Automated Overshooting Cloud Top Detection: Existing Methods and Product Applications

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Talk Outline

- Science community needs for an automated satellite imager-based overshooting top (OT) detection product

- Previous and newly emerging automated OT detection methods

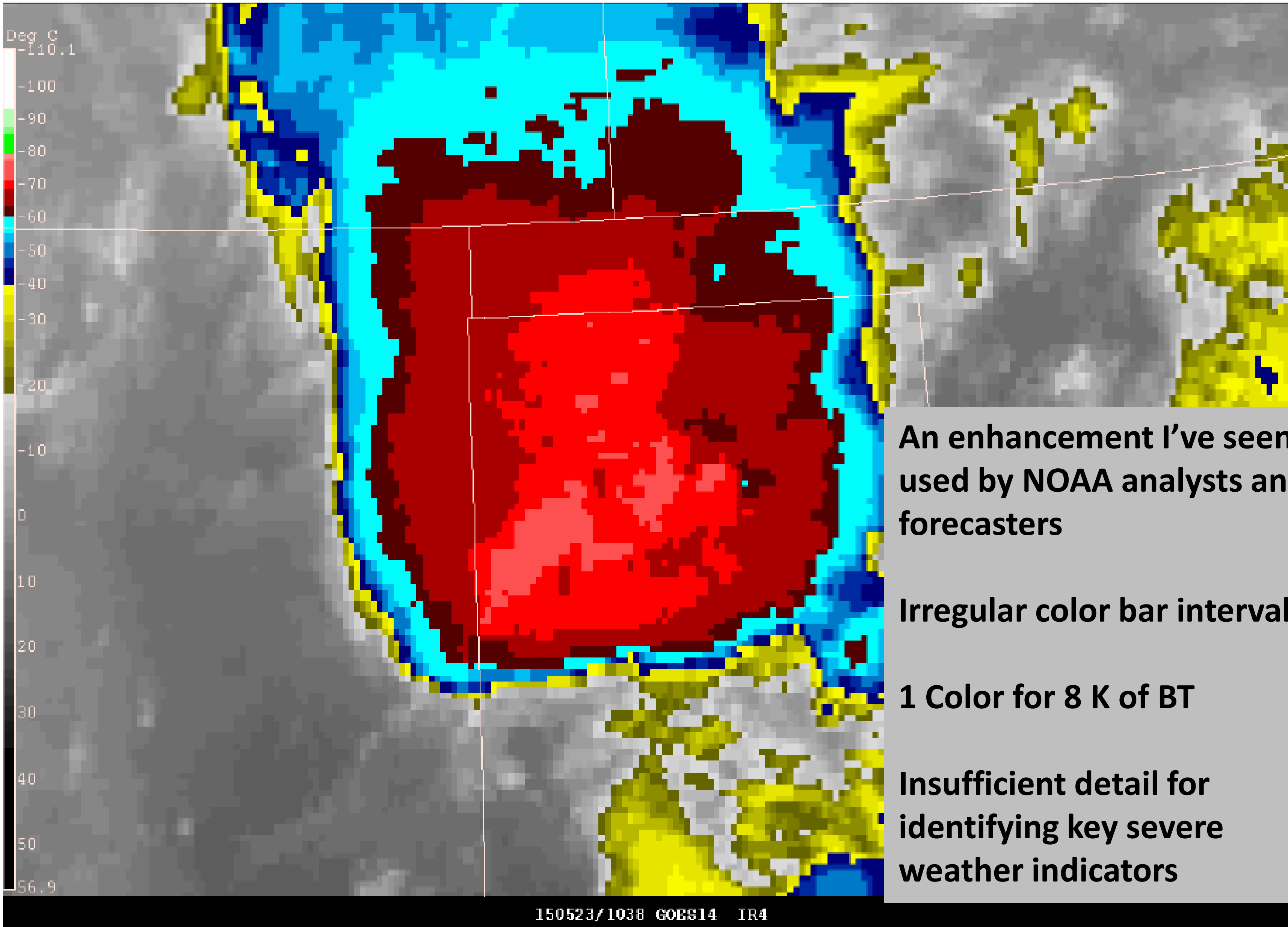
- Weather and climate applications of OT detection products

Why Bother Developing an Automated Satellite-Based OT Detection Algorithm?

FREQUENT QUESTION: If I can see an OT with my eyes in imagery, why do we need an automated OT detection product?

- **Trends in cloud top updraft intensity tell you a lot about the overall health of a storm and locations of possible hazards within a storm**
- As imager temporal resolution increases, one cannot monitor the details within the cloud tops of many storms occurring simultaneously
- Fixed IR color enhancements used in operational forecast centers can hide OT regions
- An OT detection product helps one to quickly identify where the most intense storms are within an image. This is especially useful when one is forecasting over a broad geographic region and cannot look at each and every storm in detail
- The climate community seeks to understand the frequency and location of tropopause penetrating updrafts
- An accurate OT detection algorithm applied to a long-term satellite data record can produce a climatology to determine if hazardous storm activity is changing in response to observed climate change

Example Of An IR Image In A NOAA Display System



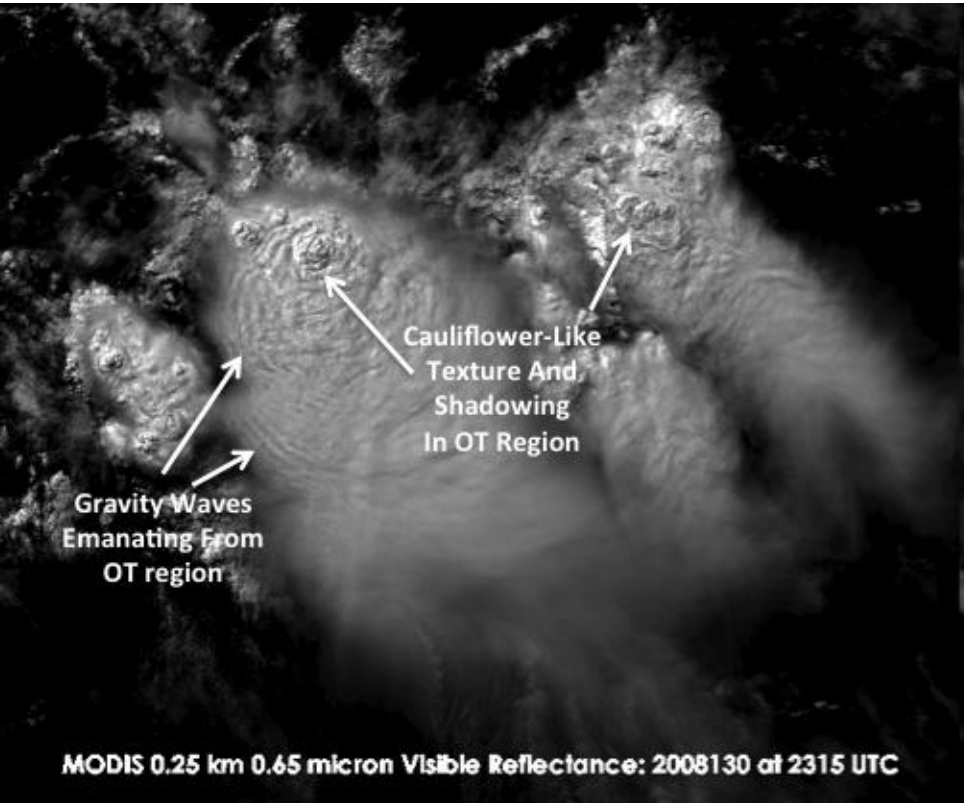
An enhancement I've seen used by NOAA analysts and forecasters

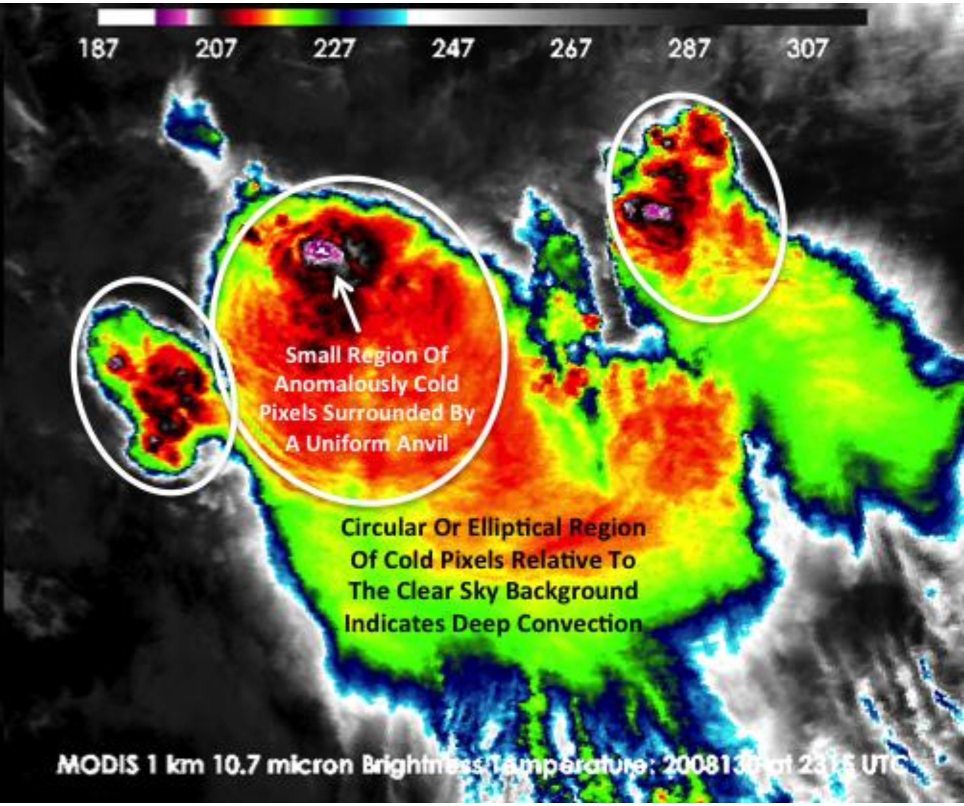
Irregular color bar intervals

1 Color for 8 K of BT

Insufficient detail for identifying key severe weather indicators

How Do Our Human Minds Identify an Overshooting Top in Satellite Imagery?





How Can A Computer Emulate The Human Mind?

- Satellite data is simply a 2-D array of numbers
- What is an "anvil" cloud? Based on reflectance or temperature value? Something more complex?
- How to quantify "texture"?
- ***We need to transform what we take for granted in our minds into computer code that can reliably detect OT features anywhere at any time***

Things To Consider When Developing OT Detection Algorithms or Interpreting Their Output

What creates a "cold spot" in IR satellite imagery?

- An active updraft region with a cloud top above the surrounding anvil
- Cloud from a decayed updraft transported by the anvil-level wind
- Gravity/ship waves, transverse bands, or other turbulent phenomena within an anvil, tropical or mid-latitude cyclone cloud system, mountain ranges, or ordinary "jet stream" cirrus

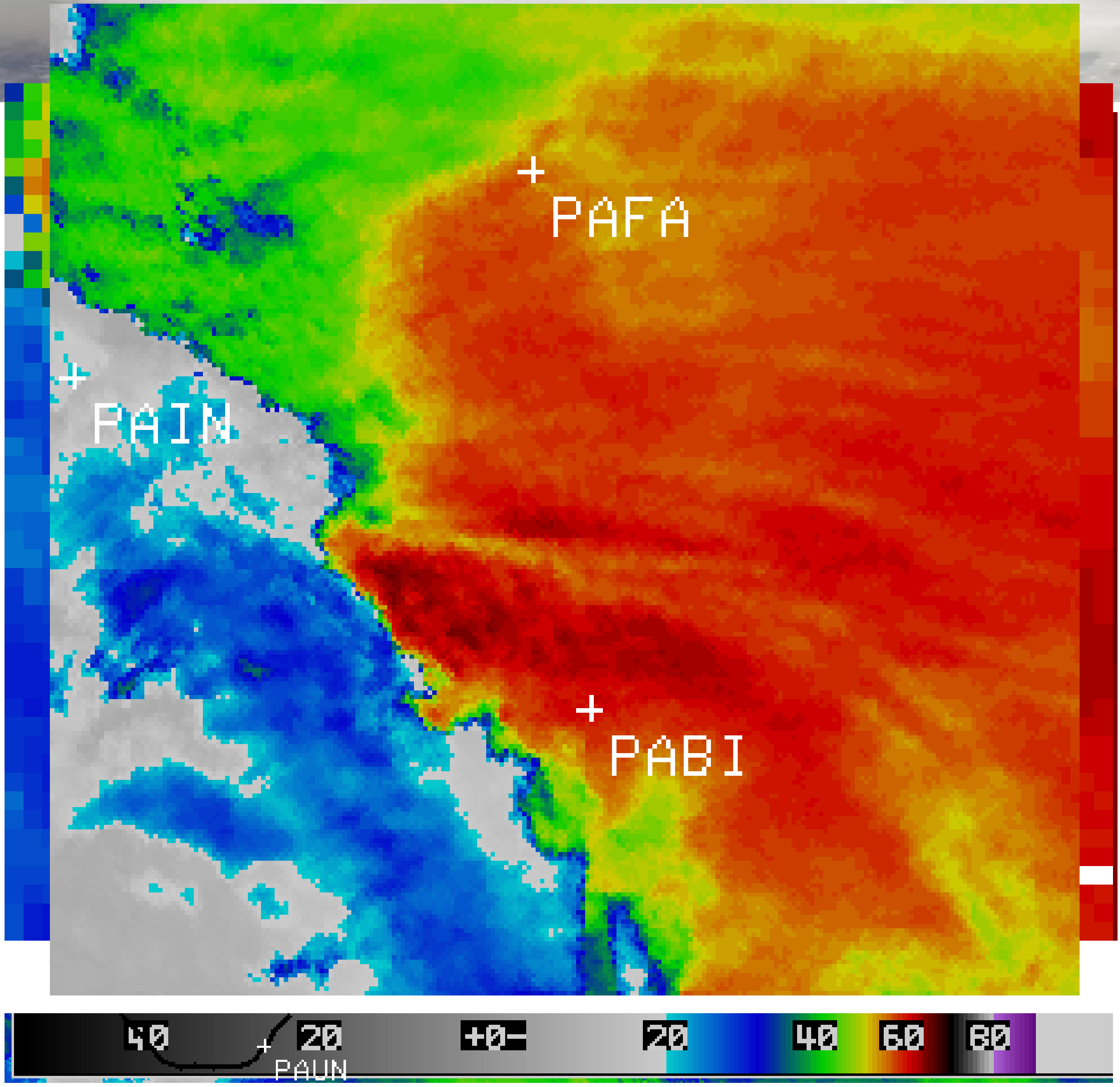
Things To Consider When Developing OT Detection Algorithms or Interpreting Their Output

OT-related cold spots can appear very similar to non-OT cold spots from an automated computer algorithm's perspective

- **You can set your 'cold spot detection' thresholds to be very strict which will help to eliminate false detections**
  - But some true OTs do not produce prominent IR signals and would not be detected with these strict thresholds

- **An IR-only OT detection approach will not effective unless you:**
  1) Take the spatial characteristics of the cloud into account
  2) Analyze visible channel imagery if available to constrain IR OT detections
  3) Bring in NWP model fields to ensure that the feature of interest is indeed overshooting convection

Where's The Severe Storm???

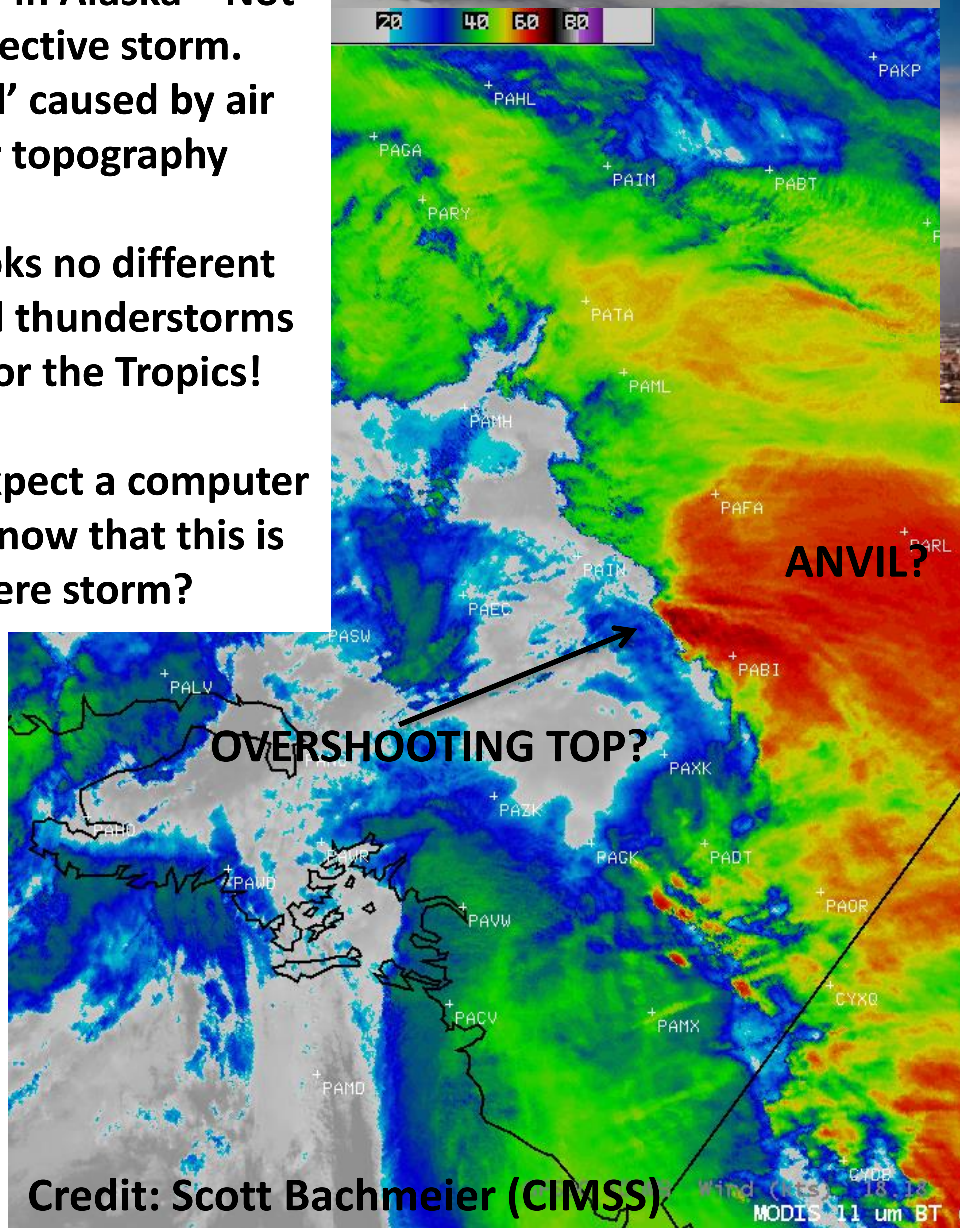


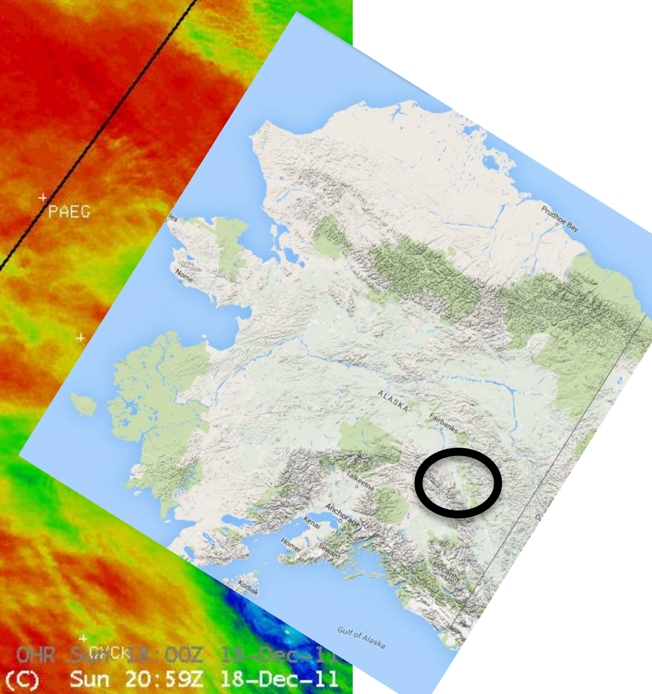
Overshooting Deep Convection???

Mid-December in Alaska = Not a deep convective storm. 'Banner Cloud' caused by air forced over topography

This scene looks no different than many real thunderstorms over Europe or the Tropics!

How can you expect a computer algorithm to know that this is not a severe storm?





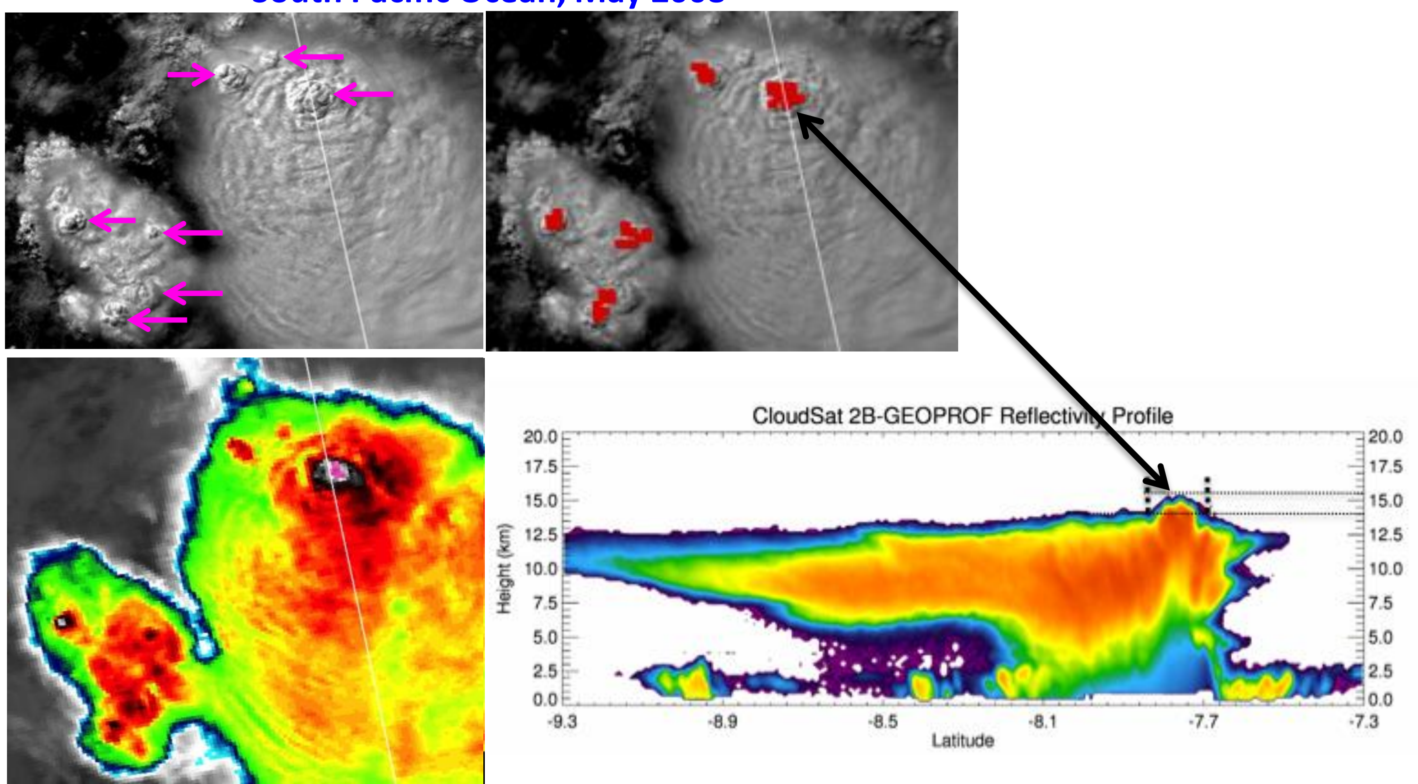
Bedka et al. (2010) IR-Based Overshooting Cloud Top Detection

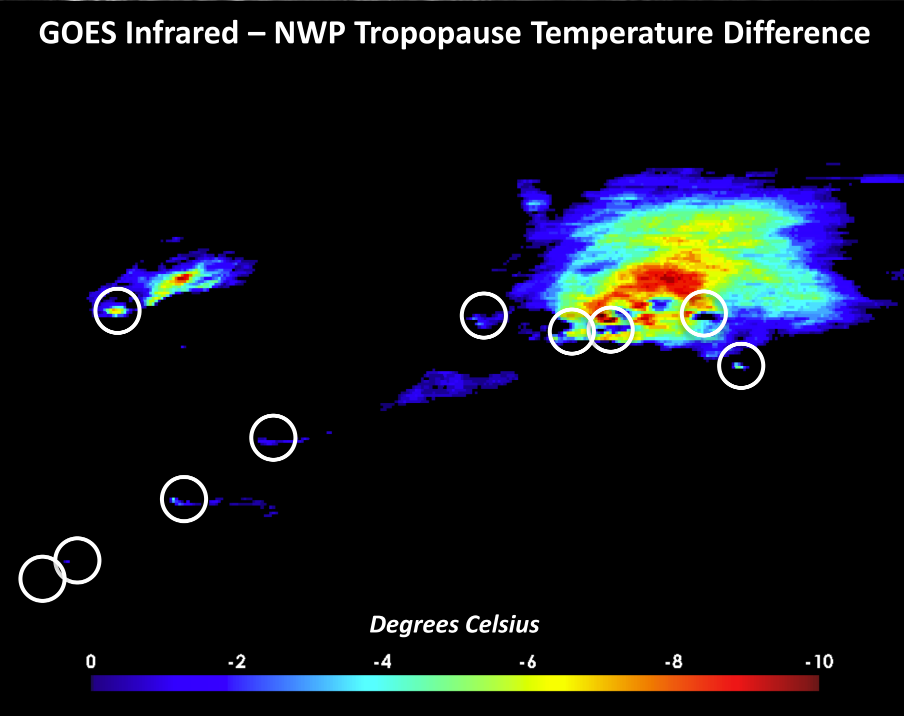
• Hazardous convective storms typically have one or more overshooting top (OT) regions

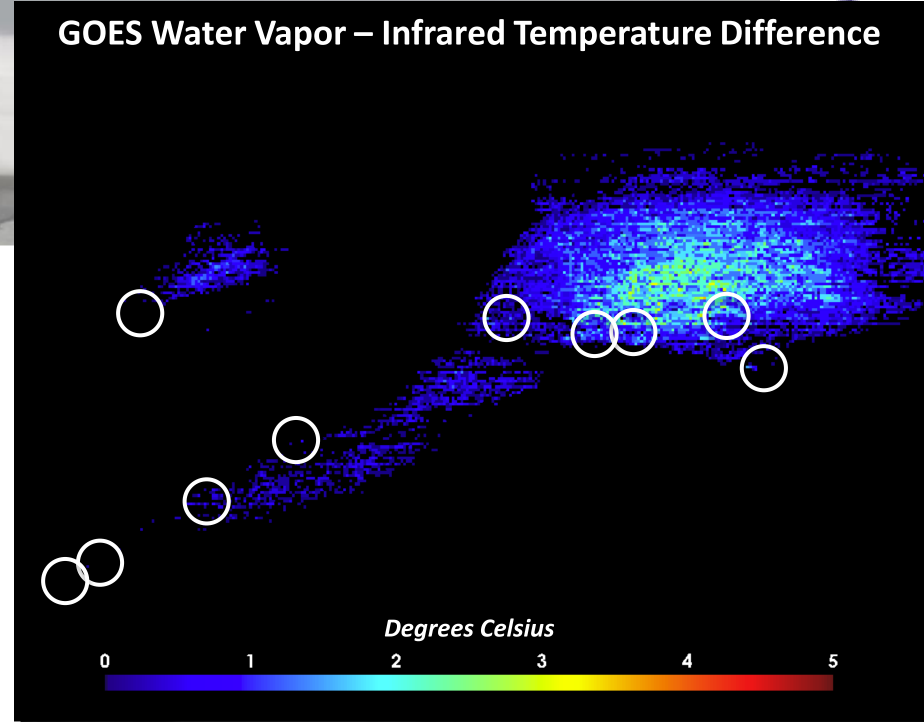
• A satellite-based OT detection method was funded by the NASA Applied Sciences Program and GOES-R ABI Aviation Algorithm Working Group for near real-time aviation safety and weather forecast applications (Bedka et al. 2010-2012)

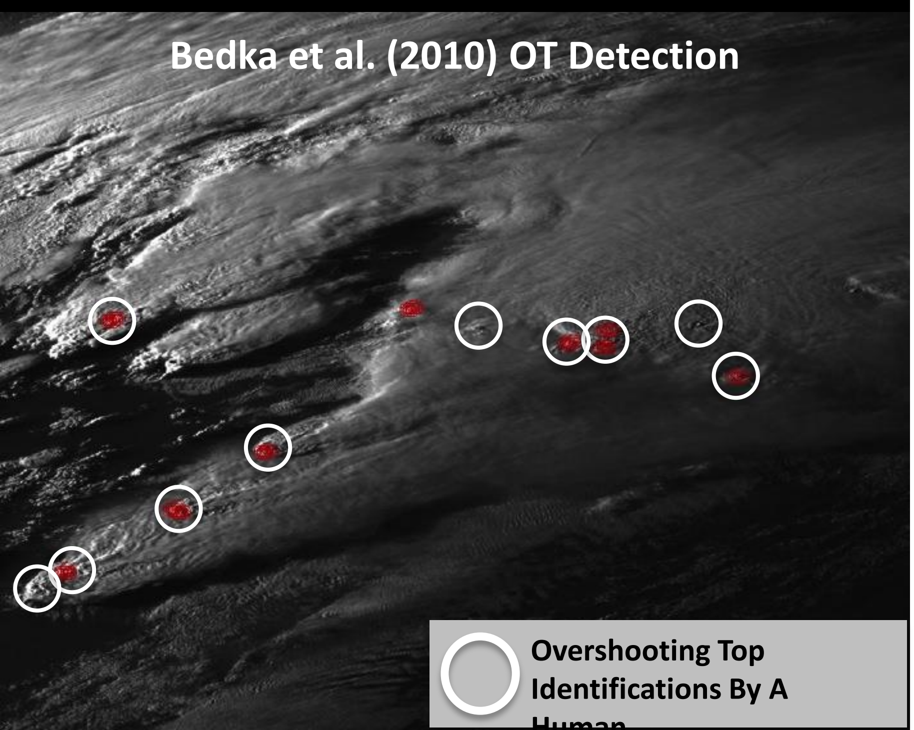
• The method uses spatial analysis and strict thresholding of satellite IR temperature/gradients combined with NWP tropopause tempature to automatically identify individual OT regions at the satellite pixel scale

MODIS 250 m Visible, 1 km IR, and Overshooting Cloud Top Detections
South Pacific Ocean, May 2008







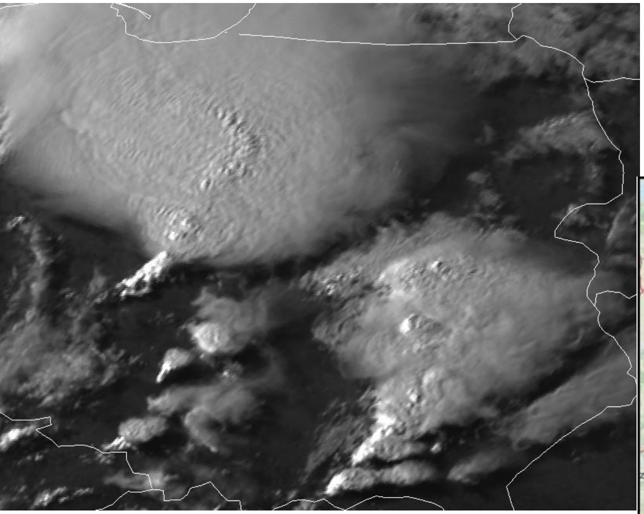


Limitations of Current OT Detection Approaches

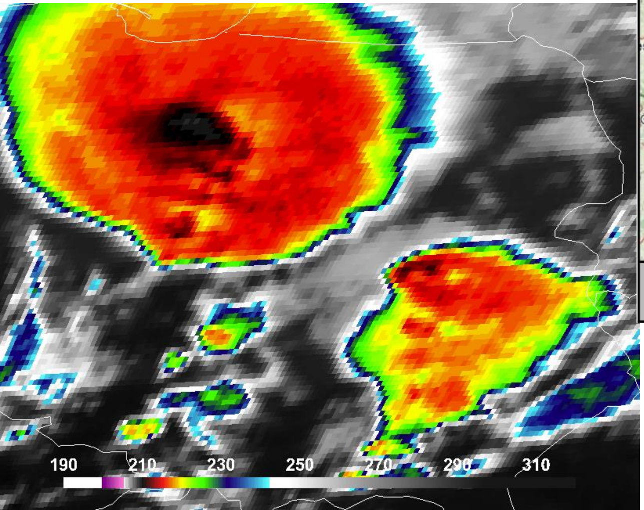
- **All approaches use fixed criteria for binary yes/no OT detection**
- Detection techniques that use water vapor imagery identify large portions of the convective anvil and typically cannot isolate only the OT regions
- IR-Tropopause temp difference can suffer if tropopause analysis is errant and can be biased by image spatial resolution
- Bedka et al (2010) is one of the few approaches that use spatial analysis of the anvil cloud for detection
- No previous approaches use the visible channel which typically provides the clearest indication of an OT due to texture and shadowing

Examples of Current OT Detection Methods

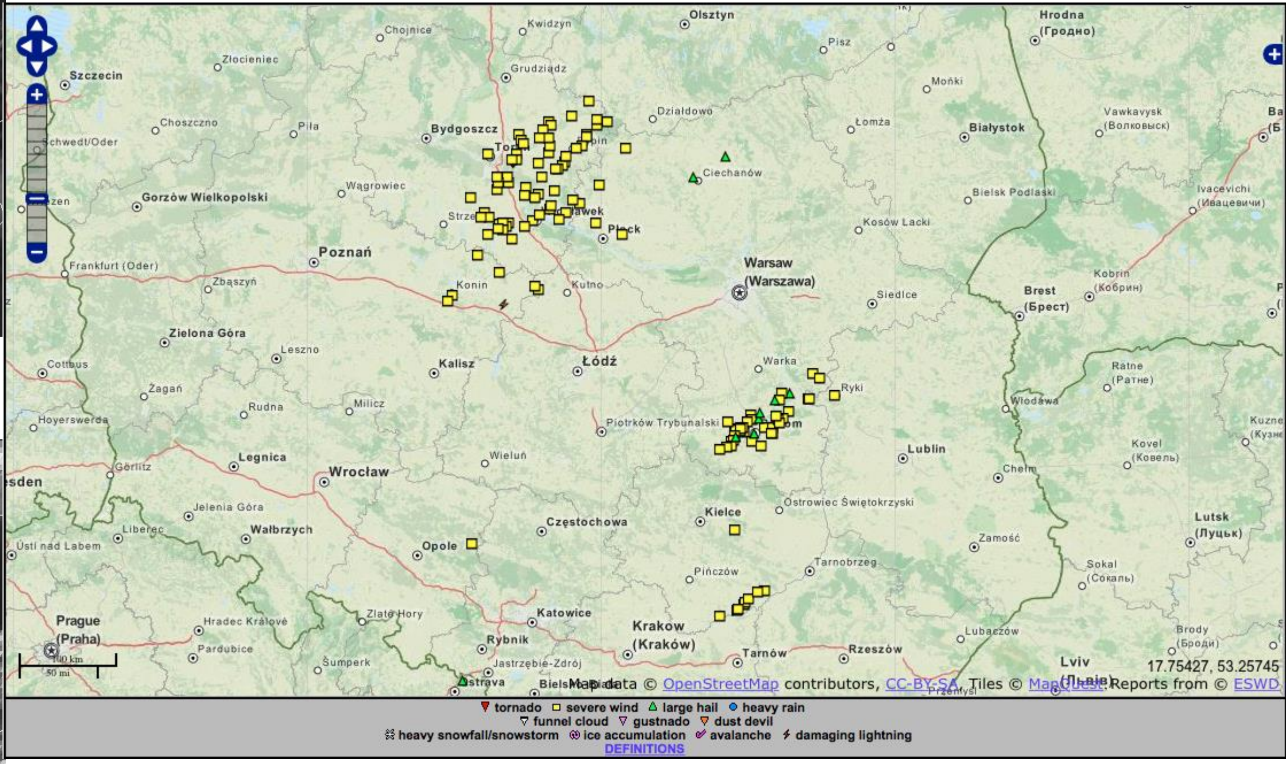
Meteosat-10 HRV: 20 July 2015 1545 UTC



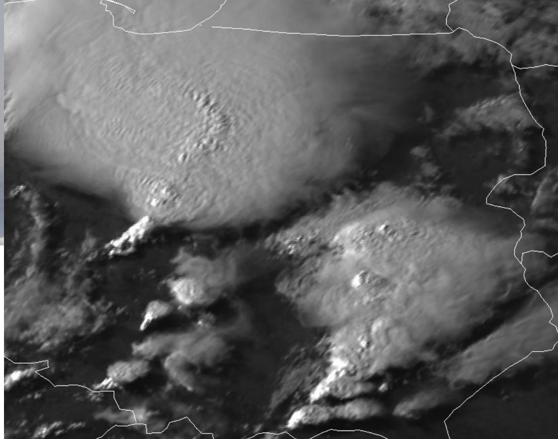
Meteosat-10 IR: 20 July 2015

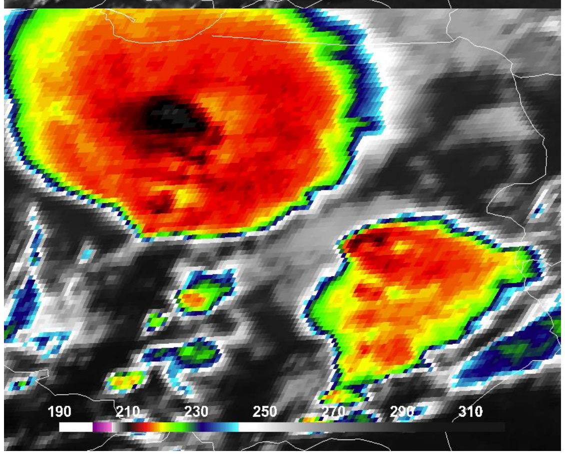


ESWD Severe Weather Reports: 20 July 2015 15-16 UTC

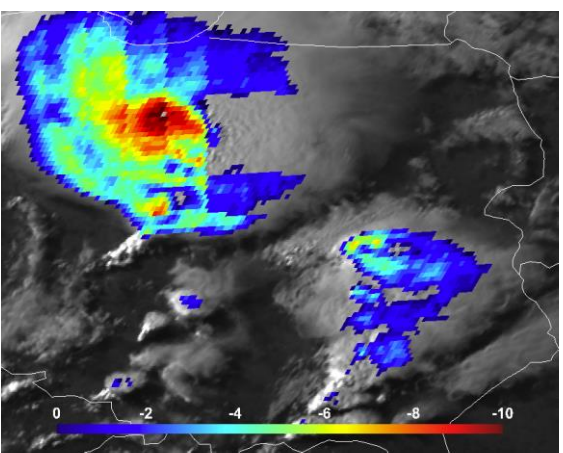


Examples of Current OT Detection Methods



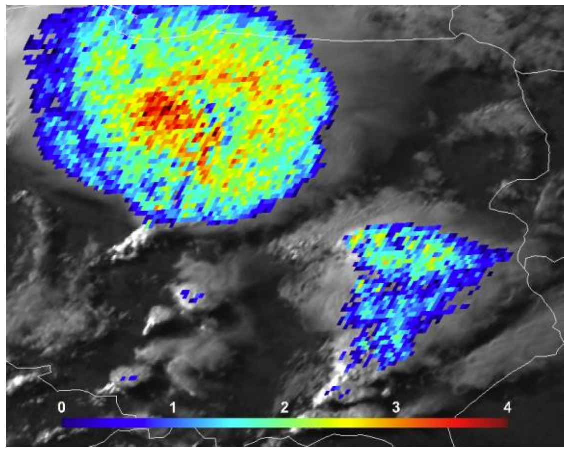


IR BT Colder Than GFS Tropopause

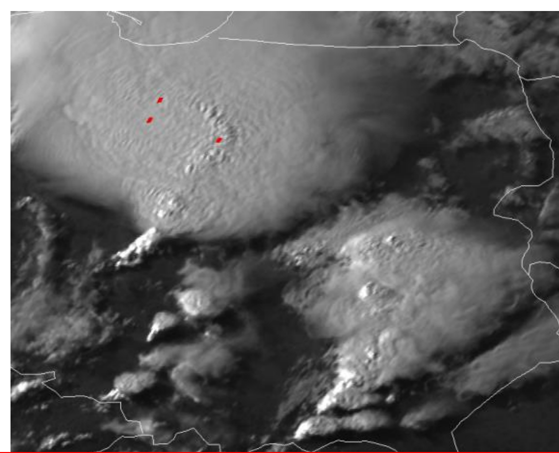


Spectral Differencing Methods

WV-IR BTD

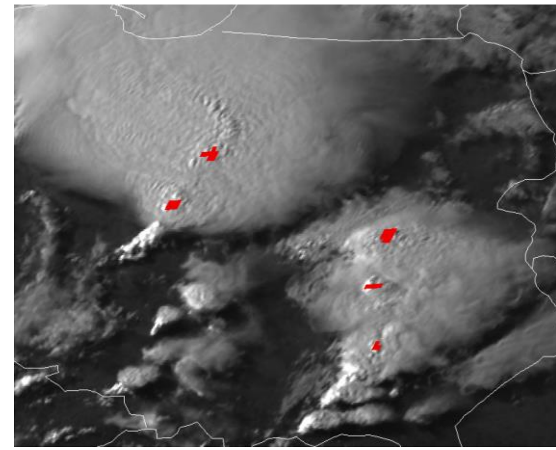


Mikus et al. COMB Method

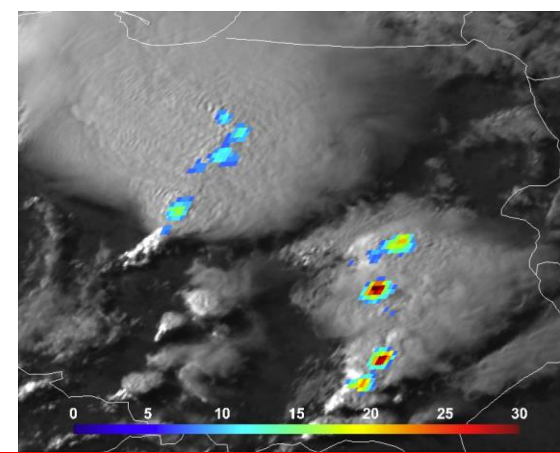


Spatial Analysis Methods

Bedka et al. (2010) IR OT-Anvil BTD

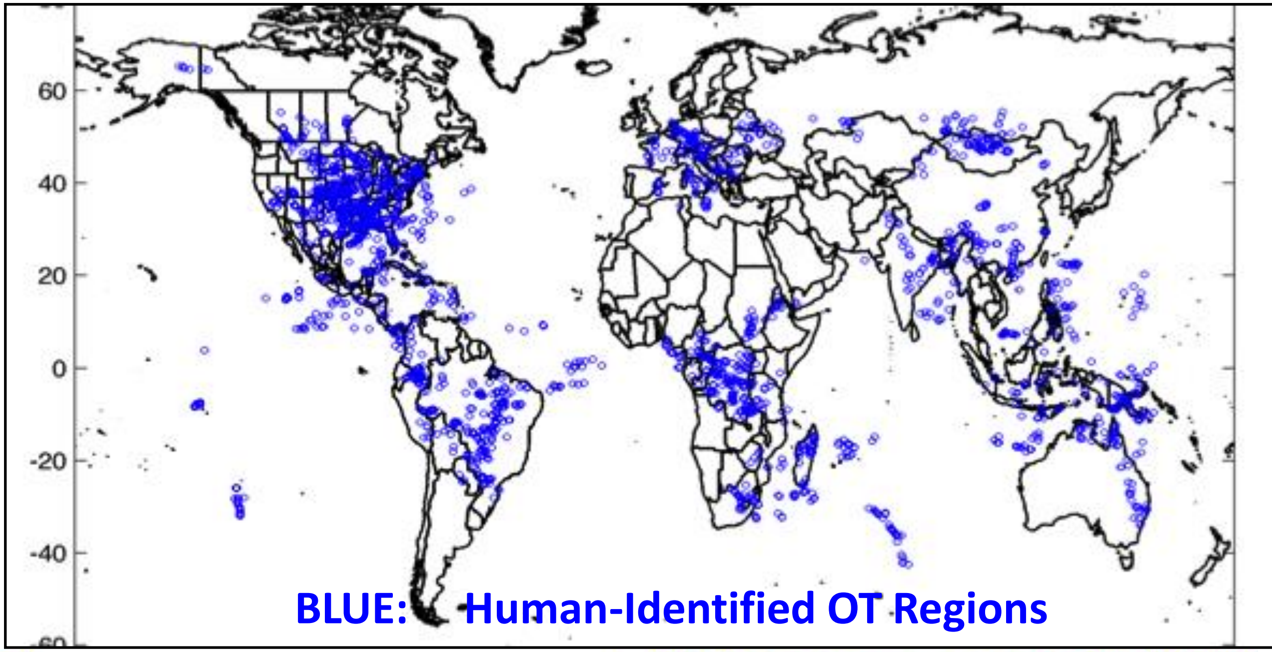


Bedka (2016) Visible Texture Detection

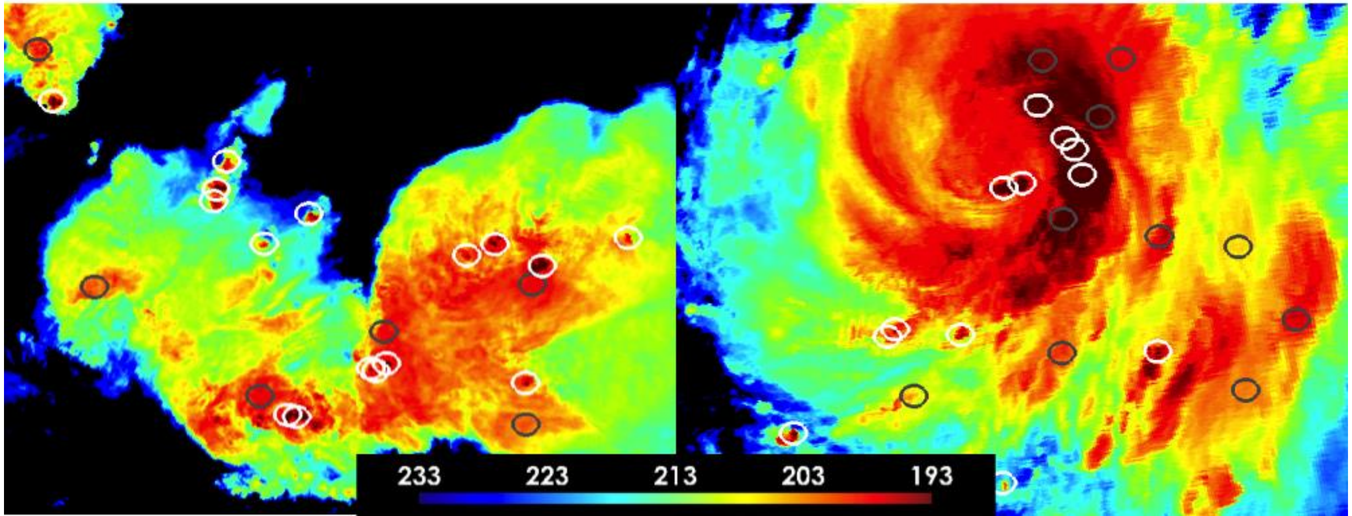


Characteristics of OT and Non-OT Anvil Regions

4000+ OT and Non-OT Anvil Regions Manually Identified in MODIS 0.25 km Visible and 1 km IR Imagery



WHITE Circle = OT Region
GREY Circle = Non-OT Anvil Region



Most Unstable Equilibrium Level

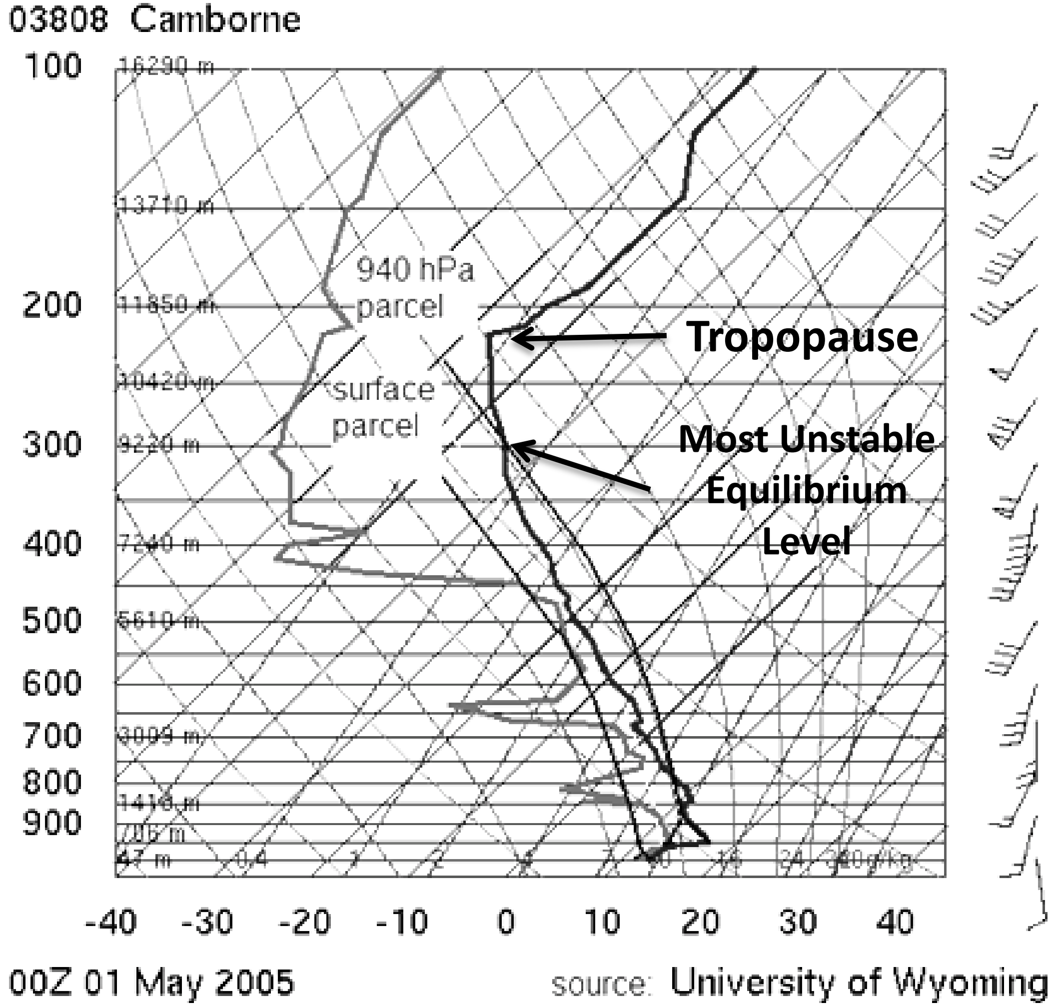
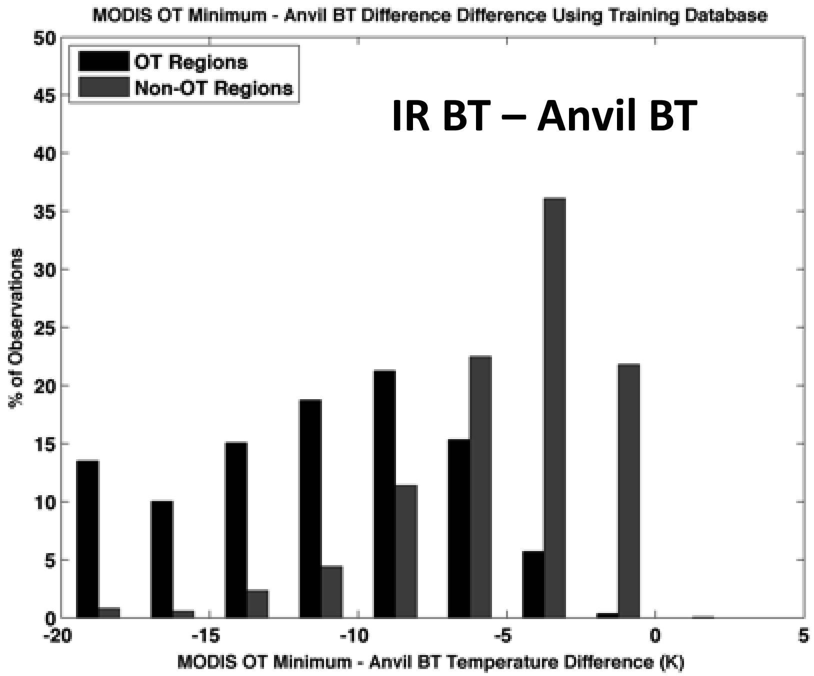
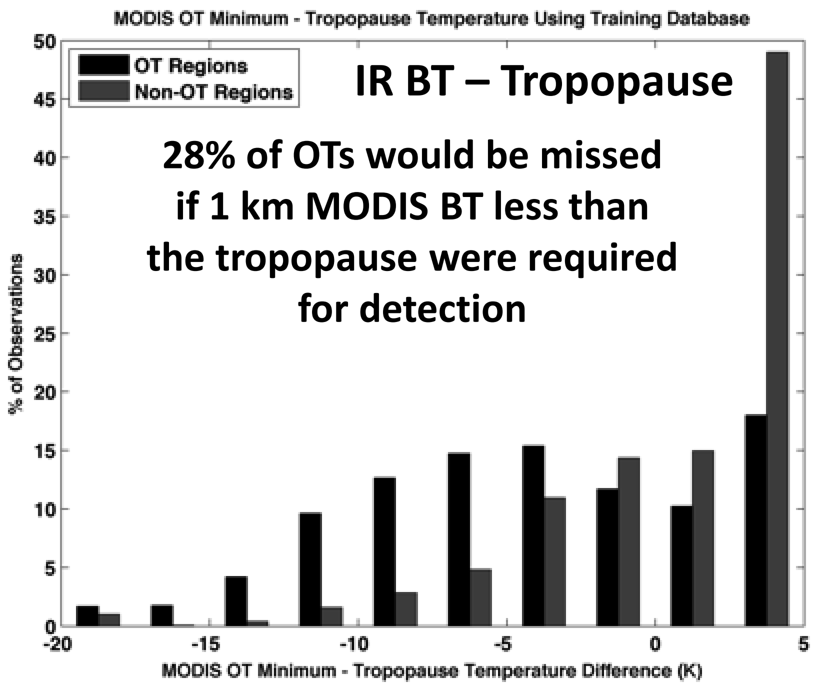


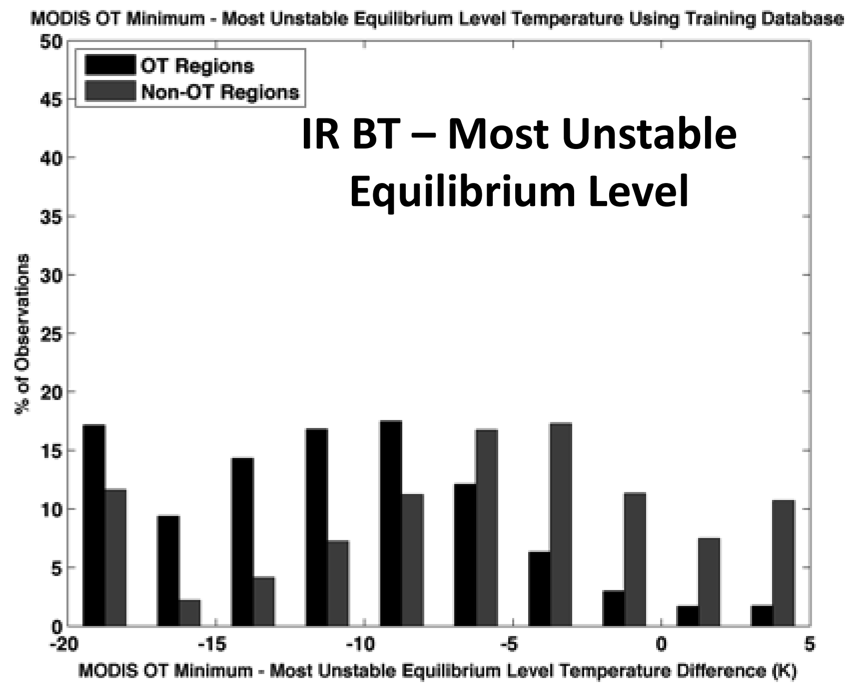
Fig. 1.2. Sounding from Camborne, UK on 1 May 2005 00 UTC, showing no surface CAPE, but a significant amount (~1000 J/kg) of CAPE for a parcel originating from the 940 hPa pressure level. A few hours later, large hail of up to 4 cm diameter fell in the Thames Valley and Chiltern Hills in southern England.

Graphic Courtesy of ESTOFEX

Histograms of OT and Non-OT Region Characteristics







QUESTIONS???

Thoughts on Development of an Optimal Satellite-Based Hazardous Convective Storm Detection Algorithm

- **An optimal framework for detecting hazardous storms and OTs should have many of the following characteristics:**

1) Mimic the process used by the human mind to identify hazardous storms
2) Dynamic, no fixed regional/seasonal thresholds
3) Probabilistic to reflect uncertainty in detection
4) Ability to seamlessly process long-term data record of global LEO and GEO imagery
5) Account for and quantify detection biases arising from variations in view angle, spatial resolution, and changes in satellites over time
6) Incorporate numerical weather analysis fields to adjust detection confidence and estimate storm severity based on storm environment

CURRENT EFFORT: Develop improved OT detection algorithm that satisfies most of these requirements, supported by the GOES-R program (Bedka and Khlopenkov (JAMC, In Review))

Probabilistic Overshooting Cloud Top Detection

GOAL: Mimic the human OT identification process using IR & visible imagery and NWP data within an automated computer algorithm

Satellite IR and Visible OT Indicators Derived Via Pattern Recognition
+ NWP Most Unstable Equilibrium and Tropopause Temperature Fields

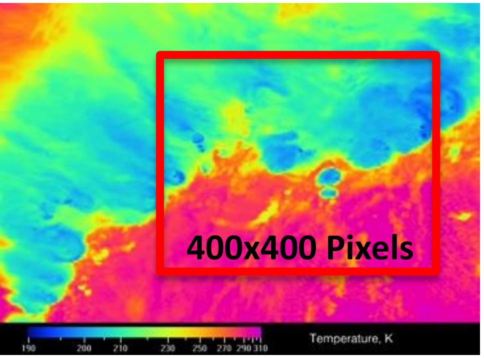
Large Training Database of Satellite + NWP Fields For Both OT and Non-OT Anvil Regions

Logistic Regression Model Used To Discriminate Between The OT and Non-OT Anvil Populations

OT Probability Product

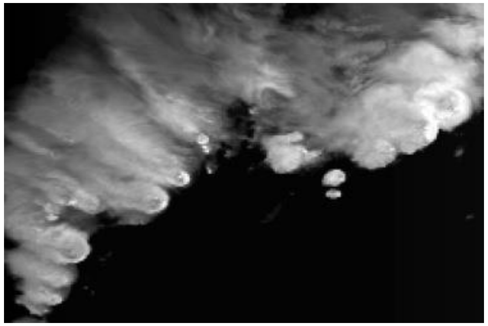
IR-Based Pattern Recognition Analysis

Input MODIS IR Temperature (BT) Image, 6 May 2007, 1925 UTC

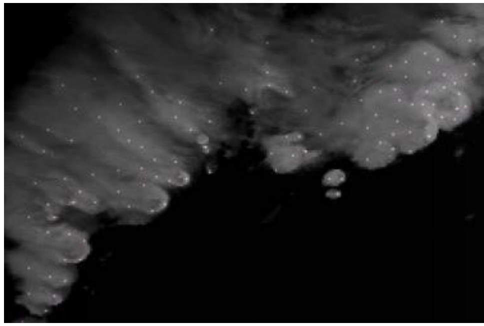


BT Score: $\mathrm{BTscore} = \left(T_{avg} - T\right)^{0.7}\left(255 - T\right)^{1.3}/16 \quad + 2\cdot\sigma(T)$

Used to eliminate need for a fixed BT threshold, enhance deep convection, and separate likely convective from non-convective clouds



Identify Local BT Score Maxima As Initial OT Candidates



Perform Spatial Analysis Of The BT Score Field Around Initial OT Candidates To Map Convective Anvils

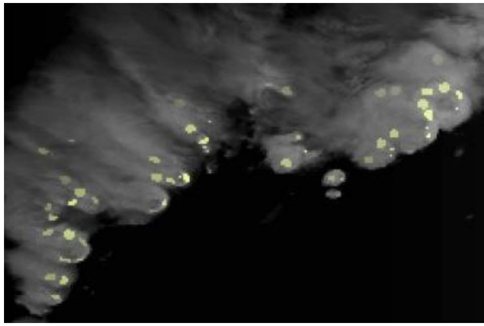
Pattern recognition used to ensure that the region being analyzed is within deep convection and 2) the feature of interest has a shape and prominence typical of OT regions

Pattern recognition uses

- OT shape correlation
- BT Score prominence relative to surrounding anvil
- Anvil flatness, roundness, and edge sharpness

The net result is a cumulative rating obtained for each possible OT region. Pixels with a non-zero rating are considered final "OT Candidate" regions

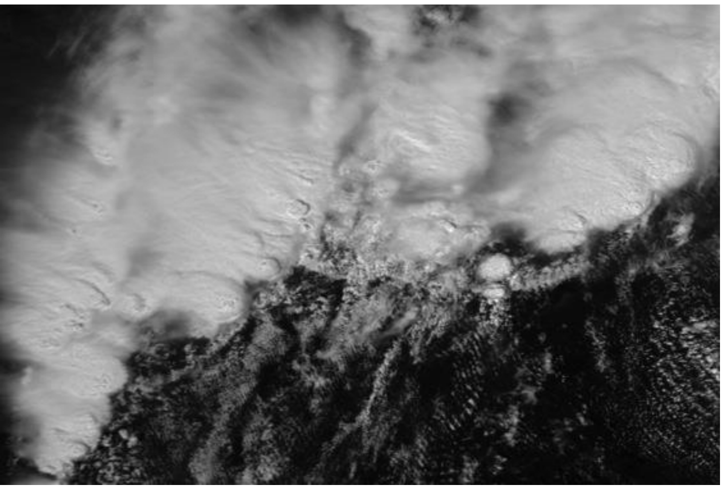
Final OT Candidate Regions Based on IR Analysis



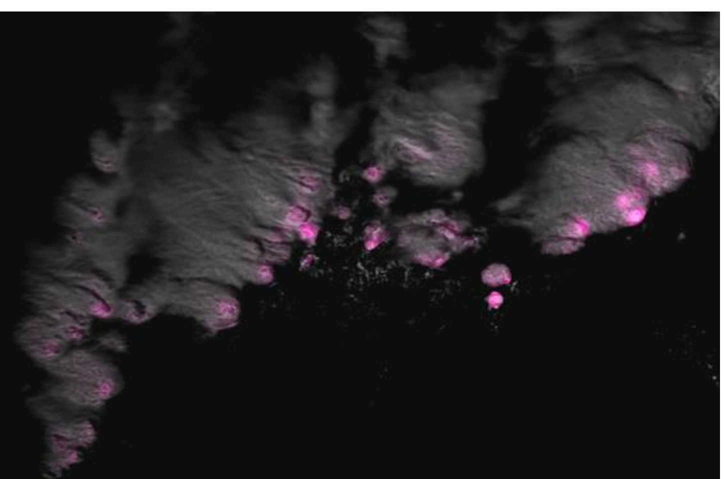
Visible Channel Analysis

Use a combination of statistical, spectral, and spatial analyses to identify anvils and quantify the degree of "texture" and shadowing present in a visible image associated with OT regions and gravity waves

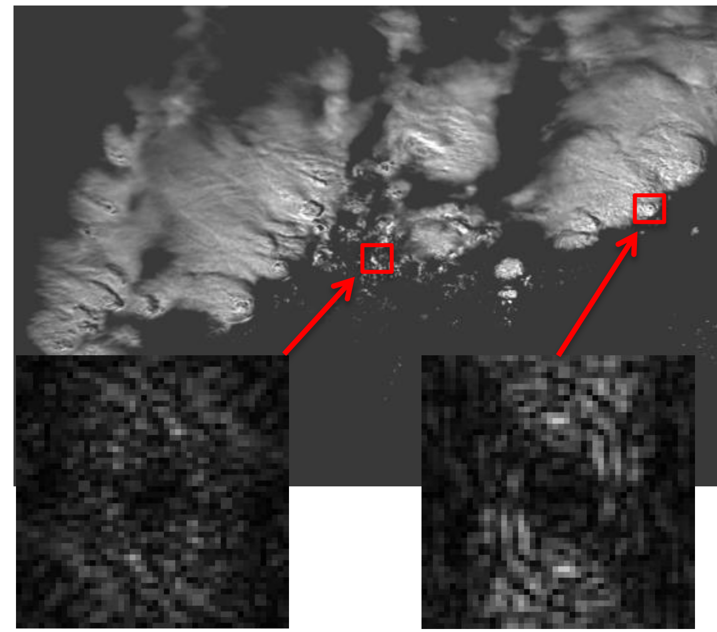
Input MODIS 1 km Visible Image



Final OT Candidate Regions Based on Visible Analysis



Statistical and Spectral Analysis To Identify Convective Anvils, OTs, and Nearby Gravity Waves



Fourier frequency spectrum of an area with random spatial variability.

No ring pattern in the spectrum

Fourier frequency spectrum of a typical OT region

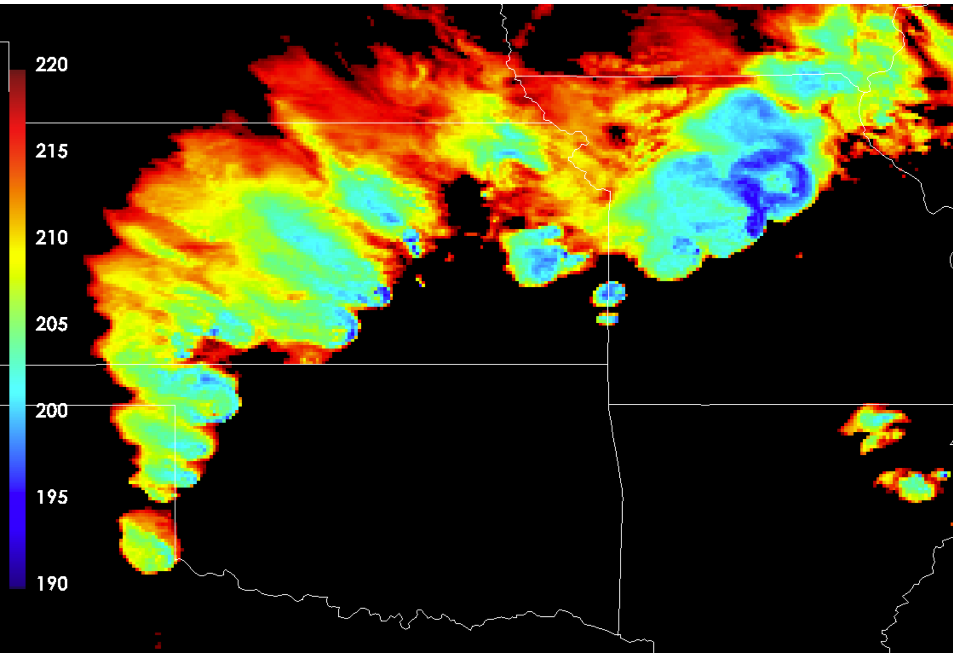
Ring fragments in the spectrum can be identified

Automated Shadow Detection Method Also Implemented

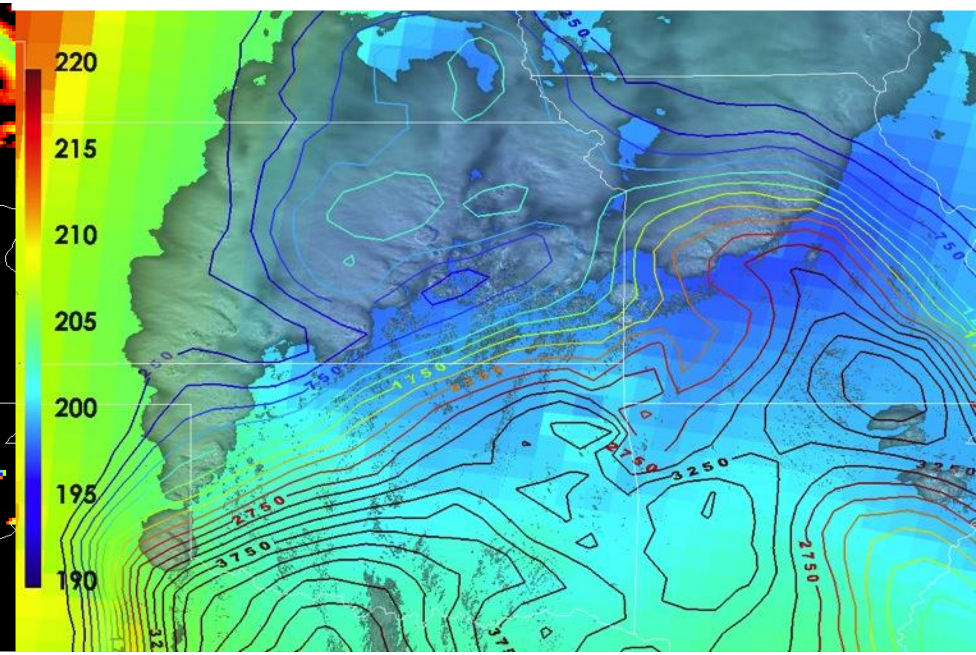
Automated Shadow Detection Method Also Implemented

Infrared Comparisons With Numerical Model Weather Analysis Fields

Input MODIS Infrared Image



MODIS Visible Overlaid With NWP Tropopause Temp and CAPE Contours



- A set of NWP- and Imager-based parameters were evaluated for statistical significance in OT detection using logistic regression

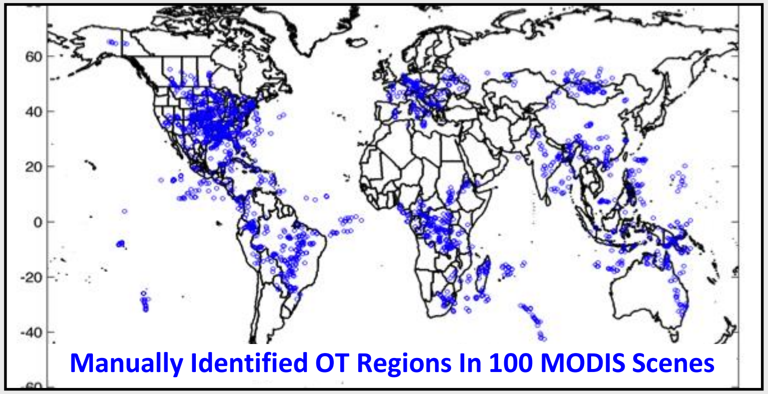
<u>Significant parameters for OT discrimination at the 99+% confidence level</u>

1) **Satellite IR – Lapse-Rate Tropopause Temperature Difference**
2) **Satellite IR– Most Unstable Level of Neutral Buoyancy Temperature Difference**
3) **OT-Anvil Mean Temperature difference (~75% contribution)**

Logistic Regression and Final OT Detection Product

A database of ~2000 OT events were manually identified in 100 Aqua MODIS 250 m visible images.

A similar number of non-OT anvil regions were also identified. This database is used to train and validate a logistic regression model to assign high detection probability to OT-like features

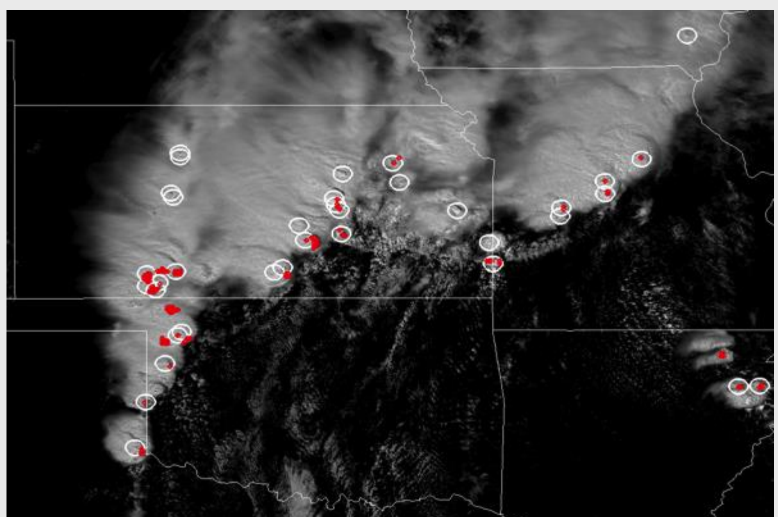


Regression Result $= W_0 + W_1*(\text{OT-Mean Anvil IR BT}) + W_2*(\text{IR BT} - \text{Tropopause Temp}) + W_3*(\text{IR BT} - \text{MU LNB Temp})$

OT Probability

$$\text{OT Probability} = \frac{1}{(1+\exp(-1*\text{Regression Result}))}$$

OT Probability ≥ 0.5 (Red) Atop Human-Identified OTs (White Circles) and 250 m Visible Imagery



NASA LaRC OT Detection Product Suite

A set of products are provided to allow a user to customize the products to best meet their needs and for use in a variety of weather and climate analysis applications

1) IR OT Detection Rating = Quantifies how much a region ‘looks like’ an OT

2) IR-Based Anvil Cloud Detection

3) OT – Anvil Mean BT Difference

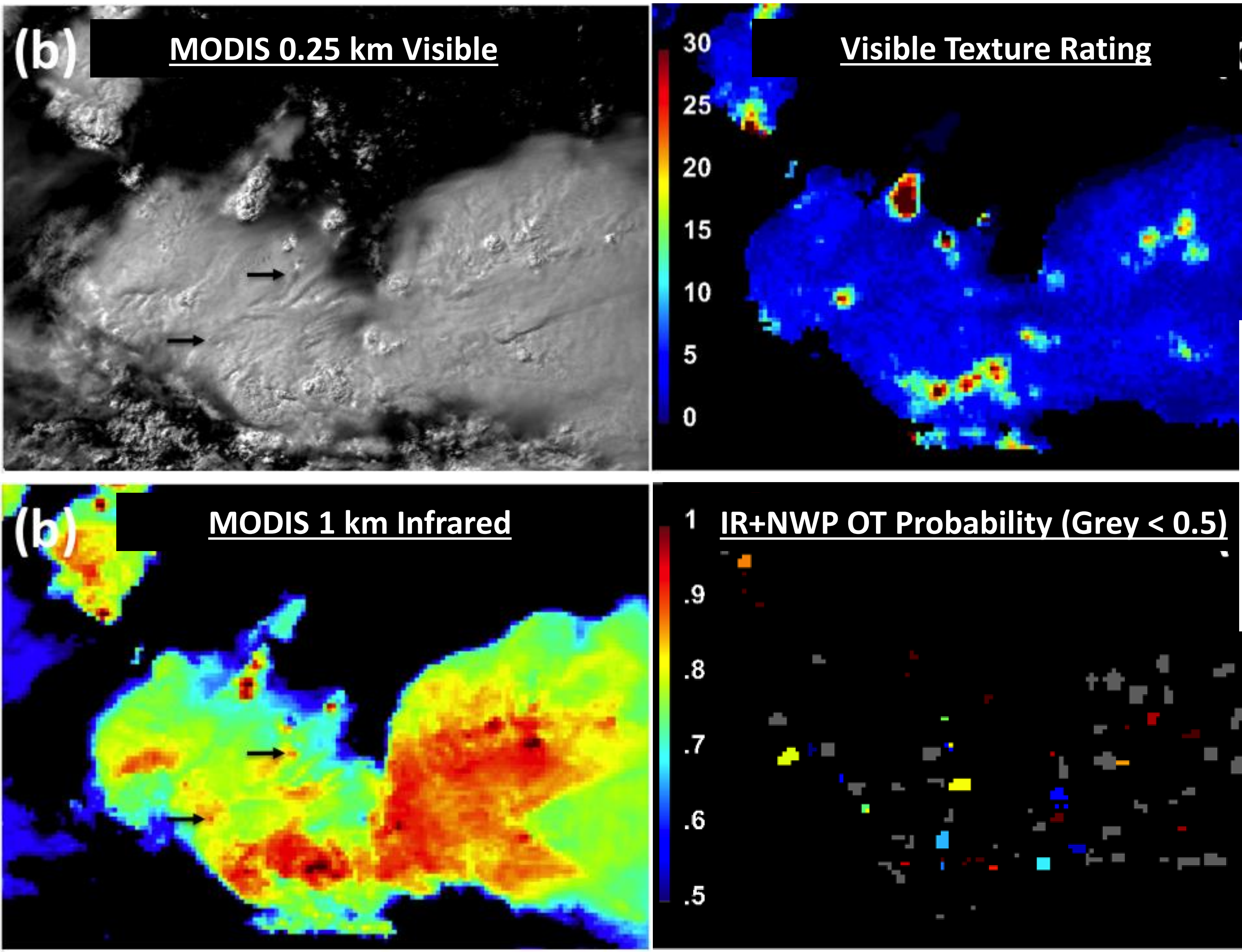
4) IR/NWP-Based OT Probability

5) Tropopause and Most Unstable Equilibrium Level Temperatures

6) Visible Texture Detection Rating

1) OT Height, Pressure, and Potential Temperature

Automated Overshooting Cloud Top Detection
Aqua MODIS, Southern Brazil, 8 March 2009 at 1735 UTC



OT Detection Accuracy

OT Probability > 0.7

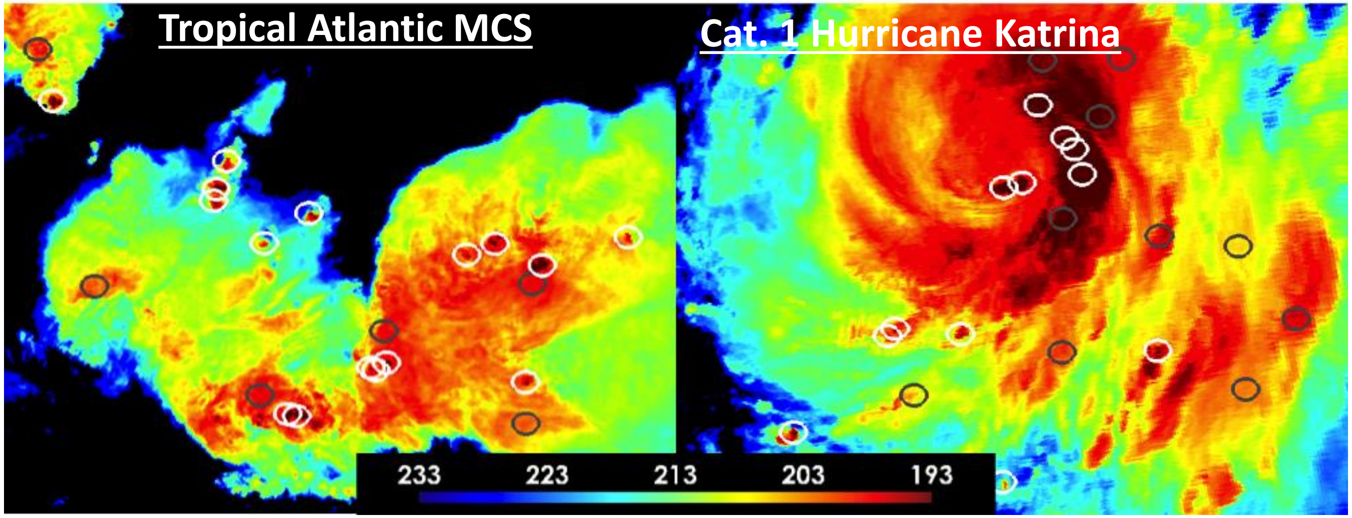
69% POD 18% FAR

OT Probability > 0.7 and Visible Texture Detection

52% POD 1% FAR

OT Detection Validation

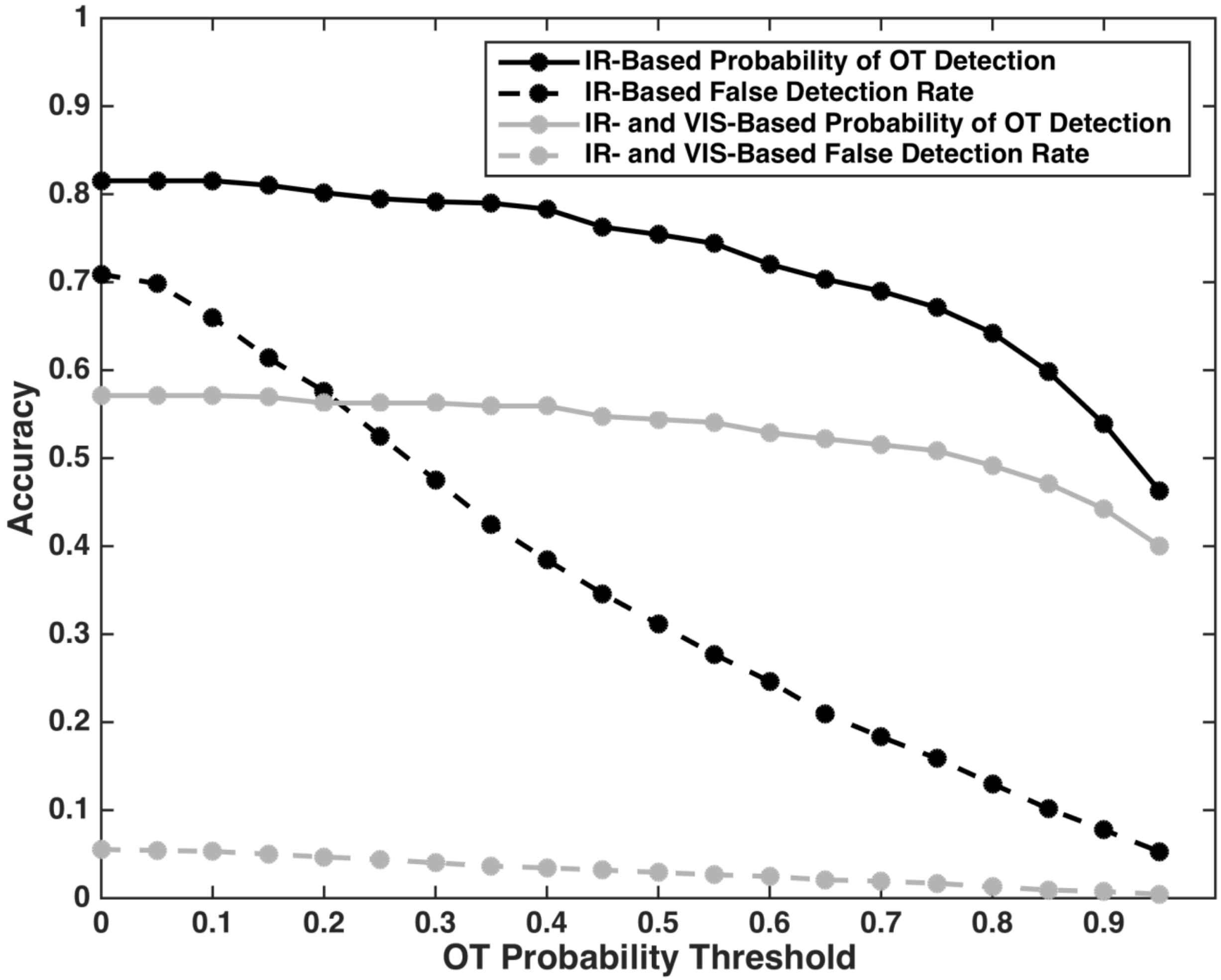
How Well Can The Algorithm Discriminate Between Human-Identified OT Regions (White Circles) and Non-OT Regions (Grey Circles)?



Number of OT Regions 809	**Number of Non-OT Regions 615**
Number of OT Regions With OT Probability ≥ 0.5 593 (41.6%)	Number of Non-OT Regions With OT Probability ≥ 0.5 58 (4.1%)
Number OT Regions With OT Probability < 0.5 or Lack of OT Detection 216 (15.2%)	Number of Non-OT Regions With OT Probability < 0.5 or Lack of OT Detection 423 (39.1%)
OT Discrimination Skill: 80.7%	

OT Detection Validation

How Does The Algorithm Perform Relative to Human-Identified OTs Across 33 MODIS Scenes?



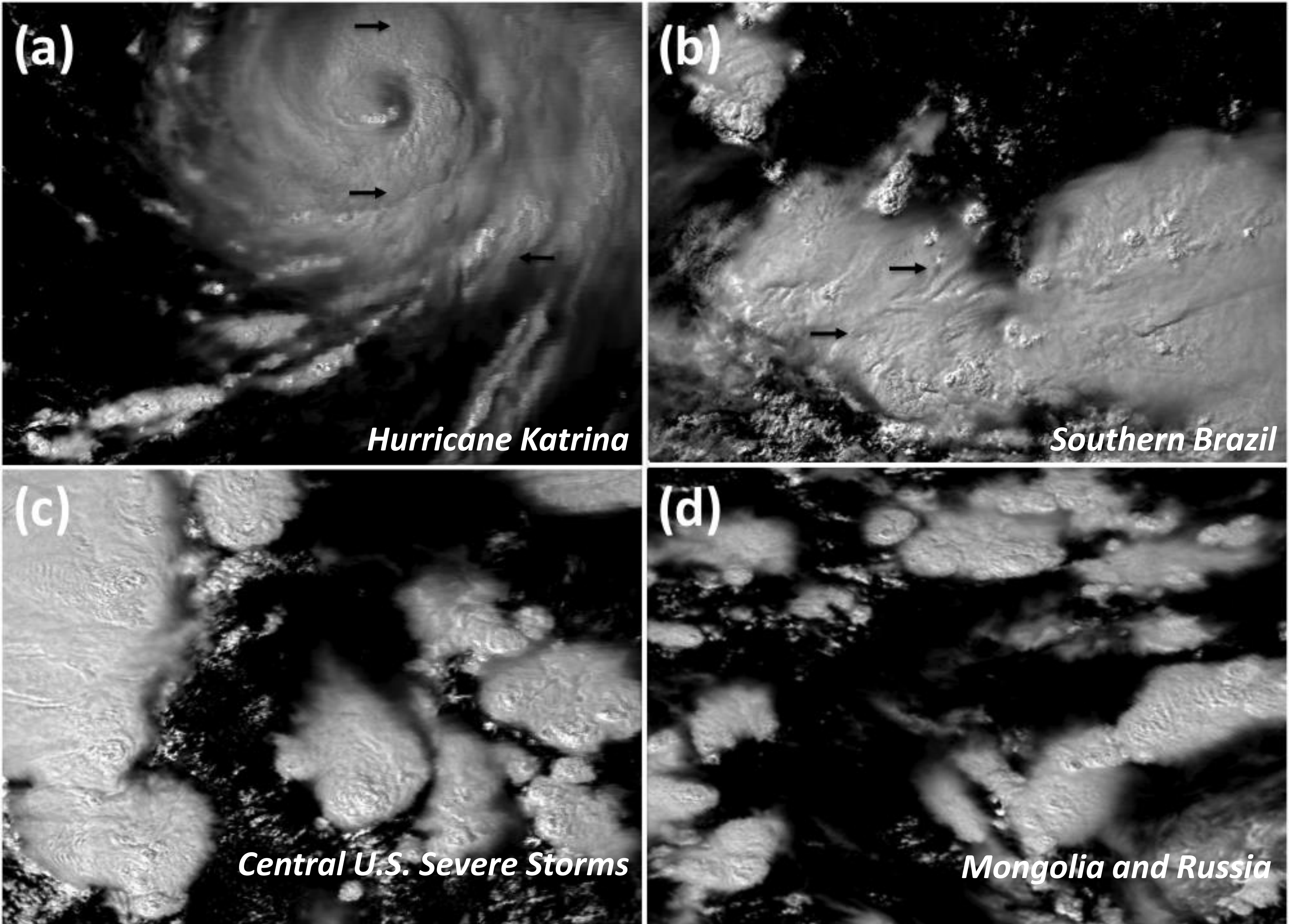
Biggest Challenge for Visible Detection
Storms with Small Anvils

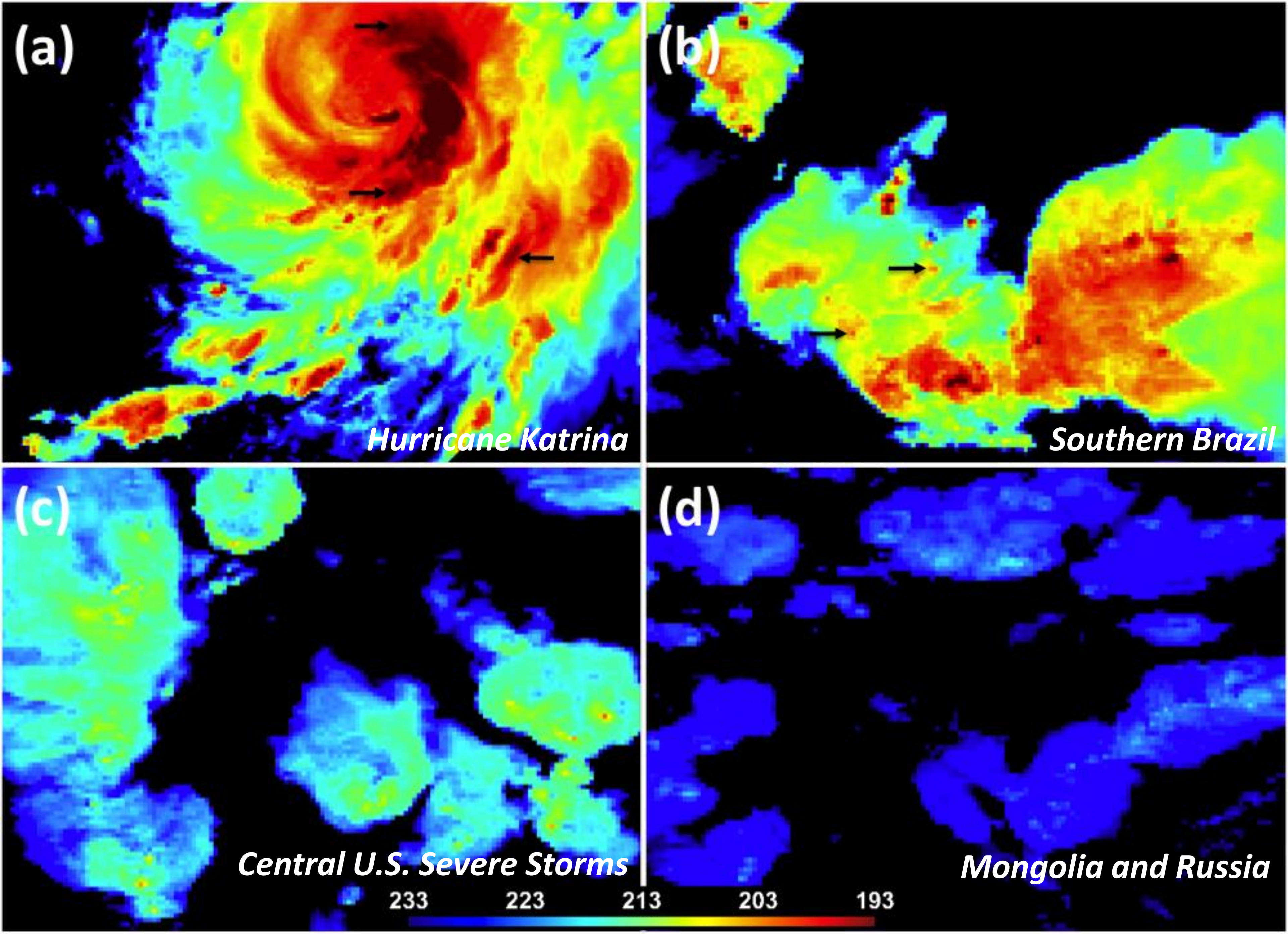
OT Detection Validation

	Probability of OT Detection (POD)	False Detection Rate (FAR)
Bedka et al. (2010) Candidates and Detection Criteria	35.1%	24.9%
Improved Candidates and Bedka et al. (2010) Detection Criteria	27.3%	1.1%
OT Probability ≥ 0.7	69.2%	18.4%
OT Probability ≥ 0.7 and VIS Rating Detection	51.4%	1.6%

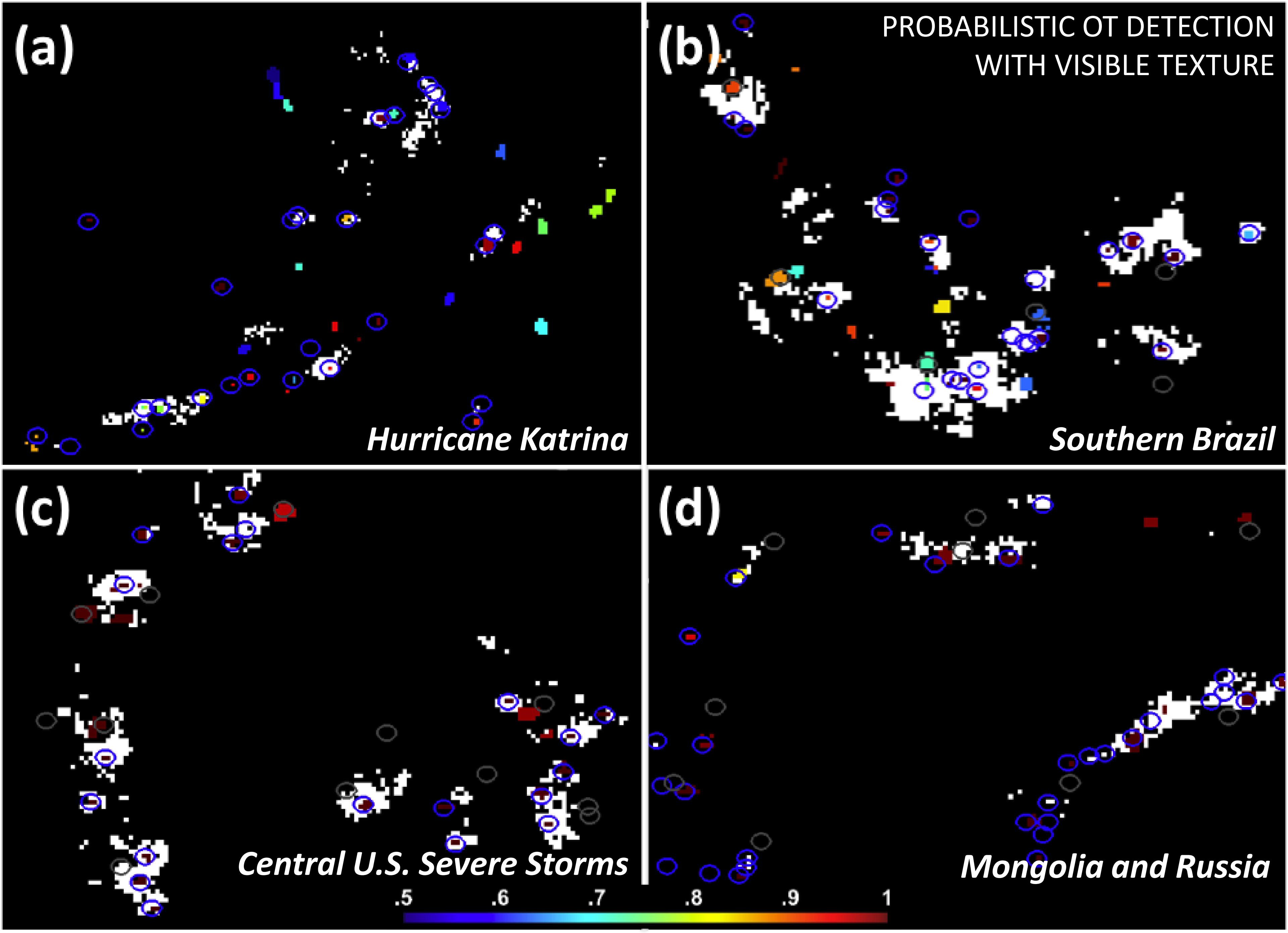
OT – Severe Weather Relationships

	OT Detection Rate US Non-Severe Storms	OT Detection Rate US Severe Storms
Improved Candidates and Bedka et al. (2010) Detection Criteria	33.0%	45.8%
OT Probability ≥ 0.7	66.5%	65.1%
VIS Rating Detection	49.0%	56.6%
OT Probability ≥ 0.7 and VIS Rating Detection	45.2%	52.4%

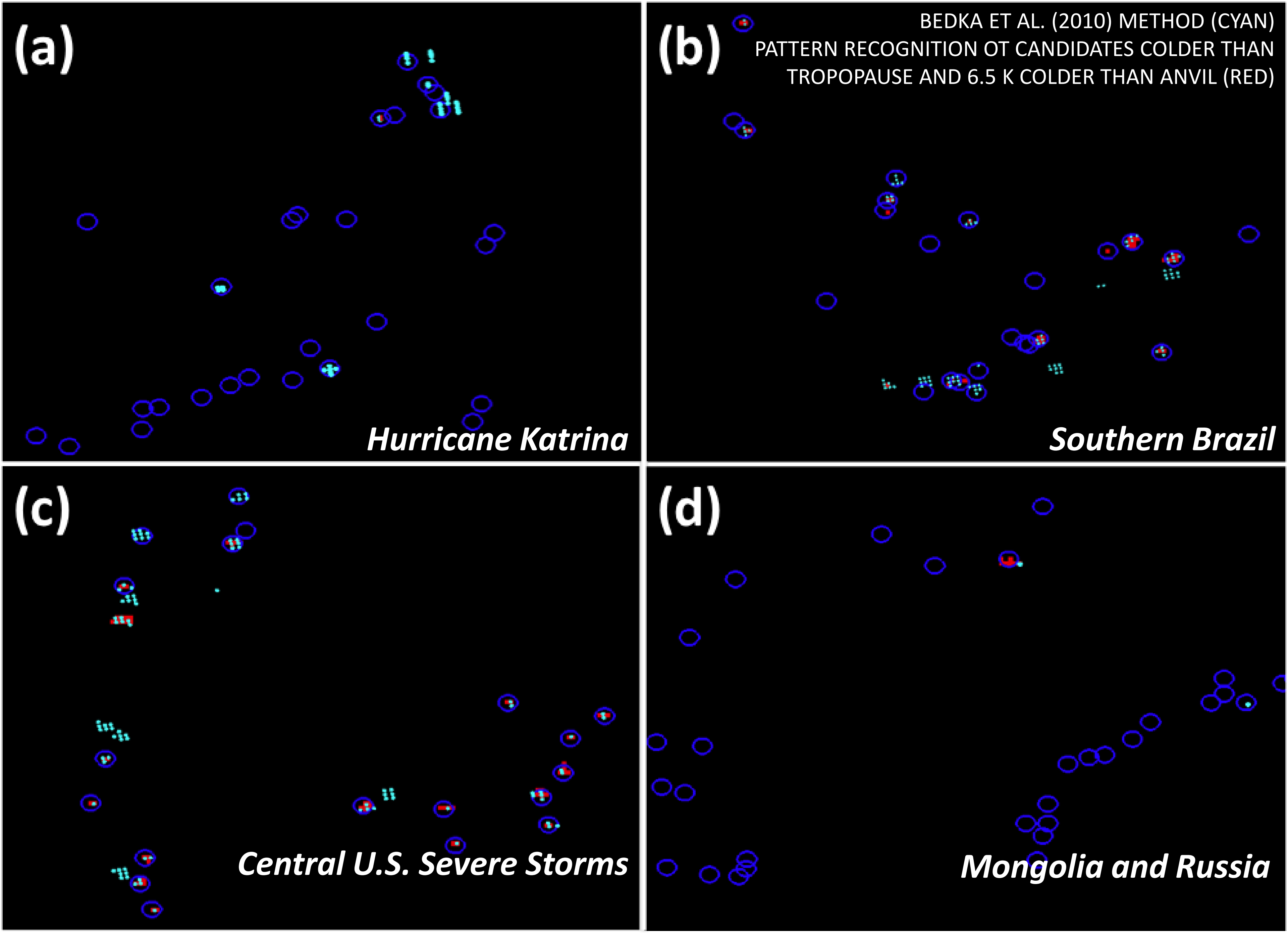

(a)
Hurricane Katrina
(b)
Southern Brazil
(c)
Central U.S. Severe Storms
(d)
Mongolia and Russia



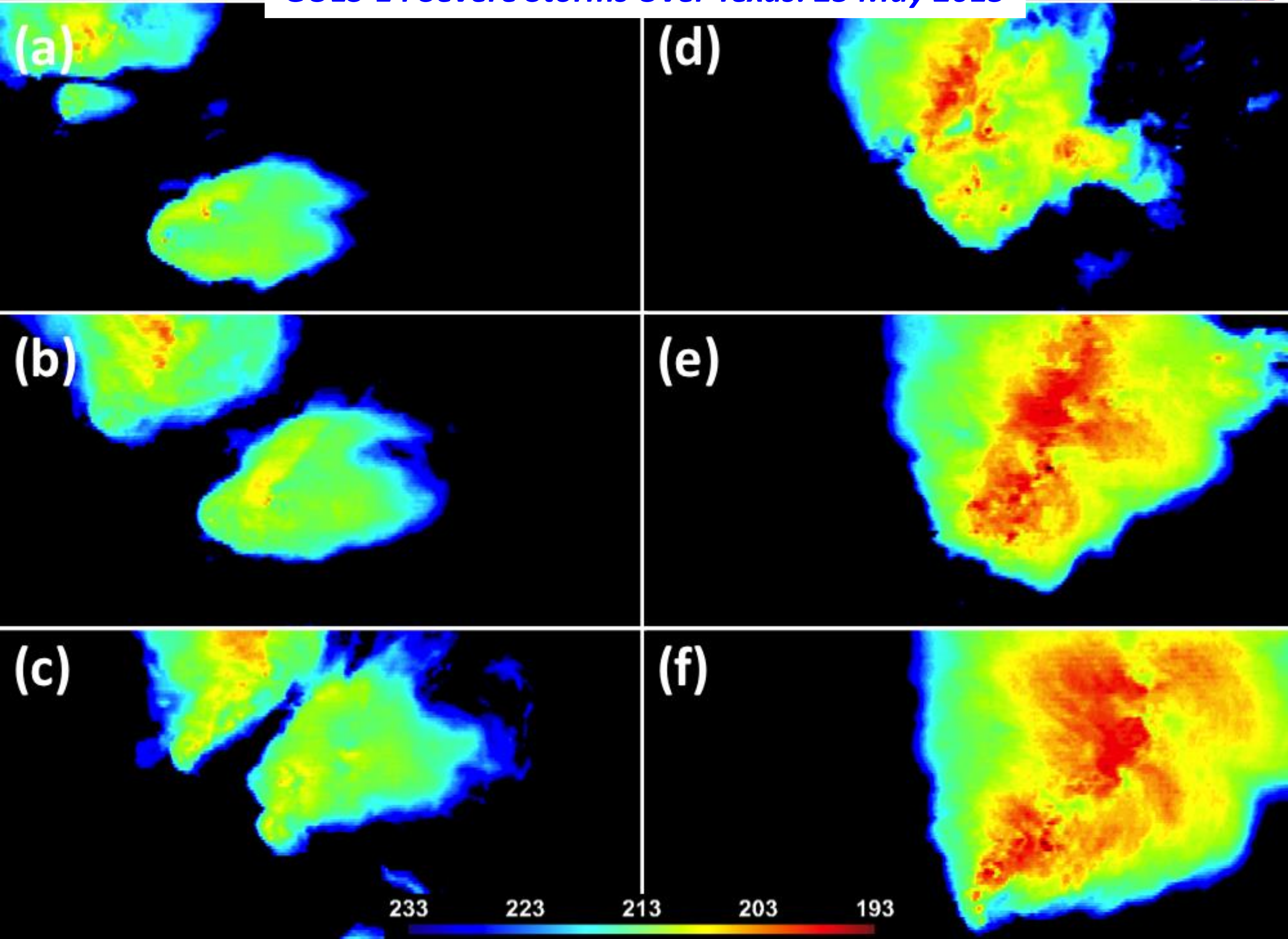
(a)
Hurricane Katrina
(b)
Southern Brazil
(c)
Central U.S. Severe Storms
(d)
Mongolia and Russia
233
223
213
203
193



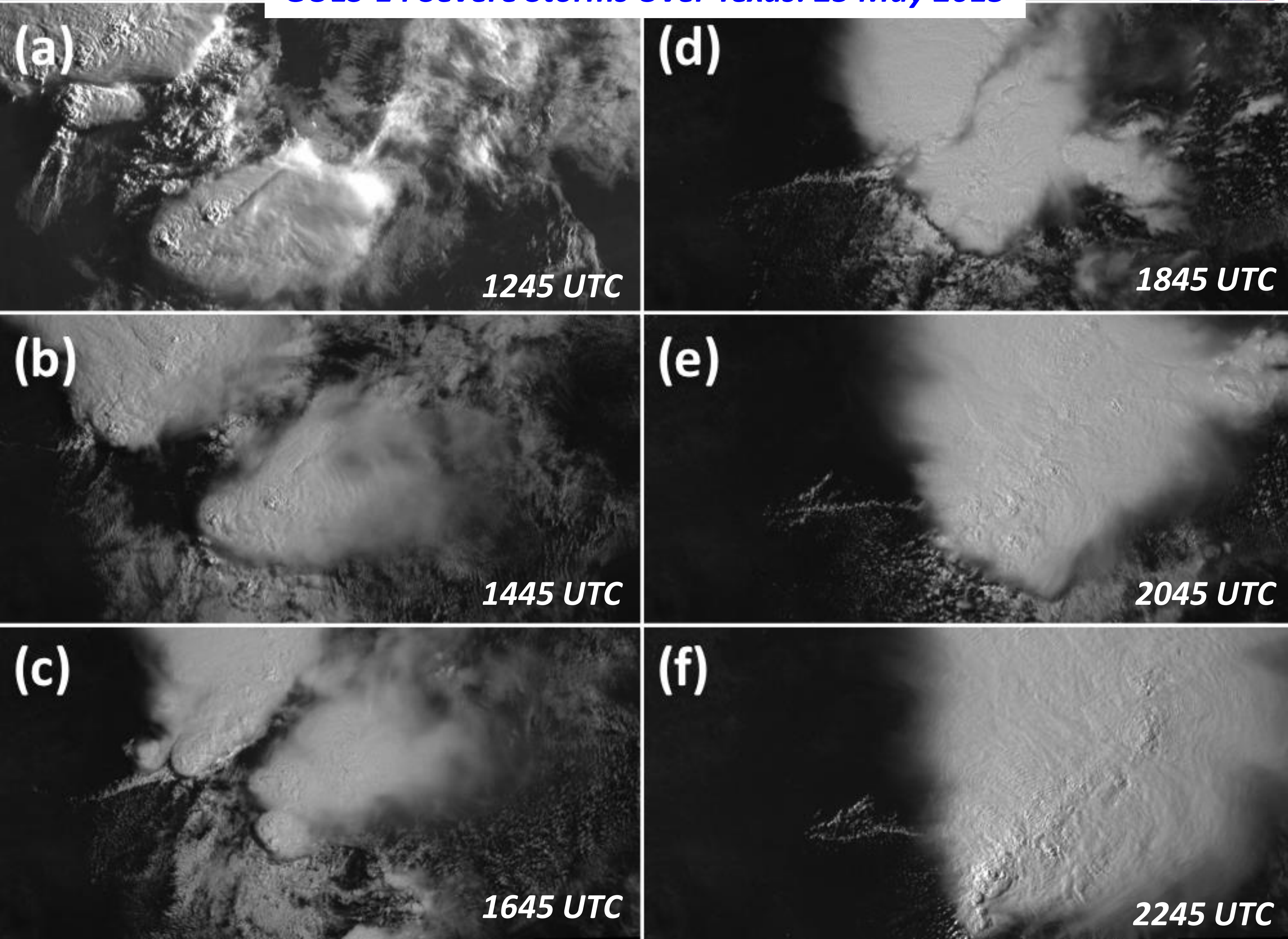
(a)
Hurricane Katrina
(b)
PROBABILISTIC OT DETECTION
WITH VISIBLE TEXTURE
Southern Brazil
(c)
Central U.S. Severe Storms
(d)
Mongolia and Russia
.5
.6
.7
.8
.9
1

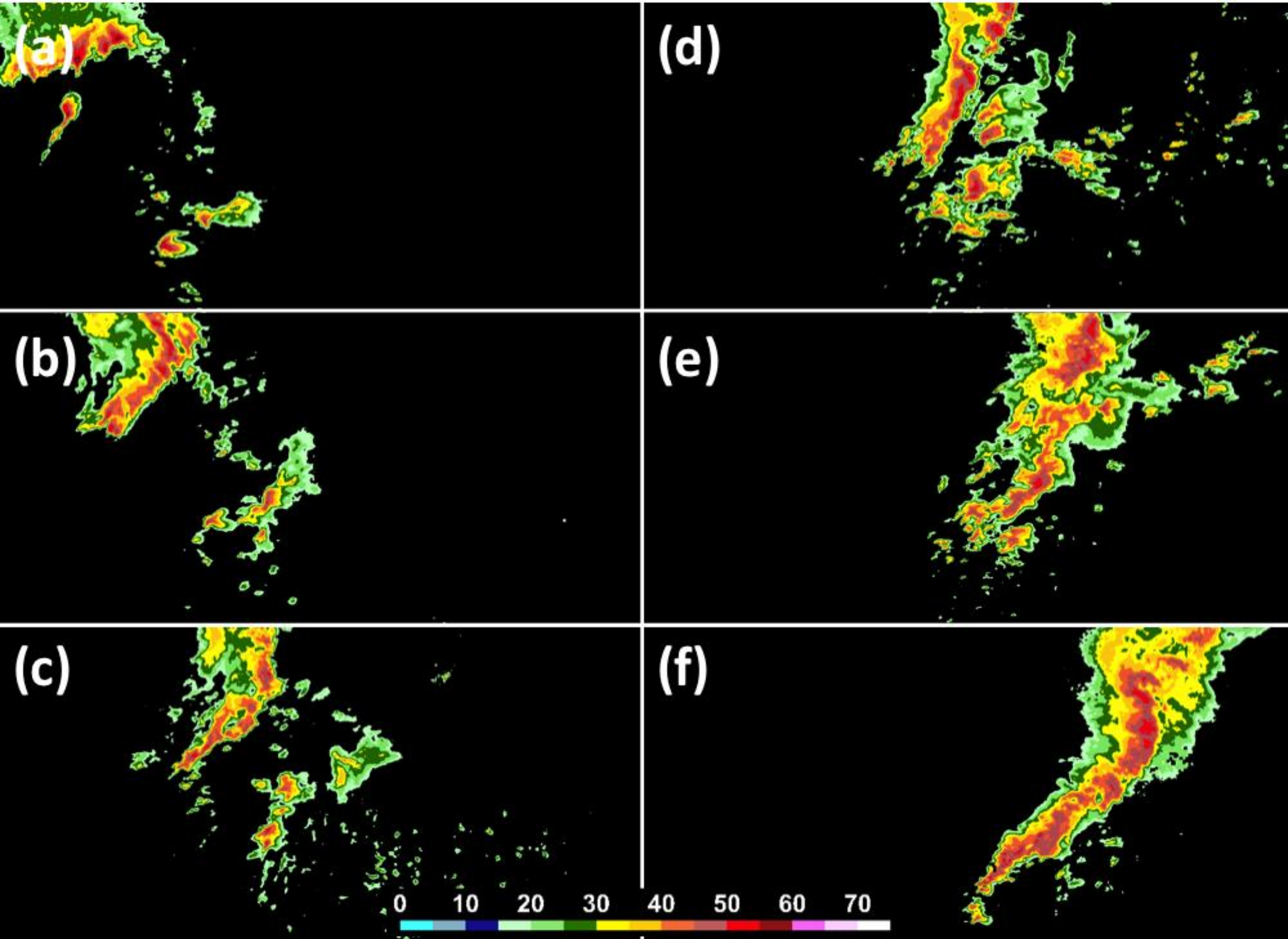

(a)
Hurricane Katrina
(b)
BEDKA ET AL. (2010) METHOD (CYAN)
PATTERN RECOGNITION OT CANDIDATES COLDER THAN
TROPOPAUSE AND 6.5 K COLDER THAN ANVIL (RED)
Southern Brazil
(c)
Central U.S. Severe Storms
(d)
Mongolia and Russia

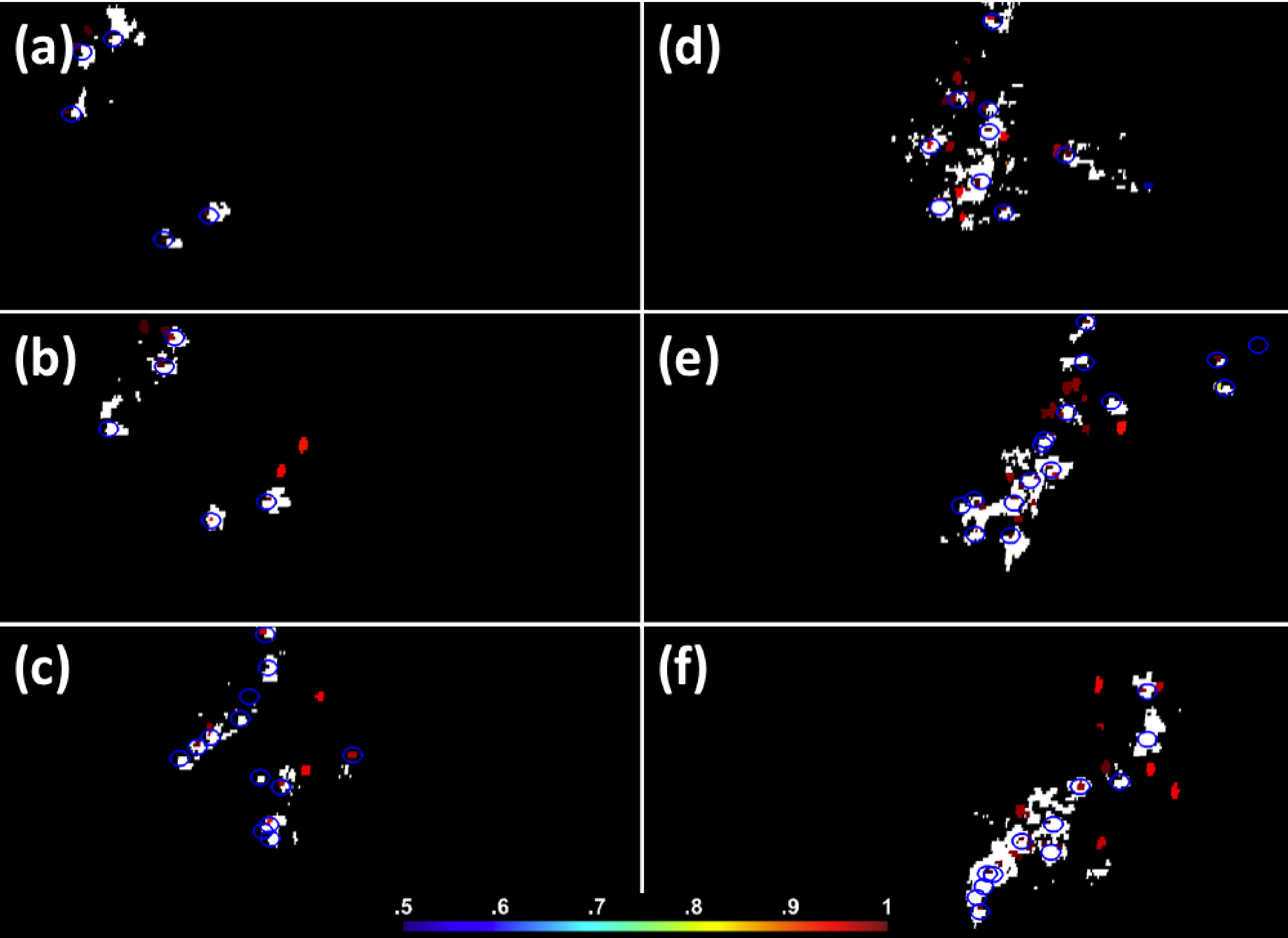
GOES-14 Severe Storms Over Texas: 25 May 2015



GOES-14 Severe Storms Over Texas: 25 May 2015




(a)
(b)
(c)
(d)
(e)
(f)
0 10 20 30 40 50 60 70


(a)
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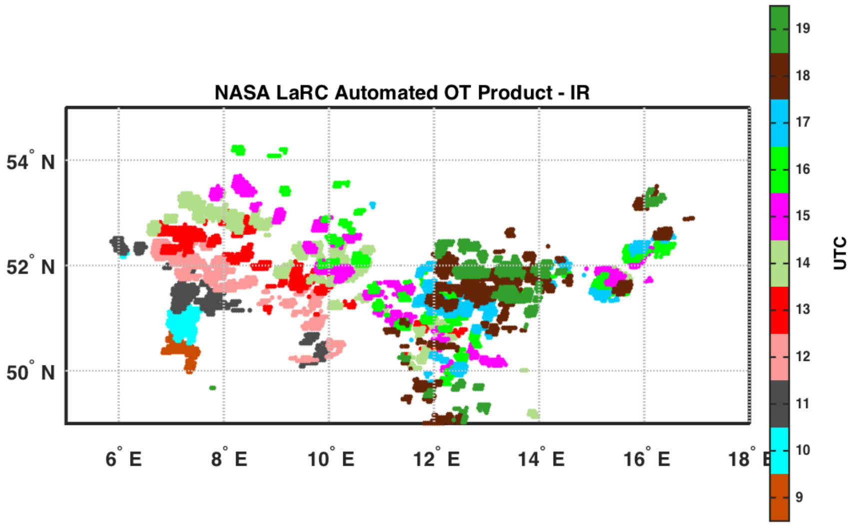
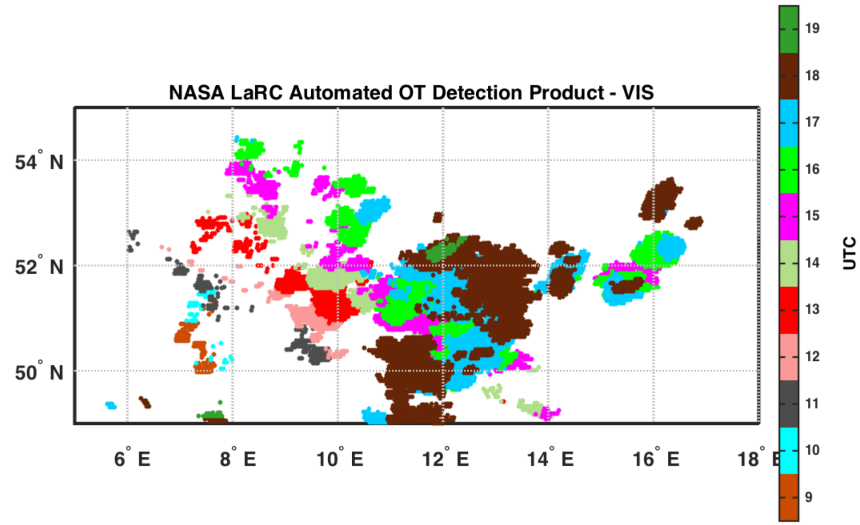
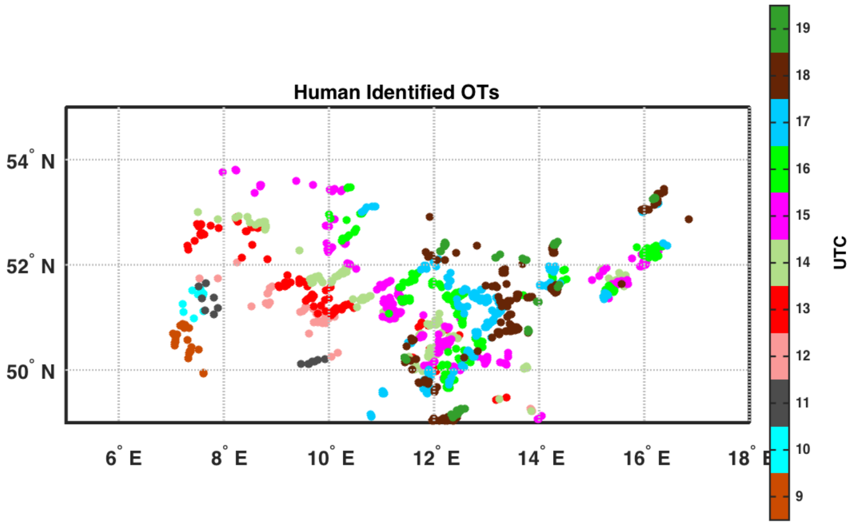
1

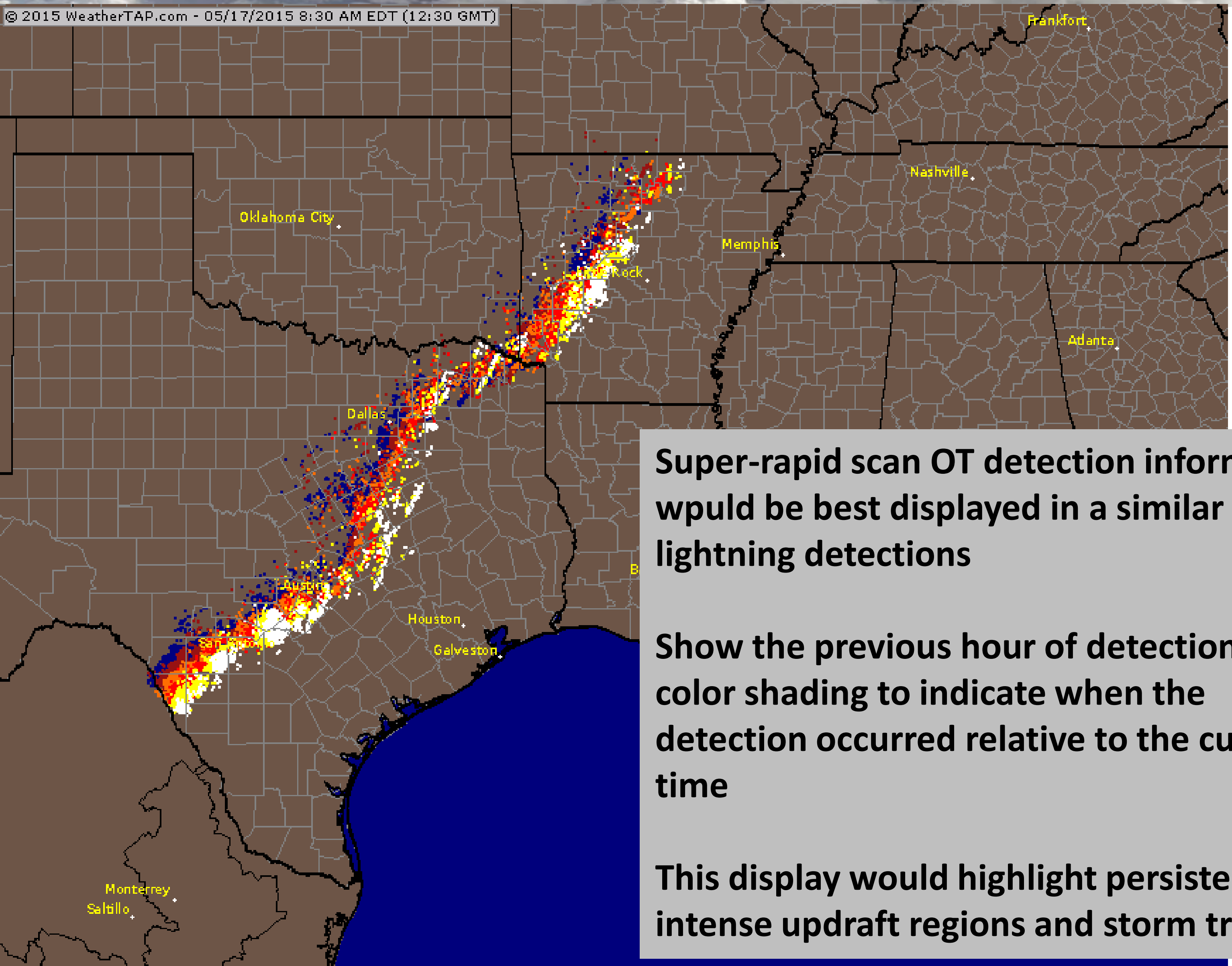
20 June 2013 MSG SEVIRI Super Rapid Scan OT Detection Map







Time Relative Lightning Detection Animation



Super-rapid scan OT detection information wpuld be best displayed in a similar way to lightning detections

Show the previous hour of detections with color shading to indicate when the detection occurred relative to the current time

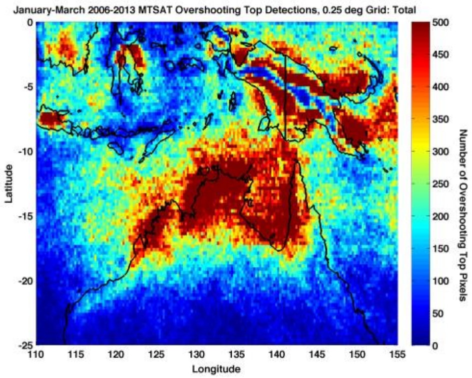
This display would highlight persistent intense updraft regions and storm tracks

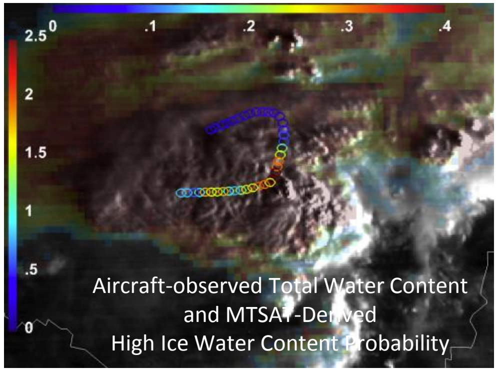
QUESTIONS???

Weather and Climate Applications of OT Detection Output

Airborne Field Campaign Planning and Safety

- Long-term OT databases created for NASA SEAC4RS and High Ice Water Content (HIWC) field campaign planning
- Product run in real-time and displayed at PREDICT/GRIP, HS3, MACPEX, SEAC4RS, and HIWC for real-time hazardous storm targeting or avoidance





OT Detection Statistical Relationships With Severe Weather

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

Dworak et al. (JAMC, 2012)

- The frequency of OT detections near confirmed severe weather events was determined during 2004-2009
- OTs detected near 55% of reports and were most often detected 25-30 mins in advance of severe weather, providing forecasters with valuable situational awareness and lead time

OT Detection Operational Demonstration Within the GOES-R Proving Ground

- GOES-R Proving Ground is designed to make the weather community familiar with new products that will be available from GOES-R Advanced Baseline Imager and Geostationary Lightning Mapper data
- The OT detection product was evaluated by forecasters from the U.S. and Europe to assess its value in their operations
- While GEO satelite data does not offer the same level of detail as radar or lightning detection data, some participants found that the OT product would be very useful to them:

"Very useful at night to highlight the strongest cells"

"Persistent overshooting tops indicated particularly long-lived strong updrafts, while the dissipation of the OT's clued forecasters to decaying convection and possible short-term wind threat as storms collapsed"

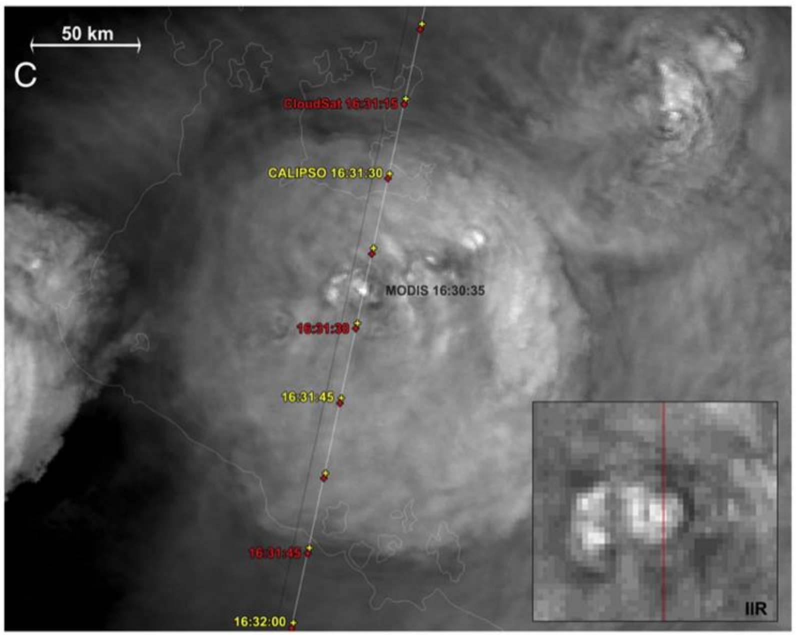
"OTD was really useful for me. I can speak for every broadcaster, we'd all love to have this product"

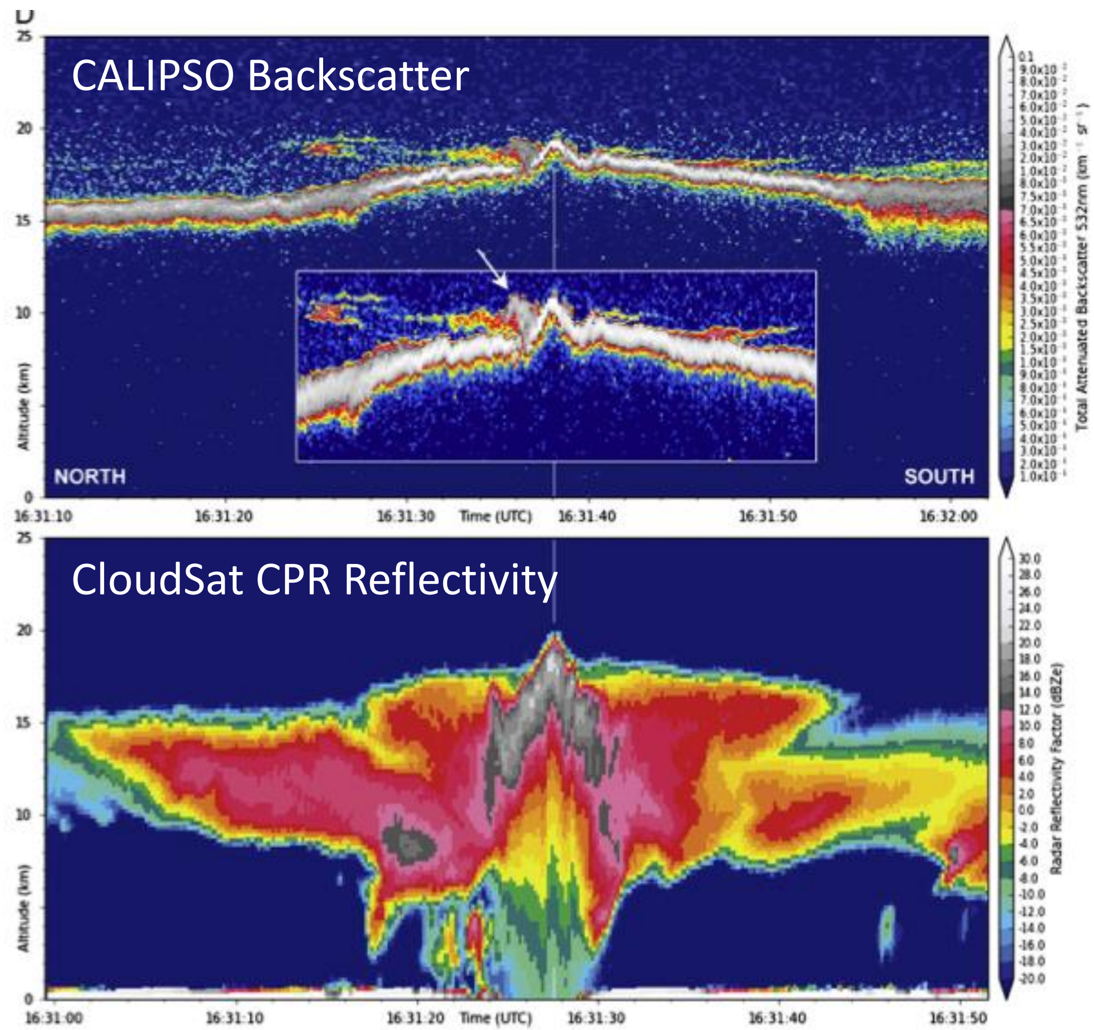
"OTD is very helpful to NOAA Center Weather Service Units for Aviation because I'm looking at a much larger area. OTD quickly shows me where the strongest updrafts are"

Ice Detrainment From OT Over Australia

"One of the most striking features seen repeatedly above the anvil top is the formation of cirrus cloud which jumps upward from behind the overshooting dome as it collapses violently into the anvil cloud" **(Fujita, 1982)**

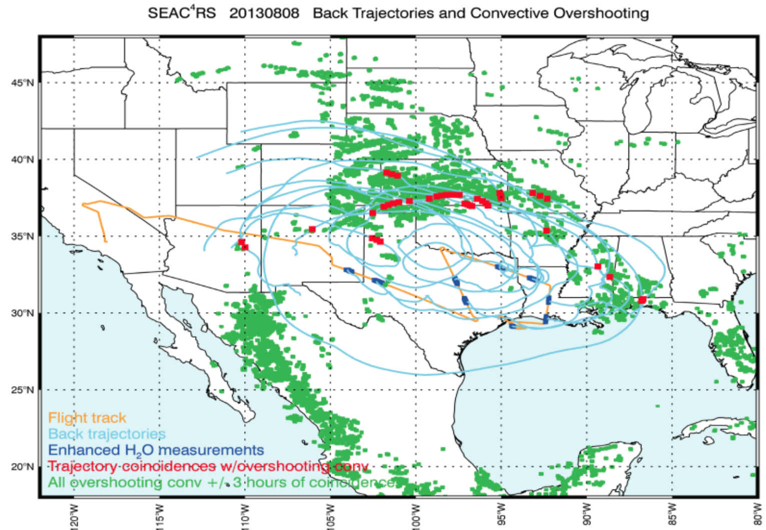
MODIS IR Over Gulf of Carpentaria
26 January 2010 1631 UTC

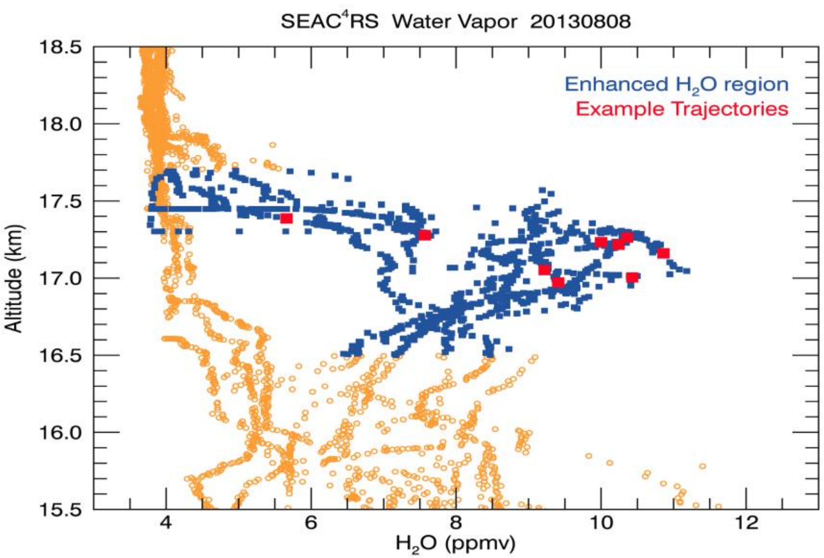




Setvak, Bedka, et al. (Atmos. Res. 2013)

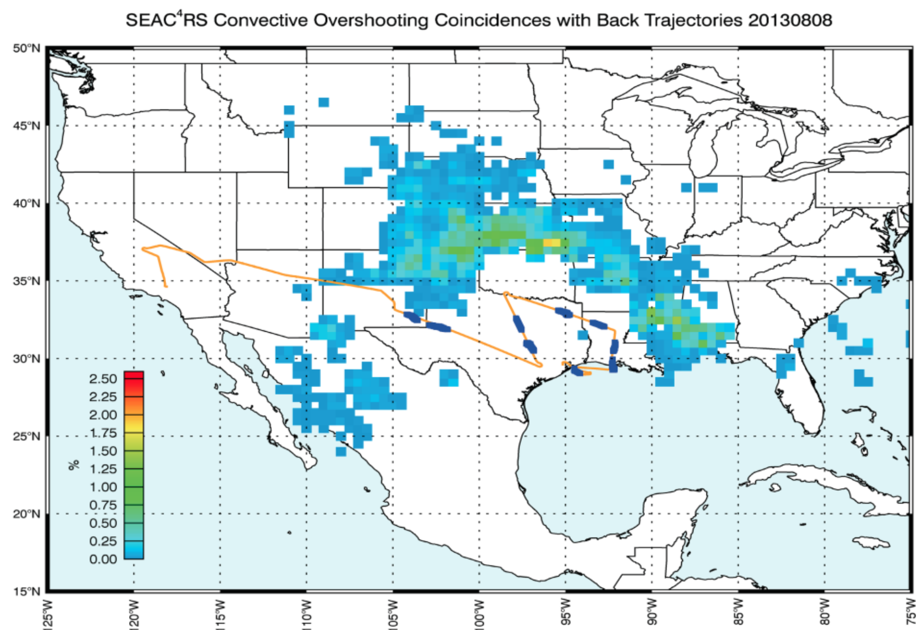
Understanding Source Regions of Enhanced Stratospheric Water Vapor Observed During SEAC4RS





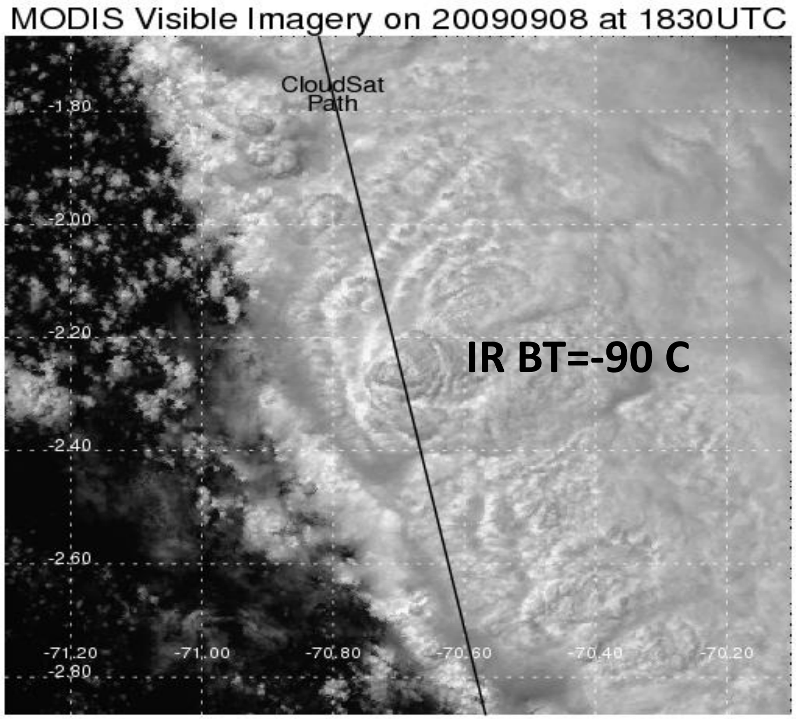
- Regions of enhanced stratospheric water vapor (WV) were observed by the NASA JPL JLH water vapor sensor aboard the NASA ER-2 aircraft during the SEAC4RS field campaign in August 2013

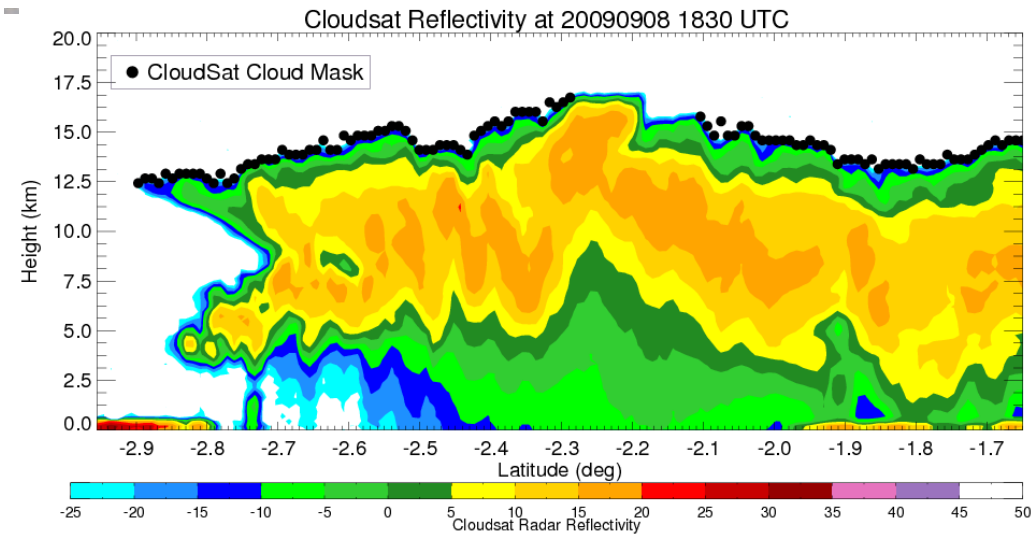
- Back-trajectories were run from the locations and height of the enhanced WV to determine where they intersected with OT detections at the same height

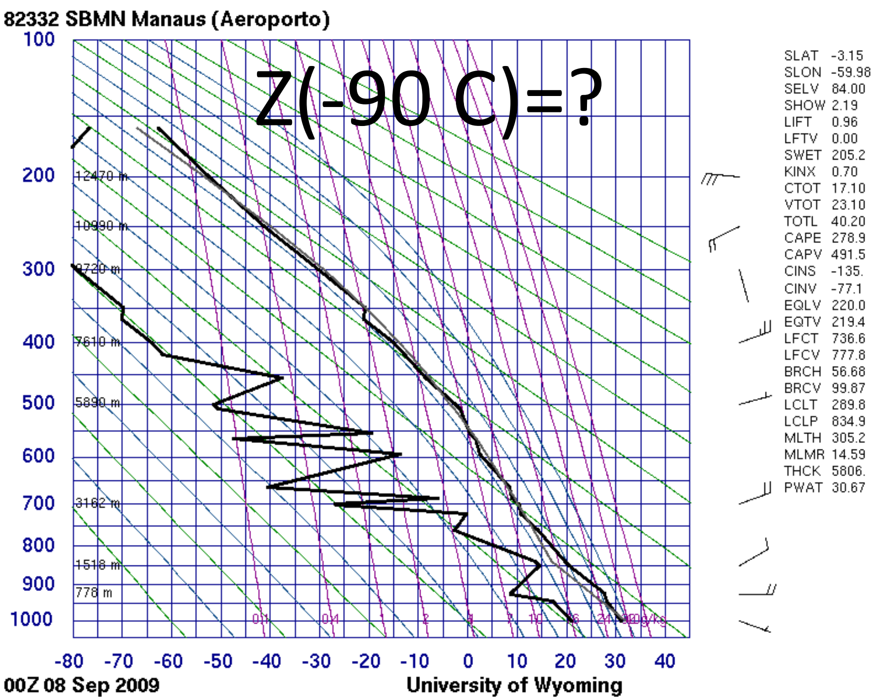


Figures Courtesy of Robert Hermann (JPL) and Eric Ray (NCAR)

Deriving OT Heights Using NASA A-Train Data

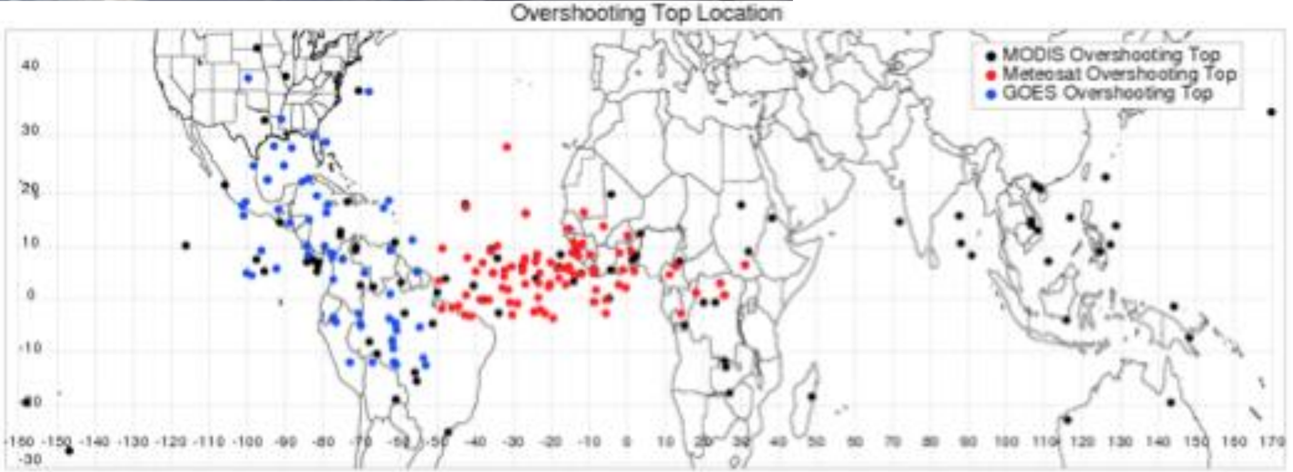


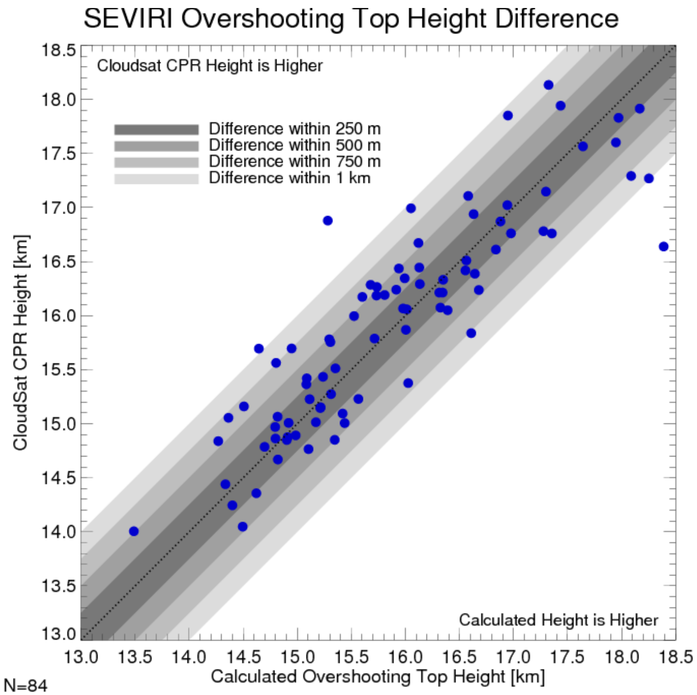




PROBLEM: If satellite IR BT is colder than any temperature within NWP profile, how do you assign a height to the OT?

Deriving OT Heights Using NASA A-Train Data





PROBLEM: If satellite IR BT is colder than any temperature within NWP profile, how do you assign a height to the OT?

ONE POSSIBLE SOLUTION:

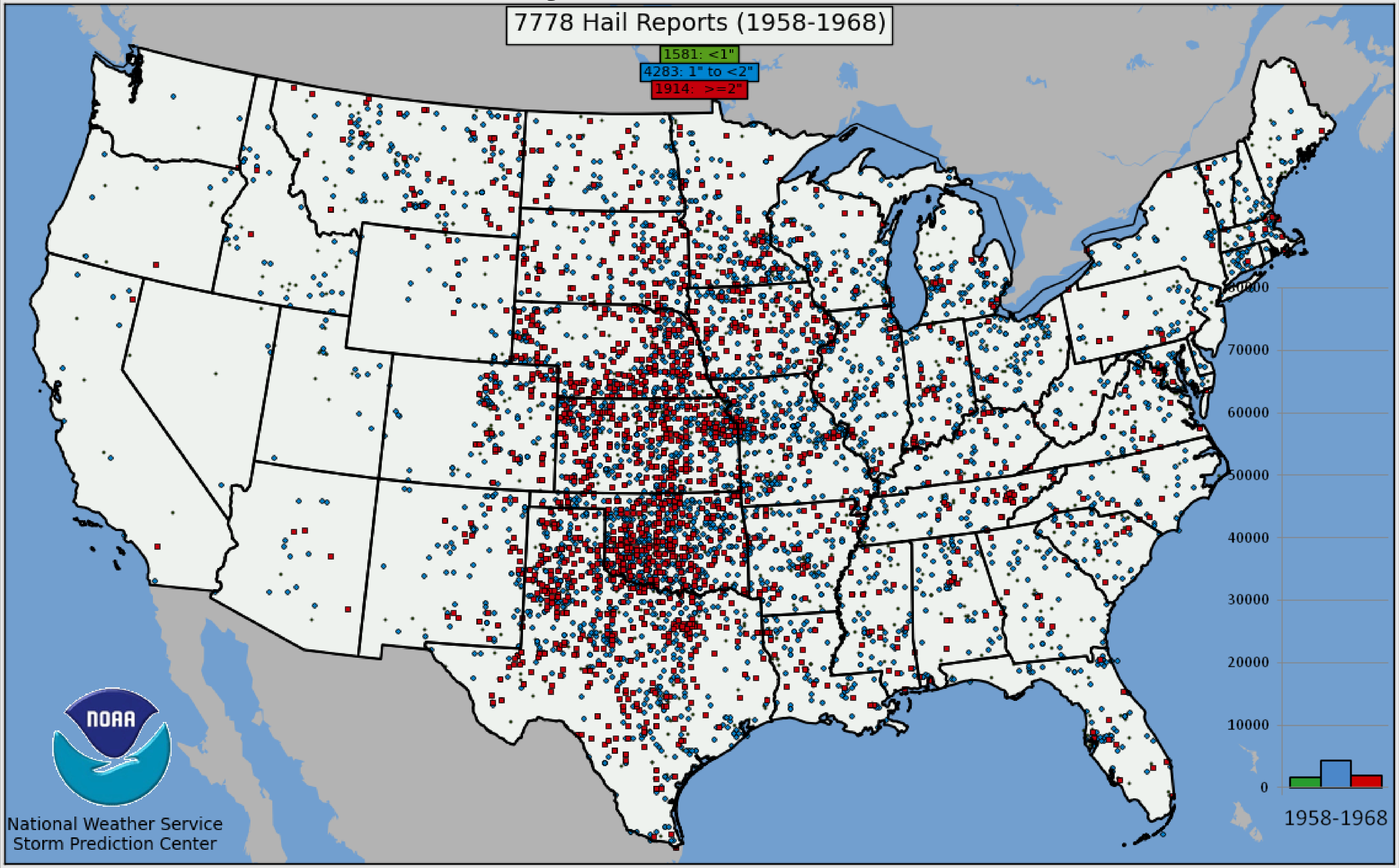
- Use co-located MODIS, geostationary imager, and CloudSat data to derive relationships between the OT-anvil BT difference and height difference
- Use anvil height and OT-Anvil BTD as the basis for increasing height beyond the anvil level

$$\text{OT Height} = \text{Anvil Height} + \frac{\text{OT BT - Anvil BT}}{\text{OT Lapse Rate}}$$

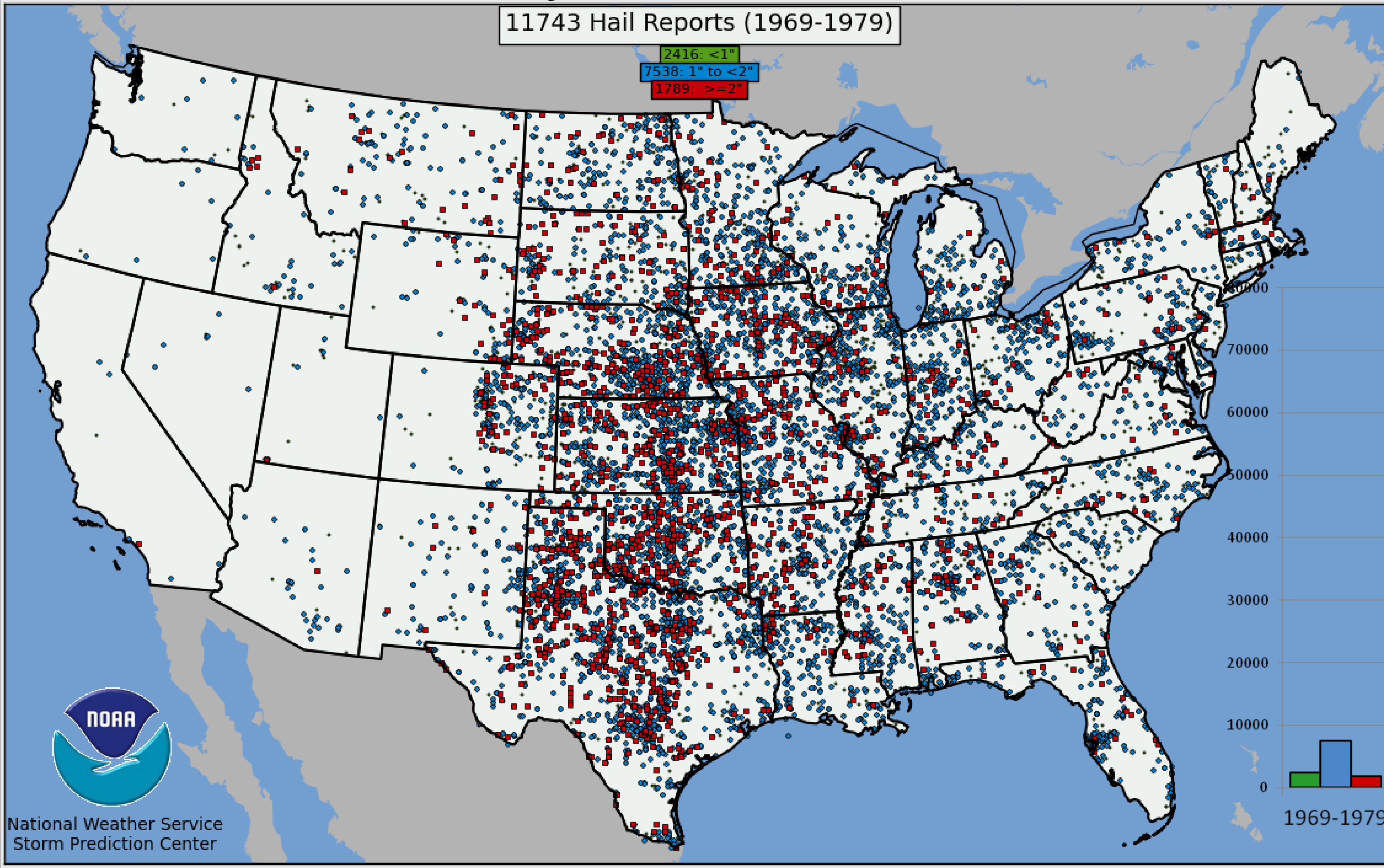
+ CloudSat-to-CALIPSO Height Adjustment

OT Lapse Rate=-7.34 K/km

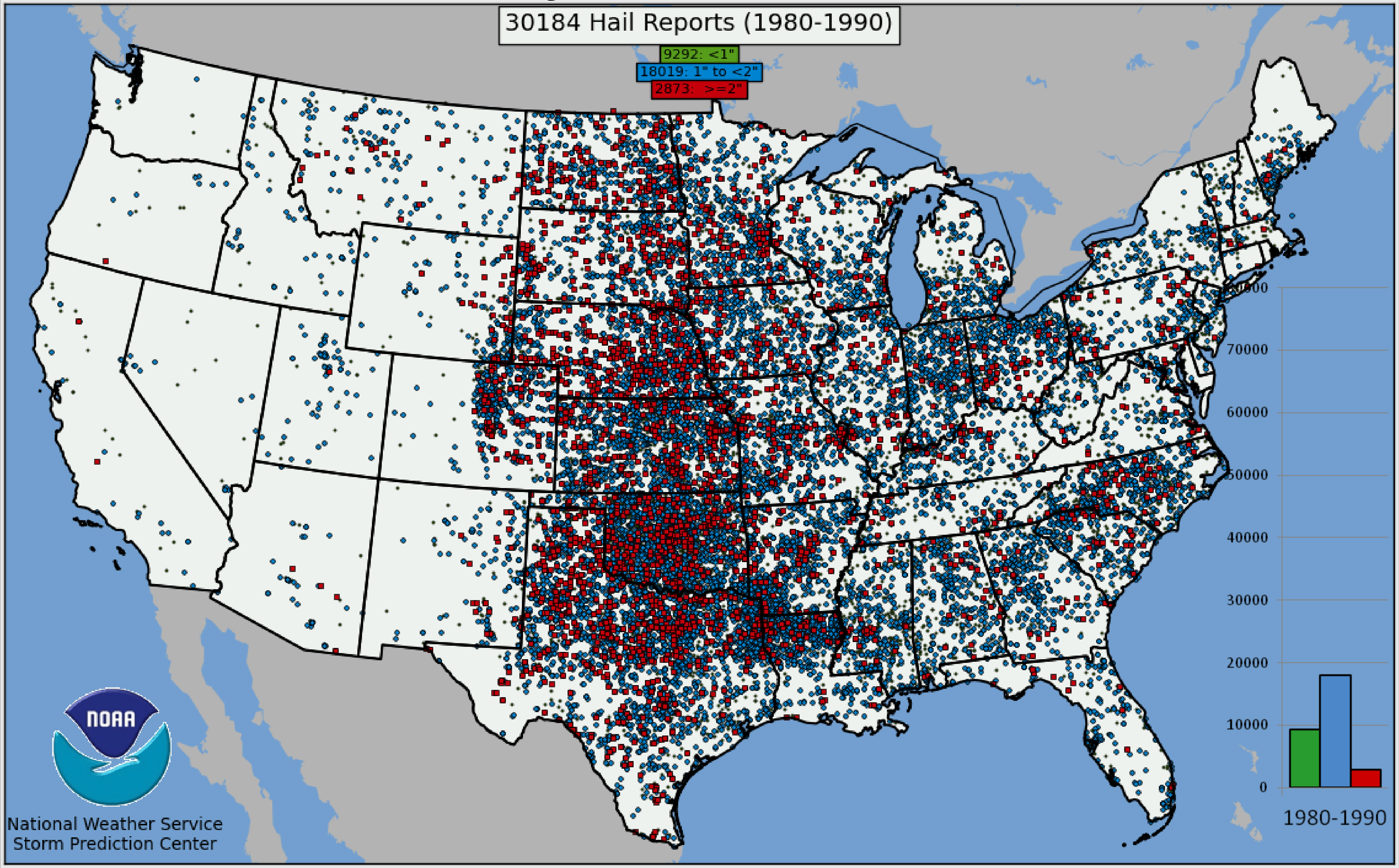
Hail – 11-years, 1958-1968



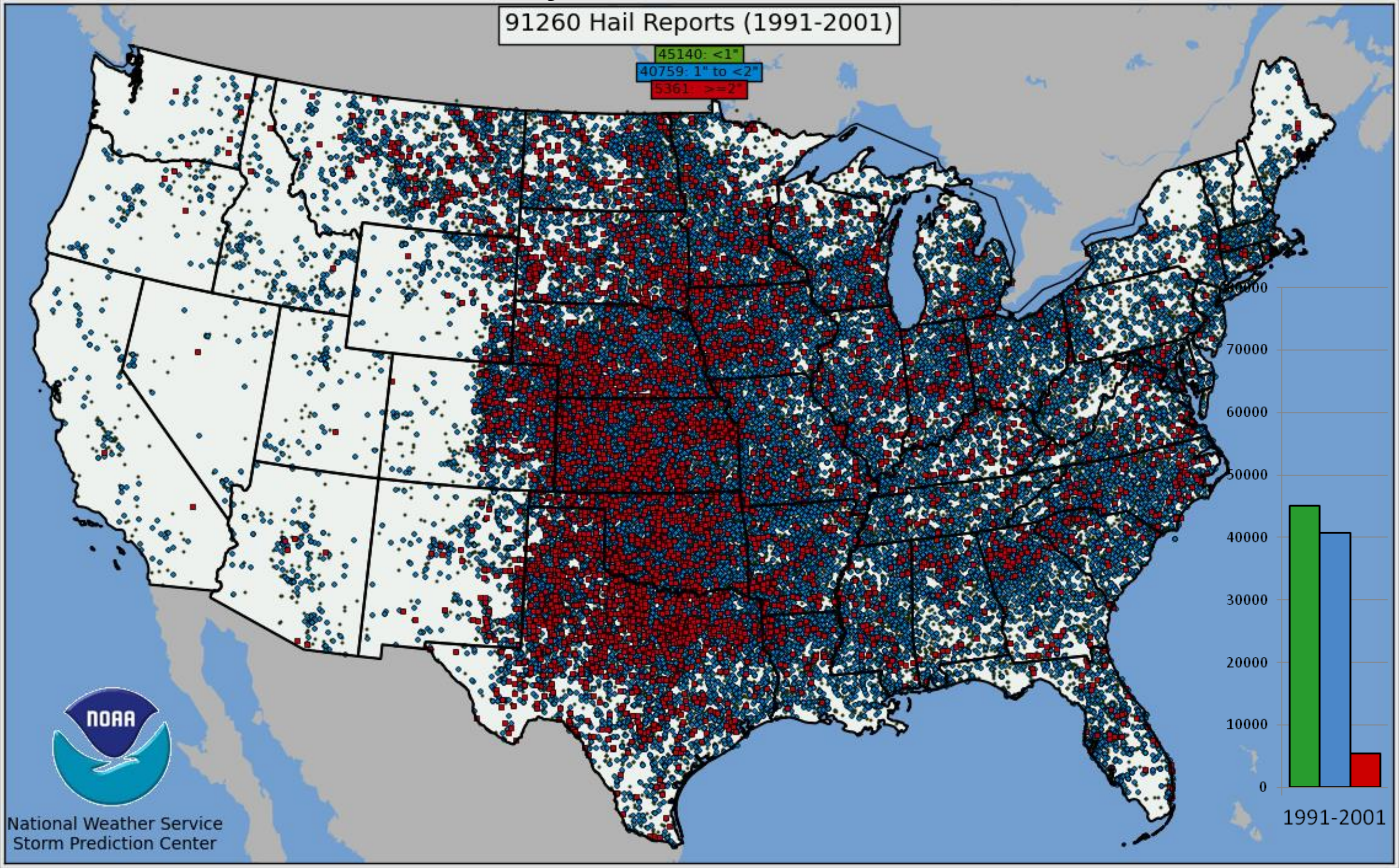
Hail – 11-years, 1969-1979



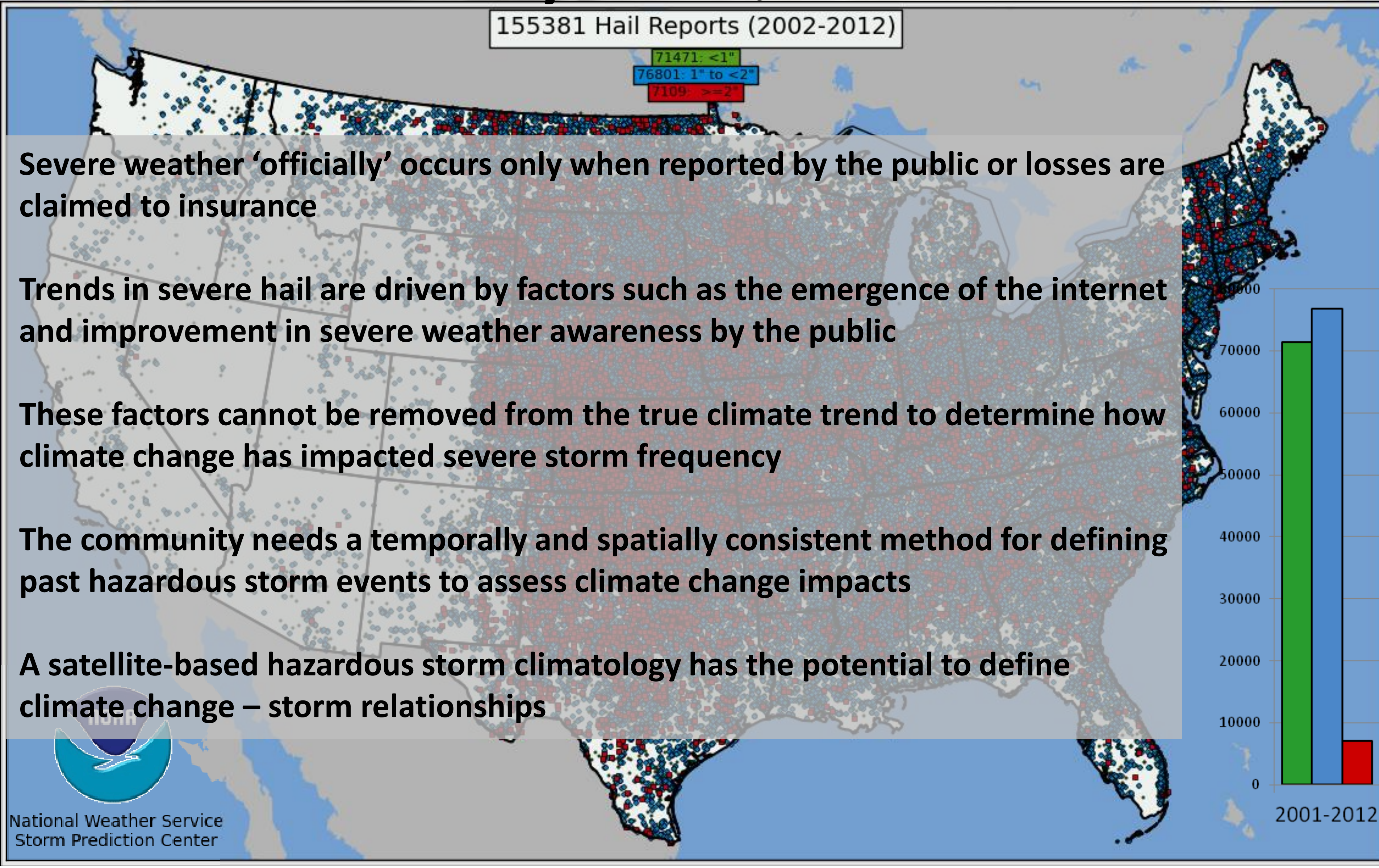
Hail – 11-years, 1980-1990



Hail – 11-years, 1991-2001



Hail – 11-years, 2002-2012



Severe weather 'officially' occurs only when reported by the public or losses are claimed to insurance

Trends in severe hail are driven by factors such as the emergence of the internet and improvement in severe weather awareness by the public

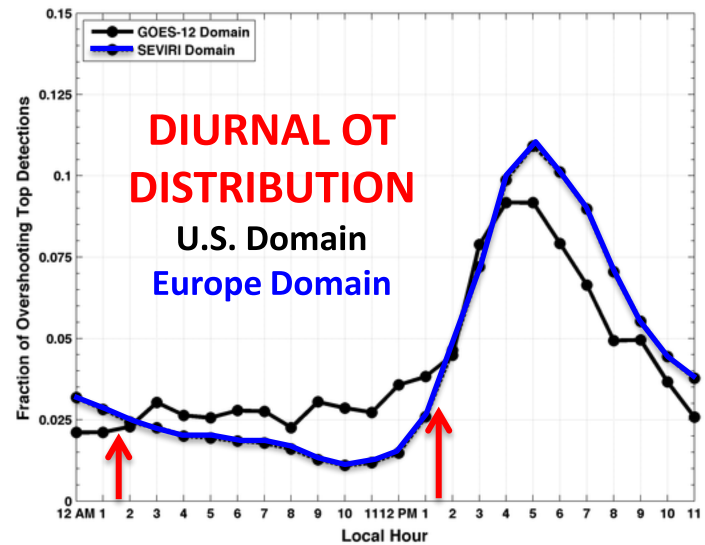
These factors cannot be removed from the true climate trend to determine how climate change has impacted severe storm frequency

The community needs a temporally and spatially consistent method for defining past hazardous storm events to assess climate change impacts

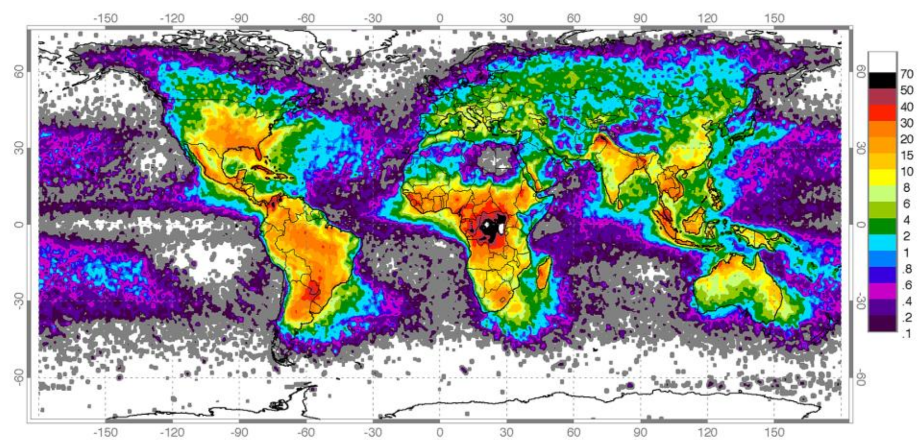
A satellite-based hazardous storm climatology has the potential to define climate change – storm relationships

Description of Previous Deep Convection Climatological Studies

- **Existing Imager-based deep convection climatology studies have relied on simple fixed thresholding of IR BTs and focus primarily over the tropics**
  - A particular threshold may work one day, but not the next
  - Entire anvil clouds are often detected, not just the active updraft region where weather hazards and UTLS transport are concentrated
- **NASA A-Train, Suomi NPP and AVHRR-based studies are hampered by the fact that the timing of peak storm activity is missed by their 1:30-2 PM overpass**
- **Storms analyzed using GEO data via the International Satellite Cloud Climatology Project (ISCCP,** Rossow and Pearl 2007**)**
  - ISCCP: 10 km resolution, 3-hourly
  - 10 km is quite coarse for studying small features like overshooting tops
- **TRMM/GPM radar profiles, imagery, and lightning flash detection data available since the late 90's**
  - Orbit inhibits repeated observation of hazardous convective storm events throughout their lifecycle
- ***Given the characteristics of these instruments and approaches. how can we determine if hazardous storm activity has changed over time?***



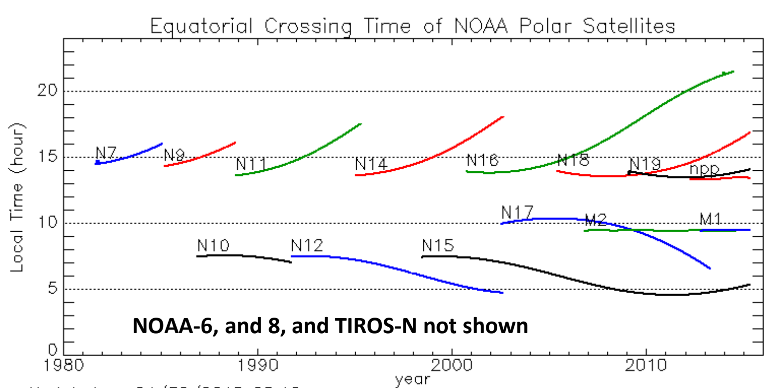
TRMM LIS Number of Lightning Flashes Per km^2



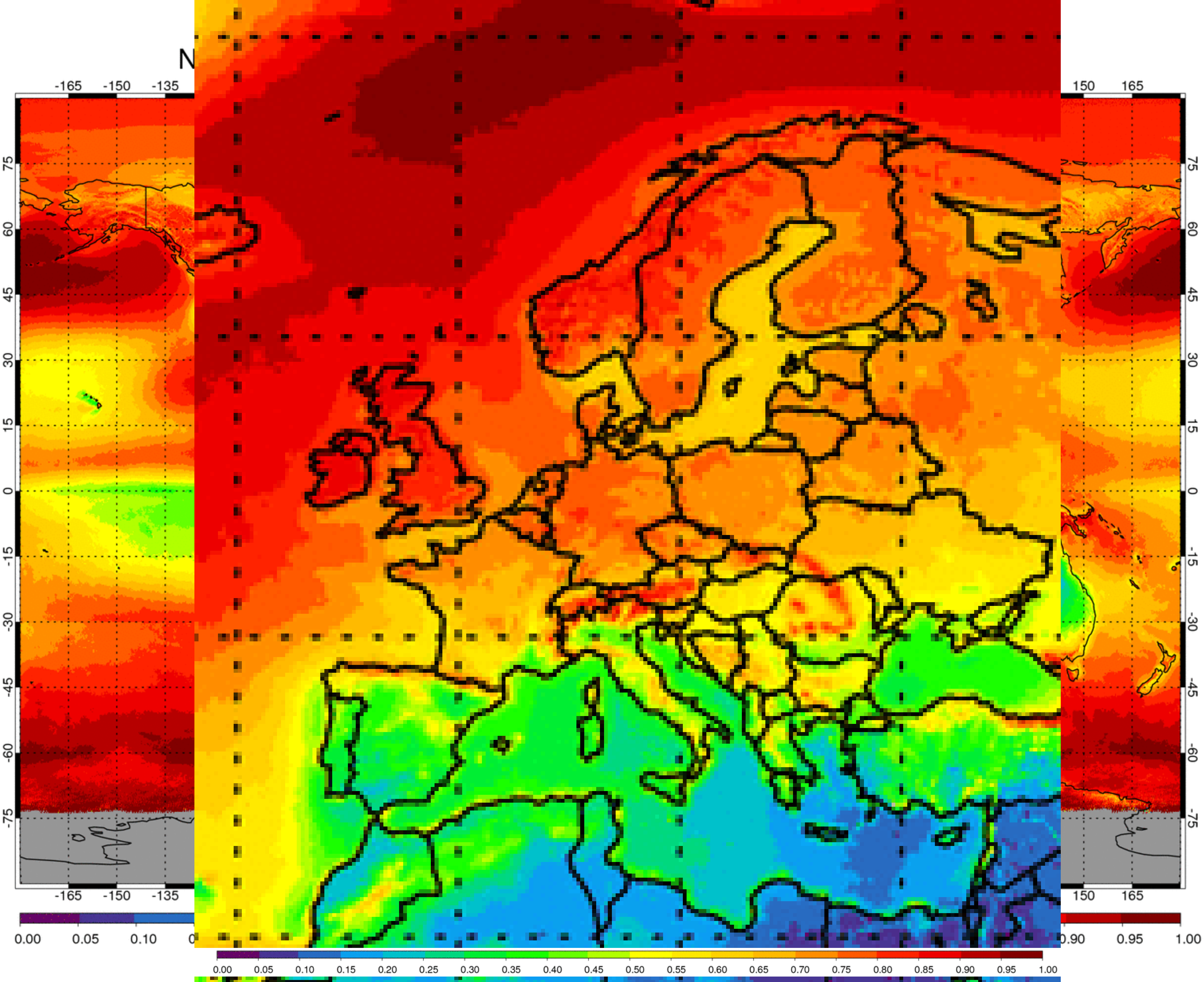
NASA LaRC AVHRR Cloud and Clear Sky Radiation Climate Data Record (CDR)

Climate Data Record Products
Calibrated 0.63, 0.86, and 1.61-μm Reflectance
Cloud Mask
Cloud Thermodynamic Phase*
Cloud Optical Depth**
Cloud Liquid Water Droplet or Ice Crystal Effective Radius**
Cloud Effective Pressure, Temperature, and Height
* CDR Quality During Daytime Only
** CDR Quality During Daytime Over Snow/Ice Free Surfaces

Additional Products Included In CDR Output
Cloud Top Pressure, Temperature, and Height
Cloud Base Pressure and Height
Overshooting Convective Cloud Top Pixel Detection
Clear Sky Pixel Skin Temperature
AVHRR/Aqua CERES-Derived Shortwave Broadband Albedo
AVHRR/Aqua CERES-Derived Longwave Broadband Flux

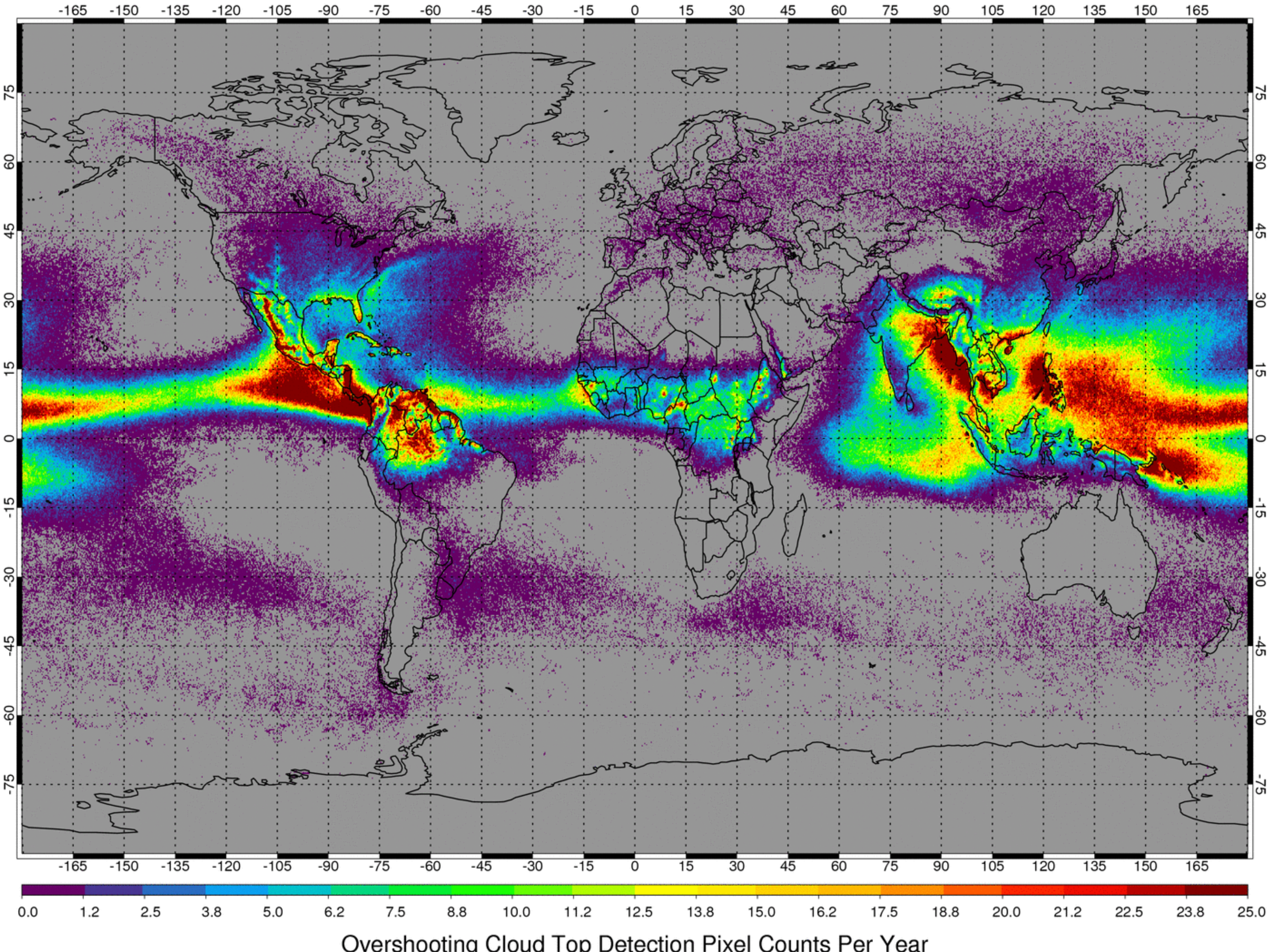


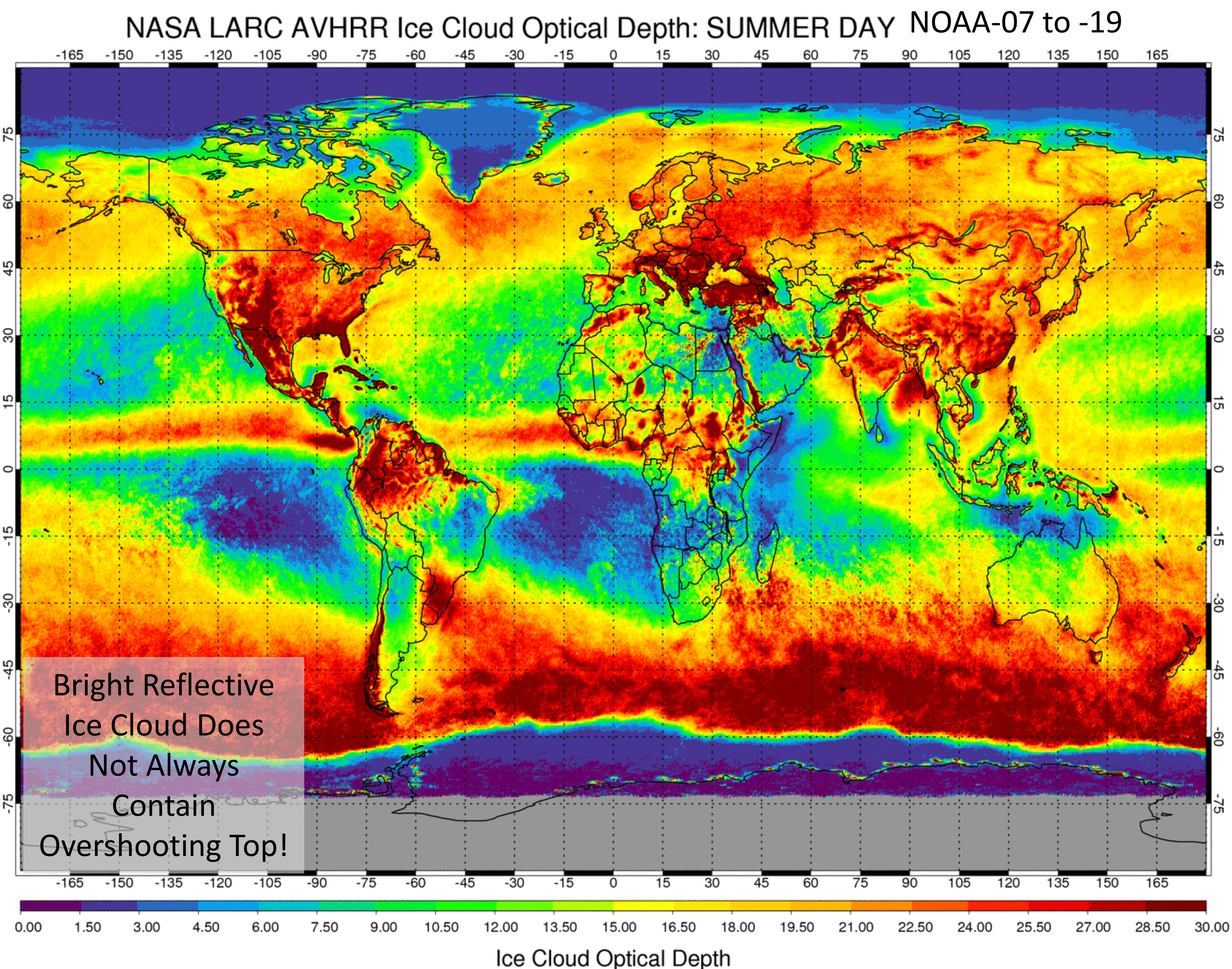
- Development of an AVHRR cloud property CDR has been supported by the NOAA NCEI CDR program since ~2010
- Processing incorporates 4 km AVHRR Global Area Coverage observations, NASA MERRA surface and vertical profile reanalyses, and a diverse set of ancillary data
- **30+ years (~25 TB) of 4 km resolution NetCDF-4 cloud CDR data from the afternoon AVHRR orbits has recently been delivered to NOAA NCEI (as of Aug 2015)**

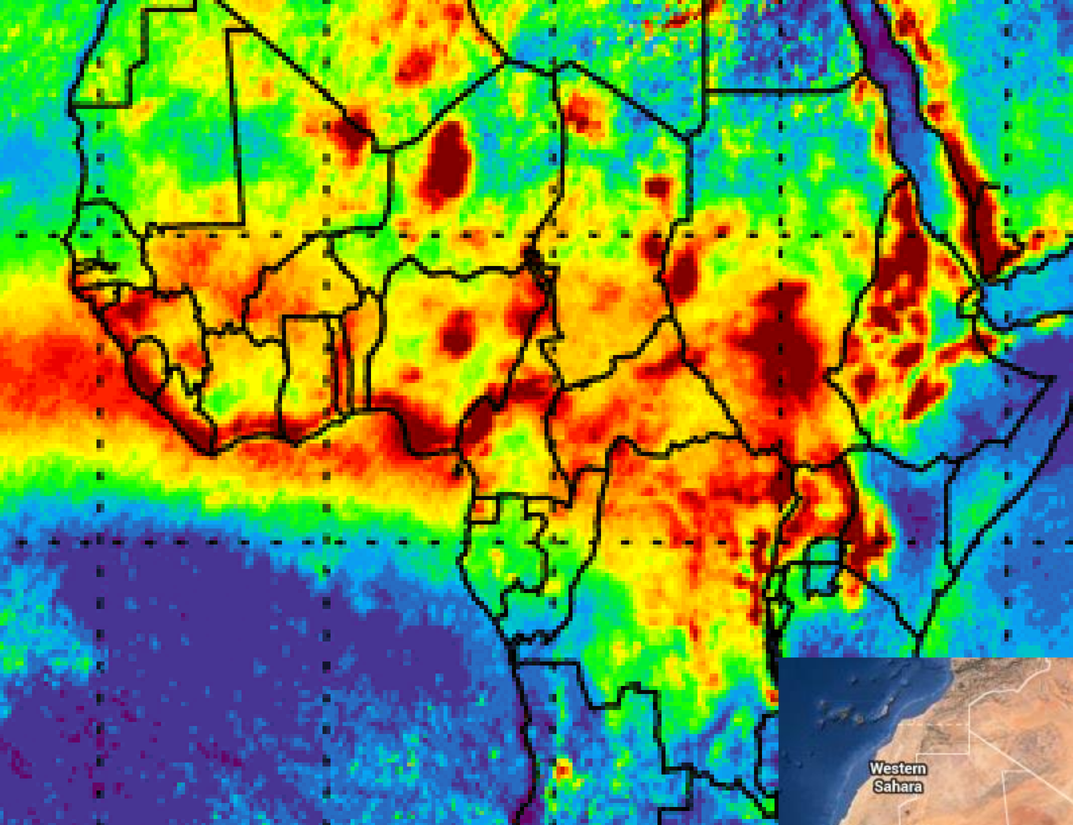


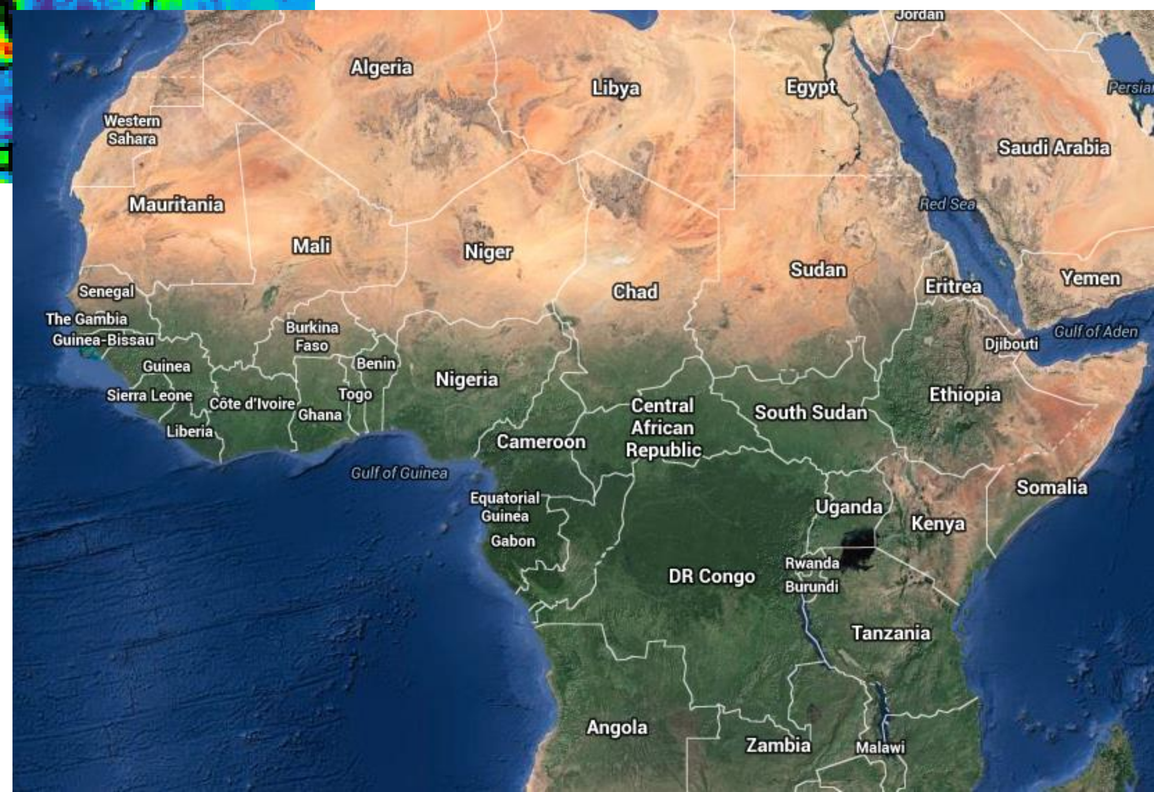
N
-165 -150 -135 150 165
75 60 45 30 15 0 -15 -30 -45 -60 -75
0.00 0.05 0.10 0.90 0.95 1.00
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70 0.75 0.80 0.85 0.90 0.95 1.00

NASA LARC 0.25-Degree Gridded AVHRR Overshooting Top Pixel Count Mean Per Season: 1982-2014 N. Hemi. Summer



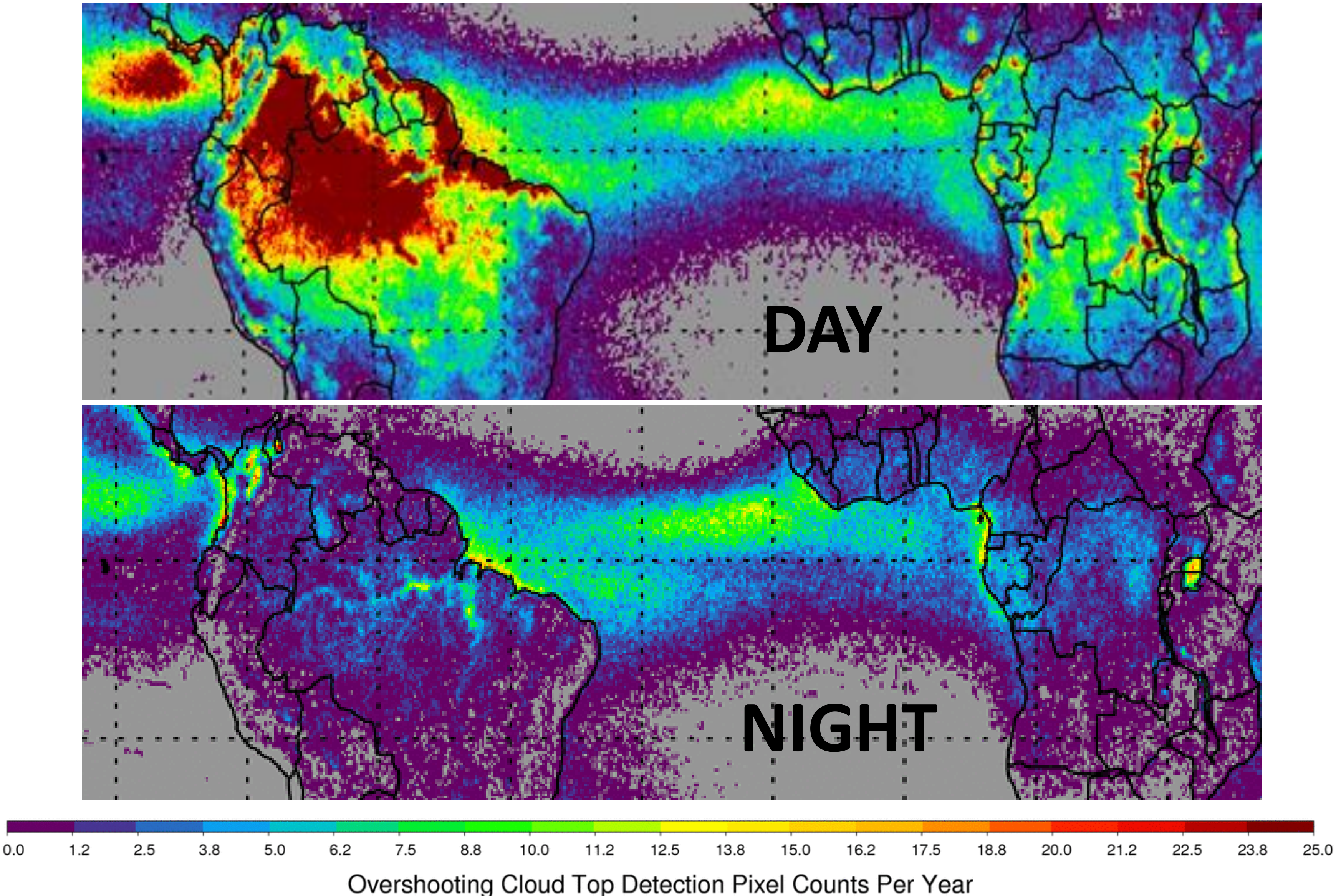

NASA LARC AVHRR Ice Cloud Optical Depth: SUMMER DAY
NOAA-07 to -19
Bright Reflective Ice Cloud Does Not Always Contain Overshooting Top!
0.00 1.50 3.00 4.50 6.00 7.50 9.00 10.50 12.00 13.50 15.00 16.50 18.00 19.50 21.00 22.50 24.00 25.50 27.00 28.50 30.00
Ice Cloud Optical Depth





Greater daytime Ice Cloud Optical Depths linked to mountainous regions, sea/lake breeze and land cover variability

AVHRR 1982-2014 Northern Hemisphere Spring OT Climatology, Day vs. Night



Why Develop a New Geostationary Imager-Based UTLS-Penetrating Storm Climatology?

- **UTLS-penetrating updrafts and evidence of above-anvil ice detrainment exhibit essentially the same patterns in visible and IR imagery, regardless of storm location or season**

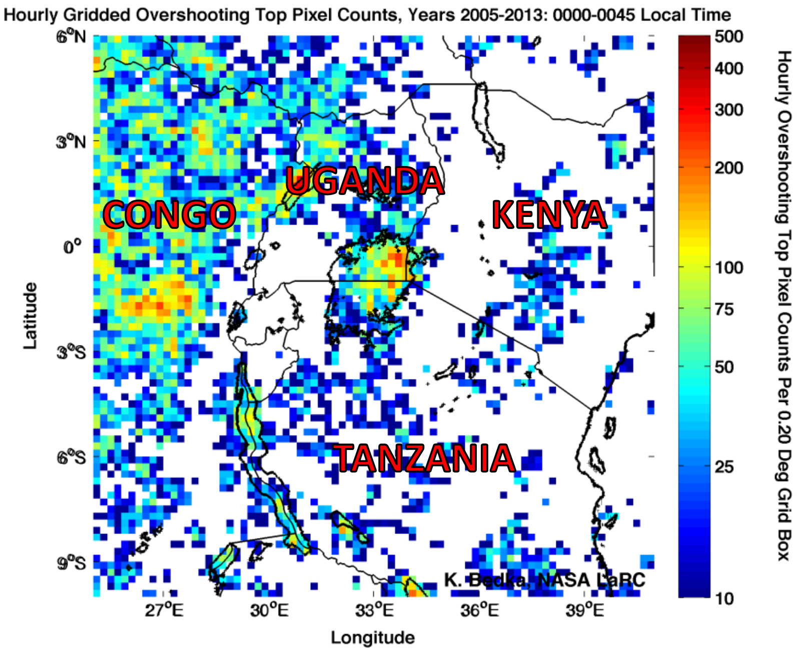
- **Geostationary (GEO) satellite imagers have been collecting detailed observations (~ 5 km/pixel, 30 min frequency) of UTLS-penetrating storms for over 20 years**

- **Despite this fact, few approaches have been developed that can produce globally consistent, "climate-quality" analyses of historical UTLS-penetrating storm activity throughout the diurnal cycle**

- **If such an approach were developed, one could determine if/how storm frequency and distribution has changed in association with observed global temperature increase and land surface changes**

- **GEO climatology would provide context and fill in the gaps between temporally sparse LEO observations**

- **UTLS-penetrating storms are also often associated with hazardous weather**
  - Strong demand from private industry for GEO-based storm analyses to develop weather hazard risk models



5-Year Full-Disk SEVIRI OT Database

Number of OT Detections Per ~200 km Grid Box | **Mean OT Temperature**

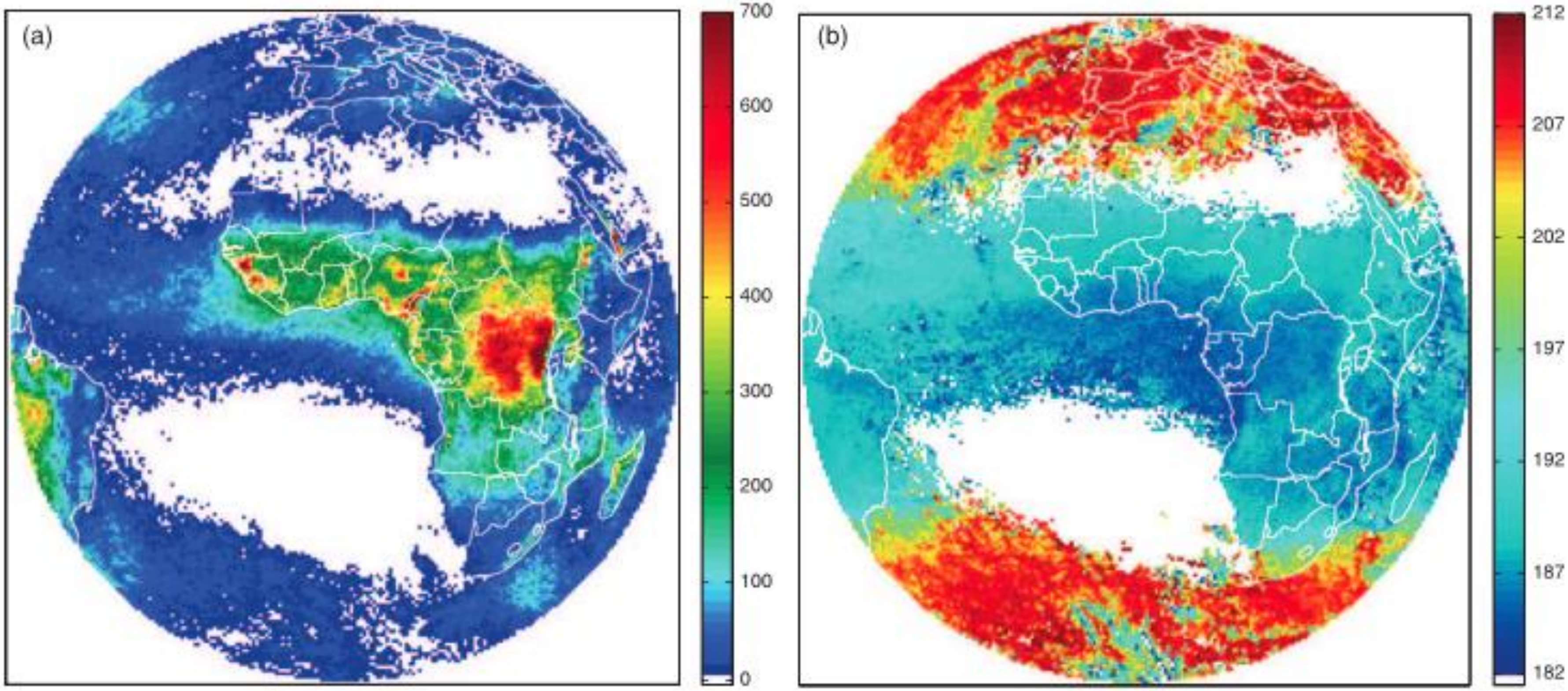


Figure 1. Spatial trends in the number of OT detections and their mean temperature for each 64 × 64 pixel grid box. Country borders and coastlines are outlined in white to aid with visualisation. (a) The total number of OT detections. Warmer colours represent higher OT detection counts. For clarity the image has been scaled to an upper limit of 700 counts, meaning that all pixels with higher counts will appear saturated in dark red. Only around 0.16% of pixels (in Central/South Africa) are affected by the scaling. White represents regions in which no OTs were detected. (b) The mean OT temperature (K) for all grid boxes. For clarity, very low temperatures have been scaled to a minimum value of 182 K which appears as dark blue.

Proud (QJRMS, 2015)

5-Year Full-Disk SEVIRI OT Database

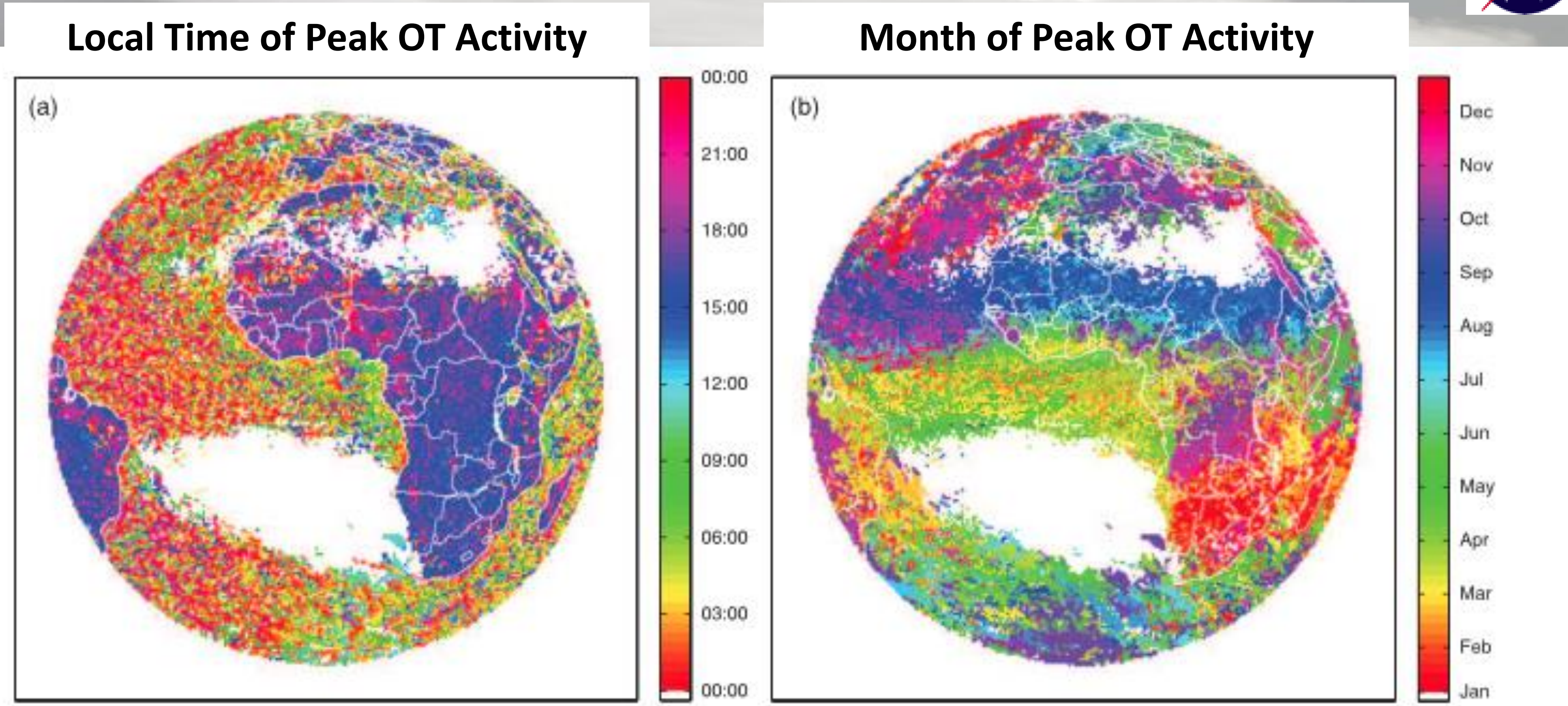


Figure 3. The (a) time of day (adjusted to local solar time) and (b) time of year for which the OT detection count peaked across the SEVIRI disk. In (b) the year is divided into 36 decades in order to reduce the amount of noise in the figure. There are three decades per month representing days 1–10, 11–20 and 21–end of month.

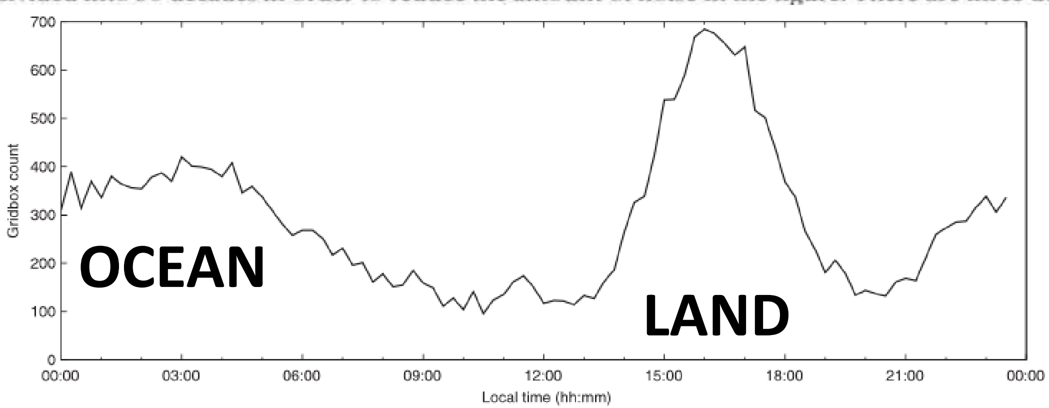


Figure 4. A histogram showing the number of grid boxes that show peak OT activity at a particular time of day.

Proud (QJRMS, 2015)

European Severe Hail Climatology

European Hail Risk
From Published Literature

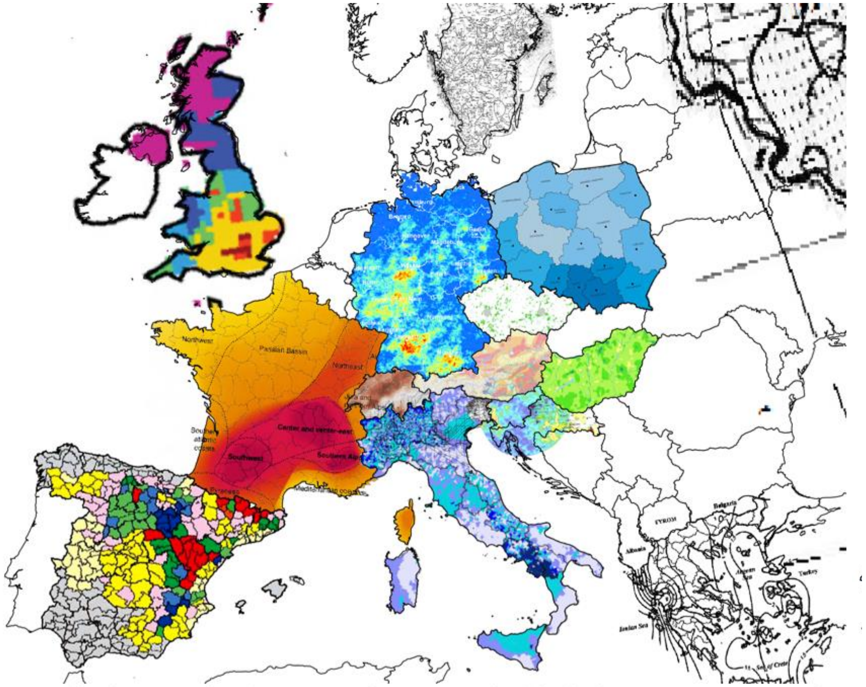
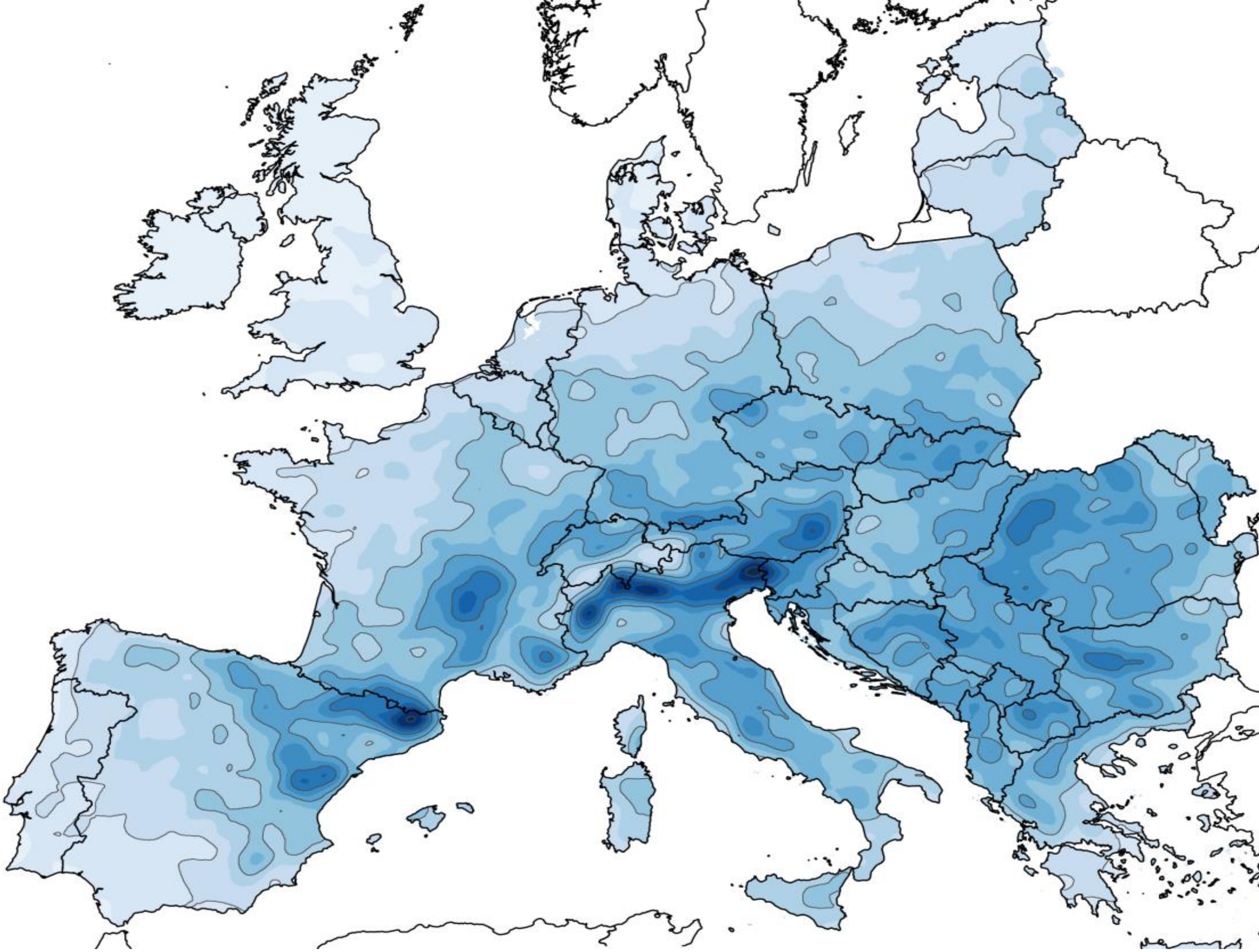
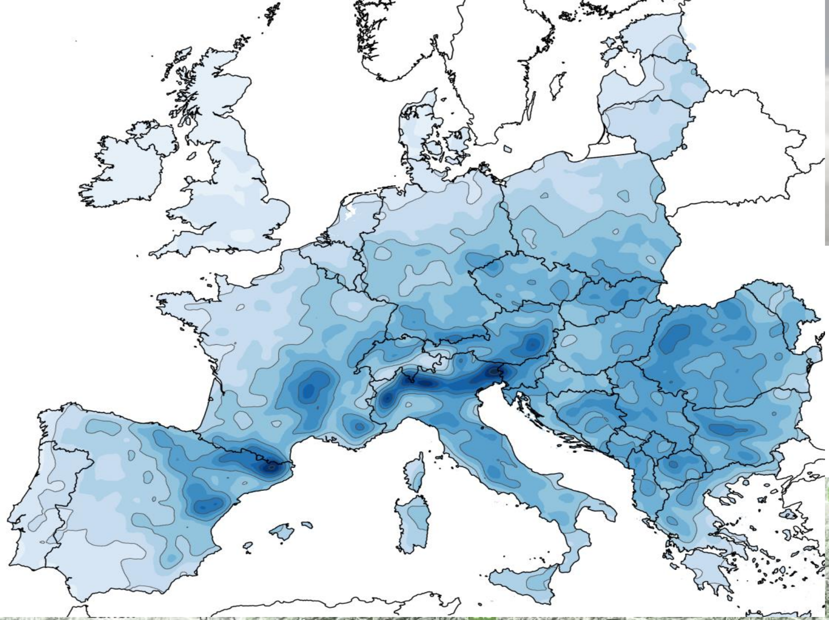


Figure 5: (left panel) A map of severe hail risk assessments for various nations across Europe from published literature. The methods used to derive these methods are inconsistent, resulting in an incoherent map that cannot be used effectively by private industry to assess hail risk. (right panel) A map of severe hail risk derived by Willis Re from a combination of 1) an 11-year database of Meteosat Second Generation overshooting convective cloud top detections, 2) hail-induced insured loss data from private industry, and 3) ground-based observations of severe hail. Darker shading indicates a greater climatological risk for severe hail. Adapted from the work of Punge et al. (Natural Hazards, 2014).





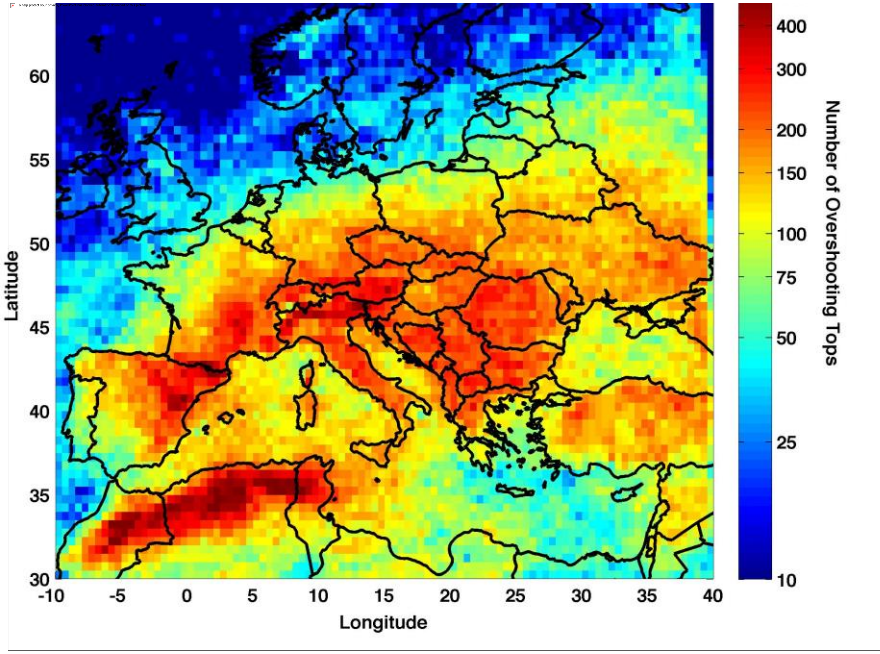

European
Hail Capital
Switzerland
Liechtenstein
Slovenia
Croatia
Bosnia and
Herzegovina
Italy
San Marino
Bern
Lucerne
Lausanne
Geneva
Annecy
Chamonix
Zermatt
Lugano
Como
Bergamo
Milan
Pavia
Turin
Genoa
Savona
La Spezia
Pisa
Livorno
Florence
Siena
Grosseto
Parma
Modena
Bologna
Ravenna
Cesena
Rimini
Ancona
San Benedetto
del Tronto
Ascoli Piceno
Pescara
Chieti
Terni
Trento
Bolzano
Bozen
Verona
Treviso
Venice
Padua
Udine
Trieste
Poreč
Rovinj
Opatija
Rijeka
Zagreb
Velika Gorica
Zadar
Šibenik
Split
Trogir
Mostar
Sarajevo
Zenica
Tuzla
Dubrovnik
Međugorje
Osijek
Pécs
Baja
Maribor
Graz
Klagenfurt
Villach
Innsbruck
Davos
St Gallen
Oberstdorf
Zell am See
Szombathely
Székesfehérvár
Veszprém
Keszthely
Siófok
Budapest
Győr
Sopron
Wiener
Neustadt
Baden
bei Wien
Bratislava
Esztergom
Vác
Dijon
Besançon
Mâcon
Vichy
Lyon
Saint-Étienne
Chambéry
Grenoble
Valence
Avignon
Nîmes
Montpellier
Sète
Aix-en-Provence
Marseille
Toulon
Cannes
Fréjus
Nice
Gap
Parc Naturel
Régional
des Ballons
des Vosges
Parc Naturel
Régional
du Morvan
Parc National
des Cévennes
Parc National
de la Vanoise
Parc national
du Mercantour
Parco
Nazionale
dello Stelvio
Nationalpark
Hohe Tauern
Adriatic Sea
Terrain
View topography and elevation
Earth

Willis Re Pan-European Hail Model

Unique Hail Risk Model for Europe

- **11 years of MSG SEVIRI OT detection data from NASA LaRC used to generate convective storm 'events'**
- European Severe Weather Database and NWP data used to develop convective storm event - severe hail relationships
- 40 countries explicitly modelled
- First model for the insurance market to cover such a variety and number of countries
- Willis Re Hail Risk Model now being widely used within the European reinsurance market
- **Punge et al. (2014, *Natural Hazards*)**

Willis Re European Hail Storm Severity Index

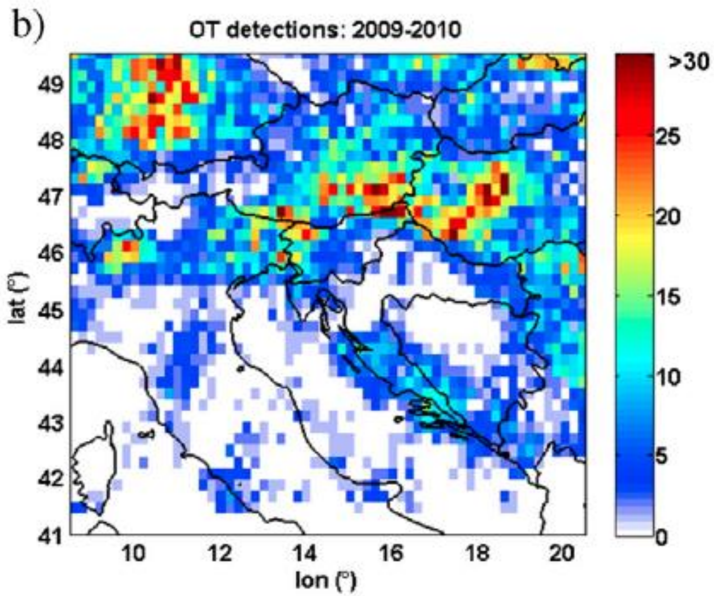


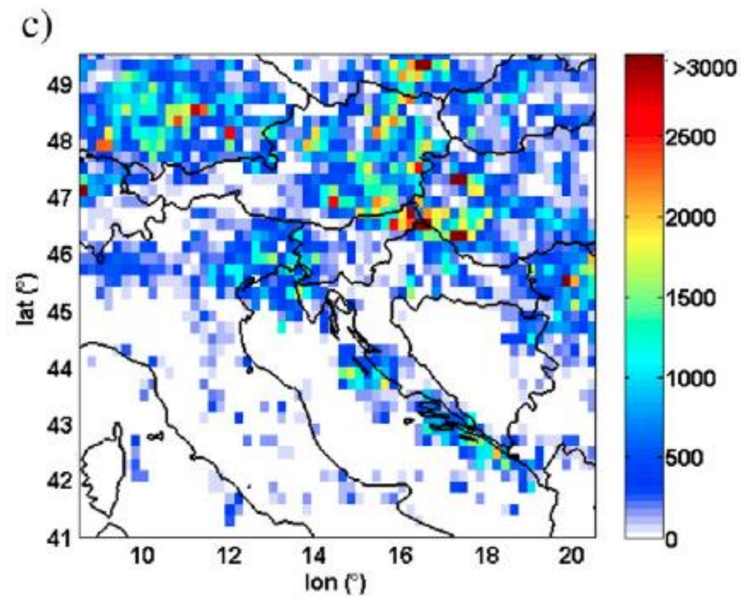
Willis Research Network

Willis Re

KIT
Karlsruhe Institute of Technology

Mikus et al. (2015) OT Detection Database Over Southeast Europe





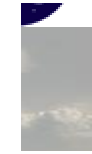


Fig. 2. a) Spatial distribution of total (IC + CG) lightning strokes computed over 0.2° × 0.2° grid boxes and b) number of OT detections using COMB method computed over 0.2° × 0.2° grid boxes from May to September 2009 and 2010. c) Number of lightning strokes 7.5 min before and after the time of the satellite scan within the range of 0.1° × 0.1° from the OT position. Spatial distribution is computed over 0.2° × 0.2° grid boxes.

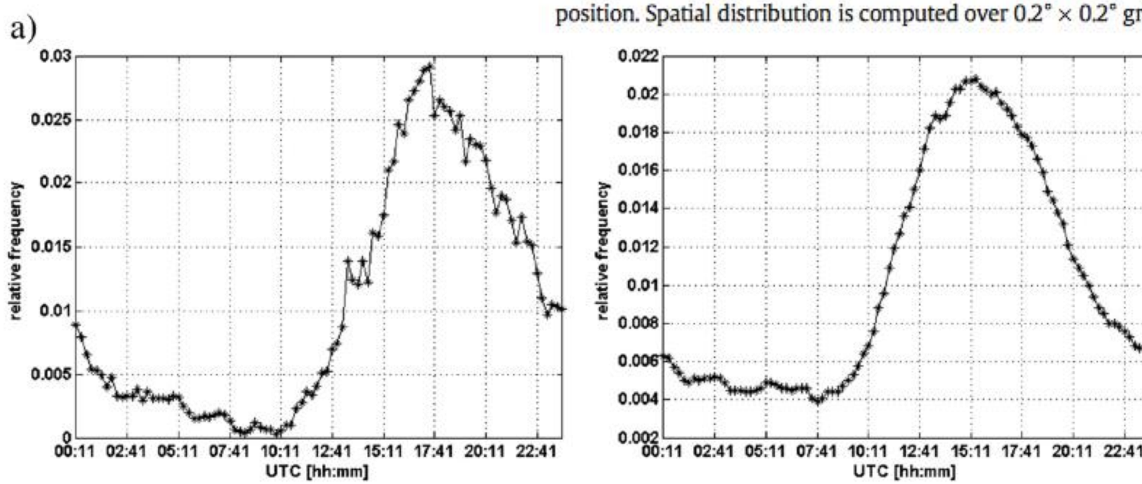


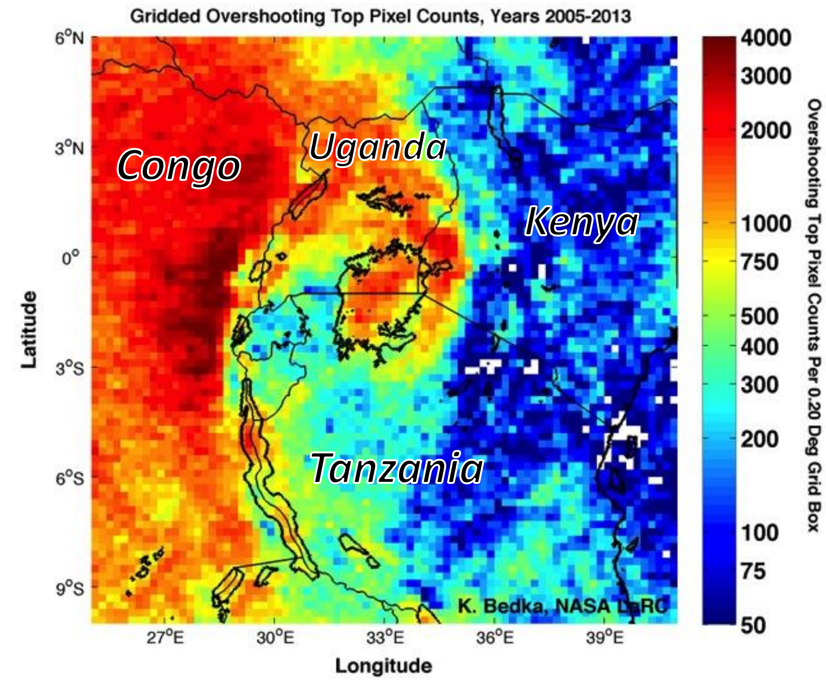
Fig. 3. Relative frequency of a) OTs detected using COMB method and b) lightning strokes, both calculated every 15 min, i.e. at the time of the satellite scan (app. 11 min after the nominal satellite time). Detected lightning strokes are grouped into 15 min bins, where number of strokes at the time of satellite scan represents a total number of all detected strokes during the time interval ±7.5 min from the time of certain satellite scan.

UTLS-Penetrating Storm Database over the African Great Lakes Region Using Bedka et al. (2010) Approach


Lethal weather on 'world's most dangerous lake'

From Errol Barnett, CNN

updated 9:48 AM EST, Thu January 17, 2013



5000+ people are killed on the African Great Lakes every year, most often caused by severe weather

NASA LaRC and international partners are determining 1) the controlling factors for the occurrence of hazardous thunderstorms over the African Great Lakes region and 2) how climate change could affect future storm activity via a regional climate model and satellite-based OT detection analysis

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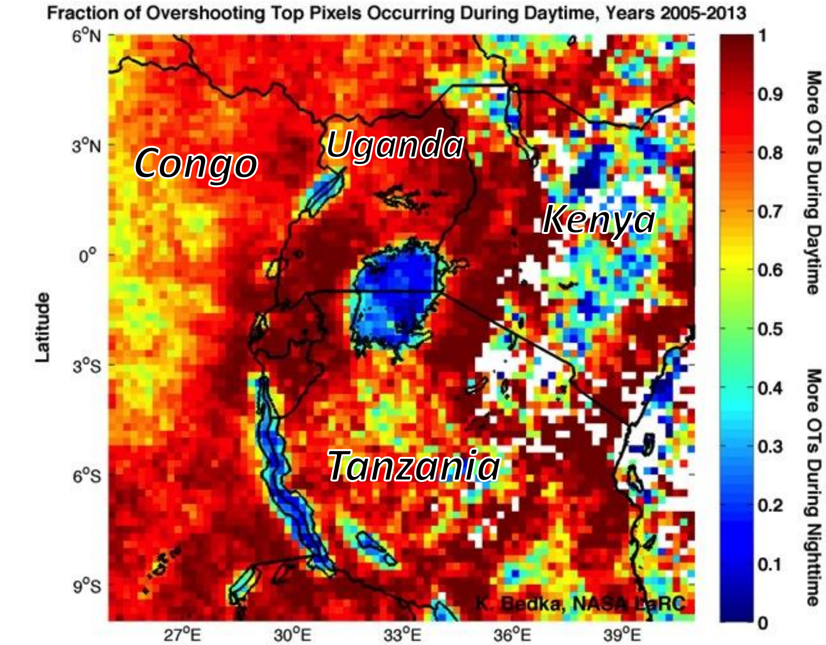
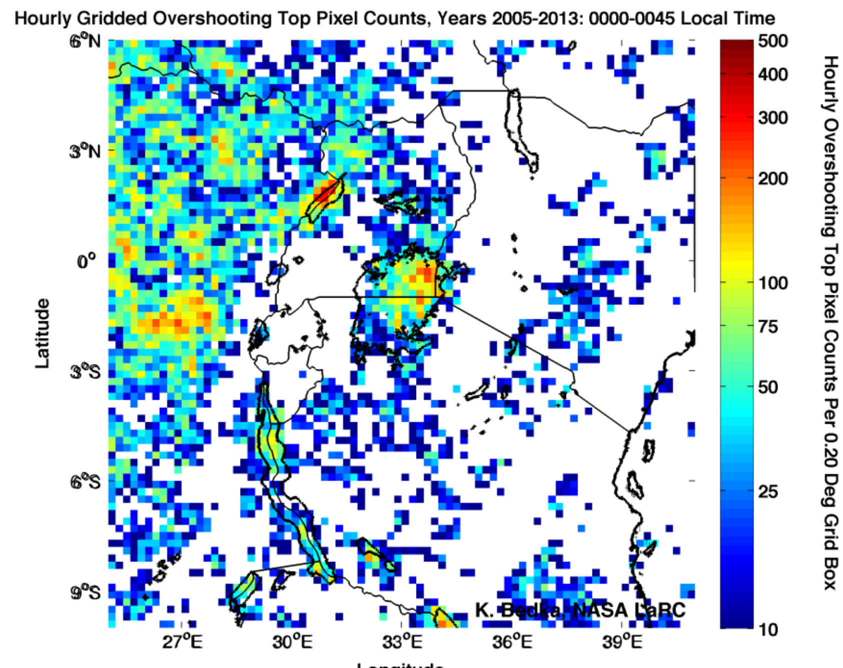
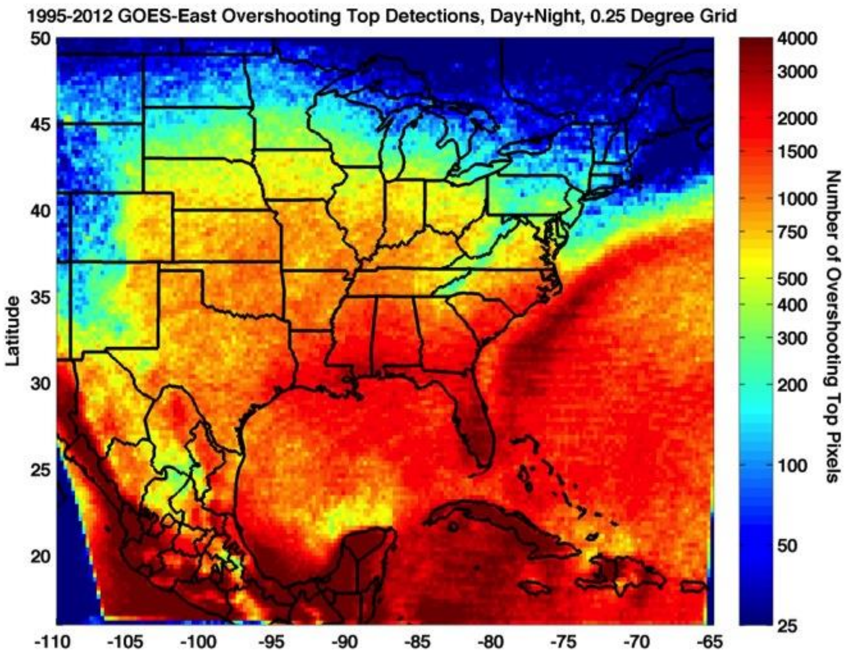
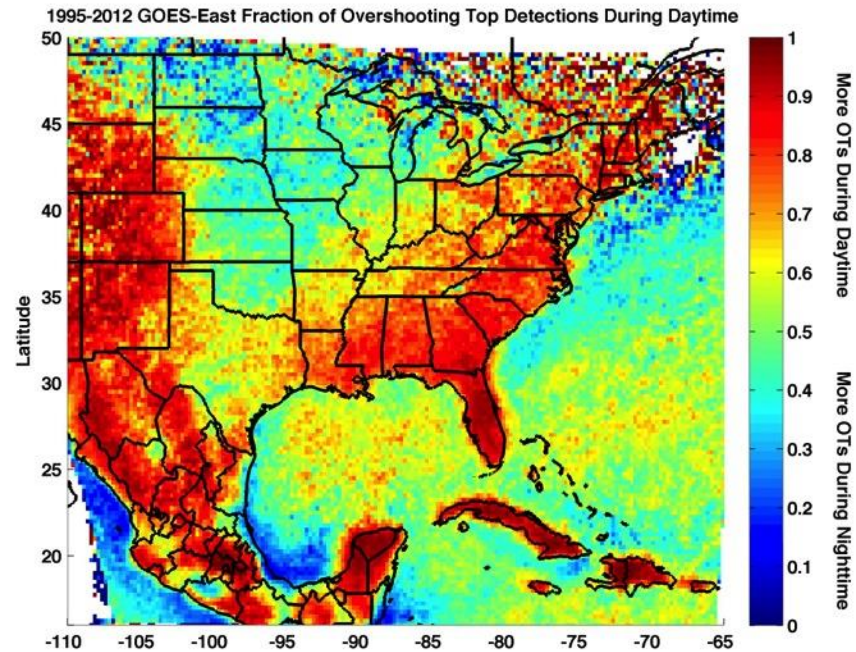


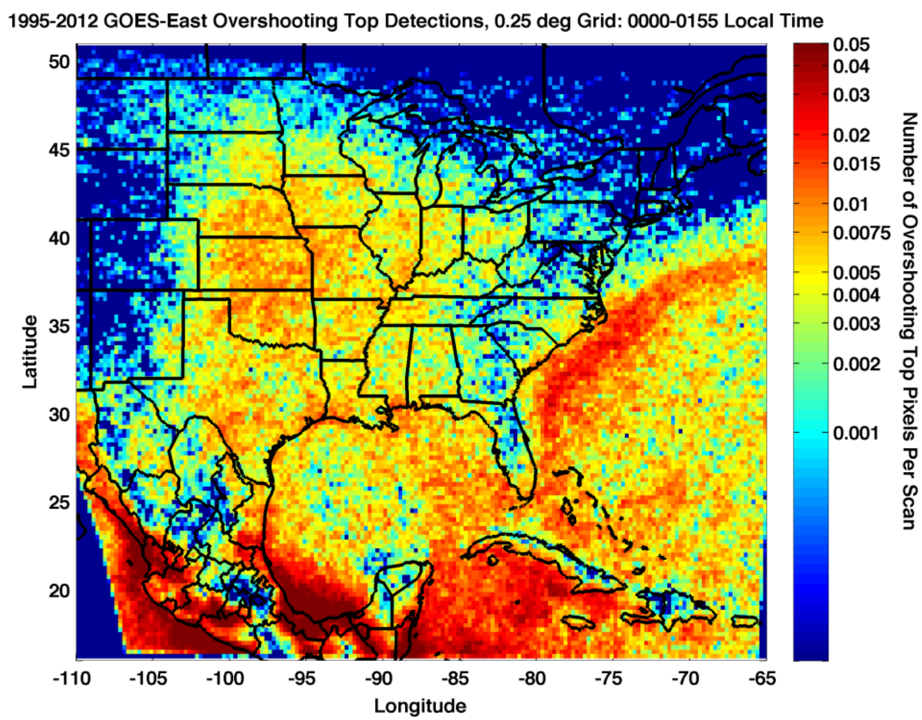






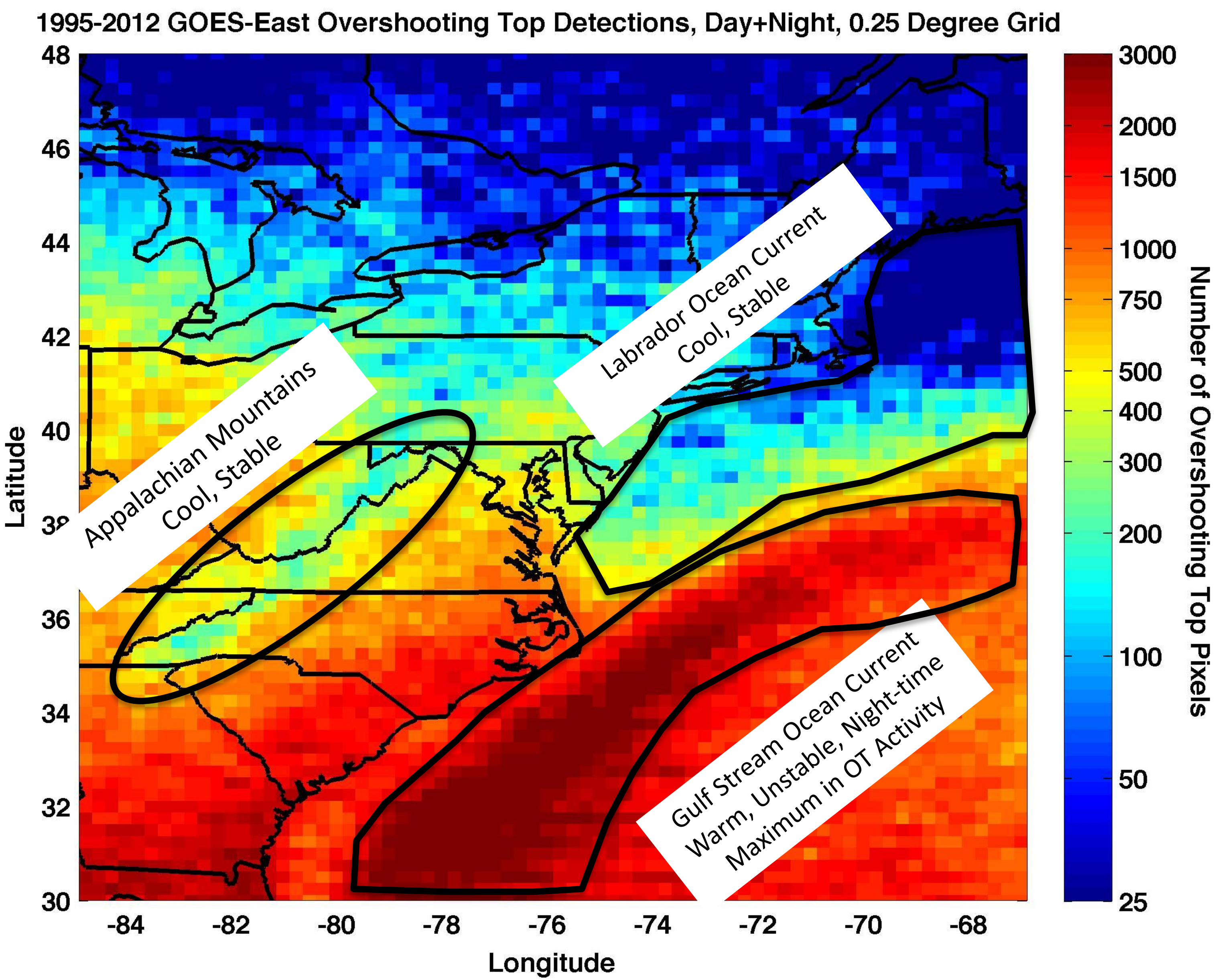
1995-2012 GOES-East OT Detections Using ~4 km Spatial Resolution Data and Two Images Per Hour

OT Detections Assigned To A 0.25 Degree Resolution Grid



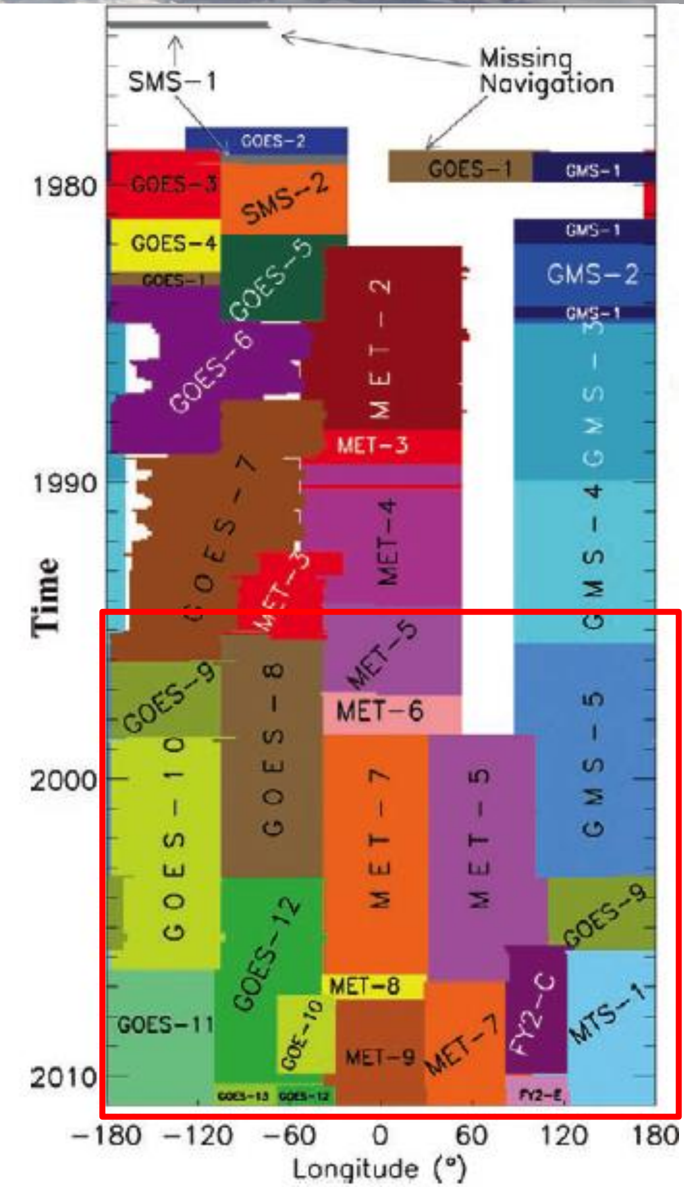
Data Courtesy of
UW-SSEC Acquired Via McIDAS

U.S. East Coast OT Climatology



Global GEO
Satellite Imager History
From Knapp et al. (BAMS, 2011)

Toward A Global GEO Climatology of Overshooting Cloud Top Events



≤ 5 km IR Spatial Resolution

- **The global constellation of geostationary (GEO) imagers have been collecting high spatial resolution (< 5 km) IR imagery since the mid-1990's. Resolution will increase by a factor of 4 in the GOES-R era.**

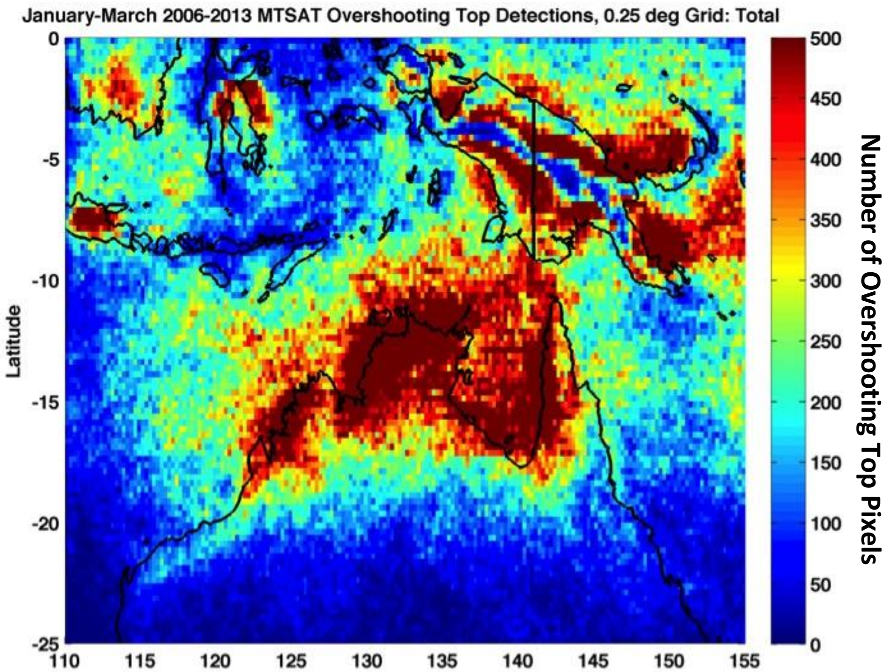
- **NASA LaRC has immediate access to the entire GEO image data archive via McIDAS. User requested data is available within < 30 seconds of request, enabling rapid development of a near-global UTLS-penetrating storm dataset**

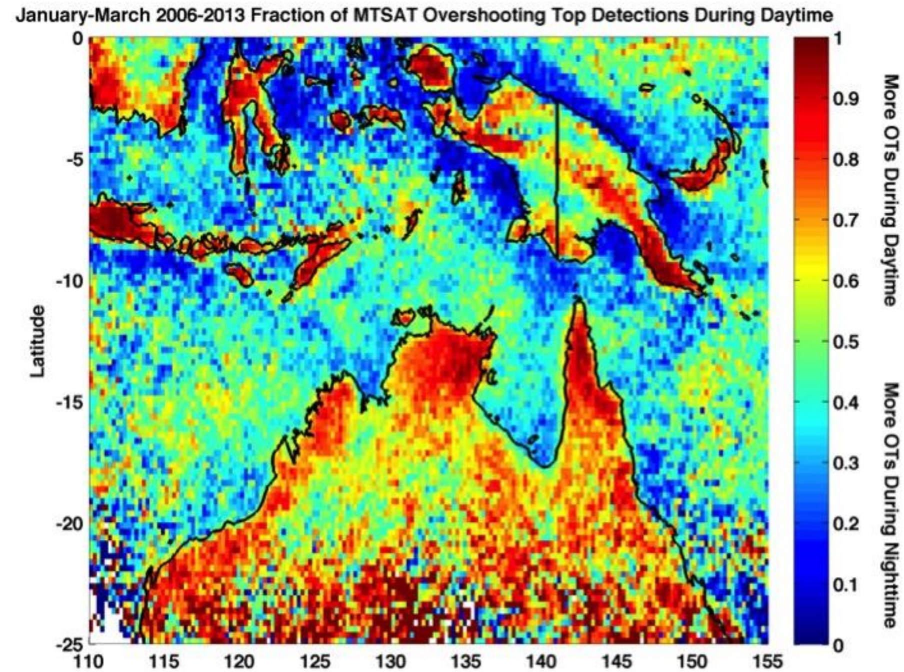
- **Remaining challenges include:**
  1) GEO IR intercalibration / trend analysis
  2) Viewing angle induced biases on IR brightness temperature

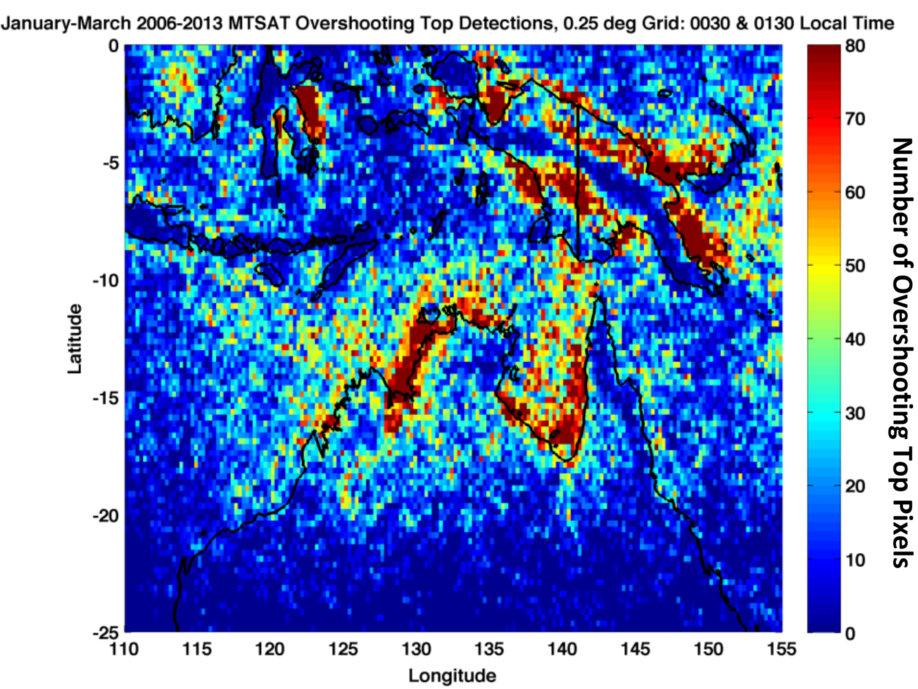
- **Challenges can be addressed by anchoring GEO calibration to stable, long-lived LEO satellite imagers, i.e. MODIS, AVHRR, or HIRS and building LEO-GEO viewing angle dependency models**

Summary

- **OT detection based on IR BT thresholding or spectral tests without taking into account the spatial characteristics of a convective cloud have not proven to be effective enough for the weather and climate community**
- **An automated overshooting cloud top (OT) detection algorithm has been recently improved in support of the GOES-R Advanced Baseline Imager program**
- **The algorithm uses advanced statistical, spatial, and spectral analyses to identify OT signatures at the individual satellite imager (~5 km) pixel scale**
- **An automated OT detection product has been demonstrated or could be used in a number of applications:**
    1) Real-time hazardous storm nowcasting
    2) Development of weather hazard risk models by the reinsurance industry
    3) Analysis of storm distribution throughout the diurnal cycle in data poor regions
    4) Analysis of the origin of anomalous stratospheric water vapor
    5) Validation of weather and climate model predictions of UTLS-penetrating storms
- **The highly efficient nature of the algorithm coupled with immediate access to the entire geostationary image archive from NASA LaRC enables development of a 20+ year OT event climate data record that can be used by the community to derive trends in hazardous storm frequency and distribution**







UTLS-Penetrating Storm Database over the Maritime Continent and Australia

- Generated using hourly data from MTSAT, January-March 2006-2013 in preparation for the international HIWC/HAIC field campaign
- Illustrates interesting diurnal variability in storm frequency and distribution associated with land vs. ocean and topography

Animation in lower-left located at:
http://cloudsgate2.larc.nasa.gov/site/people/data/kbedka/OTclimatology_2006-2013_MTSAT_HIWC_houranim.gif