Satellite-Based Detection of Deep Convective Updrafts

From 1-Minute Observations to Climate Applications

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Satellite Observations of Severe Convection

- **Temporal and spatial trends/patterns in satellite imagery can be used to infer:**
  1) **Vertical cloud growth rates**
  2) **The presence of strong upper-tropospheric convective updrafts**
  3) **Water vapor / ice injections into the lower stratosphere**
  4) **Divergence in the storm outflow layer**

- **Products to objectively identify these signatures have recently been developed**

- **These signatures and derived products can be used by forecasters to identify hazardous convective storms**

Severe Storms in Satellite Imagery From 1-Minute Observations to Climate Applications

- 1-minute GOES Super Rapid Scan Operation data can be combined with ground-based radar and total lightning observations to help us better understand how satellite imager observations will help the forecasting community in the GOES-R ABI era

- One primary advantage of satellite data over other observational platforms is the near global geographic coverage over a 30+ year time period, allowing one to develop long-term databases of satellite-derived severe storm signature detections from LEO and GEO data

- **This presentation will focus on:**

1) **Signatures in satellite imagery typically found near severe weather**
2) **An objective algorithm to detect deep convective updrafts or "overshooting tops"**
3) **1-min satellite/lightning and 5-min radar observations of hazardous storms**
4) **Long term regional and global overshooting top detection databases and applications**

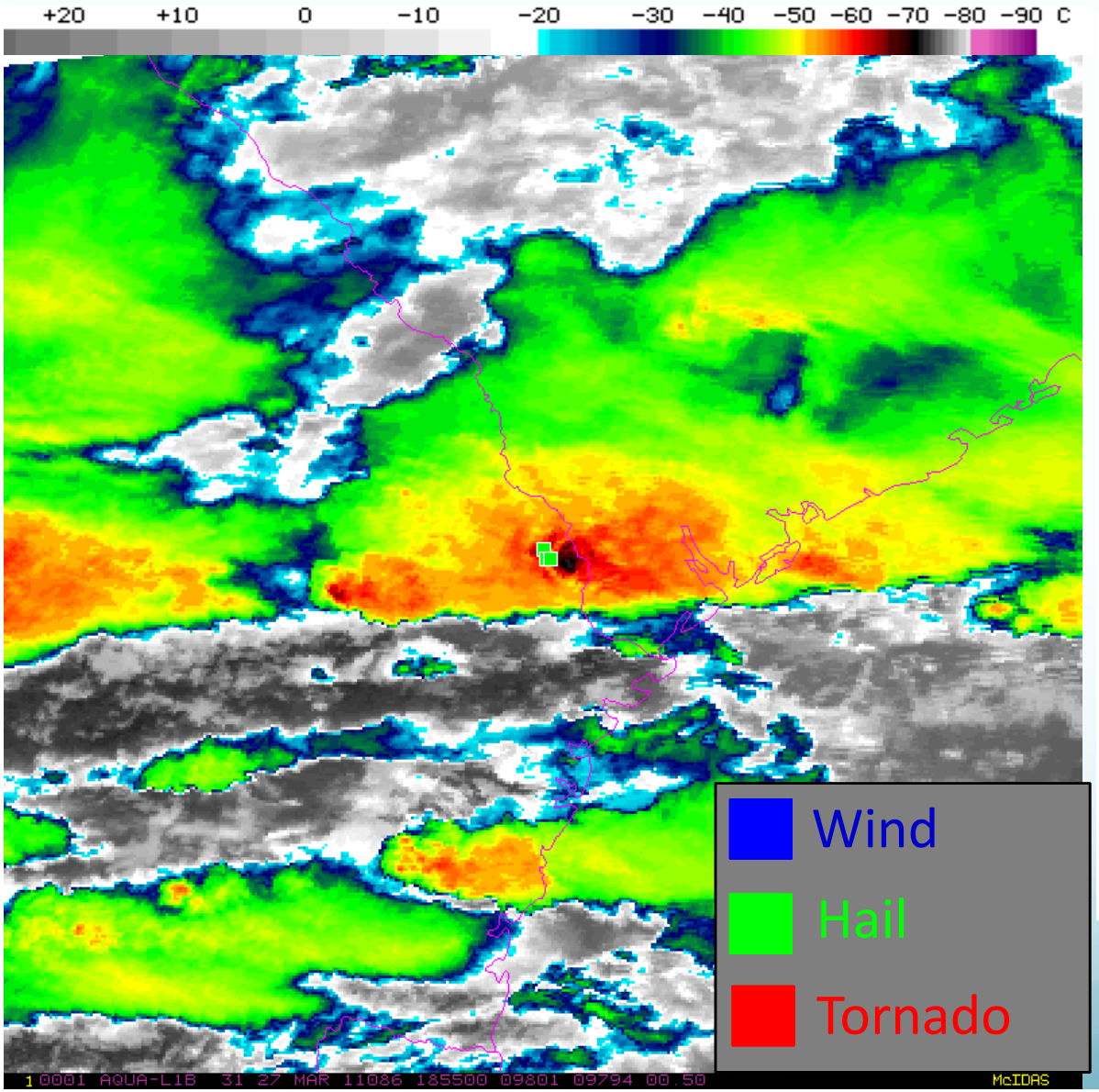
Severe Storm Signatures in Visible or Infrared Satellite Imagery

- **Rapid vertical growth during the convective initiation phase**
  - Rapid cooling = strong forcing and release of instability *(UWCI algorithm, Sieglaff, Hartung, Cinteneo)*

- **Presence of anomalous patterns within the mature storm cloud top**
  - **Indicates regions of strong and persistent updrafts**
    - **Small regions of highly textured and cold pixels relative to the smooth/warmer surrounding anvil, indicative of cloud tops "overshooting" the tropopause *(Adler, Heymsfield, Bedka)***
    - **The "enhanced-V" signature, "cold-ring" signature, and above anvil cirrus plumes *(McCann; Setvak; Brunner)***
    - Large "domes" of extremely cold pixels, often present within MCC's (*Maddox*)
    - Regions of small ice crystals near storm updrafts derived from near-IR reflectance *(Lindsey, Rosenfeld)*

- **Rapid lateral expansion of anvil cloud early in the mature phase**
  - Indicates strong updrafts and supportive outflow environment, leading to a long-lived and potentially severe storm *(Tollerud; Machado; Vila)*

MODIS Observations of Severe Storms



- Severe weather observations within 5 mins of a MODIS overpass are parallax corrected and overlaid upon the imagery, centered on a severe report location

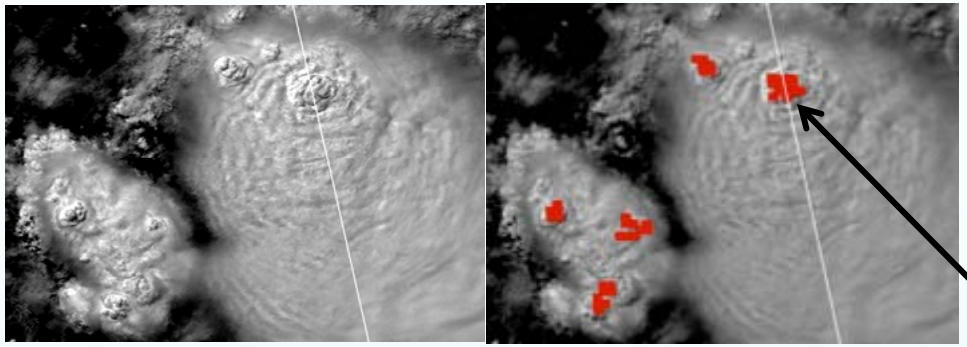
- **Severe weather is often occurring near small clusters of anomalously cold pixels that are associated with deep convective updrafts and overshooting tops**

Objective Overshooting Convective Cloud Top Detection

- A method to objectively detect overshooting convective cloud tops and the enhanced-V signature has been recently developed within the GOES-R Aviation Algorithm Working Group

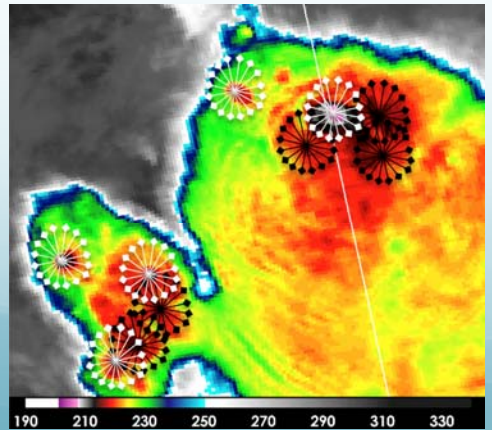
- An objective OT detection algorithm utilizes IR brightness temperature and spatial gradient thresholding with NWP tropopause temperature information to identify OTs at their characteristic spatial scale

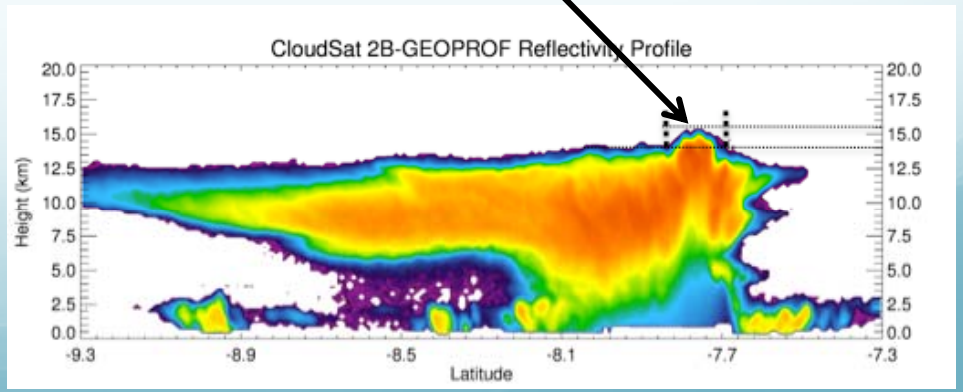
MODIS 250 m Visible and 1 km IR Window With Overshooting Top Detections



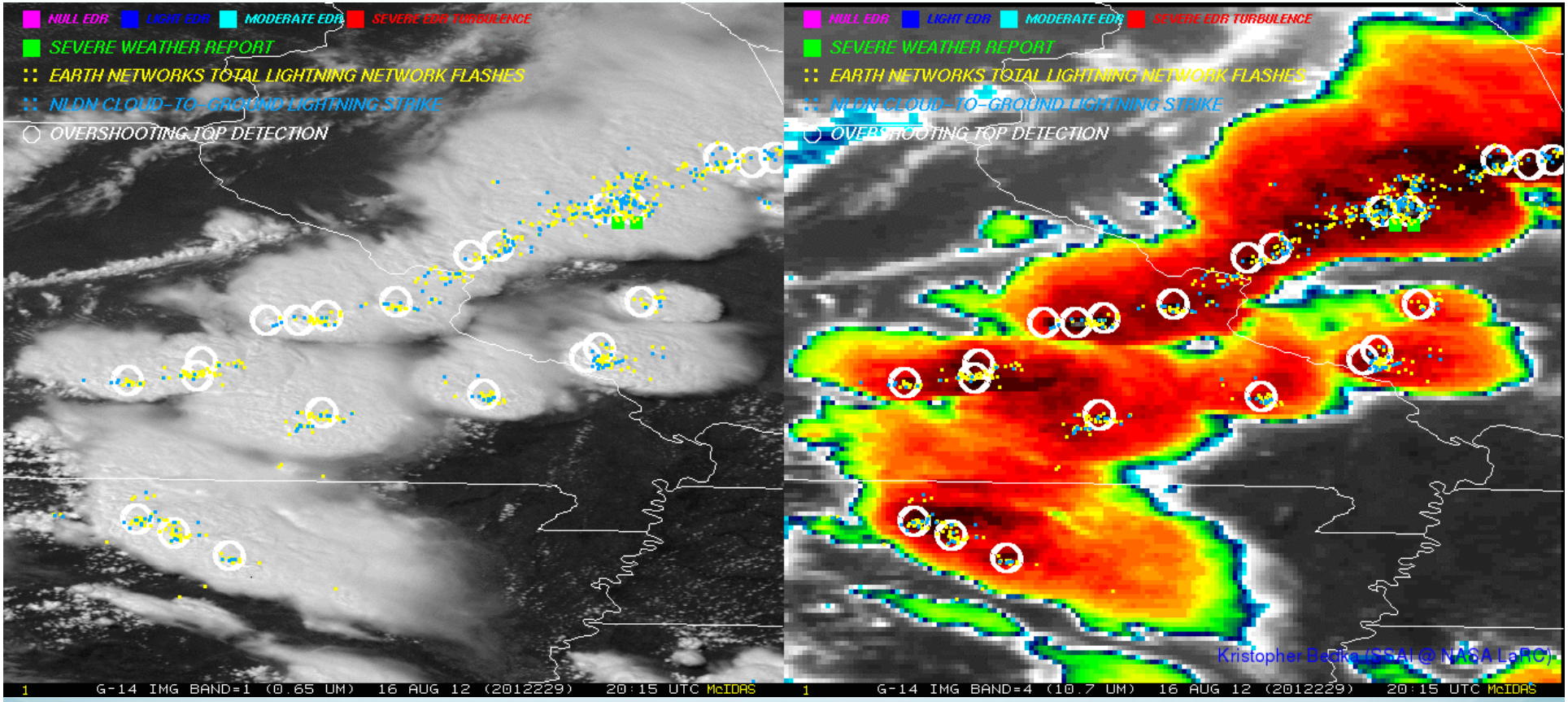
White: Region meets OT detection criteria

Black: Region not cold enough relative to surrounding anvil





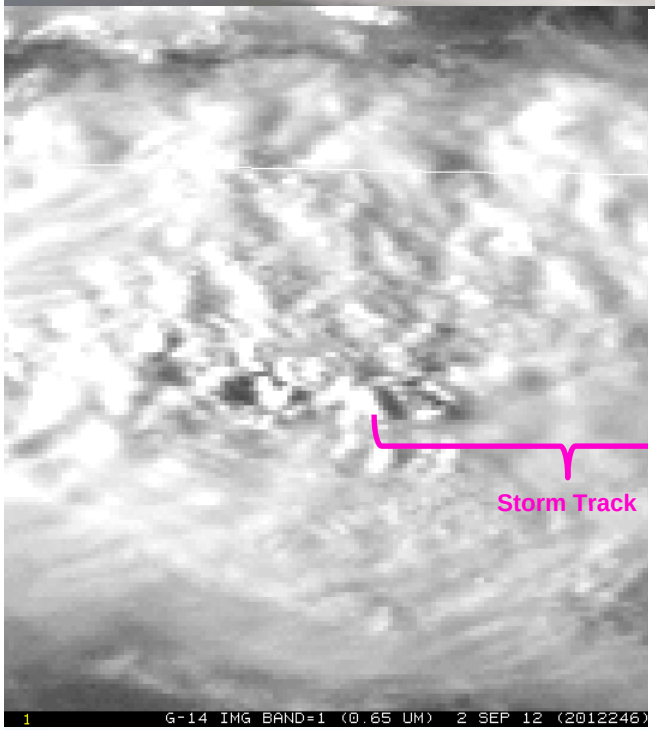
GOES-14 Super Rapid Scan Animation Overlaid with OT Detection, Total Lightning, Aviation Turbulence, and Severe Weather Reports

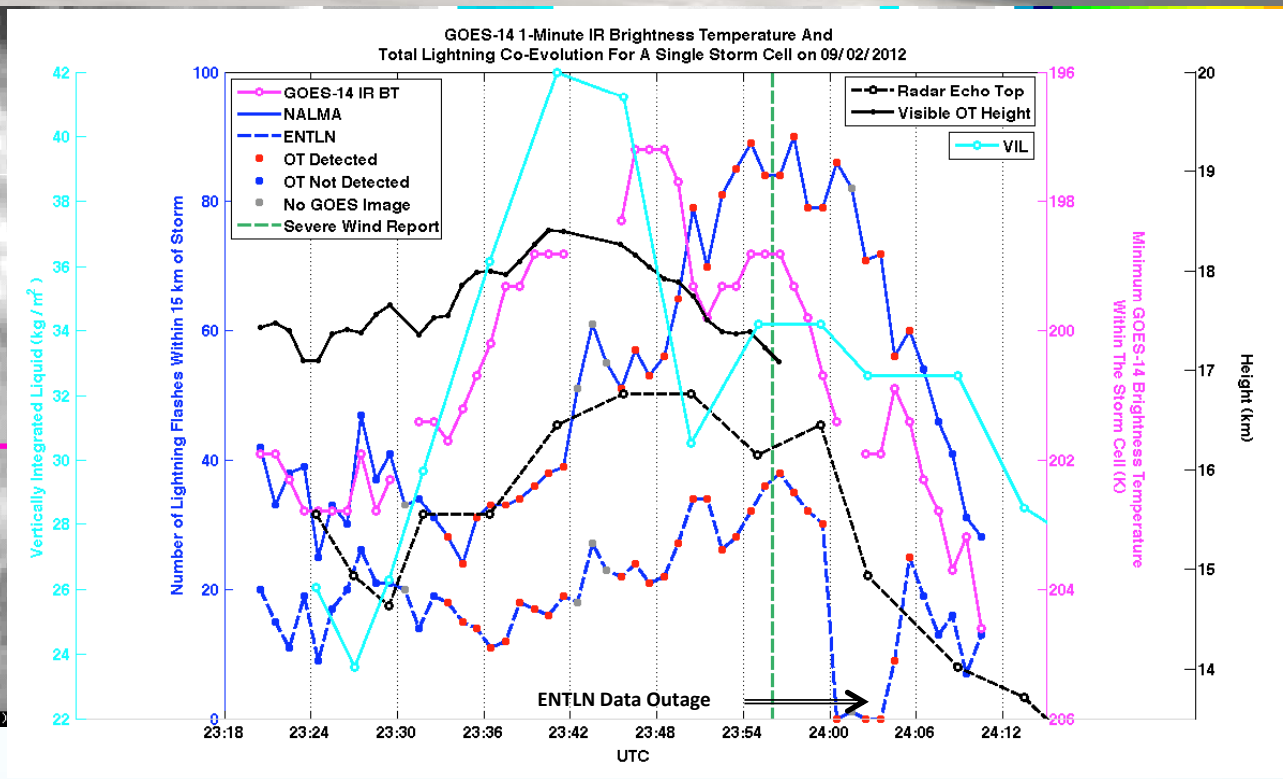


http://www-angler.larc.nasa.gov/site/people/data/kbedka/SRSO_G14_OTD_SVR_PIREP_20120816_2015-2359.gif

This animation offers a glimpse of the types of data that may be operationally available when GOES-R ABI is operating in 30 second "Mesoscale" mode

GOES-14 1-Minute SRSO: Sept 2 Over Northern Alabama

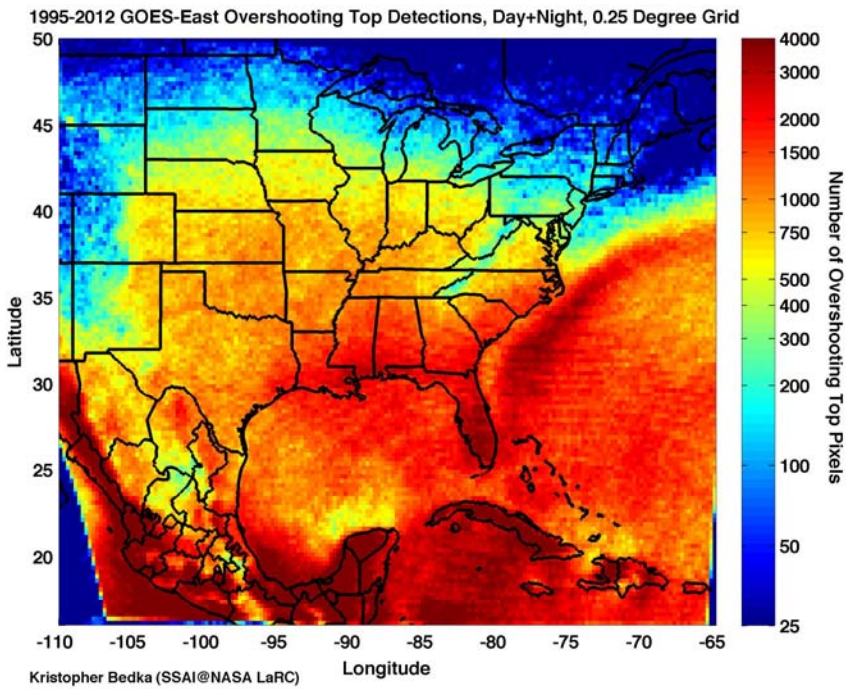


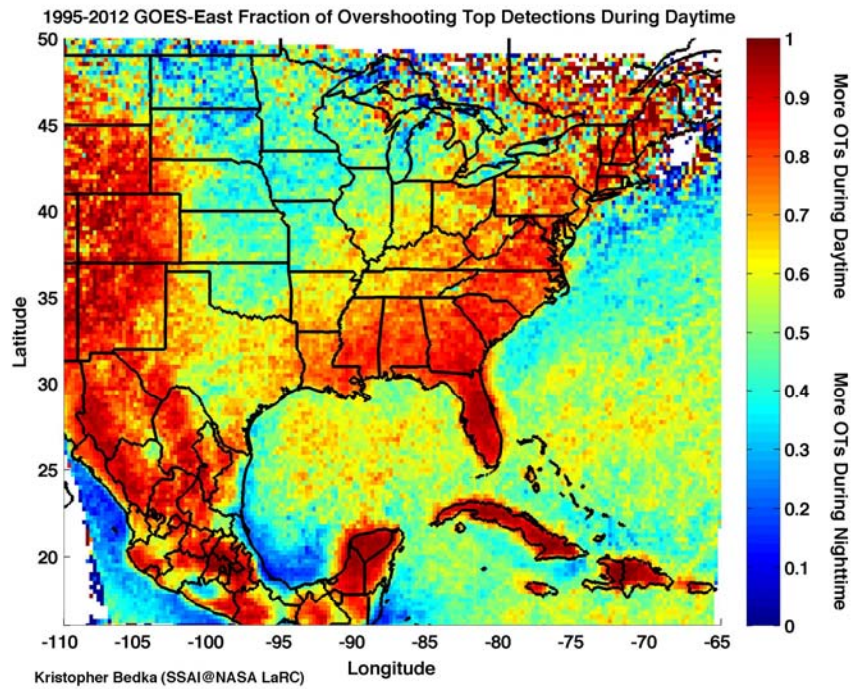


Rapid IR cloud top cooling and repeated OT detections from 2330–2348 UTC correspond with a rapid increase in total lightning activity. OTs are continuously detected for 30+ mins.

VIL, OT penetration height from visible shadow measurements + 16.2 km equilibrium level, and radar echo top peak in the 2341-2348 UTC time period in conjunction with maximum reflectivity below 5 km. VIL, IR BT, and echo top show a secondary intensification at the time of severe wind.

Lightning activity peaks at the time of severe wind in association with charge separation from increased ice-ice collision within the downdraft The ENTLN and NALMA lightning flash rate time series follow each other quite well throughout the study period.

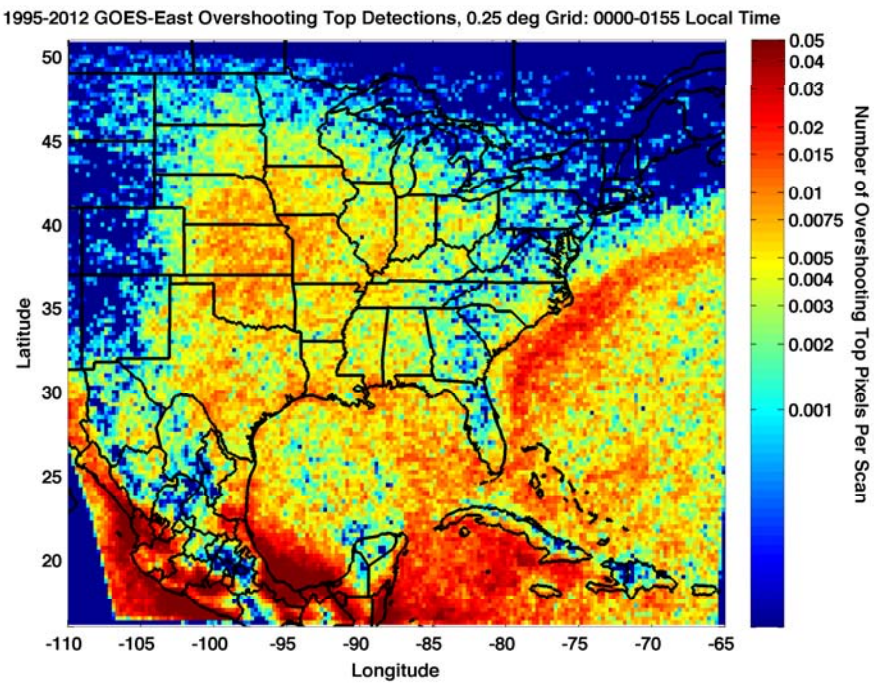




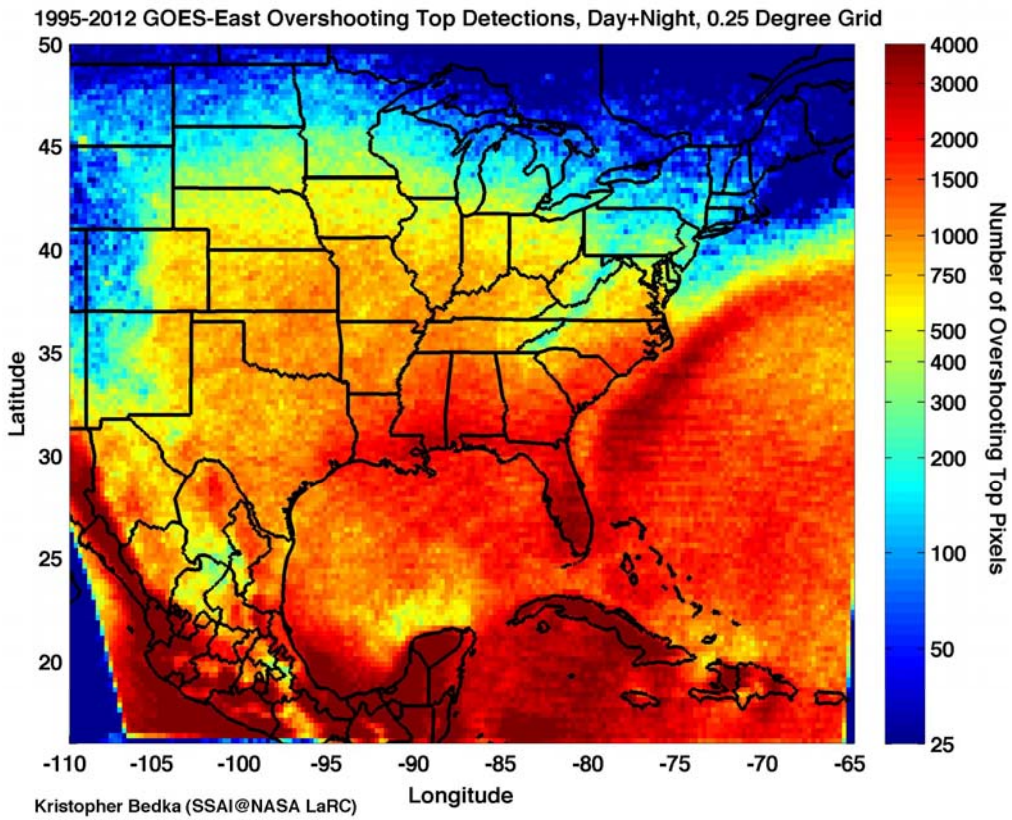
1995-2012 GOES-East OT Detections Using Full Spatial Resolution (4-6 km) and Two Images Per Hour

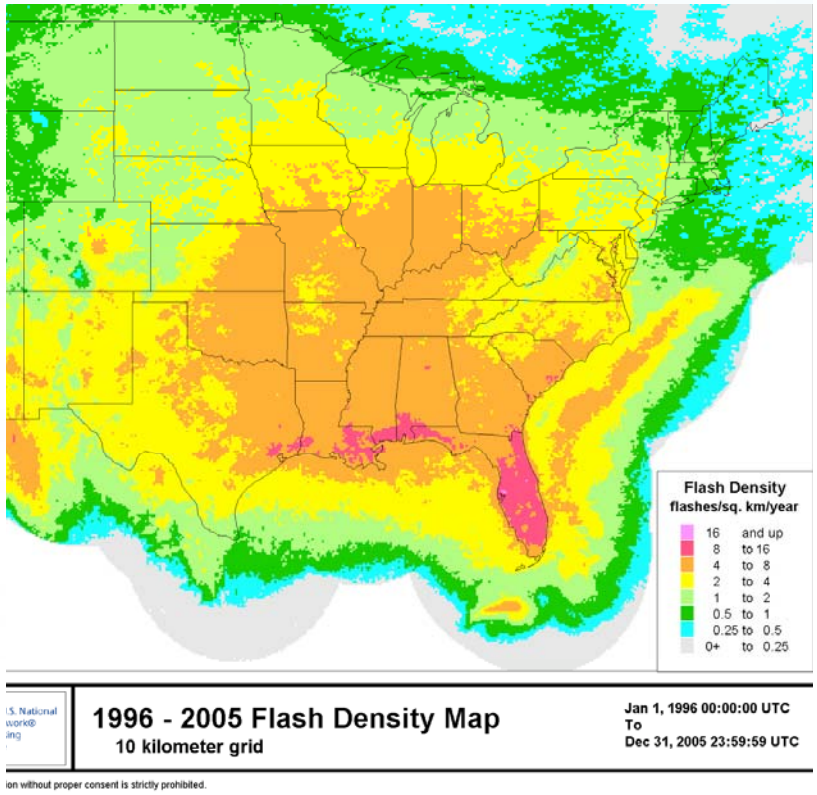
OT Detections Assigned To 0.25 Degree Resolution Grid

Animation Available Here: http://www-angler.larc.nasa.gov/site/people/data/kbedka//OTclimatology_1995-2011_houranim.gif

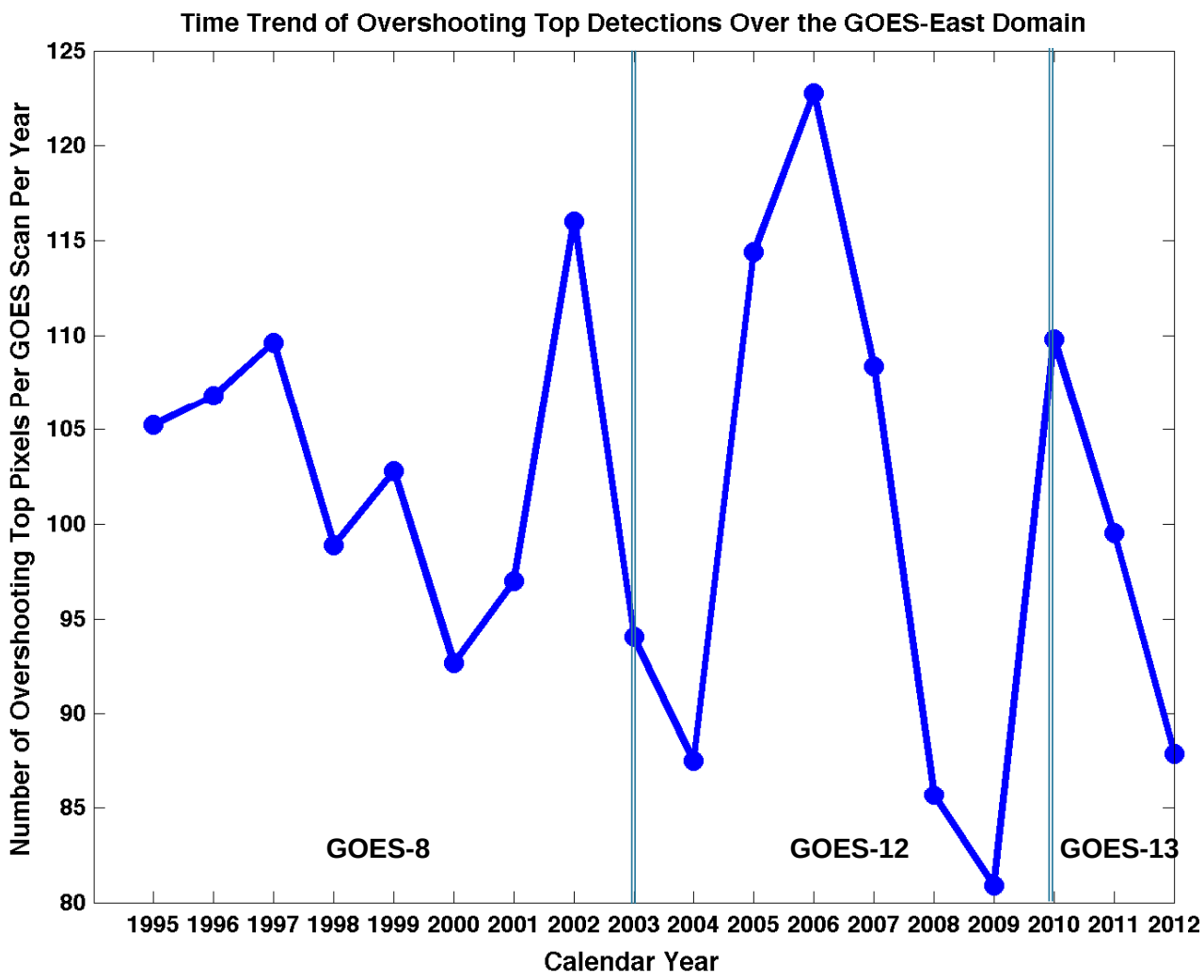


18-year GOES OT Detection vs. 10-year National Lightning Detection Network Data



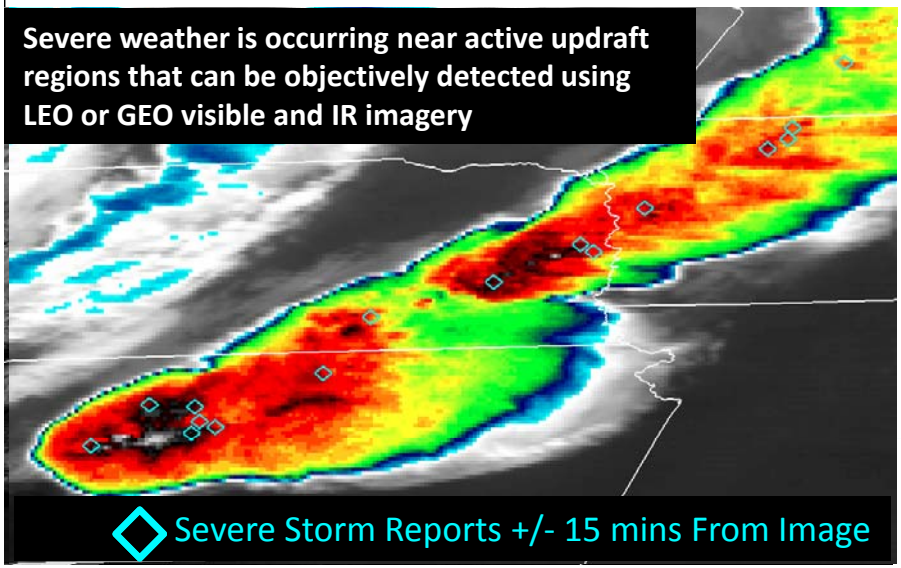


Time Trend of GOES-East Overshooting Top Detections



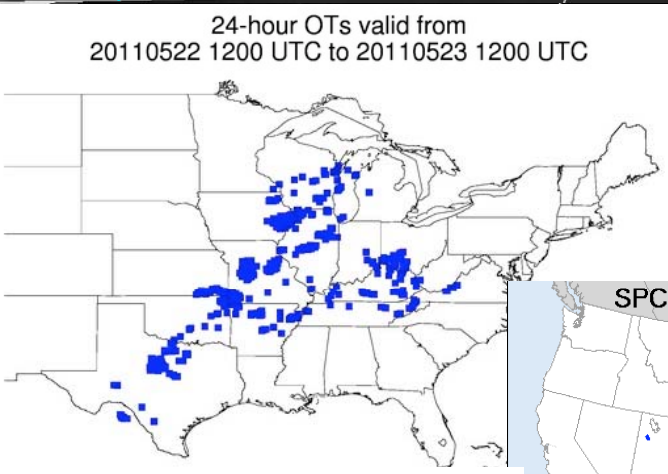
Overshooting Convective Cloud Top Detection

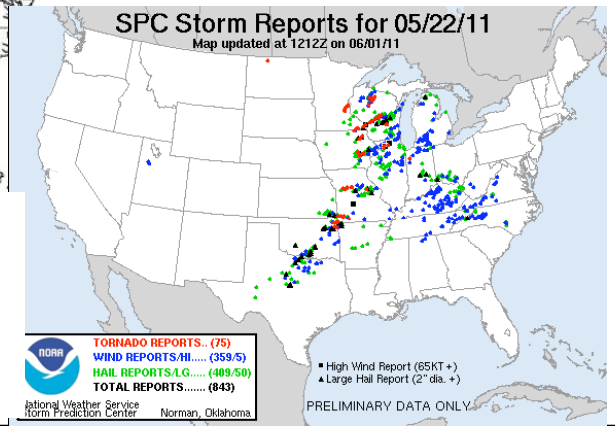
A Severe Weather Situational Awareness and Decision Aid



Frequency of Overshooting Top Detection Near Confirmed Severe Weather Events April-September 2004-2009

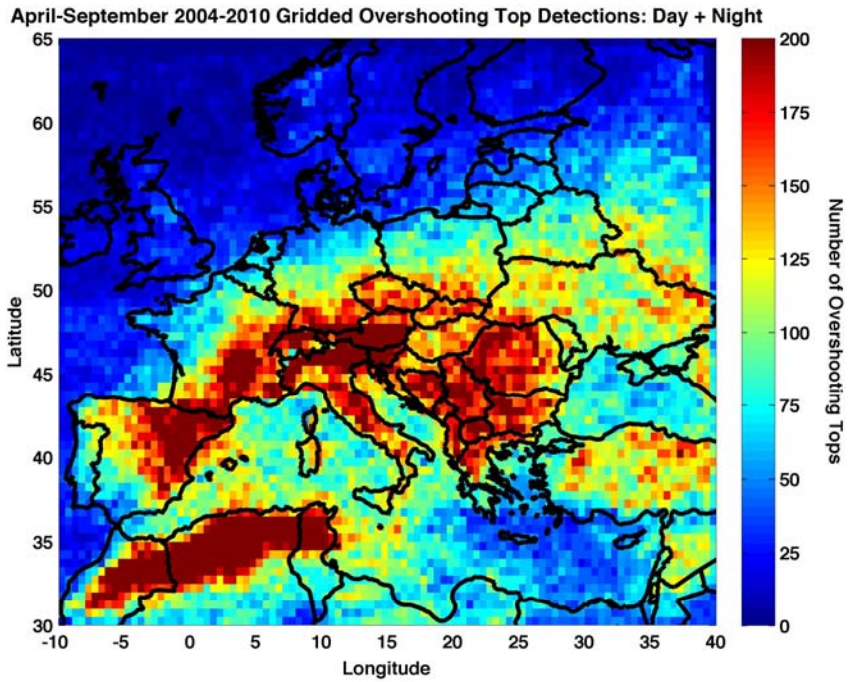
Severe Weather Type	# Severe Reports	OT Detection Match %
Tornado	4,684	56.2%
Severe Wind	52,743	58.4%
Large Hail	56,114	51.3%
Any Type	113,541	54.8%

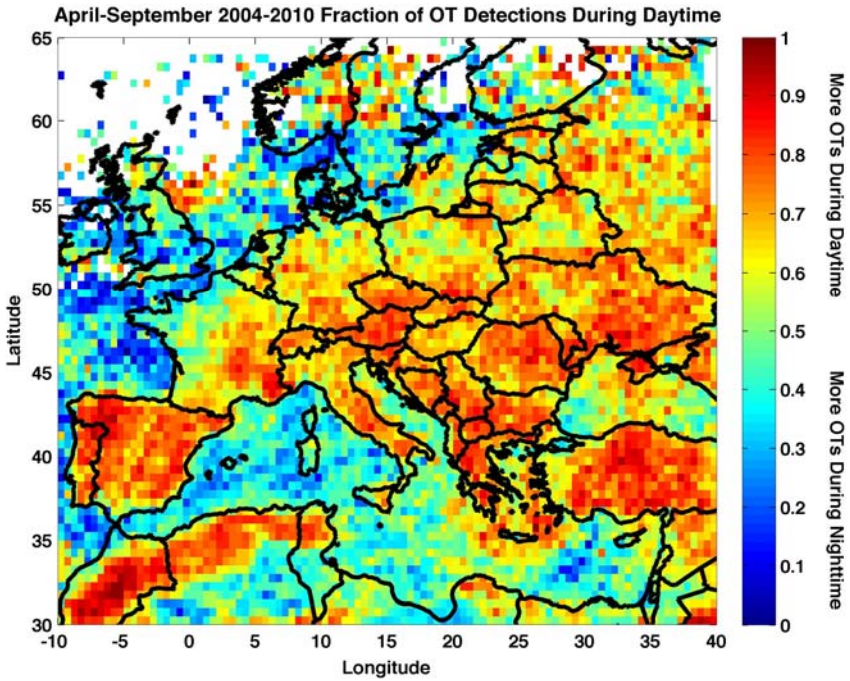


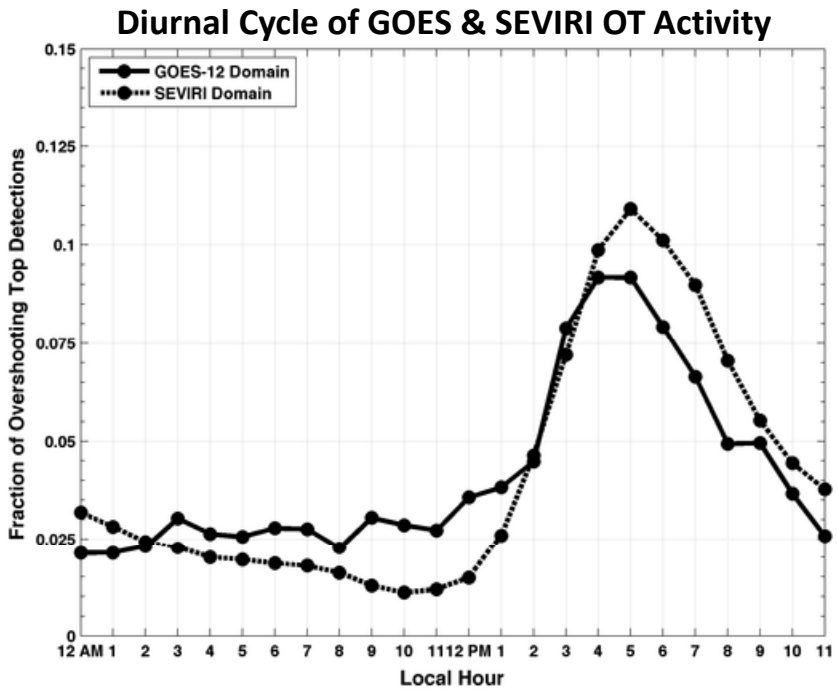


24 HOURS OF OT DETECTIONS VS. SEVERE WEATHER REPORTS
Joplin, MO Tornado Event

2004-2010 Warm Season MSG SEVIRI OT Detection Database







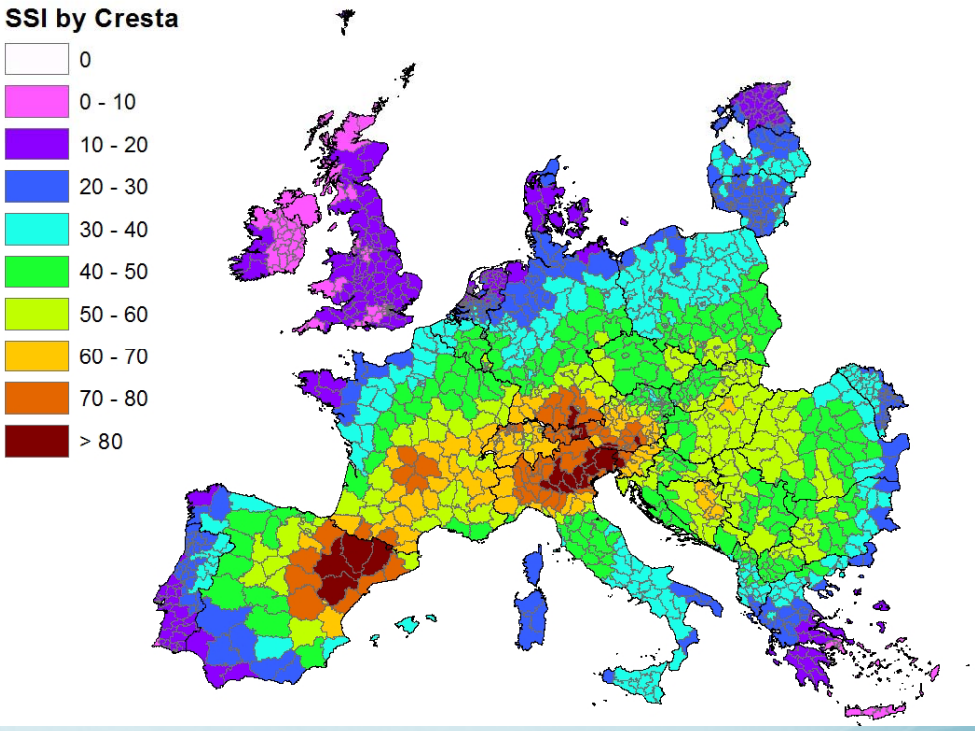
- OT maxima across the SEVIRI domain are well correlated with the presence of topographical features
- The time of peak OT activity is approximately the same between Europe and the U.S.
- OTs are more frequent over the GOES-12 domain at night. The U.S. Great Plains and Gulf Stream Ocean current both show a night-time bias in OT activity. See Bedka et al. (JAMC, 2010) for details

Willis Pan-European Hail Model

Unique Hail Model for Europe

- **40 countries explicitly modelled**
- **First model for the insurance market to cover such a variety and number of countries**
- **Model based on ~ 38,000 individual historic convective storms**
- **9 years of MSG SEVIRI satellite overshooting cloud top detection information a key component of the model**
- **Country-specific vulnerability curves**

Willis Re Hail European Storm Severity Index



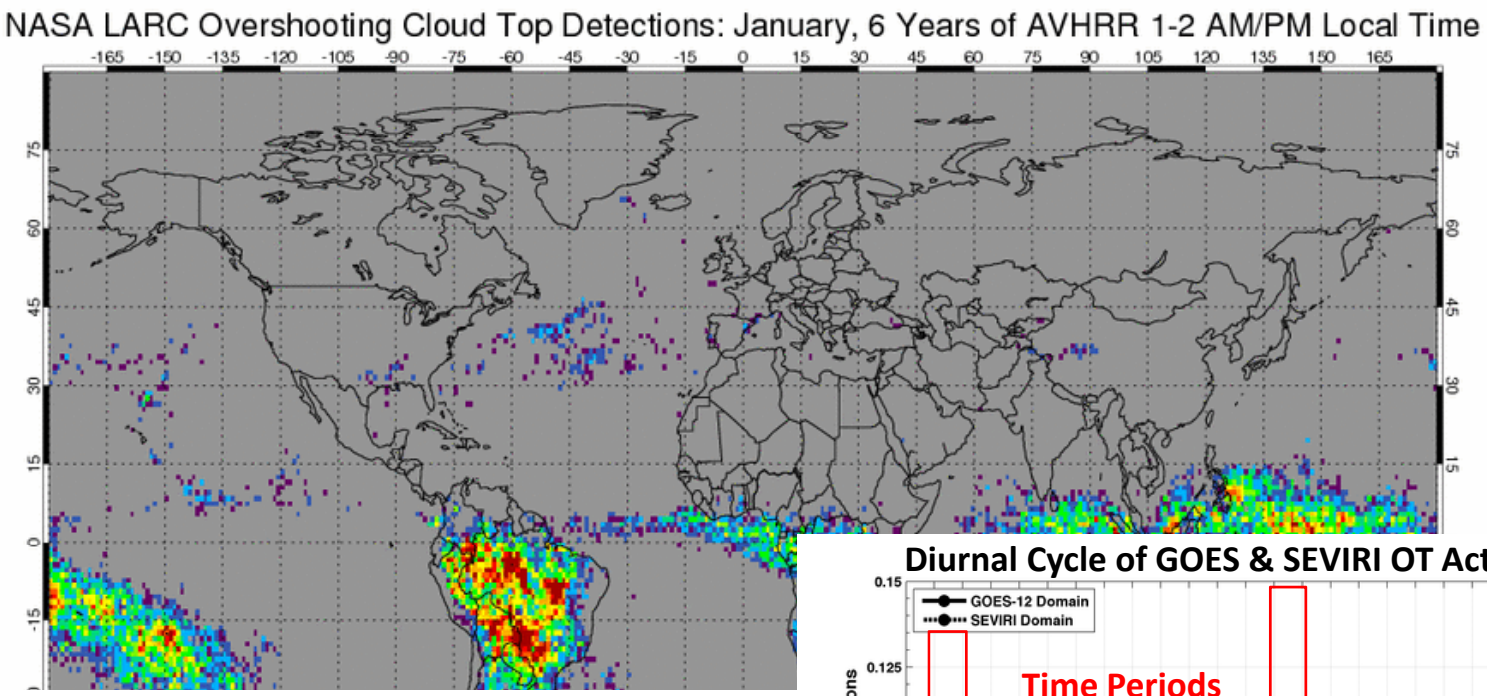
Willis Research Network

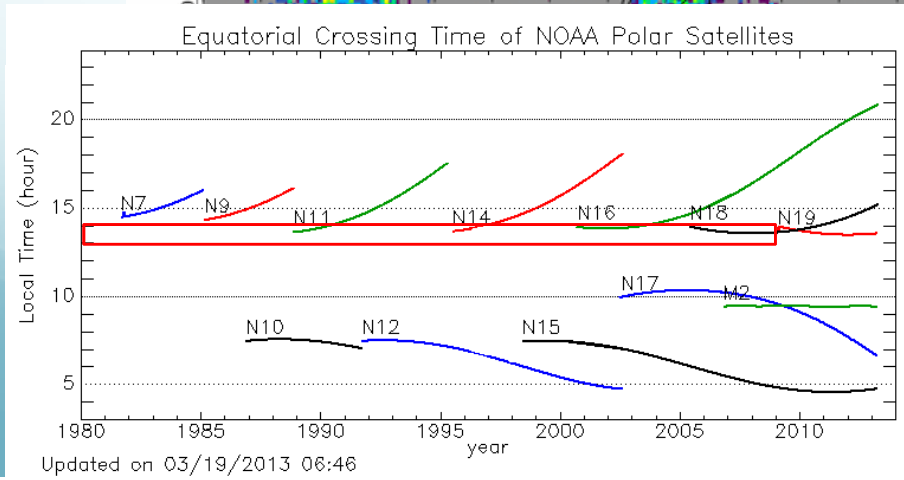
Willis Re

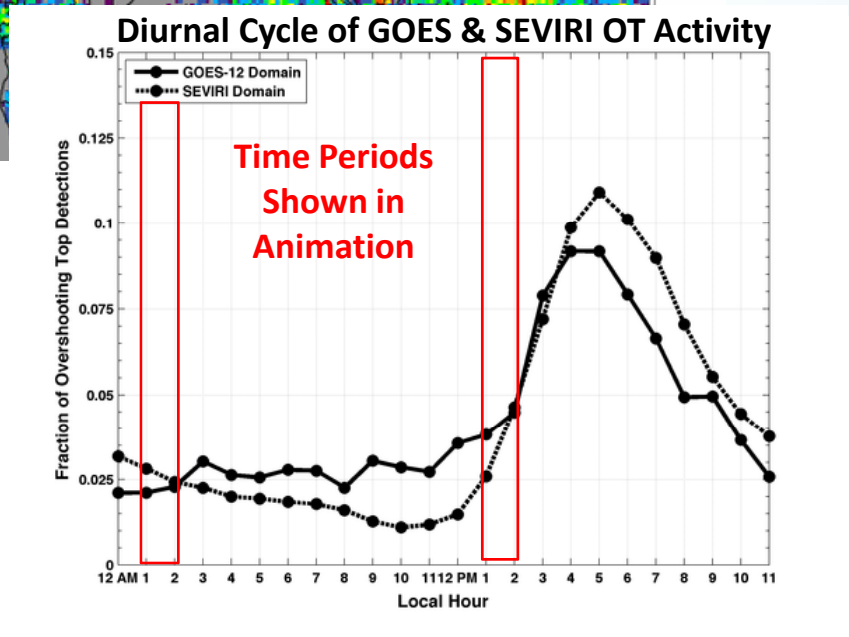
KIT Karlsruhe Institute of Technology

NOAA AVHRR Global Gridded Overshooting Top Detections 0100-0200 AM/PM Local Time, 6 Years of Orbits

OT detections will be produced for all AVHRR observations from 1978-present within a AVHRR Cloud Property Climate Data Record being developed at NASA LaRC







Summary

- Several distinct signatures often associated with hazardous weather are evident in visible and IR satellite imagery

- Overshooting cloud tops (OT) are one readily detectable feature well correlated with severe weather

- An algorithm to detect OTs has recently been developed and is currently being improved via GOES-R Risk Reduction support

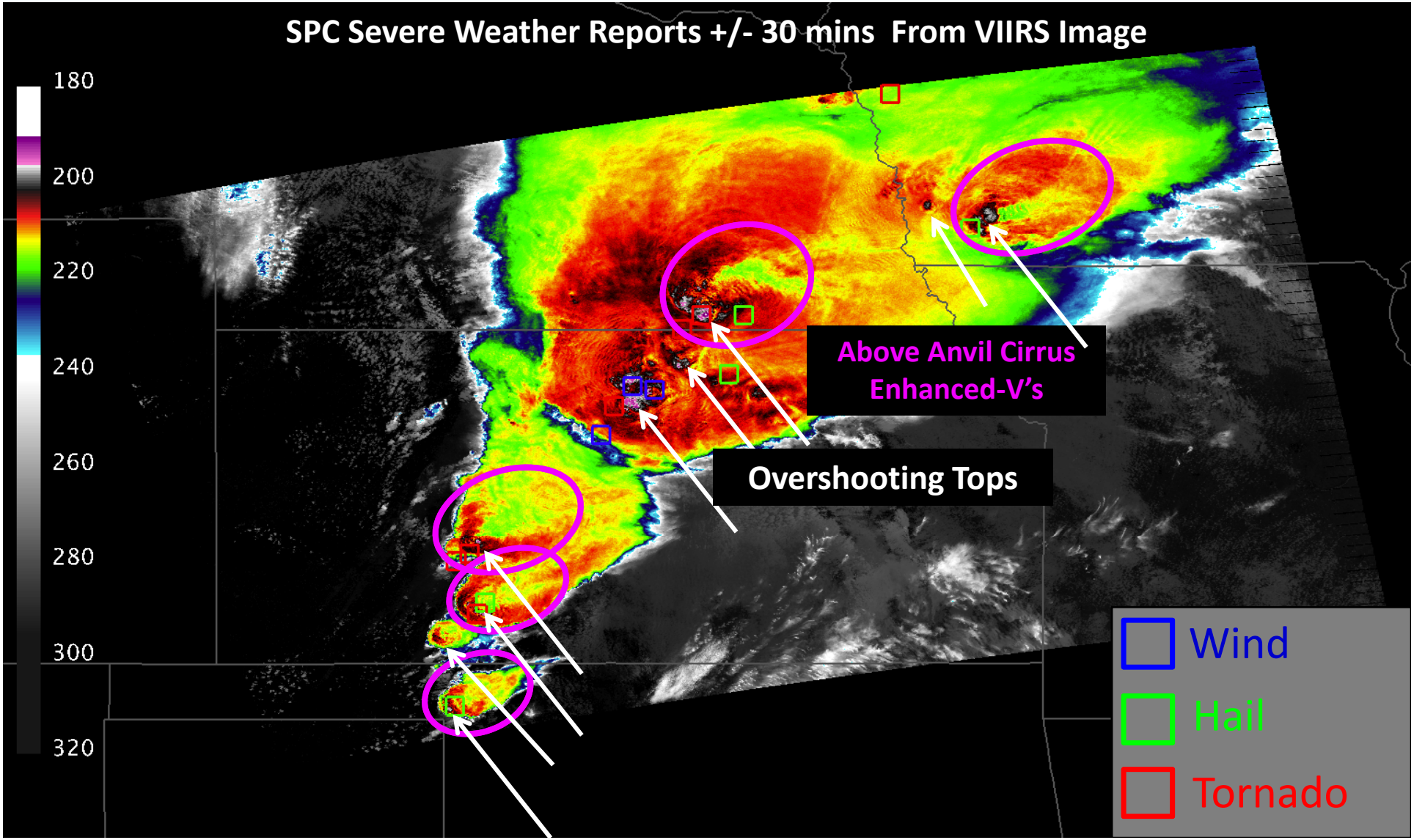
- From 1-minute GOES-14 observations of individual convective storms, we have found that:
  1) OT detections signal the beginning of storm intensification
  2) Rapid cloud top cooling is well correlated with a rapid increase in total lightning
  3) Severe wind and hail was reported shortly after rapid cloud top cooling. Hail formed during the period of intense updraft/cooling and later fell to the surface. Severe downdraft winds occurred with a collapsing echo core

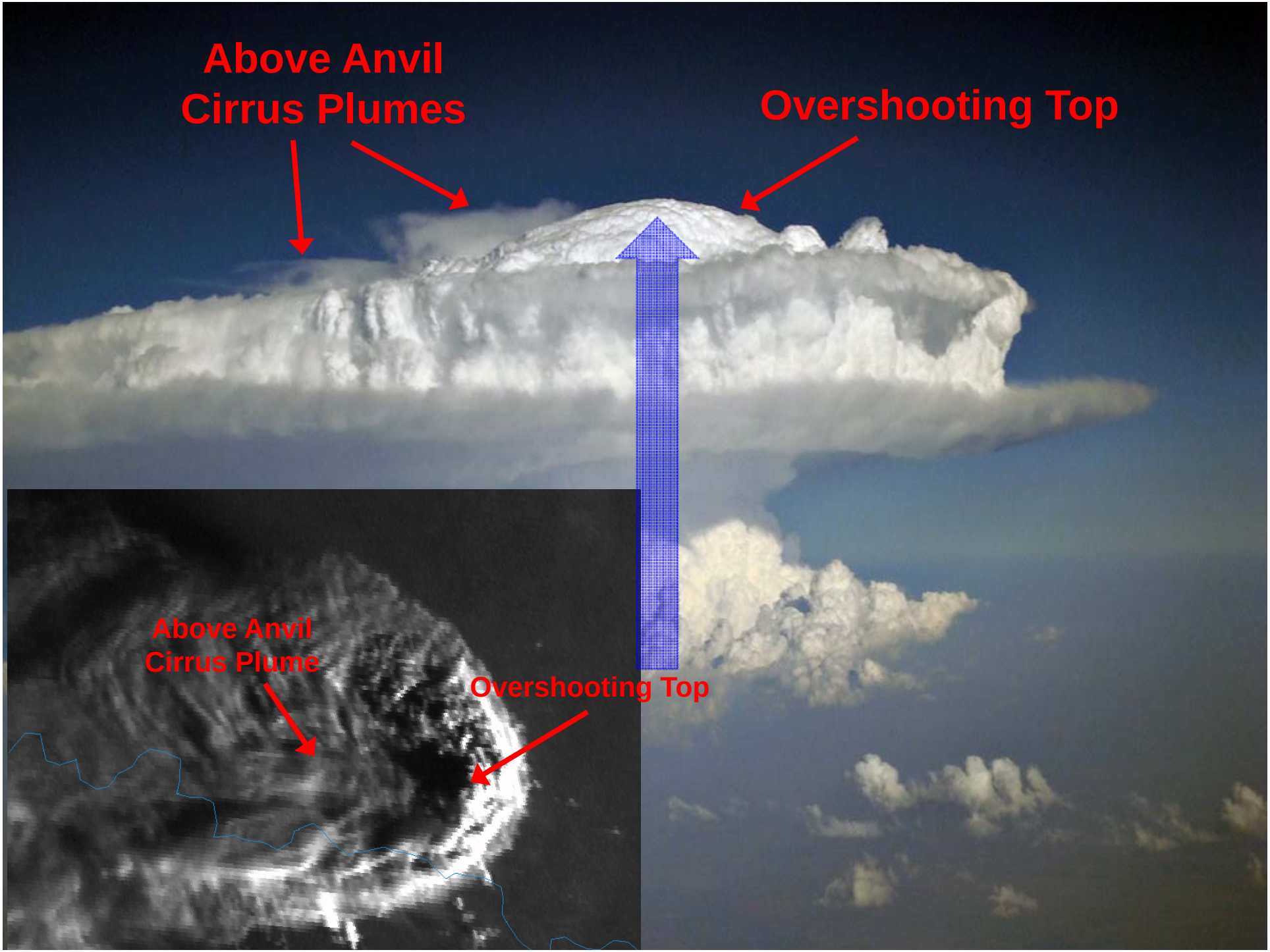
Summary

- Long-term regional databases of OT detections were used to develop:
  1) Robust OT-severe weather relationships
  2) A severe hail risk assessment over Europe, a region where a long-term spatially unbiased severe weather report database is unavailable, thus satellite data and derived products are vital

- Coarse image spatial and temporal resolution impacts objective hazardous storm detection capability, especially prior to GOES-8 in 1994. Degrading LEO imager orbits are also evident prior to 2000.
  - These issues are serious challenges to our ability to derive long-term trends in global severe storm activity

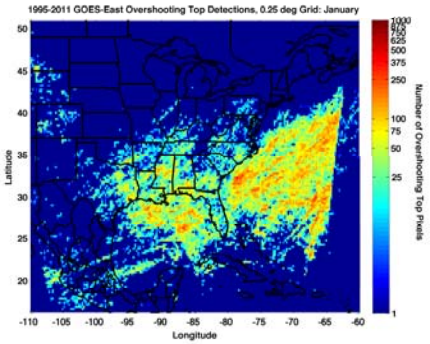
Severe Weather Reports Overlaid Upon 375 m Suomi NPP VIIRS IR Imagery



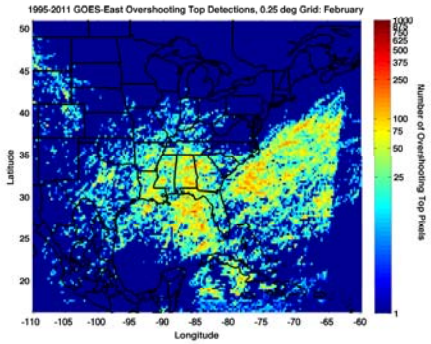

Above Anvil
Cirrus Plumes
Overshooting Top
Above Anvil
Cirrus Plume
Overshooting Top

Monthly GOES OT Detection Distributions: 1995-2011

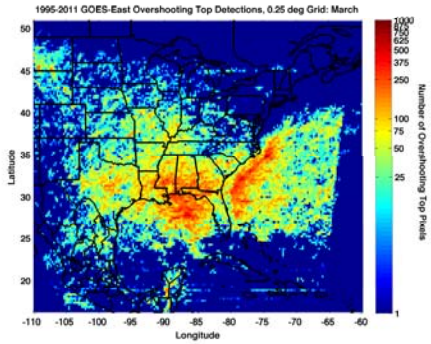
January



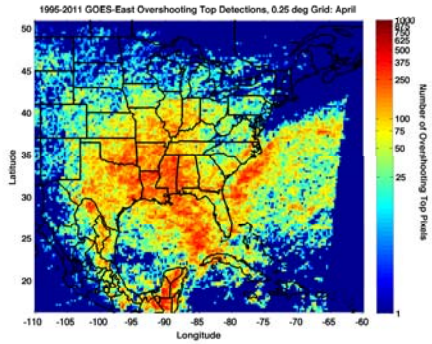
February



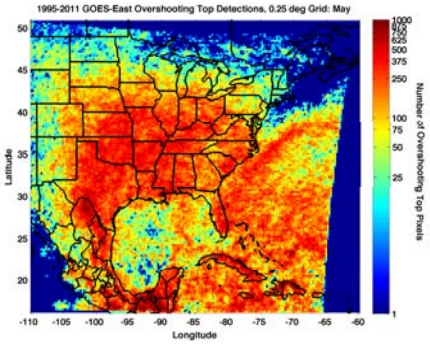
March



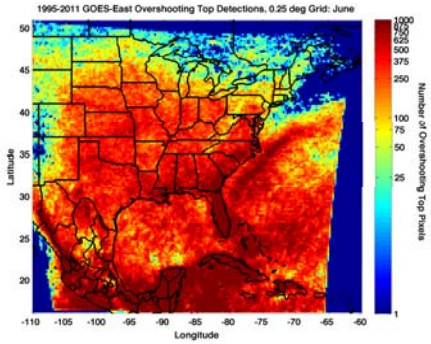
April



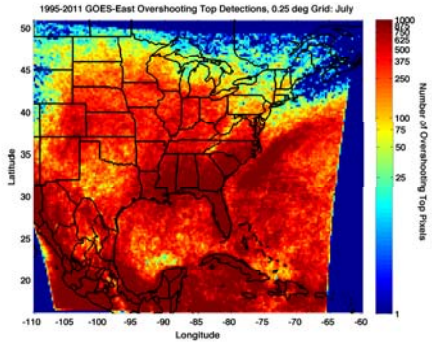
May



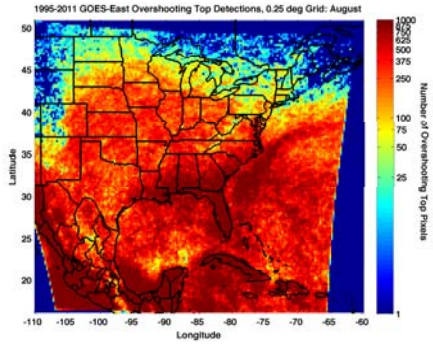
June



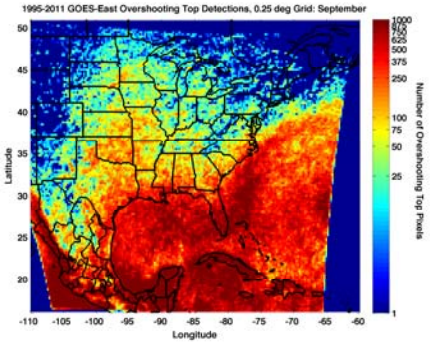
July



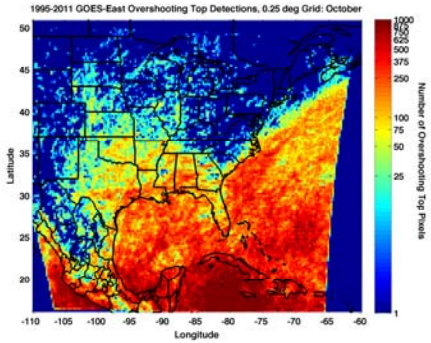
August



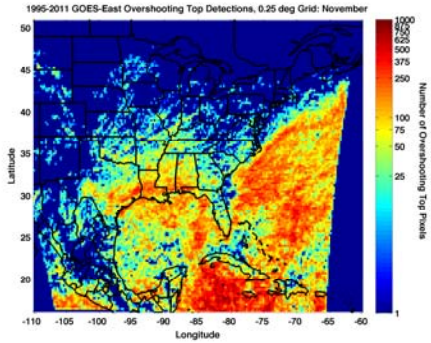
September



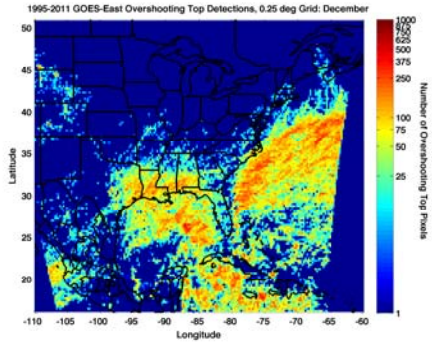
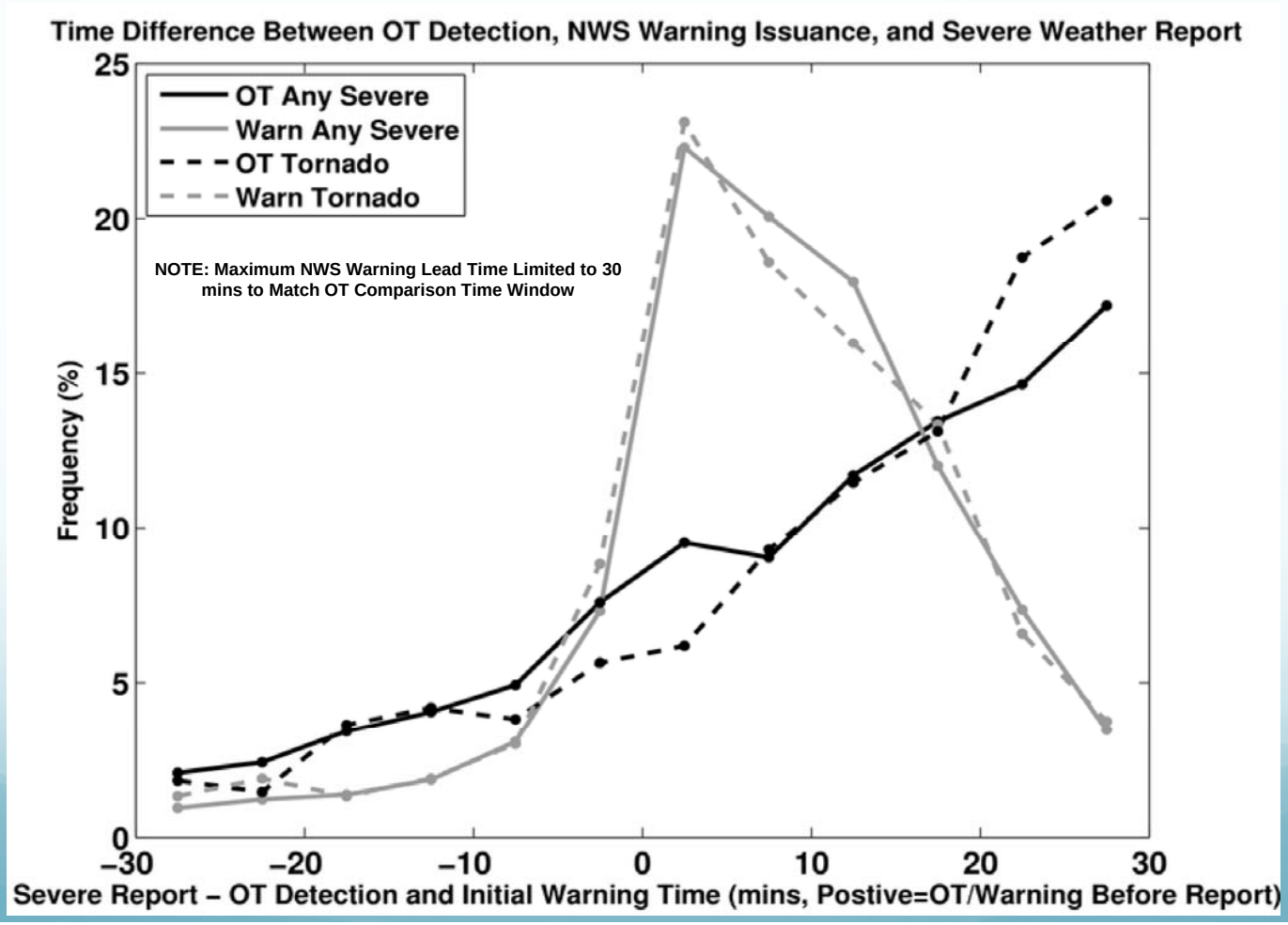
October



November



December



Satellite-Based Overshooting Top Detections Often Precede NWS Severe Weather Warnings By 20 Mins, Providing Valuable Situational Awareness Of A Hazardous Thunderstorm (Dworak et al. WAF, 2012)