GOES-R AWG Aviation Team: Overshooting Top and Enhanced-V Thermal Couplet Signature Detection

Presented By: Kristopher Bedka
SSAI @ NASA Langley Research Center

In Close Collaboration With: Jason Brunner, Lee Cronce, Richard Dworak, and Wayne Feltz
UW-CIMSS

Outline

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- Algorithm Description (7 slides)
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- Validation Approach (4 slides)
- Validation Results (3 slides)
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Executive Summary

- This ABI Overshooting Top and Enhanced-V Thermal Couplet (OTTC) detection algorithm generates two Option 2 products
- Software Version 3 was delivered in March. ATBD (80%) and test datasets are scheduled to be delivered in June 2010
- Algorithms perform spatial sampling of convective cloud tops in ABI Channel 14 IR window imagery to identify the OTTC signatures
- Validation Datasets: Overshooting top events have been identified in WRF ARW cloud-resolving model output and CloudSat radar reflectivity profiles. Over 450 enhanced-V events have been identified in MODIS and AVHRR imagery
- Validation studies indicate spec compliance for both products

Requirements and Product Qualifiers Enhanced-V/ Overshooting Top Detection

Name	User & Priority	Geographic Coverage (G, H, C, M)	Temporal Coverage Qualifiers	Product Extent Qualifier	Cloud Cover Conditions Qualifier	Product Statistics Qualifier
Enhanced "V"/Overshooting Top Detection	GOES-R	C, M **M –** Mesoscale **C - CONUS**	Day and night	Quantitative out to at least 65 degrees LZA and qualitative at larger LZA	Clear conditions down to feature of interest associated with threshold accuracy	Over enhanced V/ overshooting top cases

Name	User & Priority	Geographic Coverage (G, H, C, M)	Vertical Resolution	Horizontal Resolution	Mapping Accuracy	Measurement Range	Measurement Accuracy	Product Refresh Rate/Coverage Time (Mode 3)	Product Refresh Rate/Coverage Time (Mode 4)	Vendor Allocated Ground Latency	Product Measurement Precision
Enhanced "V"/Overshooting Top Detection	GOES-R	C	N/A	2 km	1 km	Binary yes/no detection (160 – 270K)	75% correct detection (in terms of 1 – False Alarm Rate)	5 min	5 min	159 sec	N/A
Enhanced "V"/Overshooting Top Detection	GOES-R	M	N/A	2 km	1 km	Binary yes/no detection (160 – 270K)	75% correct detection (in terms of 1 – False Alarm Rate)	5 min		159 sec	N/A

Algorithm Description

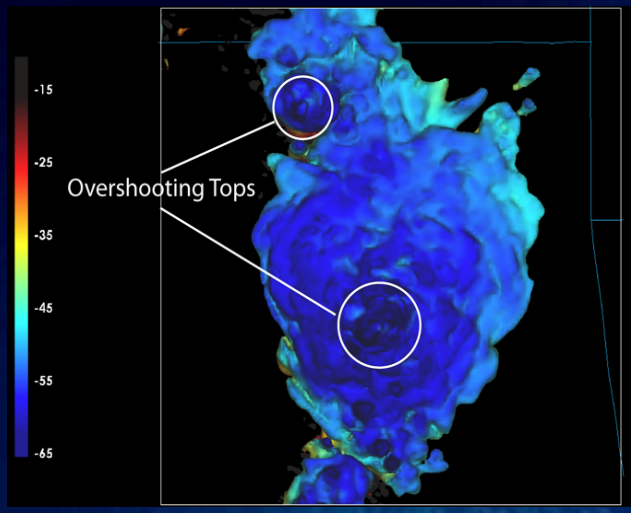
What Is An Overshooting Top?

Overshooting Top: A domelike protrusion above a cumulonimbus anvil, representing the intrusion of an updraft through its equilibrium level or the tropopause (from the AMS Glossary)

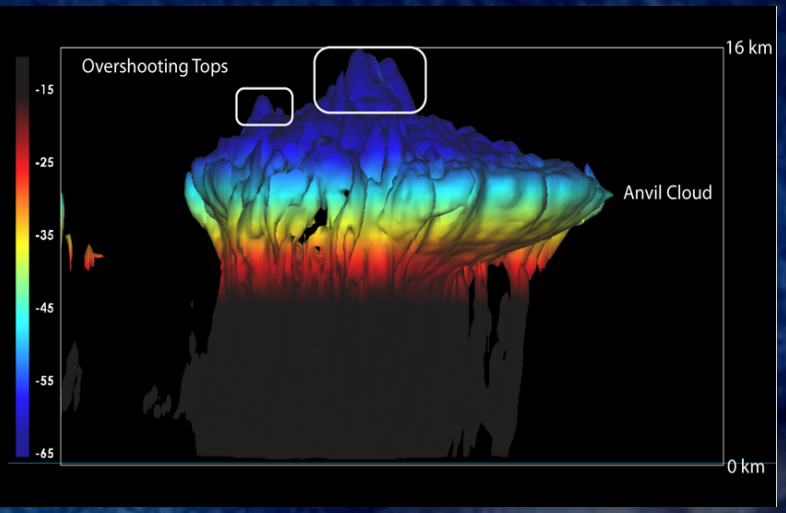
- **Small in size (< 15 km) and often short lived**
- **Indicates a storm with a very strong updraft, hazardous for aviation operations if a plane were to fly through an overshooting top (OT)**
- **Interaction of storm updraft with stable tropopause layer generates turbulent gravity waves which can propagate far away from their source region and affect air traffic**
- **Often indicates the region of a thunderstorm with localized rainfall maxima**
- **Responsible for injecting water vapor into the stratosphere. This has significant climate impacts as water vapor is an important greenhouse gas.**
- **A key component of the enhanced-V signature**

What is an Overshooting Top?

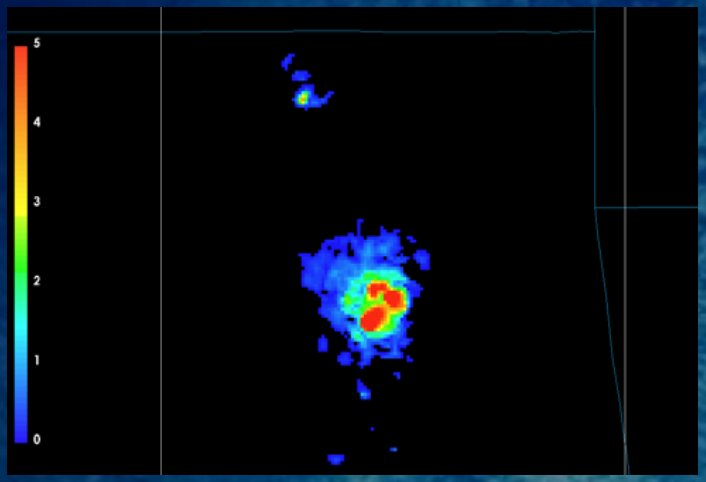
WRF Simulated ABI IR Window Cloudy Radiances



WRF 3-D Cloud Temperature Field



WRF Ice Mixing Ratio ~1 km Above Tropopause



- Ice hydrometeors are lofted into the stratosphere by strong storm updrafts, producing a characteristic "cauliflower" texture in visible imagery and a focused region (<15 km diameter) of extremely cold ~11 μm channel brightness temperatures (BTs)

- Channel differencing tests inadequate for consistently accurate OT detection

- We can use spatial gradients and thresholding of IR window (IRW) channel BTs to objectively identify OTs. We call this the "IRW-texture technique" since it uses these spatial BT gradients

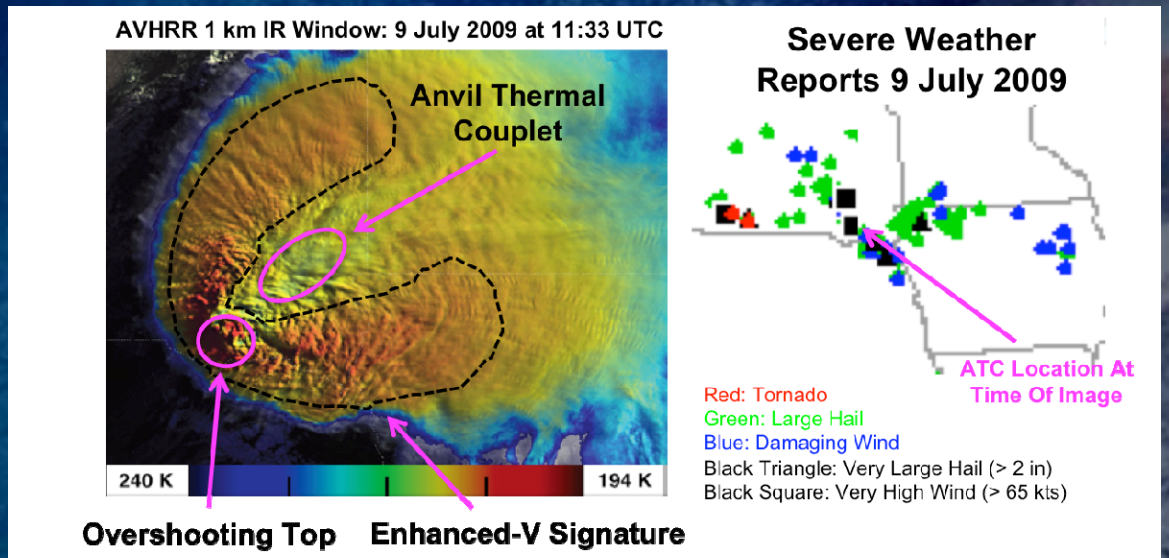
What Is An Enhanced-V?

The appearance of an enhanced-V in infrared imagery resembles a V- or boomerang-shaped area of cold IR window channel BTs bordering an area of warm BT downwind. (From *Meteorology: Understanding the Atmosphere* (Ackerman and Knox, 2001))

- **The enhanced-V is often seen in infrared satellite imagery before the onset of severe weather (damaging winds, hail, and/or tornadoes) and is an important indicator of a severe thunderstorm**

  - **McCann (MWR, 1983) found that the median lead time (time from the initial identification of the feature on satellite imagery to the first reports of severe weather on the ground) is about 30 minutes.**

  - **Brunner et al. (WAF, 2007) found that ~92% of enhanced-V storms with a specified set of temperature parameters produced severe weather during summers 2003 and 2004**

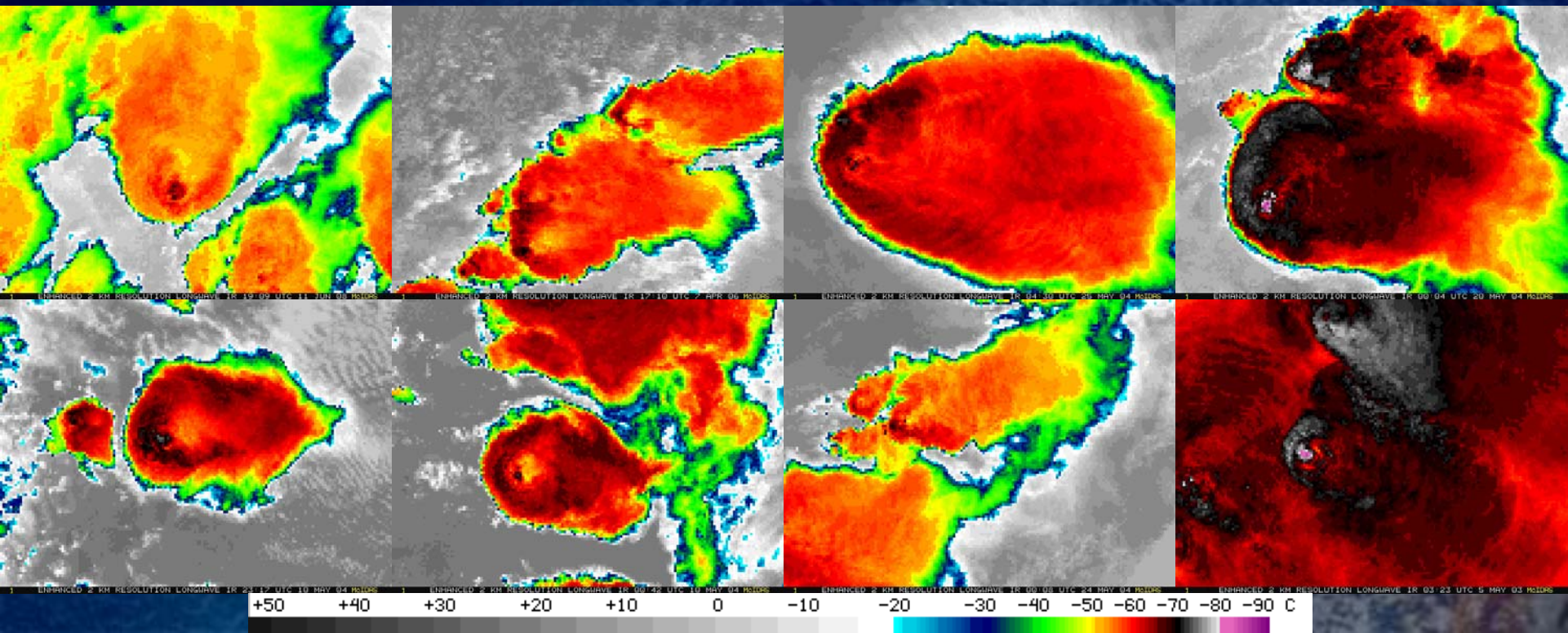


AVHRR image courtesy of Martin Setvak (CHMI)

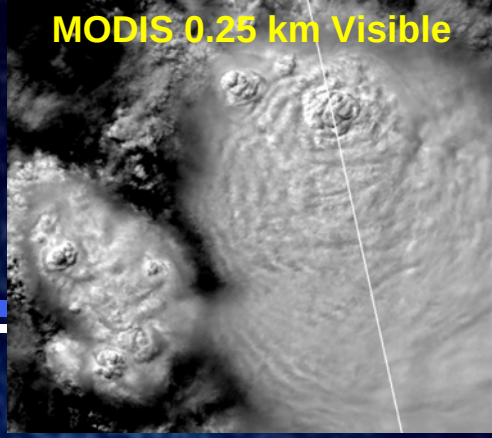
V-Signature vs. Anvil Thermal Couplet Detection

- Though the enhanced-V signature can appear quite differently in many cases, the anvil thermal couplet (ATC) is (almost) always present, making accurate detection of the ATC and thus the V-signature, far more attainable

MODIS & AVHRR IR Window Degraded to 2 km ABI Resolution
All Images Cover the Same Horizontal Distance and Use Same Color Enhancement, Illustrating Variations in the V-signature Across Events



Overshooting Top Detection Processing Schematic



INPUT: BT_{14} and NWP Tropopause

↓

Find Pixels Colder Than 215 K and NWP Tropopause

↓

Filter List of Cold Pixels To Identify Regional BT Minima: Overshoot Candidates

↓

Compute BT Difference Between Candidates and Surrounding Anvil Cloud

↓

Pixels With BT > 6.5 K Colder Than Mean Surrounding Anvil Are Overshooting Tops, Flag Remaining Pixels That Compose The Entire Top

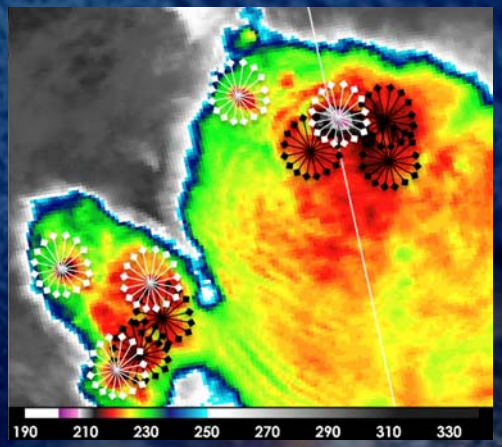
↓

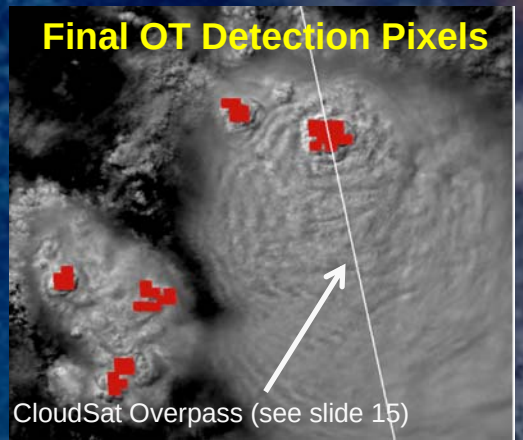
Output Overshooting Top Mask

IRW-Texture Candidate Pixels: Anvil BT Sampling

White Pinwheels: Candidate OT Significantly Colder Than Anvil

Black Pinwheels: Cloud Top BT Pattern Too Uniform=Not an OT





Enhanced-V Anvil Thermal Couplet Detection Processing Schematic

INPUT: Overshooting Top Detection Mask

↓

Search 25x50 km box in the eastern sector of the OT for potential couplets

↓

Ensure that potential couplet is not along the anvil cloud edge

↓

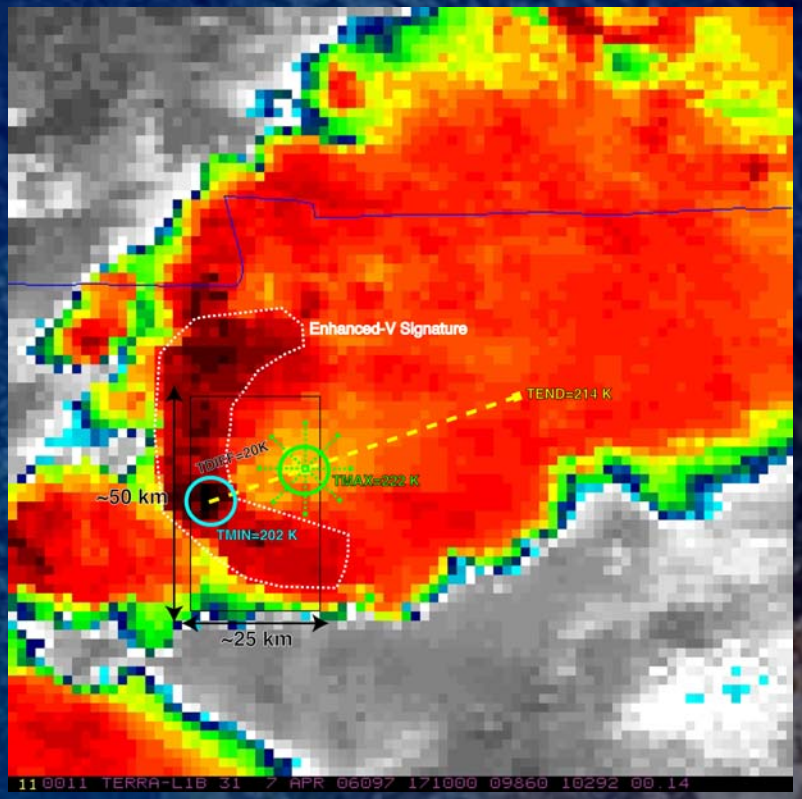
Ensure that potential couplet is a focused area of warm BT surrounded by colder anvil

↓

Ensure presence of a relatively large anvil cloud with a singular warm area

↓

Output Enhanced-V Thermal Couplet Mask



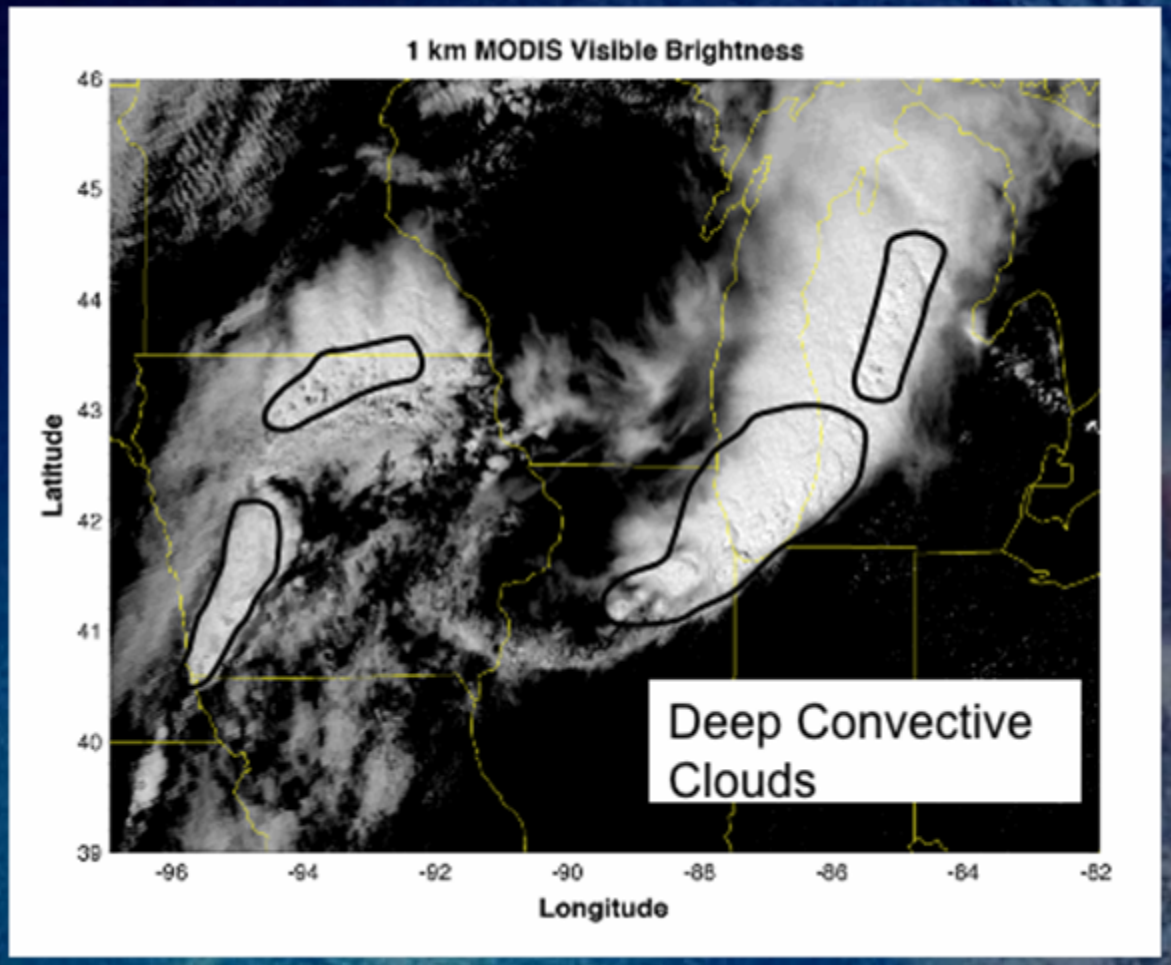
Algorithm Summary

- Input Datasets: Proxy ABI IR window data are generated from 1) 1 km AVHRR/MODIS, 2) 3 km MSG SEVIRI, and 3) 2 km WRF NWP output from UW-CIMSS. An NWP tropopause temperature analysis is used to ensure that a pixel is indeed "overshooting" the tropopause
- Overshooting top pixels are first identified
- Overshooting top detections are then passed to the enhanced-V anvil thermal couplet detection algorithm
- Thermal couplets are located within the "arms" of the enhanced-V signature, downstream (i.e. east) of the overshooting top location
- A series of tests are performed to ensure that the thermal couplet is a focused area of warm temperatures within a relatively large continuous anvil cloud, consistent with observations of enhanced-V producing storms
- Several additional parameters are output that can be used as quality control and forecasting tools for hazards such as aviation turbulence or severe weather

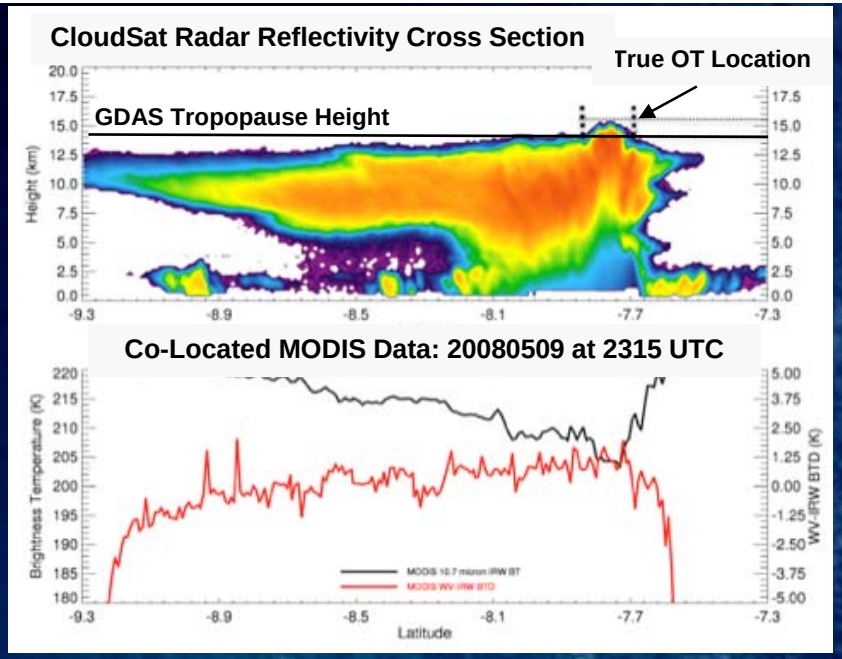
Examples of Product Output

Overshooting Top Processing and Detection Product Output

View Slide Show For Animation
OT Detection Processing Results Using Proxy ABI from 1 km MODIS

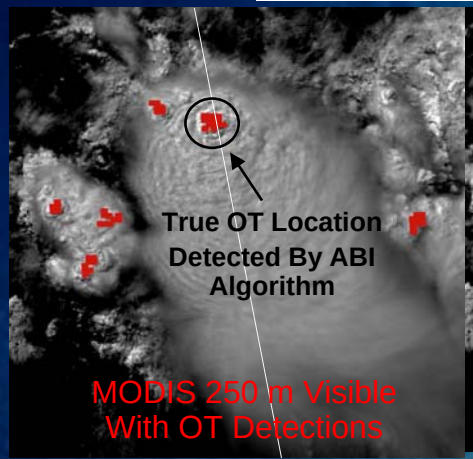


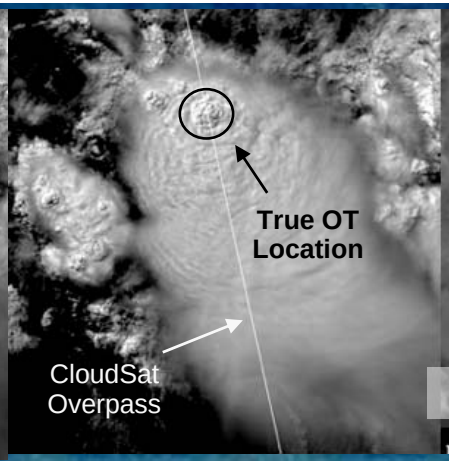
Detection of a CloudSat-Observed OT Event

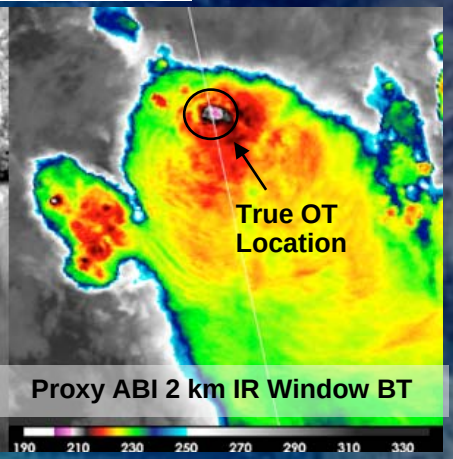


- The CloudSat-observed overshooting top has a diameter of 11 km and has a peak height 1.5 km above the GDAS tropopause

- The ABI detection algorithm accurately identifies this feature (lower-left panel) in addition to several other probable overshooting tops not directly observed by CloudSat

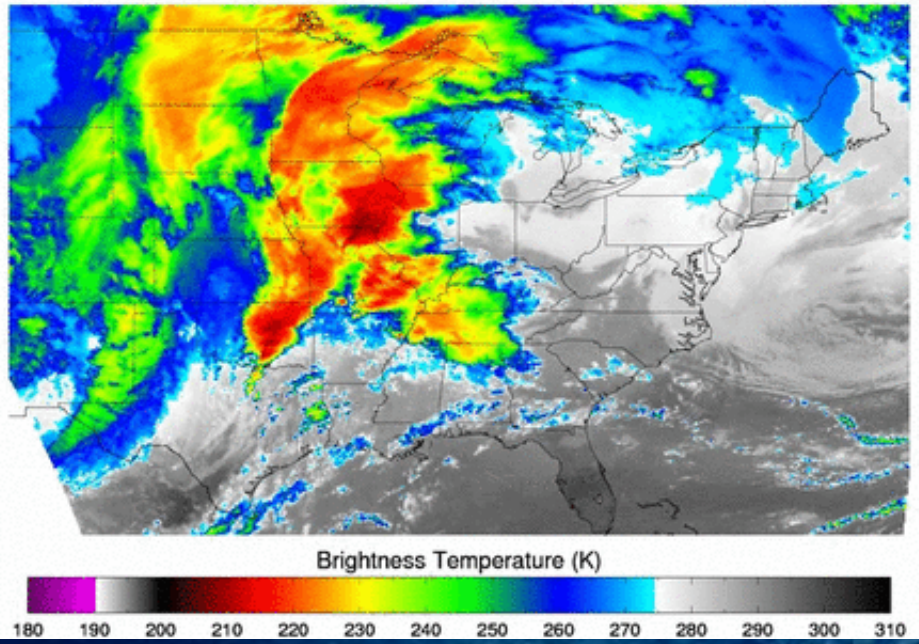




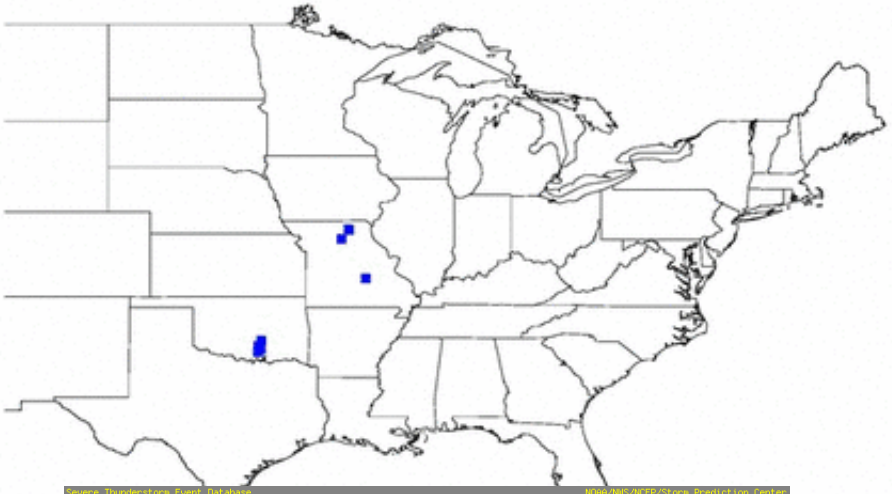


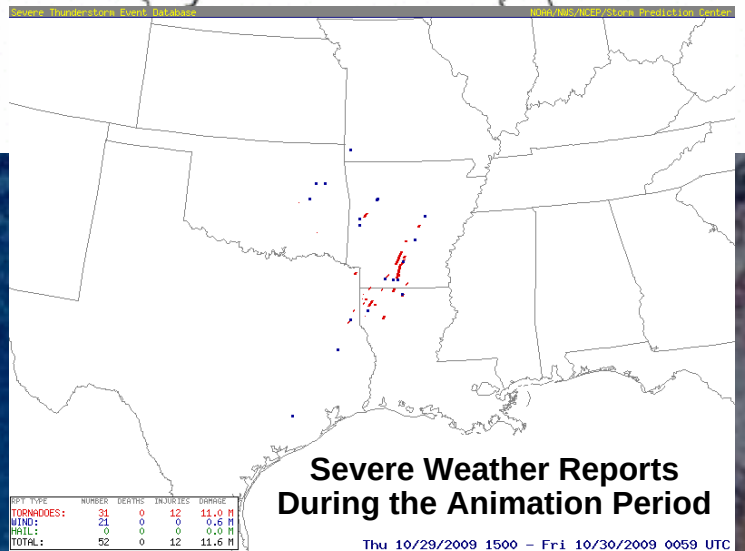
Application of OT Detection To Current GOES

GOES-12 4km IRW: 20091029 at 1515 UTC



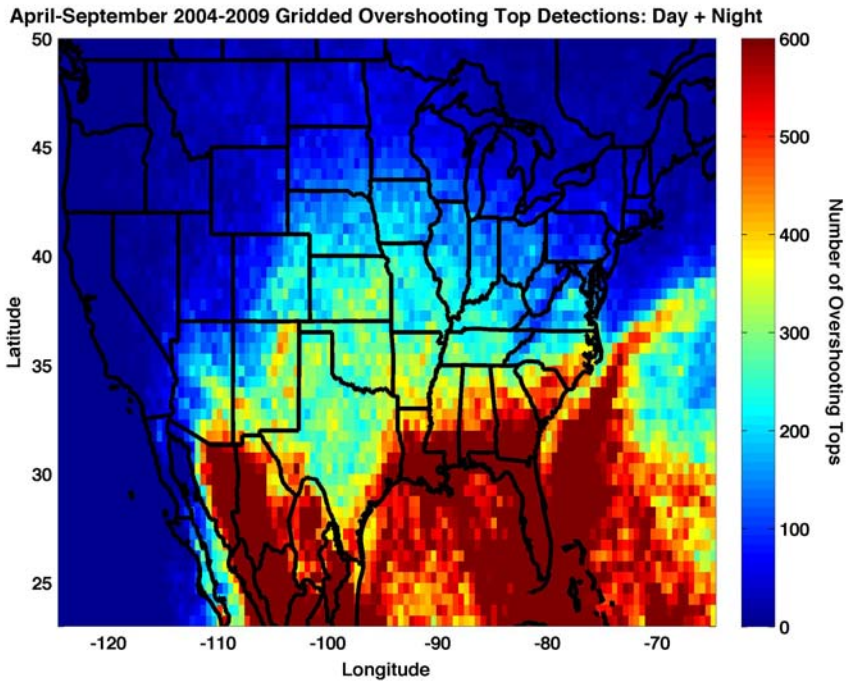
Overshooting Tops: 20091029 at 1515 UTC





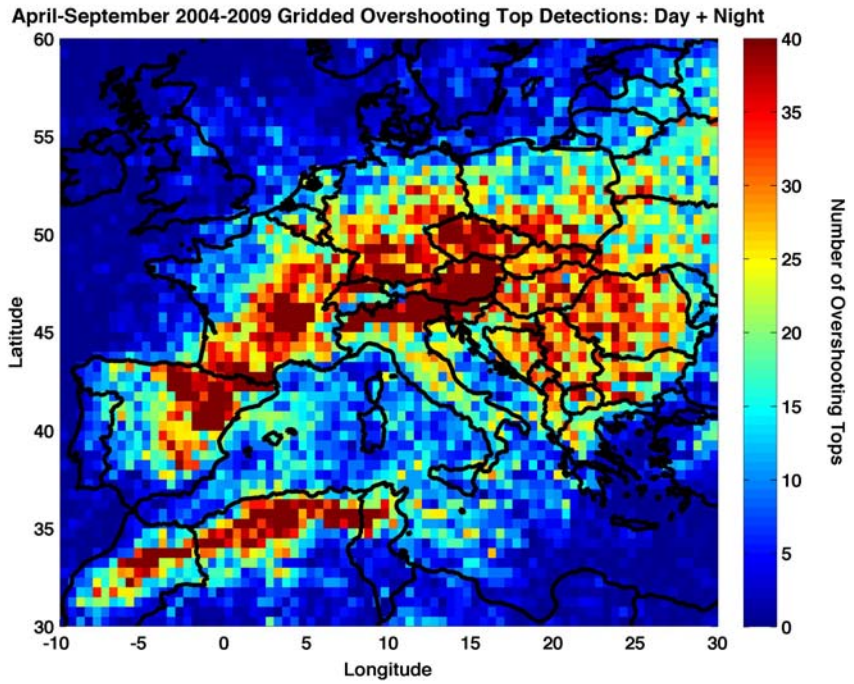
6-Year GOES and MSG SEVIRI OT Detections

GOES-12 (Includes Rapid Scans)



Bedka et al (*JAMC*, 2010)

SEVIRI (15 min Scans Only)

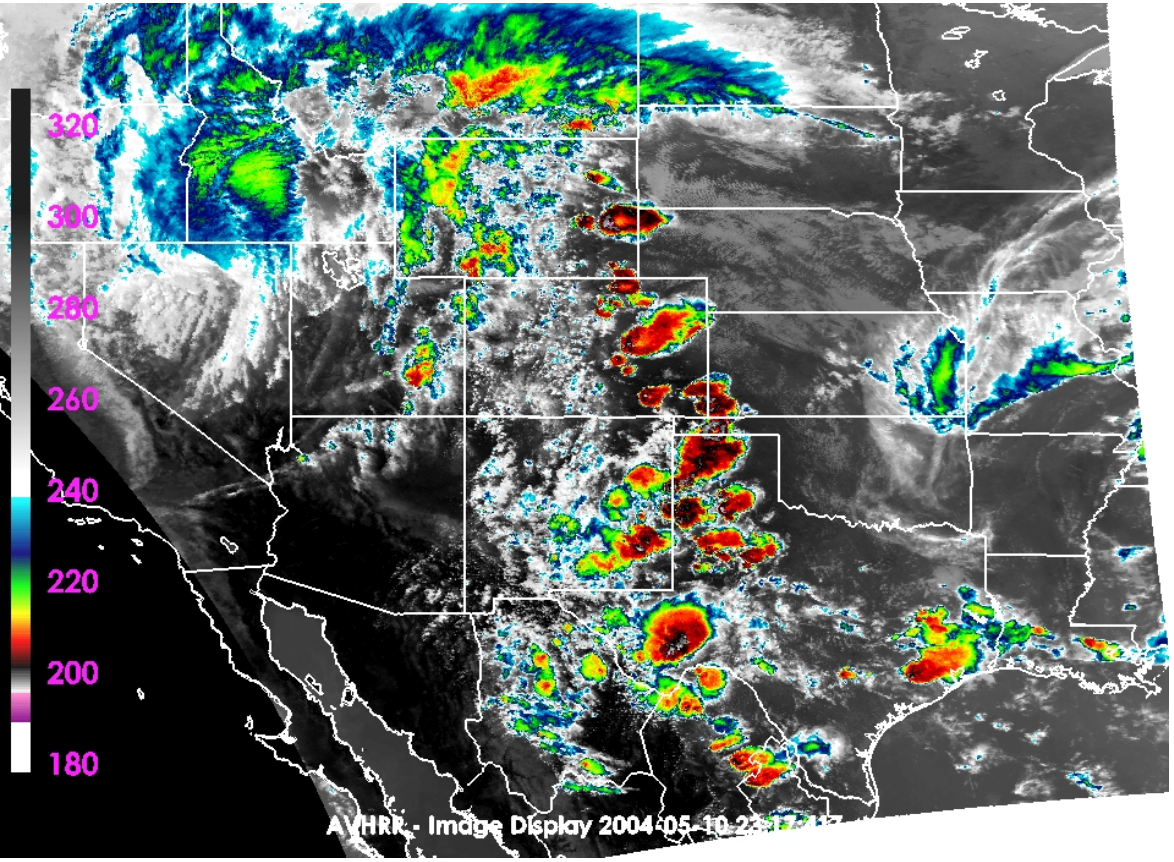


Bedka (*Atmos. Res.*, 2010)

NOTE: Color Table Ranges Do Not Match

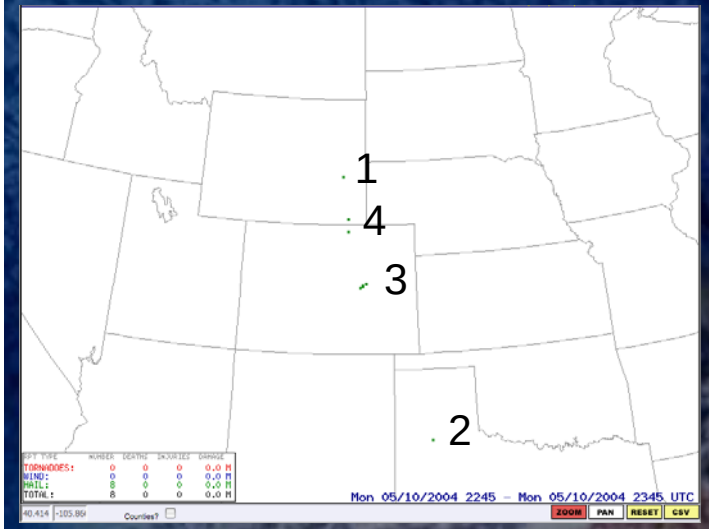
Overshooting Top and Thermal Couplet Product Output

5/10/2004 at 2317 UTC 2 km Proxy ABI From 1 km AVHRR



Severe Storm Reports +/- 30 Mins From Image Time

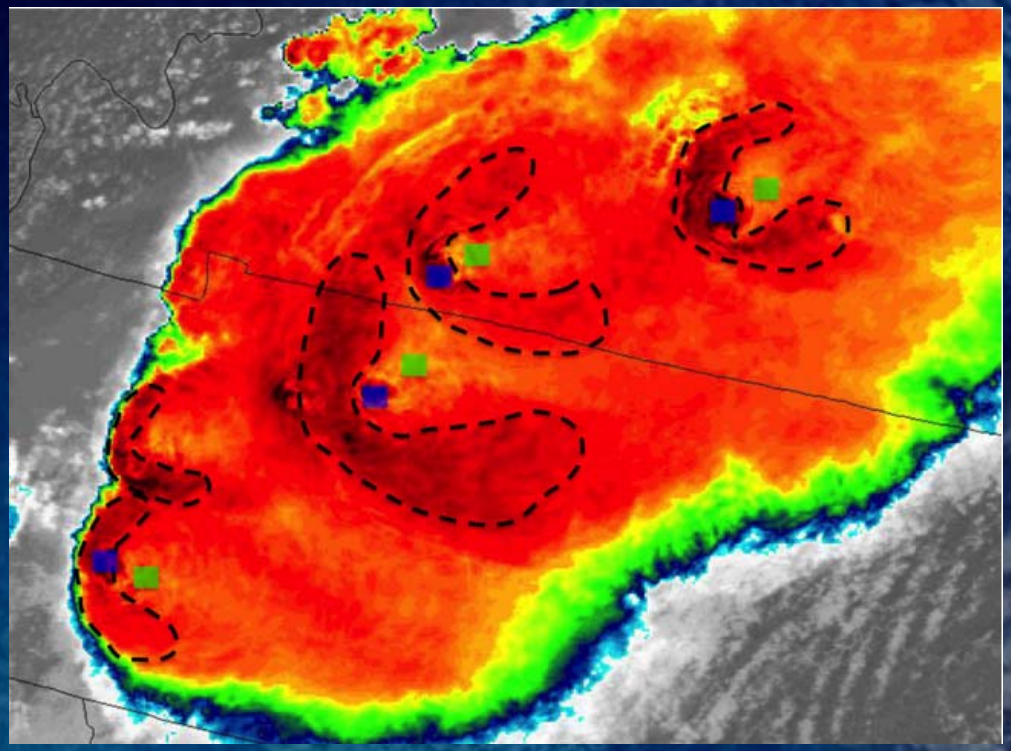
Numbers Correspond To The Storms Labeled In the Left Panels



View Slide Show to See Figures Underneath

Overshooting Top and Thermal Couplet Detection Product Output

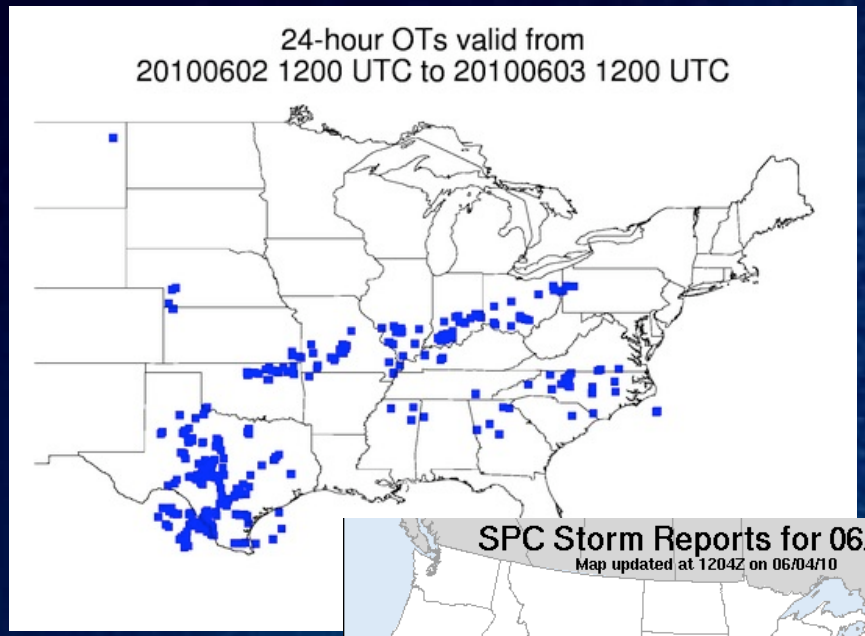
2 km Proxy ABI From 1 km MODIS 10.7 μm Imagery
4/7/2006 at 1825 UTC



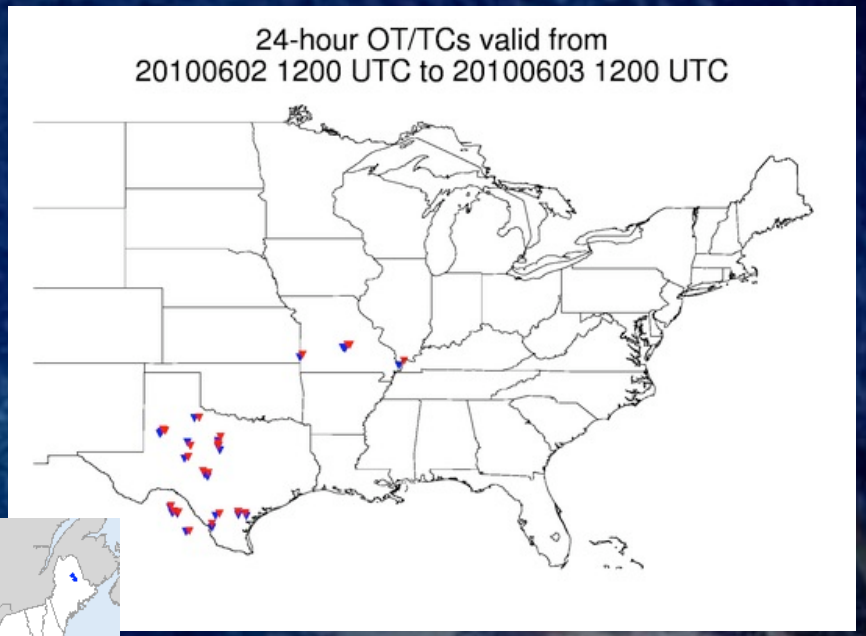
* Overshooting top location indicated by blue symbol (only OTs with thermal couplets are shown)
* Enhanced-V ATC detections indicated by green symbol
* 4 of 5 possible enhanced-V ATCs are detected accurately in this MODIS case

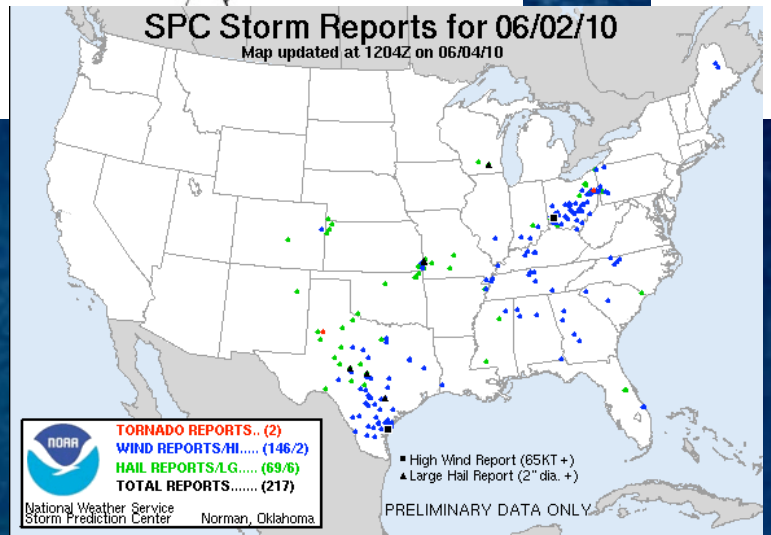
Overshooting Top and Thermal Couplet Detection Product Output During 2010 GOES-R Proving Ground

All GOES-13 OT Detections Over 24 Hr. Period



All GOES-13 OTs (blue) with Enhanced-V Thermal Couplets (red)





Validation Approach

Validation Approach: Datasets

- A database of all overshooting top and enhanced-V events does not exist. Subjective "truth" event identification is required, especially for validation of the enhanced-V signature

- Enhanced "V" Anvil Thermal Couplet Truth data
  - » Manually identified 203 true Enhanced "V" Anvil Thermal Couplets in the 55 proxy ABI cases from MODIS and AVHRR overpasses from 2003-2008 (primarily 2003 and 2004)

- Overshooting Top Truth data
  - » Manually identified 114 true Overshooting Tops that were directly observed by CloudSat from April 2008 to September 2009
    - *Direct CloudSat overpasses of overshooting tops are difficult to find due to their relatively small size and the fact that Aqua's 1:30 PM LST overpass misses the time period of most intense convection activity*
    - *2 minute time difference between MODIS and CloudSat observations also problematic for quantitative validation*

Validation Approach: Datasets

- Overshooting Top Truth data (continued)
  - » OT identifications using WRF ARW cloud resolving model output. Compare with objective OT detections from WRF-based synthetic ABI (not shown in this talk, see 80% ATBD and Bedka et al. (*JAMC*, 2010))

CloudSat-based Overshooting Top Validation Approach

- CloudSat selected over CALIPSO because CALIPSO cloud top height product is limited to the GEOS-5 tropopause and CloudSat allows us to better see the vertical structure of the deep convection

- The highest cloud top must be at least 0.5 km above the surrounding anvil cloud for 2 adjacent CloudSat profiles to ensure the presence of a coherent OT signature.

- This implies that the smallest OT in the final OT database can be ~3.4 km in diameter in the along track direction (CloudSat spatial resolution=1.7 km).

- For daytime events, Aqua MODIS 250 meter spatial resolution visible imagery along the CloudSat overpass is also analyzed to further verify that CloudSat observed an OT.

- OT events that meet these criteria are assigned to the final OT database.

CloudSat-based Overshooting Top Validation Approach

- CloudSat observed OTs are treated as both single coherent entities (i.e. “top regions”) and as the individual pixels that compose the top

- This distinction is important because a detection method may not identify every pixel within an OT along the CloudSat track but could identify some portion of the top region and this should be rewarded

- The exact location and spatial extent of an OT is subjectively determined through examination of the CloudSat 2B-GEOPROF profile

- The following metrics are used to evaluate the accuracy of IRW-texture and WV-IRW BTD OT detections: 1) OT pixel FAR and 2) probability of detection (POD) of all possible top regions

- $$\text{OT Pixel FAR} = \frac{\text{Number of incorrect OT pixel detections along CloudSat overpass}}{\text{Total number of OT pixel detections along CloudSat overpass}}$$

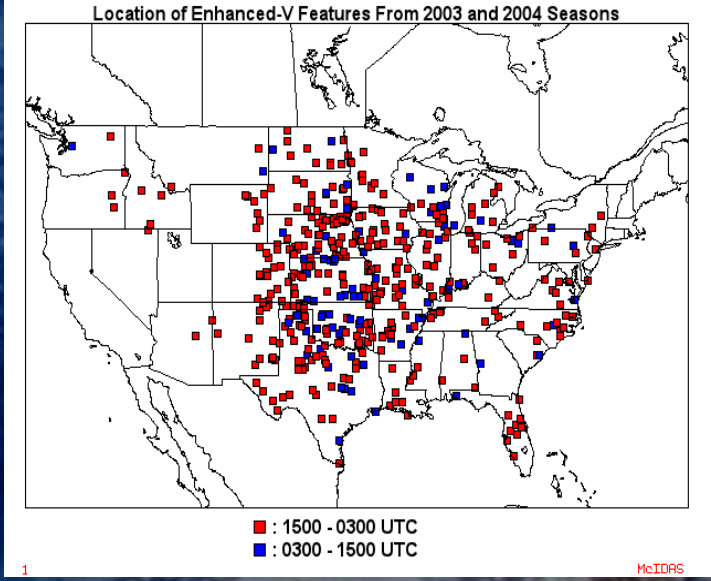
$$\text{OT Top Region POD} = \frac{\text{Number of accurately detected top regions along CloudSat overpass}}{\text{Total number of top regions along CloudSat overpass}}$$

Enhanced-V Thermal Couplet Detection Validation Approach

* Brunner et al. (*WAF*, 2007) have manually identified 450 enhanced-V cases within MODIS and AVHRR data during Summer 2003 and 2004. Additional V cases from recent years have also been identified.

* 1 km MODIS and AVHRR longwave IR (~11 micron) imagery have been remapped to ABI navigation and spatial resolution to simulate future ABI imagery

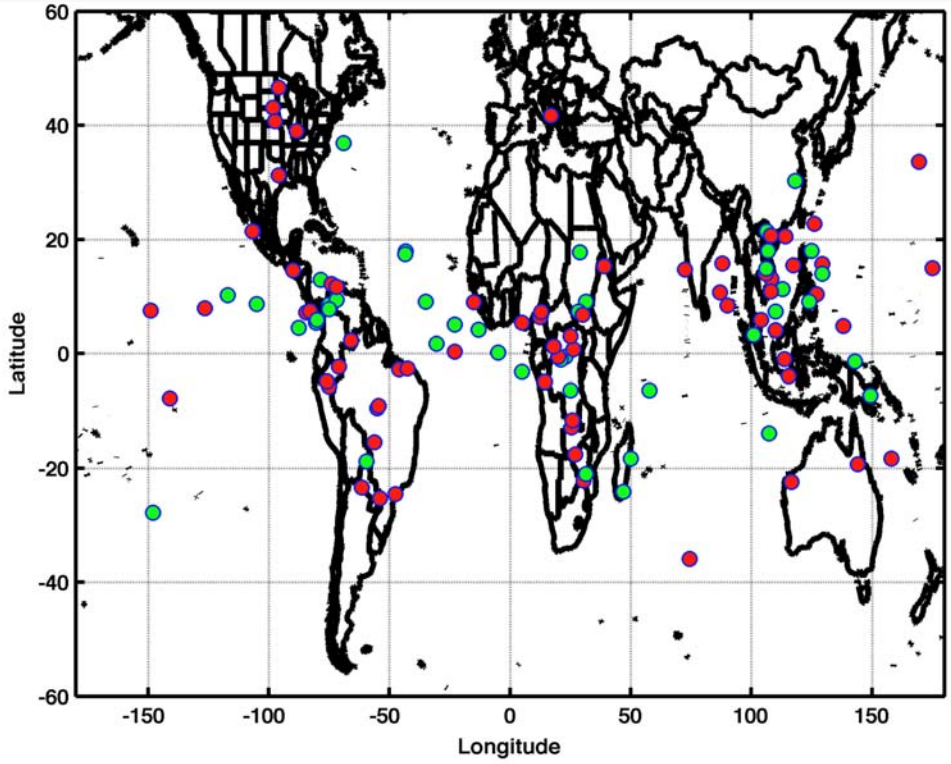
* The enhanced-V anvil thermal couplet detection algorithm is run for about half of these manually identified V cases (203 of 450) and POD/FAR statistics are computed over the entire MODIS/AVHRR overpass



Validation Results

Comparisons of OT Detection Performance Relative to CloudSat

Locations of 114 CloudSat Observed Overshooting Tops From April 2008 to September 2009



CloudSat Observed OTs Detected By ABI Algorithm
CloudSat Observed OTs Missed By ABI Algorithm

- OTs are detected more often over land than water
- Errant NWP tropopause temperature analysis over water could contribute to this
- Heymsfield et al. (2010) shows that the maximum upward vertical motion in land-based convection is of greater magnitude and at a higher vertical level than convection over ocean
- OTs over land would likely be of larger magnitude and would therefore appear more prominently in IRW imagery, leading to a higher detection rate using the IRW-texture method

Comparisons of OT Detection Performance Relative to CloudSat

OT Detection Method	OT Pixel FAR	ABI OT Detection Product FAR Requirement	OT Top Region POD	Total Number of OT Detection Pixels Along CloudSat Track for the 108 Cases
ABI OT Algorithm (with GDAS Tropopause Temp Check)	16.1%	25%	75.4%	943
ABI OT Algorithm (without GDAS Tropopause Temp Check)	60%	25%	92.1%	2612
Global Convective Diagnostic (WV-IRW BTD > 1 K Currently Operational at Aviation Weather Center)	75%	N/A	79.5%	7119
ABI OT Algorithm (Applied to Current GOES and MSG SEVIRI)	18.3%	N/A	57.6%	252 (60 Cases)

Anvil Thermal Couplet Detection Performance Relative to Brunner et al. V-Signature Database

Probability Of Detection	False Alarm Ratio	Accuracy Requirement
62% (126 accurately detected / 203 V-signature events)	24% (40 false detected / (40 false detected + 126 accurately detected))	25%

- 76% of all detected enhanced V anvil thermal couplets were associated with severe weather.
- 66% of non-detected enhanced V anvil thermal couplets were associated with severe weather, indicating that the ABI algorithm focuses on high impact events
- Spatial resolution has significant impact on thermal couplet detection. Current GOES POD: 12.8%, current GOES FAR: 5.9%

Summary

- The ABI Overshooting Top and Enhanced-V Algorithms provide a new capability for objective detection and prediction of hazardous aviation weather and severe storms
- Improved ABI spatial and temporal resolution will offer a significantly better detection capability
- Algorithms meet all performance and latency requirements
- These products are currently being evaluated via the GOES-R Proving Ground at the 2010 NOAA Storm Prediction Center Hazardous Weather Testbed

Steps to Reach 100% Algorithm Maturity

- More validation and evaluation, look into microwave-based OT observations (TRMM PR, WSR-88D). Process and validate entirety of the 450 enhanced-V thermal couplet event database of Brunner er al. (*WAF*, 2007)
- Reduce OT false alarm in cold season non-convective, high and optically thick cirrus plumes
- Refine enhanced-V detection settings to further reduce false alarm while preserving POD
- Continue to meet algorithm development/documentation milestones