Use of NASA LaRC Geostationary Satellite-Derived Products to Characterize and Nowcast High Ice Water Content Encounters

Kristopher M. Bedka[1], C. Yost[2], P. Minnis[1], L. Nguyen[1], R. Palikonda[2], D. A. Spangenberg[2], and W. Smith Jr.[1]

[1]NASA Langley Research Center, Hampton, VA
[2]Science Systems & Applications, Inc. (SSAI), Hampton, VA

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Objectives

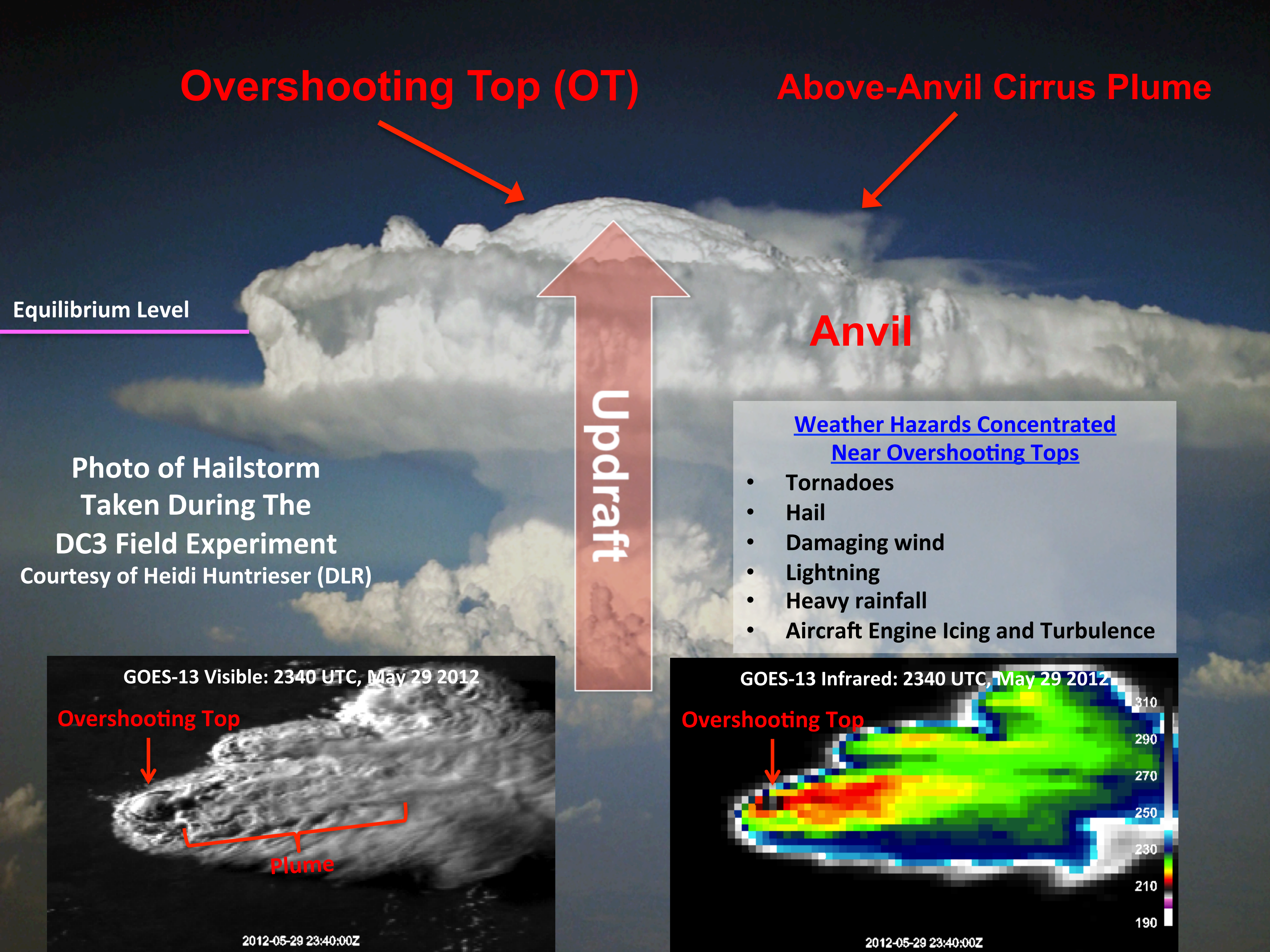
- **Identify which satellite observations/retrievals are best correlated with HIWC based on data from the 2010 Darwin and Cayenne, 2012 Santiago, 2014 Darwin, 2015 Cayenne, and 2015 NASA HIWC “Florida” campaigns**

- **HIWC associated with deep convection so we seek to analyze:**
  - IR window channel (~11 microns) brightness temperatures (BTs) near to or colder than the tropopause to identify deep convection
  - Water vapor (~6.5 microns) - IR window channel BT difference (WV-IR BTD) to further confirm the presence of deep convection
  - Cloud microphysical properties that could be indicative of HIWC
    - Small ice crystals R_{eff}, large cloud optical depth COD, and/or large ice water path IWP
  - Updraft and gravity wave regions where HIWC is likely to be generated
    - Automated IR+NWP cold spot and visible channel textured region (‘Overshooting Top’) detection methods

- **Combine satellite obs/retrievals to estimate the likelihood of HIWC using data from any operational passive geostationary satellite imager across the globe**

Aircraft/Satellite Datasets

- **Aircraft Datasets**
  - **Total water content (TWC) from IKP2: Darwin, Cayenne, and NASA HIWC Florida (Strapp)**
    - Darwin IKP2 version 4.0
    - Cayenne IKP2 version 5.0
    - Florida IKP2 version 1.0
  - **Static air temperature (SAFIRE)**
- **Satellite Datasets**
  1. **Darwin: MTSAT-1R (rapid scan, 10-minute imagery)**
  2. **Cayenne: GOES-13 (half-hourly)**
  3. **NASA HIWC-Florida: GOES-13 (5-15 min imagery) and GOES-14 (“Super Rapid Scan” 1-min imagery, Bedka et al. (JAMC 2015))**
     - ~6000 total satellite pixel - aircraft matches across 46 flights
     - ~4-km IR spatial resolution at nadir; 1-km res visible imagery
  - **Cloud property retrievals from SatCORPS (Satellite ClOud & Radiation Property retrieval System); Minnis et al. (SPIE, 2008; TGRS, 2011)**
    - Cloud phase (water/ice), boundaries, optical depth (COD), effective particle size, water path, etc.
  - **Overshooting top detection database (Bedka & Khlopenkov, JAMC 2016)**
    - Visible texture rating based on Fourier frequency analysis of high-res 1-km visible imagery
    - IR-only OT Probability rating based on identification of prominent IR temperature minima (i.e. cold spots”) in anvil clouds + IR temperature comparisons with NWP fields


Overshooting Top (OT)
Above-Anvil Cirrus Plume
Equilibrium Level
Anvil
Updraft
Photo of Hailstorm
Taken During The
DC3 Field Experiment
Courtesy of Heidi Huntrieser (DLR)
Weather Hazards Concentrated
Near Overshooting Tops
• Tornadoes
• Hail
• Damaging wind
• Lightning
• Heavy rainfall
• Aircraft Engine Icing and Turbulence
GOES-13 Visible: 2340 UTC, May 29 2012
Overshooting Top
Plume
2012-05-29 23:40:00Z
GOES-13 Infrared: 2340 UTC, May 29 2012
Overshooting Top
310
290
270
250
230
210
190
2012-05-29 23:40:00Z

Bedka and Khlopenkov (JAMC, 2016)
Visible and IR-Based 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 Image Pattern Recognition + NWP Forecast or Reanalysis Data

↓

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

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

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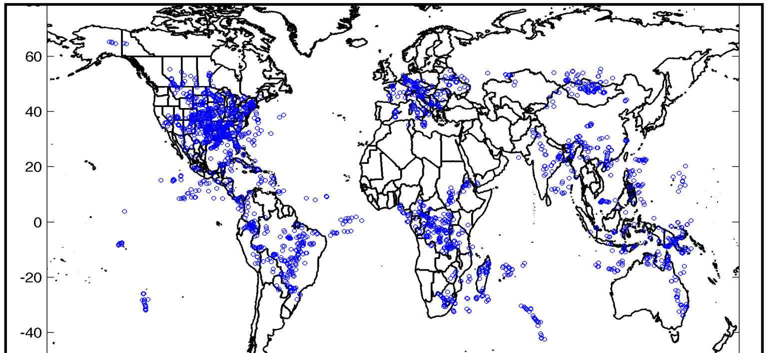
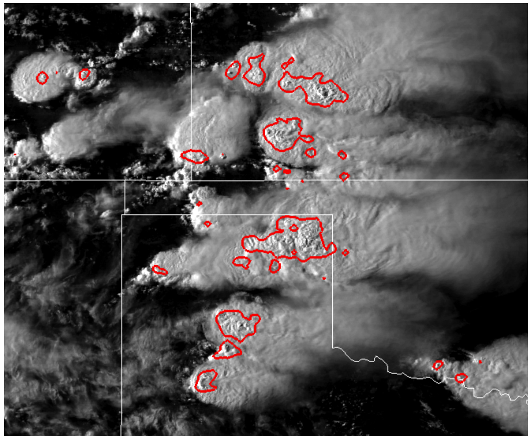
Visible OT Texture Detection, IR+NWP OT Probability, and IR Anvil Detection Products

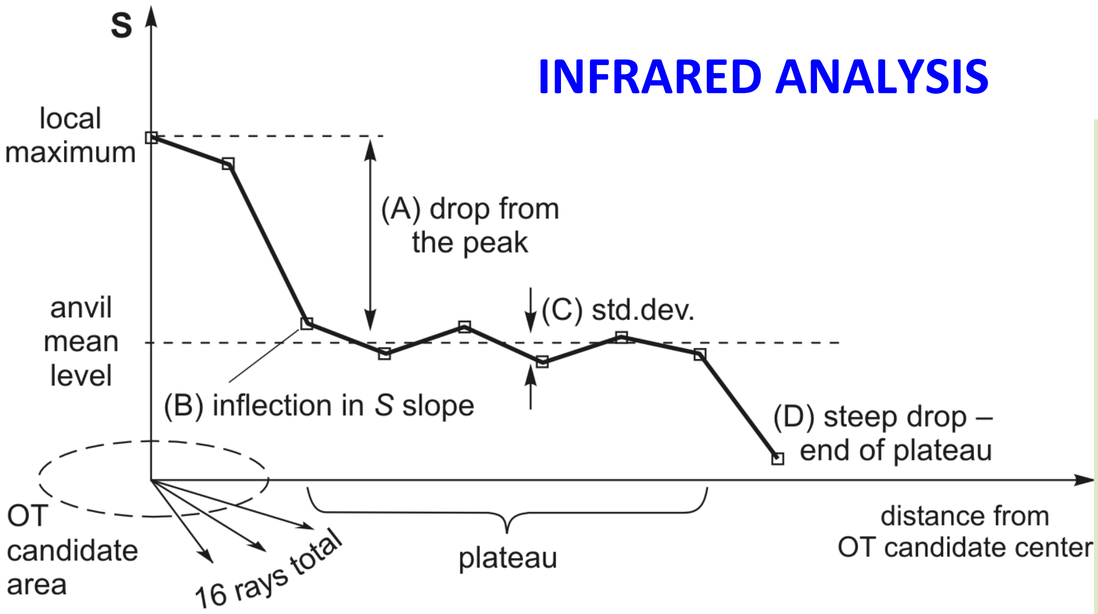


2000+ Manually Identified OT Regions In 100 MODIS Scenes

Automated Visible Texture Detection
Overlaid on GOES Visible Satellite Imagery



OT Pattern Recognition Analyses



Normalize IR BT relative to regional 400x400 pixel window)BT distribution. We call this a "BT Score"

Pattern recognition used to ensure that the cold region being analyzed is 1) within deep convection and 2) has characteristics typical of OTs

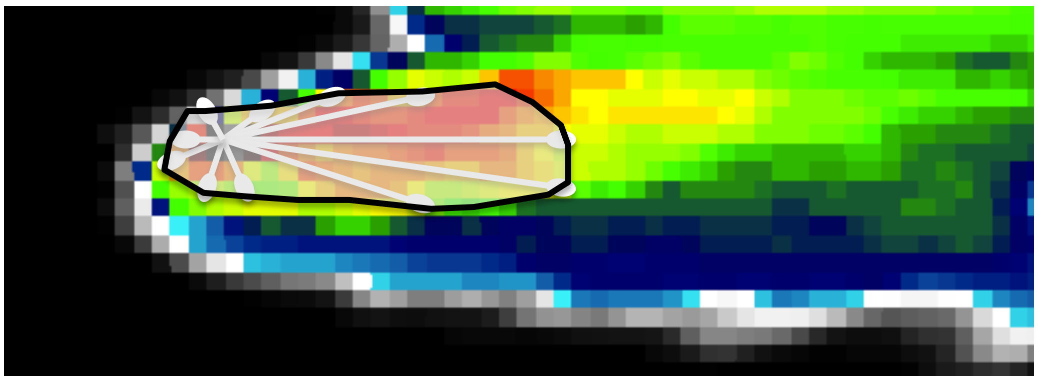
Pattern recognition uses

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

The net result is a cumulative rating for each possible OT region. Pixels with a non-zero rating at the end of all the tests above are considered final "OT Candidate" regions

OT Candidates are then assigned an OT Probability based on BT comparison with anvil mean BT, NWP tropopause and equilibrium level temps

Logistic regression applied to large training database of human-identified OT and non-OT regions to derive weights for each parameter. OT-anvil BTD is the



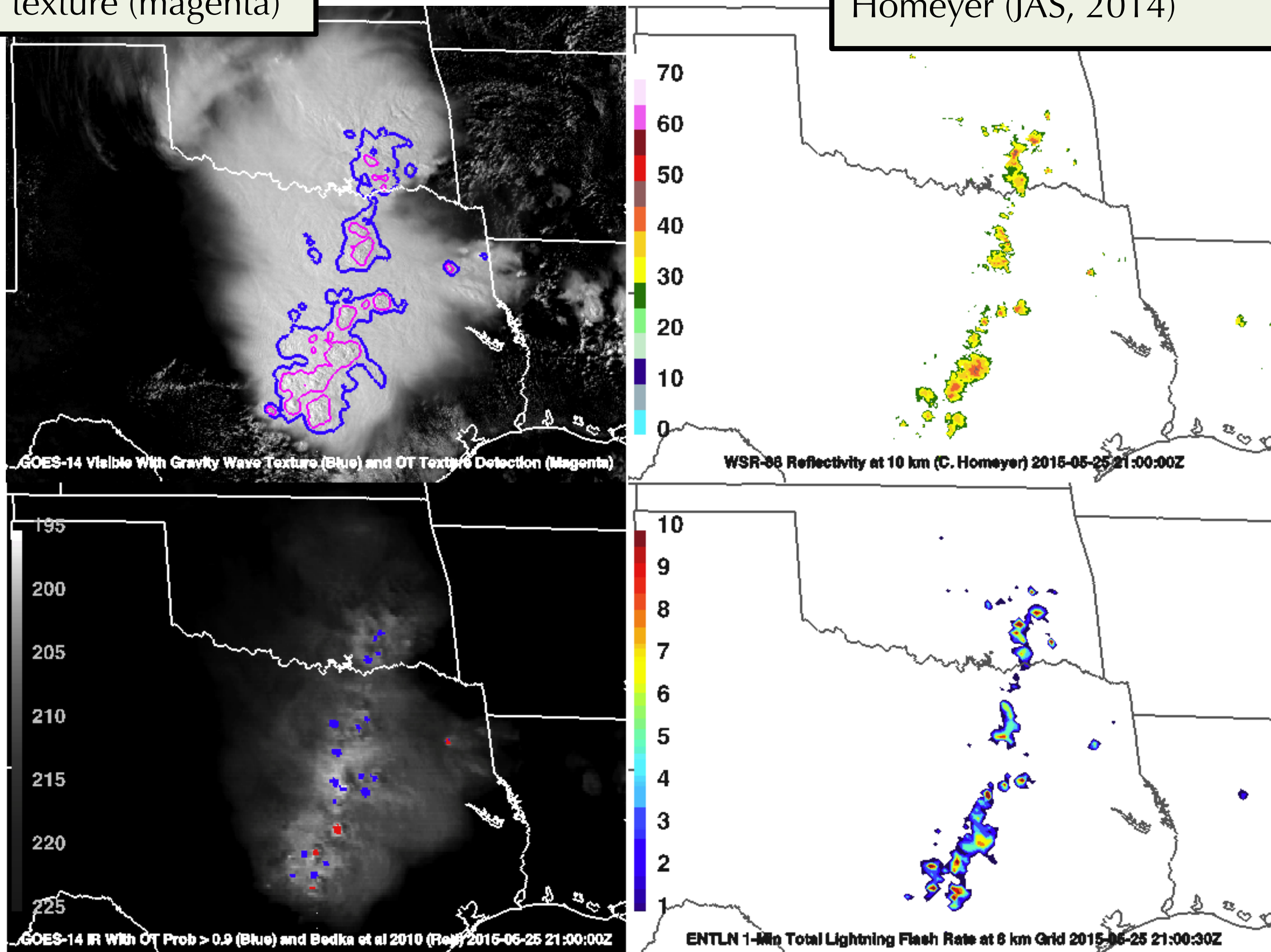
VISIBLE ANALYSIS

- **Identify anvil clouds by spatial analysis and thresholding of calibrated visible reflectance**
- **Quantify texture via pattern recognition within Fourier transforms computed in small windows in anvils**
- **Detect OT-induced shadows at high solar zenith angle**

Automated Visible Channel Texture & IR OT Detection
GOES-14 Super Rapid Scan Animation, 25 May 2015

Updraft/gravity wave texture (blue)
Significant (OT) texture (magenta)

WSR-88D radar reflectivity @ 10 km
Homeyer (JAS, 2014)



IR OT Probability > 0.9 (blue)
Bedka et al. (2010) OT Detection (red)

ENTLN 1-min Total Lightning Flash Rate

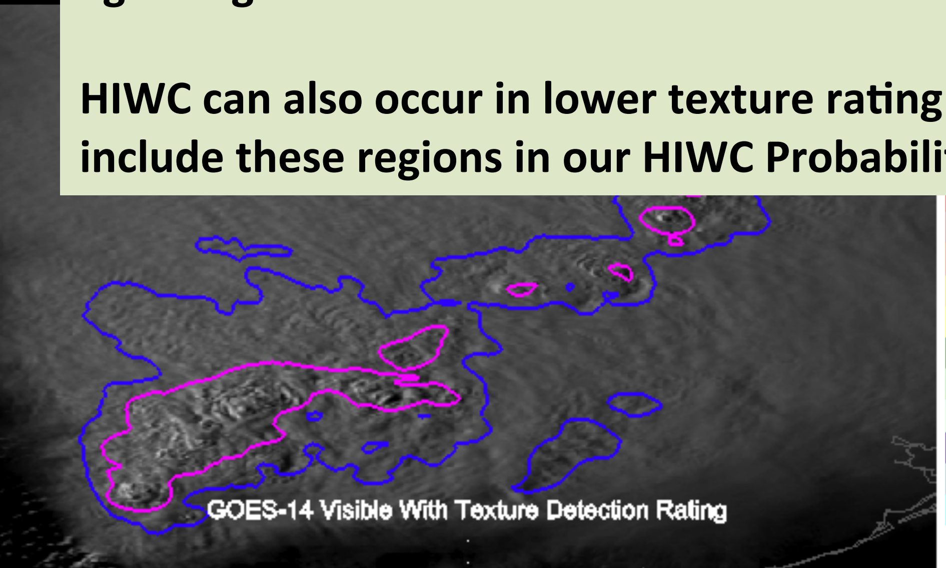
The storm complex shown here is quite large, but the OT detection products are able to pick out the most active and intense parts of the storm. These areas coincide with high radar reflectivity and total lightning activity.

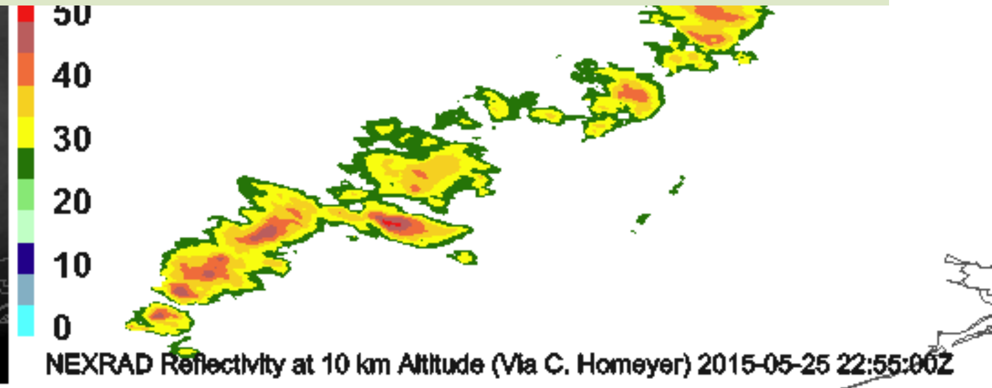
Automated Visible Channel Texture & IR OT Detection
GOES-14 Super Rapid Scan Zoomed Examples, 25 May 2015

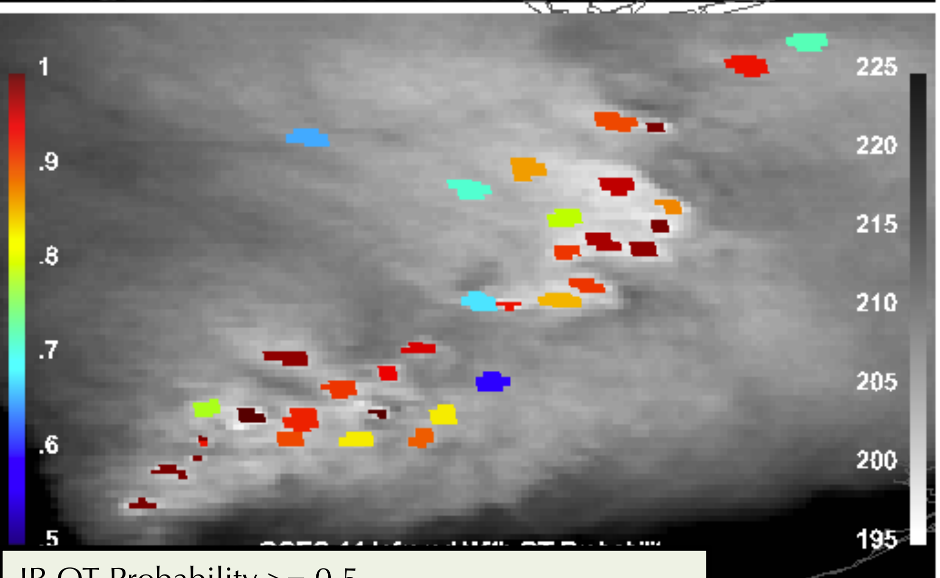
Up
Sig

Significant texture and high OT Probability best correlated with strong radar and lightning cores

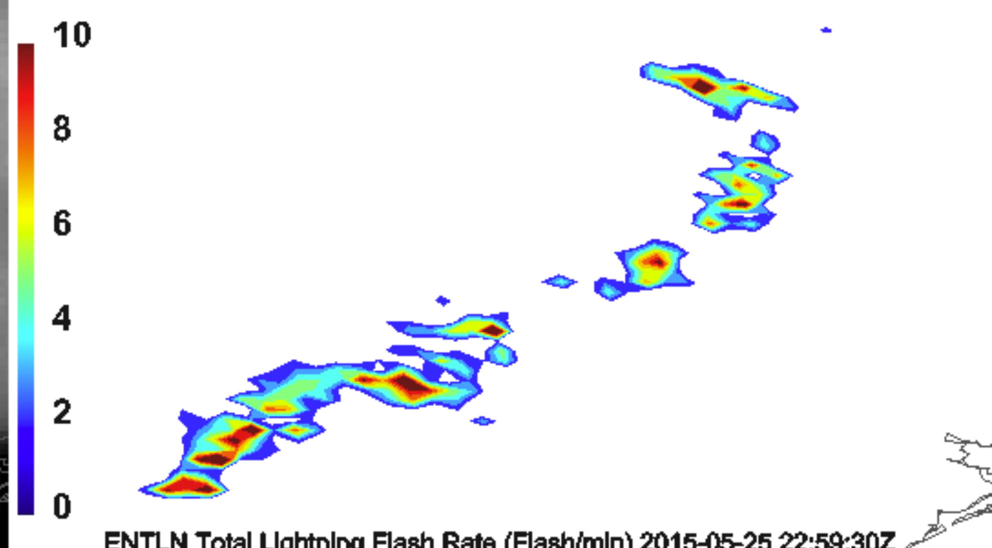
HIWC can also occur in lower texture rating and OT Probability so we also need to include these regions in our HIWC Probability model development







IR OT Probability >= 0.5
High Probability confined to core regions



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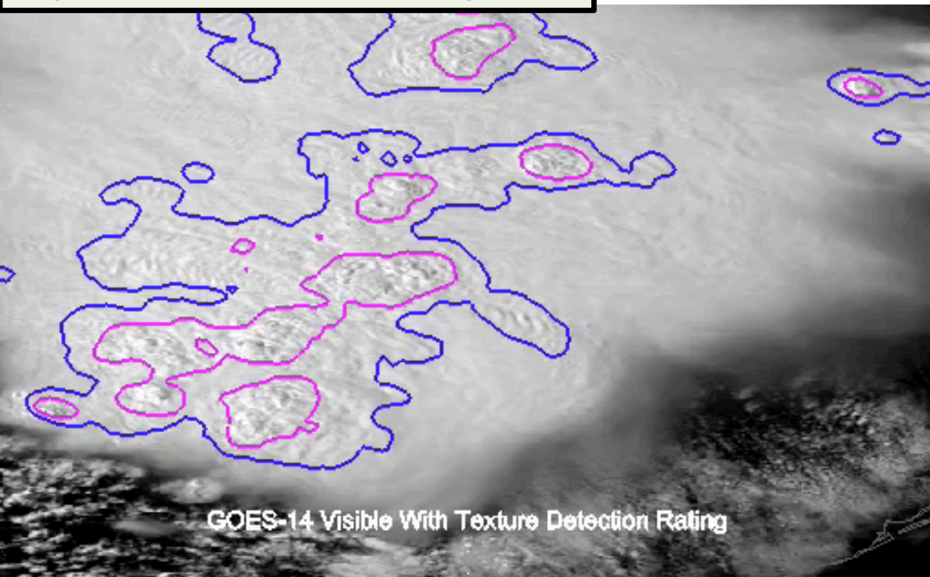
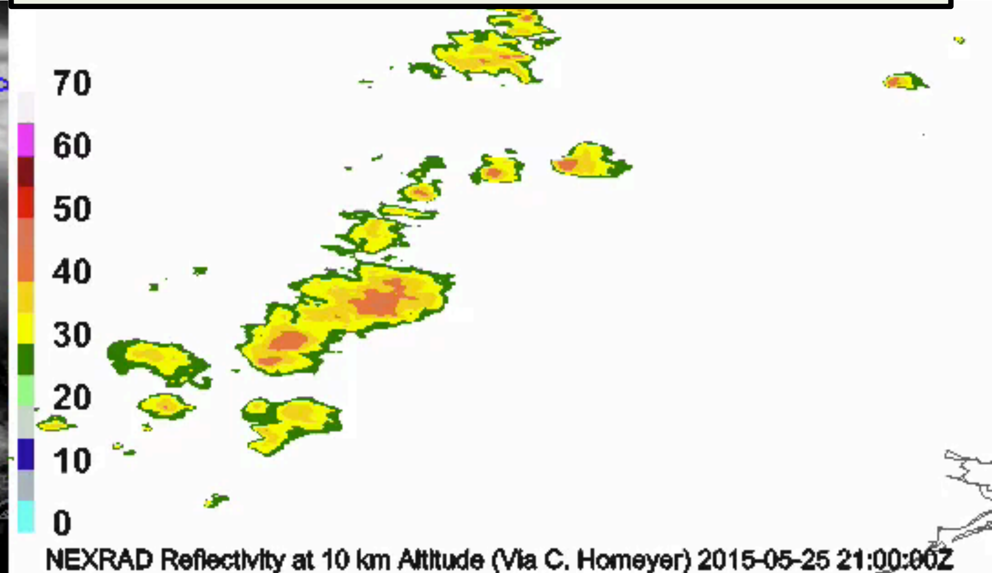
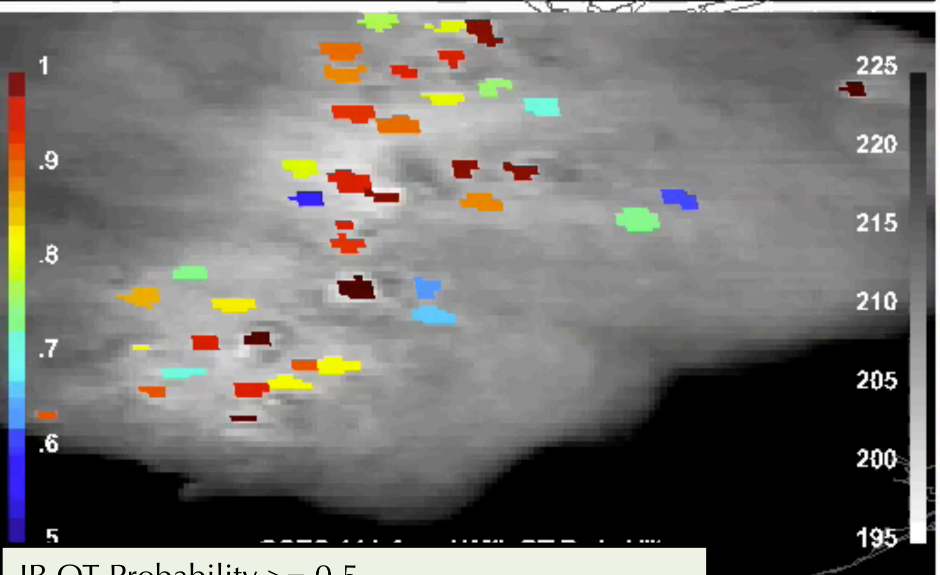


WSR-88D radar reflectivity @ 10 km
Homeyer (JAS, 2014)





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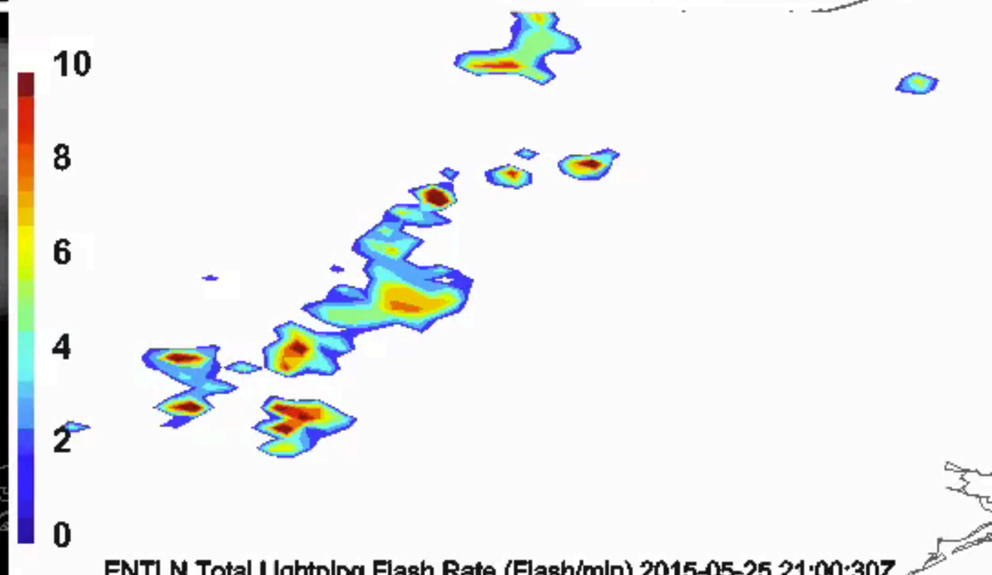


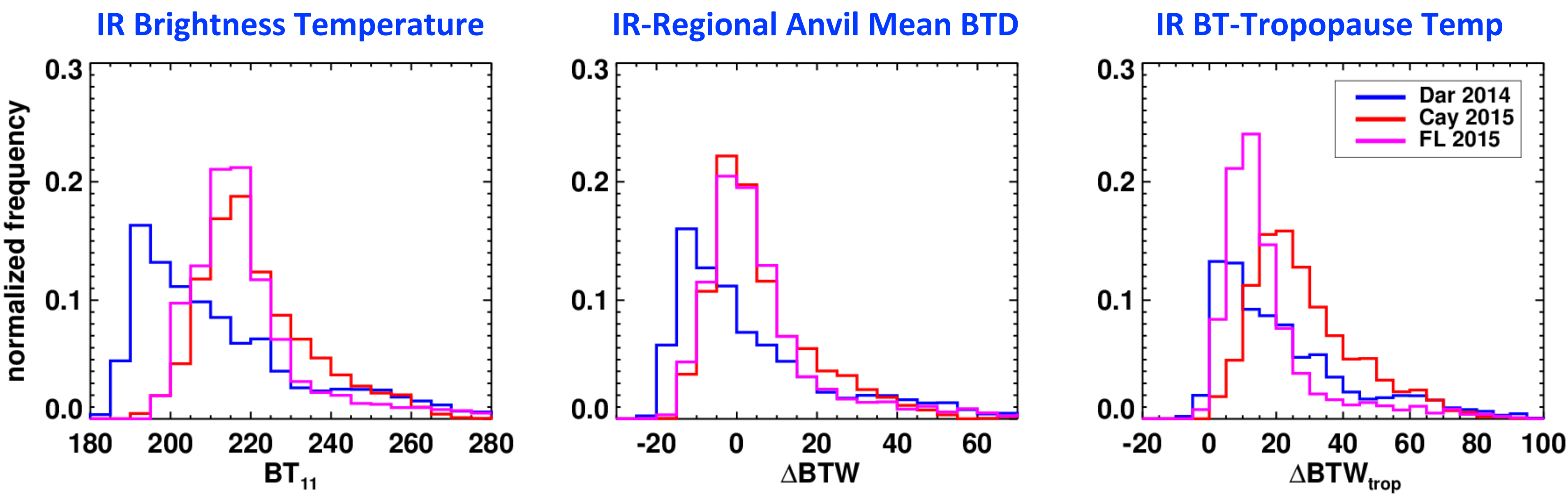
ENTLN 1-min Total Lightning Flash Rate

Normalizing IR Brightness Temperature

- **IR BT (i.e. BT_{11}) distributions for Darwin, Cayenne, and Florida campaigns are not very similar – Darwin histogram peak 30 K colder than Cayenne/Florida. Need to normalize so that HIWC diagnostics can be applied consistently across the globe**

- **Tried 2 approaches to normalize temperatures:**
  1. IR BT – WMO lapse rate tropopause temperature to determine proximity of cloud top to tropopause
  2. IR BT – regional mean anvil IR BT to assess cloud height difference relative to regional convection

- **Darwin 2014 cloud tops co-located with research aircraft were closest to tropopause, followed by Florida, and lastly Cayenne 2015. The IR-tropopause approach is more robust, easier to implement operationally across the globe, and has proven useful in other studies (Gryzch et al. (SAE, 2015))**



Collocated Aircraft/Satellite Observations

- **Match mean cloud properties in 2x2 pixel box to aircraft position, +/- 5 mins of each other**
- **Typical cruise speed of Falcon-20: 180 m/s**
- **45-s averages of aircraft data, equivalent to 8 km distance**
- **Aircraft and satellite obs matched with max window of 5 mins**
- **TWC > 0.01 g m^{-3} considered in-cloud threshold**

IKP2 total water content TWC [g m^{-3}], 45-s averages. 8 HIWC encounters on this flight

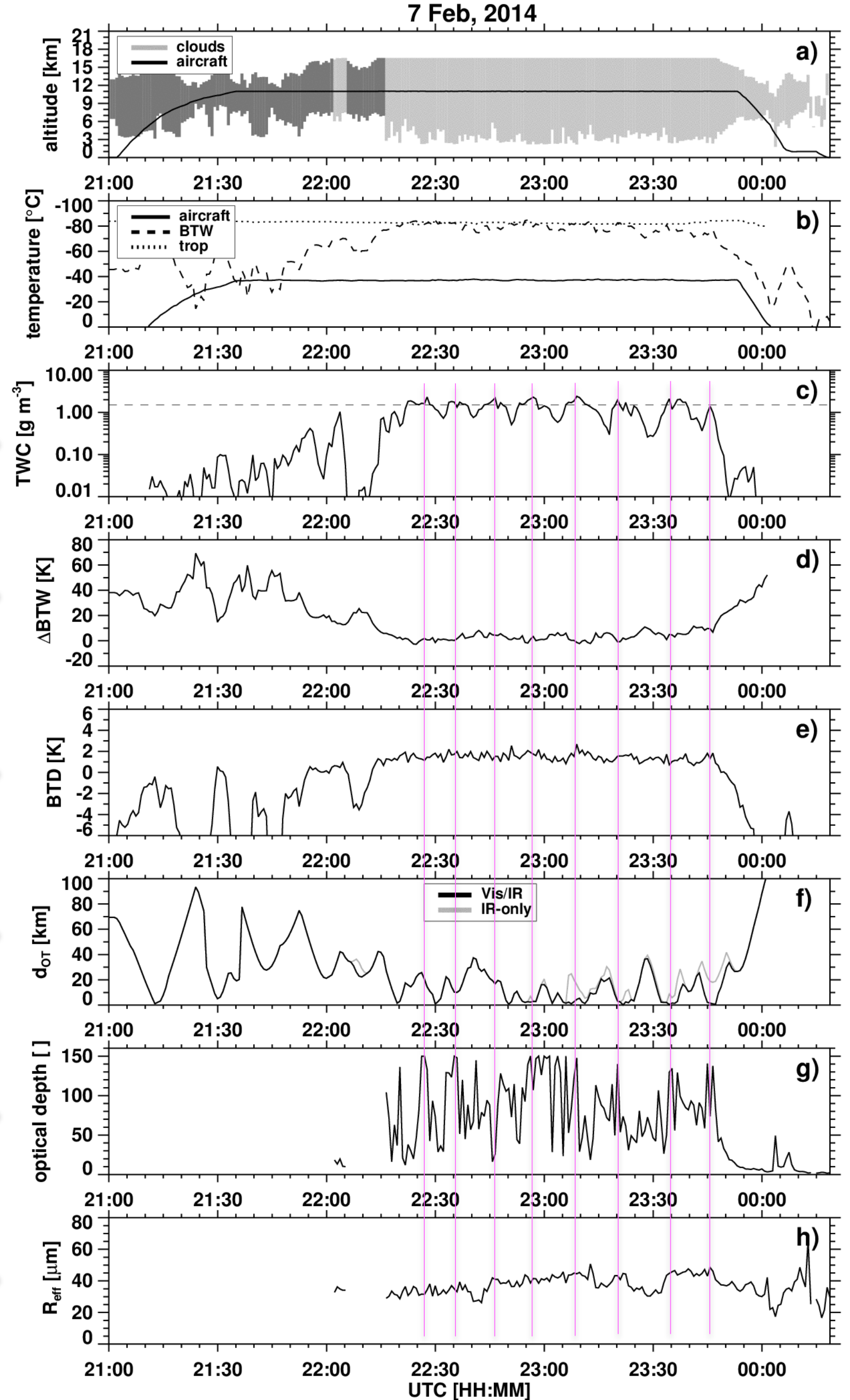
Negative OT-tropopause temp diff indicate convective cores and their outflow

Positive WV-IR BTD indicates deep convection

Distance from Falcon's position to nearest prominent cold spot or textured "OT" region

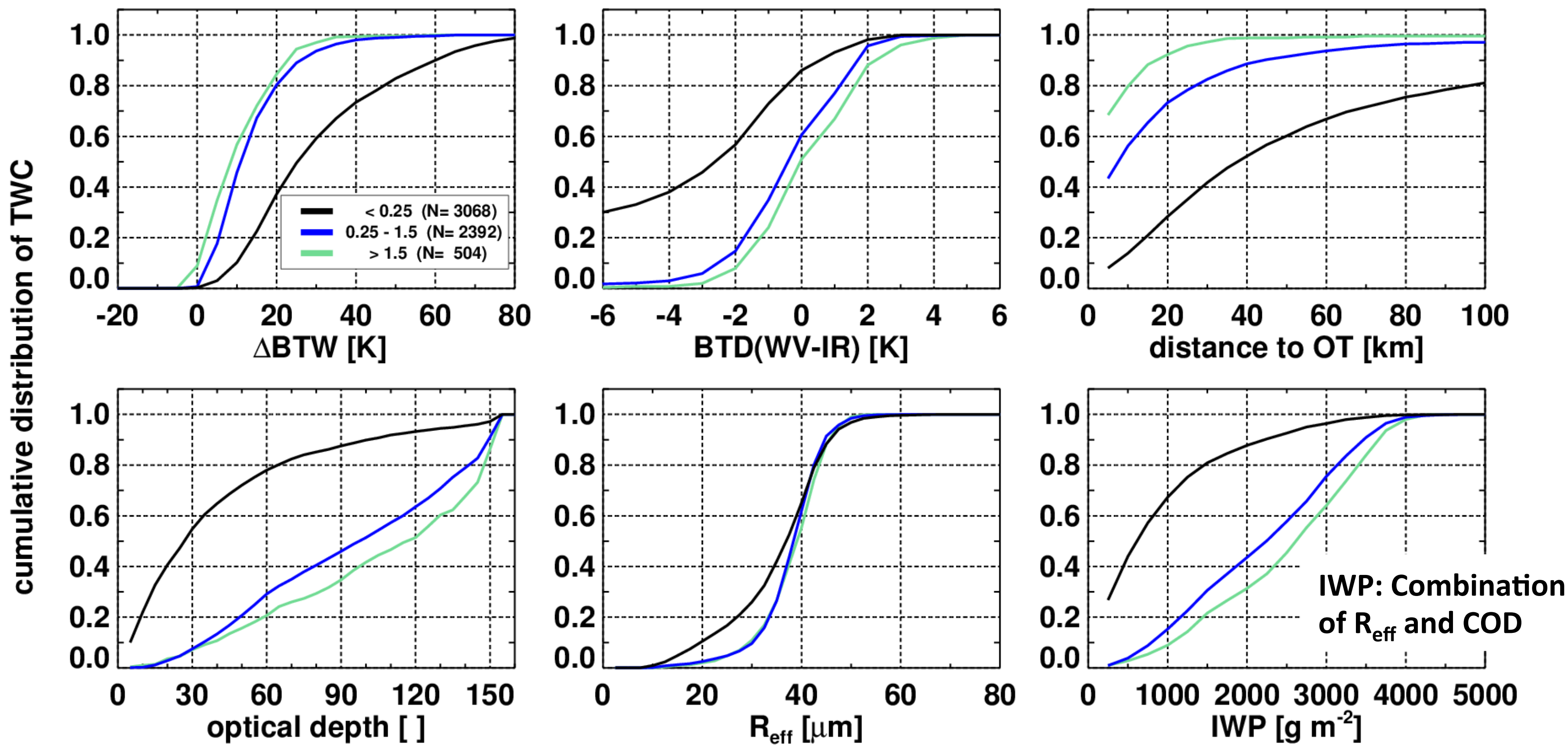
COD > 30 indicative of convective clouds. COD peaks (100+) during HIWC encounters but also adjacent to HIWC

Variations in particle size weakly correlated with TWC



Cloud Properties Coincident with HIWC: Darwin-14, Cayenne-15, NASA HIWC-Florida

- Examined fractional occurrence of TWC with different satellite observations/retrievals
- Some statistical separation between 0.25-1.5 g m^{-3} category and 1.5+ g m^{-3} for all parameters except R_{eff}
- **65% (98%) of TWC > 1.5 g m^{-3} were within 10 (50) km of an OT**
- No single satellite observation indicates certainty of HIWC
- Correlation among the different parameters, i.e. not independent
- How can we combine parameters to derive a “probability of HIWC” product?



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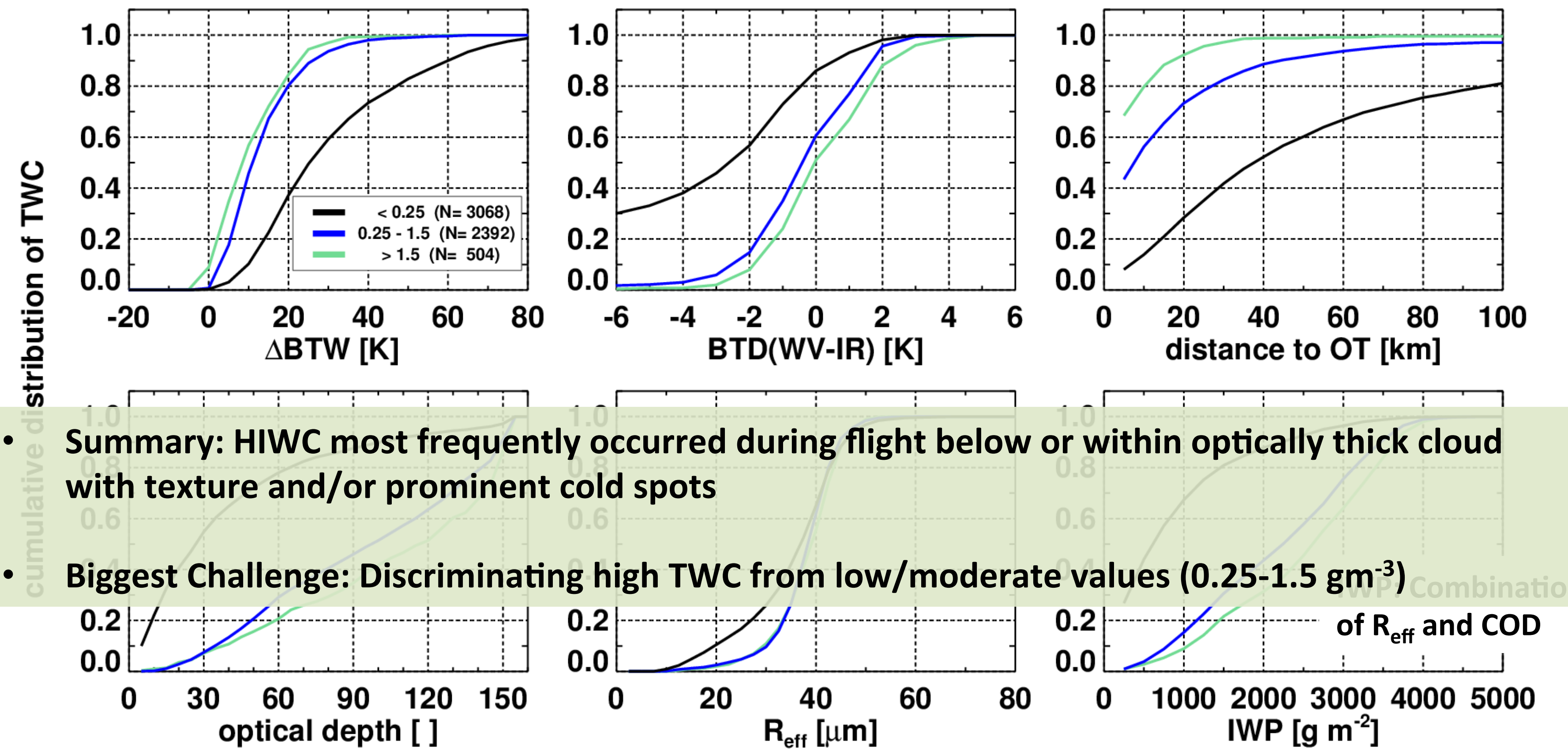
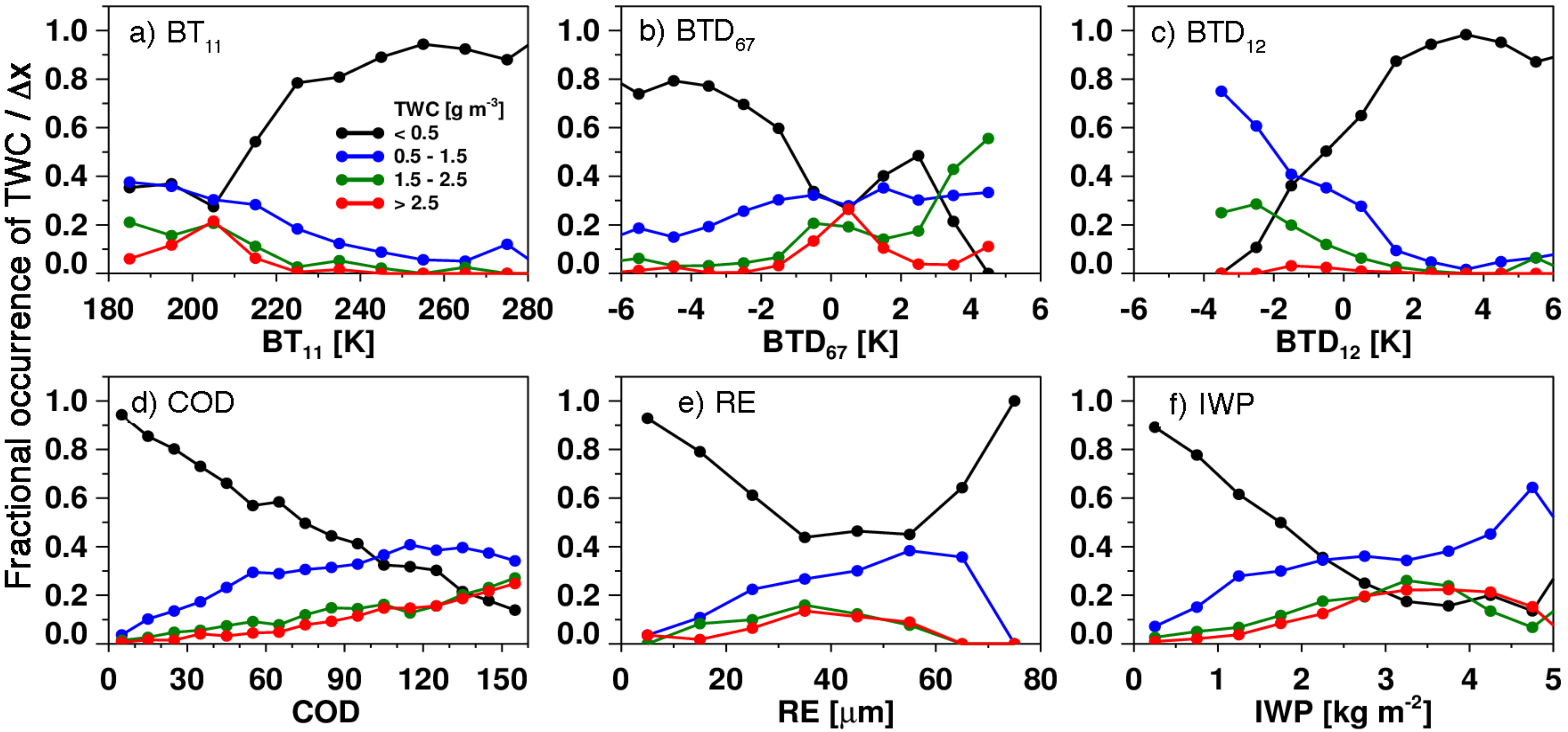


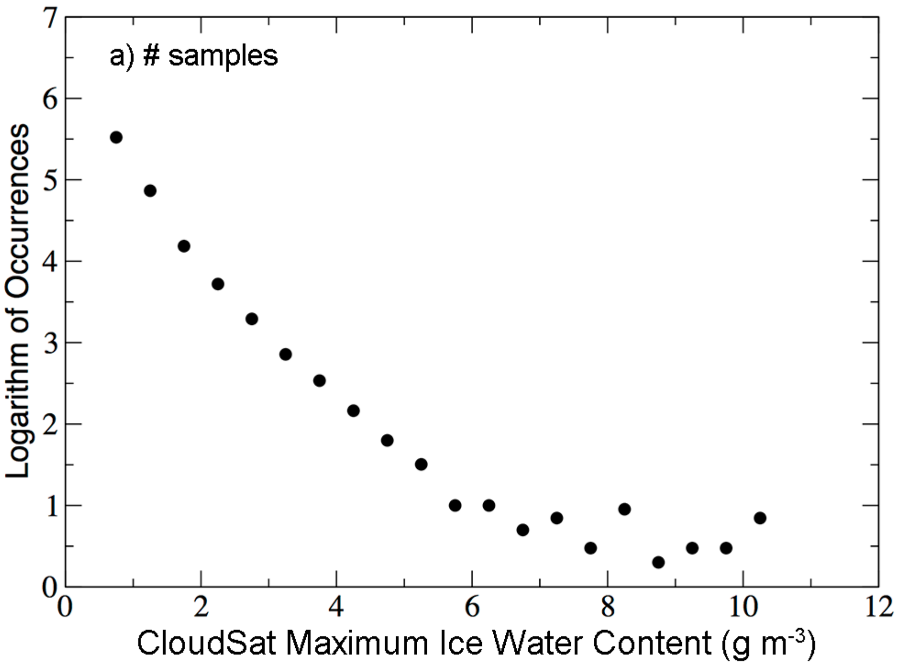
- **Summary: HIWC most frequently occurred during flight below or within optically thick cloud with texture and/or prominent cold spots**
- **Biggest Challenge: Discriminating high TWC from low/moderate values (0.25-1.5 gm^{-3})**

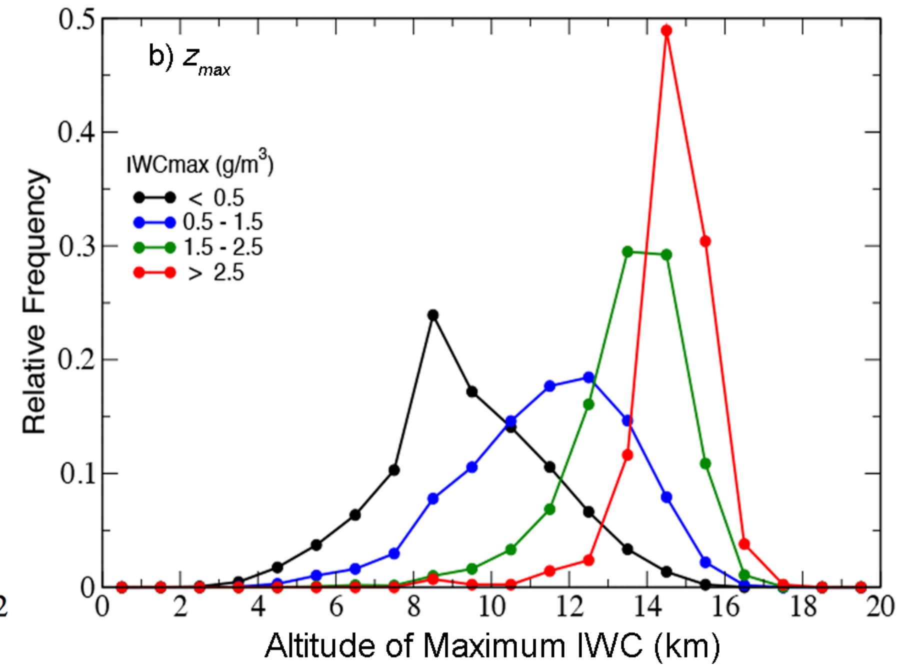
GEOsat Cloud Properties Coincident with HIWC: Cayenne-10, Darwin-10, Santiago, and Darwin-14,



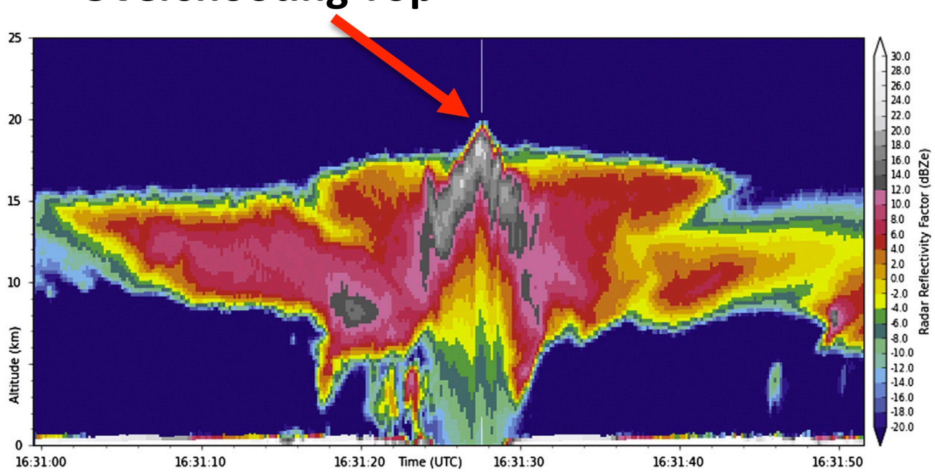
- **Similar to the previous analyses, flight within or beneath cold, optically thick convective anvils most likely to experience HIWC**

Vertical Distribution of CloudSat IWC





Overshooting Top

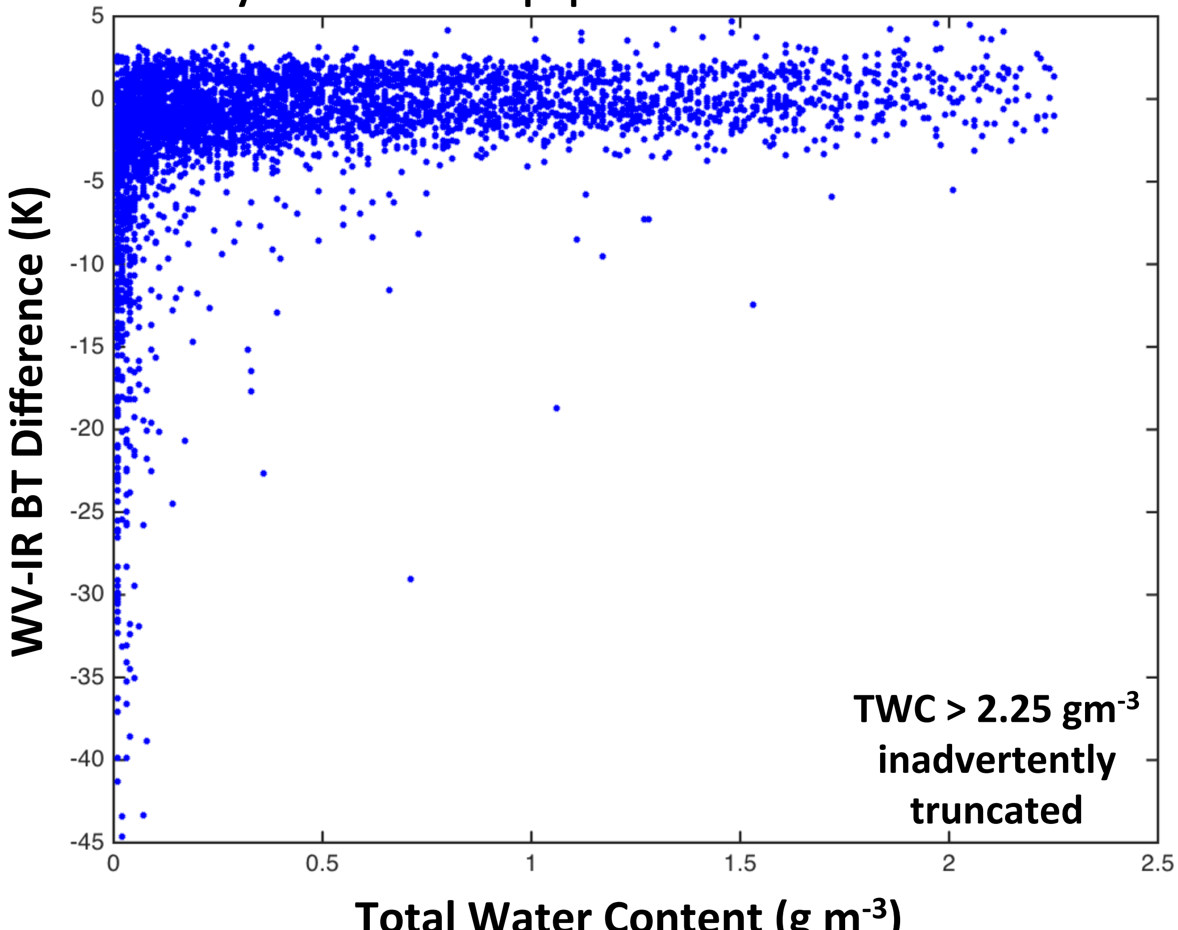


Setvak et al. (Atmos Res., 2013)

- **Height of max IWC is well correlated with IWC magnitude**
- **Previous results tie IWC extremes to convective cores**
- **CloudSat radar signal attenuates strongly in core regions, inhibiting profiling deeper into the cloud where an even greater IWC could be located. So by default, the max IWC is near storm top**
- **The pattern shown above again points to convective cores being responsible for HIWC**

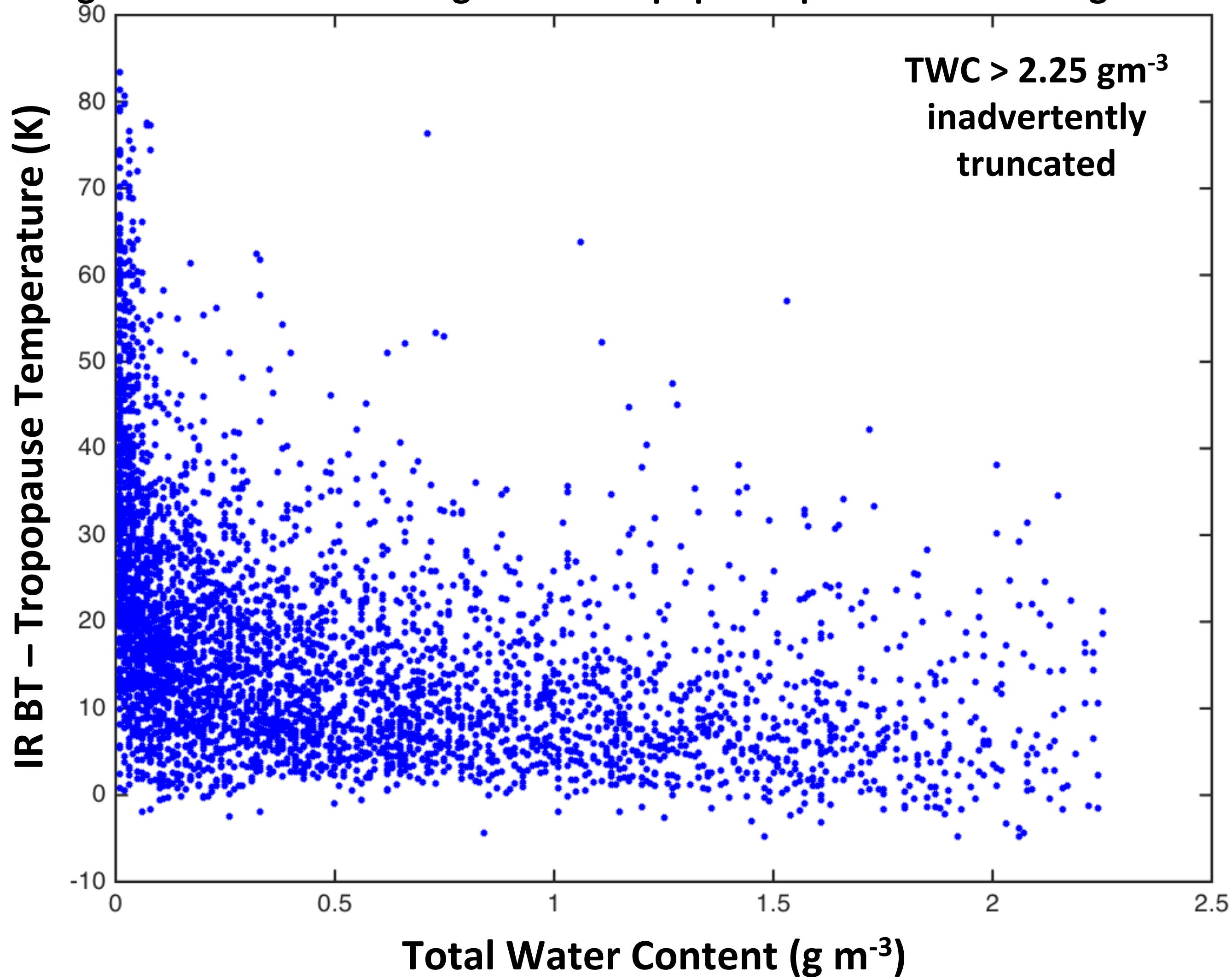
WV-IR BTD – Total Water Content Relationship

- Much of dynamic range in WV-IR BTD vs TWC relationship is gone by 0.1 g m^{-3}. Slope in mean BTD for 0.1+ TWC points is ~1 K between 0.25 and 2.5 gm^{-3}.
- 1 K noise in WV channel BT at cold temperatures is common. Considering differences in WV channel spectral response across global GEO imagers and view angle dependencies, the BTD is ineffective for a probabilistic HIWC nowcast purposes
- Nearly all TWC > 0.5 g m^{-3} occur when BTD > 4 K, but these points are all cold temperatures relatively near to the tropopause so the BTD is not of much help



IR BT minus Tropopause – Total Water Content Relationship

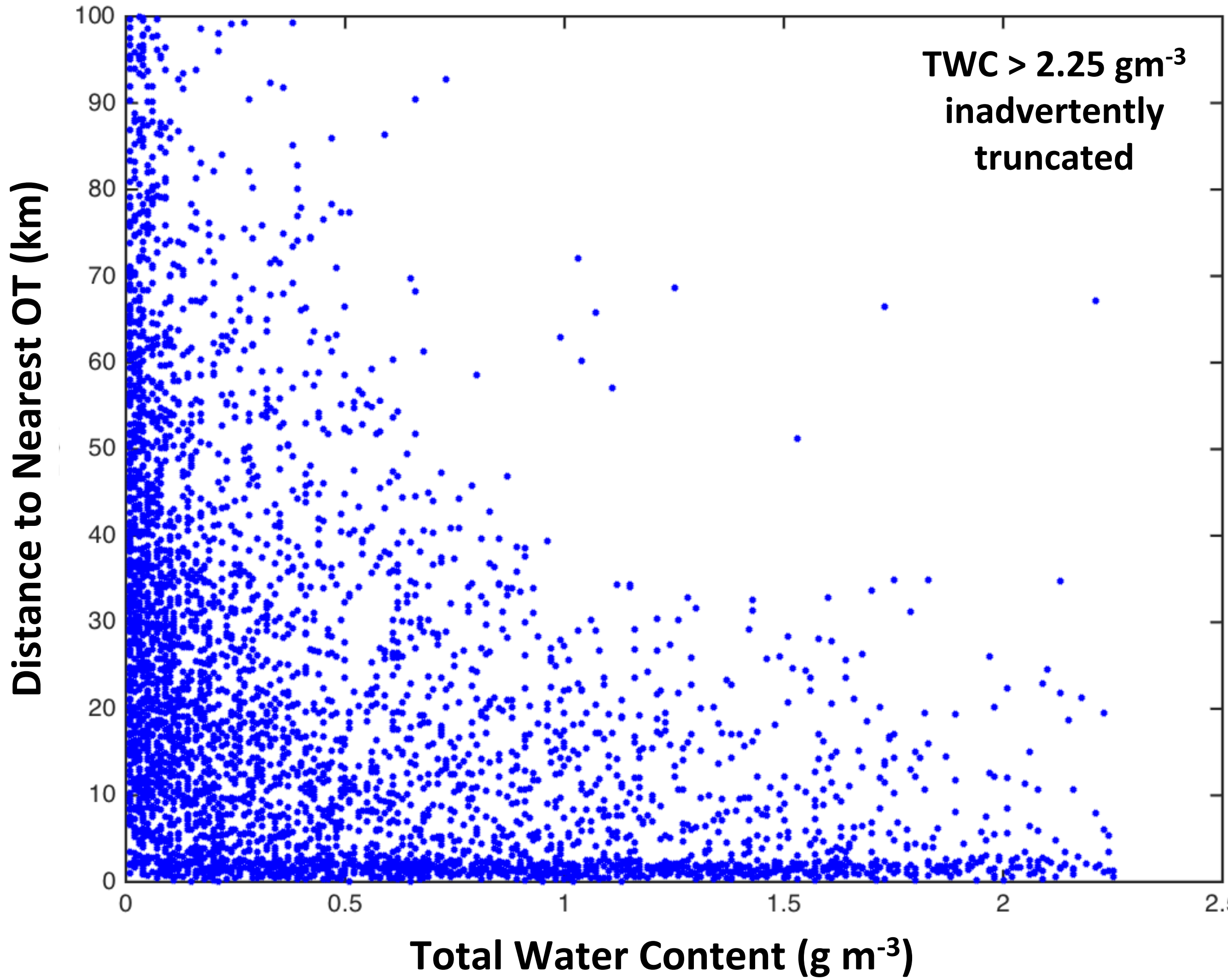
- **Exponential relationship between IR-Trop and TWC. Much of dynamic range in IR-Trop vs TWC relationship is gone by 0.25 g m^{-3} TWC**
- **Nearly all TWC > 0.5 g m^{-3} occur when IR-Trop < 40 K**
- **Very few segments in cloud with significant tropopause penetration during the 3 campaigns**



Distance to Nearest OT – Total Water Content Relationship

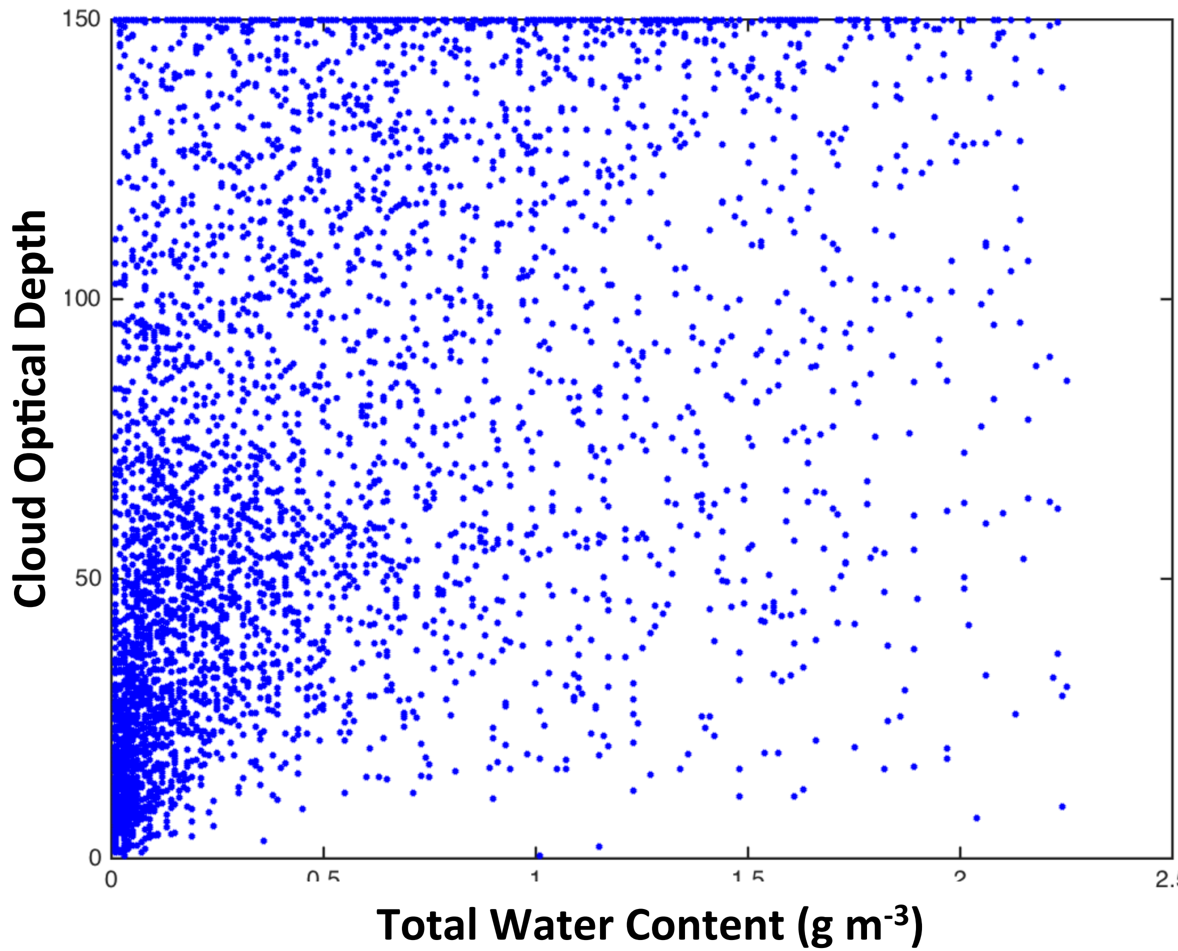
- **Exponential relationship between distance to nearest visible texture or cold spot (DOT) and TWC**

- **Nearly all TWC > 0.5 g m^{-3} occur when DOT < 40 km. Only 1.2% of TWC > 0.5 occurred for DOT > 100. Many low TWC close to OT as well; caused by liberal texture rating threshold in OT product?**

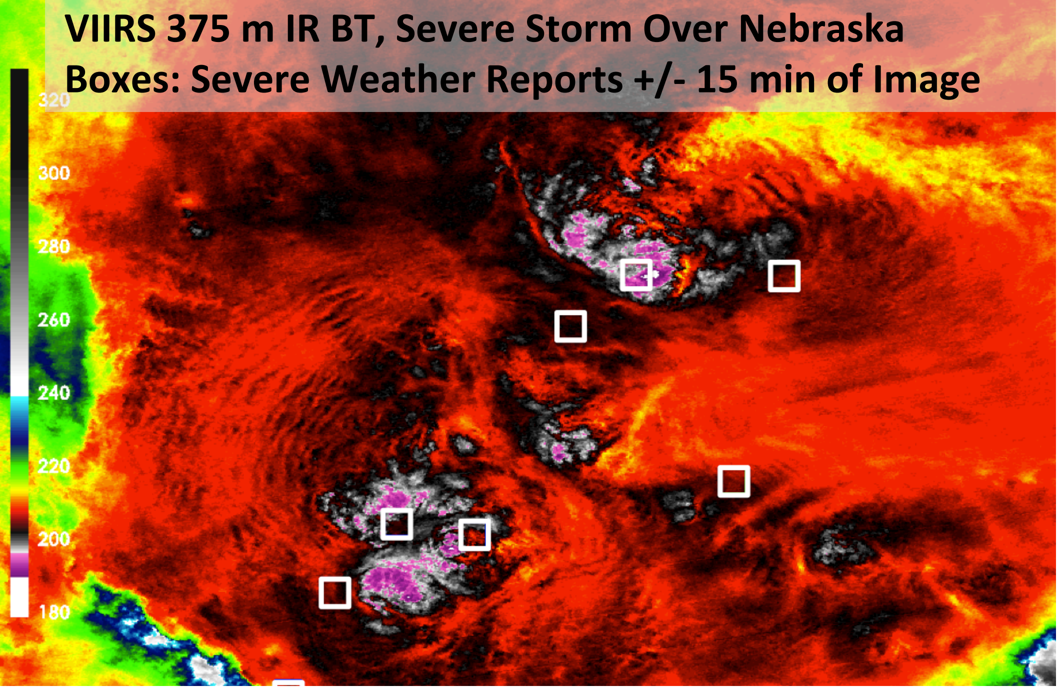


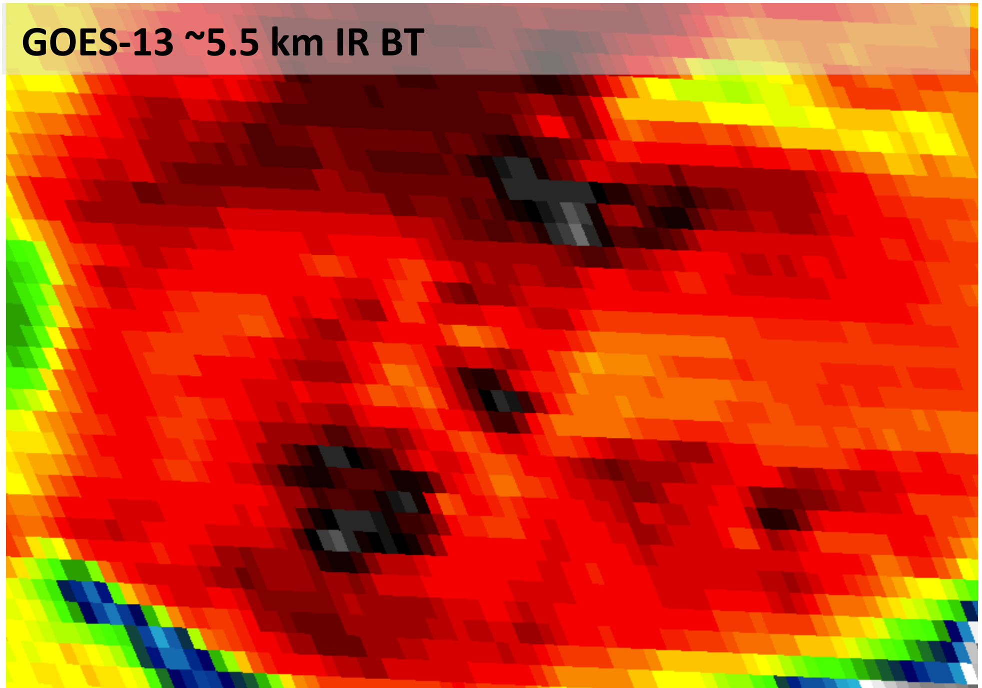
Cloud Optical Depth – Total Water Content Relationship

- The common assumption is that the brightest, most optically thick pixels are intense storms that are most likely to generate HIWC. But the distribution below doesn't necessarily show this.
- The mean COD-TWC relationship is linear but outliers are abundant
- A relatively high likelihood for HIWC for low (< 50) COD, small convective turrets exceeding the size of a satellite pixel? Temporal/spatial mismatch between aircraft/satellite pixel? Cloud shadowing/texture? Retrieval problems at high solar zenith angle?



TWC > 2.25 gm^{-3} inadvertently truncated





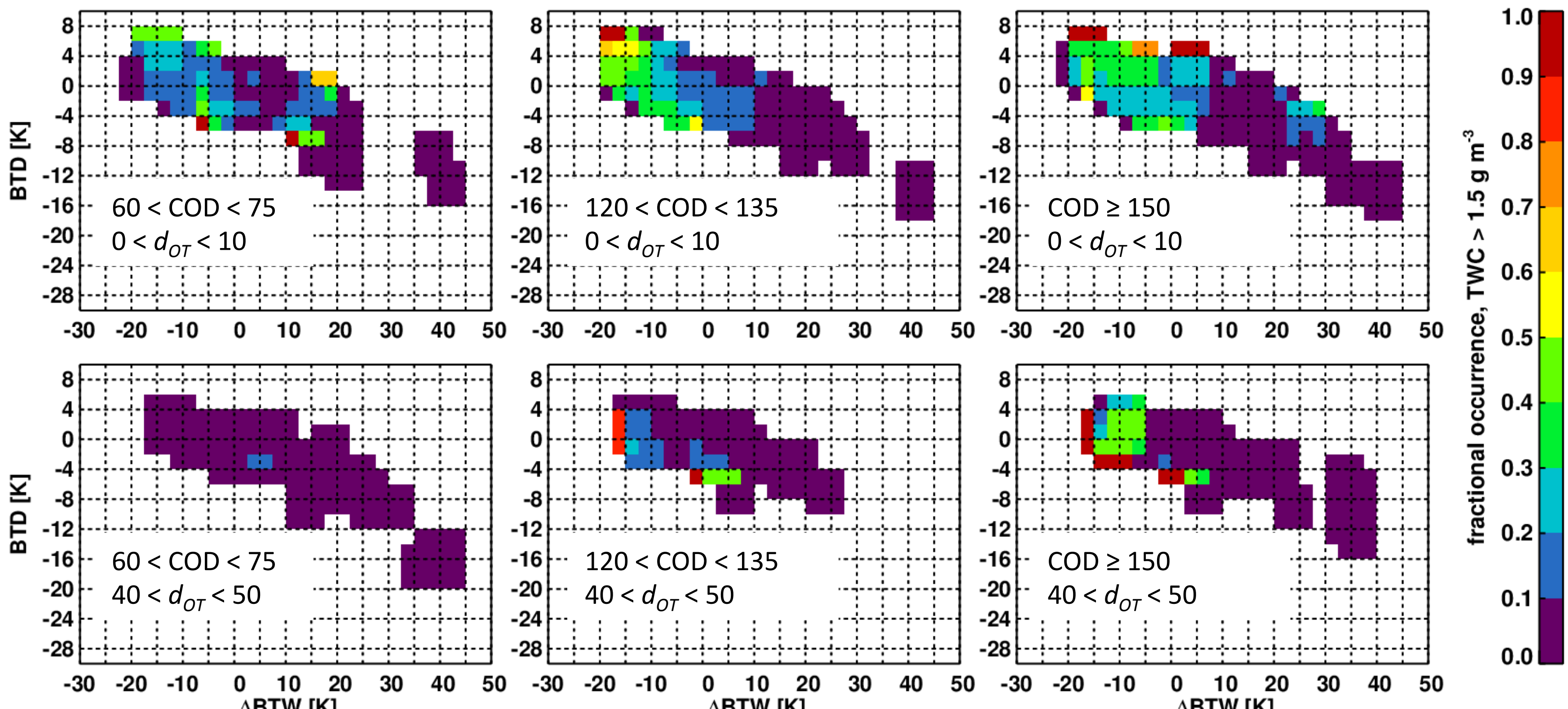
Impact of Imager Spatial Resolution on Hazardous Storm Appearance

- **High spatial resolution data are critical for resolving the coldest IR BTs present within storm tops**
- **IR BT within OT regions are found to be 7-12 K colder in 1 km LEO than GOES**
- **375 m VIIRS IR BTs are up to 15 K colder than GOES for the most intense storms in this case**
  - 200+ VIIRS pixels for 1 GOES IR pixel
- **We expect OT regions observed by GOES-R ABI to be at least 5 K colder than what is observed by current GOES**
- **Improved ABI resolution will allow for forecasters to better recognize OTs and rapid updraft intensification leading to hazardous weather**

Probability of High Ice Water Content Algorithm Development and Validation

Development of Probability of HIWC (PHIWC) Products
Approach #1: Probability Joint Histogram

- Fractional occurrence of HIWC as function of:
  - ΔBTW (indicator of relative storm intensity)
  - BTD (presence and strength of overshoot)
  - Cloud optical depth (COD > 30 indicative of deep convection)
  - OT proximity
- Use satellite-aircraft matched dataset to derive statistics and develop algorithm
- Multi-dimensional analysis of fractional occurrence distribution designed to enhance product and address parameter inter-dependencies
  - Use distributions as a look-up table of HIWC fractional occurrence



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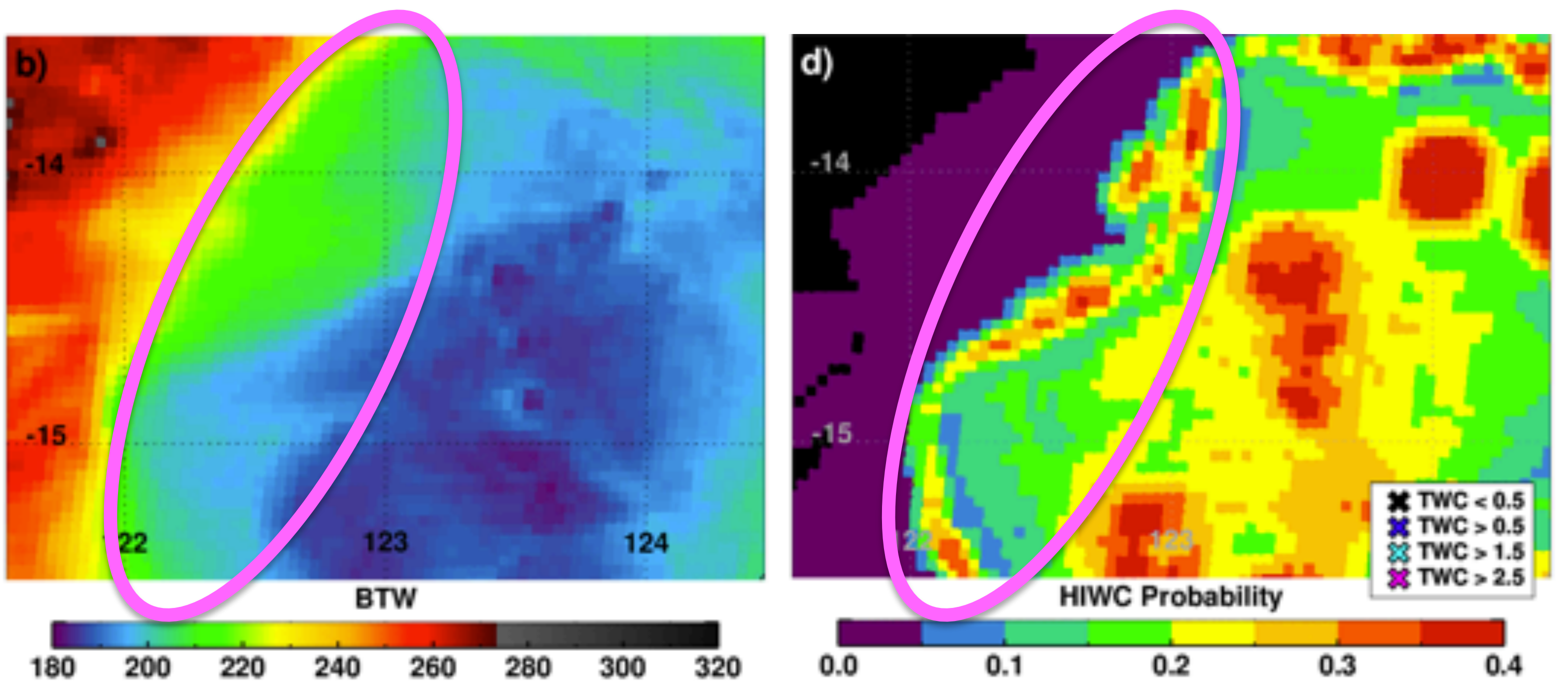
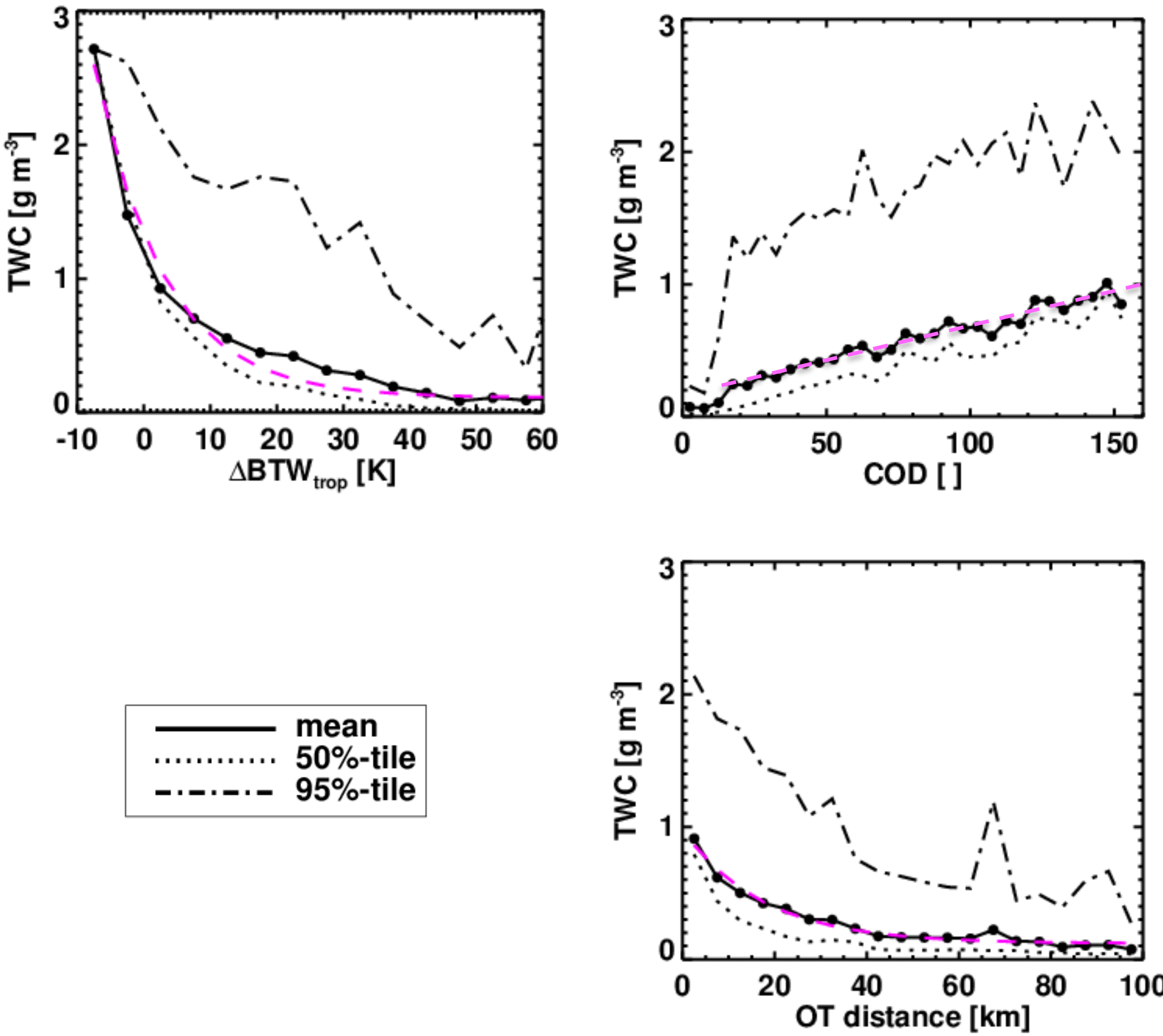
  - OT proximity
- Use satellite-aircraft matched dataset to derive statistics and develop algorithm
- Multi-dimensional analysis of fractional occurrence distribution designed to enhance product and address parameter inter-dependencies
  - Use distributions as a look-up table of HIWC fractional occurrence
- **Primary Issue: Inadequate sampling of entirety of parameter space, coupled with negative influence of "outliers", can generate strange and seemingly non-physical probabilities, producing a product that has confusing visual artifacts at times**

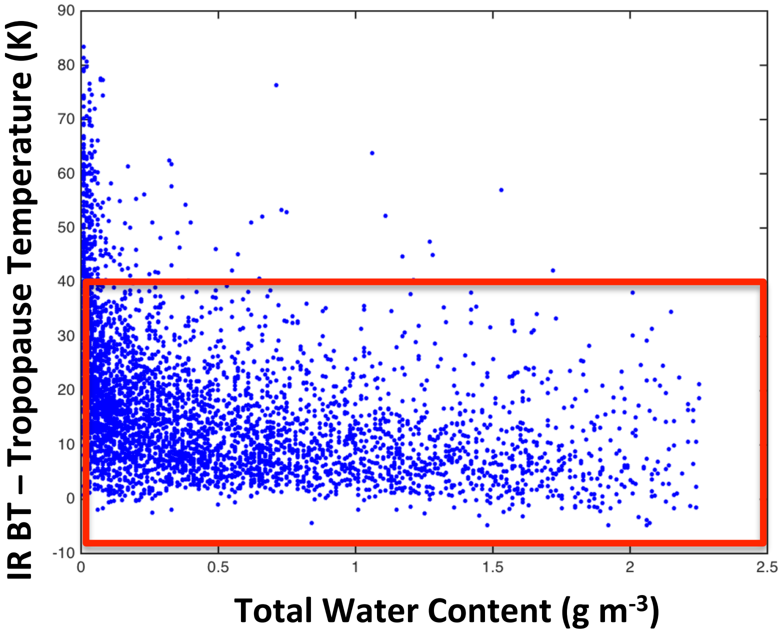


Development of Probability of HIWC (PHIWC) Products
Approach #2: Probability by Statistical TWC Fit

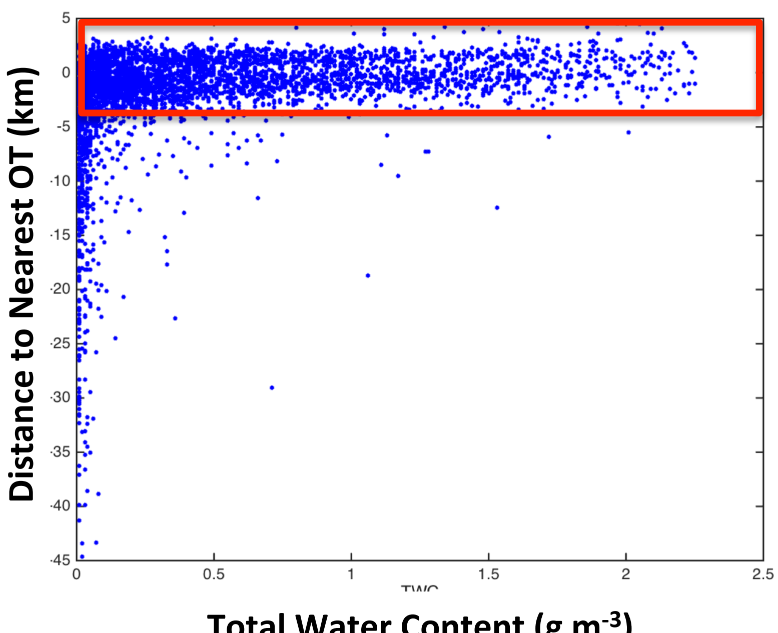


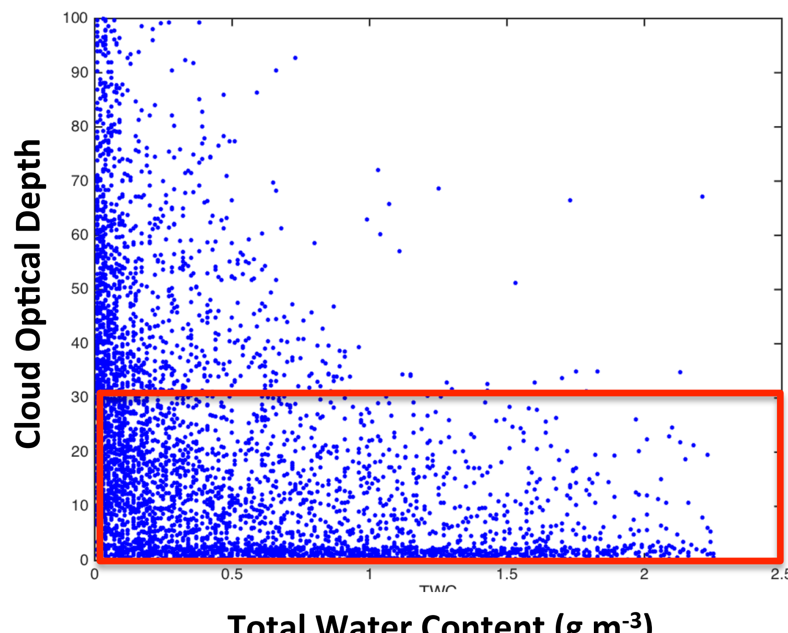
- Fit a curve or line to the mean of the TWC-parameter distribution
- Net result is a TWC "prediction" for a given parameter.
- Cap the prediction at an HIWC threshold (i.e. 1 gm^{-3}) and set high (low) end of fit to be probability of 1 (0)
- Multiply parameter probabilities together, weight however desired and take the root of the result to achieve final HIWC probability

Development of Probability of HIWC (PHIWC) Products
Approach #3: Threshold Based Binary Mask



- Pick a TWC threshold you wish to identify
- Find the parameter set best associated with that TWC population. Set the mask=1 for pixels that meet your criteria
- This approach has been adopted by other HAIC-HIWC groups such as Defer et al. (SAE, 2015)





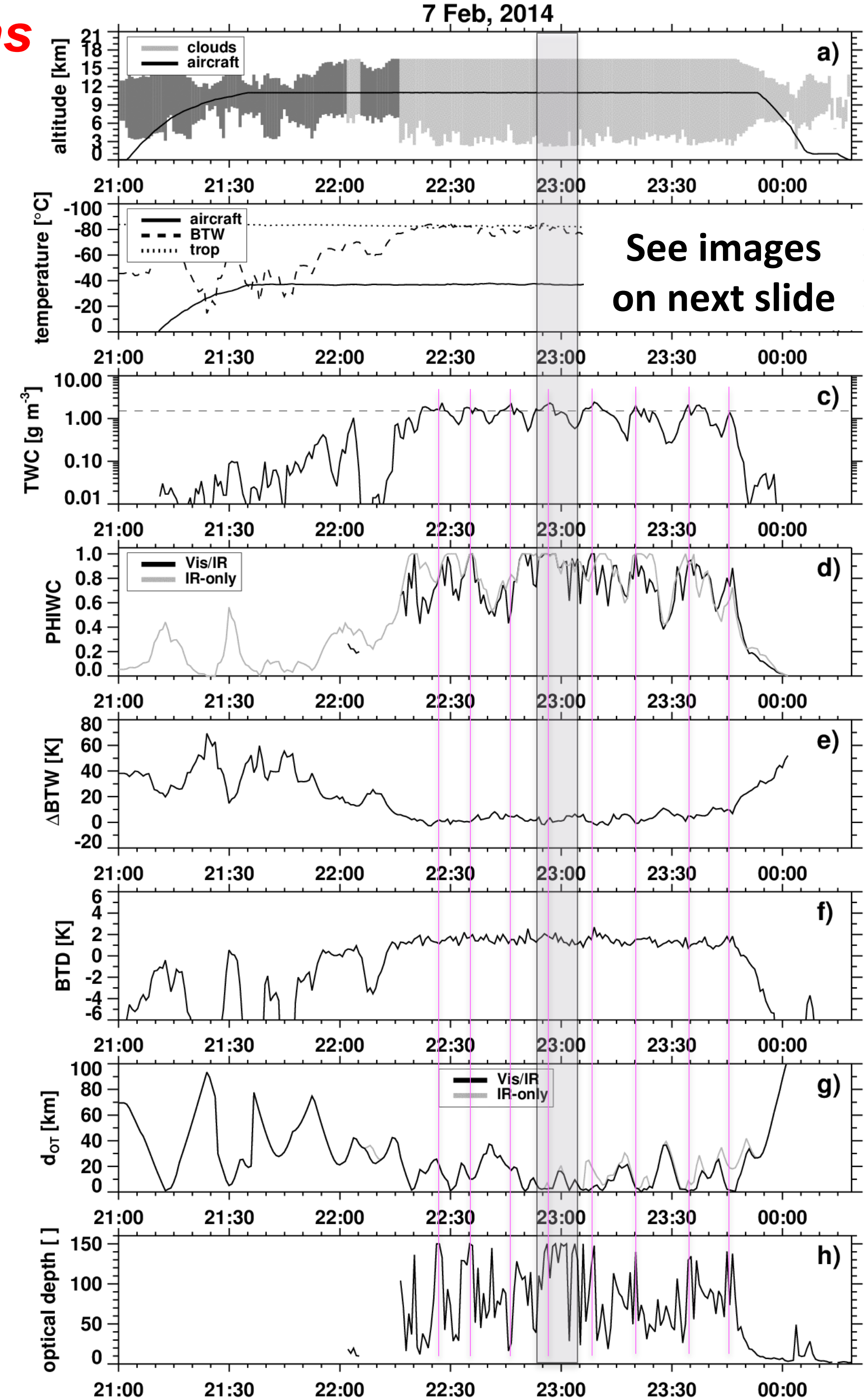
Collocated Aircraft/Satellite Observations Darwin and 10-min MTSAT Data

PHIWC Approach #2

IKP2 total water content TWC [g m^{-3}], 45-s averages. 8 HIWC encounters on this flight

Vis/IR & IR-only PHIWC give consistent results and follow TWC trend

TWC peaks are in close proximity to detected cold spots/texture

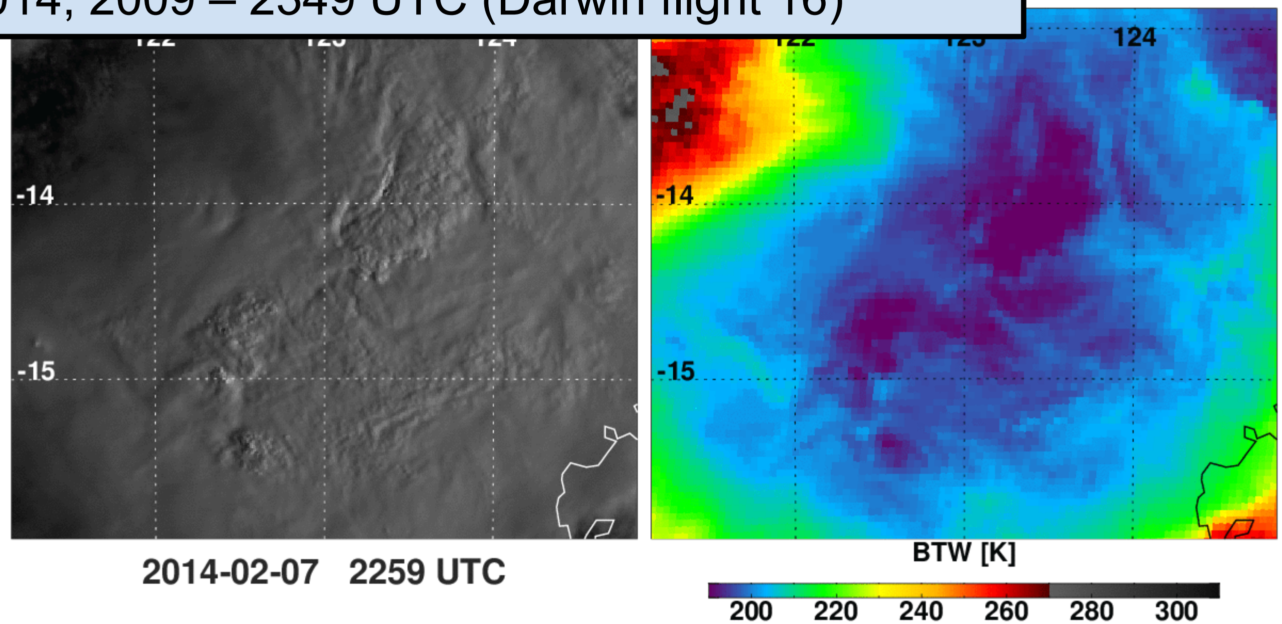


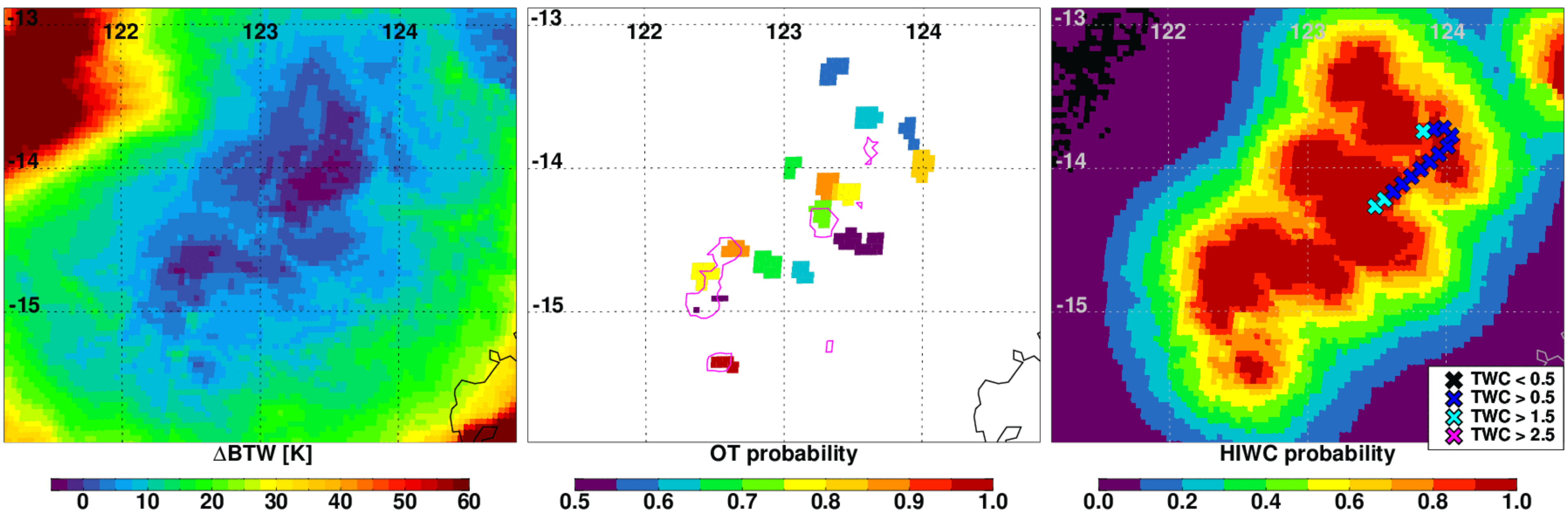
2-Parameter PHIWC Example

Distance to OT and IR-Tropopause Temp Difference

7 Feb, 2014; 2009 – 2349 UTC (Darwin flight 16)

- **TWC > 1.5 correspond to PHIWC ~1.0**
- **TWC > 0.5 correspond to PHIWC > 0.9**

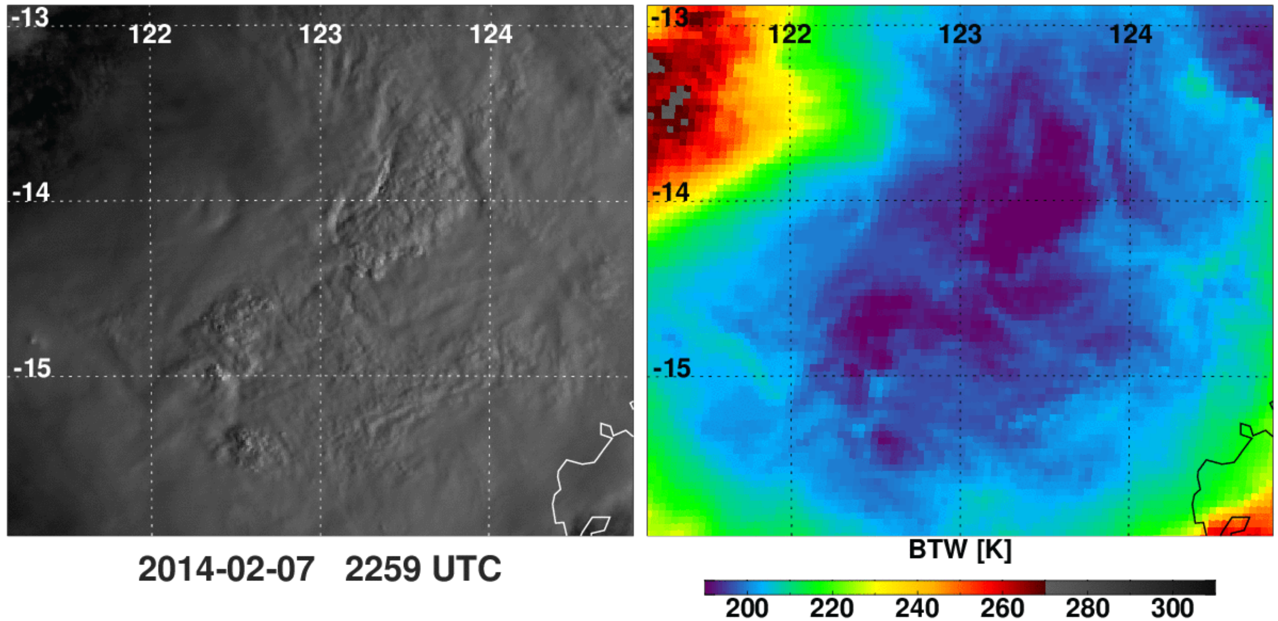


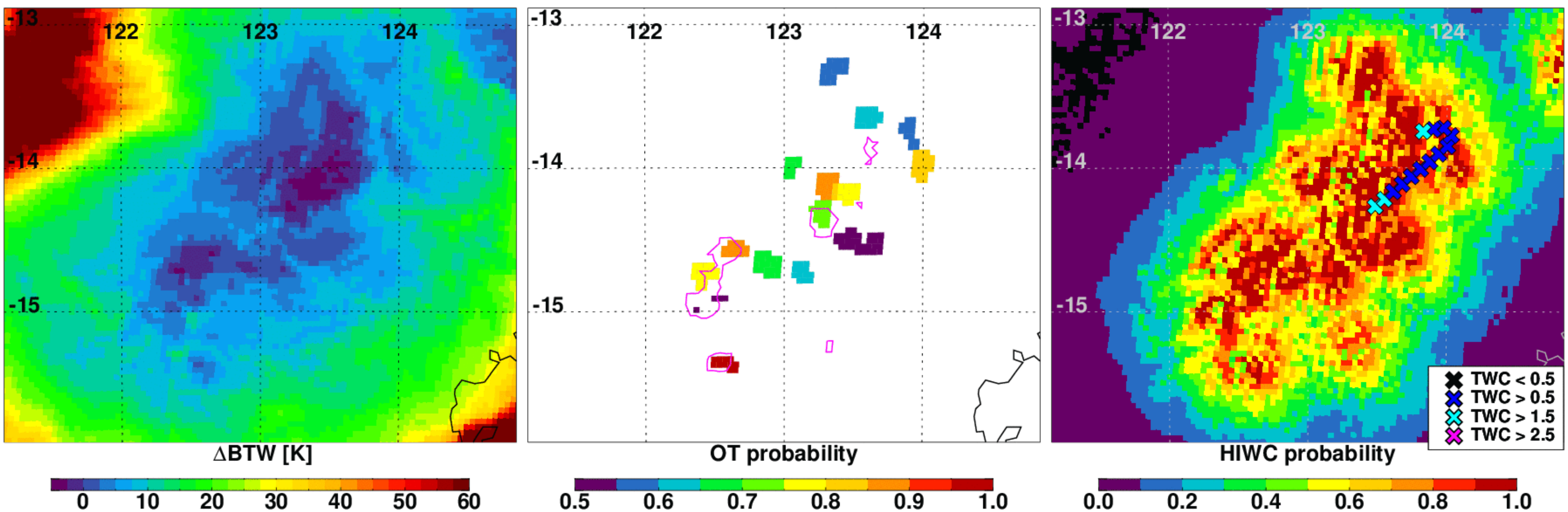


3-Parameter PHIWC Example

Distance to OT, IR-Tropopause Temp Difference, and Cloud Optical Depth

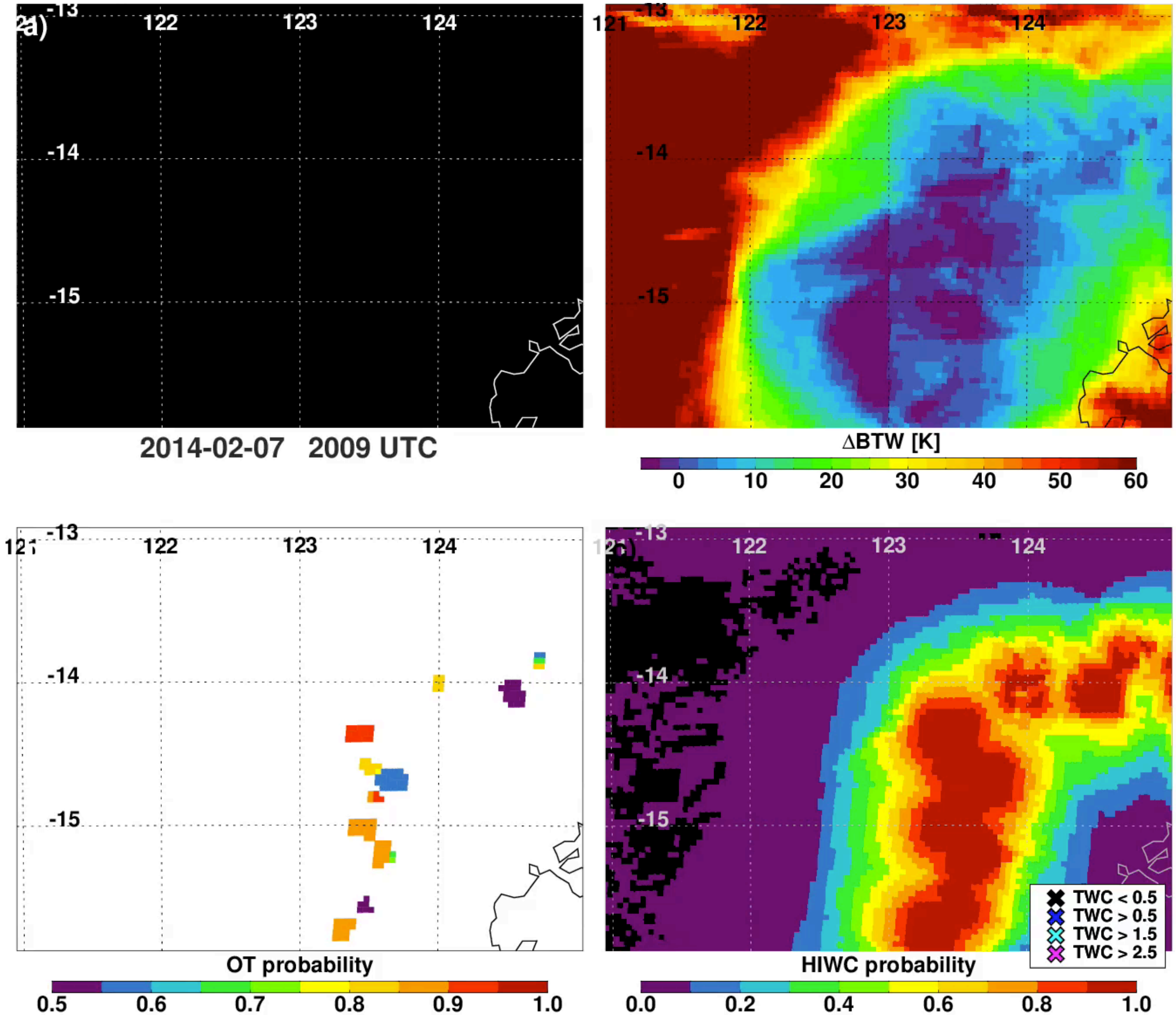
- **Inclusion of cloud optical depth adds mesoscale structure induced by texture in visible image**
- **Future version will include a smoothed COD to preserve bright cloud signal but remove “noisy” variability**





PHIWC Animation: 10 Min MTSAT Data

7 Feb, 2014; 2009 – 2349 UTC (Darwin flight 16)



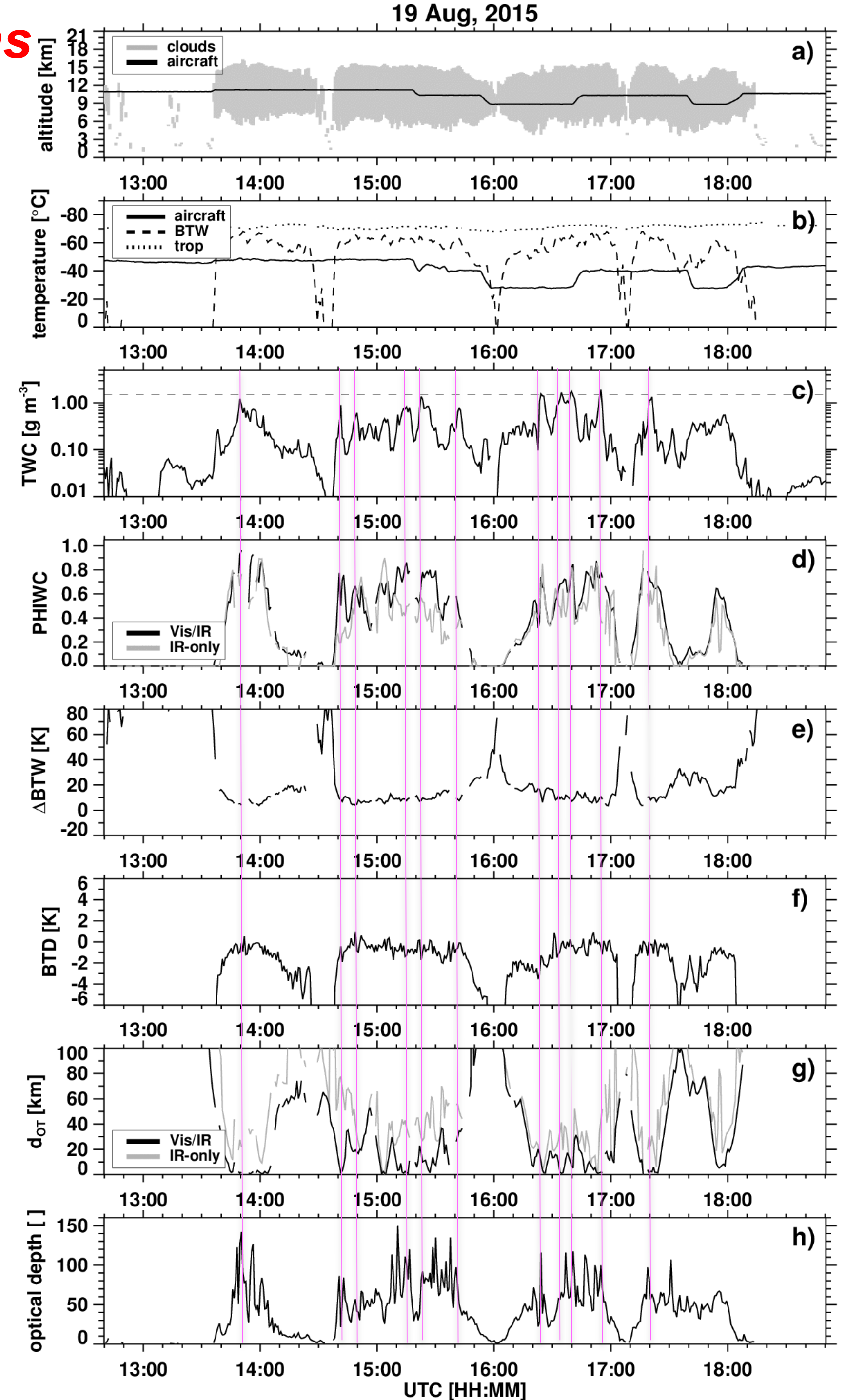
Co-located Aircraft/Satellite Observations HIWC-Florida and 1-min GOES Data

- **Very high temporal resolution of GOES-14 during super rapid scan observations for GOES-R experiment (SRSOR, Schmit et al. (JARS, 2014), Bedka et al. (WAF, 2016)) enables precise co-location between satellite and TWC observations**

- **The PHIWC trend follows the TWC very well. High PHIWC (> 0.7) captures nearly all high TWC events**

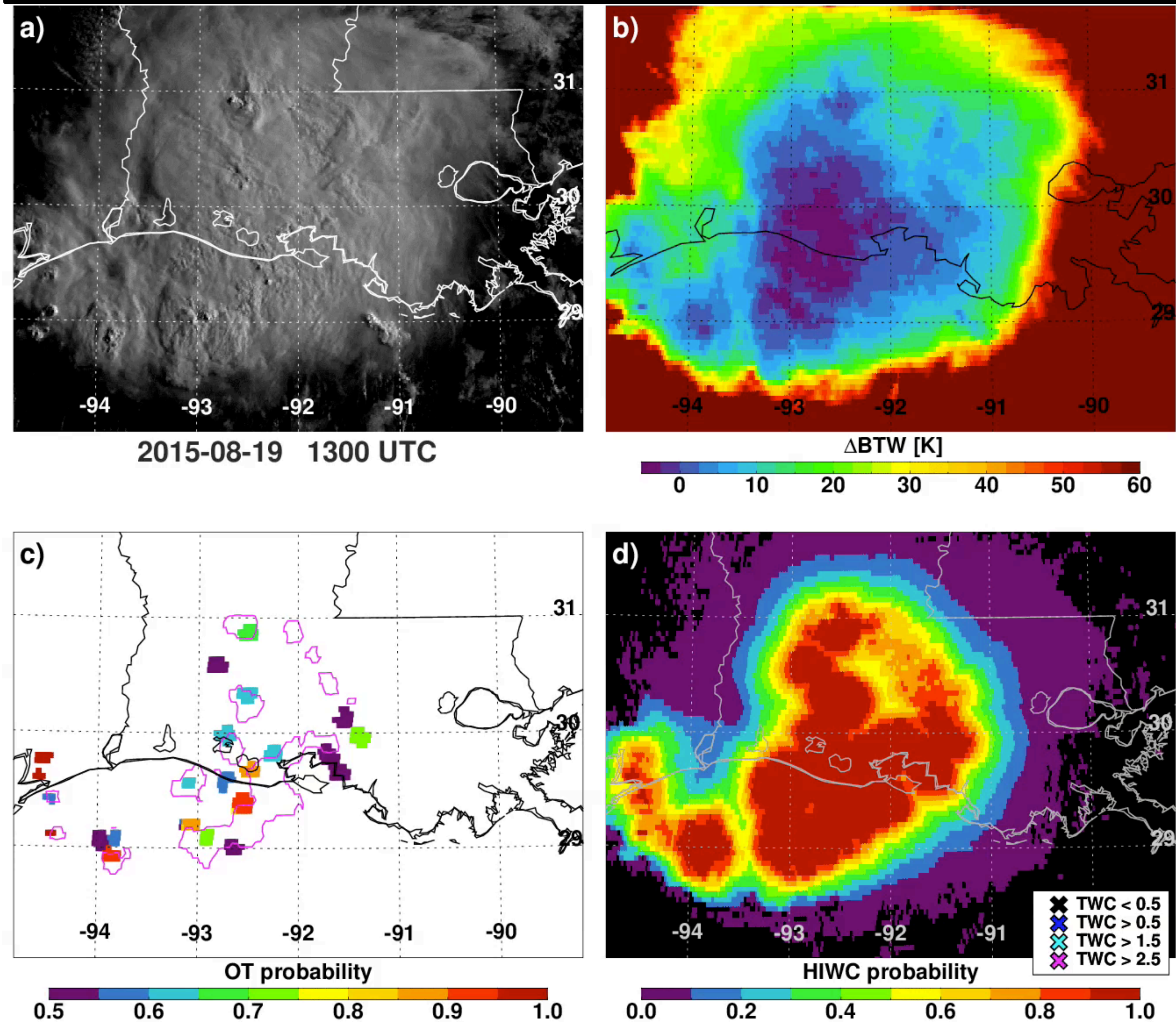
- **Low distances to OT the primary driver of these high PHIWC. Some events (~1522 and 1541) occurred close to visible texture but not IR cold spots, yielding lower night-time probabilities**

Note: Some images didn't process properly within the OT detection script, leading to a few gaps in time series

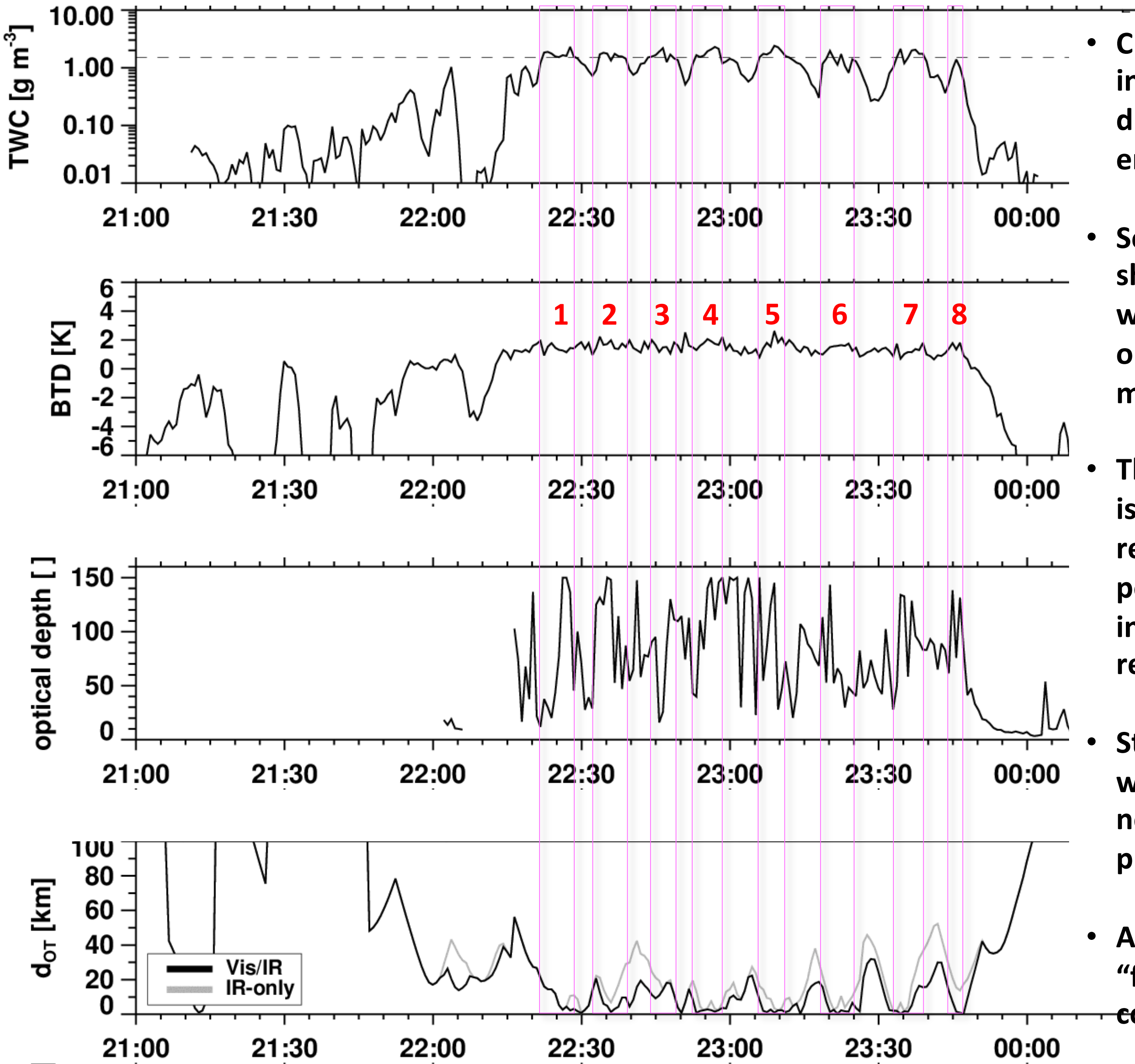


HIWC Probability Animation: 1-Min GOES Data

19 August 2015: 1300 – 1830 UTC



Challenges With Statistical Validation of Nowcast Products



- Characteristic signals of HIWC present in satellite products at some time during each of the 8 HIWC encounters.
- Some duration of several encounters show weak satellite indicators that would result in low PHIWC, despite our usage of 2x2 pixel windows in matching and 45-sec TWC mean
- This behavior could be due to various issues such as 1) coarse temporal resolution of satellite imagery, 2) possible imager navigation errors, 3) inadequate parallax correction, all resulting in image-aircraft mismatches
- Statistical PHIWC – TWC comparisons would generate POD/FAR metrics not necessarily representative of ”true product performance”
- As a group, we need to agree upon a “fair” statistical framework to compare products

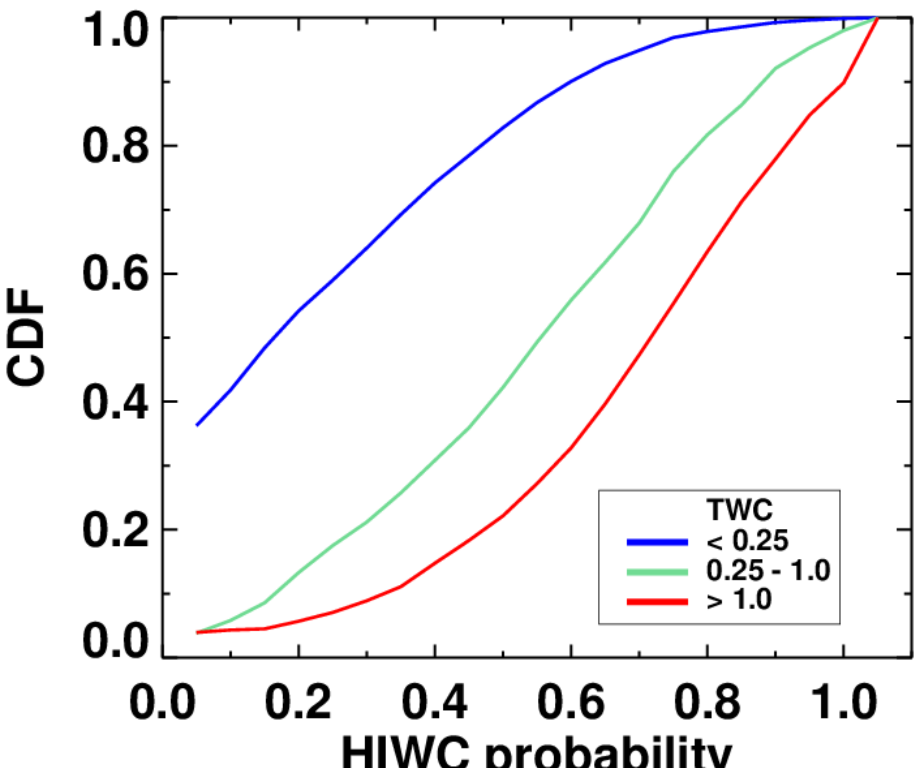
HIWC Probability Verification/Validation

- **PHIWC CDFs for low (blue), moderate (green), and high TWC (red)**
  - 0.25 gm^{-3} 52nd percentile (%), 0.5 gm^{-3} 67th %, 1.0 gm^{-3} 84th %, 1.5 gm^{-3}, 92nd %

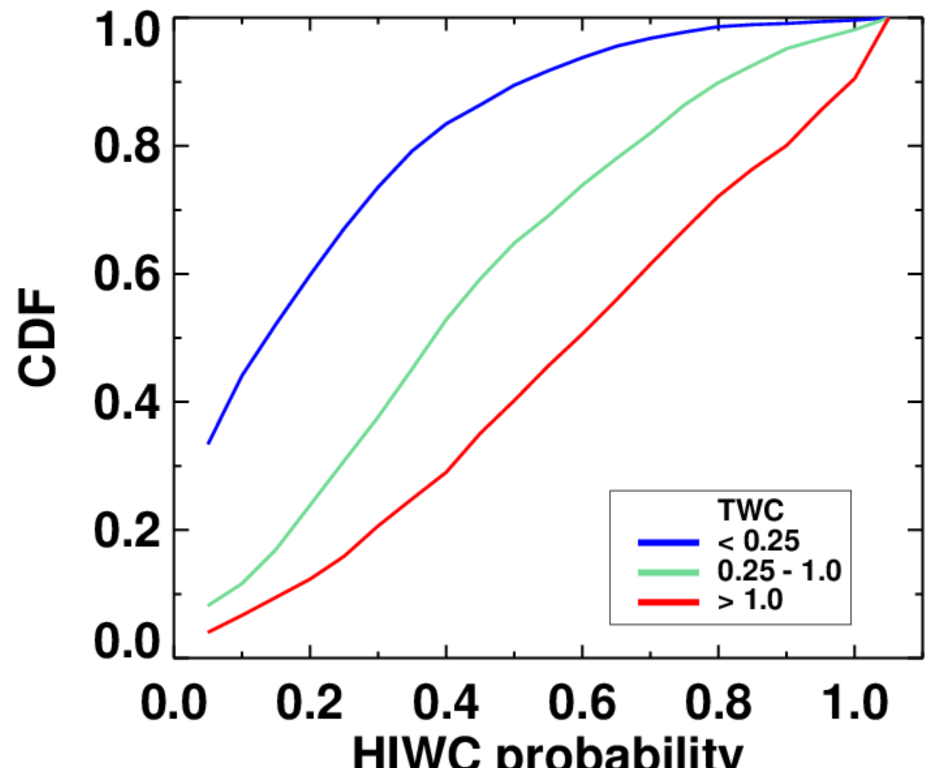
- **PHIWC for high TWC (red) clearly greater than low TWC values. Not as much separation between high and moderate due to comparable signals in passive imagery/products**

- **Daytime product emphasizes higher PHIWC for high TWC. 80% (62%) of high TWC events have daytime (night) PHIWC > 0.5**

Vis/IR (daytime) 2-param method

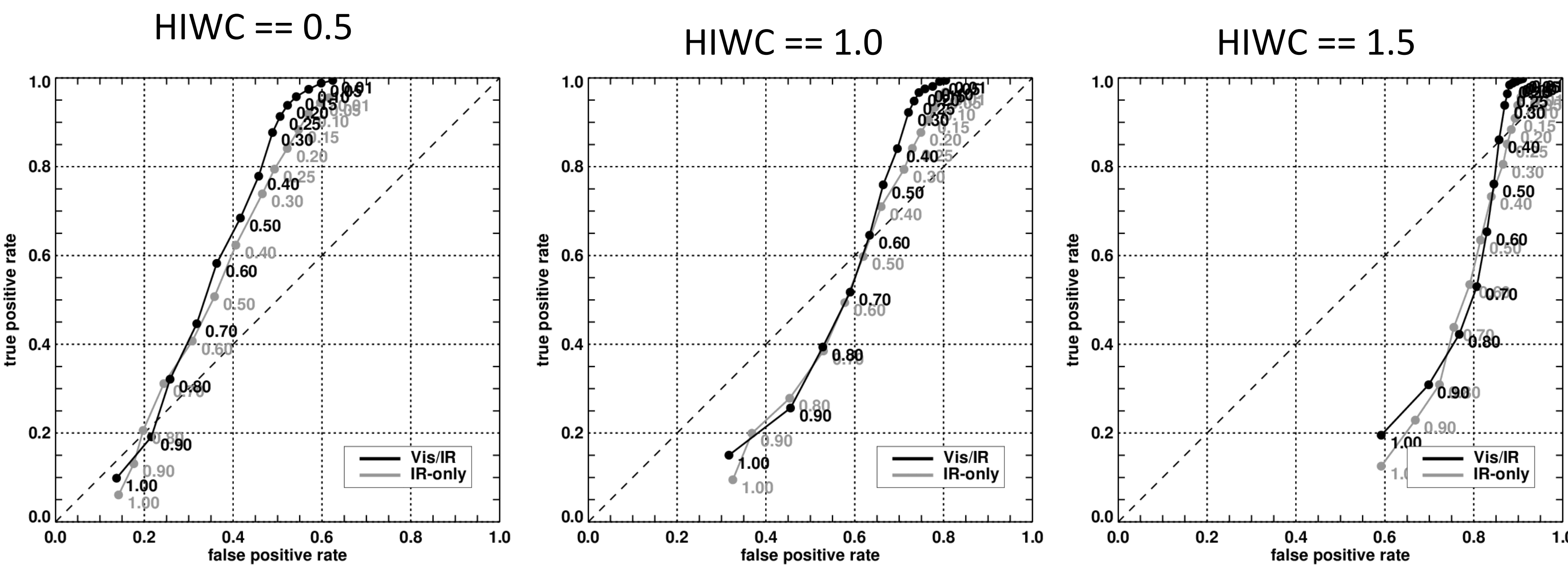


IR-only (nighttime) 2-param method



2-Parameter HIWC Probability Validation

Distance to OT and IR-Tropopause Temp Difference



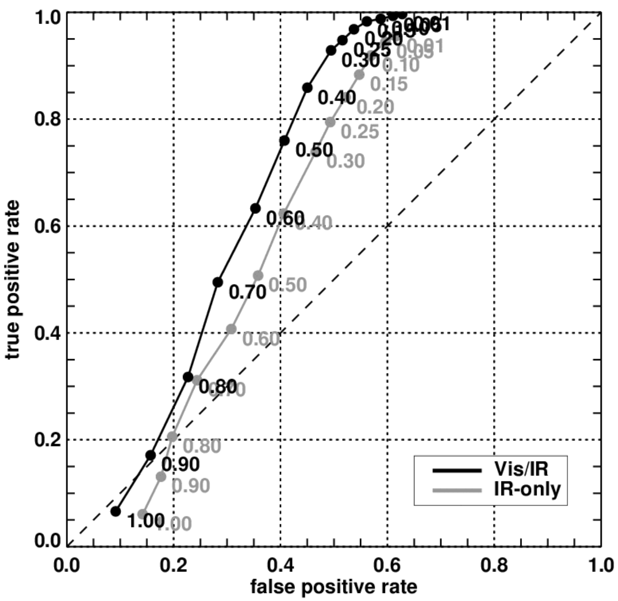
- Lack of unique signal in satellite products for HIWC==1.5 causes high false alarm rate

- Product performance is more representative of trends we see in flight time series (slides 24 and 28)

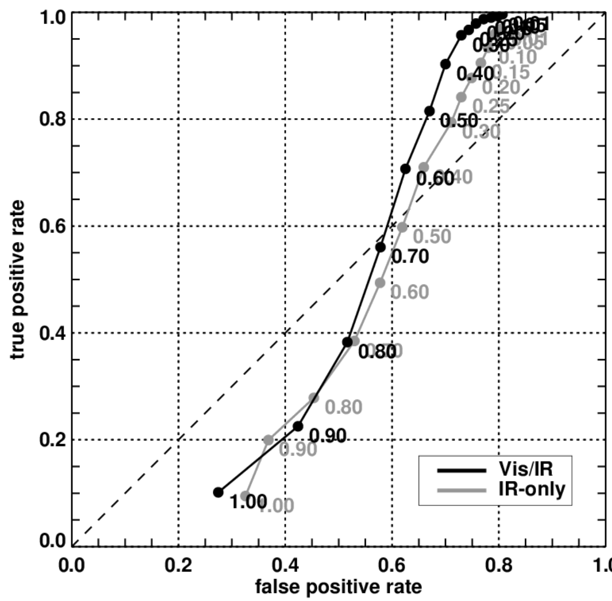
3-Parameter HIWC Probability Validation

Distance to OT, IR-Tropopause Temp Difference, and Cloud Optical Depth

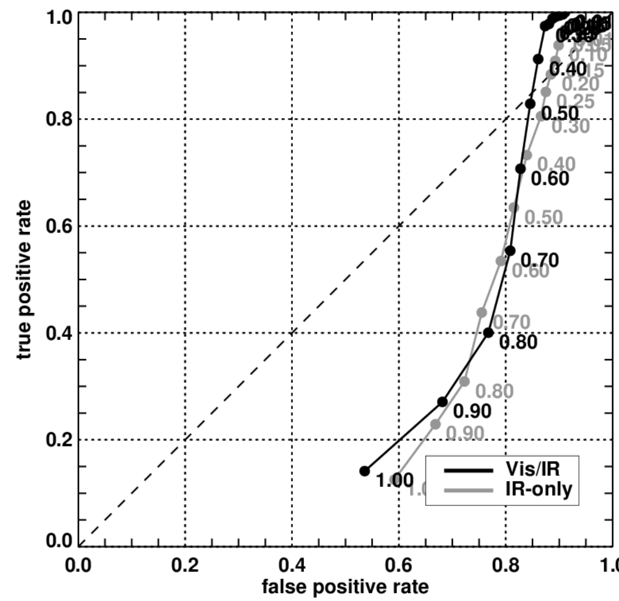
HIWC == 0.5



HIWC == 1.0



HIWC == 1.5



- Inclusion of cloud optical depth reduces HIWC == 0.5 POD by 10% and HIWC == 1.0 by 5%

- Reduces POD by 5% for HIWC == 1.5 with no FAR improvement

Threshold Based Binary HIWC Mask Validation

- **LaRC HIWC MASK: 40 km from OT, > -4 WV-IR BTD, BT-trop <= 40 K**
- **Not a significant improvement in FAR for 2-param PHIWC product over mask, but PHIWC provides confidence in detection whereas mask is simply yes or no. Probabilistic product more desired by operational forecasters**

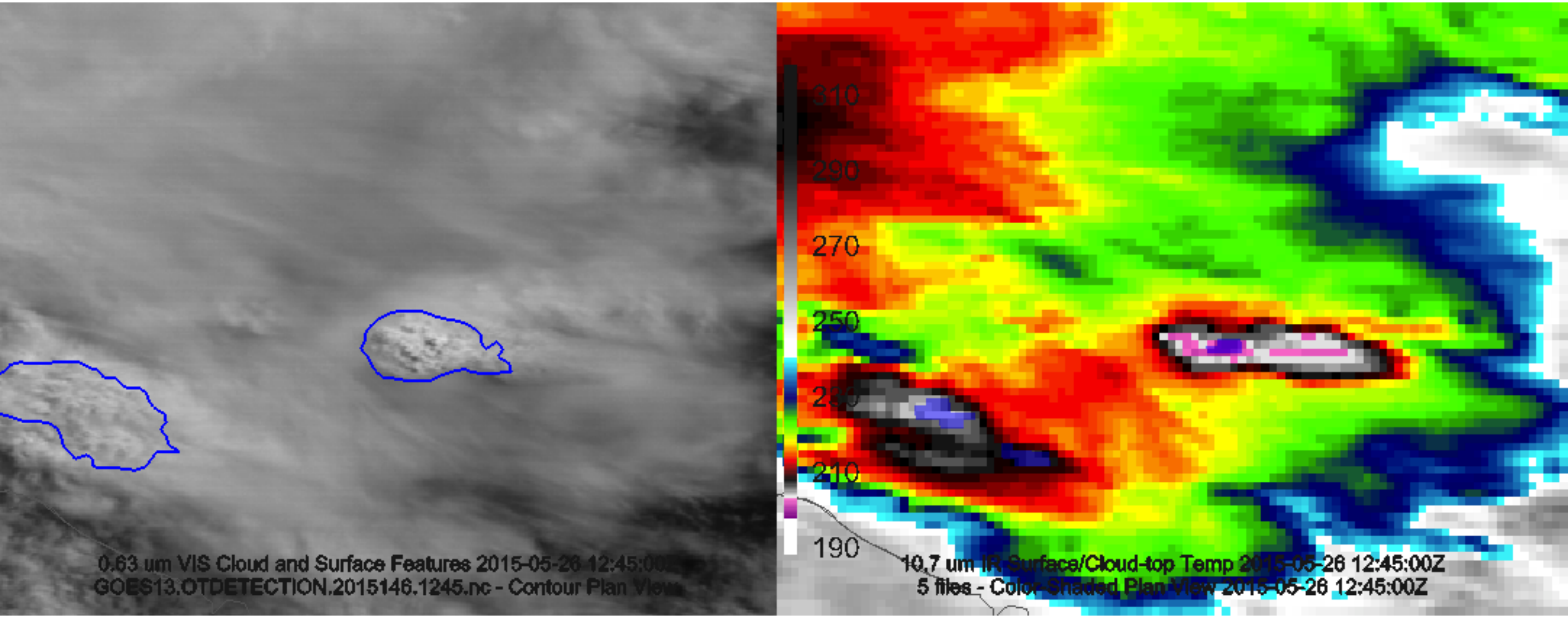
45-s TWC Threshold	45-s TWC Percentile	HIWC Mask POD	HIWC Mask FAR	2-Param PHIWC FAR for Mask POD
1.50	92%	0.93	0.87	0.87
1.00	84%	0.91	0.72	0.71
0.50	67%	0.84	0.49	0.47
0.25	52%	0.84	0.34	0.29

Characteristics of Missed HIWC Events and False Positives

GOES-13 26 May 2015: 1245 UTC

Blue contour: LaRC Visible Texture Detection

Blue semi-transparent block: OT Probability > 0.5

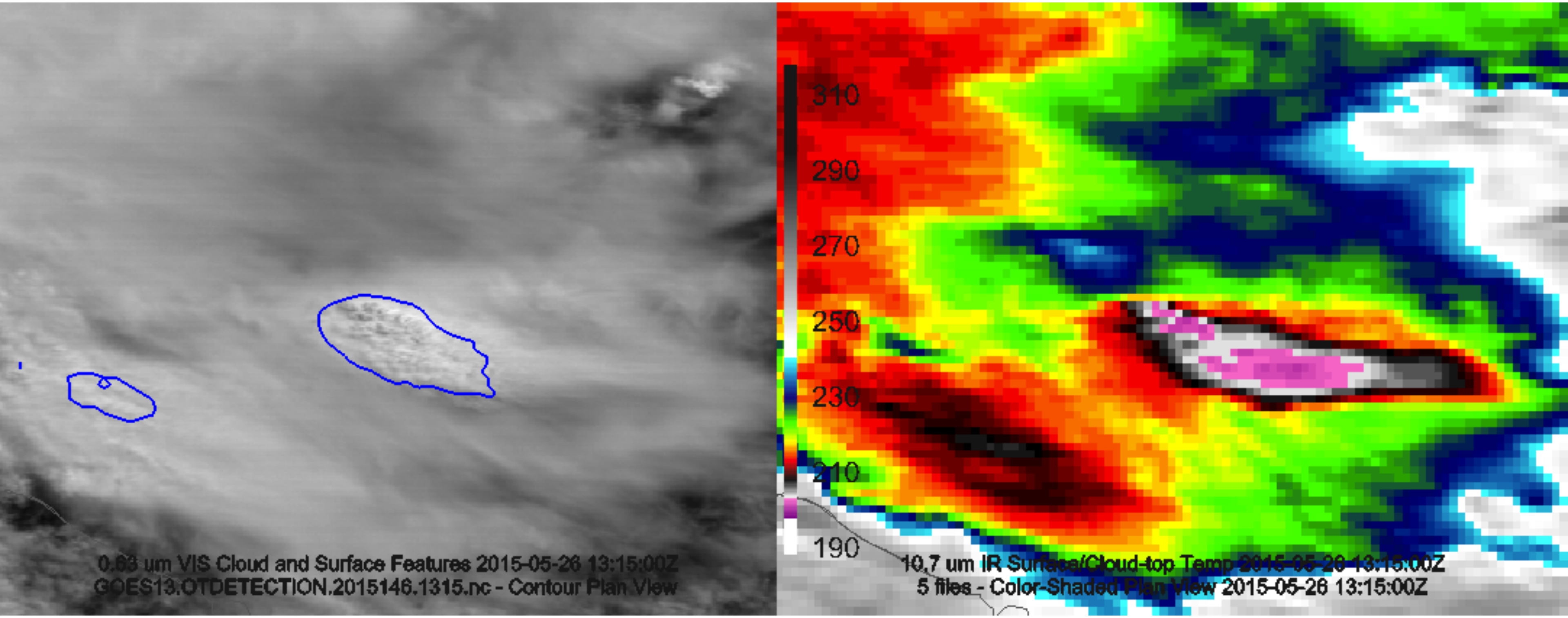


Characteristics of Missed HIWC Events and False Positives

GOES-13 26 May 2015: 1315 UTC

Blue contour: LaRC Visible Texture Detection

Blue semi-transparent block: OT Probability > 0.5



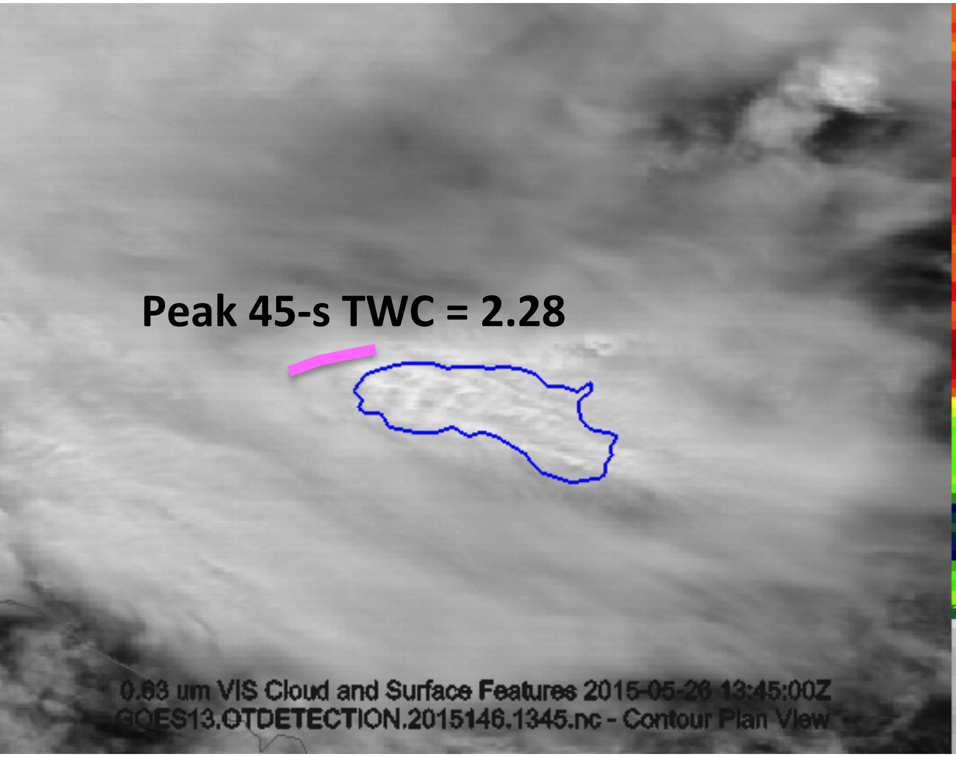
Characteristics of Missed HIWC Events and False Positives

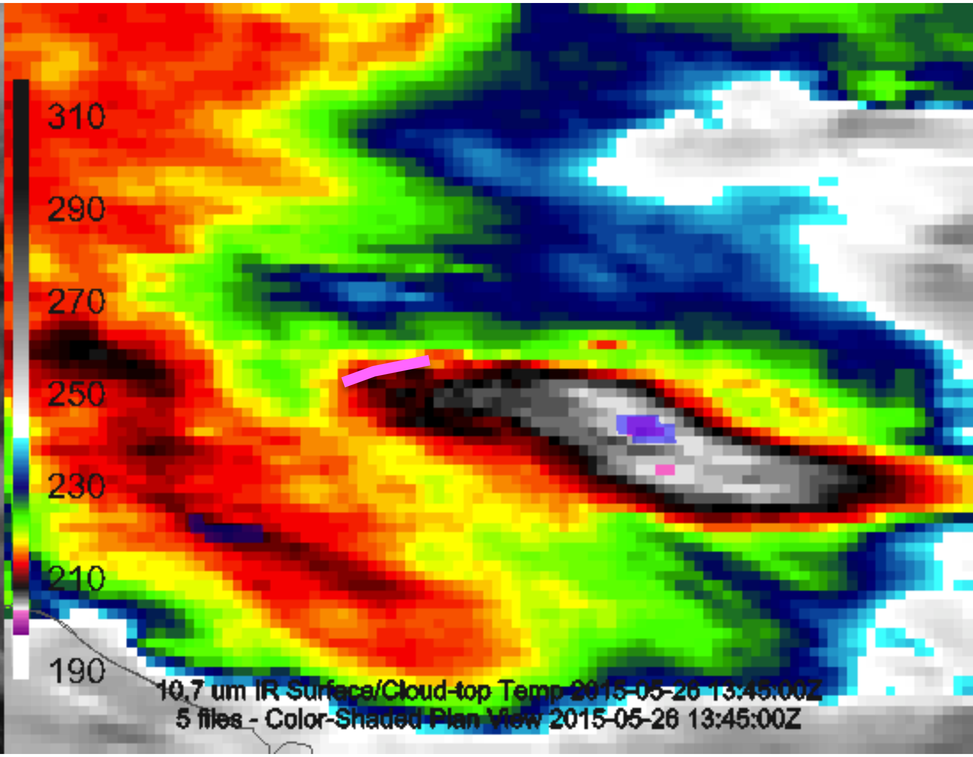
GOES-13 Missed Event: 26 May 2015: 1345 UTC

Blue contour: LaRC Visible Texture Detection

Magenta: HIWC Encounter

Blue semi-transparent block: OT Probability > 0.5





Aircraft flew along edge of cold IR temperature and textured region but did not penetrate coldest pixels

Close distance to visible texture detection (< 10 km) but warm IR BT at aircraft location, weak WV-IR BTD, and reduced optical depth relative to brighter/colder region make the region hard to detect using parameter space consistent with vast majority of HIWC eventsc

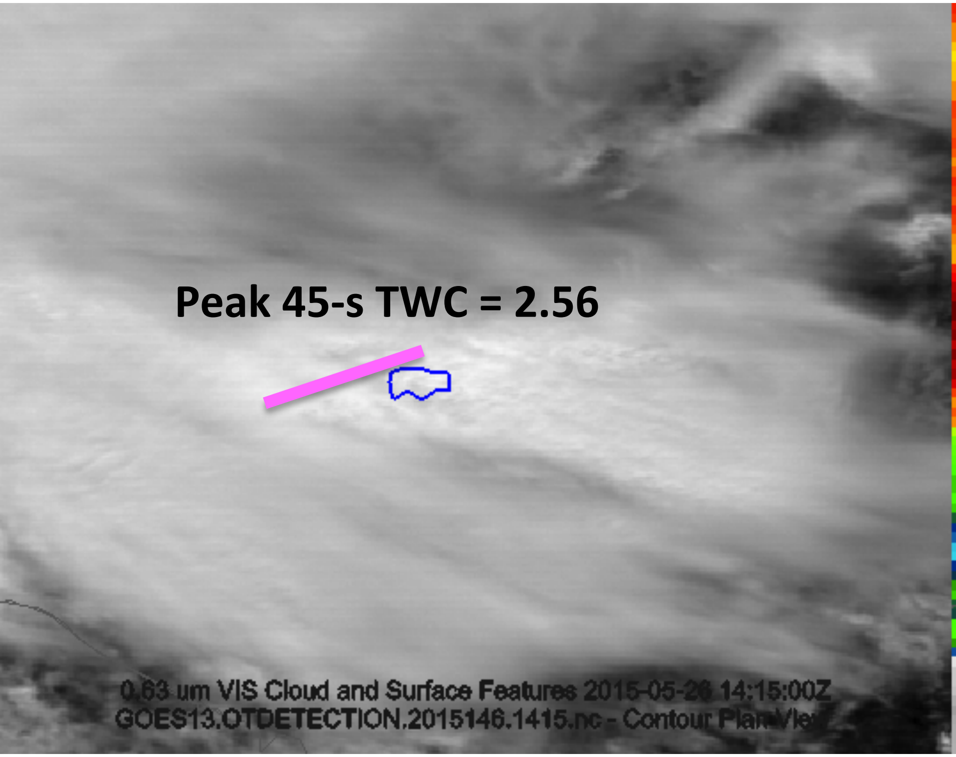
Characteristics of Missed HIWC Events and False Positives

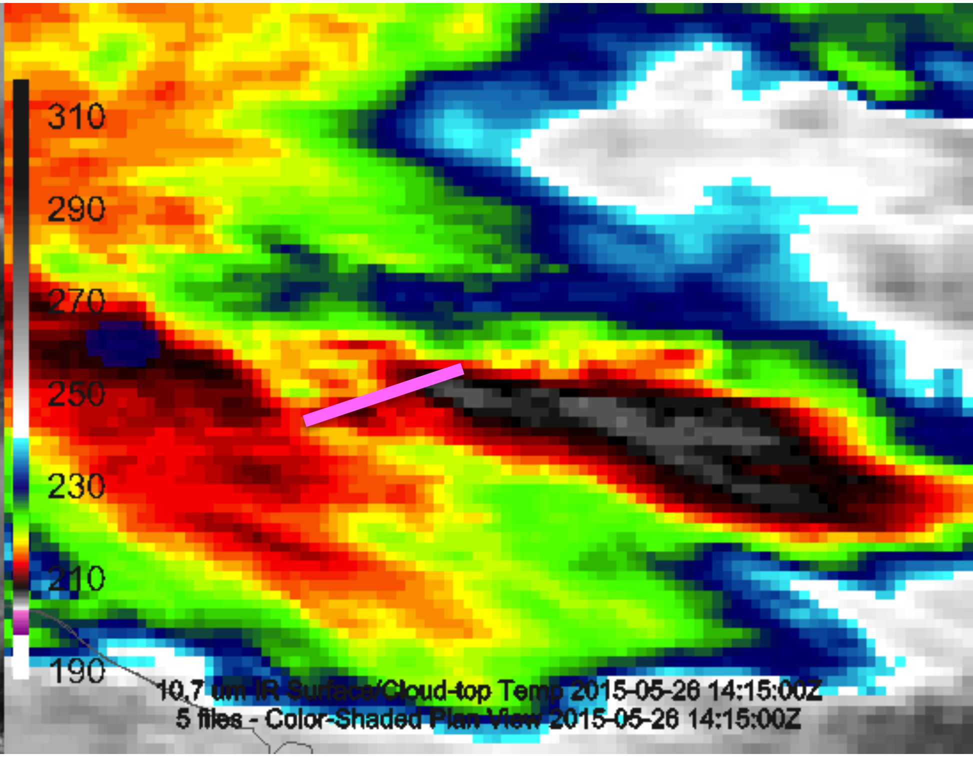
GOES-13 Missed Event: 26 May 2015: 1415 UTC

Blue contour: LaRC Visible Texture Detection

Magenta: HIWC Encounter

Blue semi-transparent block: OT Probability > 0.5





Aircraft flew along edge of cold IR temperature and textured region but did not penetrate coldest pixels

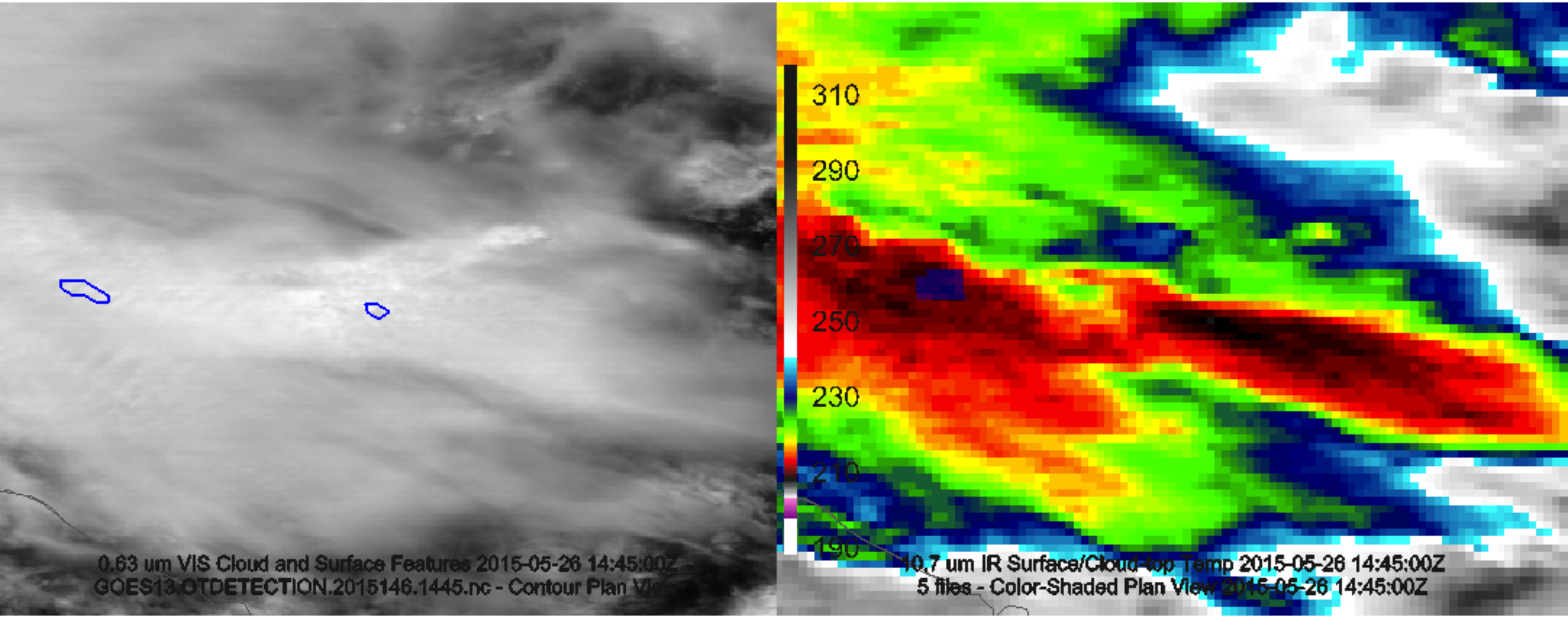
Close distance to visible texture detection (< 10 km) but warm IR BT at aircraft location and weak WV-IR BTD make the region hard to detect using parameter space consistent with vast majority of HIWC events

Characteristics of Missed HIWC Events and False Positives

GOES-13 26 May 2015: 1445 UTC

Blue contour: LaRC Visible Texture Detection

Blue semi-transparent block: OT Probability > 0.5

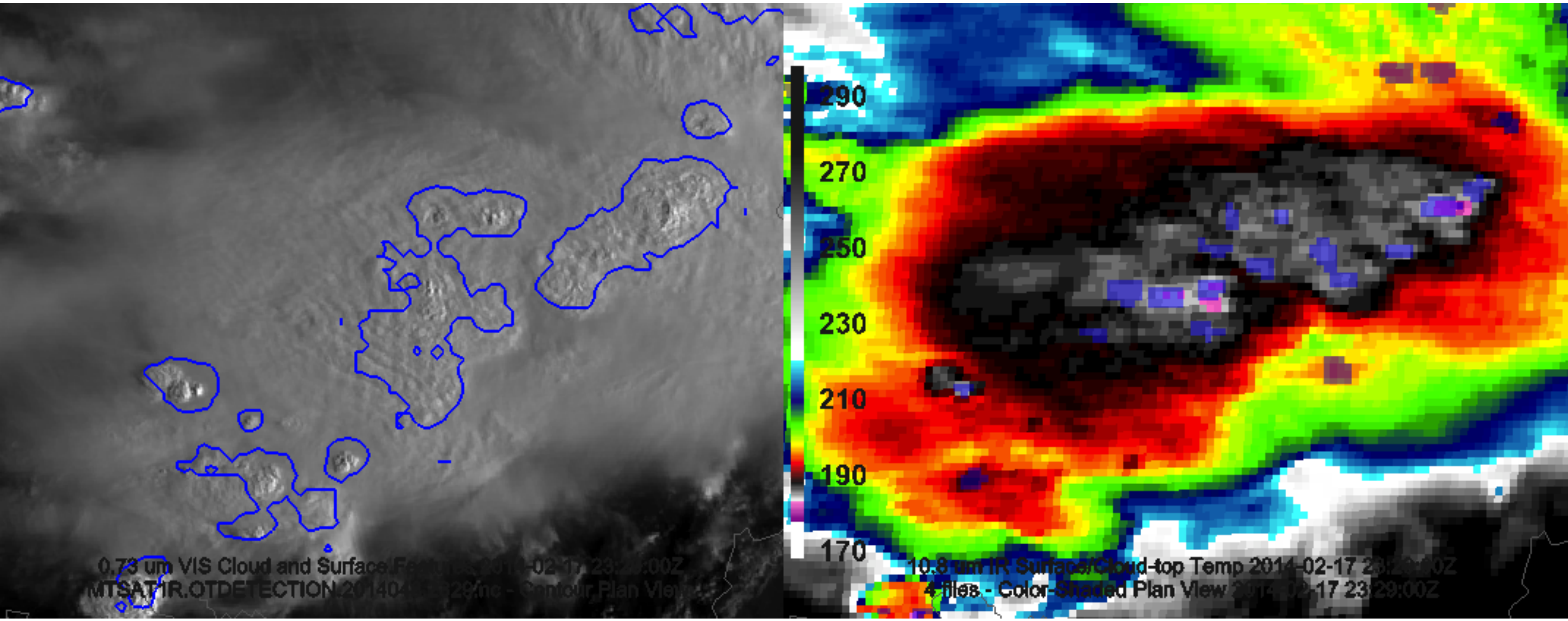


Characteristics of Missed HIWC Events and False Positives

MTSAT-1R False Positive: 17 February 2014: 2329 UTC

Blue contour: LaRC Visible Texture Detection

Blue semi-transparent block: OT Probability > 0.5

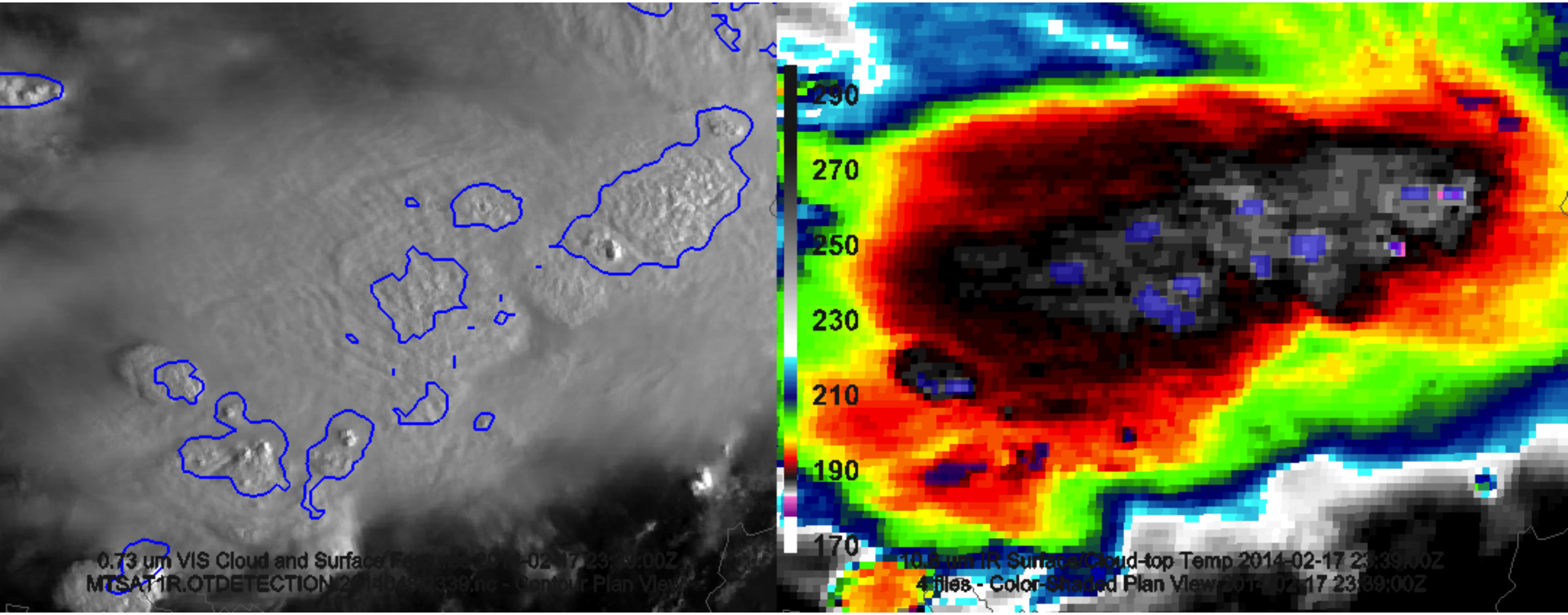


Characteristics of Missed HIWC Events and False Positives Based on Probability of HIWC Scores

MTSAT-1R False Positive: 17 February 2014: 2339 UTC

Blue contour: LaRC Visible Texture Detection

Blue semi-transparent block: OT Probability > 0.5

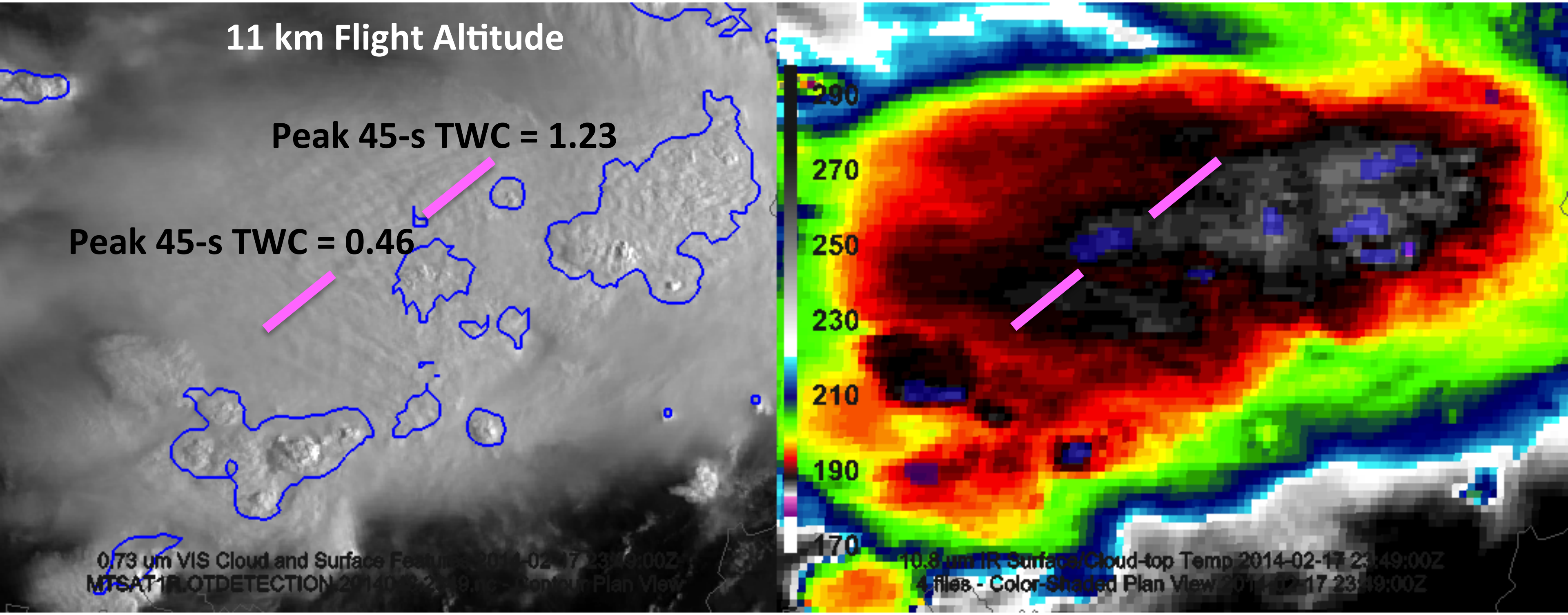


Characteristics of Missed HIWC Events and False Positives Based on Probability of HIWC Scores

MTSAT-1R False Positive: 17 February 2014: 2349 UTC

Blue contour: LaRC Visible Texture Detection

Magenta: Low and Moderate TWC Encounter **Blue semi-transparent block: OT Probability > 0.5**



Aircraft flew beneath very cold, optically thick anvil region (190 K) with many gravity waves near to prominent cold spot. This parameter combination triggered a high HIWC probability.

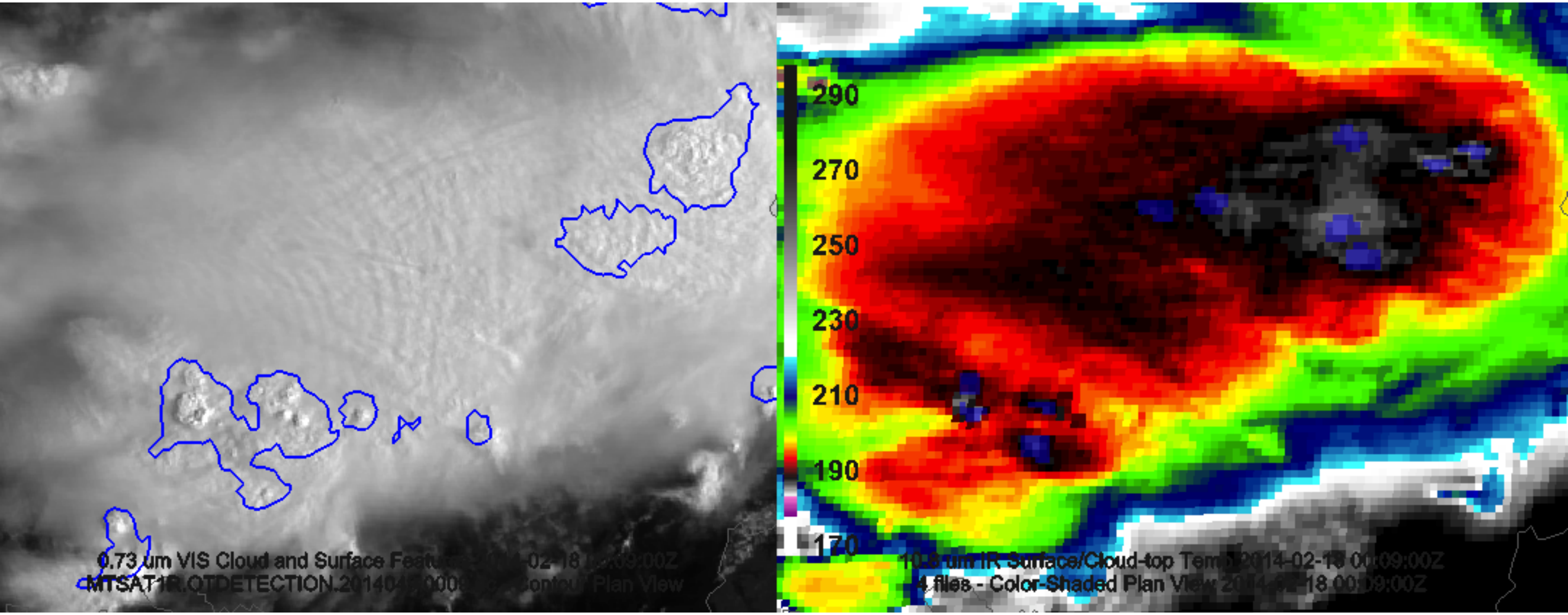
Region likely is not connected to updraft beneath the anvil. There is no way of knowing this via an automated algorithm based on the MTSAT-observed cloud characteristics. There is also virtually no difference in pixel appearance between the regions where 0.46 and 1.23 g m^{-3} are present! Only temporal trend to differentiate is that the 1.23 observation is co-located with a prominent convective core that dissipated 20 mins prior

Characteristics of Missed HIWC Events and False Positives

MTSAT-1R False Positive: 18 February 2014: 0009 UTC

Blue contour: LaRC Visible Texture Detection

Blue semi-transparent block: OT Probability > 0.5



Evidence of Small Ice Crystals At Cloud Top: Himawari-8 AHI

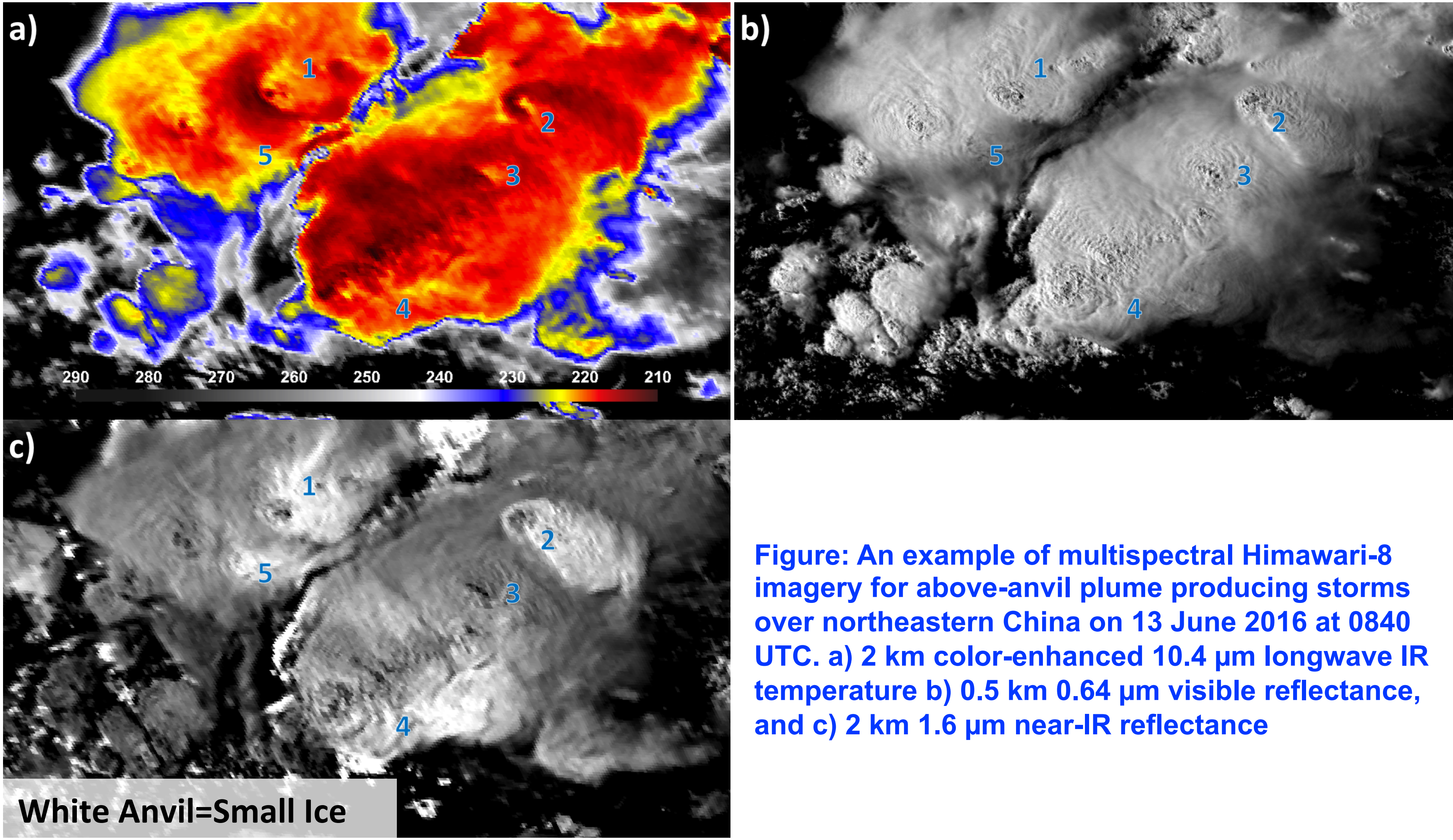


Figure: An example of multispectral Himawari-8 imagery for above-anvil plume producing storms over northeastern China on 13 June 2016 at 0840 UTC. a) 2 km color-enhanced 10.4 µm longwave IR temperature b) 0.5 km 0.64 µm visible reflectance, and c) 2 km 1.6 µm near-IR reflectance

Enhanced 1.6 µm reflectance (White Shading, 1,2,4,5 above) indicate smaller ice crystals at cloud top detrained from updrafts with greater vigor than neighboring storms (Levizanni and Setvak 1996; Lindsey et al. 2006; Rosenfeld et al. 2008). Small ice can be correlated with warm anomalies in anvil (i.e. enhanced-V signatures, above-anvil cirrus plumes)

Summary

- Based on HIWC-HAIC total water content (TWC) field measurements, we developed a satellite-based technique to estimate probability of HIWC (PHIWC)
- Little sensitivity in satellite-derived products to TWC > 0.25 g m^{-3}
- HIWC rarely observed outside a 40 km radius from a textured and/or cold region
- Texture and OT Probability threshold quite liberal, causing low to moderate TWC to be detected too
- IR BT-tropopause difference used to help confine HIWC probability to cold regions
- Validation shows highest PHIWC for HIWC events. Statistical metrics based on pixel scale POD/FAR can paint an unrealistic picture of product accuracy
- We have immediate ability to implement prototype PHIWC product on any near-real-time GEOSat domain including Himawari-8 and GOES-R ABI. See GOES-13 product imagery at http://clouds.larc.nasa.gov/overshooting-tops

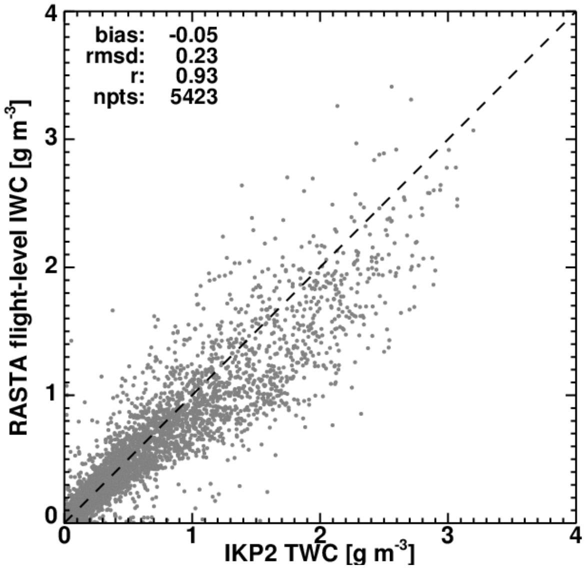
Future Work

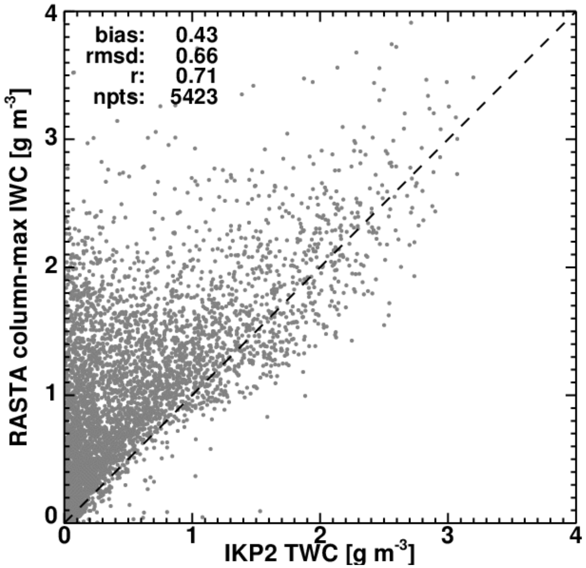
- Confine visible texture detection closer to convective cores. Smooth COD before applying to PHIWC product
- Finalization of MODIS-CloudSat HIWC diagnostic and PHIWC nowcasting papers
- Analysis of "outliers", i.e. low (high) TWC in favorable (unfavorable) satellite-derived parameters
- Further analysis of HIWC-Florida campaign datasets
  - Flights days with 1-minute GOES-14 imagery very valuable
  - Collocate on-board weather radar with satellite observations
- Continue analyses with RASTA and CloudSat retrievals
  - Use profiling technique to estimate altitude of HIWC from satellite obs
  - Parameterization based on satellite cloud properties (e.g., T, IWP) and CloudSat retrievals

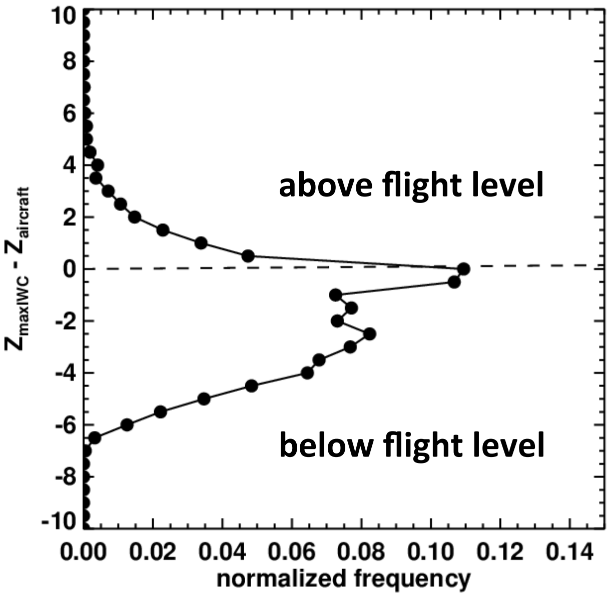
Extra/Backup Slides

RASTA Radar Retrievals: Should We Use Column Max vs. Flight Level For Nowcast Algorithm Development

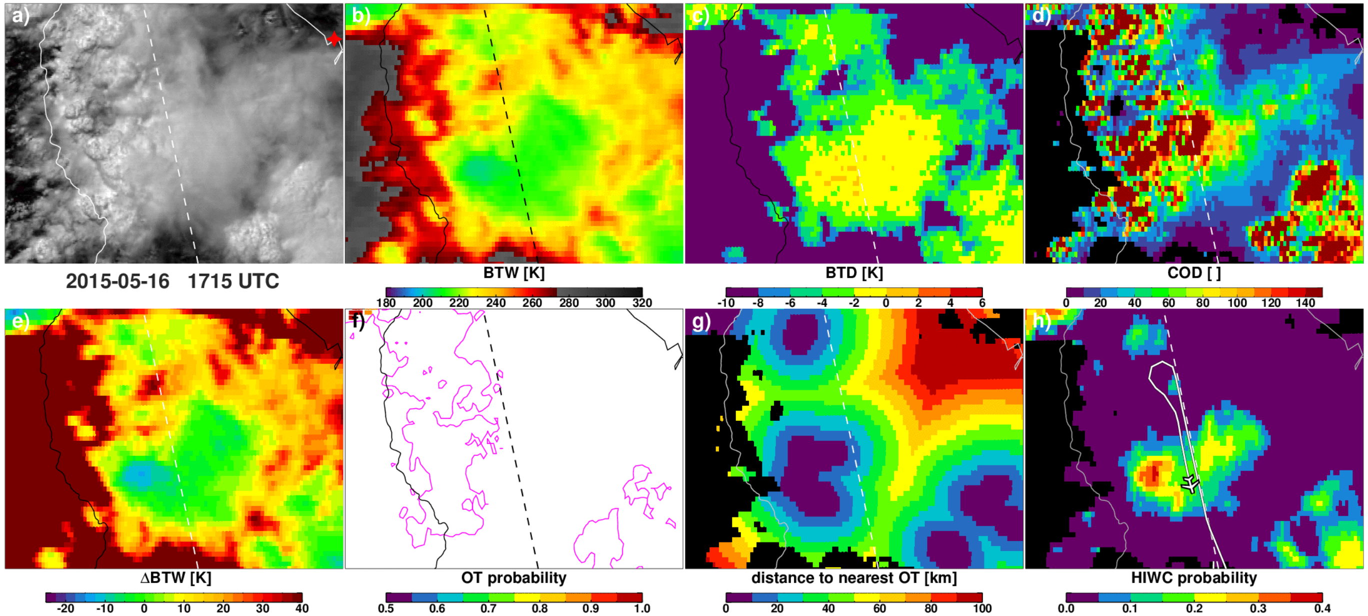
- RASTA flight-level IWC also compares very well to IKP2 (left)
- Column max values can be much larger than what was observed at flight level (right)
- Max IWC often occurred up to 4 km below flight level (below)
- Use radar retrievals to improve satellite HIWC identification



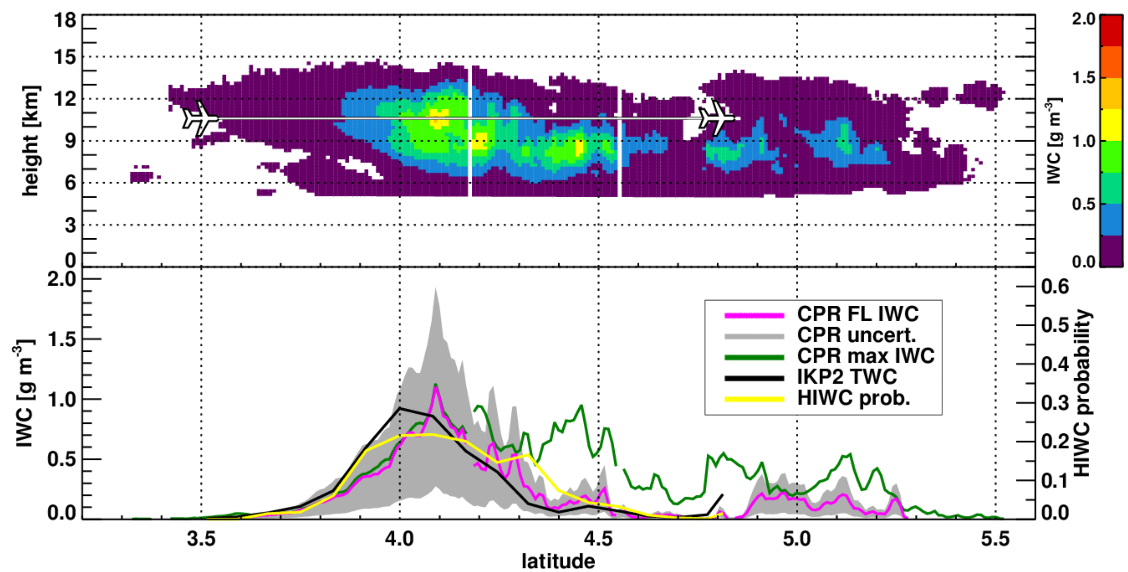




Incorporating Radar Retrievals



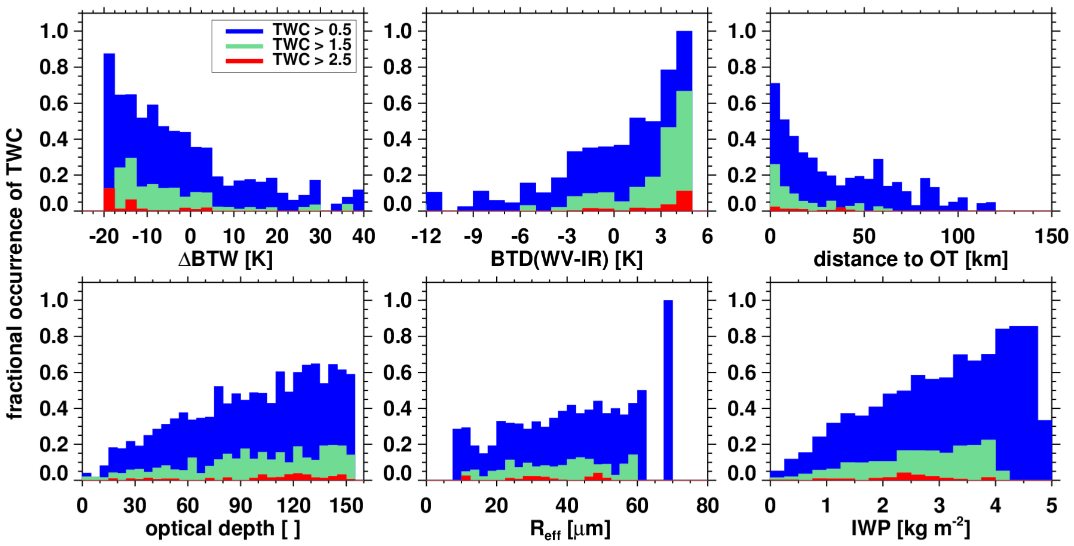
- CloudSat overpass of Cayenne domain on May 16, 2015 @ 1720 UTC
- CloudSat IWC retrievals at flight level agree well with IKP2 TWC
- CloudSat reveals higher IWC below flight level
- PHIWC follows TWC trends closely but PHIWC should be higher where CPR max IWC is higher
- Only one CloudSat overpass but RASTA IWC retrievals are available



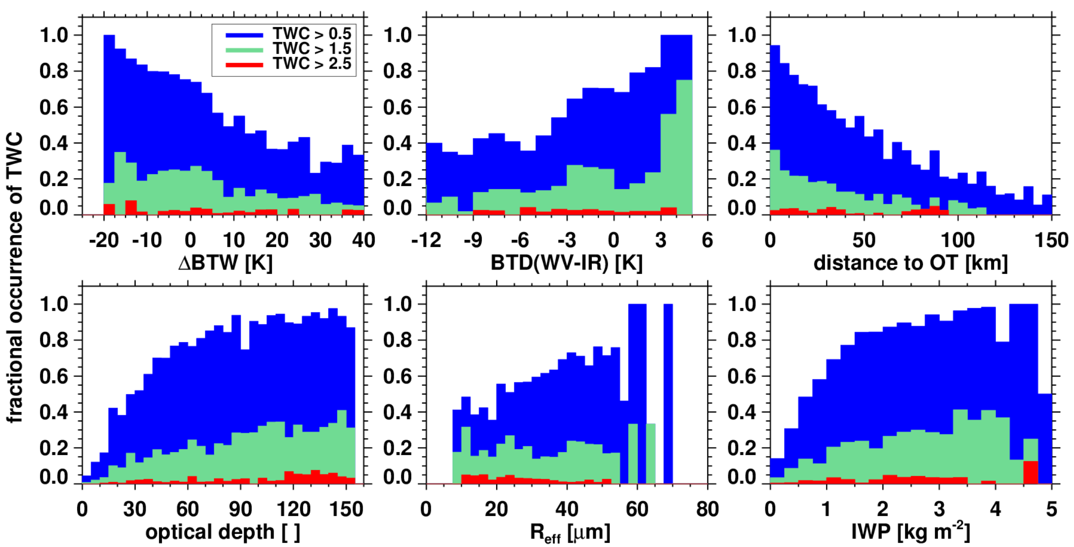
RASTA Radar Retrievals

- RASTA IWC fractional occurrence looks similar to IKP2 but larger
- Fractional occurrence of IWC > 1.5 still < 0.50 in most cases, even very near OTs
- HIWC exists up to ~100 km away from OT detections
- Still no usable signal for IWC > 2.5

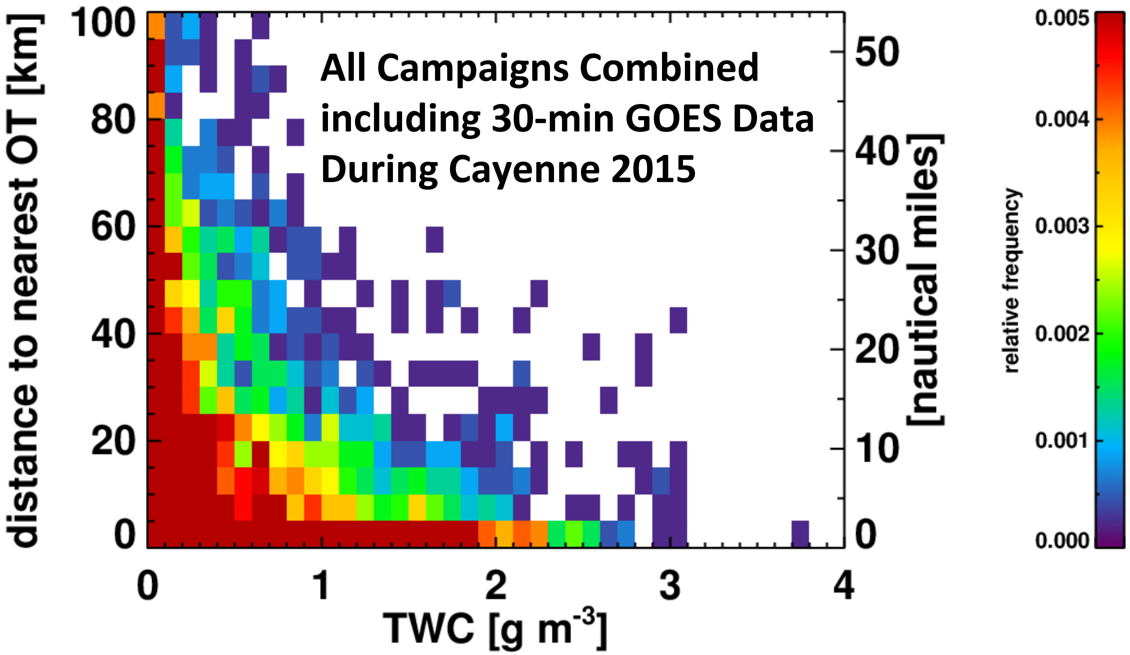
TWC from IKP2

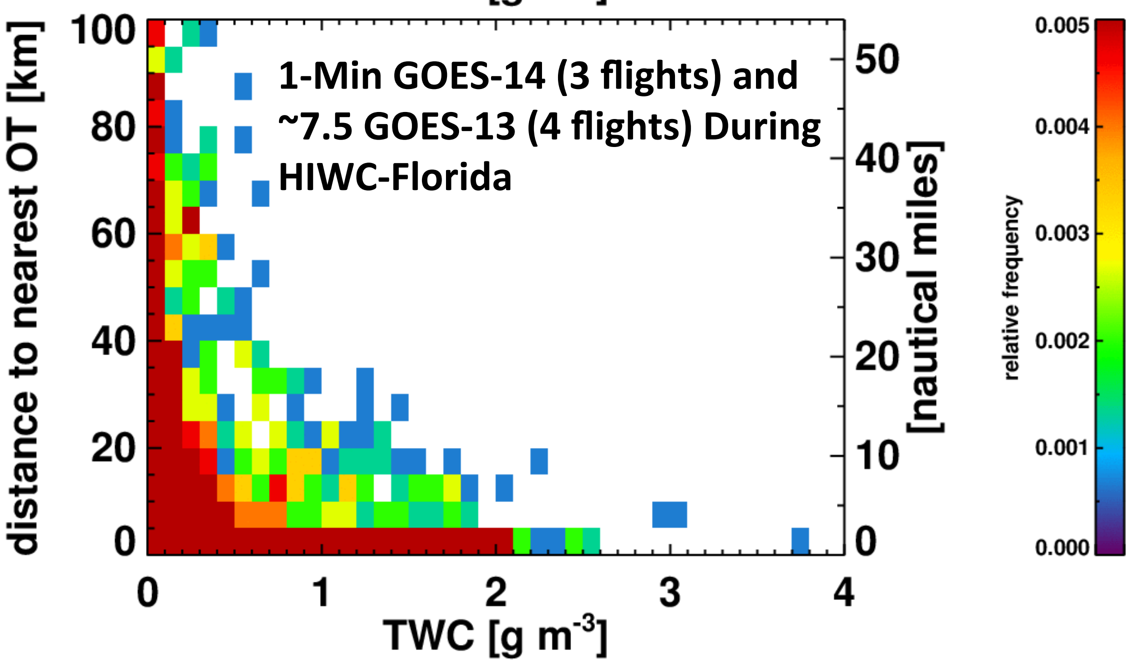


IWC from RASTA



Impact of Image Temporal Resolution on OT-TWC Relationships



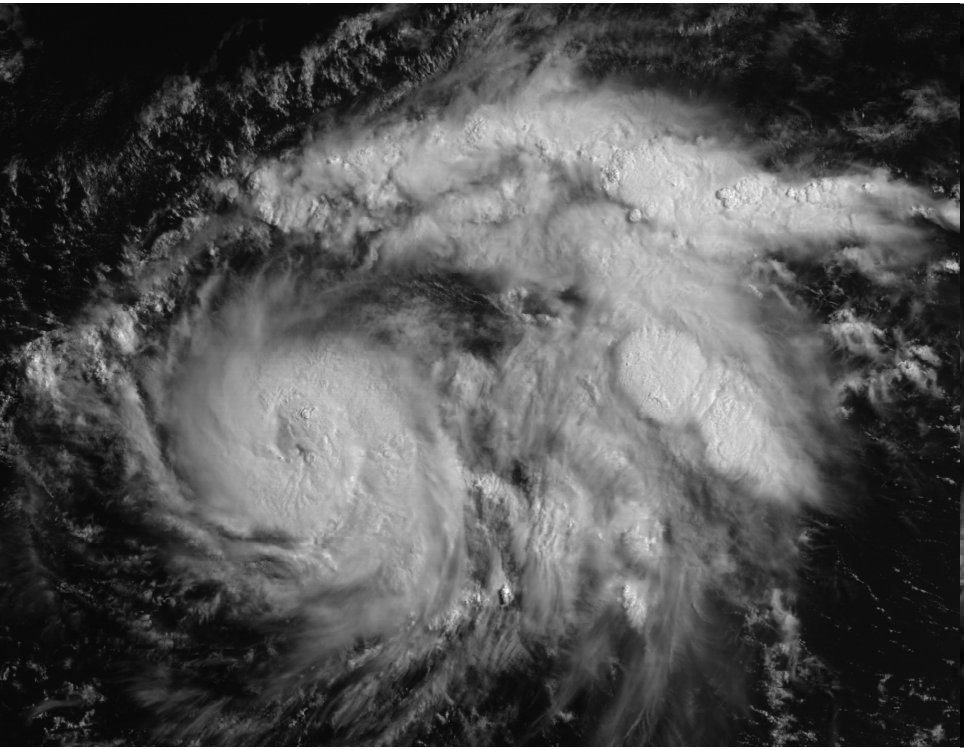


- Overshooting cloud tops can evolve very rapidly!
- Some last for 5-mins whereas those in supercell storms can persist continuously for over an hour
- The time window for matching cloud top properties with TWC was up to 10 mins during 2015 Cayenne.
- OTs can grow and decay in 10 mins, blurring OT-TWC relationships
- **Use of up to 1-min frequency GOES data reduces scatter, clearly showing the strong relationship between moderate to high TWC and distance to OT**

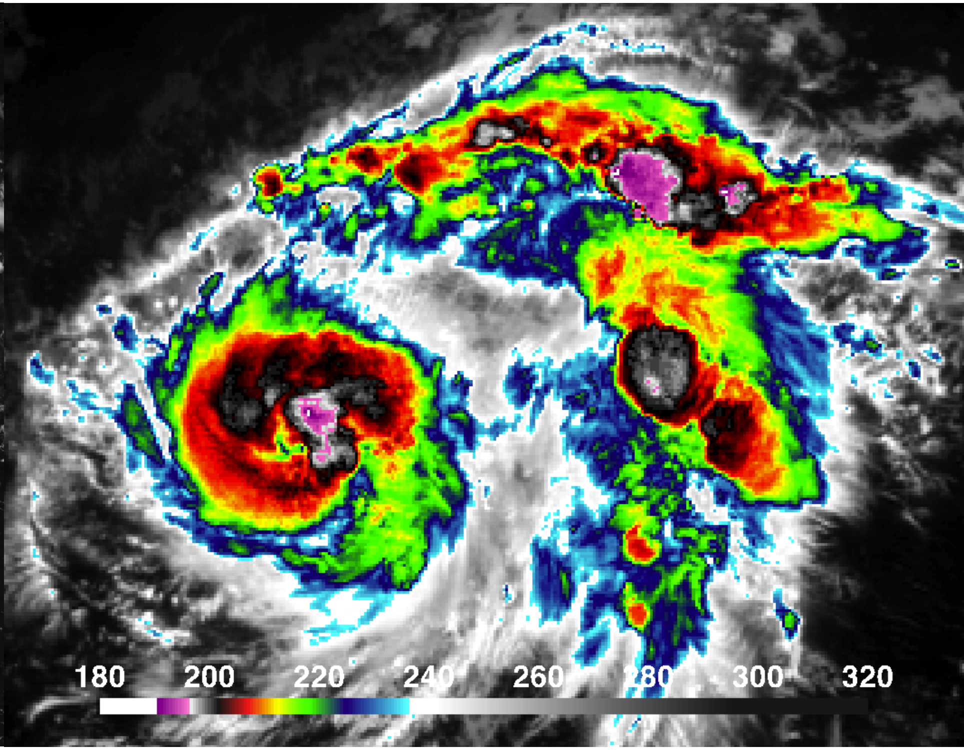
Visible and IR-Based Probabilistic Overshooting Cloud Top Detection

Bedka and Khlopenkov (JAMC, 2016)

GOES-15 Visible Image of Hurricane Guillermo



GOES-15 Color-Enhanced Infrared Image

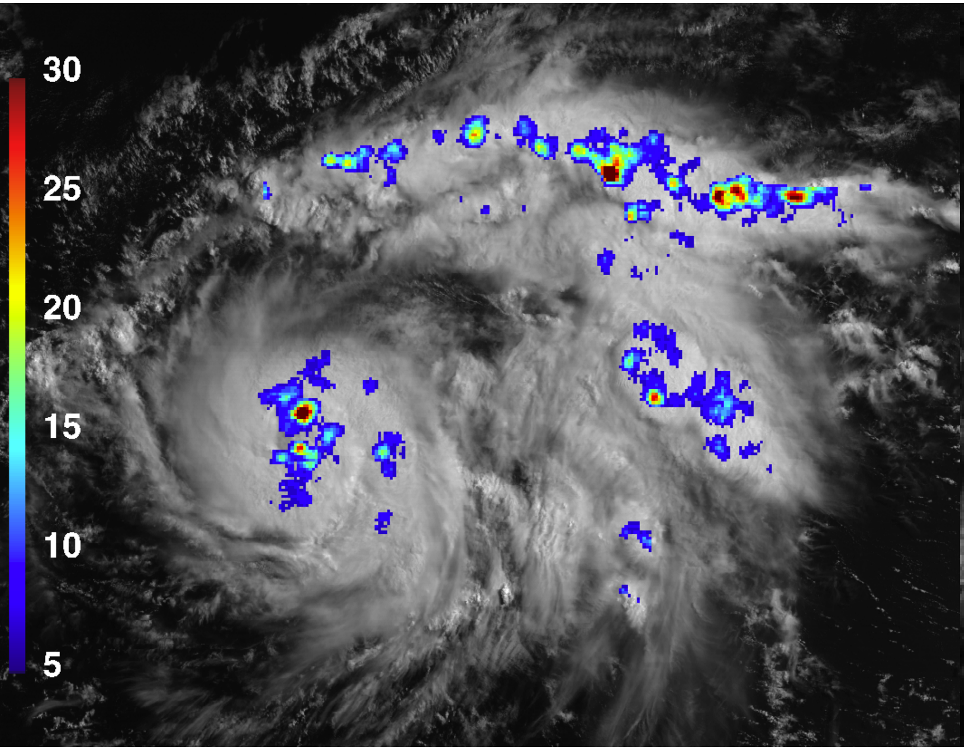


GOAL: Mimic the human mind's overshooting top identification process using IR & visible imagery combined with numerical weather prediction model data within an automated computer algorithm

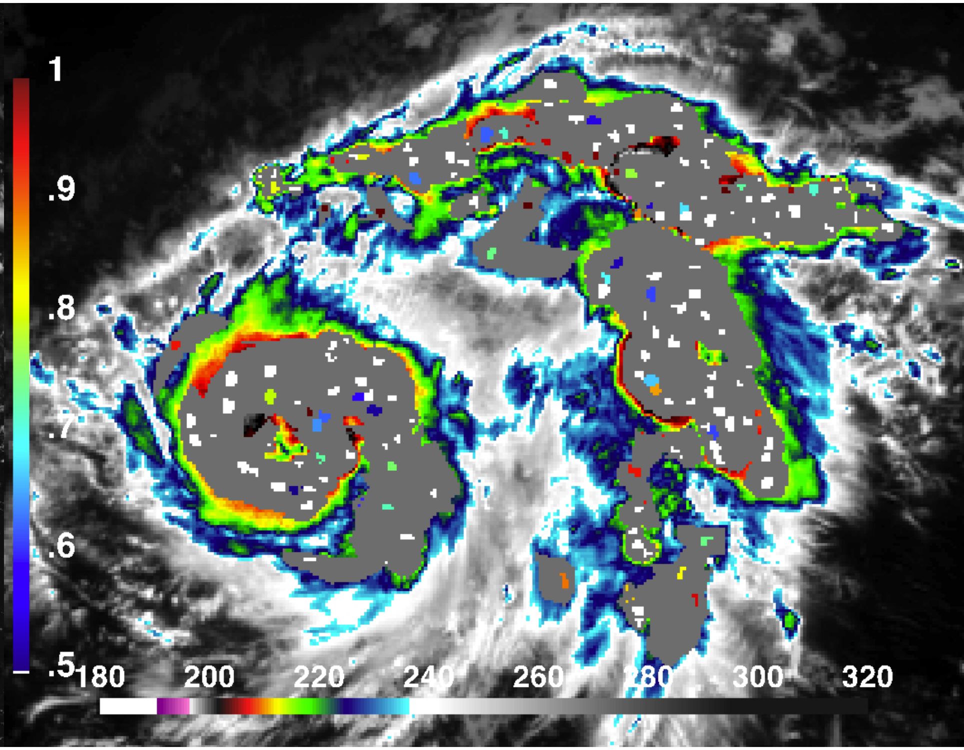
Visible and IR-Based Probabilistic Overshooting Cloud Top Detection

Bedka and Khlopenkov (JAMC, 2016)

Visible Texture Detection Rating



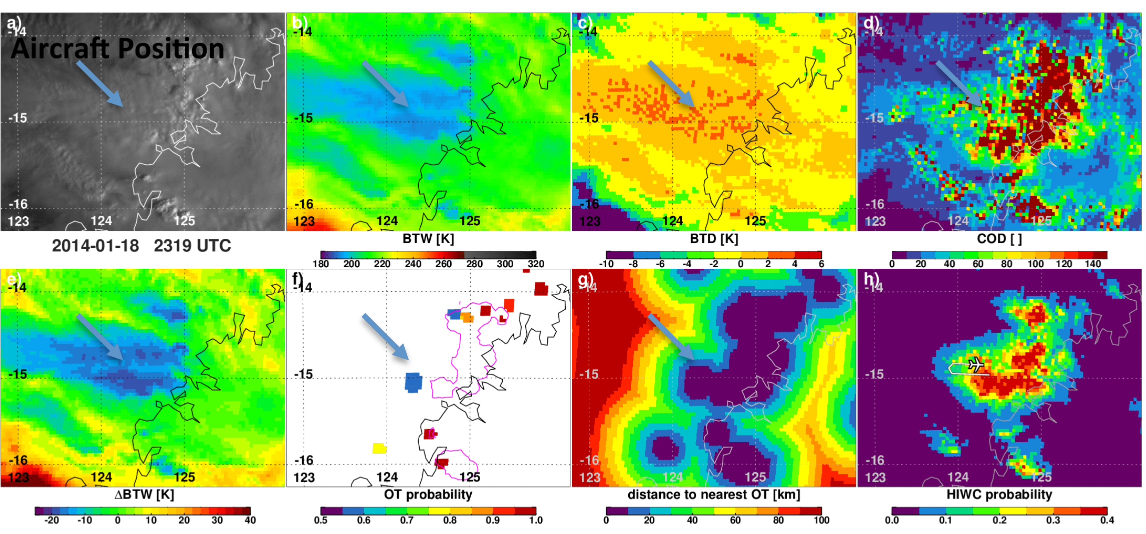
Infrared Cirrus Anvil Detection (Grey) Overlaid With OTProbability >= 0.5 (Colored Dots) OT Probability < 0.5 (White Dots)

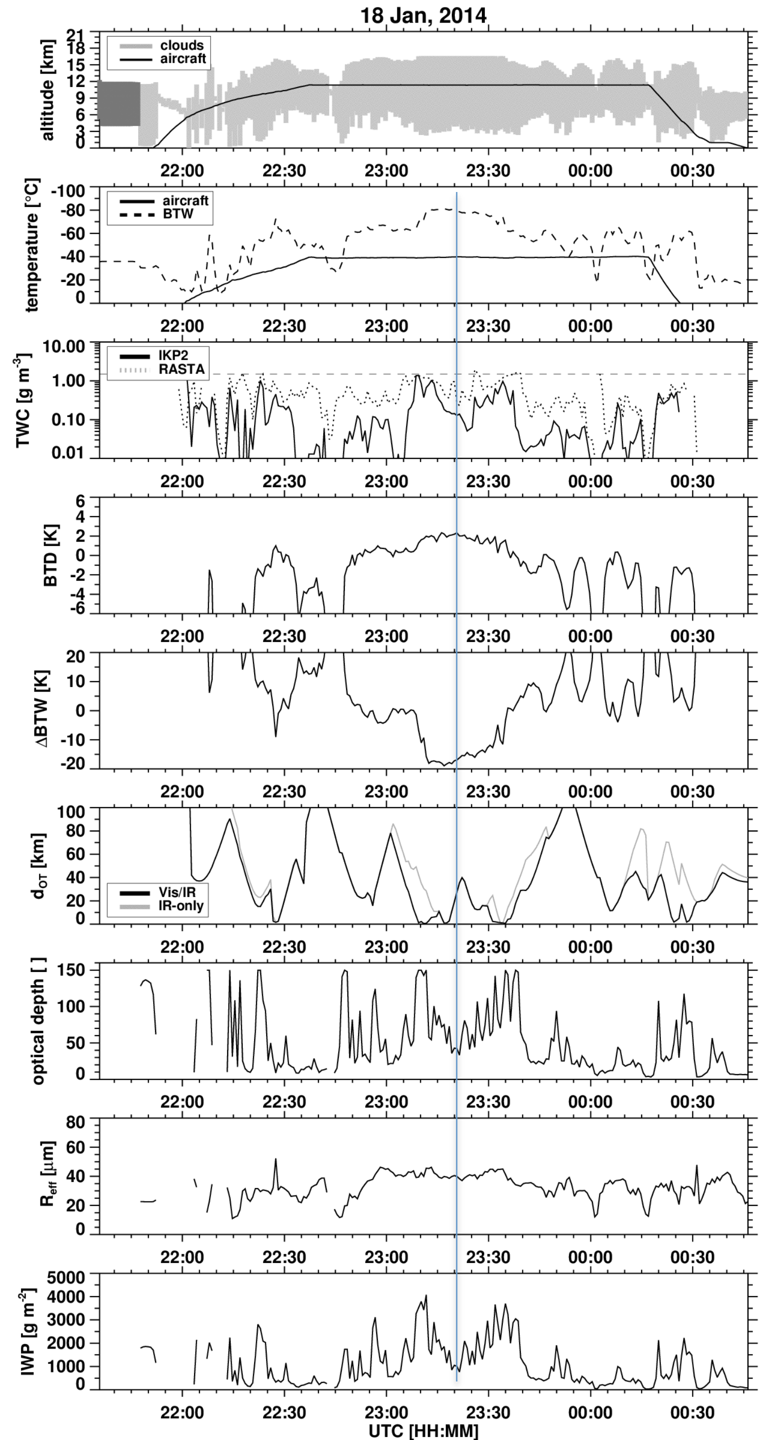


GOAL: Mimic the human mind's overshooting top identification process using IR & visible imagery combined with numerical weather prediction model data within an automated computer algorithm

Low IR Temperature Alone Not a Good HIWC Indicator!

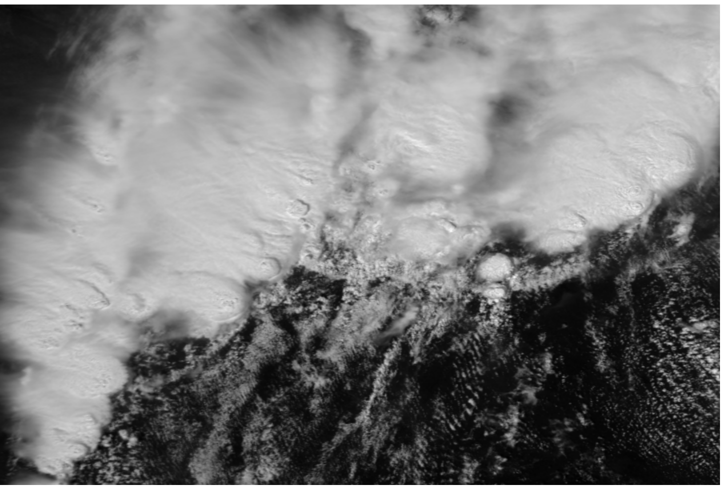
- At the time of this scene, IR BT (i.e. BTW) are almost the coldest at any point during the flight and WV-IR BTD was also quite large.
- Yet TWC values were around 0.2 g m^{-3} at this time
- The cold region above where the aircraft flew was produced by outflow from OTs to the east along the Australia coastline
- Relatively low optical depth and large distance from IR OT or textured region were indicators that the HIWC was unlikely
- Some HIWC nowcast algorithms may use IR BT as a key parameter, and this case illustrates the downsides of such an approach. Spatial structure of the cloud also needs to be taken into account!



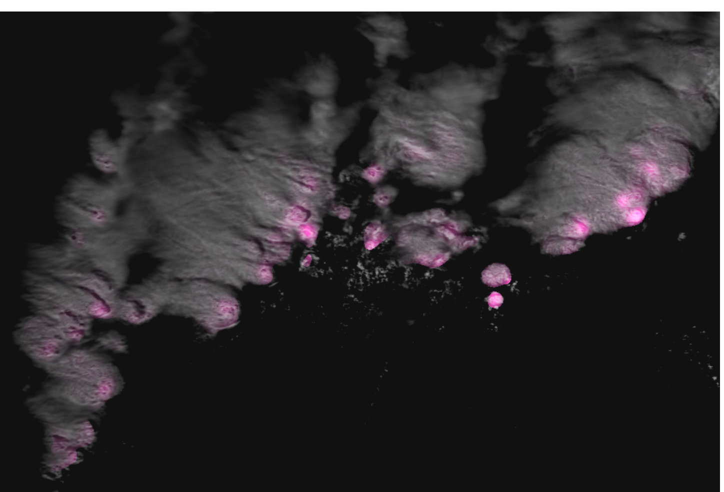


Visible Channel Pattern Recognition

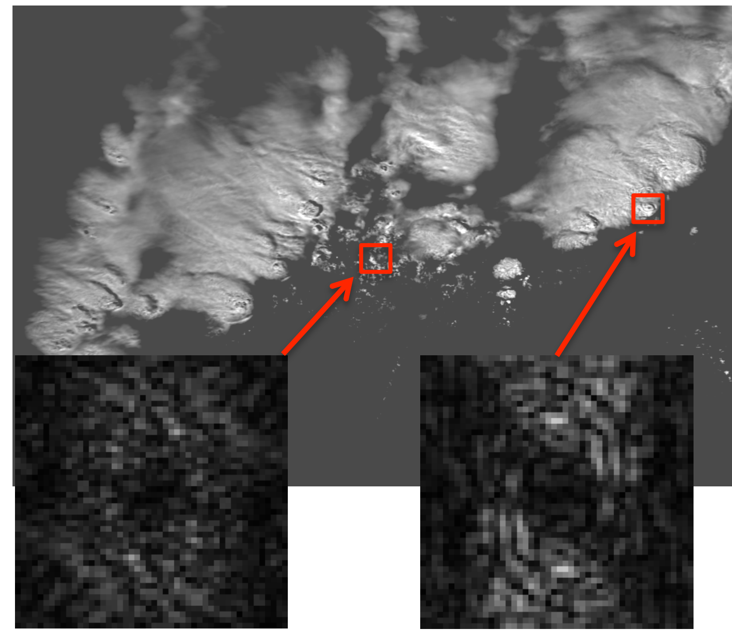
Input MODIS 1 km Visible Image



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