On the Role of Next Generation Geostationary Satellite Data in Improving Severe Storm and Tornado Prediction

Steven Weiss and William Line

NOAA/Storm Prediction Center, Norman, OK

10th Symposium on New Generation Operational Environmental Satellite Systems
2014 AMS Annual Meeting, Atlanta, GA

February 3, 2014

Outline of Presentation

- Tornadoes, Severe Thunderstorms and Societal Impacts
  - Basic Tornado Information
  - Some Major Historical Tornadoes
- Severe Storm Forecasting and GOES-R
  - Product Improvements
  - Expected Benefits

Some Tornado Background

Each Year: About **1,300 tornadoes** touch down across the United States causing an average of **$1.1 billion in damage** and over **80 deaths**

2011 – A Historic Tornado Year

Annual Totals

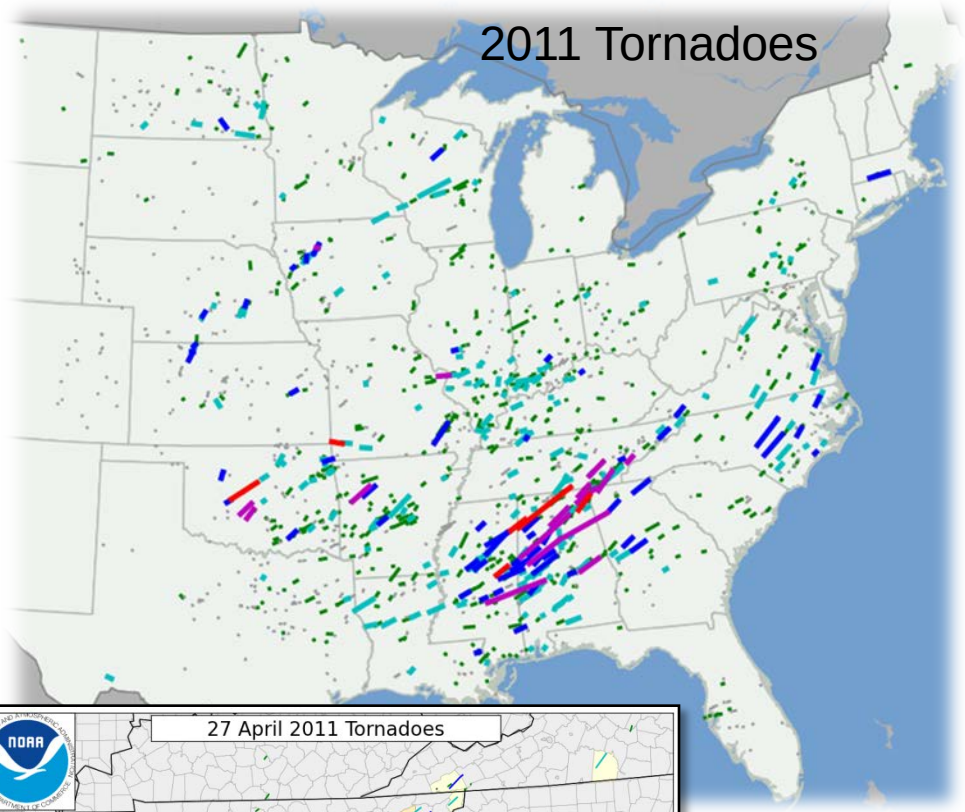
- **1690 tornadoes (2nd)** - *Final*
  - Current record 1,817 in 2004
- **553 direct fatalities**
  - 2nd deadliest in combined record
  - NOAA + historical research
    - 551 deaths in 1917
    - 552 deaths in 1936
    - 794 deaths in 1925

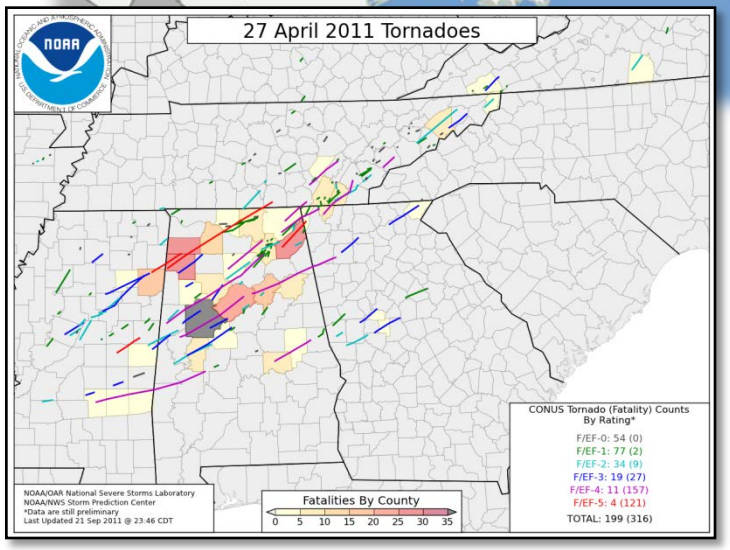
April

- **759 tornadoes** – A new record
  - 208 tornadoes on April 27 alone
- **363 fatalities**
  - Most in modern era (since 1950)
  - 319 on April 27 alone

Joplin – May 22

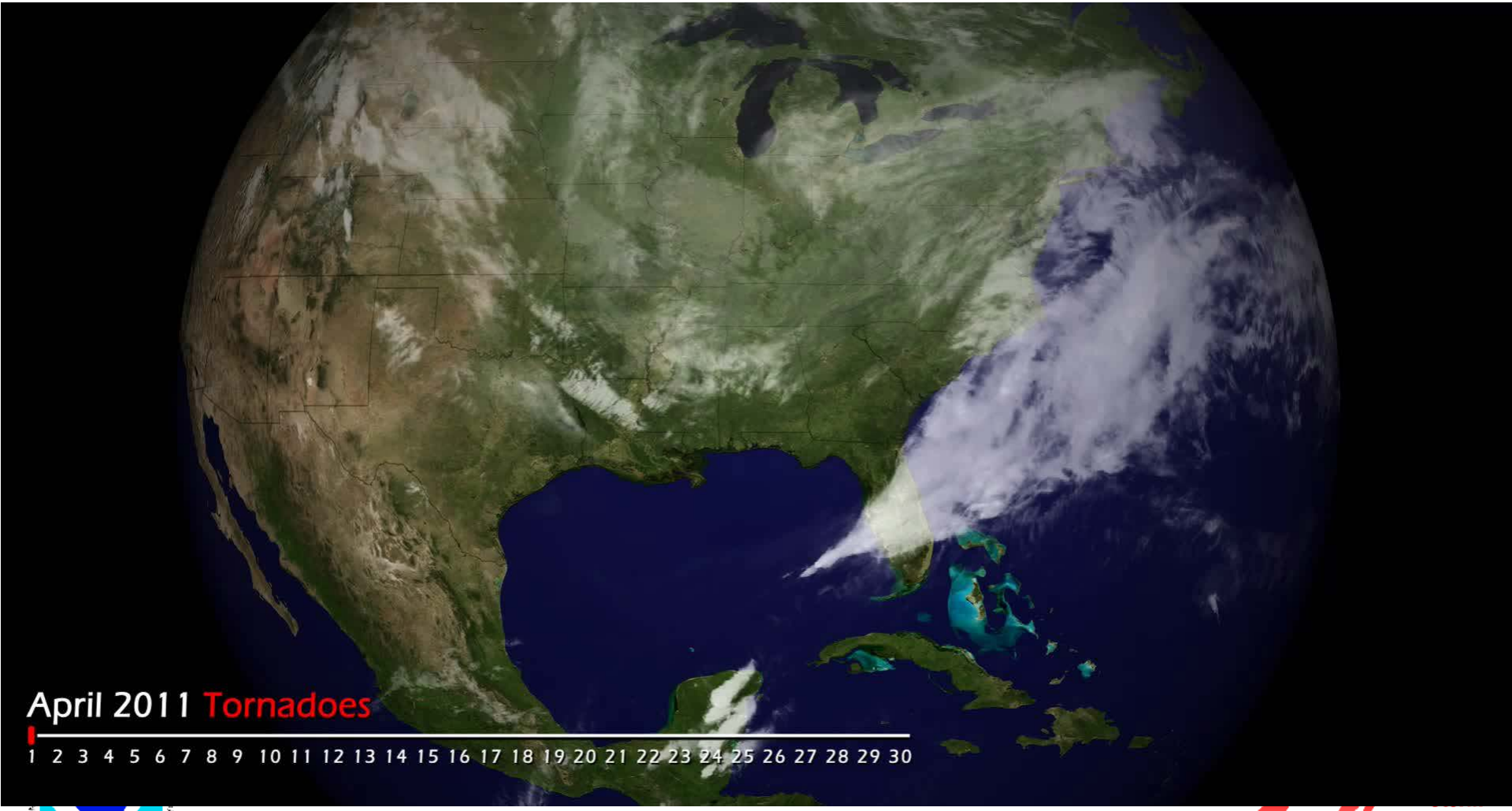
- **Deadliest single tornado since 1947**
  - **160 deaths**





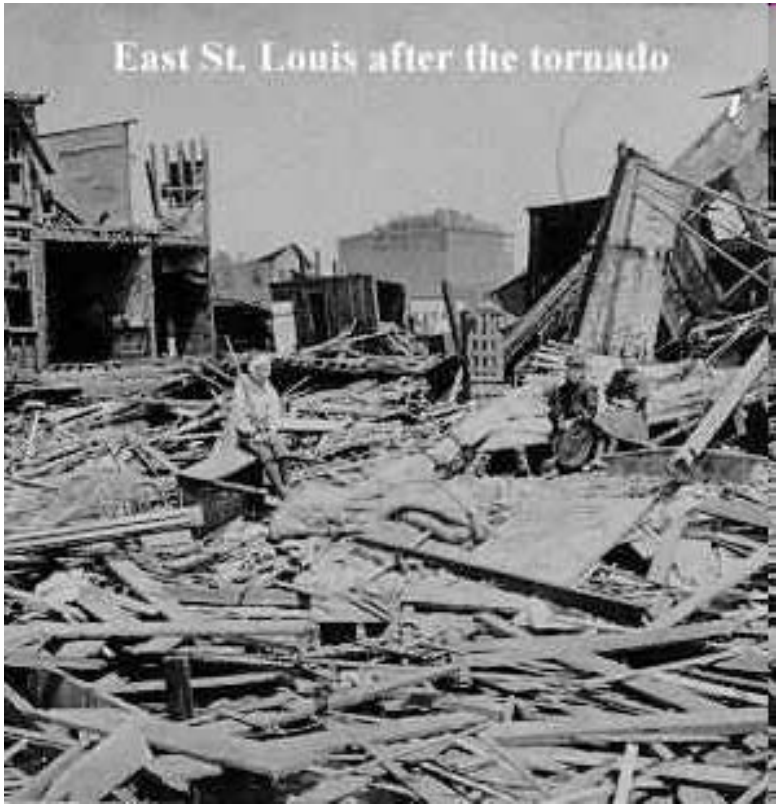
Record April 2011Tornadoes: A Satellite Summary

tornado reports appear as red dots



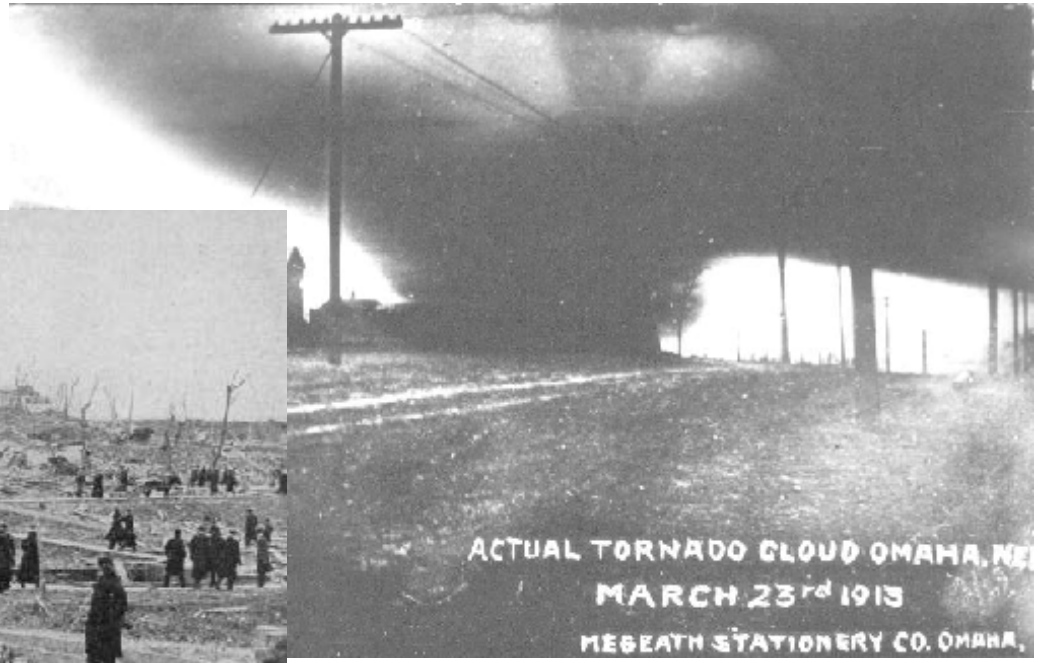
Some Historic Tornadoes

St. Louis Tornado May 27, 1896



F5: 255 killed Thousands injured

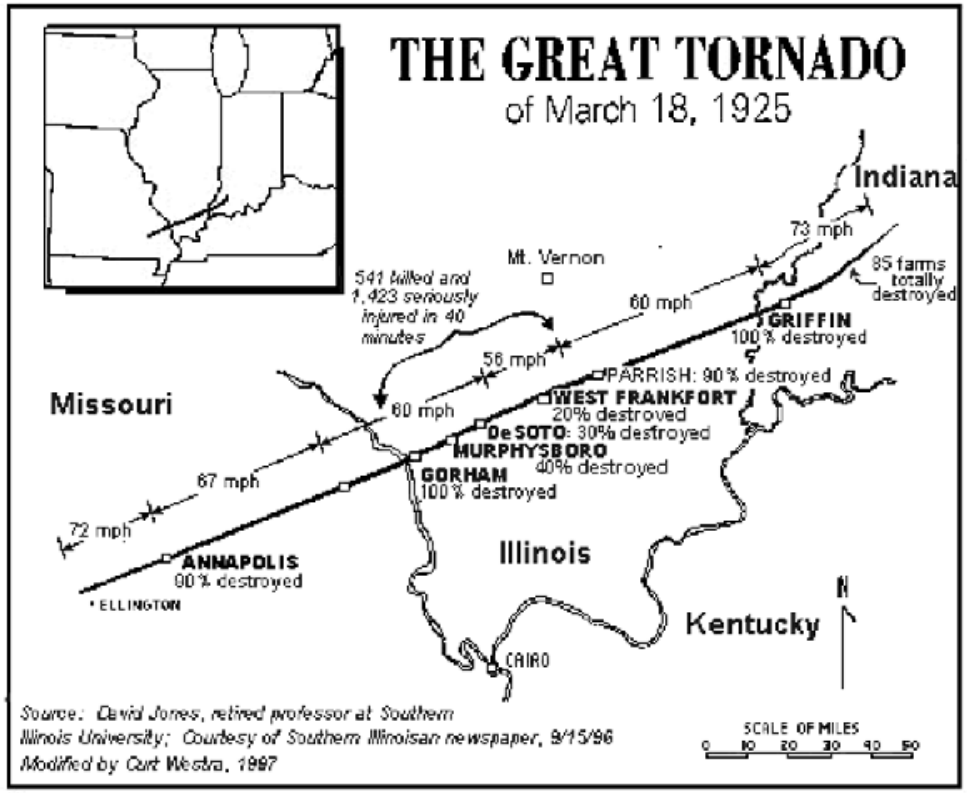
Easter Outbreak March 23, 1913



OMAHA TORNADO—SEARCHING THE RUINS
THIS PICTURE SHOWS MEN AND WOMEN IN THE RUINS OF THEIR HOMES, SEARCHING FOR VALUABLES

F4: 168 killed 590 injured

Tri-State Tornado March 18, 1925



F5: 695 killed 2027 injured

Tupelo MS-Gainesville GA Outbreak
April 5-6, 1936

Tupelo 216 killed 700 inj **Gainesville 203 killed 1600 inj**

17 tornadoes and 446 total deaths

Flint, MI Tornado June 8, 1953

EXTRA The Flint Journal Eight Pages Tornado News EXTRA

STORM DEAD NOW 109
650 JAM HOSPITALS

Ten Million Dollar Damage Estimate

List of Dead

Sioux Falls, S. D. Visitors Among Those Injured

Coldwater Road Area Is Leveled

A tornado roared down on the Flint area Monday night and altered an eight-mile-long path of devastation along Coldwater Rd., leaving 108 dead and more than 650 injured in its wake.

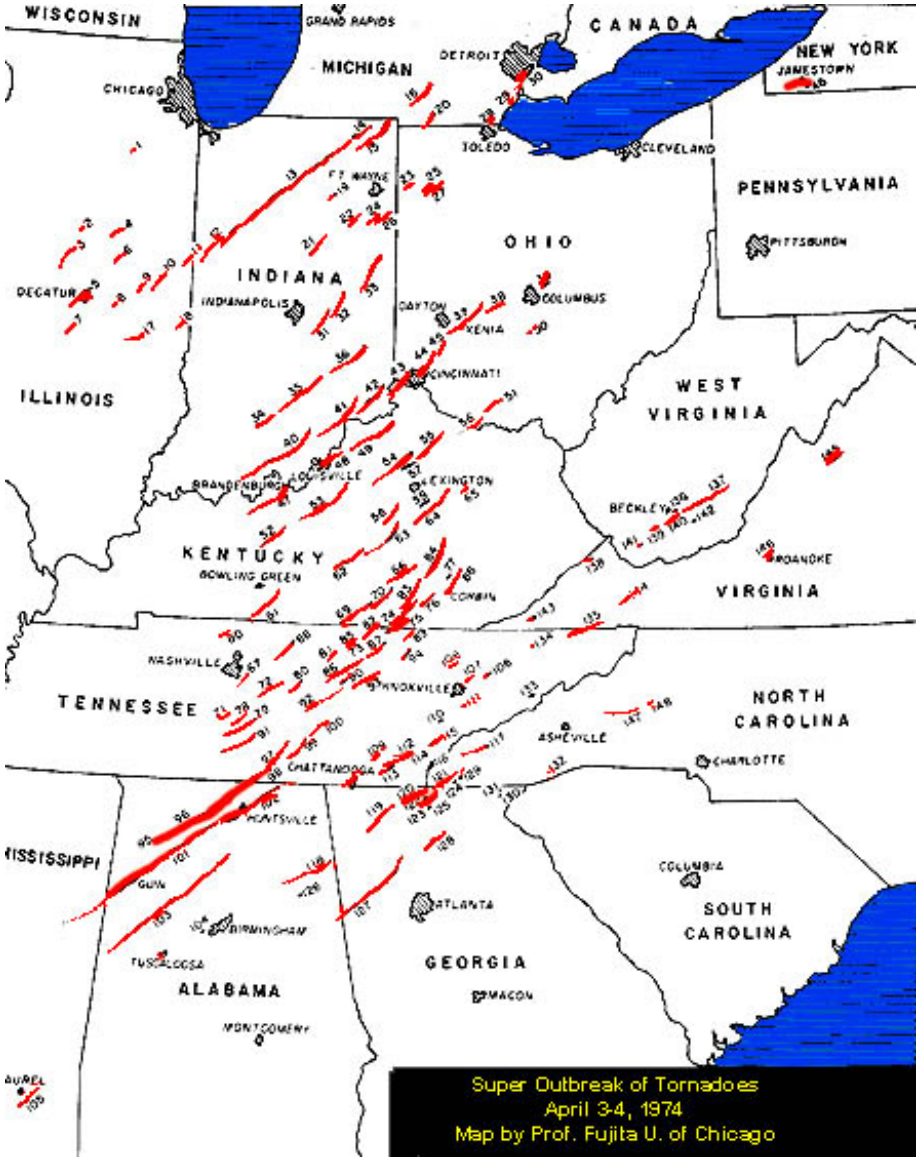
THE FLINT JOURNAL PHOTO

F5: 115 killed, 844 injured
Last tornado with 100+ deaths until Joplin, MO in 2011

Palm Sunday Outbreak April 11, 1965

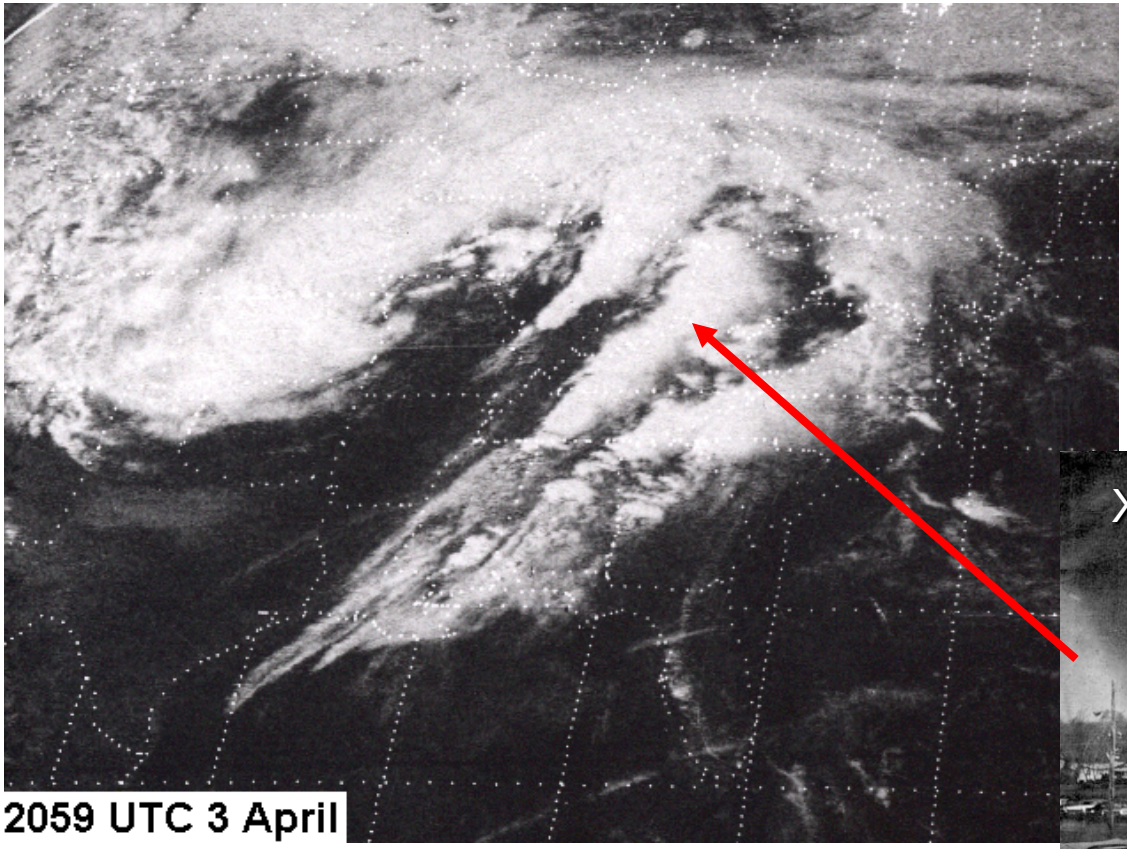
47 Tornadoes, 271 killed
Great Lakes States

April 3, 1974 Super Outbreak



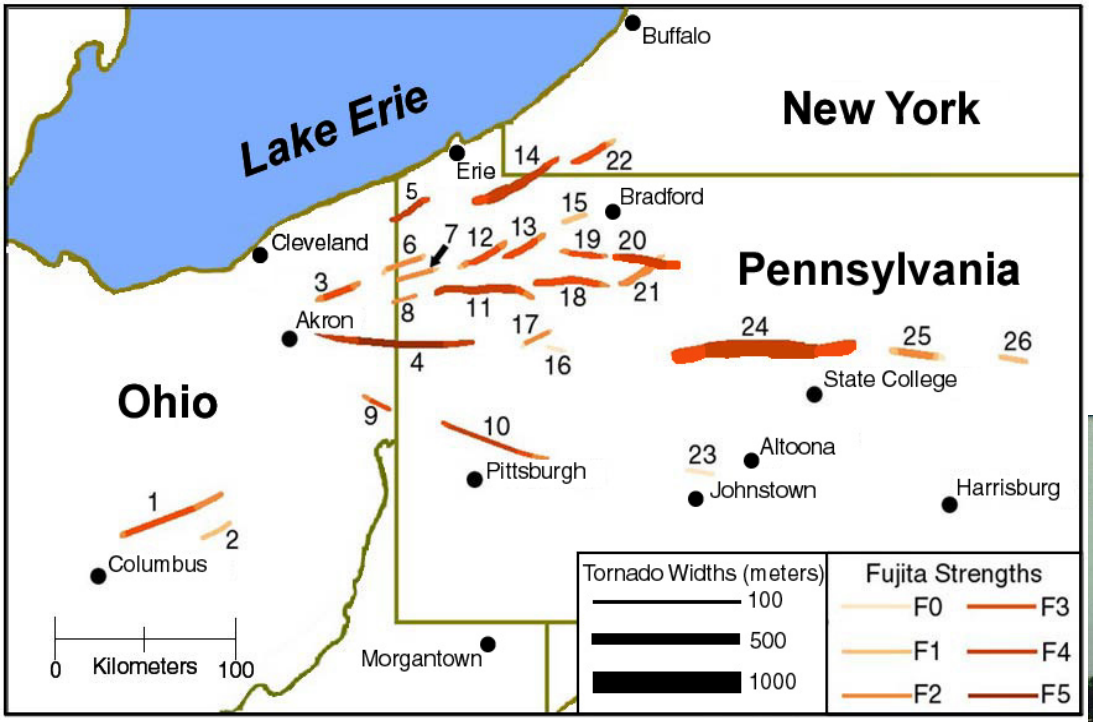
- **148 Tornadoes**
- **48 Killer Tornadoes**
- **310 Fatalities**
- **5454 Injuries**
- **10 States Declared Disaster Areas**

April 3, 1974 Super Outbreak



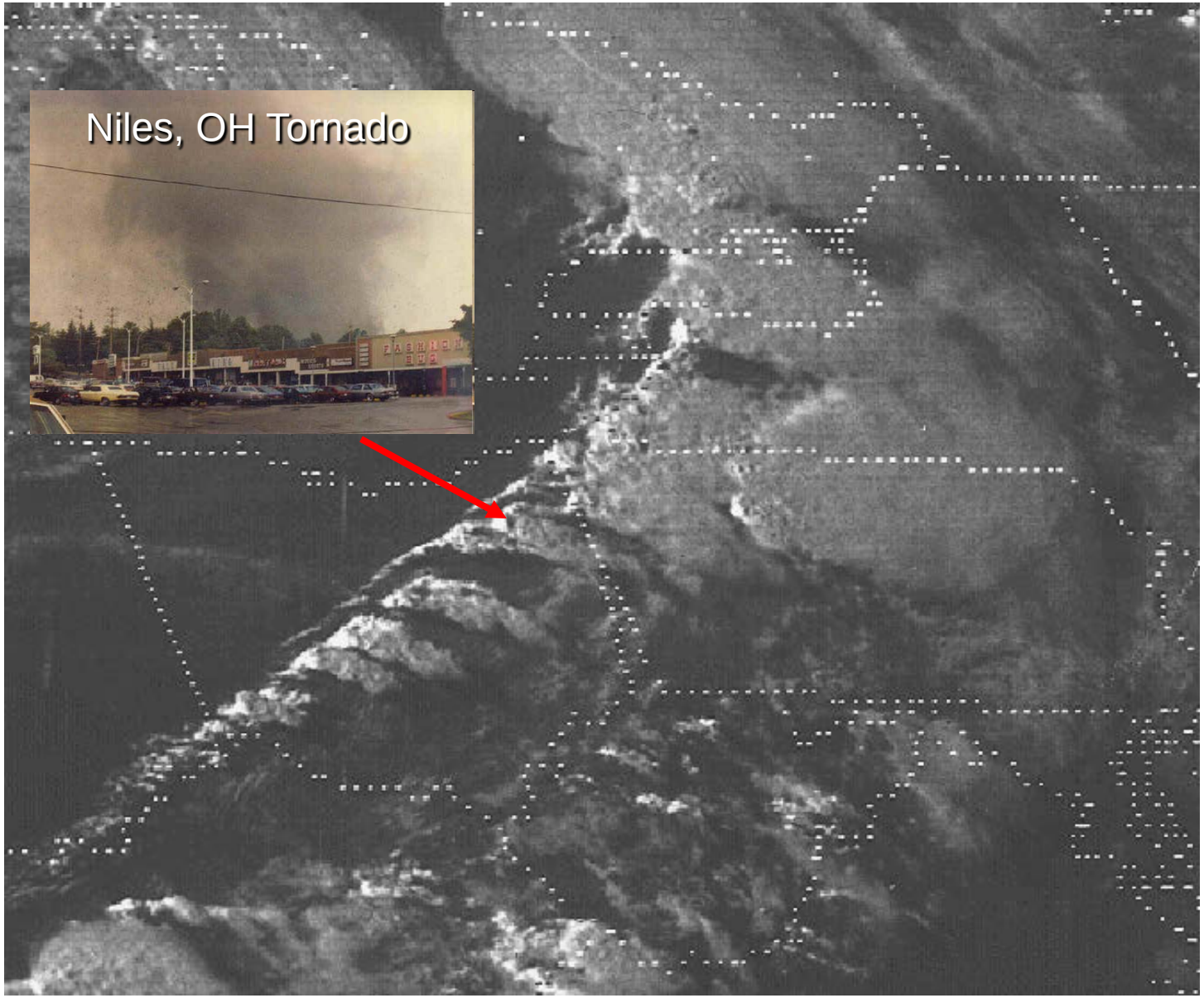
- An early use of visible ATS III satellite imagery to observe tornado-producing thunderstorms

May 31, 1985 Tornado Outbreak

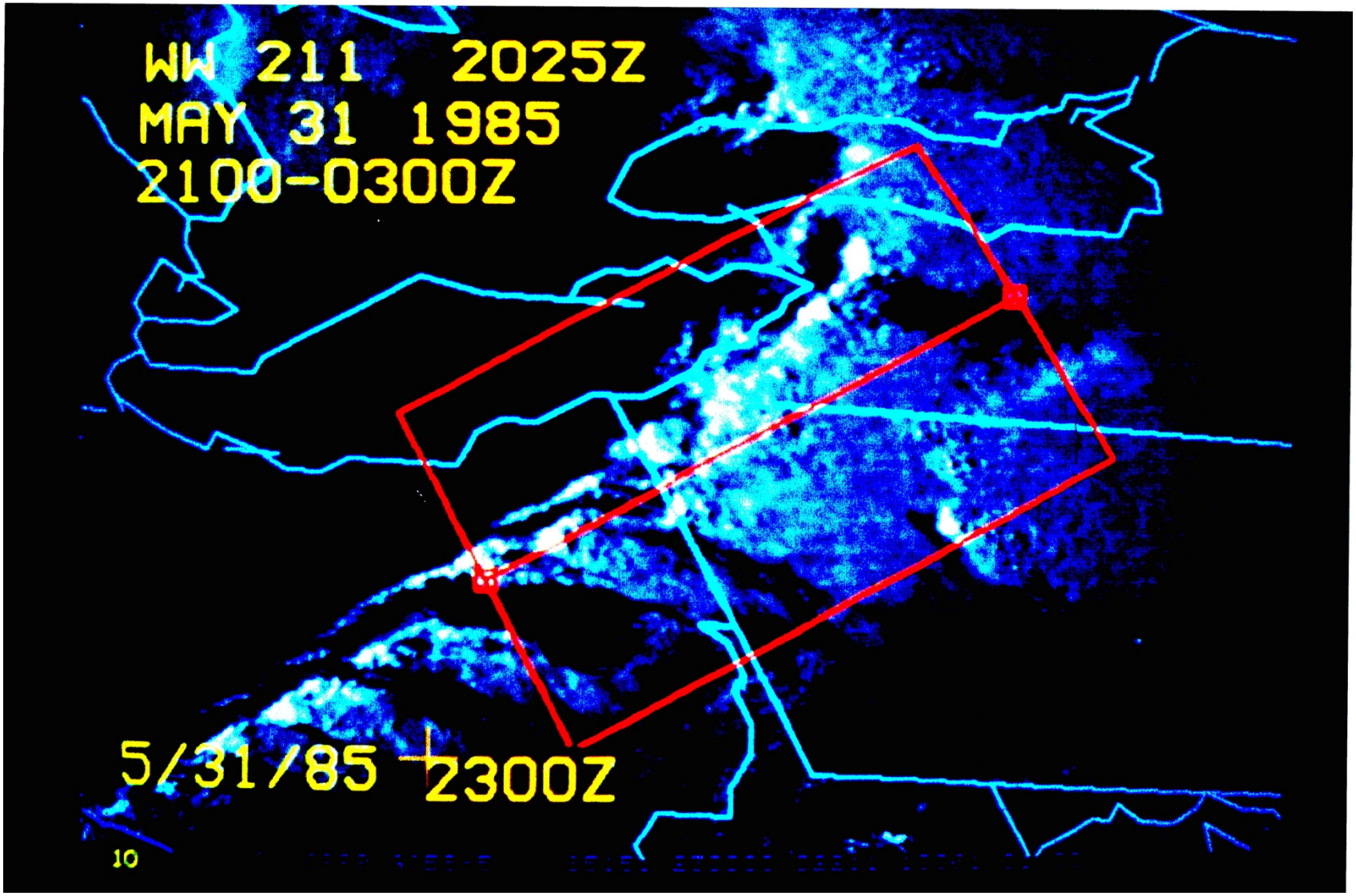


76 Fatalities and 876 Injuries

Visible GOES Imagery 2300 UTC 31 May 1985



Tornado Watch Over Visible Imagery



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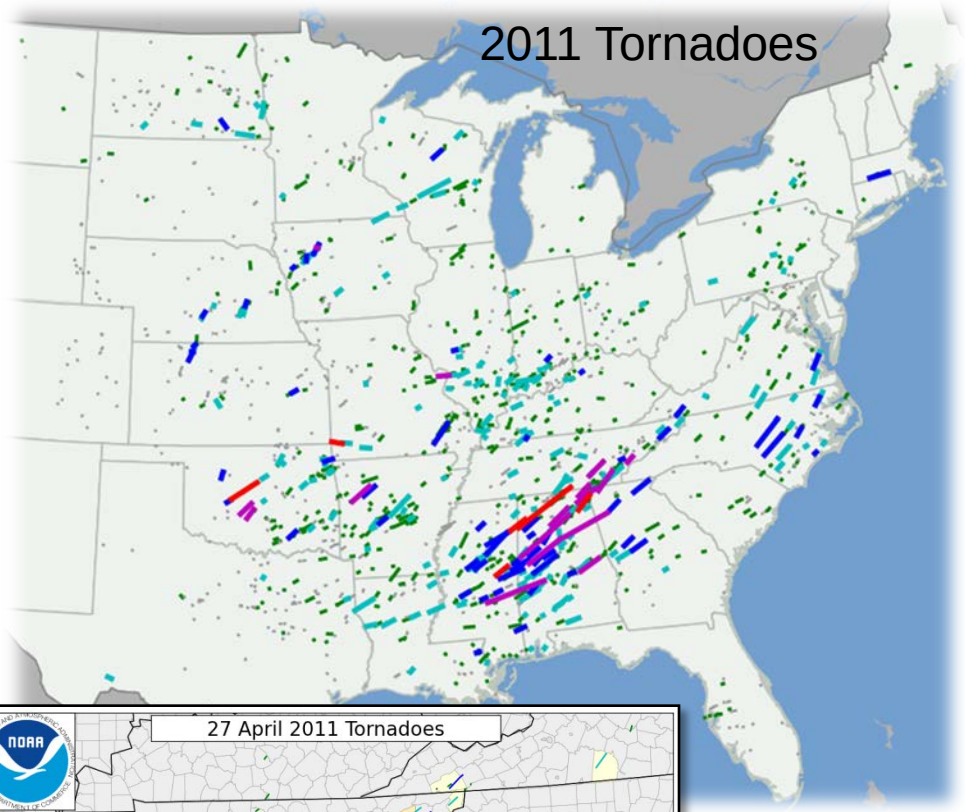
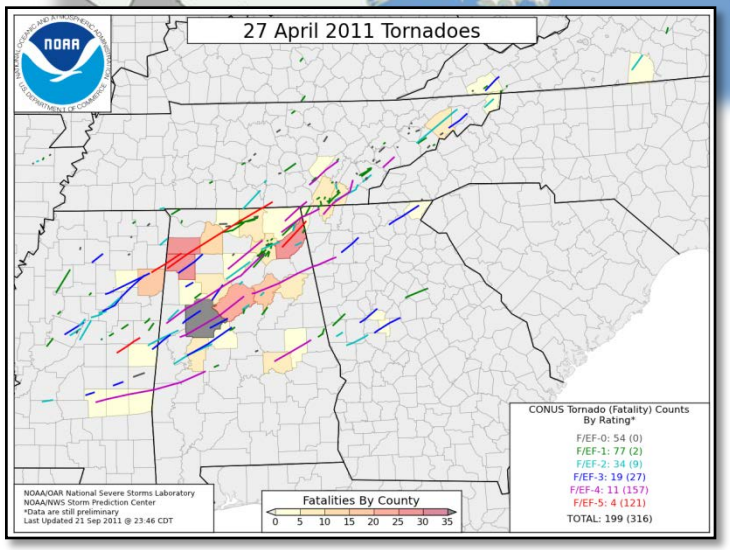
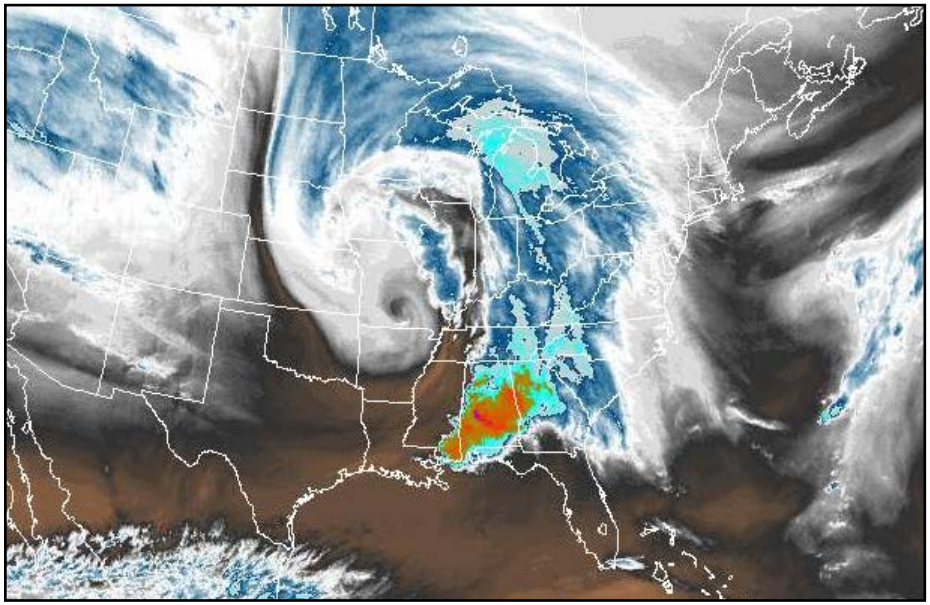
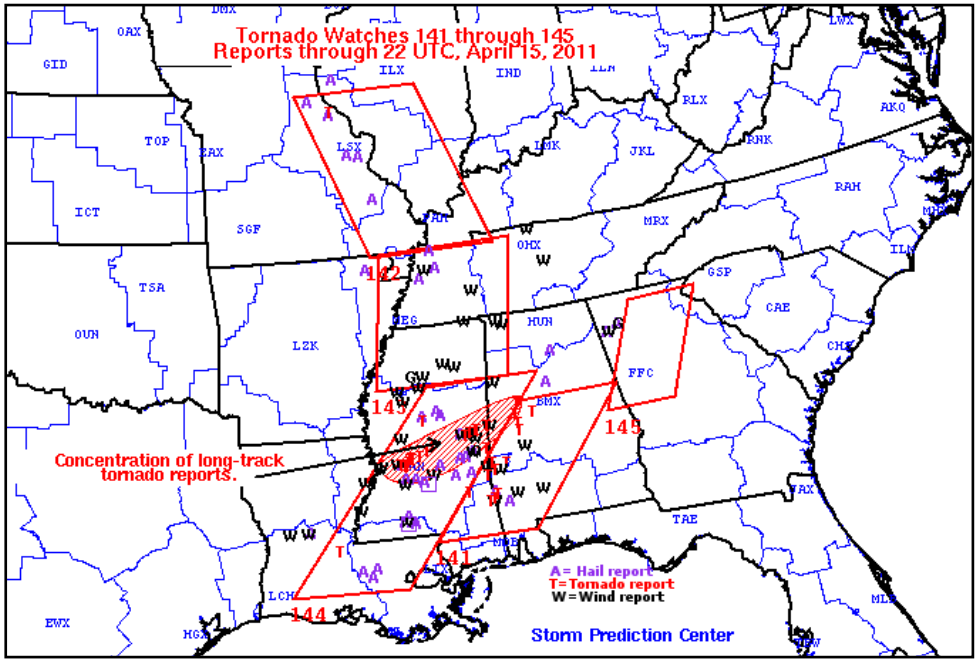




April 15, 2011

AL-AR-GA-IL-KY-MO-MS: 73 tornadoes, 10 deaths, 60 inj., $153M

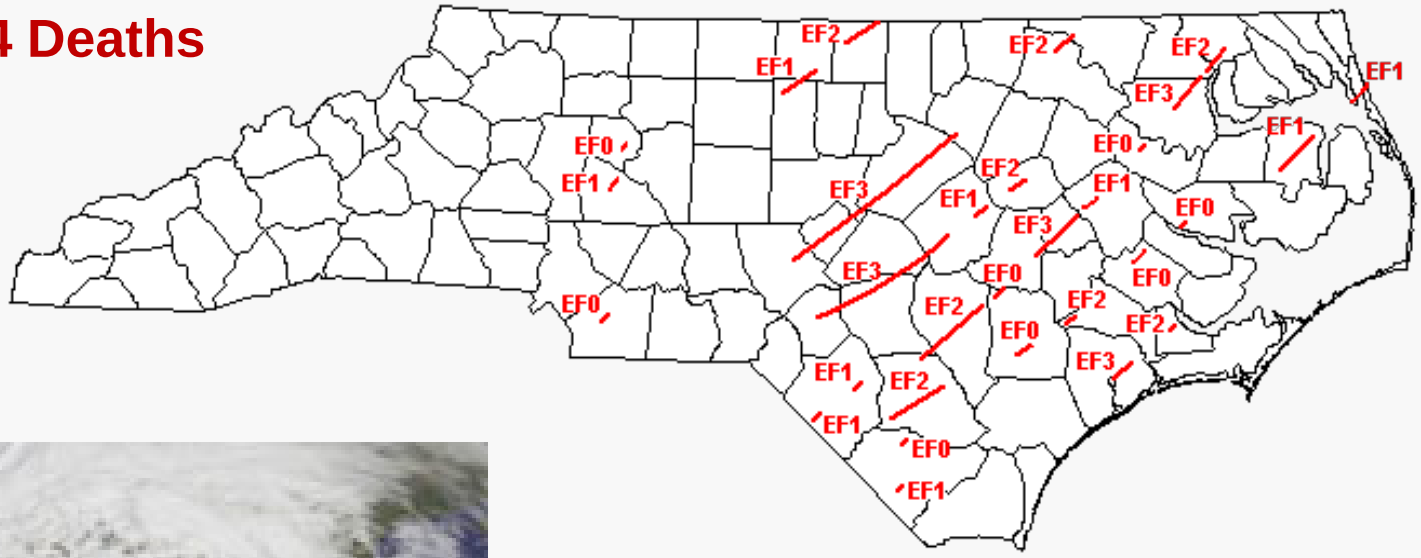




North Carolina Tornado Outbreak – April 16, 2011

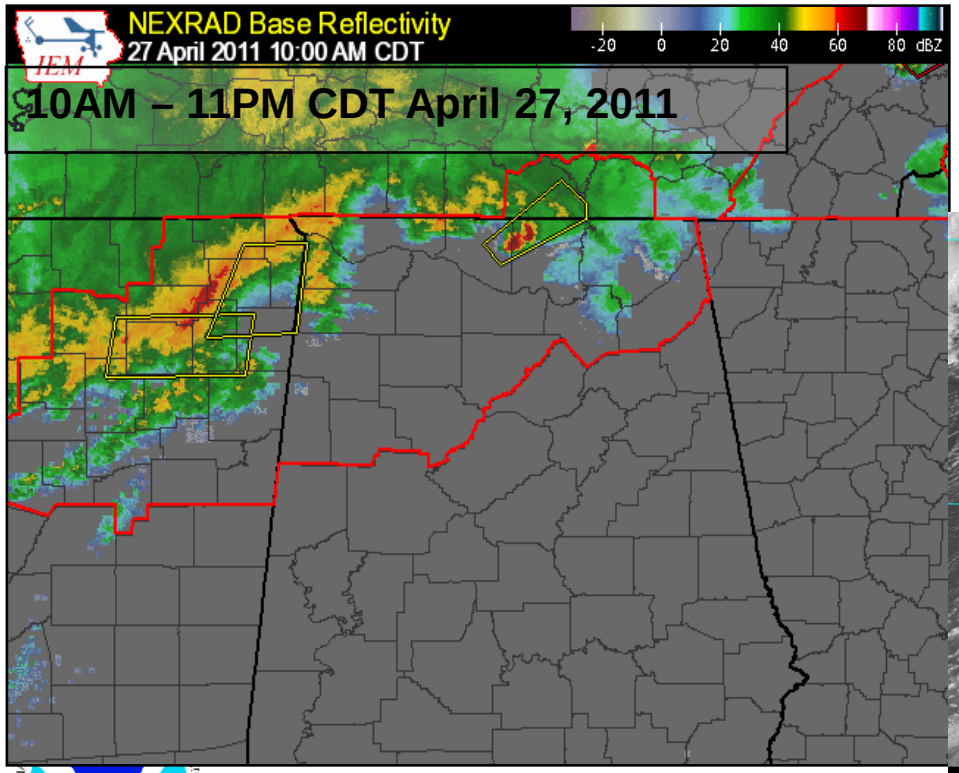
31 Tornadoes, 24 Deaths

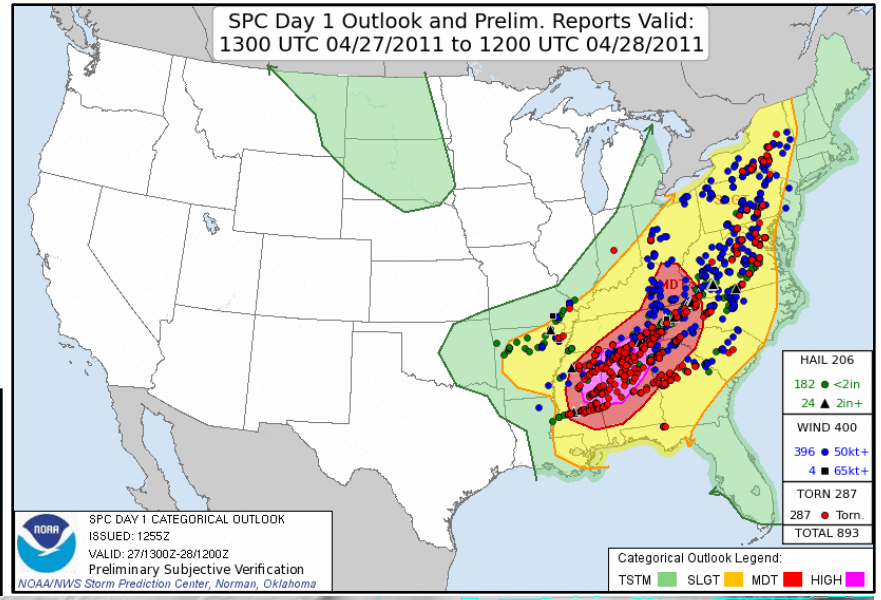
8 EF0
10 EF1
8 EF2
5 EF3

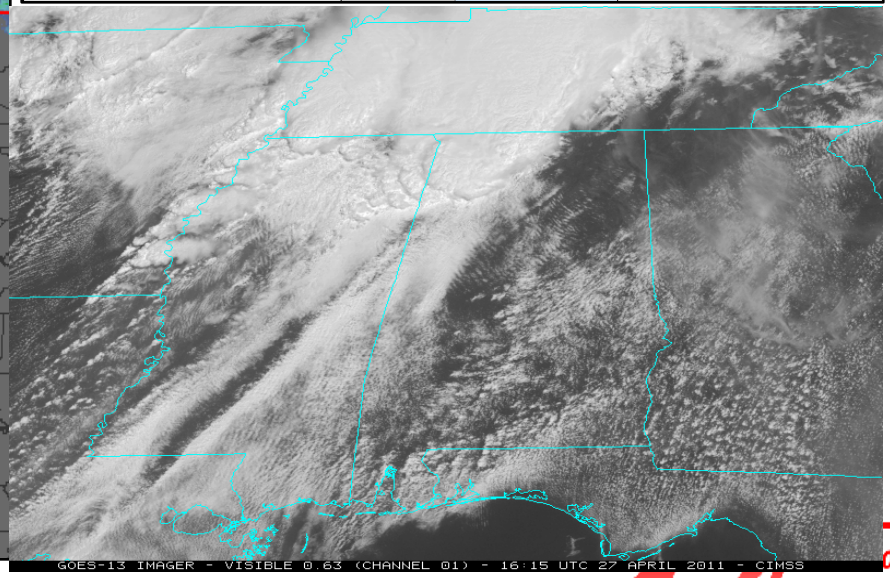


St. Andrews subdivision, Sanford

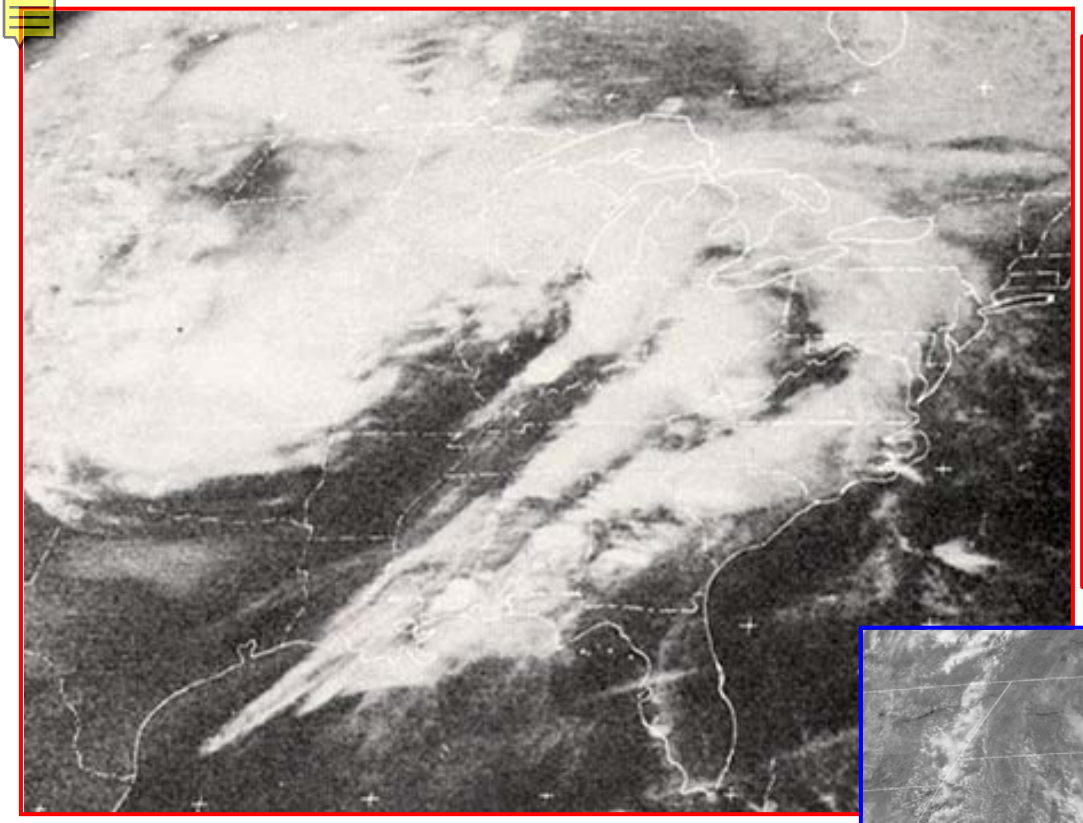
April 27, 2011 Deep South Super Outbreak







Tuscaloosa, AL (EF4, 64 deaths) & Madison County, AL (EF5, 72 deaths)

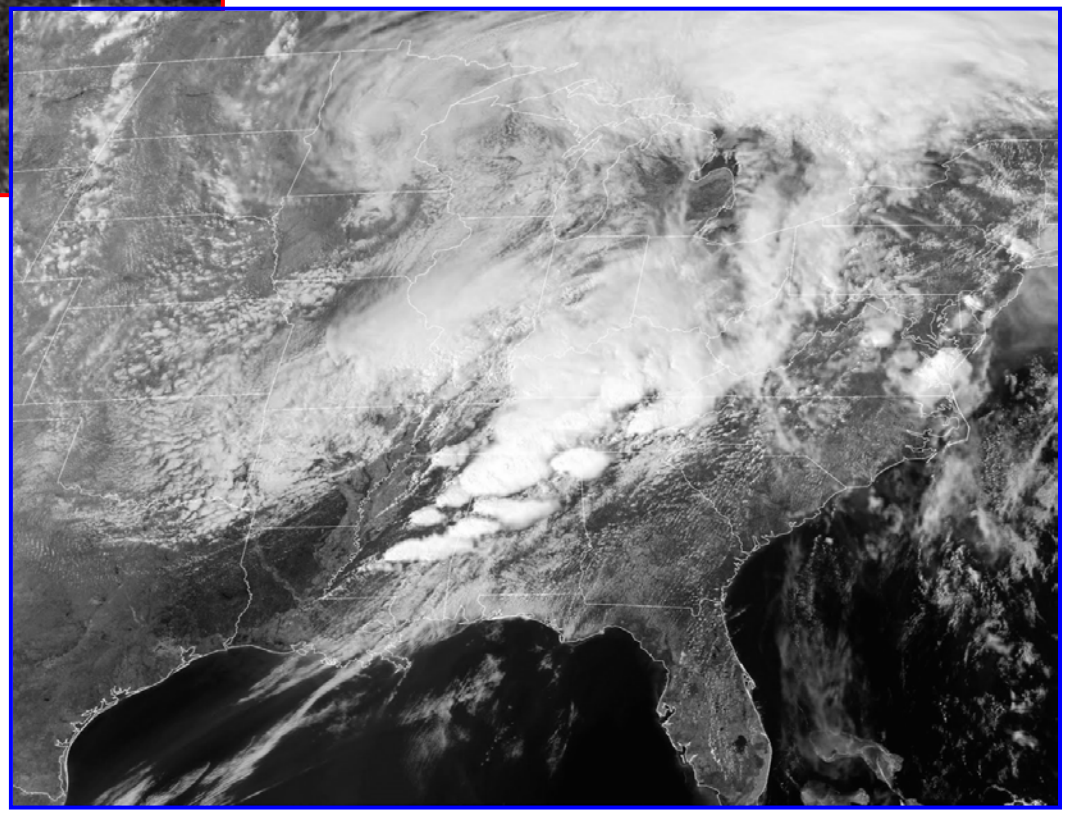


April 3-4, 1974 Super Outbreak

- 148 tornadoes across 13 states
- 6 F5 (2 in AL), 24 F4
- **Fatalities: 310 (77 AL; 71 KY)**
- Tornado Track Length: ~2500 mi
- Tornado Time: ~50 hours

April 27-28, 2011 Super Outbreak

- 208 tornadoes across 16 states
- 4 EF5 (3 in AL), 11 EF4
- **Fatalities: 319 (235 AL)**
- Tornado Track Length: ~2500 mi
- Tornado Time: ~50 hours



May 22, 2011: Joplin, MO EF-5, 160 Deaths, 700+ Injuries

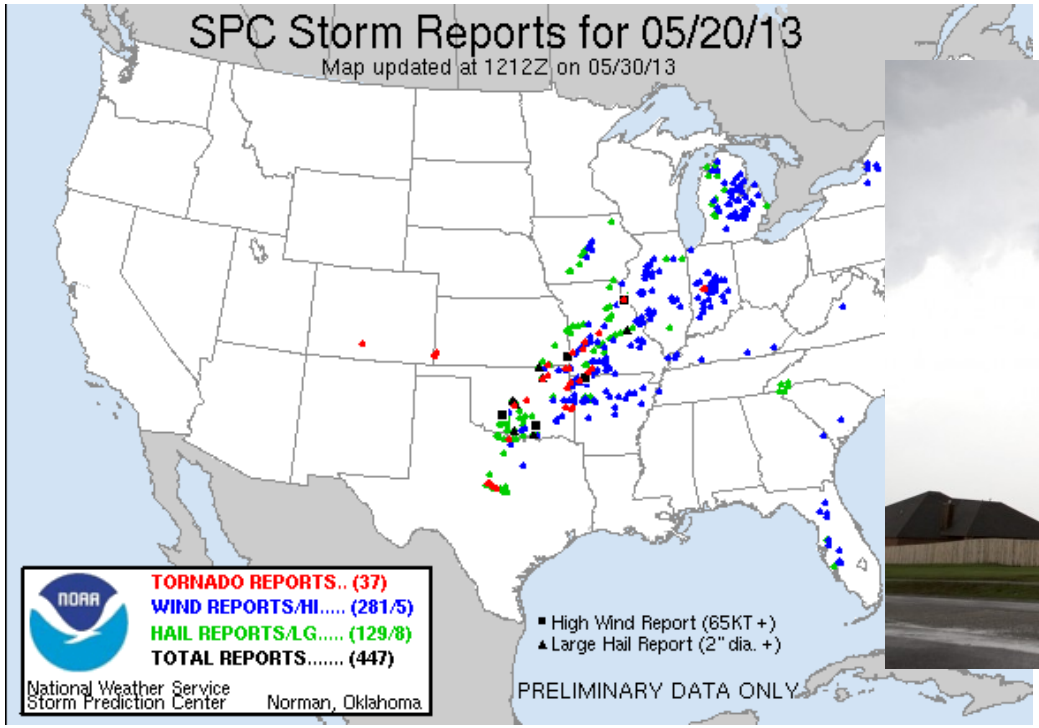
Aerial View of Tornado Path

Joplin, Missouri Neighborhood: Before / After

Lower chance of survival from an EF5 outside of a safe room or underground shelter.

May 20, 2013 – EF-5, Moore, OK; 24 Killed

- 17 mile path length; up to 1.3 miles wide
- Most tornado deaths from a single tornado in 2013
- Two schools, a hospital and hundreds of businesses/houses destroyed
- Complex stormscale interactions with dryline/cold front resulted in rapid storm intensification in central Oklahoma



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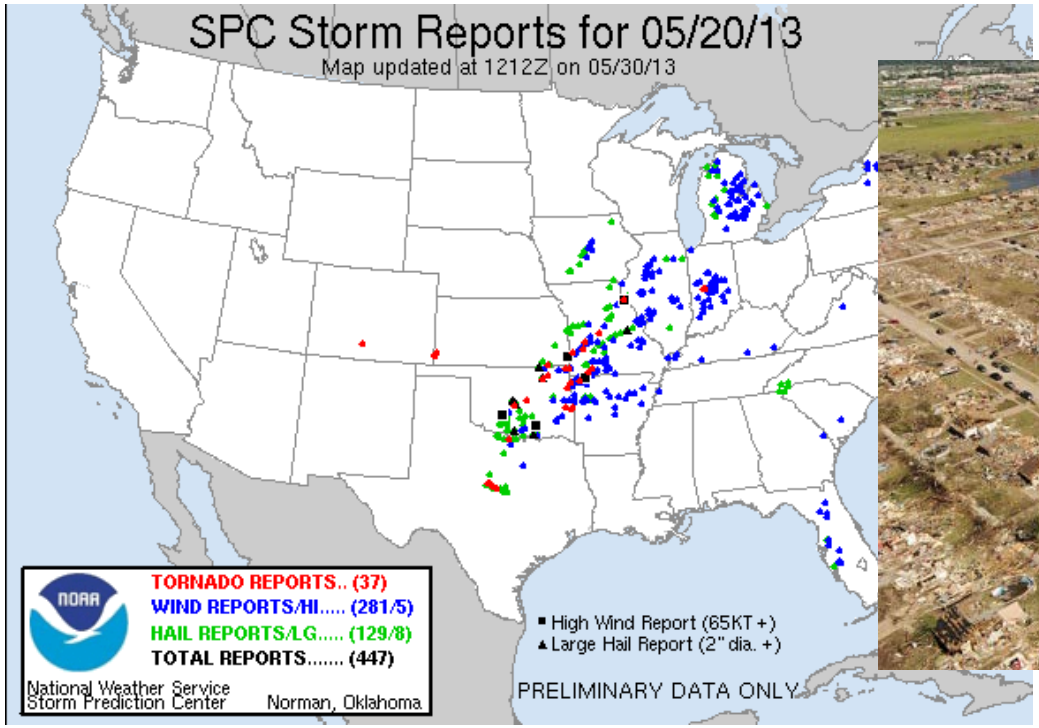

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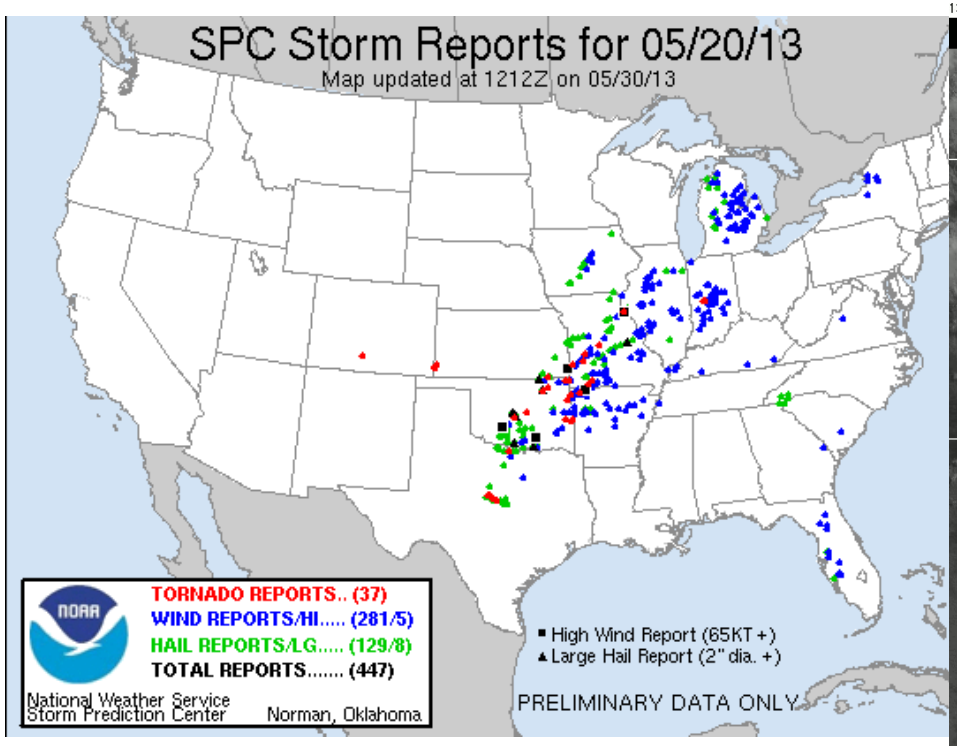
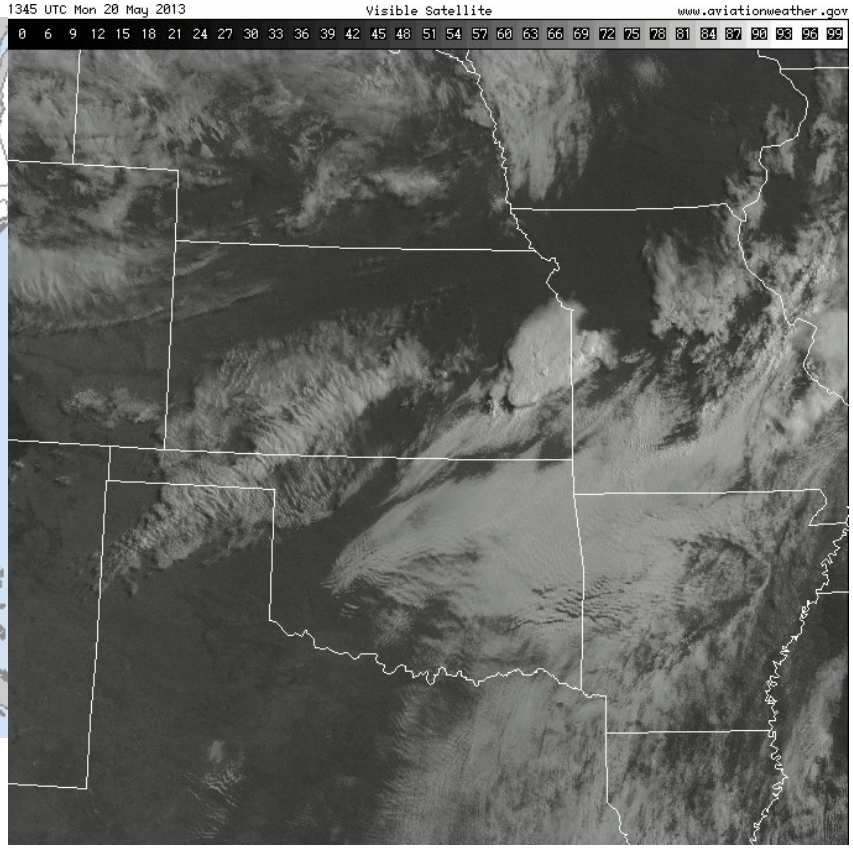
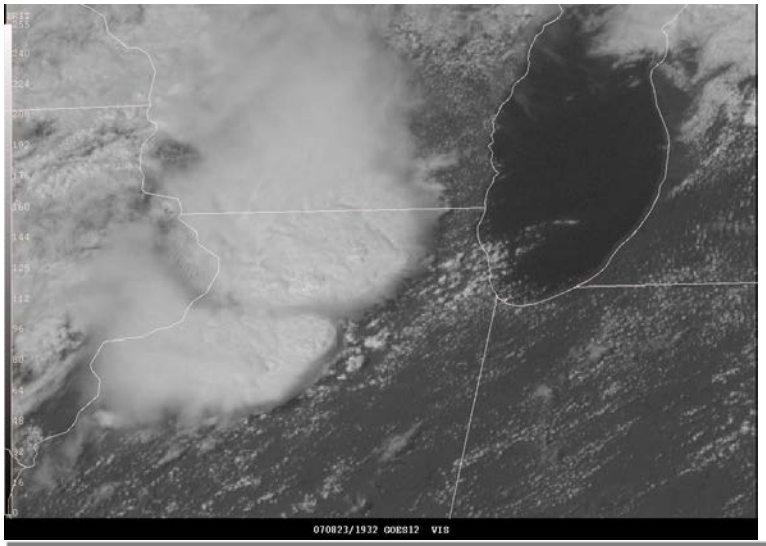
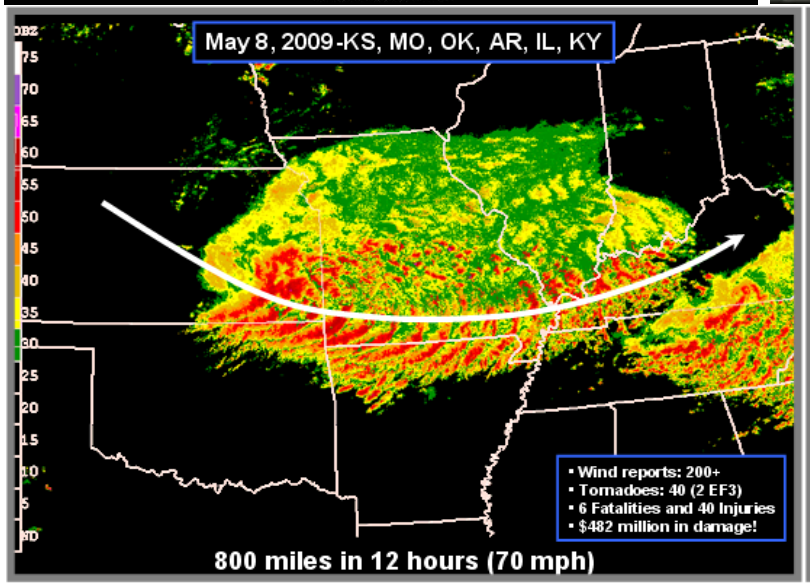


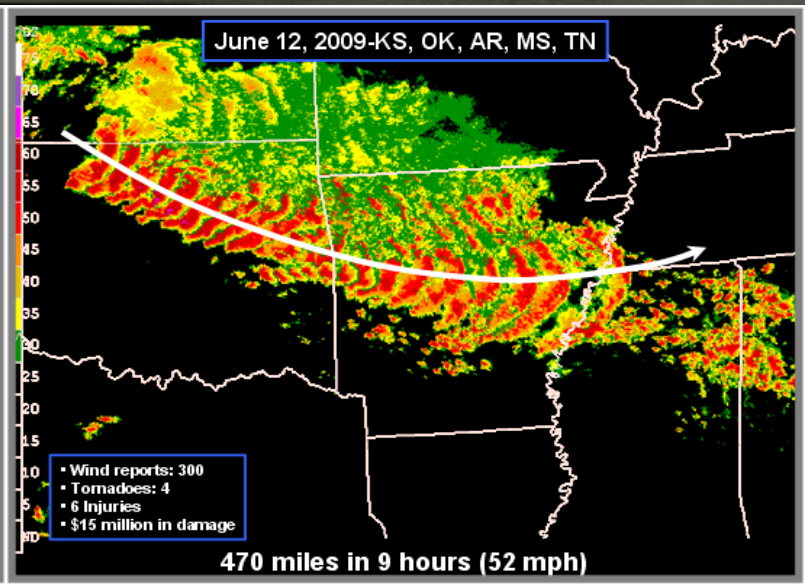


Derechos

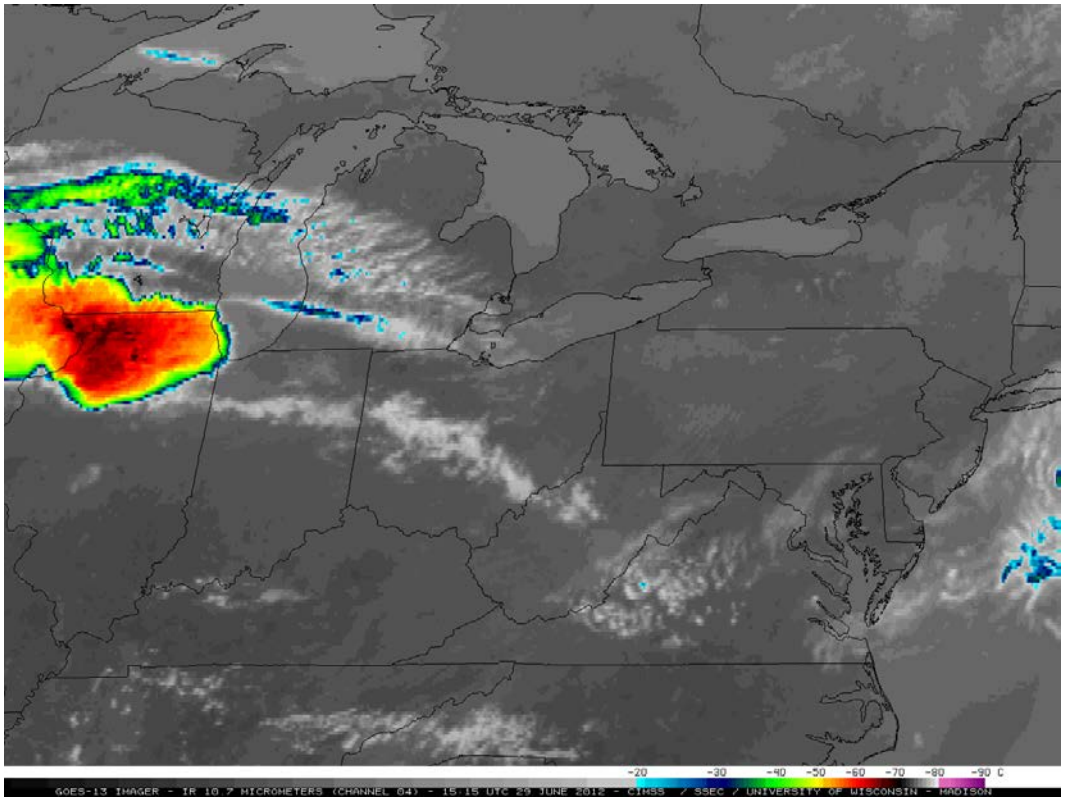
Long-Lived Convectively Produced Windstorms







IR Satellite - June 29, 2012 Derecho



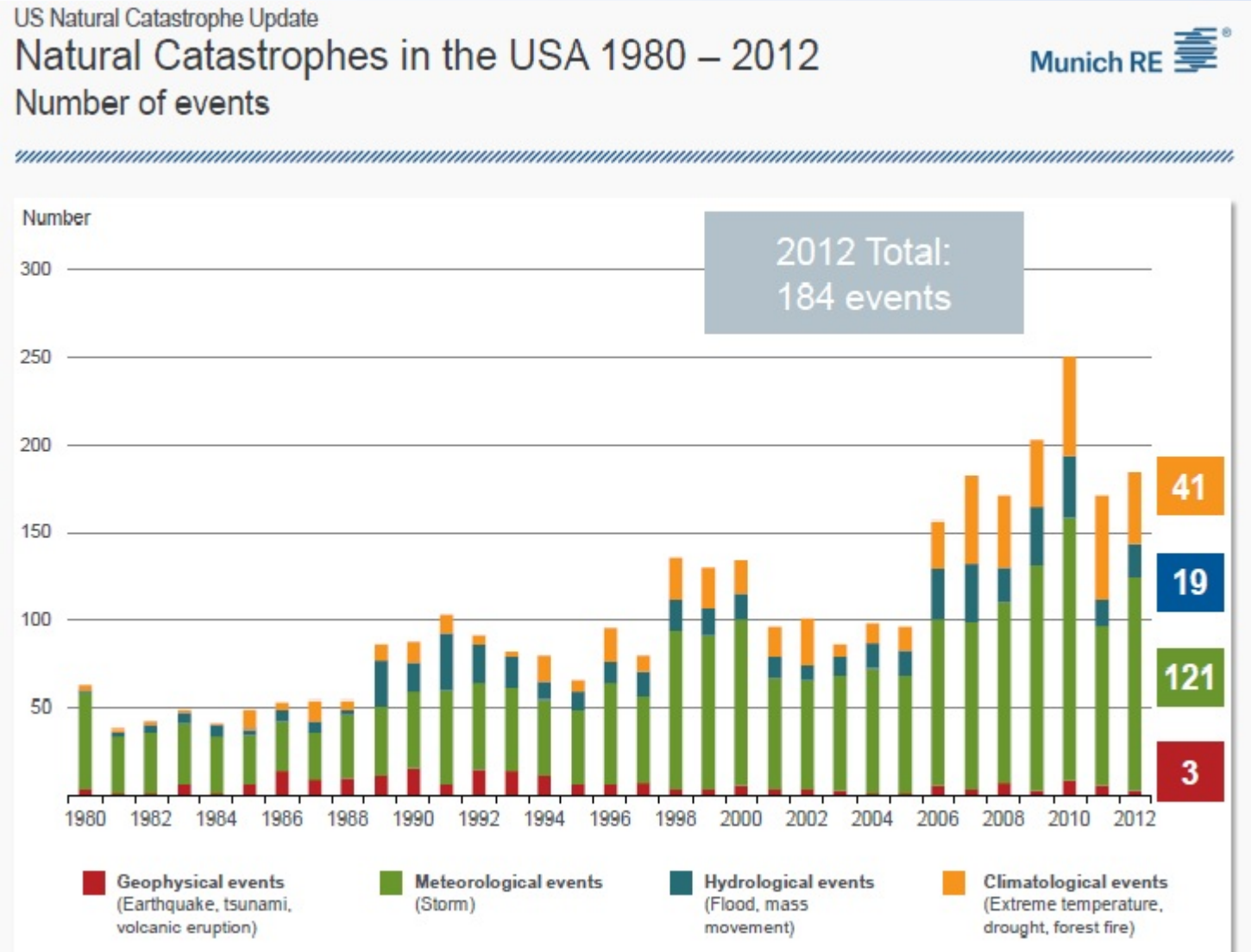
Courtesy
UW-CIMSS

Derecho traveled 600 miles in 10 hours - average speed of 60 mph

- 13 people killed directly - mostly due to falling trees
- More than 4 million customers lost power (some for up to a week or more)
- 34 people died in the extreme heat in the days following the derecho in areas without power
- Estimated $2.9 billion in damages

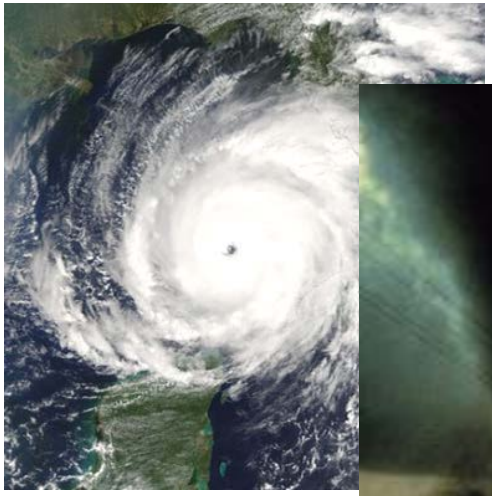
Over the past 30+ years…

Our Vulnerability to High-Impact Weather Has Increased



Weather Impacts on Society

Since 1980 the US has experienced 140 weather-related disasters costing at least $1 billion in standardized losses (4.2 disasters per year)



Hurricanes

Tornadoes

Floods

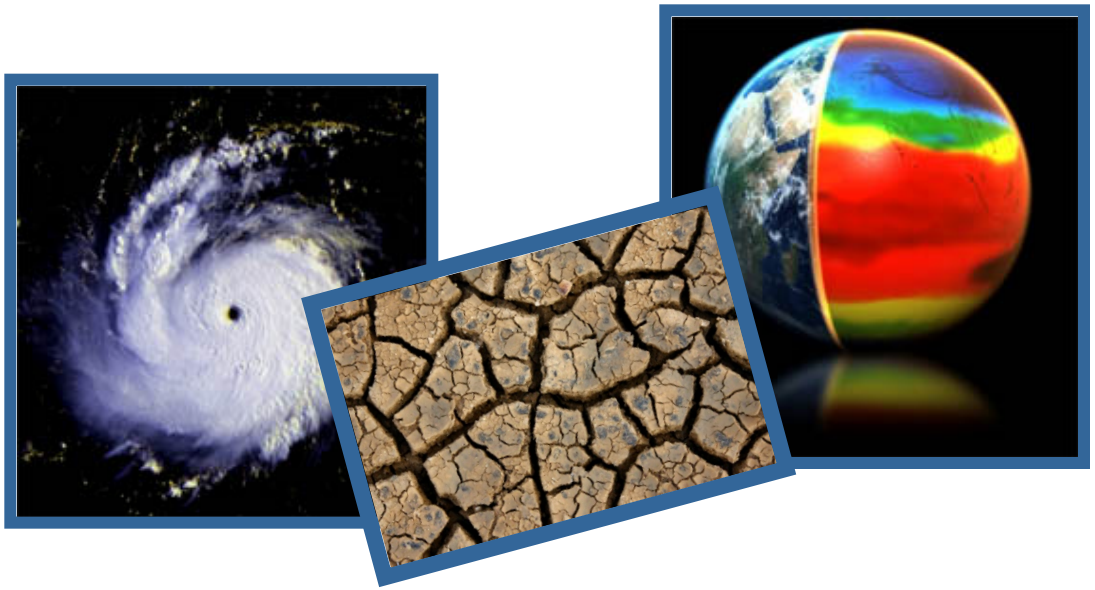
Blizzards

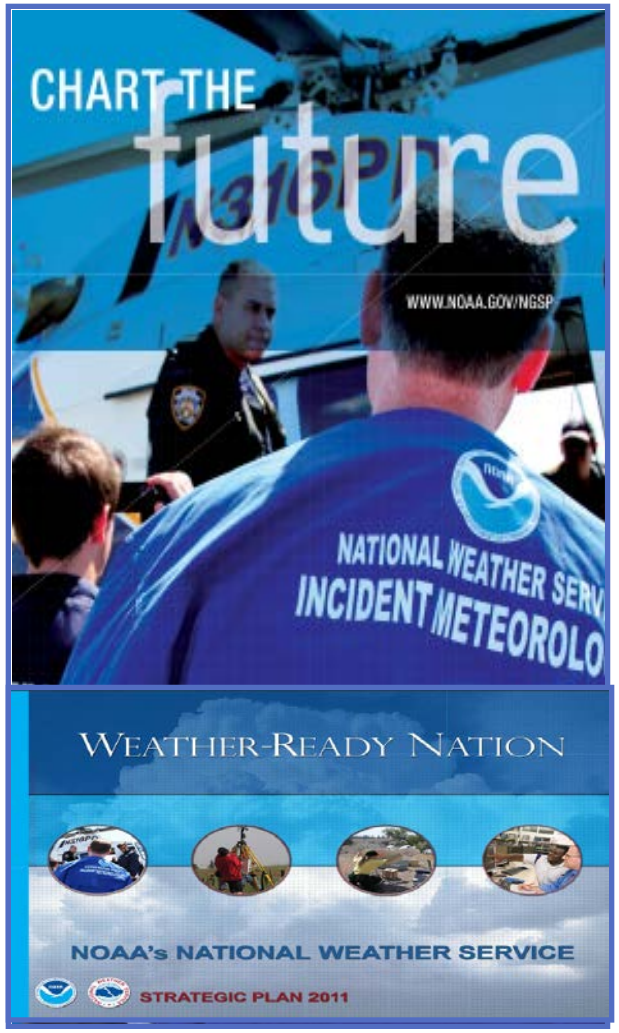
During 2011- 2013, there were 33 $1 billion disasters and <u>more than half were caused by tornadoes & severe thunderstorms</u>

How Do We Better Protect Society?

Build a Roadmap to a
Weather-Ready Nation

Society is Prepared for and Responds to Weather-Dependent Events





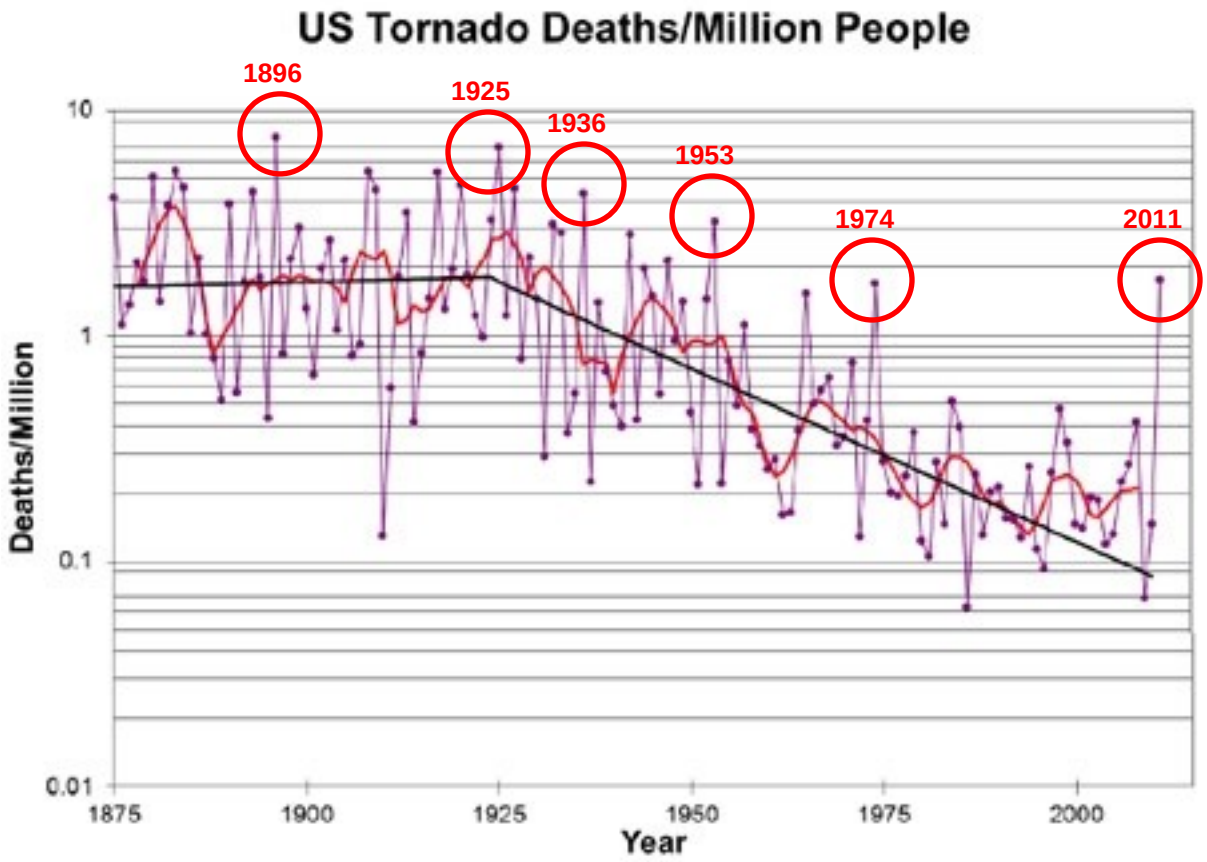
Weather-Ready Nation Initiative

Flexible response to meet contingencies

- **Improved precision of weather and water *forecasts*** and effective *communication* of risk to local authorities
- **Innovative science & technological solutions**
- Improve weather decision support services
- Strengthening joint partnerships
- Work with weather enterprise partners and emergency management community

Tornado Forecasting Today

- Tornado fatalities have generally decreased compared to 50-100 years ago, but…

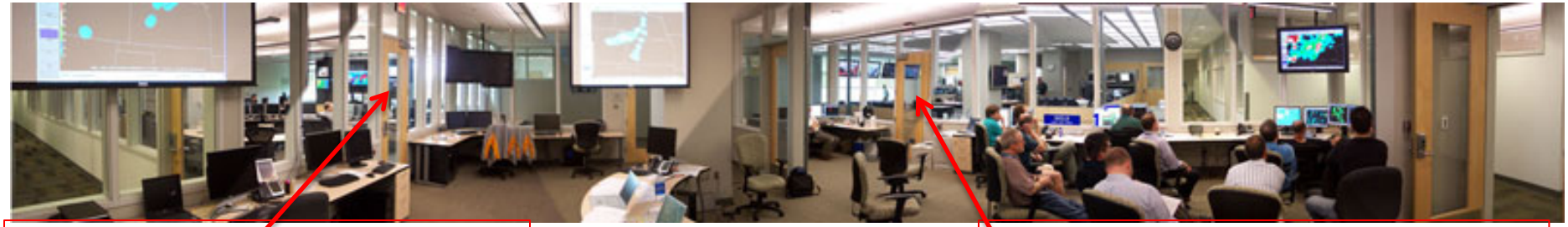


Tornado Forecasting Today

- Tornado fatalities have generally decreased compared to 50-100 years ago, but…
- Increasing population and spread of urban areas place more people and structures at risk
- **Continued improvements in science and technology are needed**
- A key ingredient is accurate analysis and prediction of the atmosphere
- **Satellites provide the only uniform high resolution sampling over large areas**

NOAA Hazardous Weather Testbed

Where practitioners and researchers work together…



NWS Norman Forecast Office:
Local Responsibility

Storm Prediction Center:
Nationwide Responsibility

Warning Research

Forecasting Research

Satellite-based Research

Experimental
Warning
Program

Detection and prediction of hazardous weather events ***up to several hours in advance***

Experimental
Forecast
Program

Prediction of hazardous weather events from ***a few hours to a week in advance***

GOES-R Proving Ground at SPC

(GOES-R/JPSS PG Session 7; Wed, 10:30 am, C111)

- Integrate GOES-R products into real-time operational testing prior to launch
  - Day-1 readiness
- Goals
  - Provide product developers with feedback on product usefulness/performance through detailed interactions with forecasters and real-time testing
  - Provide forecasters with product education and operational familiarity
  - Bring a satellite perspective to the heart of “Doppler radar country” in Norman, OK

GOES-R Improvements

Performance Capability	GOES I-M	GOES N-P	GOES R
Visible Resolution	1 km	1 km	0.5 km
IR Resolution	4-8 km	4-8 km N 4 km O/P	1-2 km
Full Disk Coverage Rate	30 min	30 min	5 min
Rapid Scan Imaging Mode	7.5 min	7.5 min	30 sec
# of Channels	5	5	16
Solar Monitoring	GOES-M only	Yes	Yes
Lightning Detection	No	No	Yes 8km <20 sec latency
Operate through Eclipse	No	Yes	Yes
Ground System Backup	Limited	Limited	Limited
Archive and Access	Limited	Limited	Yes
S/C Raw Data Volume	2.6 Mbps	2.6 Mbps	75 Mbps

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Archive and Access	Limited	Limited	Yes
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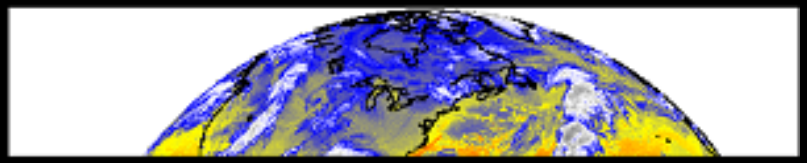
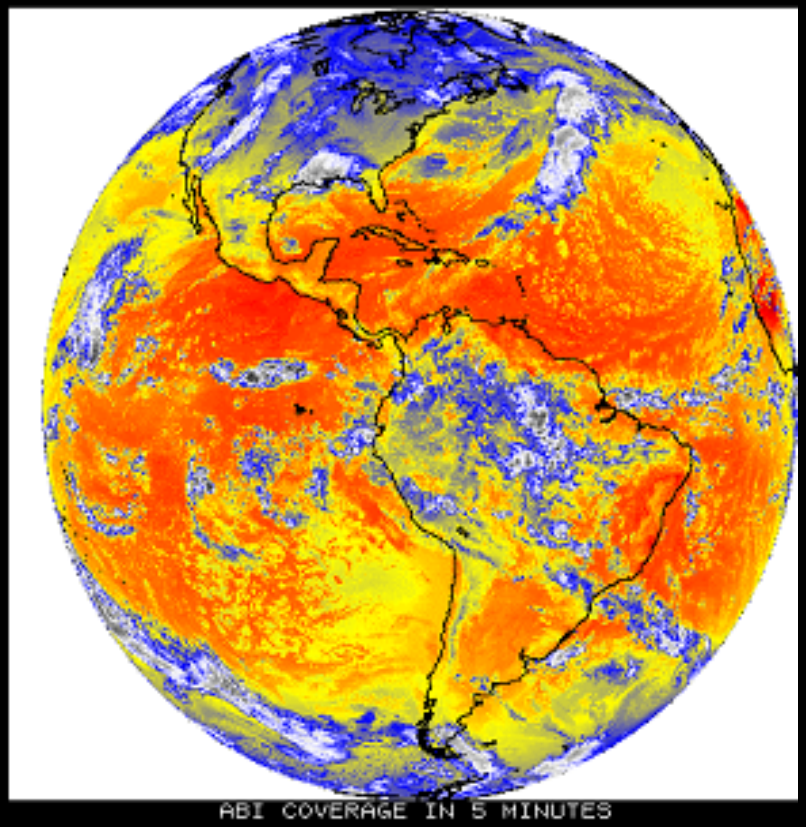
Much Faster ABI Imaging Speed

5 Minute Coverage

GOES I/P



GOES-R



ABI images the earth approximately five times faster than the current Imager.

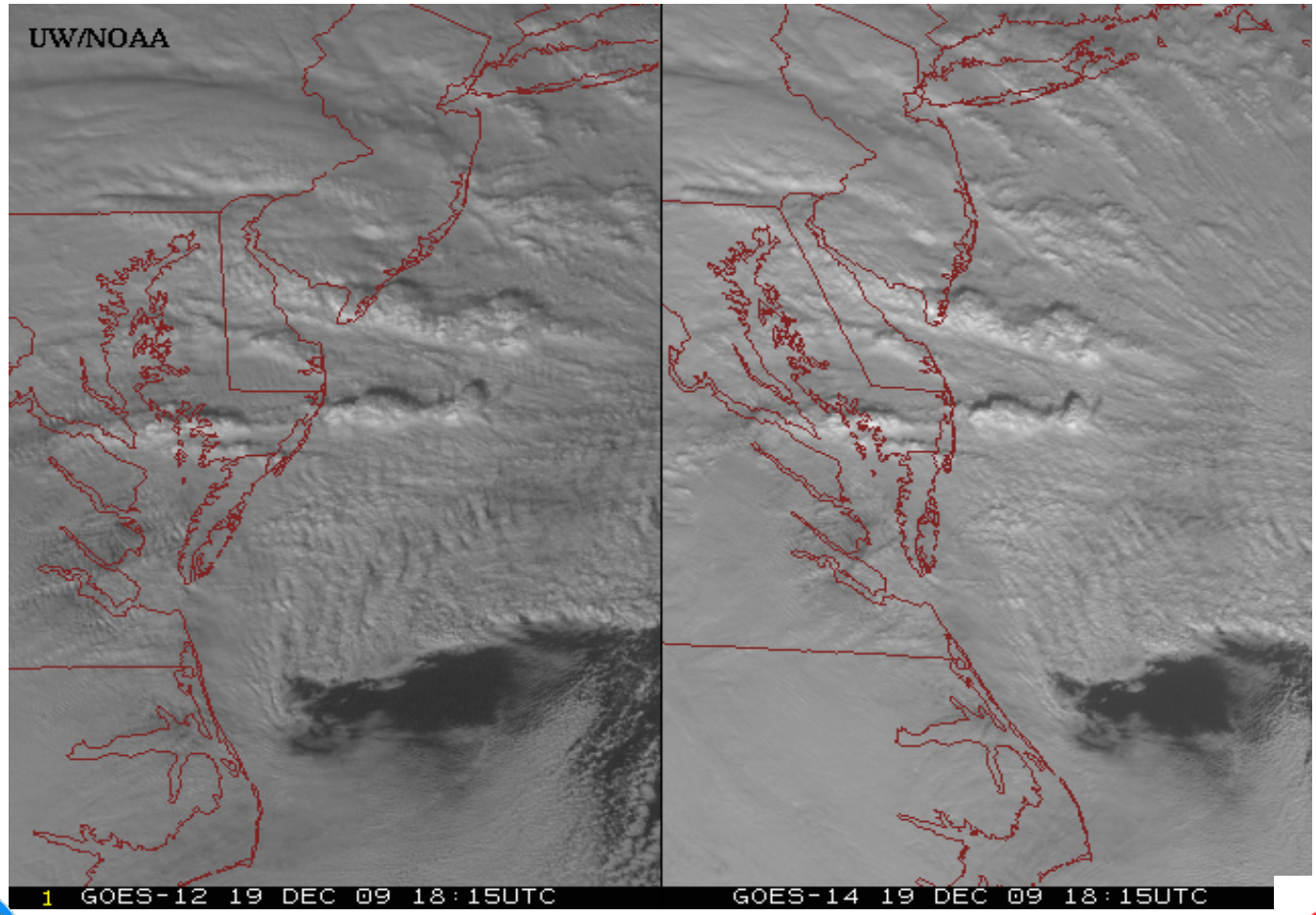
1/5 Disc

Full Disc

Much Faster Imaging Speed

GOES-14 1-Min Science Test - Super Rapid Scan

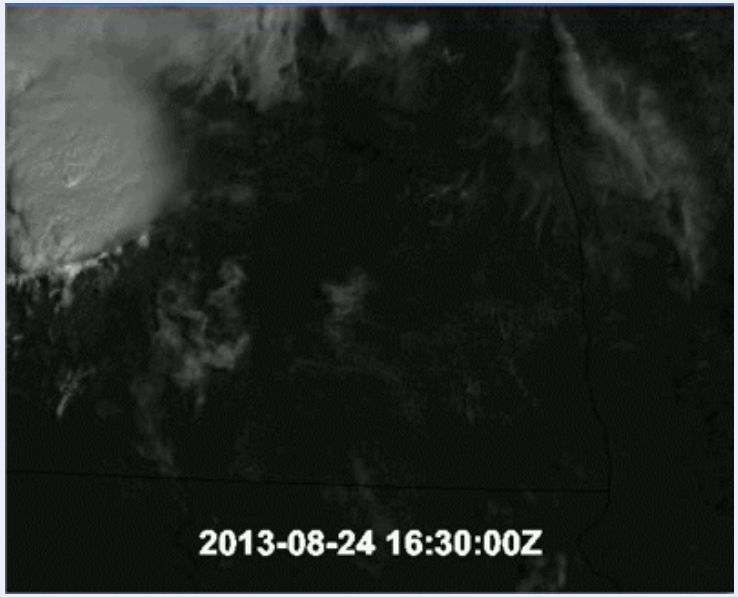
(More details by Schmit et al., Tue; 2:00 pm; C111)



Forecaster Feedback

Super Rapid Scan Operations

SRSOR referenced in SPC Mesoscale Discussion 1764 on August 24, 2013



MESOSCALE DISCUSSION 1764
NWS STORM PREDICTION CENTER NORMAN OK
1238 PM CDT SAT AUG 24 2013

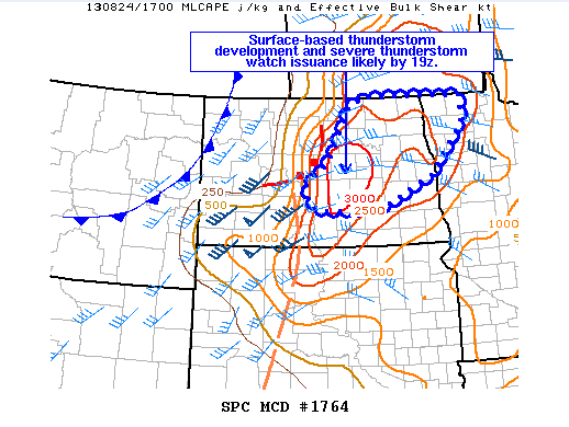
AREAS AFFECTED...CENTRAL/NE ND AND NW MN

CONCERNING...SEVERE POTENTIAL...WATCH LIKELY

VALID 241738Z - 241915Z

PROBABILITY OF WATCH ISSUANCE...80 PERCENT

SUMMARY...SURFACE-BASED THUNDERSTORM DEVELOPMENT IS EXPECTE
NEXT COUPLE OF HOURS /BY ABOUT 19Z/...BY WHICH TIME A SEVER
THUNDERSTORM WATCH IS LIKELY.



DISCUSSION...SUPER RAPID SCAN VISIBLE LOOPS SHOW THE DEVELOPMENT OF BOUNDARY LAYER CUMULUS ACROSS CENTRAL ND...NEAR THE INTERSECTION OF A SURFACE TROUGH AND THE COLD POOL WITH THE ONGOING STORMS NW OF BIS. STRONG SURFACE HEATING AND CONTINUED MOISTENING HAVE BOOSTED MLCAPE VALUES TO 2500-3000 J/KG AS CONVECTIVE INHIBITION WEAKENS ACROSS CENTRAL ND. THUS...THE RISK FOR SURFACE-BASED STORM DEVELOPMENT IS INCREASING EARLY THIS AFTERNOON. ONCE NEW STORMS FORM...THE ENVIRONMENT WILL SUPPORT ORGANIZED CLUSTERS/LINE SEGMENTS. THE KBIS VWP ALSO SAMPLED MIDLEVEL FLOW OF 40-50 KT...WHICH WILL CONTRIBUTE TO SUFFICIENT DEEP-LAYER VERTICAL SHEAR FOR SOME RISK OF SUPERCELLS. REGARDLESS...CONVECTION APPEARS LIKELY TO EVOLVE INTO A LINE/SMALL MCS LATER THIS AFTERNOON/EVENING...WITH AN ACCOMPANYING RISK FOR DAMAGING WINDS AND LARGE HAIL. AS A RESULT...A SEVERE THUNDERSTORM WATCH WILL LIKELY BE NEEDED BY ABOUT 19Z.

..THOMPSON/DIAL.. 08/24/2013

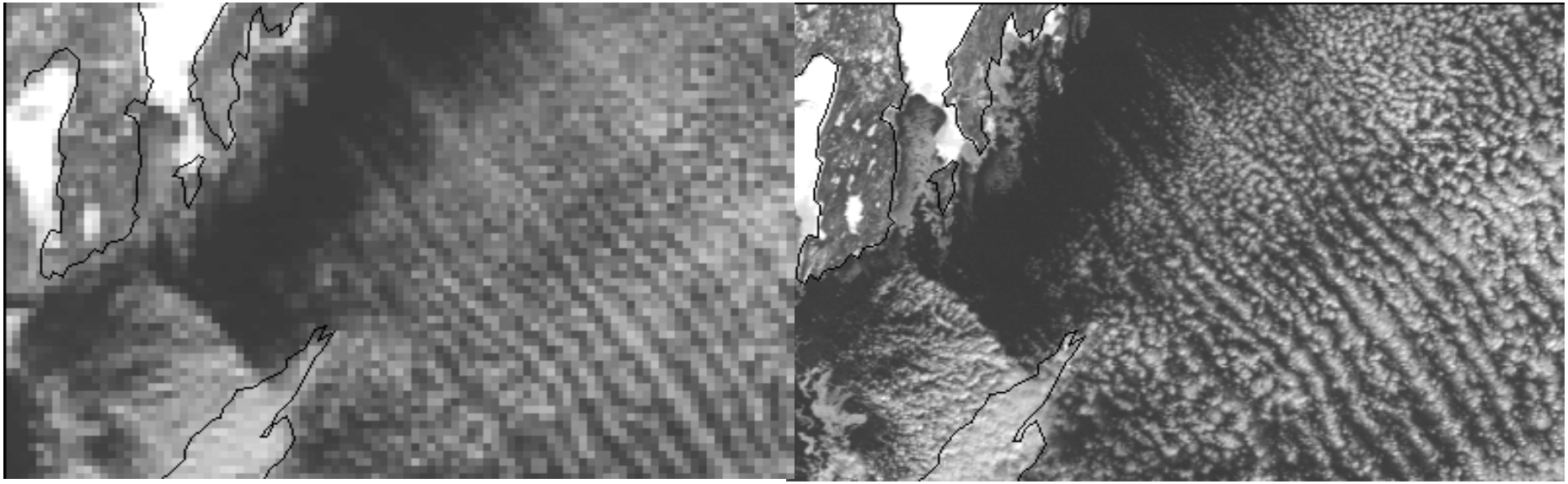
ATTN...WFO...FGF...BIS...

LAT...LON 48969599 48439595 47379696 46739848 46660025 46810067
47180077 47660012 47879996 48379970 48769949 49019899
48969599

GOES-R Improvements

Performance Capability	GOES I-M	GOES N-P	GOES R
Visible Resolution	1 km	1 km	0.5 km
IR Resolution	4-8 km	4-8 km N 4 km O/P	1-2 km
Full Disk Coverage Rate	30 min	30 min	5 min
Rapid Scan Imaging Mode	7.5 min	7.5 min	30 sec
# of Channels	5	5	16
Solar Monitoring	GOES-M only	Yes	Yes
Lightning Detection	No	No	Yes 8km <20 sec latency
Operate through Eclipse	No	Yes	Yes
Ground System Backup	Limited	Limited	Limited
Archive and Access	Limited	Limited	Yes
S/C Raw Data Volume	2.6 Mbps	2.6 Mbps	75 Mbps

More Details in Convective Clouds



Current GOES 1 km Resolution

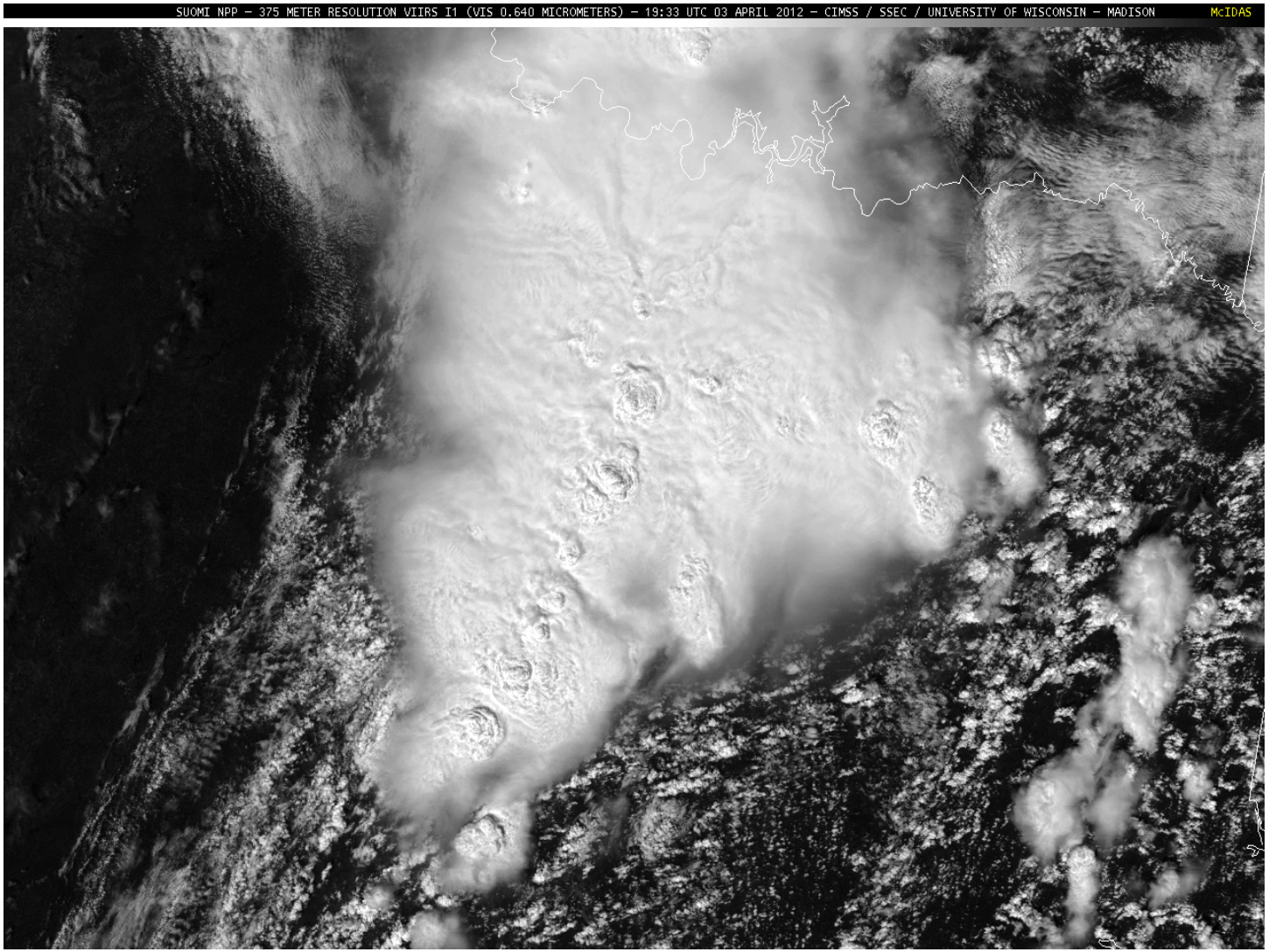
GOES-R 0.5 km Resolution

Provided by Jim Gurka – GOES-R Program Office

More Details in Convective Clouds

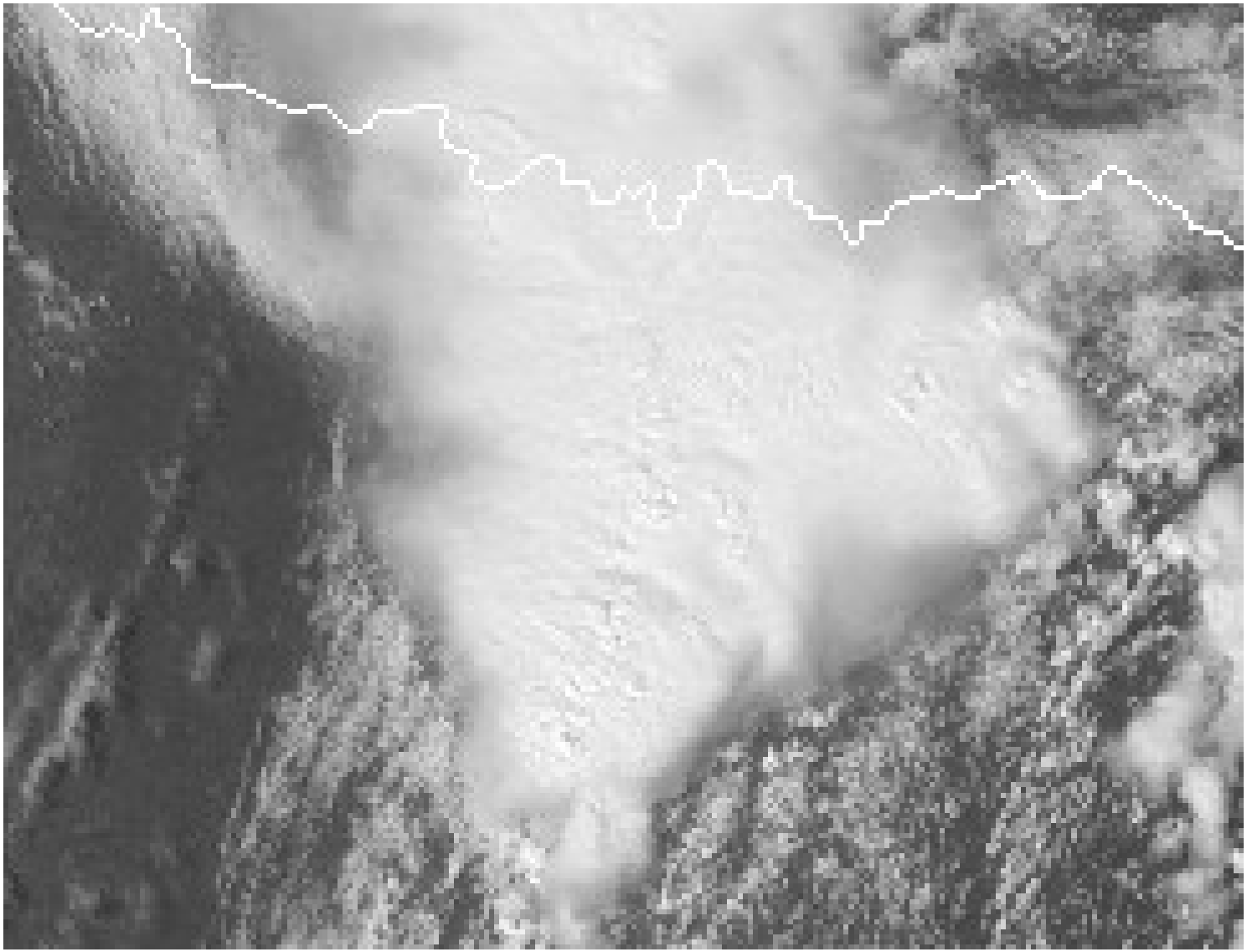
Visible and IR from Suomi NPP

1930z 3 April 2012 – Tornadoes in North Texas



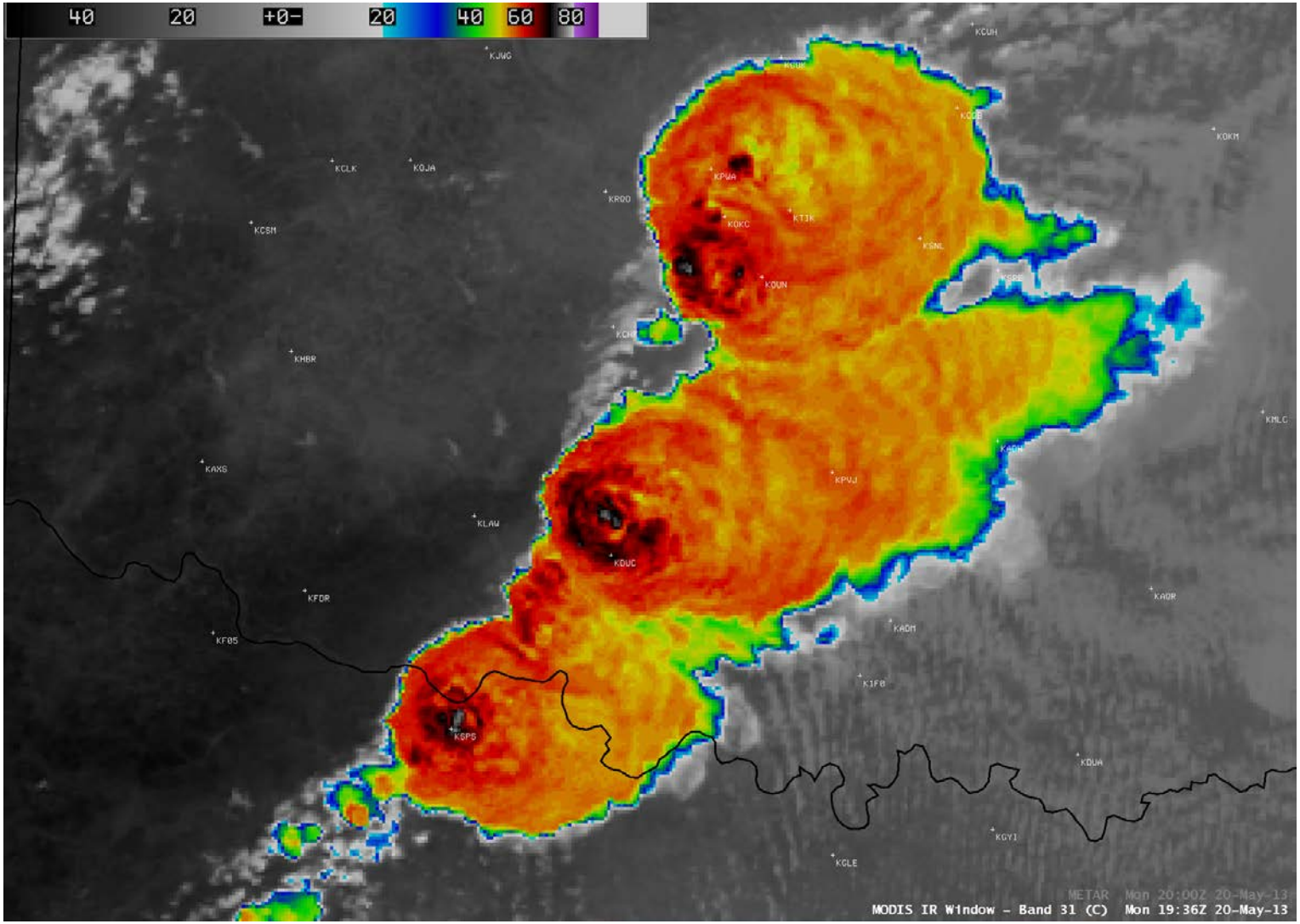
Courtesy UW-CIMSS

Current GOES Visible Image 3 April 2012



Current GOES (4 km) and MODIS (1 km) IR Imagery

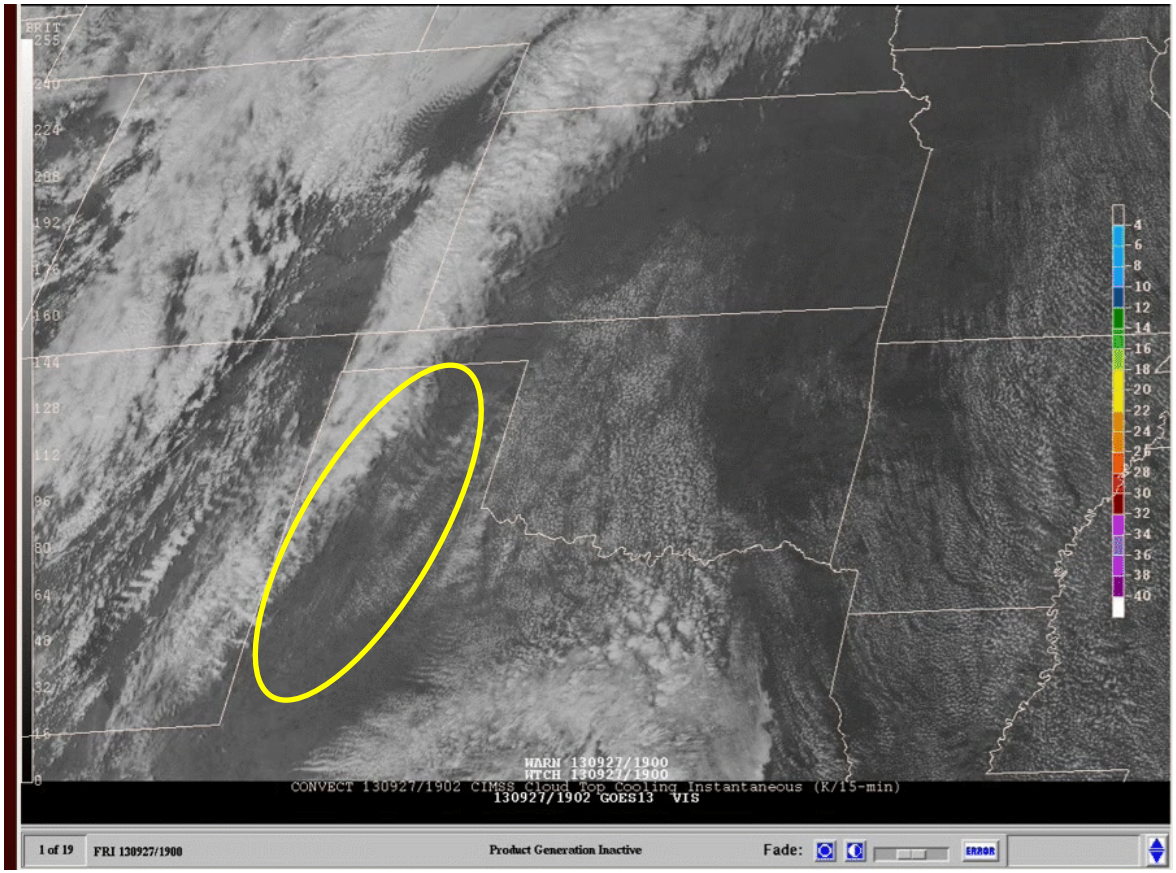
~1935z 20 May 2013 Moore, OK Tornado Day



Courtesy UW-CIMSS

Cloud Top Cooling

September 27, 2013

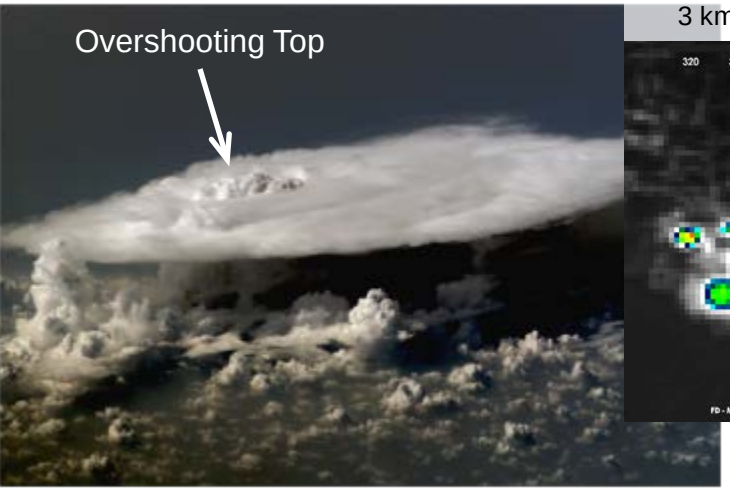


CTC product utilized by SPC Lead Forecaster in Severe Thunderstorm Watch issuance

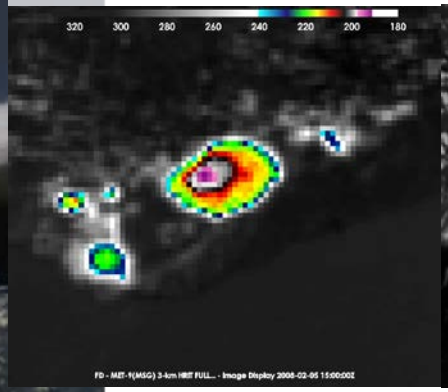
Overshooting-Top and Enhanced-V Signatures

(Often Associated with Severe Weather)

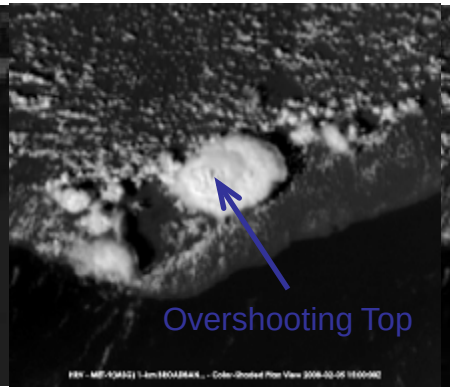
Photo From International Space Station



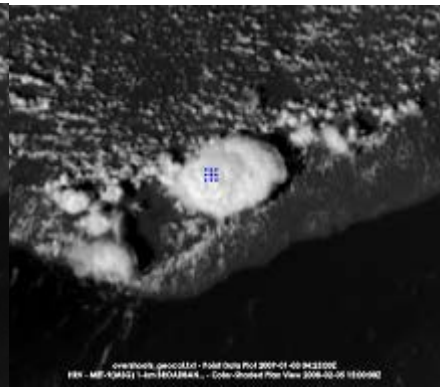
3 km MSG SEVIRI 10.8 µm



1 km MSG SEVIRI Visible

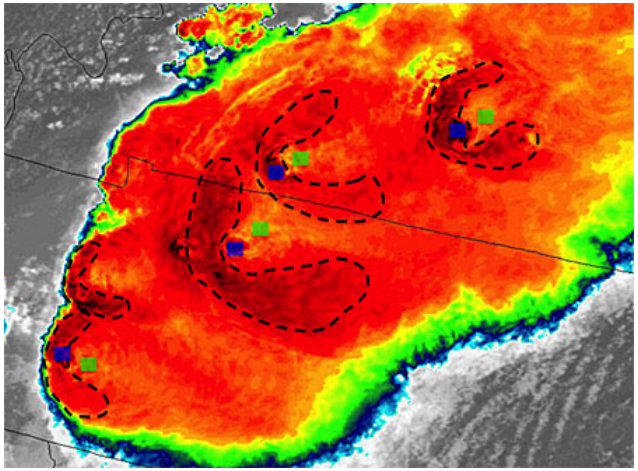


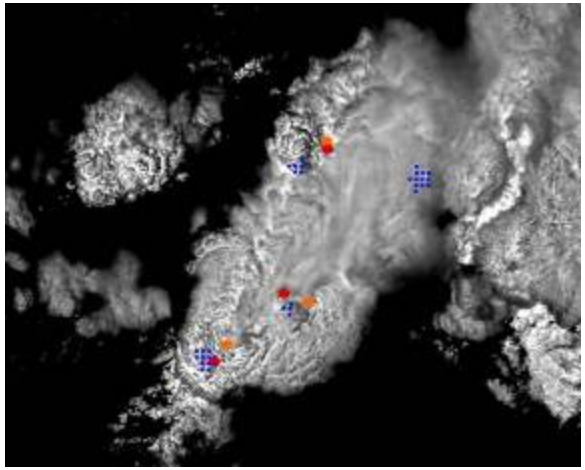
1 km MSG SEVIRI Visible
With Overshooting Detection



Overshooting Top Detections,
Enhanced-V/Thermal Couplet Detections, and Severe
Hail Reports Atop MODIS 250 m Visible

1 km MODIS 11 µm

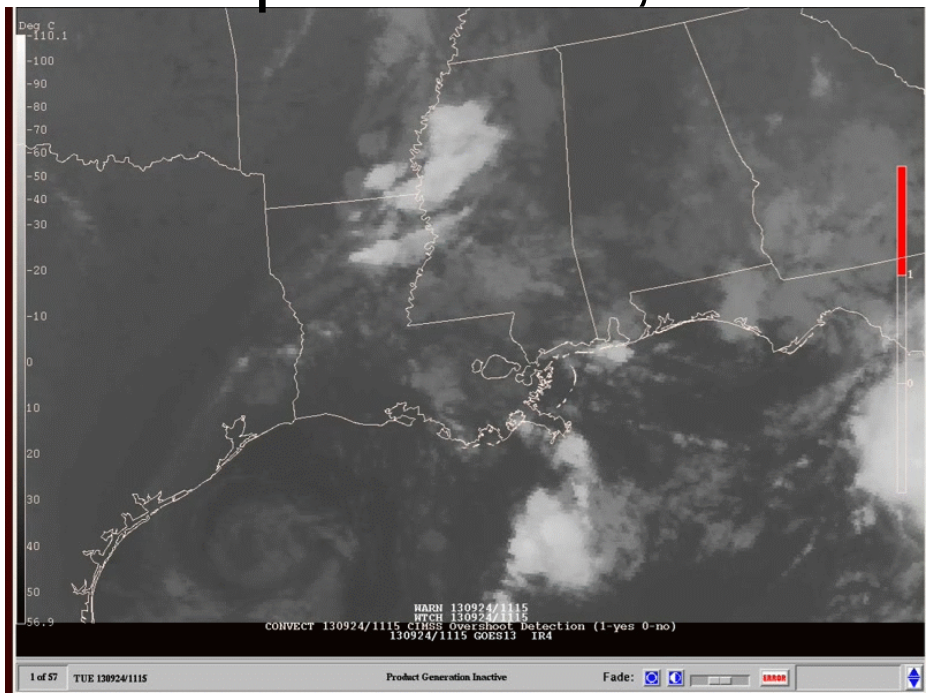




Courtesy of K. Bedka (NASA), J. Brunner and W. Feltz (UW-CIMSS)

Overshooting Top Detection

September 24, 2013



- Similar to the CTC product, forecasters like that it highlights a feature that may not be so obvious, allowing the forecaster to spend less time analyzing the imagery.

- SPC Forecaster Comments
  - *"I like that it helps to make OTs stand out."*
  - *"Though it is not critical, it is nice information to have available."*
  - *"Helps with situational awareness. It confirms some of what we already know during the day in areas of good radar coverage."*
  - *"Could be useful at night and over the ocean to better quantify what is happening regarding where the strongest updrafts are."*

GOES-R Improvements

Performance Capability	GOES I-M	GOES N-P	GOES R
Visible Resolution	1 km	1 km	0.5 km
IR Resolution	4-8 km	4-8 km N 4 km O/P	1-2 km
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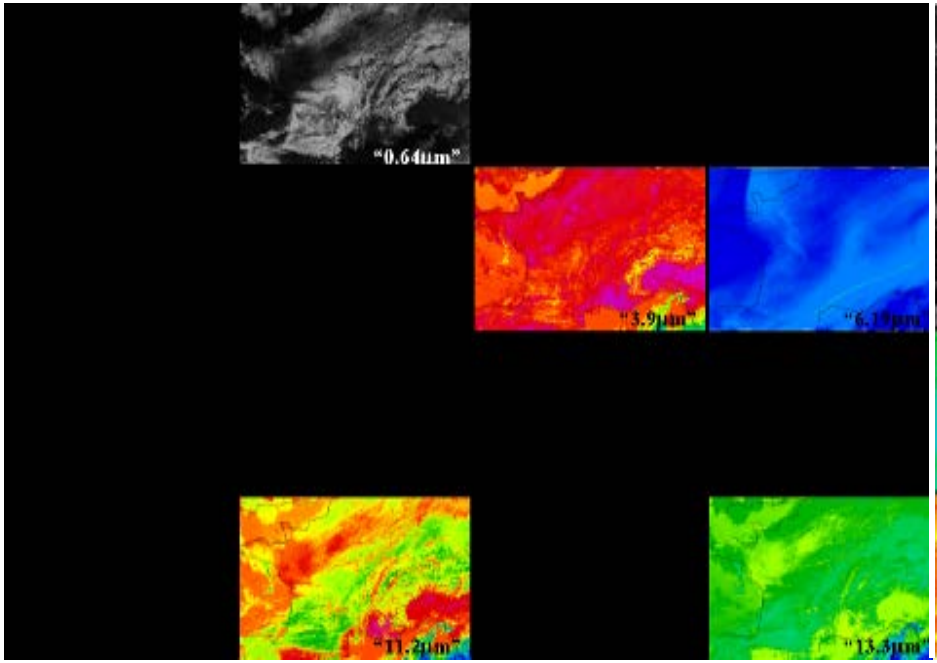
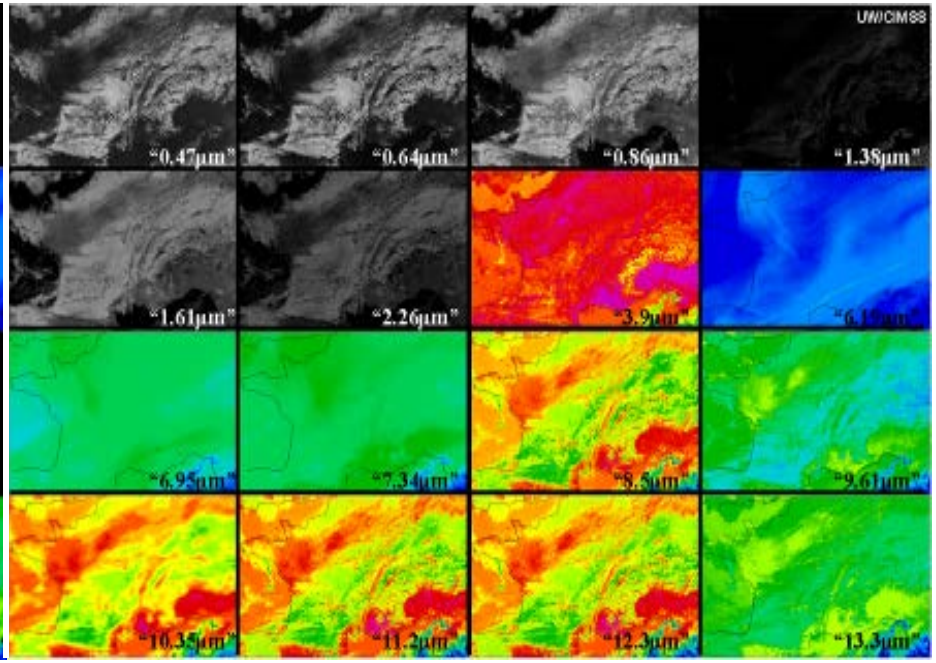
Lightning Detection	No	No	Yes 8km <20 sec latency
Operate through Eclipse	No	Yes	Yes
Ground System Backup	Limited	Limited	Limited
Archive and Access	Limited	Limited	Yes
S/C Raw Data Volume	2.6 Mbps	2.6 Mbps	75 Mbps

Advanced Baseline Imager (ABI)

Current GOES Imager
1 Visible and 4 IR Bands



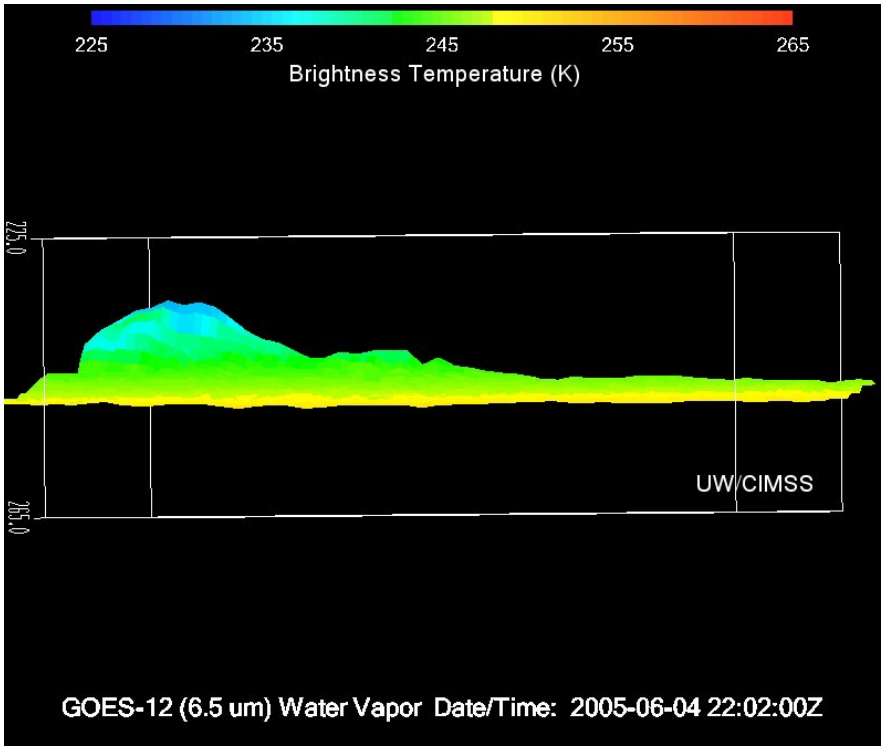
GOES-R Advanced Baseline Imager
2 Visible and 14 IR (3 WV Bands)



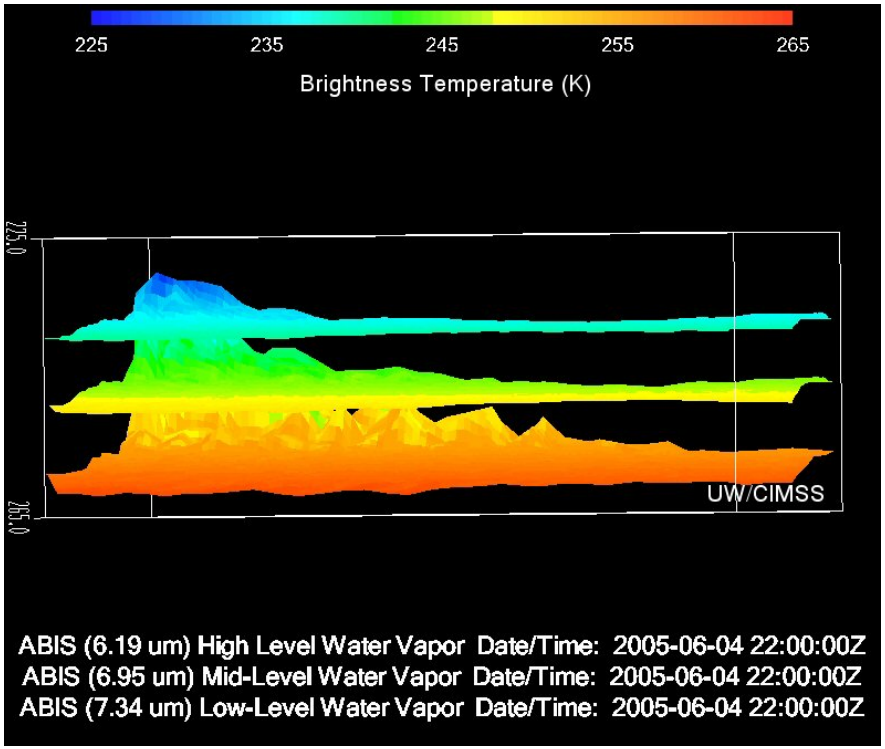
The ABI will improve every product from the current GOES Imager and will introduce a host of new products for severe weather forecasting, fire and smoke monitoring, volcanic ash advisories, and more.

Three ABI WV Bands

Accurate specification of the vertical distribution of moisture is essential to improve thunderstorm forecasting



Current GOES



ABI

Courtesy of W. Feltz, UW-CIMSS

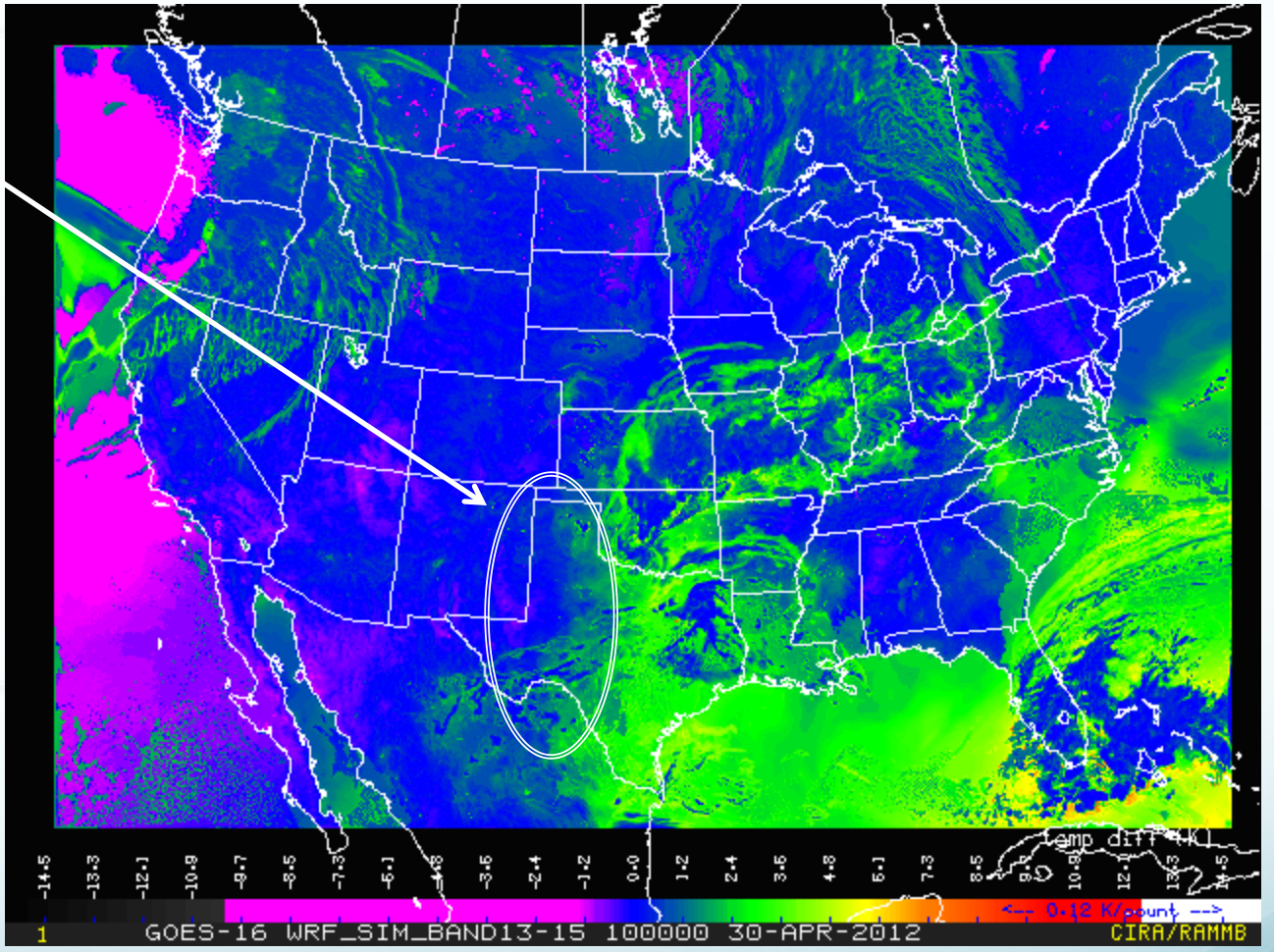
ABI "Split Window" Band Differencing (Band 13 minus 15)

(More details by Lindsey et al., Wed. 11:30 am; C111)

Band difference between 10.35 and 12.3 µm can detect increase in low-level moisture convergence that often precedes cloud and thunderstorm formation

Note storm formation in west Texas – a maximum in the 10.35-12.3 µm is evident prior to cloud initiation

We'll zoom in on the next slide



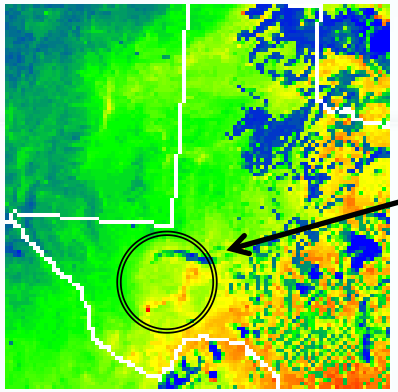
Synthetic GOES-R Tb(10.35) – Tb(12.3)

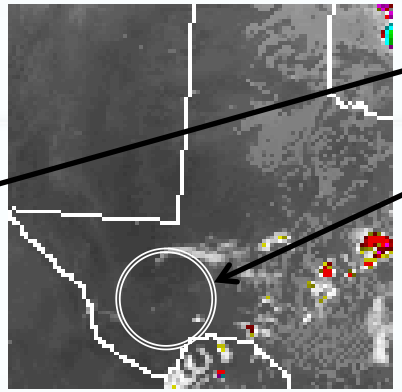
Courtesy of D. Lindsey & L. Grasso (CSU-CIRA) and C.Velden (UW-CIMSS)

10.35-12.3 µm

10.35 µm

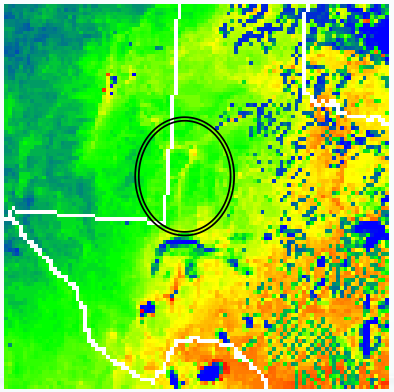
1800 UTC

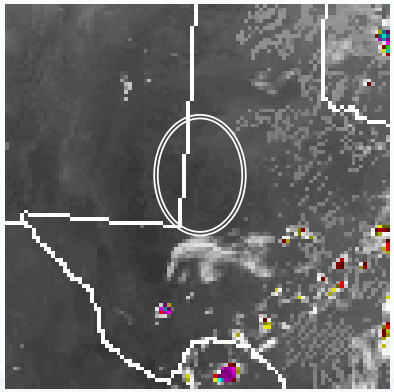




- Note the yellows and reds (maxima) in the 10.35-12.3 images, and the corresponding lack of clouds in the IR images

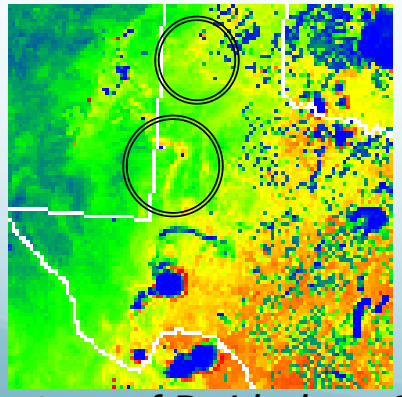
1900 UTC

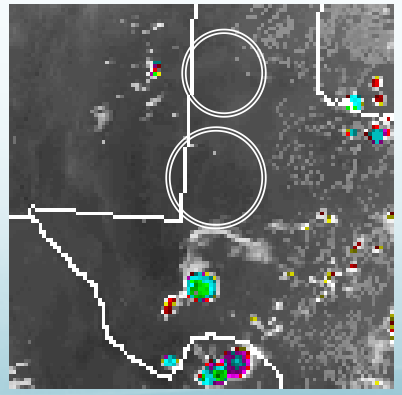


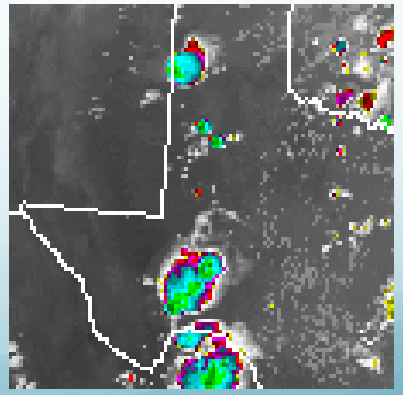


- By 2200 UTC, convective initiation had occurred in these areas, so forecasters would have a few hours notice as to the likely location of where storms would form

2000 UTC







2200 UTC

Courtesy of D. Lindsey & L. Grasso (CSU-CIRA) and C. Velden (UW-CIMSS)

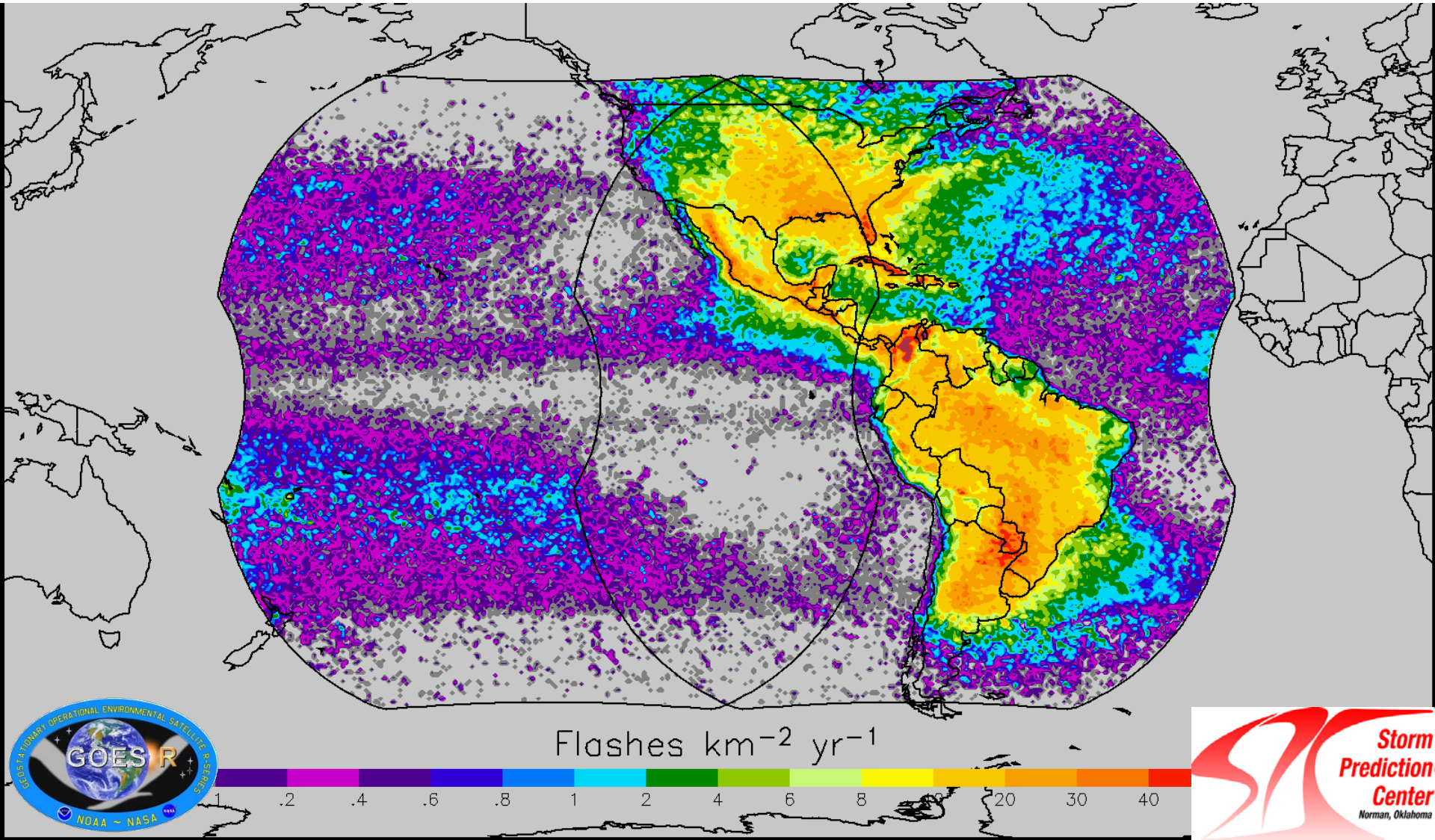
GOES-R Improvements

Performance Capability	GOES I-M	GOES N-P	GOES R
			0.5 km
			1-2 km
			5 min
			30 sec
			16
			Yes
			Yes 8km <20 sec latency
			Yes
			Limited
			Yes
			75 Mbps

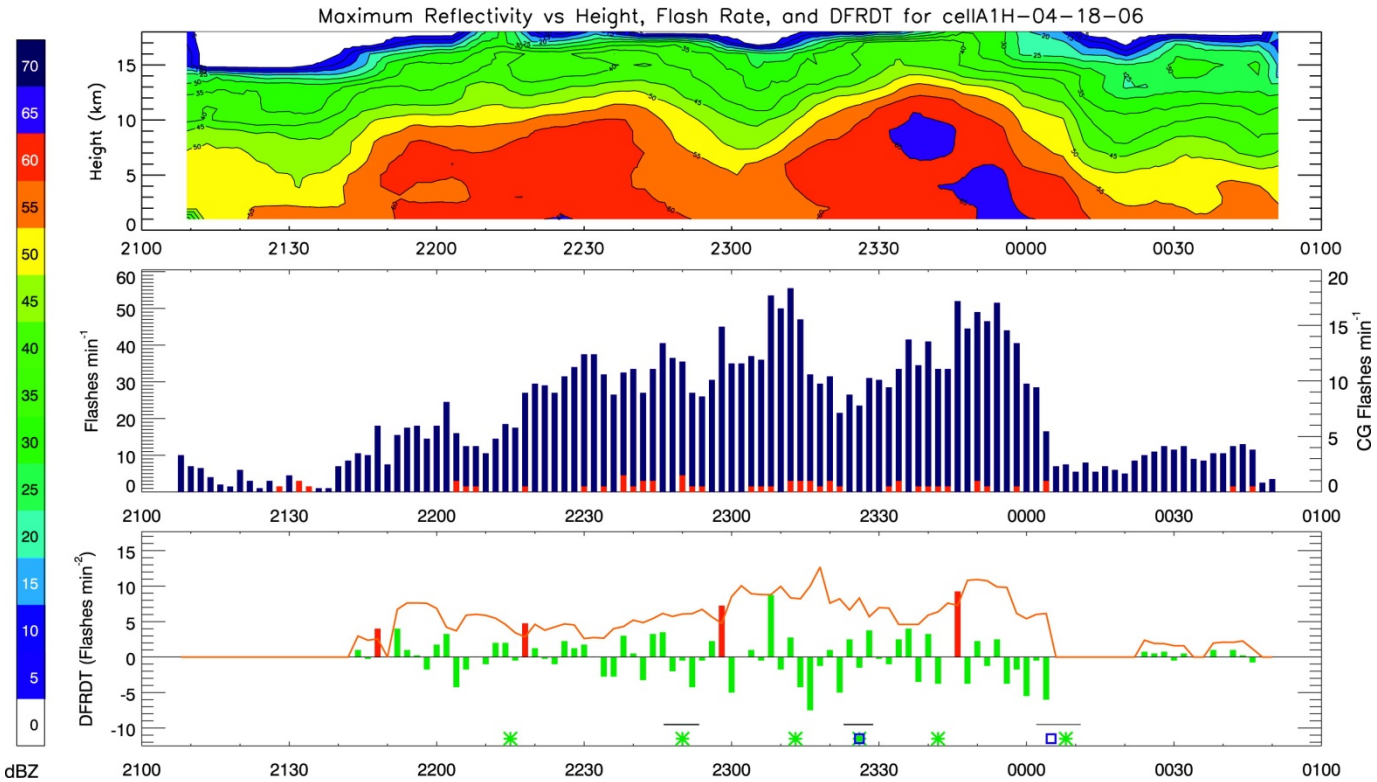
GOES-R/S Total Lightning Mapper

Based on TRMM LIS Data

(Lightning Session 8, Wed. 1:30 pm, C111)



Total Lightning in a Severe Storm in Alabama 18 April 2006



Time-Height Radar Cross-Section

Total Lightning (Purple) versus Cloud-to-Ground Lightning (Red)

Total Lightning "Jumps" (Red Bars) preceded severe weather reports

Total lightning provides a much better indicator of storm electrification and severe weather potential compared to cloud-to-ground lightning alone

Courtesy of C. Schultz (UAH)

Concluding Remarks

- Geostationary satellite imagery provides a foundational cornerstone to tornado and severe thunderstorm forecasting in the US
  - SPC forecasters depend heavily on GOES data
- Current GOES-R Proving Ground evaluations are providing pathways for GOES-R products to improve severe weather analysis and prediction after GOES-R is launched