

# GOES-R Risk Reduction Research on Satellite-Derived Overshooting Tops



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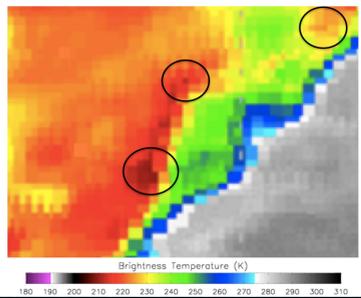
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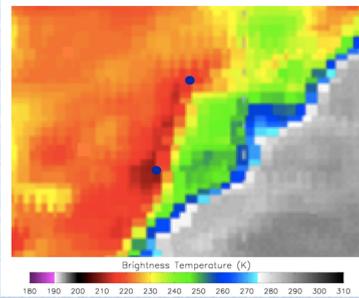
## Introduction

- Satellite-derived overshooting tops are presented as temperature anomalies, which can be converted to altitude for practical applications, such as aviation.
- Two branches of an IR-based overshooting top detection algorithm exist and have been improved. Future work includes fusing them into one algorithm.
- GOES-R will allow even better detection due to improved spatial and temporal sampling.

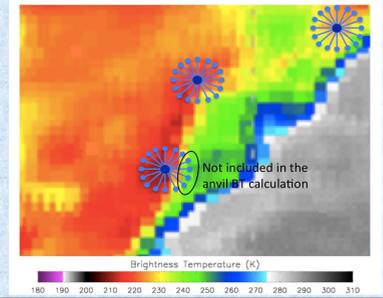
## Satellite-Based Objective Overshooting Top Detection Algorithm



Using geostationary satellite imagery, find minima in the 11  $\mu\text{m}$  brightness temperature (BT) field colder than 215 K.



Sample the surrounding anvil at an  $\sim 8$  km radius in 16 radial directions. At least 5-of-16 anvil cloud pixels must be colder than 225 K. Compute the mean BT of these anvil pixels.



Overshooting tops are identified as either:  
 1. Having a BT colder than the tropopause temp. and 6.5 K colder than the surrounding anvil BT  
 2. Having a BT 9 K colder than the surrounding anvil BT. (9 anvil pixels required)

## Calculating the Height of Overshooting Tops

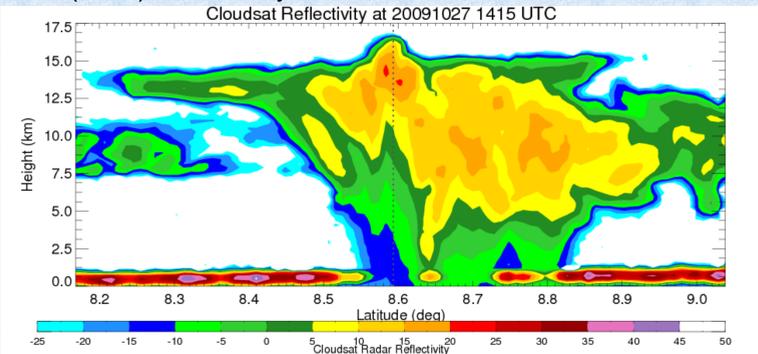
**Motivation:** Overshoots are calculated in temperature space but applications, such as aviation, desire overshoots in a height/altitude reference.

$$\text{Overshoot Height} = \text{Overshoot Anvil Height} + \frac{\text{Overshoot BTD}}{\text{Lapse Rate}}$$

- **Overshoot Anvil Height:** the height of the anvil BT in a NWP model profile of temperature and height
- **Overshoot BTD:** Overshoot BT – Anvil BT
- **Lapse rate:** median of 107 MODIS overshoot lapse rates.

$$\text{Overshoot Lapse Rate} = \frac{\text{Overshoot BTD}}{\text{CloudSat height} - \text{Overshoot Anvil Height}}$$

**CloudSat height:** highest-in-atmosphere CloudSat Cloud Profiling Radar (CPR) Reflectivity  $\geq -25$  dBZ for the overshoot.



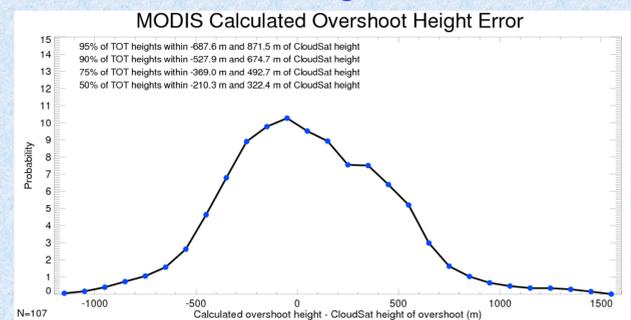
Profile of an overshoot in the from the CloudSat CPR. The CloudSat height is the height of the  $-25$  dBZ contour at the dotted line.

## MODIS Overshoot Height Error

Monte Carlo approach:

1. Divided into 2 groups
2. Calculate the lapse rate for first group, use to calculate the overshoot height for second group.
3. Repeat 50 times

Nearly 50% (75%) of MODIS calculated overshoot height are within 300m (500m) of the CloudSat height.

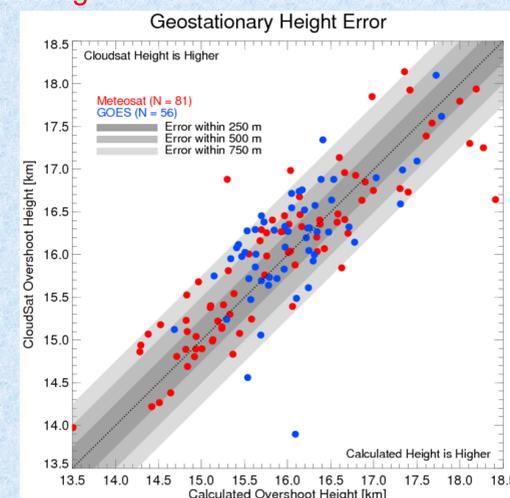


## Geostationary Overshoot Height Error

Approach:

1. Convert geostationary overshoot and anvil BT to be more "MODIS-like".
  - Linear regression equations based on 514 (351) collocated Meteosat (GOES) and MODIS overshoots.
2. Find height of new anvil BT using NWP.
3. Calculate overshoot height using median MODIS lapse rate.

About 51% (68%) of Meteosat and 39% (59%) of GOES calculated overshoot heights are within 300m (500m) of the CloudSat height.



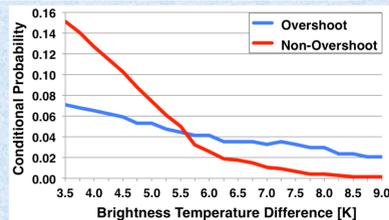
## Increasing Overshoot Detection in Tropical Cyclones

**Motivation:** Dense clouds in tropical cyclones (TCs) can reduce overshoot BTD. **Goal:** Allow overshoots with a BT > the tropopause temp. and BTD < 9 K to be identified if within 150 km of the TC center.

Calculate Overshoot Probability:  $P(C_{\text{overshoot}} | \mathbf{F}) = \frac{\prod_{i=1}^N P(F_i | C_{\text{overshoot}})}{P(\mathbf{F})}$

Potential Parameters (**F**):

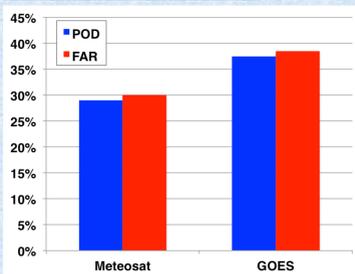
1. Overshoot BTD
2. Overshoot BT – Tropopause Temp.
3. Water vapor BT – Overshoot BT
4. 12.0  $\mu\text{m}$  BT – Overshoot BT (Meteosat Only)
5. 13.3  $\mu\text{m}$  BT – Overshoot BT
6. Number of overshooting pixels
7. Number of anvil pixels



Conditional probability for BTd. If BTd is the only parameter, a BTd=3.5K overshoot would have a probability of 32.0%.

Optimal parameters/probability have highest Critical Success Index, based on visibly-identified overshoots in 250m-resolution MODIS imagery.

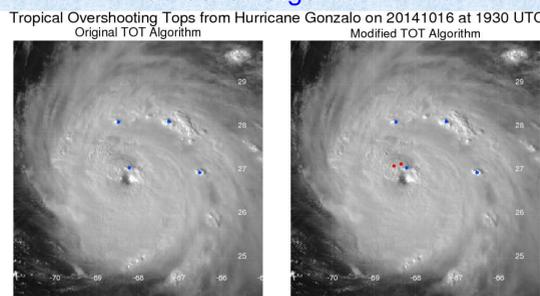
## Independent results:



29.0% (37.5%) POD and 30.0% (38.5%) FAR for Meteosat (GOES).

Higher POD and FAR for GOES than Meteosat result of optimal parameters used.

Low POD is a result of spatial resolution, as about 40% of visible MODIS TOTs are not identified by the geostationary overshooting top detection algorithm.



Example: original (left) and new (right) tropical overshooting top detection for Gonzalo (2014). The blue dots represent overshoots detected by the original algorithm and the red represent additional overshoots detected with the modified algorithm.

## Probabilistic Overshooting Top Detection Using Multi-Spectral Satellite Imager Data

**PROBLEM:** Though the Bedka et al. (2010) OT detection product has been widely used for weather analysis/forecasting, climate research, and by private industry, fixed detection thresholds and lack of sophisticated pattern recognition can reduce overall detection accuracy. Issues such as these can 1) inhibit identification of trends in hazardous storm activity associated with climate change and 2) cause some severe weather events to be missed, reducing the product's utility for severe weather forecasting.

**SOLUTION:** Mimic the process used by the human mind to identify overshooting cloud tops using visible & infrared satellite imagery and numerical weather prediction (NWP) model data within an automated computer algorithm. This will serve to eliminate fixed thresholds and provide a probabilistic OT detection

**METHODOLOGY**  
 Satellite IR and Visible OT Indicators Derived Via Visible and IR 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 OT and Non-OT Anvil Populations  
 OT Probability Product

**Step 1. Identify Candidate OT Regions Using IR Imagery**  
 Input image of MODIS 2007/05/06 15:20 channel 31 BT, reduced to 4 km/pix to emulate the current GOES spatial resolution and to smooth out surface features that can adversely impact OT pattern recognition.  
 BT score:  $\frac{BT_{\text{top}} - BT_{\text{anvil}}}{BT_{\text{top}} - BT_{\text{base}}} \times 100$   
 is used to eliminate non-OT regions and to filter convective from non-convective clouds.  
 Local peaks of BT score are first identified. These locations are used as candidates for the subsequent cloud anvil analysis.  
 Pattern recognition quantifies the following scene characteristics. This is done to ensure that 1) the region being analyzed is indeed a convective cloud and 2) the feature of interest has similar shape and prominence typical of OT regions.  
 • Shape correlation  
 • Pixel prominence compared to window average and surrounding anvil  
 • Anvil flatness and roundness  
 • Distinct edge of anvil  
 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.  
 Boundaries of anvil clouds are automatically defined via pattern recognition. The BT difference between OT candidates and the anvil is computed to identify significant ULTS penetrations.  
 Final candidate OT locations (yellow shading) based on IR analysis overlaid on the BT score image.

**Step 2. Identify Regions With OT-Like Texture Using Visible Imagery**  
 Input image of channel 04 Visible reflectance, reprojected to 1 km/pix  
 Input response function of band 04. Note the spectral sensitivity, being higher in the visible.  
 Final candidate OT locations (pink) based on Visible analysis overlaid on the input reflectance image.

**Step 3. Estimate Magnitude of Overshooting Via Comparison of IR Temperature With NWP Model Fields**  
 Connective available potential energy (CAPE, contours) overlaid upon the Visible reflectance and tropopause temperature.

**Step 4. Optimally Weight Satellite + NWP Parameters Using A Known Database of MODIS OT Events To Produce The Final OT Detection Probability**  
 • Use of satellite-based parameters alone does not produce a sufficiently accurate OT detection  
 • IR BT, IR BT - Anvil BT Difference, Visible Rating, IR BT - tropopause temp, and IR BT - most unstable equilibrium level temp were statistically significant predictors at the 99% level. Each of these parameters were derived for OT and non-OT anvil regions manually identified in 1000 go-miss MODIS imagery.  
 • A logistic regression model is trained to discriminate between the OT and non-OT anvil populations using these parameters as input. An OT Detection Probability ranging from 0 to 1 is derived for each candidate OT and a Probability greater than 0.5 is considered to be an OT.  
 A database of ~1900 OT events were manually identified in 1000 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.  
 Input image of MODIS 2007/05/06 15:26 channel 31 BT, reduced to 4 km/pix  
 Final OT detections (red) overlaid top OTs manually identified in 250 m Visible imagery.

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