Presentation 1A.3

A Probabilistic Pattern Recognition Method for Detection of Overshooting Cloud Tops Using Satellite Imager and Numerical Weather Analysis Data

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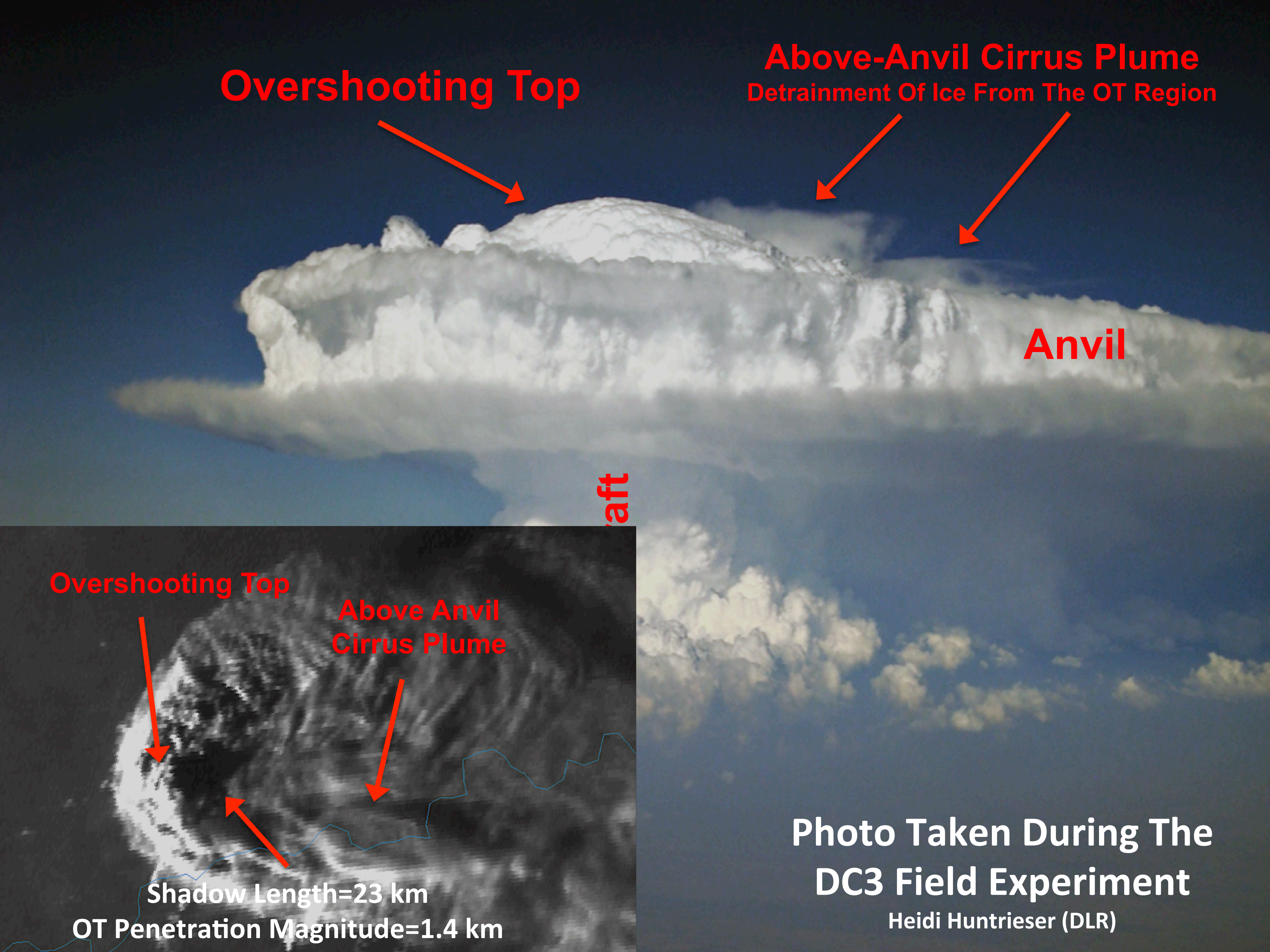
This work is supported by the
NOAA GOES-R Risk Reduction Research Program


Overshooting Top
Above-Anvil Cirrus Plume
Detrainment Of Ice From The OT Region
Anvil
Overshooting Top
Above Anvil
Cirrus Plume
Shadow Length=23 km
OT Penetration Magnitude=1.4 km
Photo Taken During The
DC3 Field Experiment
Heidi Huntrieser (DLR)

Introduction

- **Hazardous convective storms produce unique signatures in satellite imagery that can be used to infer dynamical processes occurring within the storm**
  1) Rapid vertical cloud growth during initiation phase (cloud top cooling)
  2) ***Locations of strong convective updrafts (overshooting tops)***
  3) Stratospheric moisture/ice injection (above-anvil cirrus plumes)

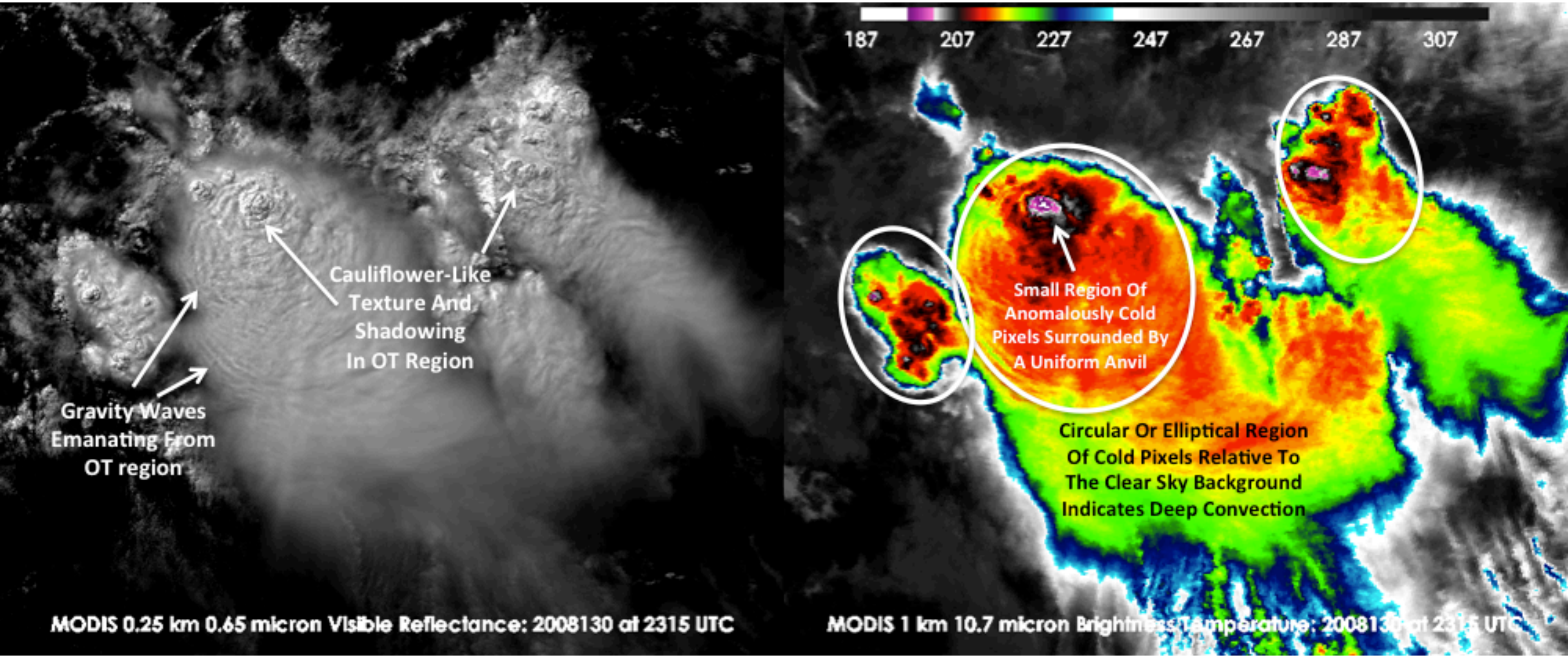
- **Weather radar observations are widely used for hazardous storm identification and forecasting**
  - Radar data only freely available and well calibrated over the U.S., limited length of data record, gaps in network preclude radar data use for long-term global climate studies

- **Polar-orbiting imagers have been operational for a 35+ year time period. High-resolution geostationary imagers have been operational for 20+ years, providing detailed observations of hazardous convective storms throughout the diurnal cycle**

- **Supported by the NOAA GOES-R Risk Reduction Research Program, NASA Langley has developed a pattern recognition method to identify hazardous overshooting updrafts using data from any satellite imager**

- **This overshooting updraft detection product is designed to be used in both forecast operations and for development of long-term climate data records of global hazardous convective storm events**

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



<u>How Can A Computer Emulate The Human Mind?</u>

- 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 overshooting top features anywhere at any time

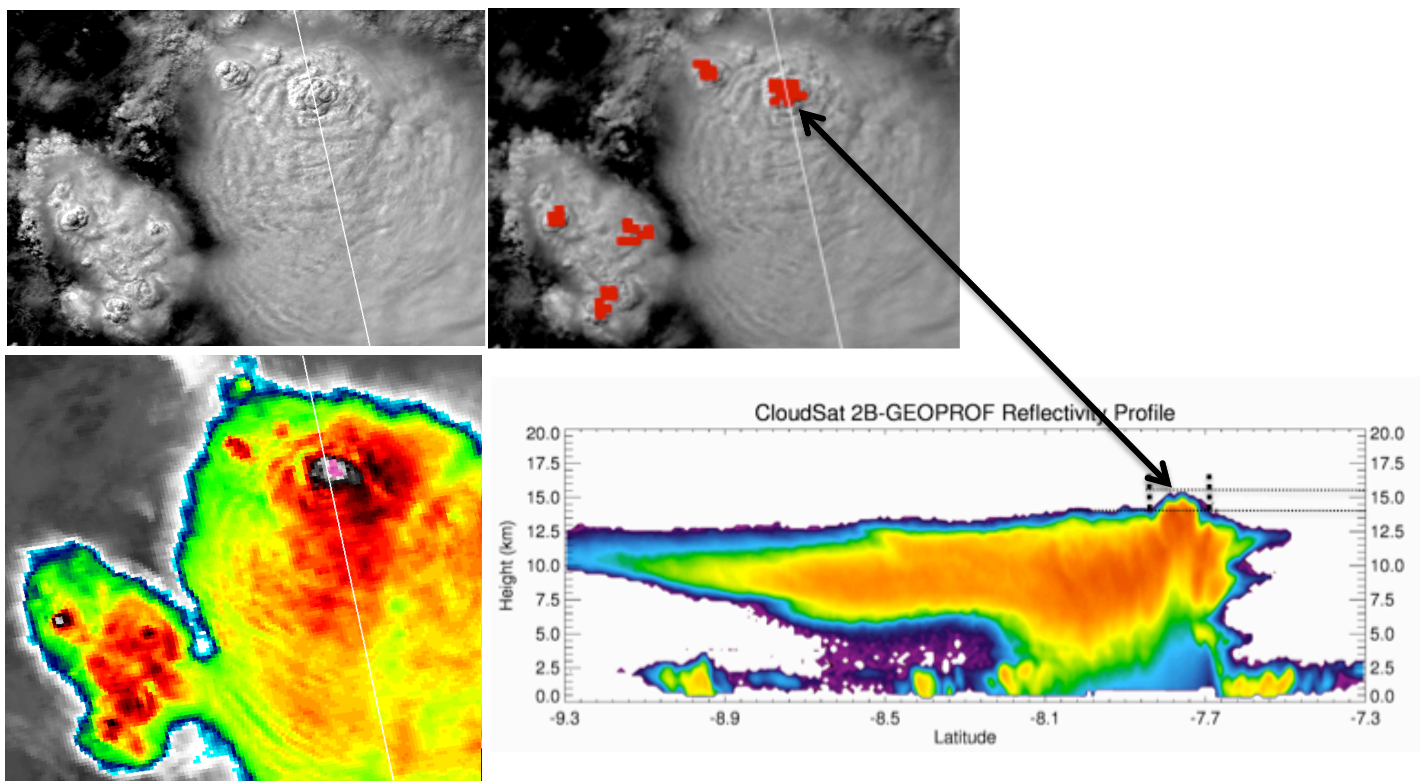
Bedka et al. IR-Based Overshooting Cloud Top Detection

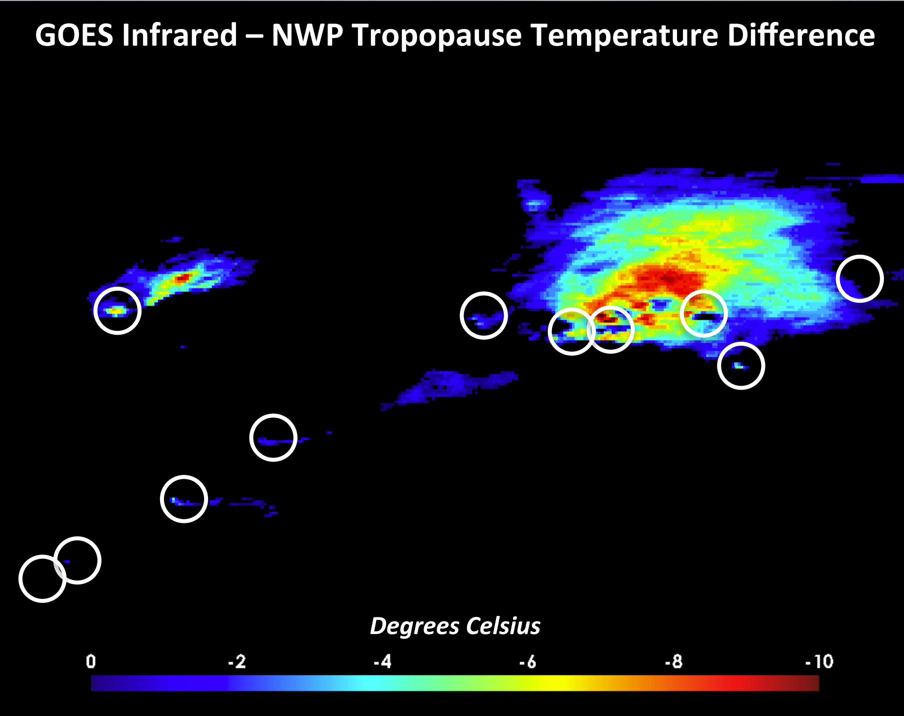
- **Hazardous convective storms typically have one or more overshooting tops (OTs)**

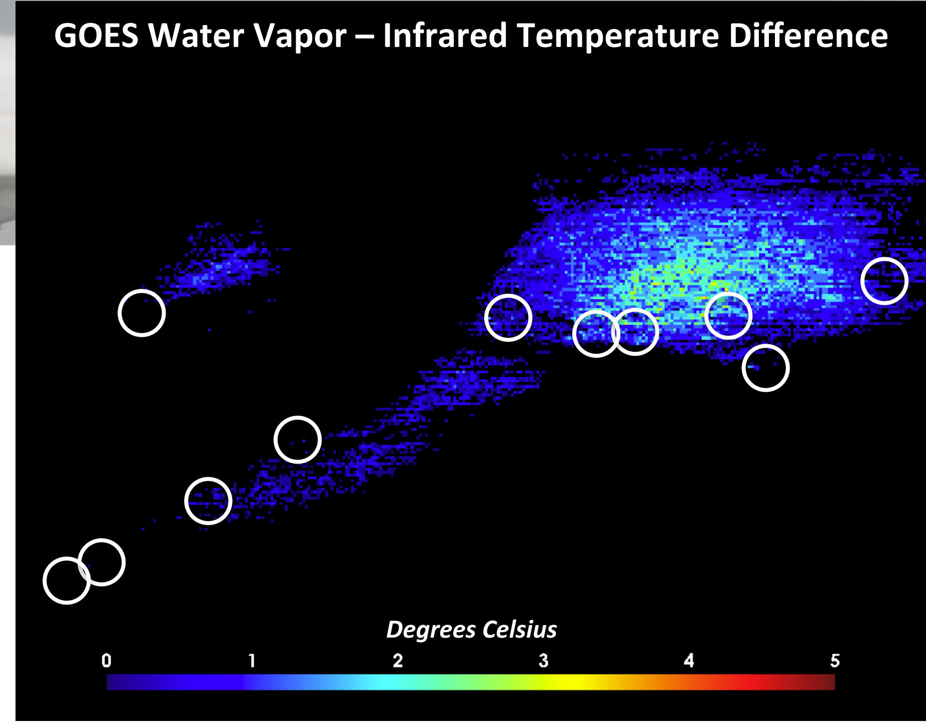
- **A satellite-based method to detect hazardous convective clouds was initially funded by the NASA Applied Sciences Program and later the GOES-R ABI Aviation Algorithm Working Group for aviation safety and weather forecast applications (Bedka et al. 2010-2012)**

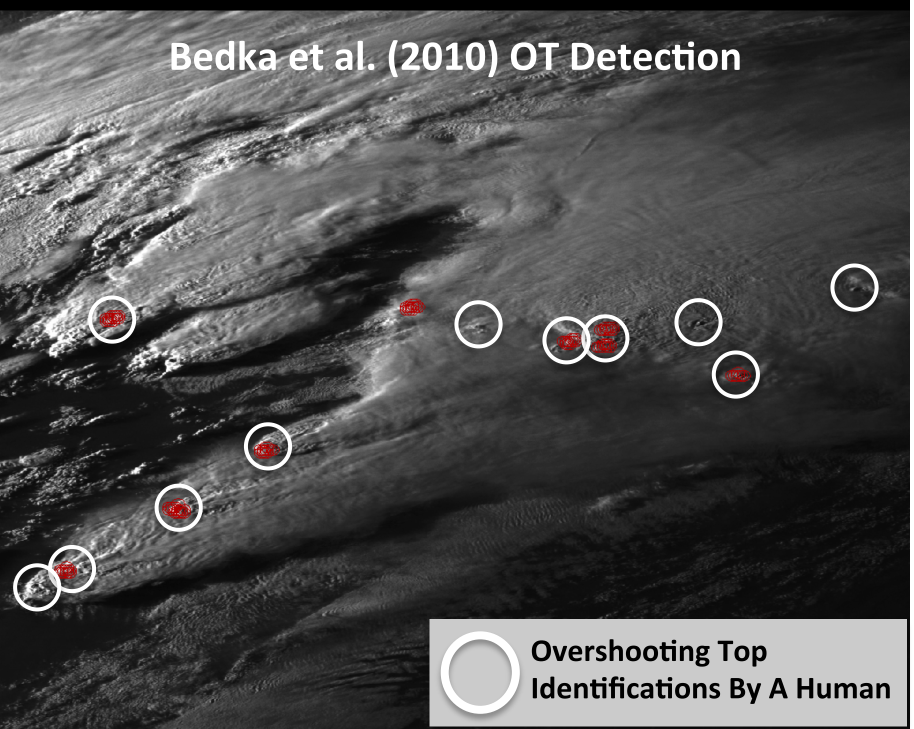
- **The method uses spatial analysis and thresholding of satellite IR temperature combined with NWP tropopause to automatically identify individual OTs pixels using data from any GEO or LEO imager**

MODIS 250 m Visible, 1 km IR, and Overshooting Cloud Top Detections









Limitations of Current OT Detection Approaches

- **All approaches use fixed criteria for binary yes/no OT detection**
- Detection techniques that use WV signals identify large portions of the convective anvil and are incapable of isolating only OT regions.
- Bedka et al (2010) is the only approach that uses spatial analysis of the anvil cloud for detection
- No approches use the visible channel which typically provides the clearest indication of an OT. Variations in solar illumination throughout a day makes automated visible-based OT recognition especially challenging

Probabilistic Overshooting Cloud Top Detection

GOAL: Mimic the process used by the human mind to identify overshooting cloud tops (OTs) using visible & infrared satellite imagery and numerical weather prediction (NWP) model data within an automated computer algorithm

Satellite IR and Visible OT Indicators Derived Via Image Pattern Recognition
+ NWP Instability 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 Two Populations

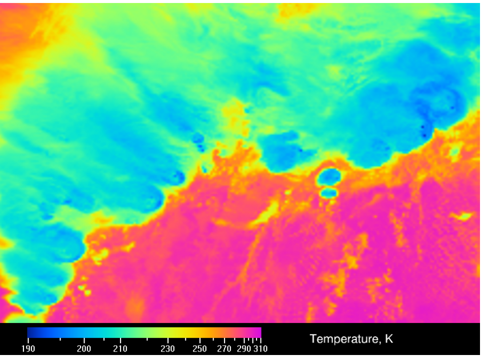
OT Probability Product

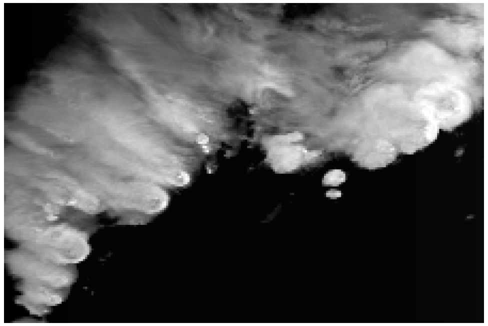
Infrared Channel Analysis

BT Score: $\text{BTscore} = \left(T_{avg} - T\right)^{0.7}\left(255 - T\right)^{1.3} / 1600 + 2 \cdot \sigma(T)$

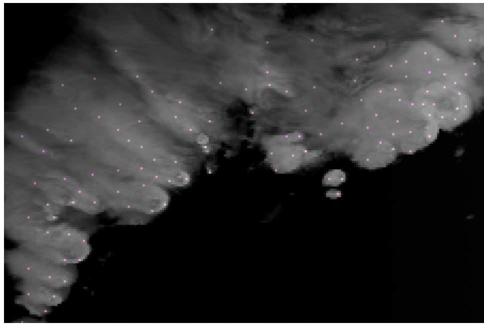
Used to eliminate need for a fixed BT threshold, enhance deep convection, and filter convective from non-convective clouds

Input MODIS IR Temperature (BT) Image, Remapped To 4 km/Pixel

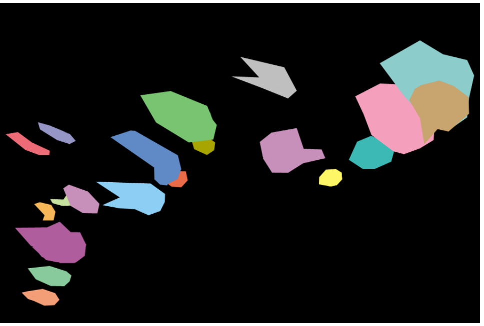




Identify Local BT Score Maxima As Initial OT Candidates



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

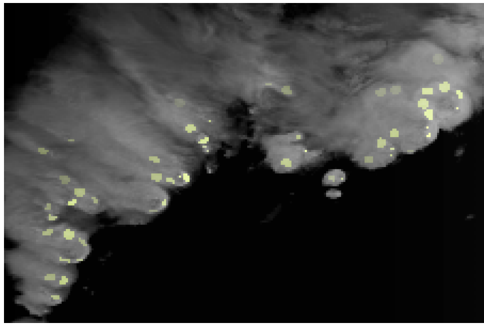


Pattern recognition quantifies the following scene characteristics. This is done to ensure that 1) the region being analyzed is indeed deep convection and 2) the feature of interest has similar shape and prominence typical of OT regions

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

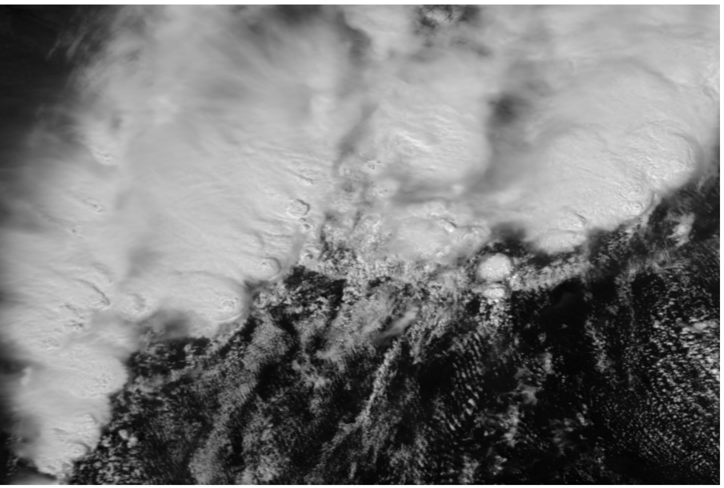
The net result is a cumulative rating obtained for each possible OT region. Pixels with a non-zero rating are considered as final candidate OT regions

Final OT Candidate Regions Based on IR Analysis

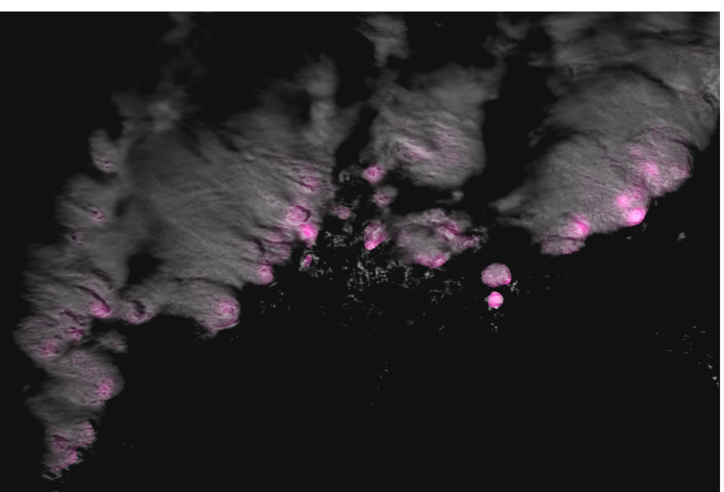


Visible Channel Analysis

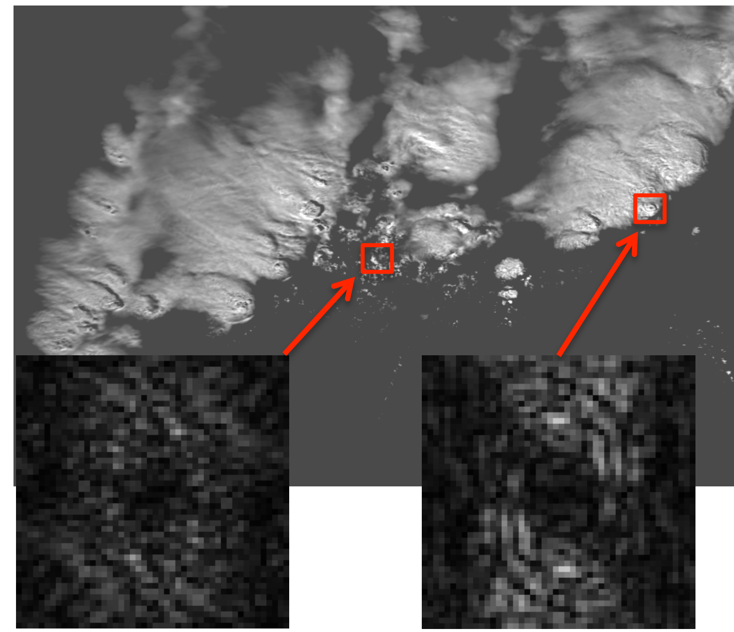
Input MODIS 1 km Visible Image



Final OT Candidate Regions Based on Visible Analysis



Non-linear Brightness Correction to Highlight Convective Clouds and Suppress Other Cloud Types



Fourier frequency spectrum of an area with random spatial variability.

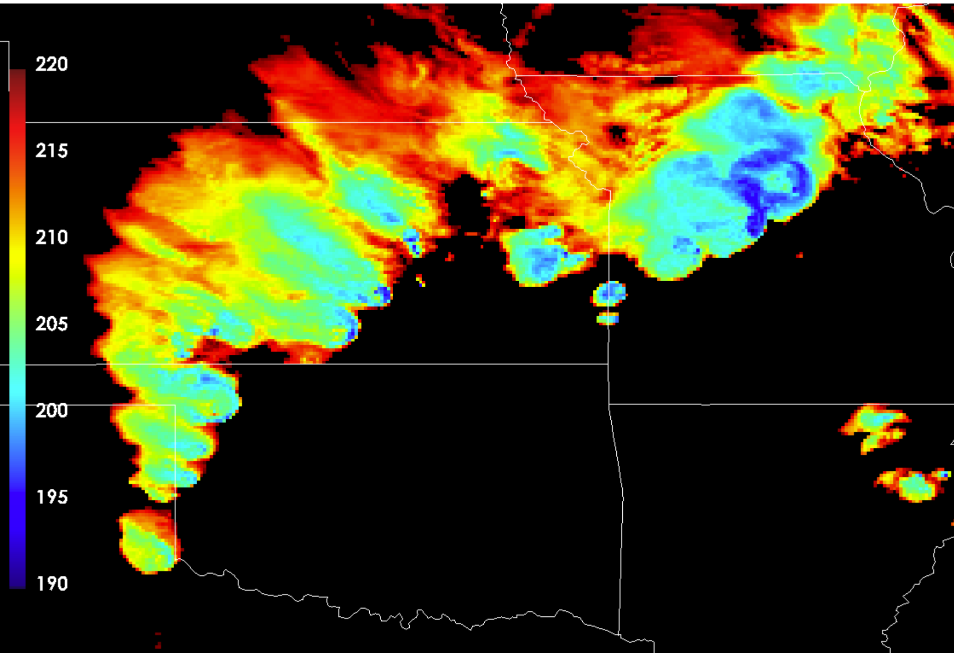
No ring pattern in the spectrum

Fourier frequency spectrum of a typical OT region

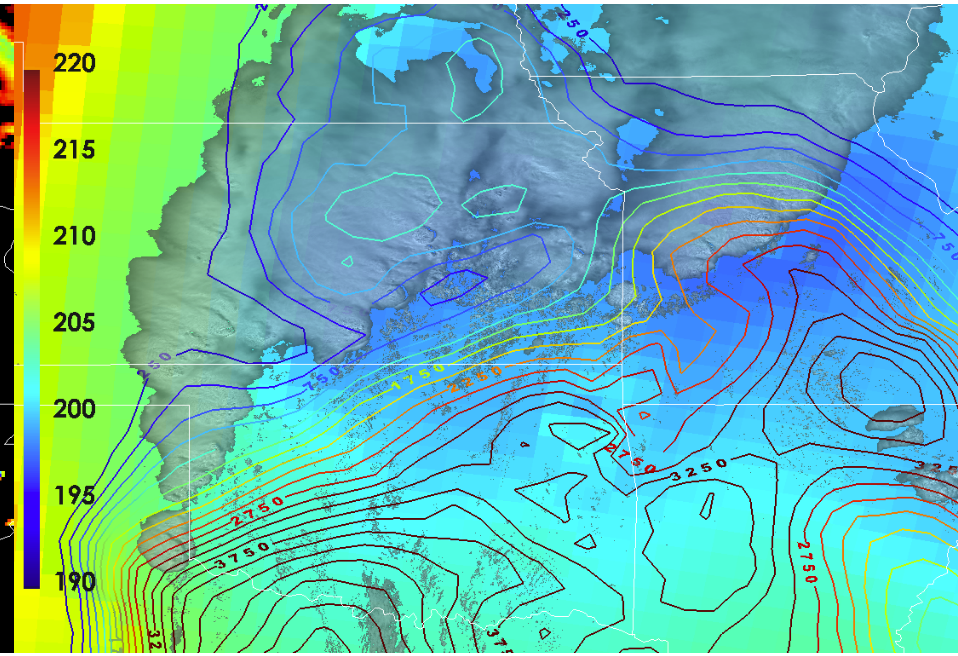
Ring fragments in the spectrum can be identified

Infrared Comparisons With NWP Model Fields

Input MODIS Infrared Image



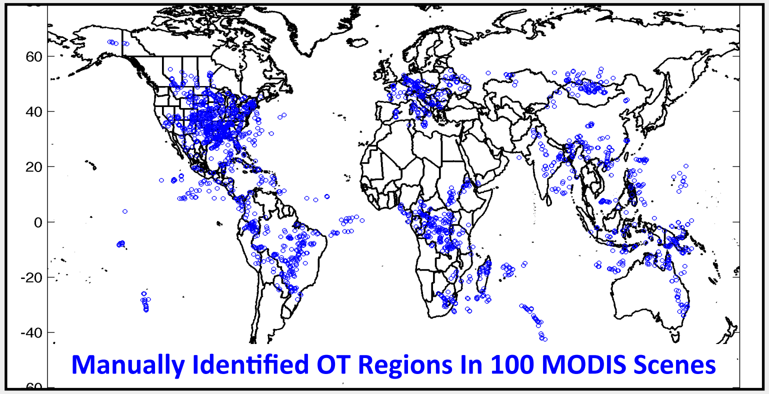
MODIS Visible Overlaid With NWP Tropopause Temp and CAPE Contours



- **A set of NWP-based parameters were evaluated for statistical significance in the logistic regression model**
- **The Satellite Infrared – Tropopause Temperature and Infrared – Most Unstable Equilibrium Level Temperature differences were significant for OT discrimination at the 99+% confidence level**

Logistic Regression and Final OT Detection Product

A database of ~2000 OT events were manually identified in 100 daytime 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 identify only OT-like features

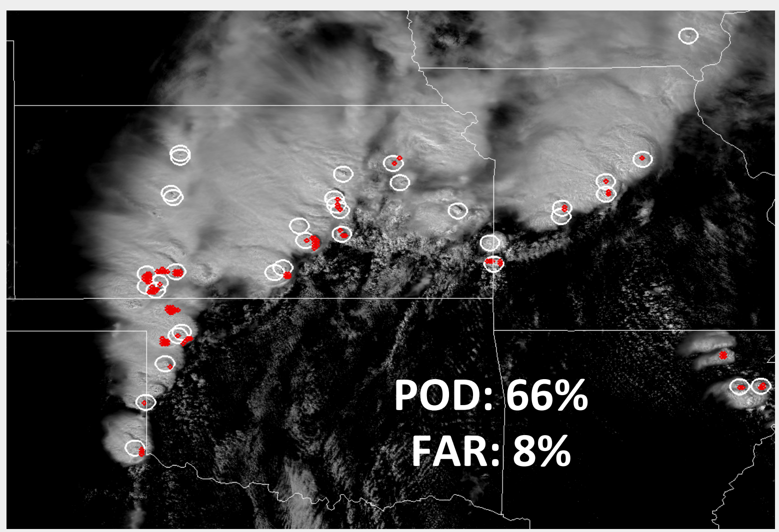


$$Regression\ Result = W_0 + W_1 * IR\ BT + W_2 * (OT - Mean\ Anvil\ IR\ BT) + W_3 * Visible\ Texture\ Rating + W_4 * (IR\ BT - Tropopause\ Temp) + W_5 * (IR\ BT - MU\ Equilibrium\ Level\ Temp)$$

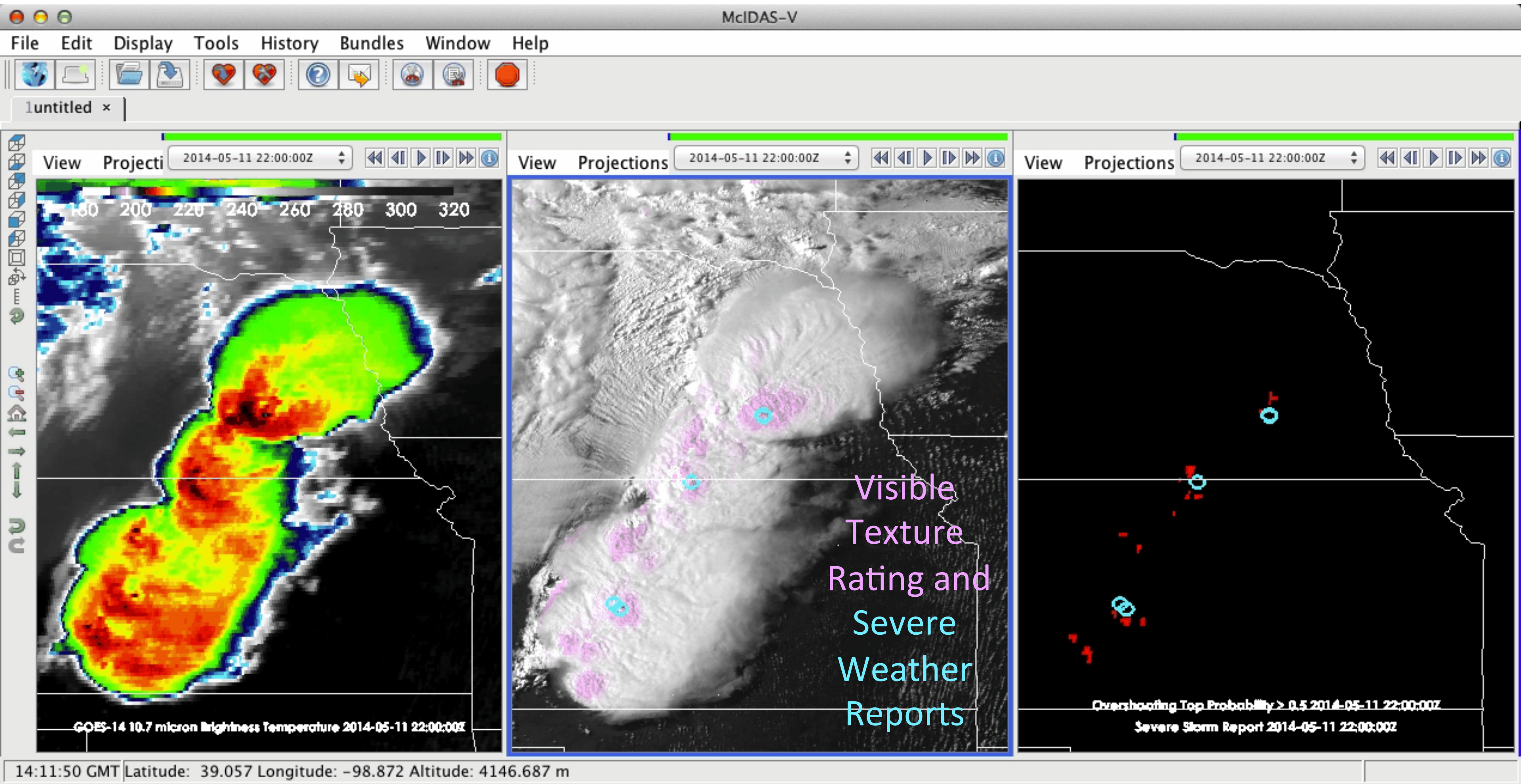
OT Probability

$$\frac{1}{(1+\exp(-1*Regression\ Result))}$$

OT Probability ≥ 0.5 (Red) Overlaid Upon Manual OT Identifications (White Circles) and 250 m Visible Imagery



GOES-14 1-min Super Rapid Scan
OT Detection Animation: 11 May 2014

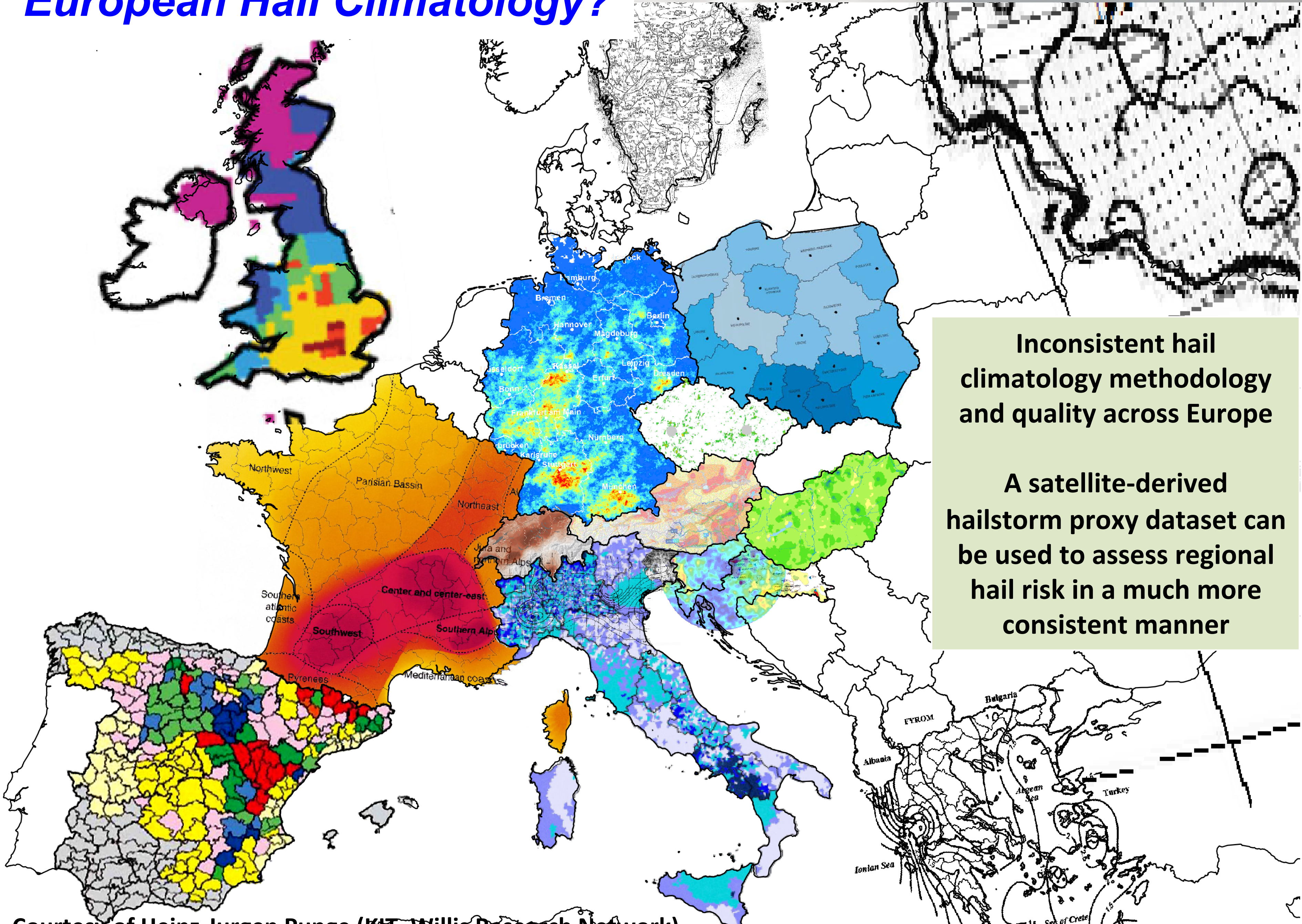


GOES-14 Super Rapid Scan
IR Temperature

Visible + IR + NWP Overshooting
Top Probability > 0.5
Overlaid With Severe Reports

SATELLITE-BASED OVERSHOOTING CLOUD TOP DETECTION PRODUCT APPLICATIONS

European Hail Climatology?



Inconsistent hail climatology methodology and quality across Europe

A satellite-derived hailstorm proxy dataset can be used to assess regional hail risk in a much more consistent manner

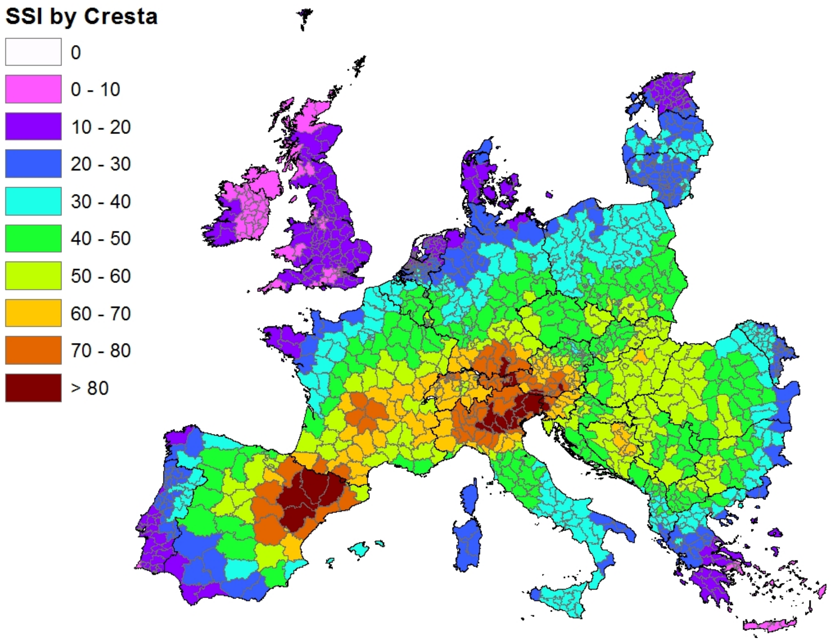
Courtesy of Heinz-Jurgen Punge (KIT, Willis Research Network)

Willis Re Pan-European Hail Model

Unique Hail Risk Model for Europe

- **11 years of MSG SEVIRI OT detection data used to generate convective storm 'events'**
- European Severe Weather Database 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
- Stochastic simulation of 8,000 years
- 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

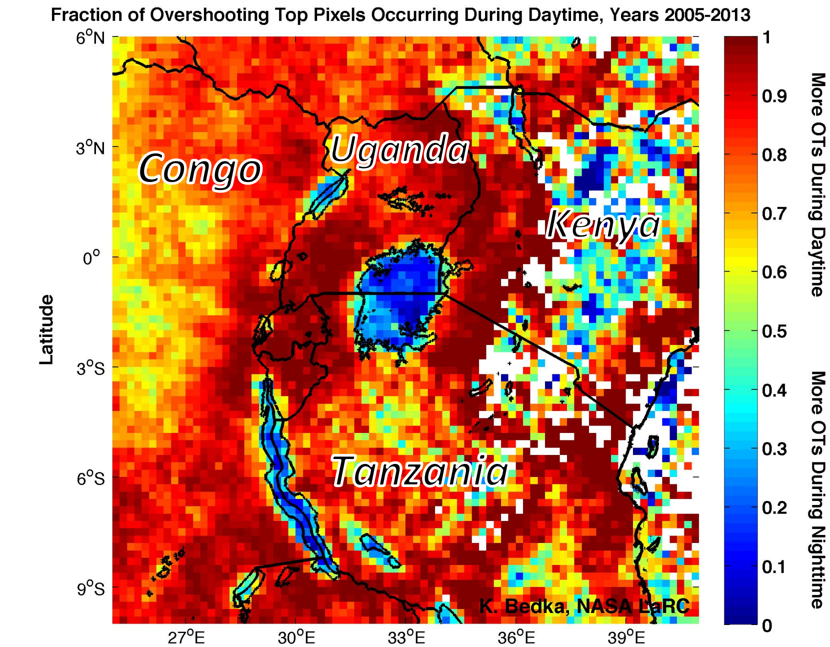
NASA

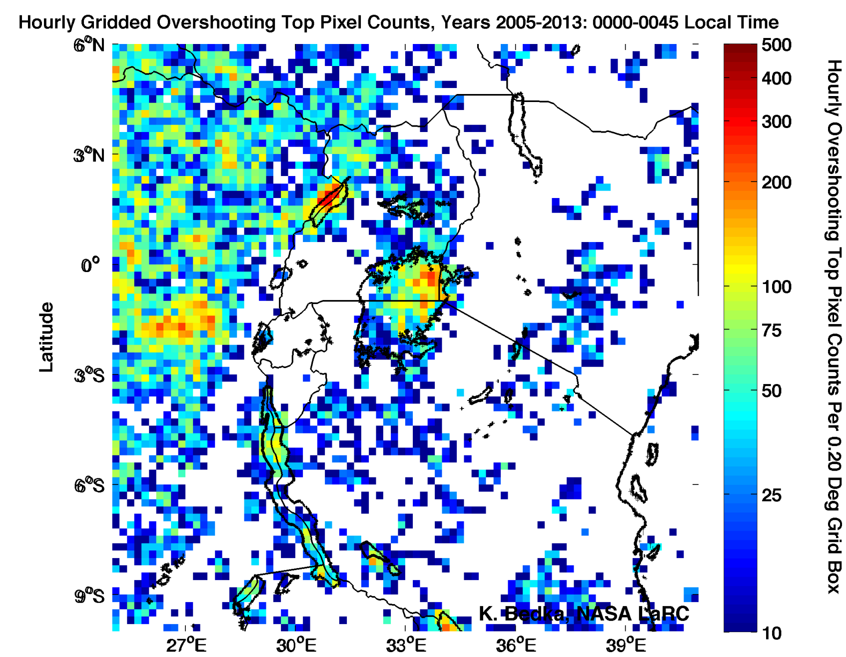
Hazardous Storm Event Database over the African Great Lakes Region

Lethal weather on 'world's most dangerous lake'

CNN World

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

Determine the controlling factors for the occurrence of hazardous thunderstorms over the African Great Lakes region via a regional climate model and satellite-based OT detection

OT Detection Product Demonstration Within The GOES-R Proving Ground

- **GOES-R Proving Ground is designed to make the weather community familiar with new products that can be produced from GOES-R Advanced Baseline Imager and Geostationary Lightning Mapper data**

- **The Bedka et al. OT detection product has been evaluated by forecasters at several NOAA National Forecast Centers to assess product value in their operations**

- **Many participants have found the OT detection (OTD) product to be useful in their operations:**

  "Very useful at night to highlight the strongest cells"

  "OTD helps to identify locations with stronger updrafts better than IR imagery alone. Strong to severe weather and/or intense rainfall typically correlates well with the OTD product"

  "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"

Summary

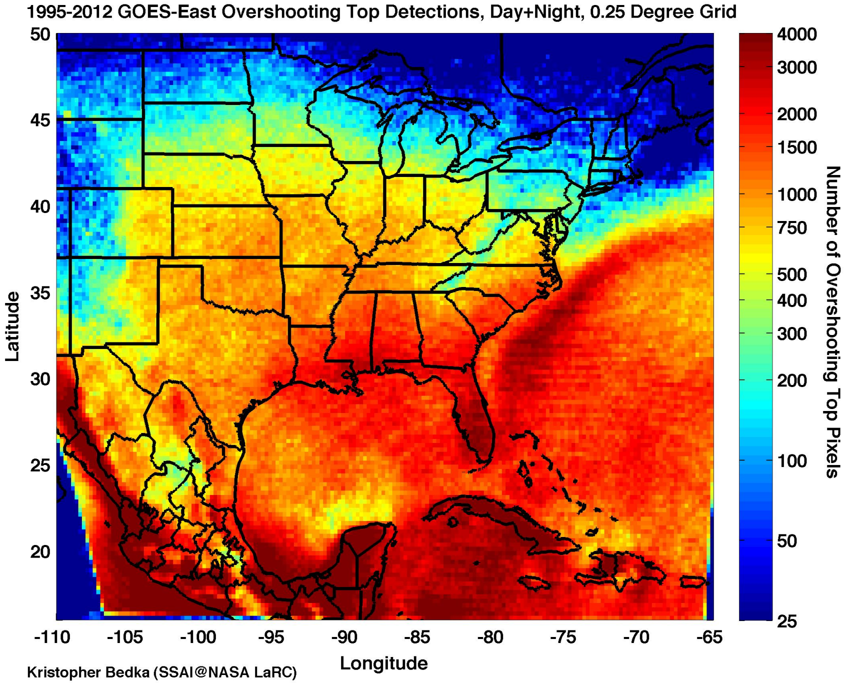
- **Use of fixed detection thresholds have limited the utility of existing overshooting top (OT) detection algorithms for generating climate-quality data records of global hazardous storm events**

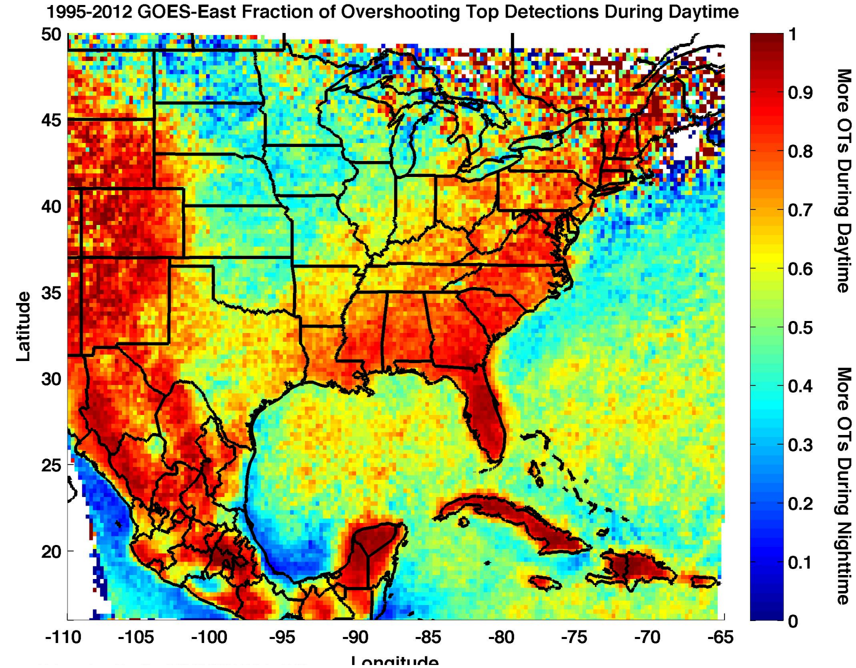
- **The GOES-R Risk Reduction Research Program has supported development of a probabilistic satellite-based OT detection approach that will provide temporally and spatially consistent identification of hazardous storm cells**

- **Key enablers of this work include:**

1) State-of-the-art data acquisition, visualization, and analysis via McIDAS
2) Sophisticated pattern recognition using satellite visible and infrared channel information
3) Incorporation of storm thermodynamic environment information from Reanalysis data
4) Immediate access to the global GEO satellite data record and the Reanalysis data record extending back to the 1980's

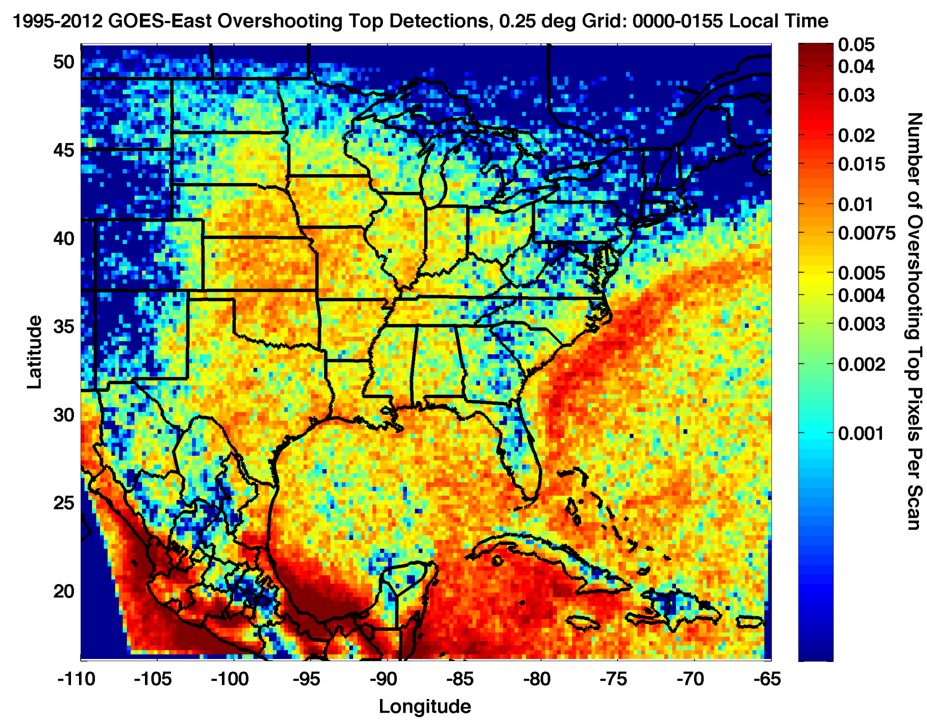
- **The reinsurance industry has shown strong interest in OT detection products but there are numerous other potential customers and applications, especially for GEO-based datasets**





1995-2012 GOES-East OT Detections Using ~4 to 8 km Spatial Resolution Data and Two Images Per Hour

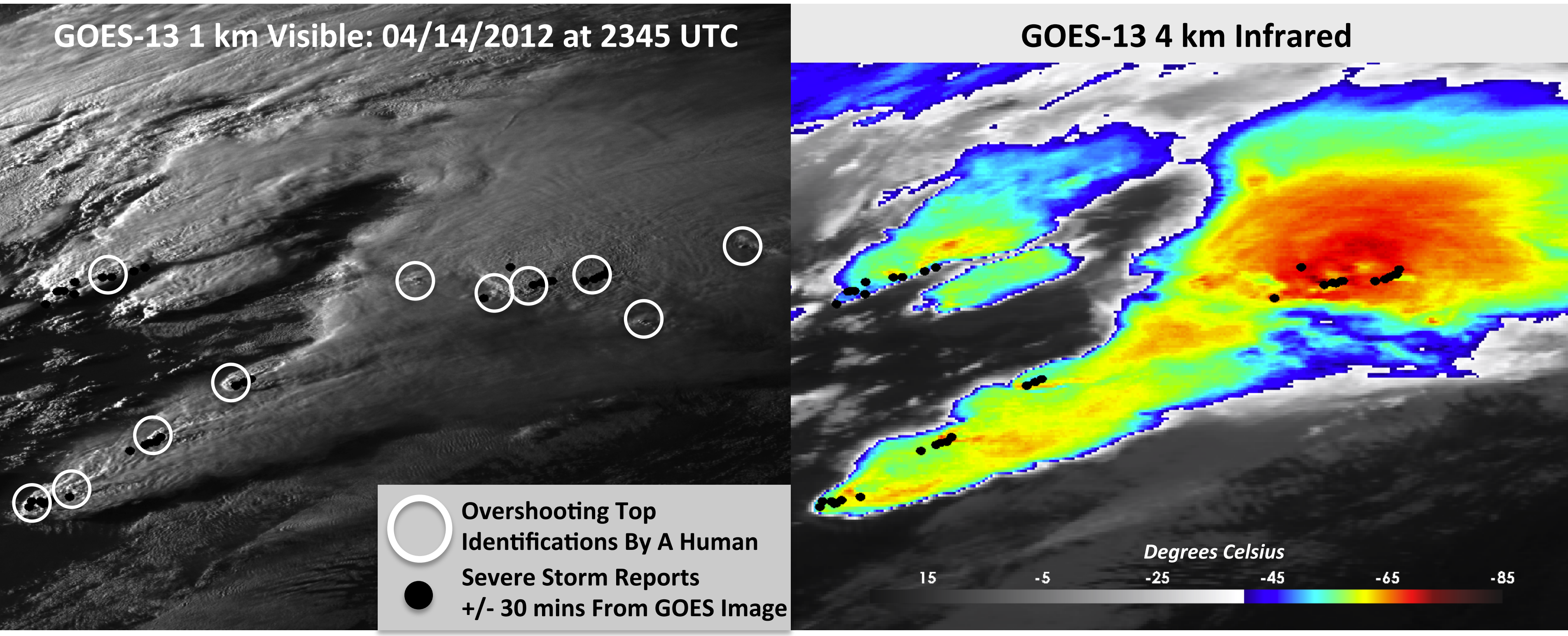
OT Detections Assigned To A 0.25 Degree Resolution Grid



Data Courtesy of UW-SSEC Acquired Via McIDAS

BACKUP SLIDES

Hasn't Someone Already Developed A Method To Detect Overshooting Tops?



Vaisala NLDN Lightning Flash Density