CloudSat-derived Morphology of Deep Convection over Tropical Oceans

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Introduction

According to the Intergovernmental Panel on Climate Change, cloud feedbacks "remain the largest source of uncertainty in climate sensitivity estimates" (IPCC AR4). And while tropical deep convection is an important element of Earth's climate system, a dearth of literature exists regarding the spatial scales on which deep convection organizes. In this study, we use observations from the CloudSat 94-GHz cloud-profiling radar and co-located ECMWF reanalyses from June 2006 to April 2011 to investigate the morphology of deep-convective clouds over tropical oceans.

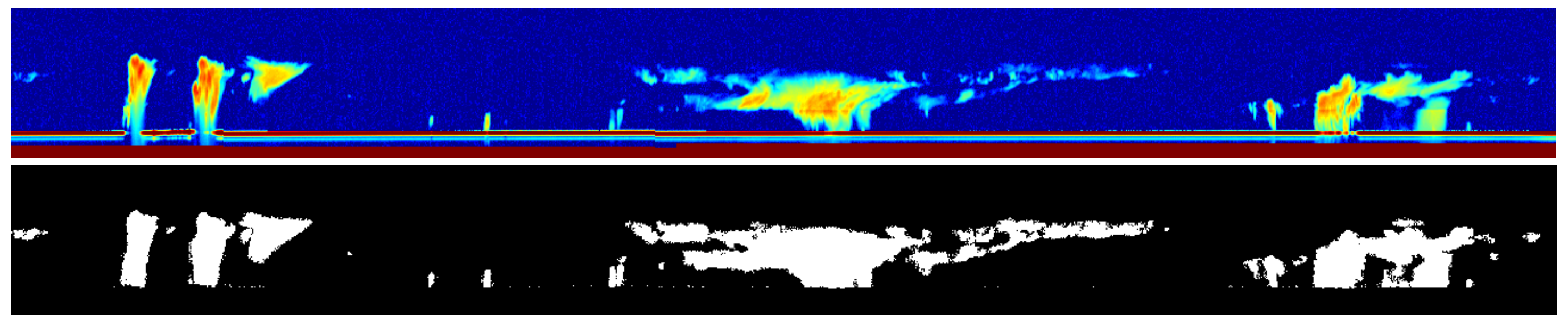
Our research questions are as follows:

1. Broadly, what do deep-convective clouds look like over tropical oceans? What is the range of spatial scales across which deep convection occurs?
2. How does convective core morphology interact with anvil morphology? What relationship, if any, exists between convective core attributes and anvil attributes?
3. How does sea-surface temperature affect cloud morphology as well as other quantities such as cloud-top temperature and anvil optical depth?

Cloud Objects

Identifying Deep-Convective Cloud Objects over Tropical Oceans:

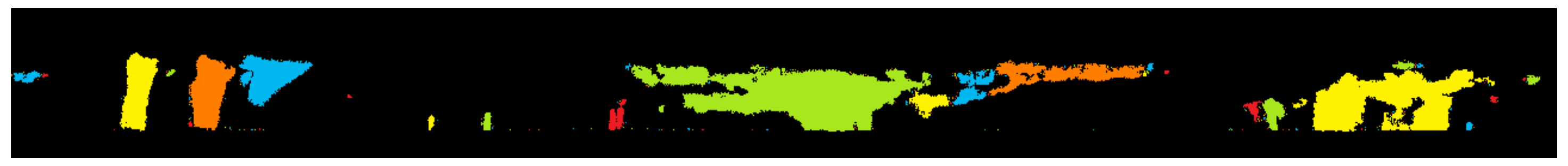
1.Identify "cloudy" pixels in CloudSat retrievals:



Pixels must meet the following criteria to be designated "cloudy":

- ✓ Radar reflectivity signal of at least −28 dBZ_e.
- ✓ Cloud mask value (from the CloudSat 2B-GEOPROF product) of at least 20.

2.Use a "paint bucket" algorithm to define "cloud objects":



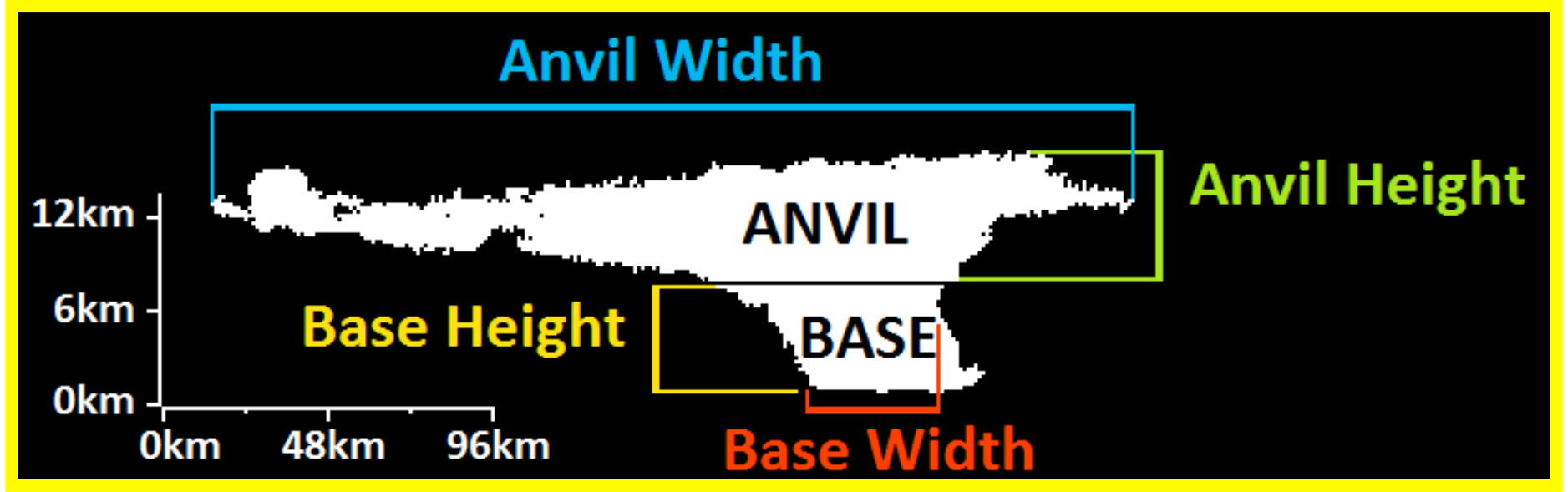
3.Determine which of these cloud objects qualify as "deep-convective cloud objects over tropical oceans":

Cloud objects must meet the following criteria to be included in our analysis:

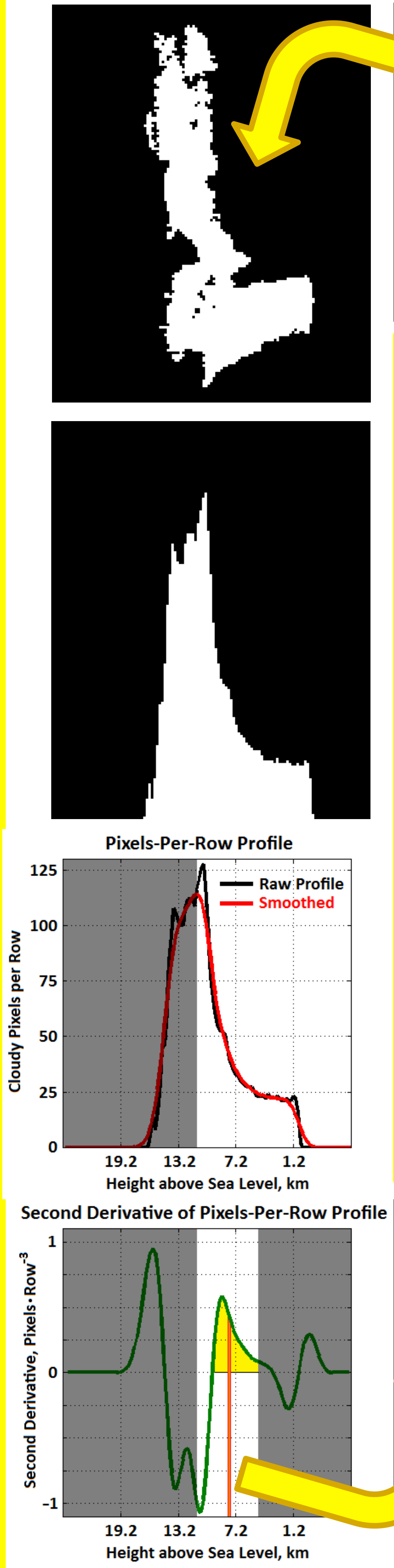
- ✓ At least 200 pixels in size.
- ✓ 100% of pixels below 30° latitude and observed between 1 PM and 2 PM local time, i.e., associated with one of CloudSat's afternoon equator crossings.
- ✓ 100% of pixels over water.
- ✓ At least one pixel labeled as "deep convection" by the 2B-CLDCLASS product.
- ✓ Significant vertical extent: cloud objects must extend above 11000 m above sea level and must extend below 1400 m.
- ✓ Anvil-finding and core-counting algorithms (see next section) locate an anvil and at least one core.

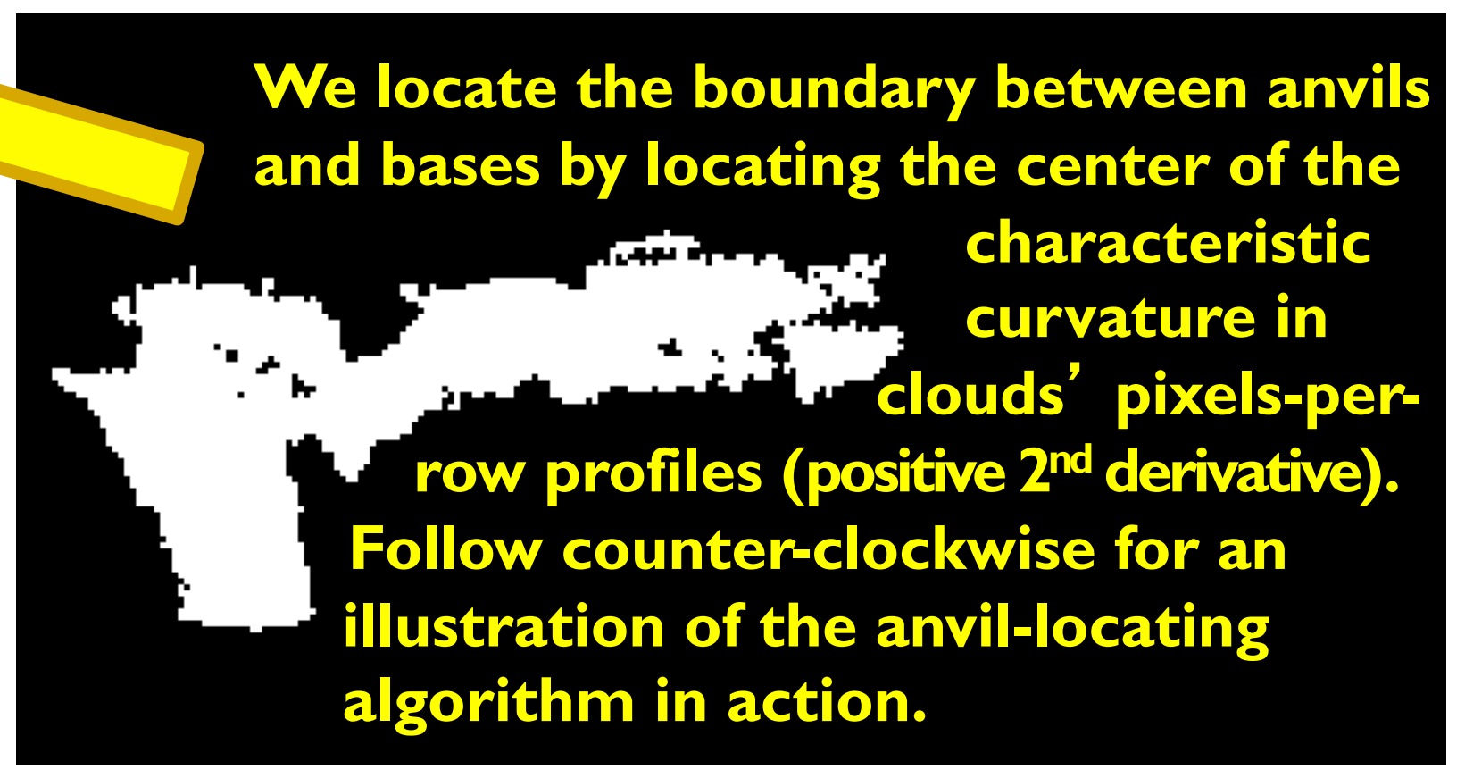
Defining *Morphology*

Some key terms:



Locating the Anvil-Base Cutoff:

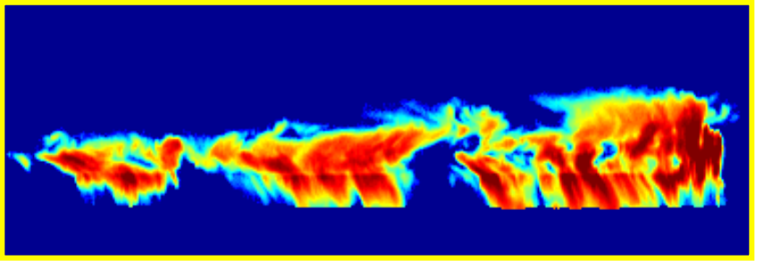




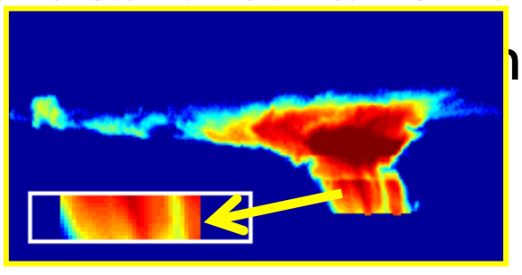
We locate the boundary between anvils and bases by locating the center of the characteristic curvature in clouds' pixels-per-row profiles (positive 2nd derivative). Follow counter-clockwise for an illustration of the anvil-locating algorithm in action.

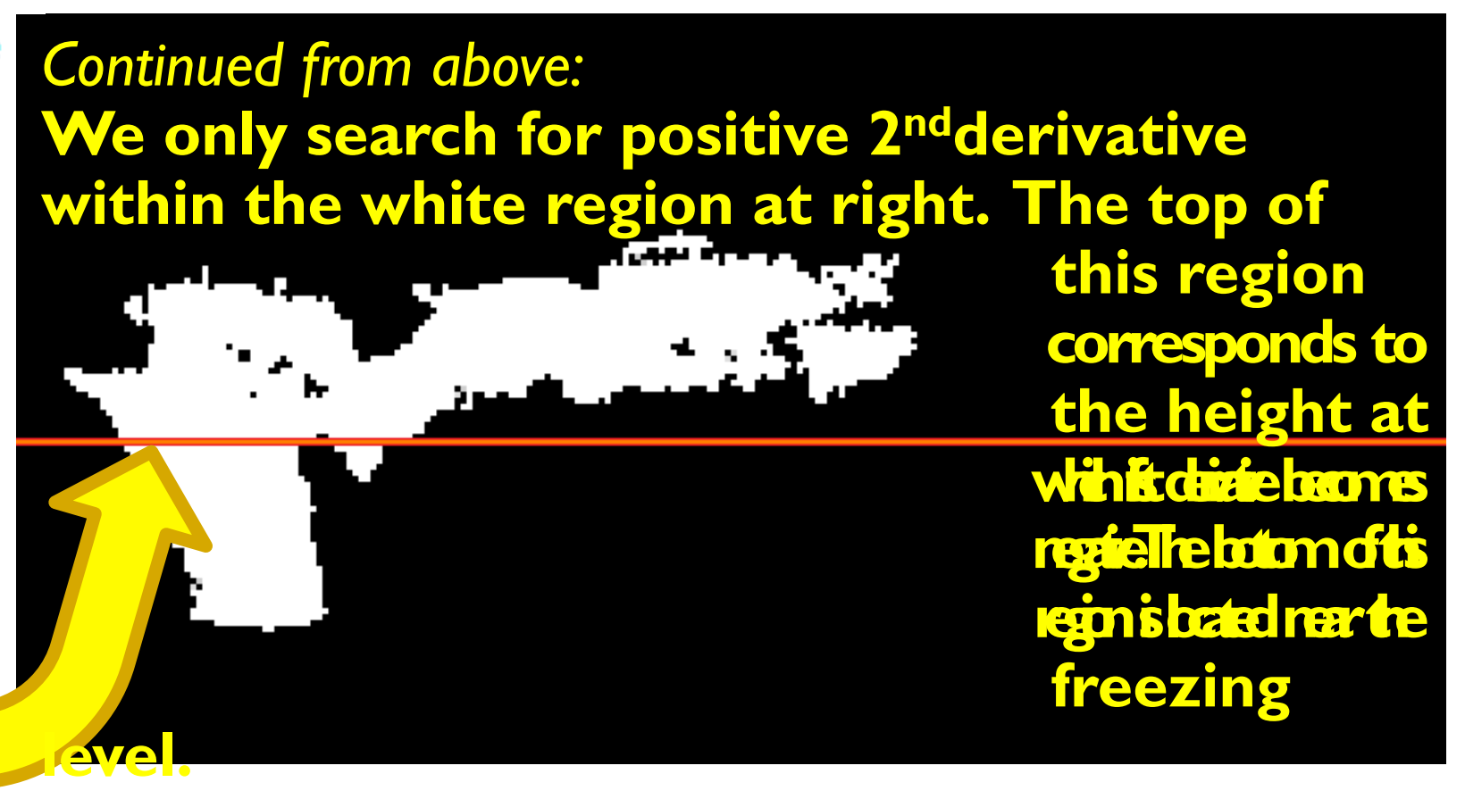
Counting Convective Cores:

Many clouds in our dataset appear to contain multiple convective cores. Additionally, our paint-bucket algorithm currently makes no attempt to perform surgery on "conjoined" cloud objects such as this



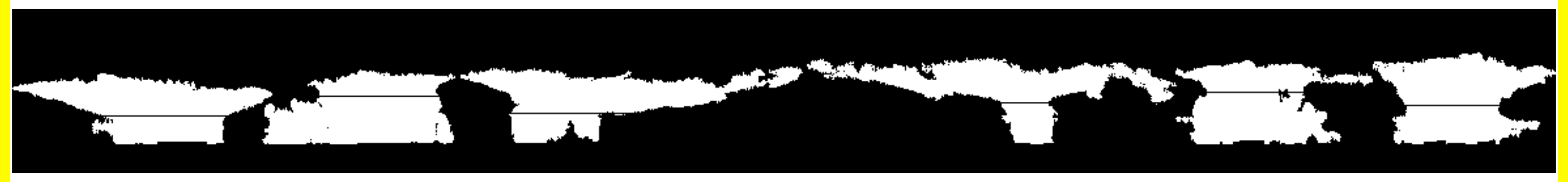
In our analysis, we account for the presence both of multiple convective cores and of conjoined cloud objects though a core-counting algorithm. This algorithm estimates the number of convective cores in a given cloud object by counting the number of local maxima in reflectivity in each of 11 lower cloud levels, focusing on columns with considerable vertical extent. For the cloud object below, we obta hree convective cores:





Continued from above:
We only search for positive 2nd derivative within the white region at right. The top of this region corresponds to the height at which it derivative becomes negative. The bottom of this region is located near the freezing level.

Works well across a variety of cloud shapes:

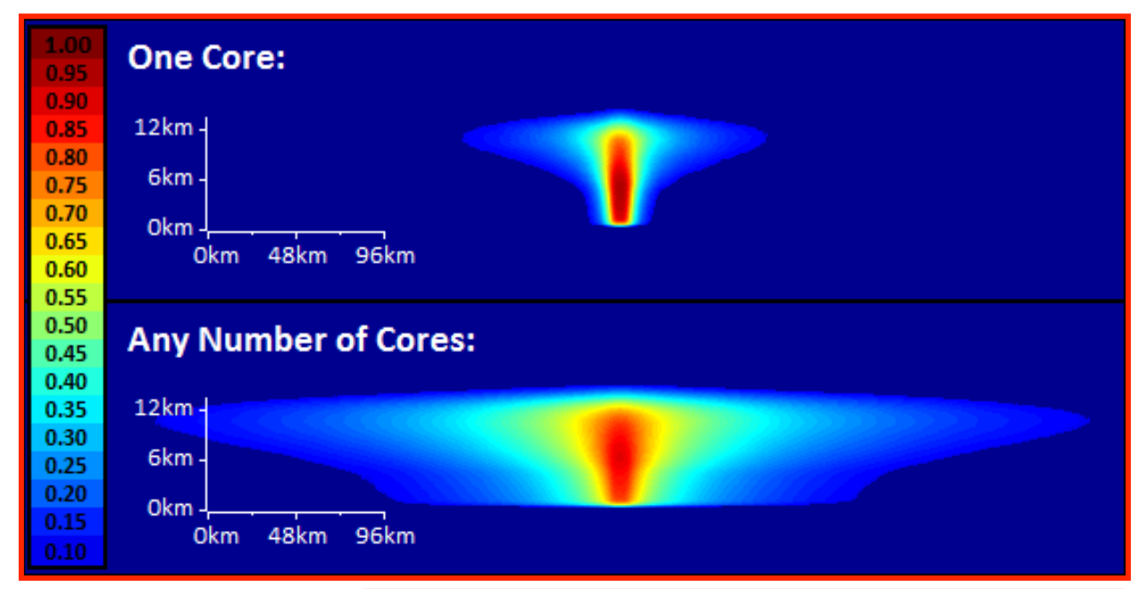


Results

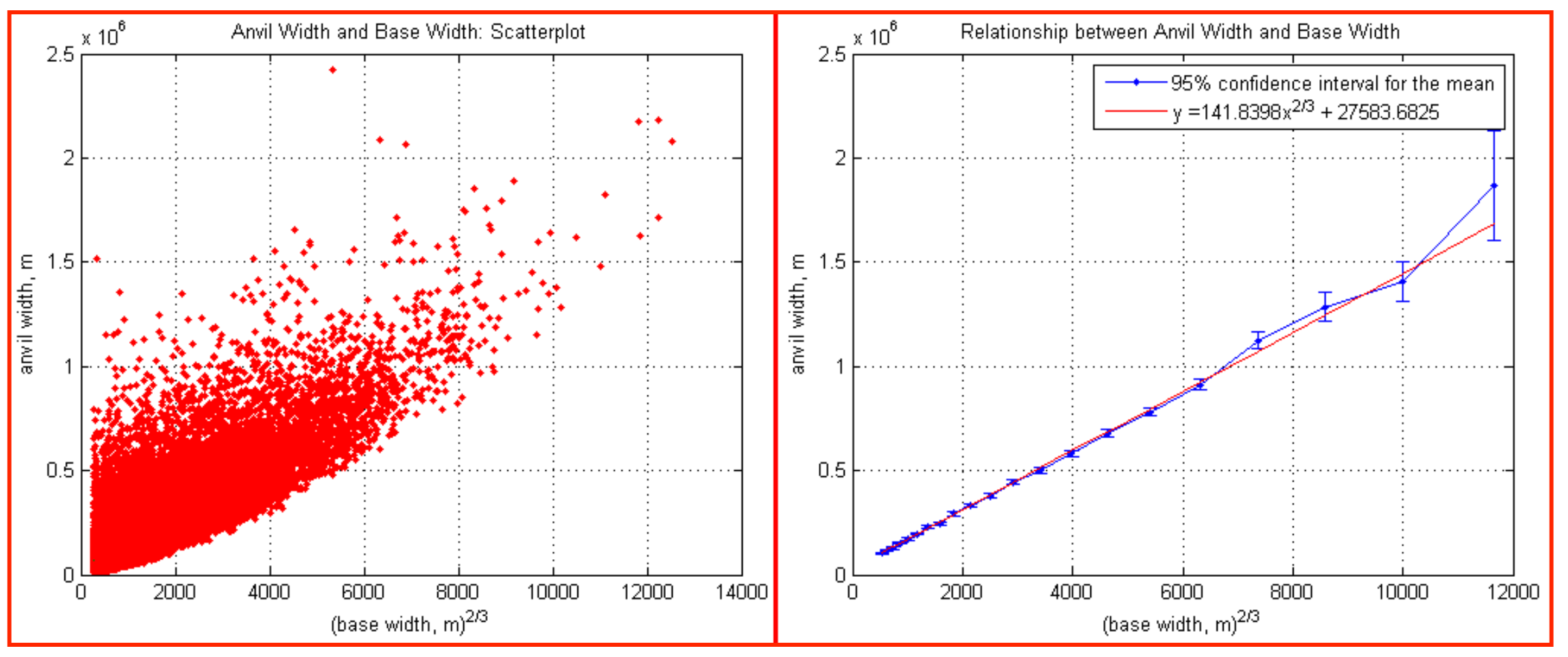
The average deep-convective cloud:

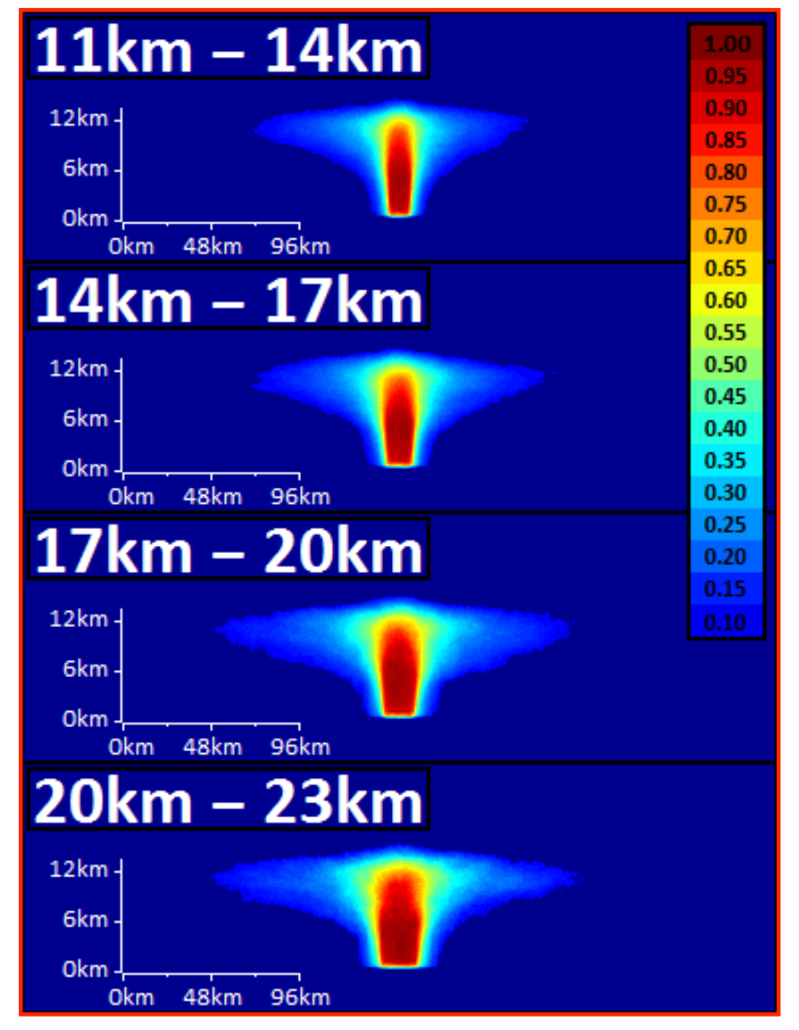
The composite cloud profiles here are obtained by "averaging" various black-and-white cloud profiles together and then applying a color scale.

	One Core	Any # of Cores
Number of Clouds	6279	24838
Mean Base Width (m)	11743	79915
Mean Anvil Width (m)	102780	256670
Mean Anvil Optical Depth	7.13	7.82
Mean Cloud-Top Temperature (K)	218.42	215.08
Mean Cloud-Top Height (m)	13629	14382
Height of the "Core" (m)	6694	6676
Height of the "Anvil" (m)	6405	7227

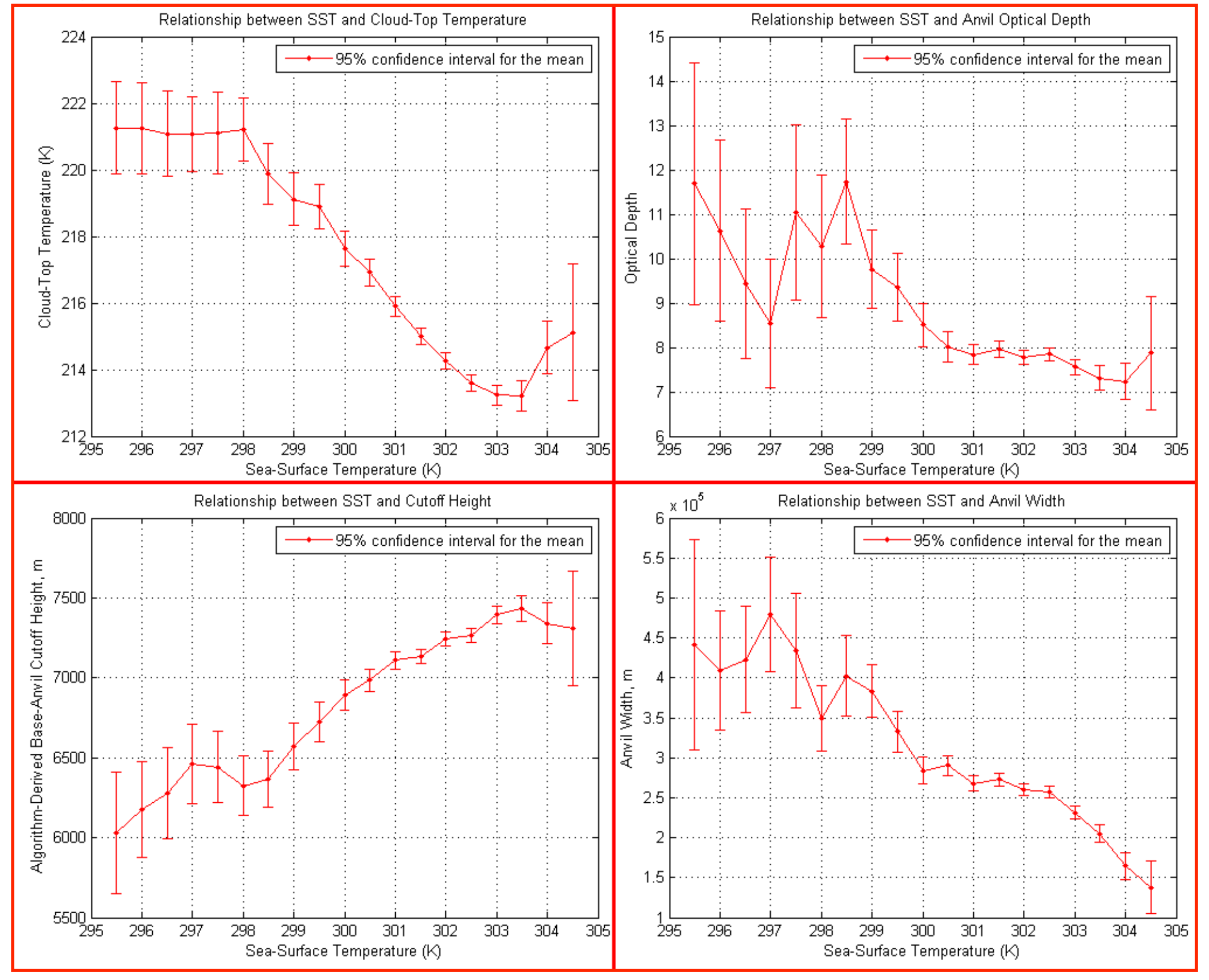


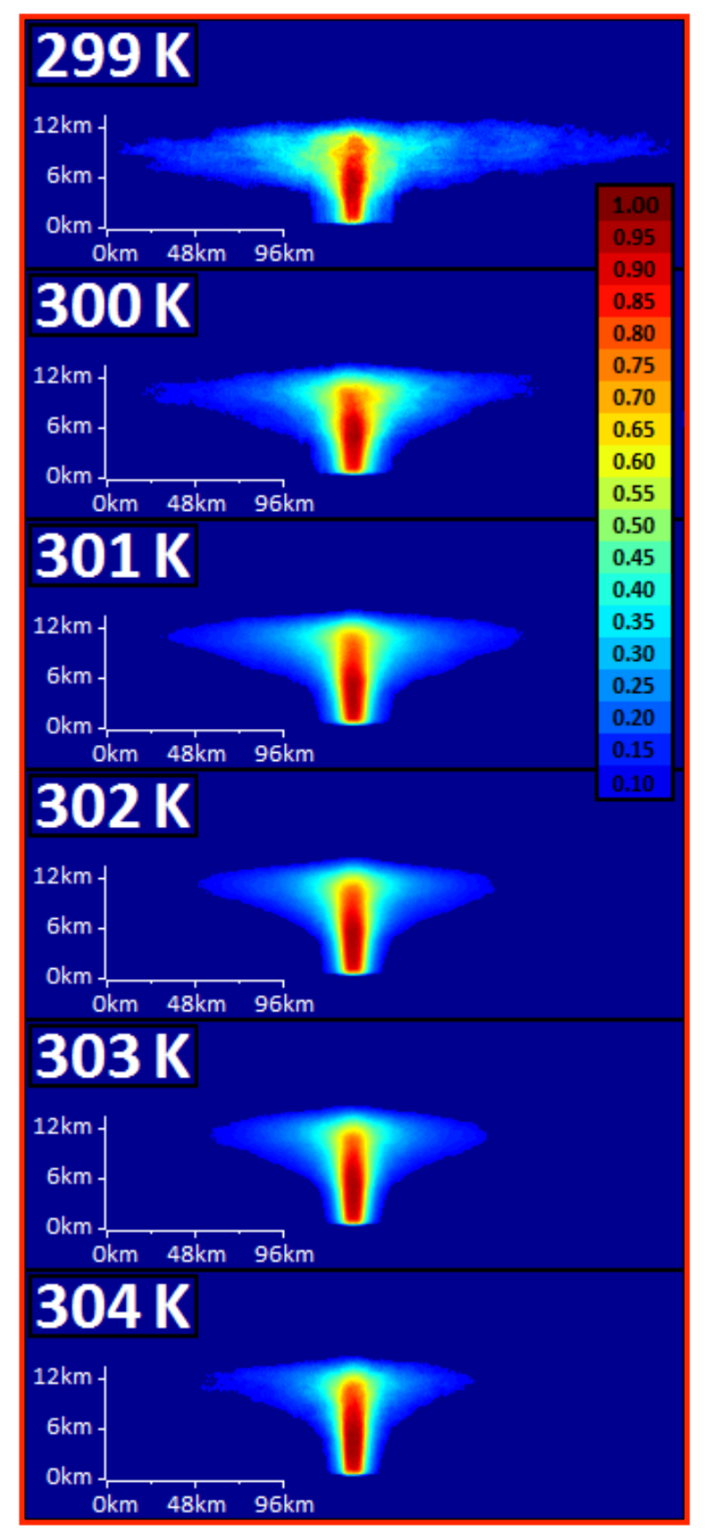
As cloud-base width increases:





As SST increases:





Conclusions

1. Cloud object-based approach yields valuable insights into the structure of deep-convective clouds over tropical oceans.
2. For clouds with base widths above 10 km, we observe a robust scaling relationship: **Anvil Width $\propto$ (Base Width)$^{2/3}$**.
3. We observe significant changes in cloud morphology with changes in sea-surface temperature. We observe that as sea-surface temperature increases, so does convective vigor: cores and anvils become narrower, and the transition from base to anvil occurs at a higher height. We also observe a significant decrease in cloud-top temperature and a non-trivial decrease in anvil optical depth with increasing sea-surface temperature.

This work has been supported by the National Science Foundation Science and Technology Center for Multi-Scale Modeling of Atmospheric Processes, managed by Colorado State University under cooperative agreement No. ATM-0425247. M. R. Igel would like to acknowledge the funding of CloudSat grant 5-319160.