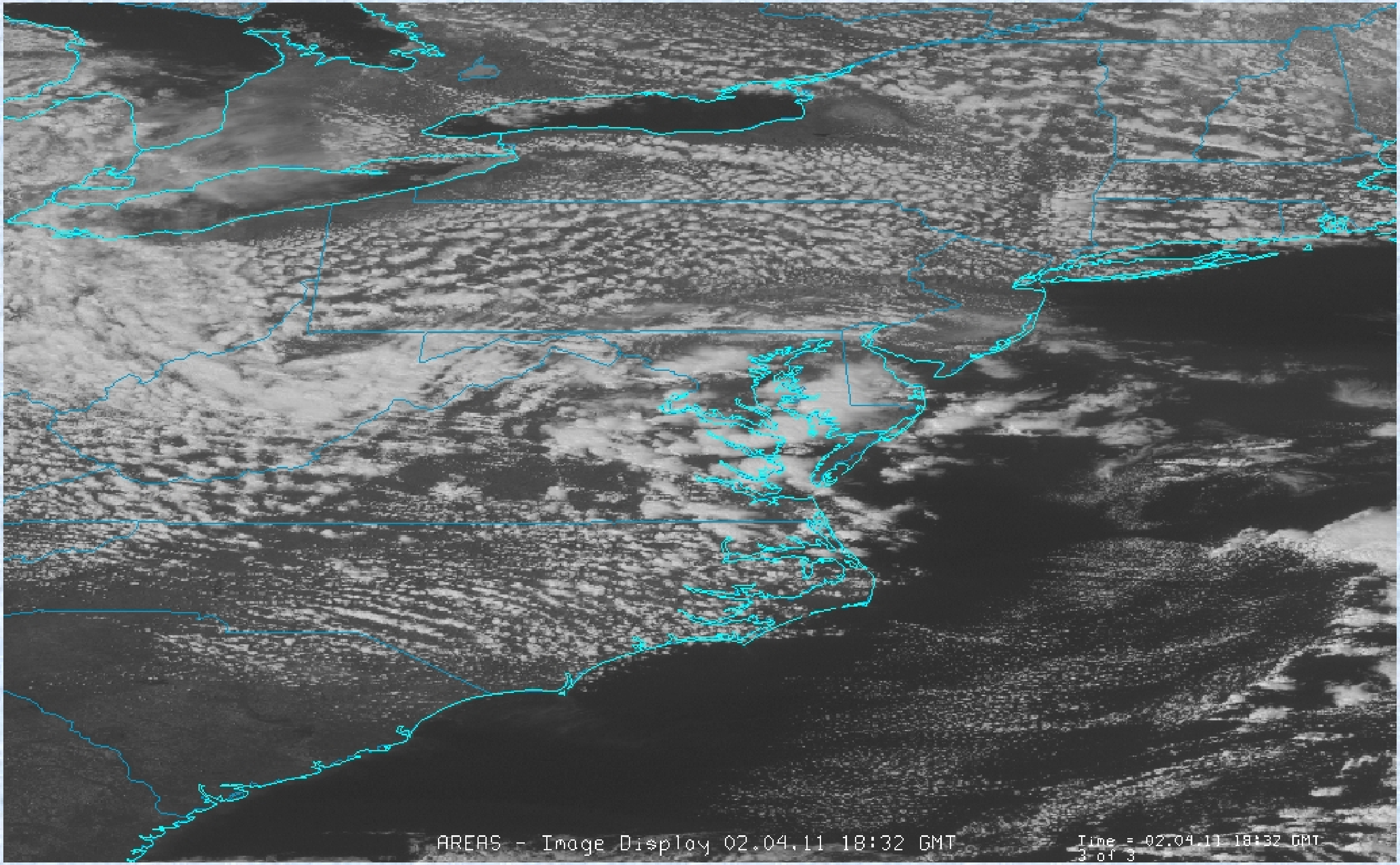
Cumulus Clouds

- “Seed” for thunderstorms
- Made of liquid water
- Air is rising quickly
- Fair weather if there is no vertical development
- Will make precipitation if clouds grow tall enough
- If the clouds are thick enough, all of the light from the sun is <u>scattered</u> and <u>absorbed</u> by the cloud, causing the cloud to appear dark.

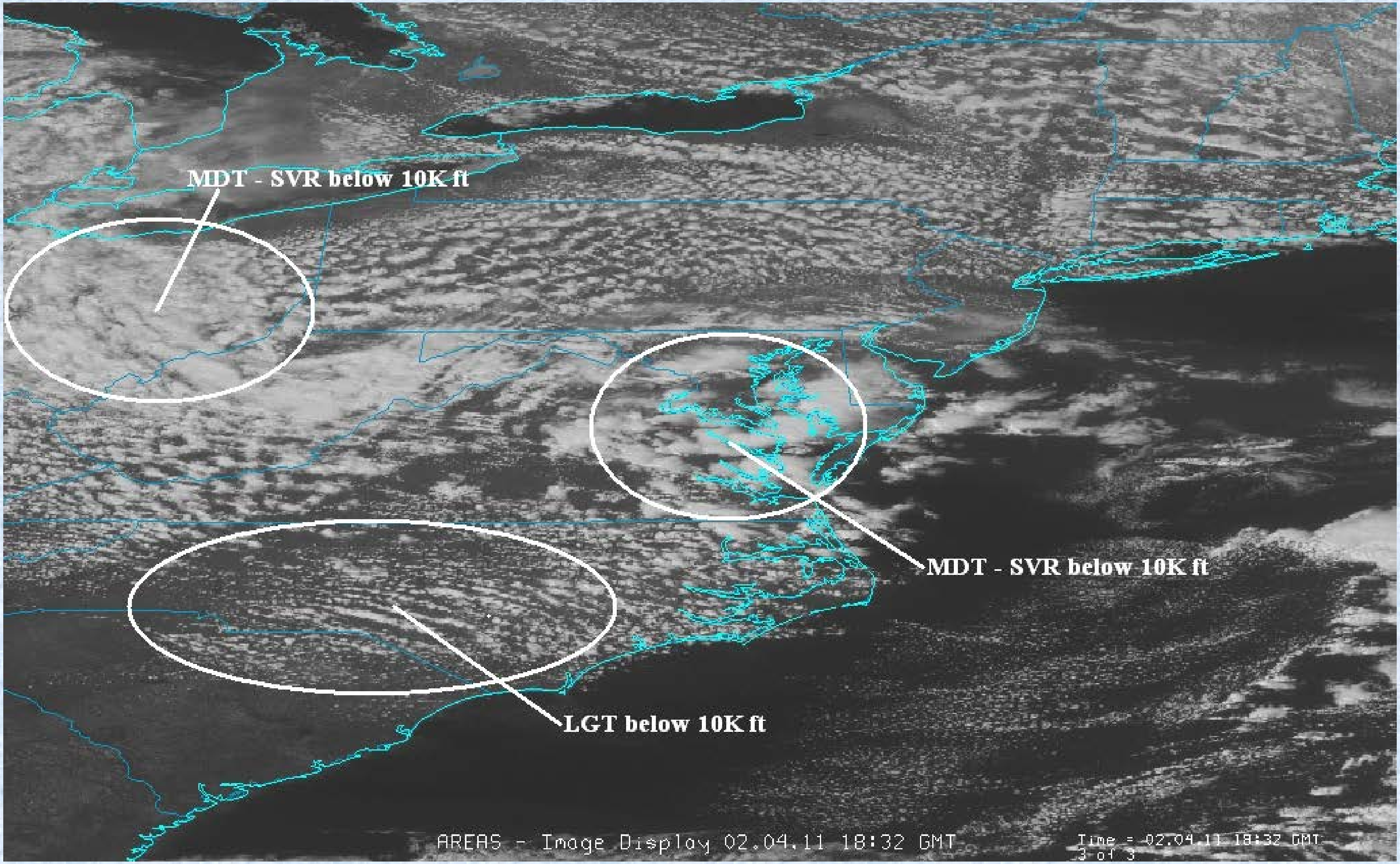
Jet Stream Turbulence



Turbulence Detection



Turbulence Detection



Thunderstorm Downburst

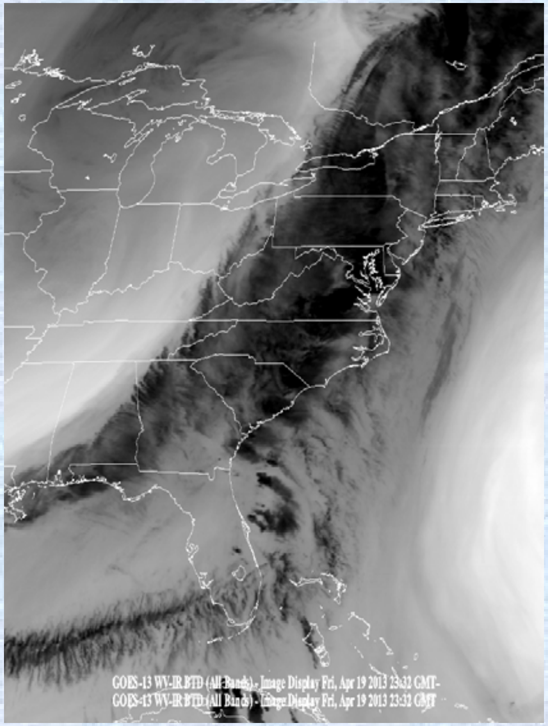
- Strong downdraft produced by a convective storm (or thunderstorm) that causes **damaging winds** on or near the ground. (Fujita and Wakimoto 1981)
- Serious hazard to sailing vessels due to inclined winds that can cause a knock-down.

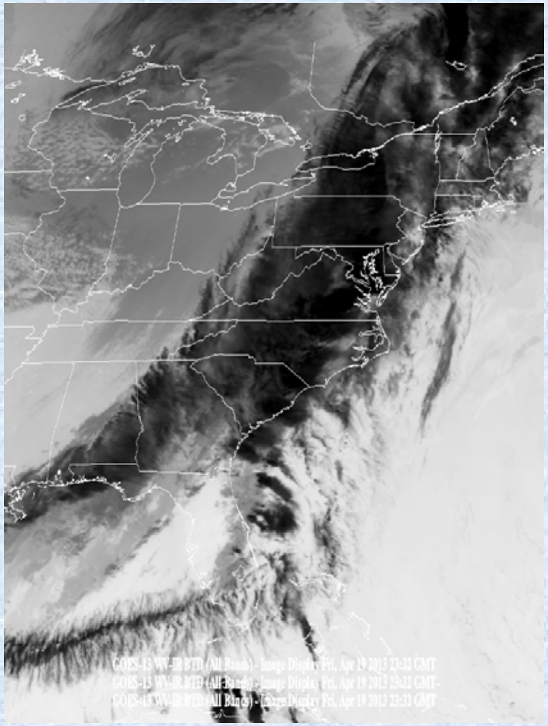
GOES Convection Product

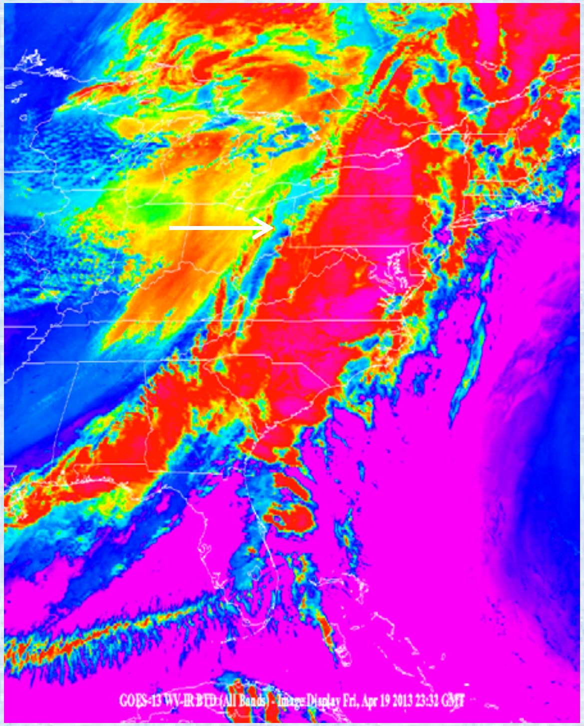
- Bispectral GOES imager product (Pryor 2010):
- The BTD between GOES water vapor (6.5μm) and thermal infrared (11μm) bands can highlight regions where severe outflow wind generation (i.e. downbursts, microbursts) is likely due to the channeling of dry mid-tropospheric air into the precipitation core of a deep, moist convective storm.
- Readily apparent in BTD imagery is a "dry-air notch" that signifies the channeling of dry air into the rear flank of a convective storm.

GOES Convection Product

- Enhanced band 3 – 4 BTD image showing well-defined dry air notches.



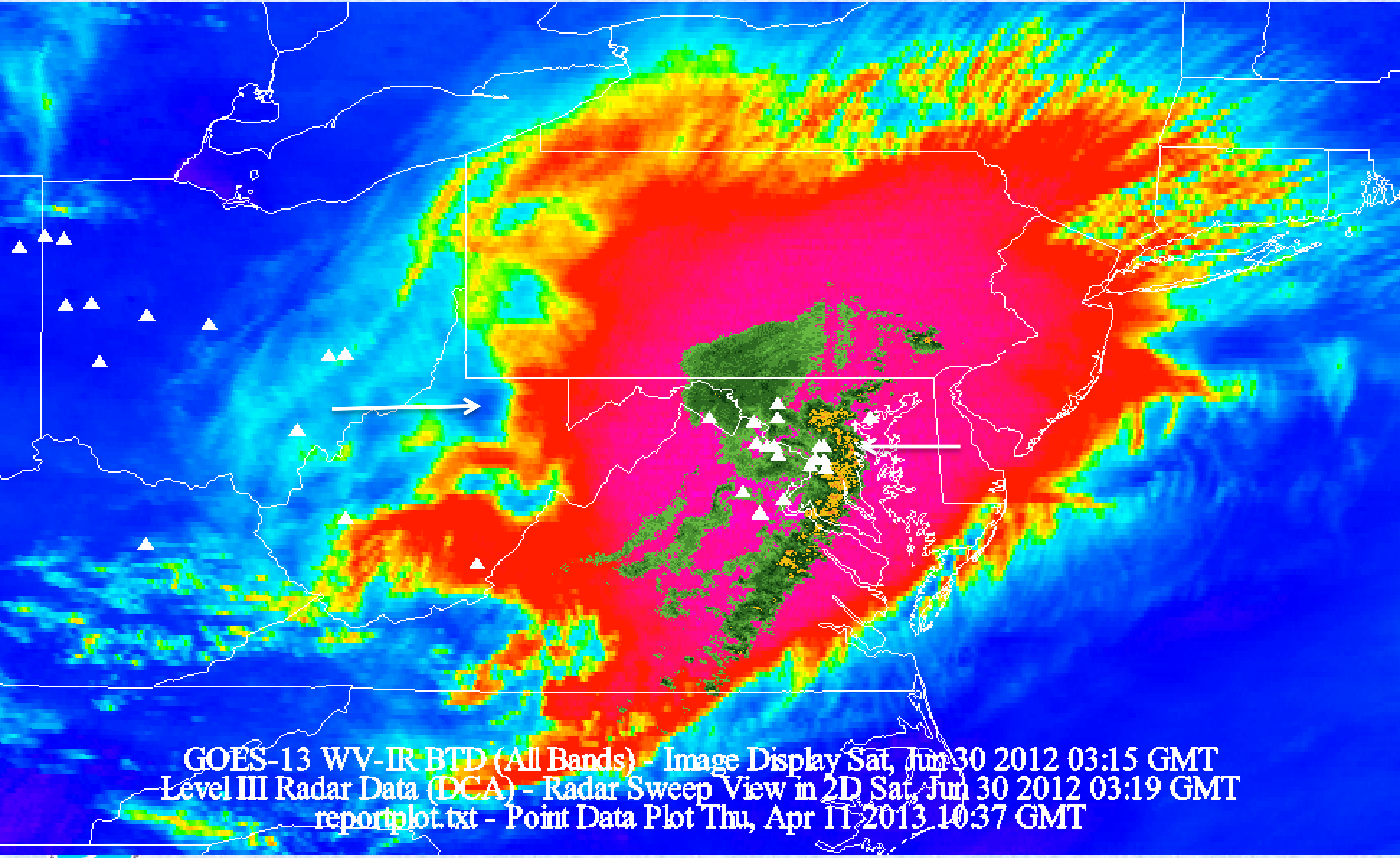




WV BT - IR BT = BTD

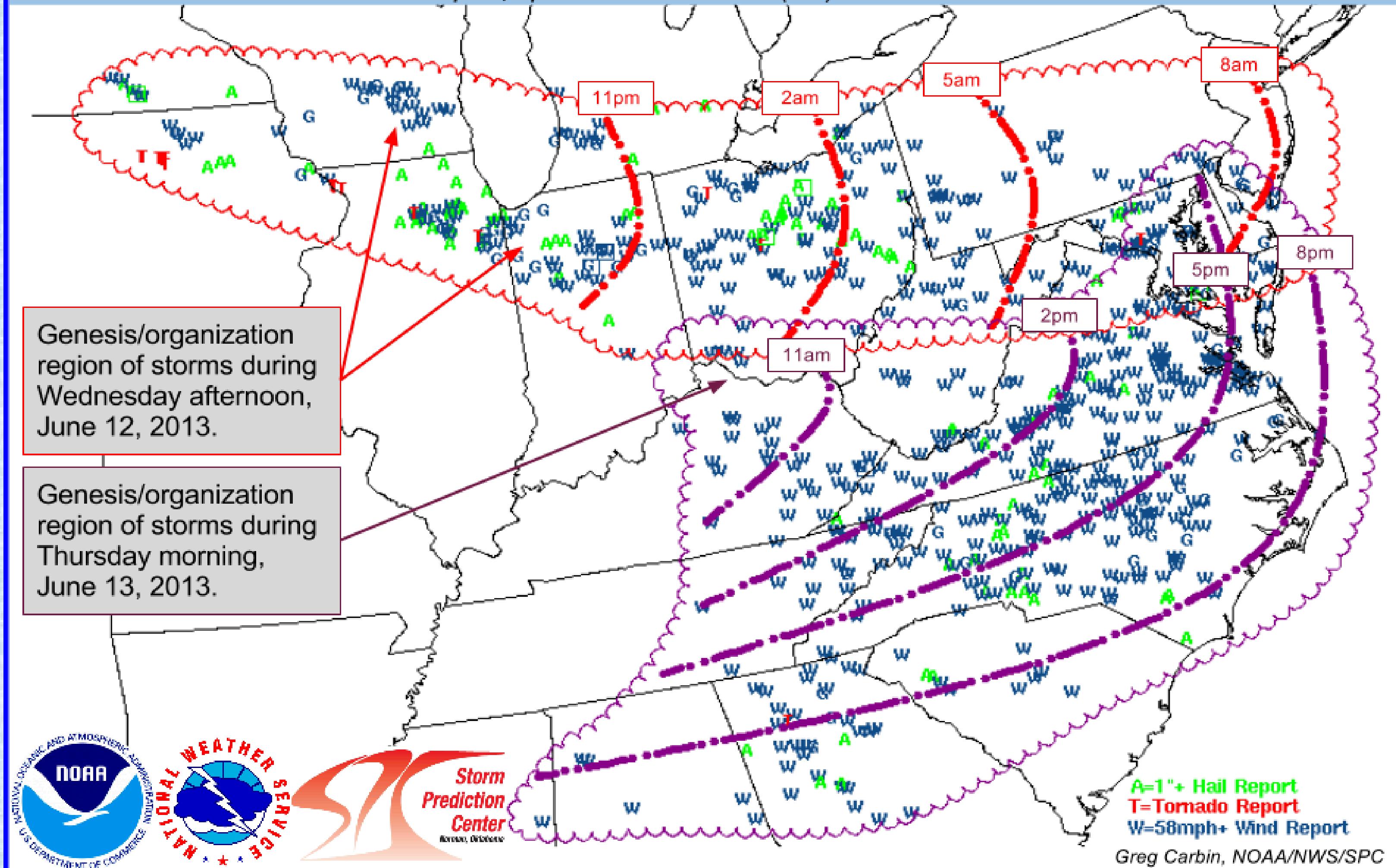
http://www.star.nesdis.noaa.gov/smcd/opdb/kpryor/mburst/mbimg.html

GOES-13 RSO WV-IR BTD/Radar

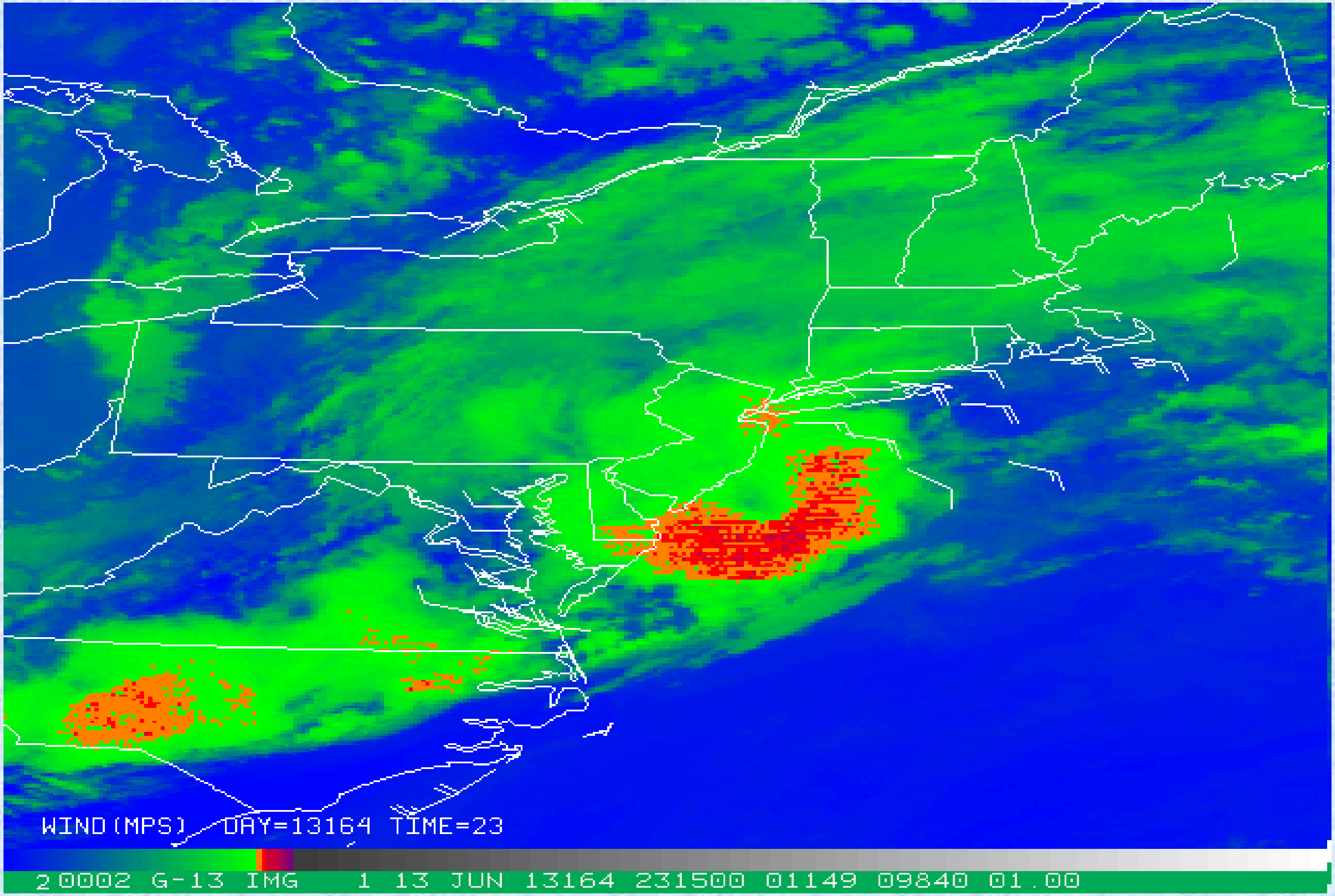


June 12 and 13, 2013 Severe Wind/Derecho Events
Midwest and Mid Atlantic

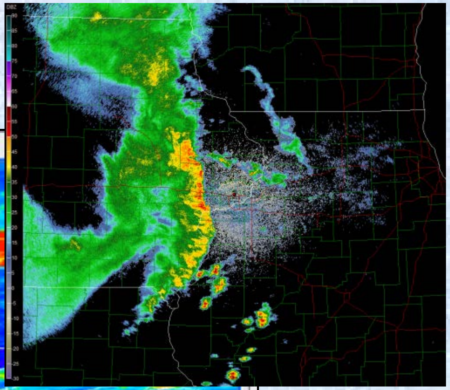
Reports, squall line location and time (EDT):

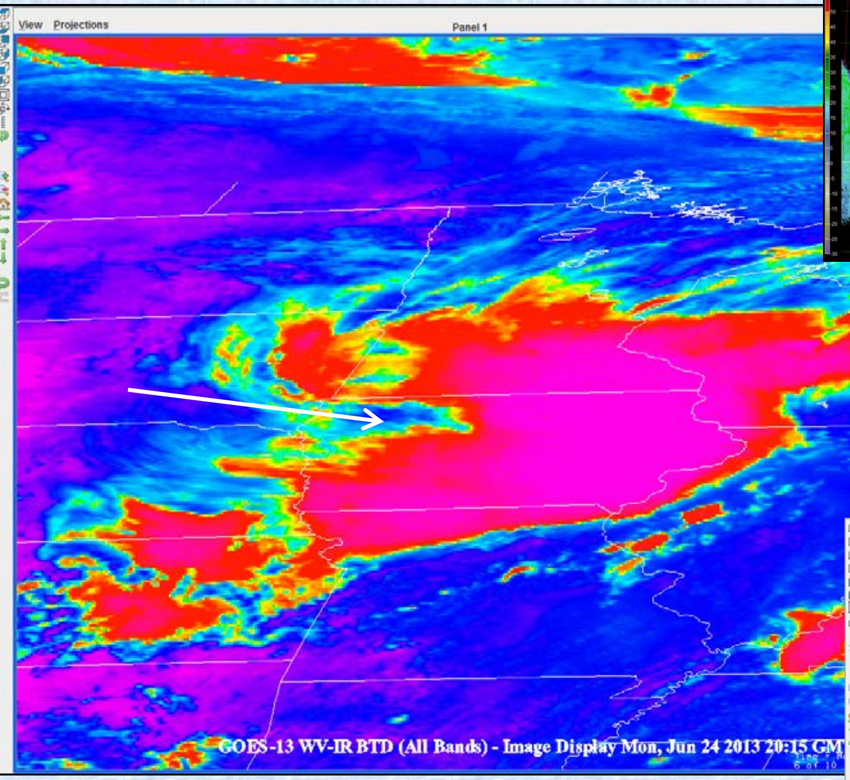


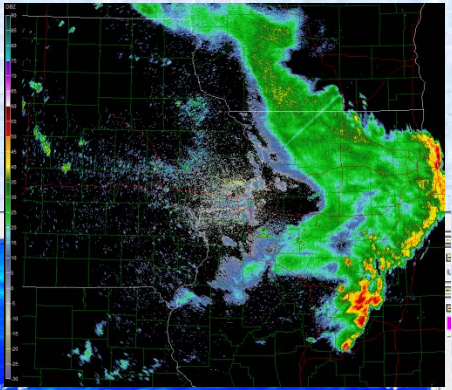
GOES-13 WV-IR BTD

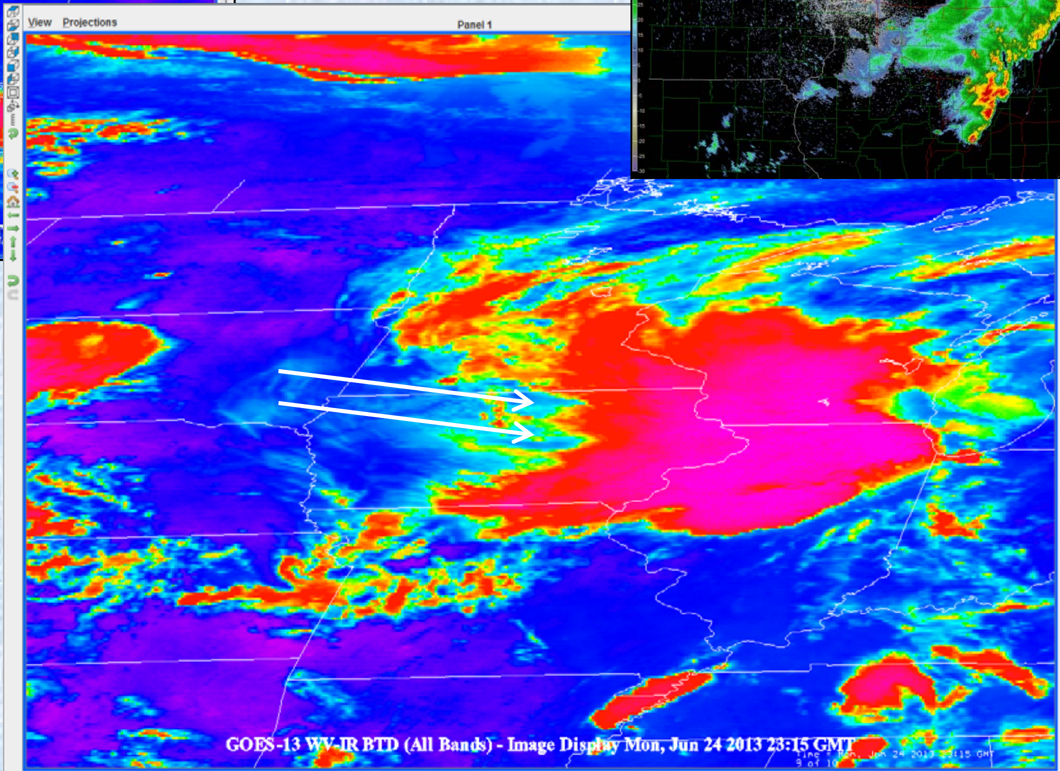


Satellite – BTD









Arrows indicate location of dry air notches apparently associated with subsidence and the rear-inflow jet.

Conclusions

- The GOES imagery for earth observing is based on energy measured in different wavelength bands:
  - formulas that add or subtract satellite measured temperatures to show regions of land cover change and hazards.
- Products that detect fog, volcanic ash, and severe-wind producing thunderstorms use GOES infrared channels.
- Visible channels can be used to distinguish cloud types.

Questions?

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