Characterizing and Diagnosing HIWC Conditions with Passive Satellite Imagery

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Objectives

- Identify which satellite observations/retrievals are most useful for identifying HIWC

- HIWC is generally associated with convection so look for…
  - Positive differences between water vapor channel (~6.7 microns) and IR window channel (~11 microns) brightness temperatures (+BTD)
  - Storms that are more intense relative to other storms in the region (compare pixel window brightness temps (BTW) to mean anvil BTW)
  - Cloud microphysical properties that are indicative of HIWC (large cloud optical depth COD or ice water path IWP)
  - Active updraft regions where HIWC is likely to be generated (via OT/updraft detection methods)

- Optimally combine satellite obs/retrievals to quantify the likelihood of HIWC

Aircraft/Satellite Datasets

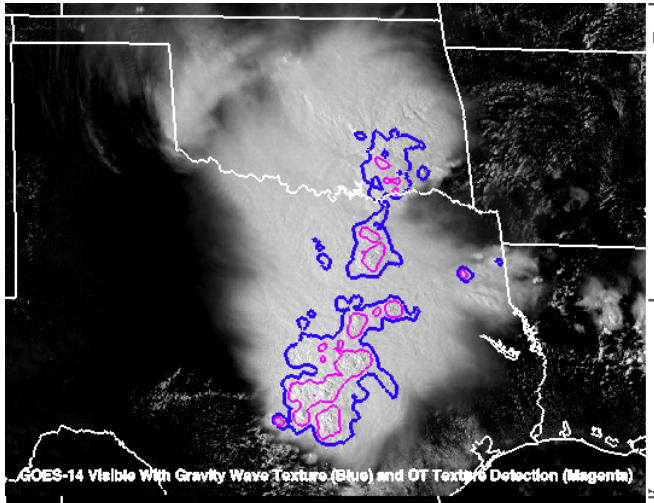
- **Aircraft Datasets**
  - Total water content (TWC) from IKP2, Darwin & Cayenne (Strapp)
    - Cayenne IKP2 data is draft version
  - Static air temperature (SAFIRE)

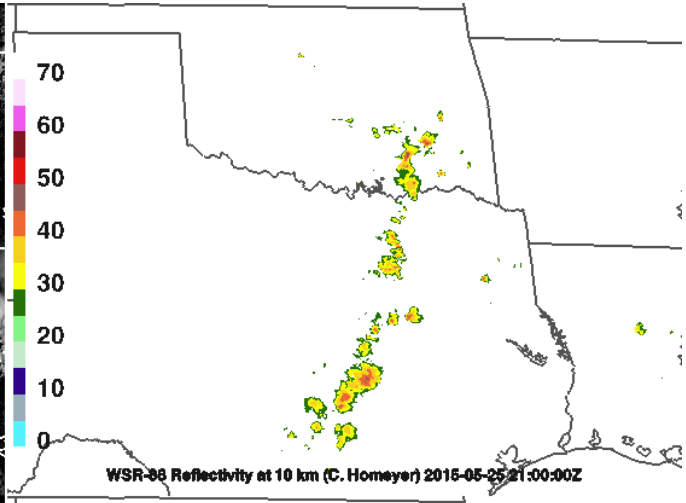
- **Satellite Datasets**
  - Darwin: MTSAT-1R (rapid scan, 10-minute imagery)
  - Cayenne: GOES-13 (half-hourly)
  - ~4-km spatial resolution at nadir; 1-km res available for visible imagery
  - Cloud property retrievals from SatCORPS (Satellite ClOud & Radiation Property retrieval System); Minnis et al. (SPIE, 2008; TGRS, 2011)
    - Cloud phase (water/ice), boundaries, optical depth (COD), effective particle size, water path, etc.
  - Overshooting top database (Bedka & Khlopenkov, JAMC 2016, in press)
    - Visible texture rating based on Fourier frequency analysis of high-res 1-km visible imagery
    - IR-only OT Probability rating based on spatial analysis of temp gradients in cold clouds

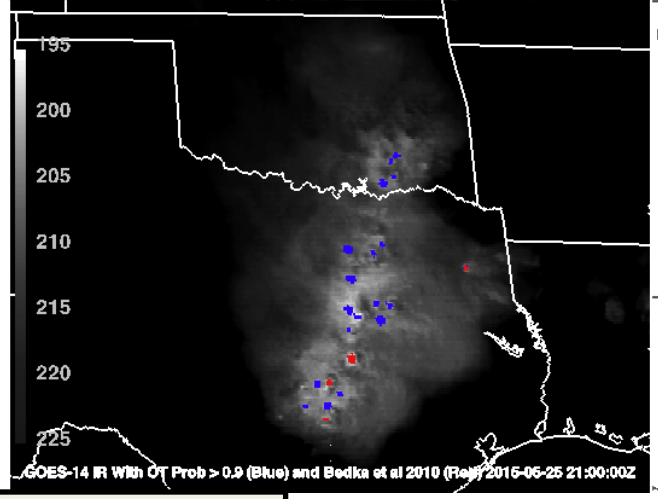
Automated Texture & OT Detection

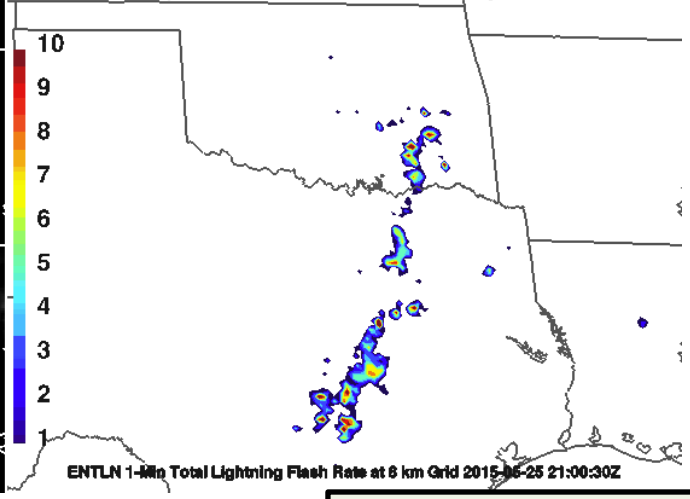
updraft/gravity wave texture (blue)
significant (OT) texture (magenta)

WSR-88D radar reflectivity @ 10 km









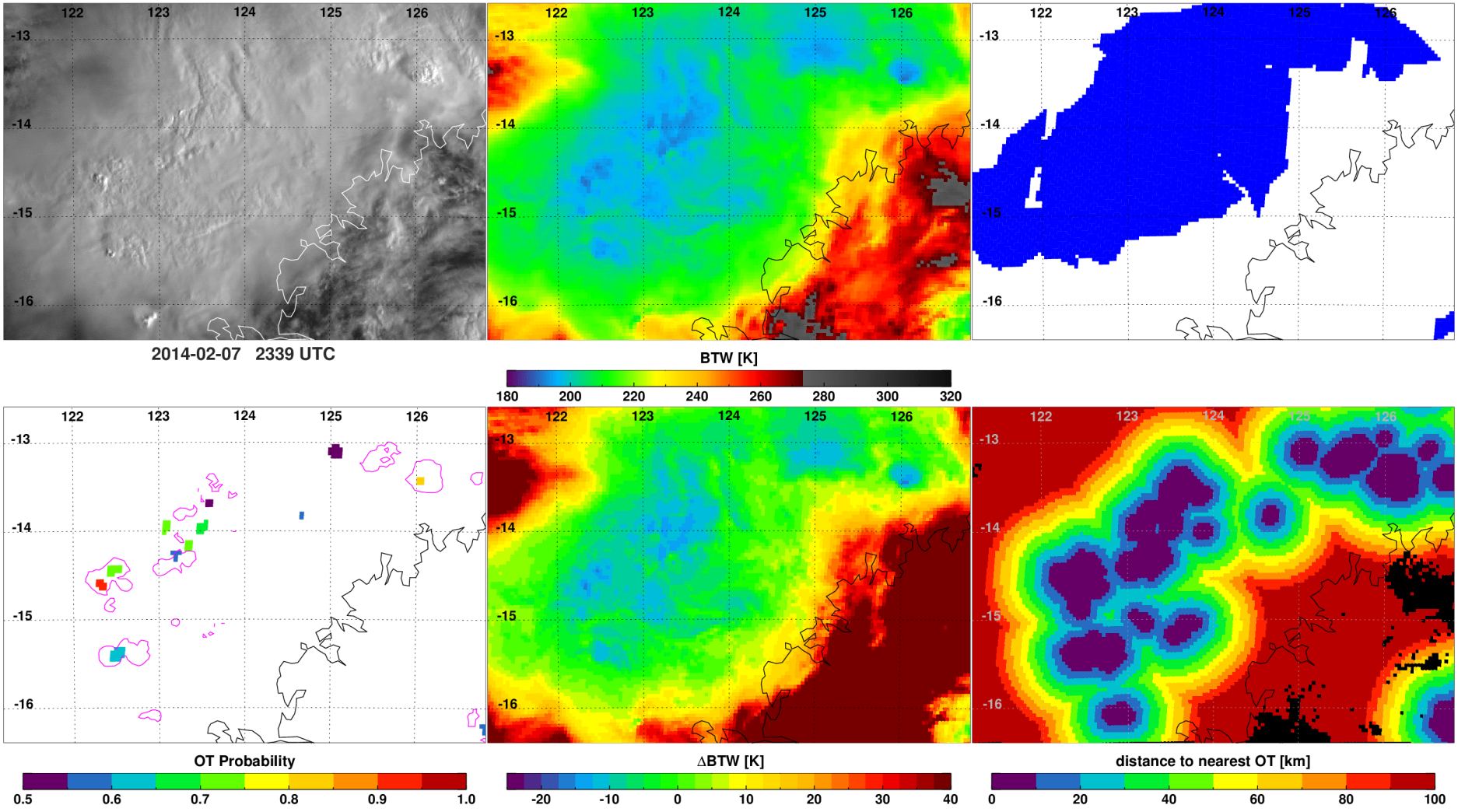
IR OT Probability > 0.9 (blue)

ENTLN Total Lightning Flash Rate

The storm shown here is quite large, but the visible texture product is able to pick out the most active and intense parts of the storm. These areas coincide with high radar reflectivity and total lightning activity.

Overshooting Top (OT) Products

- OT Datasets, example from Darwin (Feb 7)
  - Anvil mask: identifies broad areas of uniformly cold pixels surrounding embedded IR BT minima
  - IR-based OT probability: based on BT difference from mean temp of anvil, most unstable equilibrium level, and tropopause temperature
  - Visible texture rating: elevated ratings for gravity wave features, highest ratings for “textbook" OTs
  - Compute ΔBTW and distance to nearest OT or texture detection



Collocated Aircraft/Satellite Observations

- Match mean cloud properties in 2x2 pixel box to aircraft position
- Typical cruise speed of Falcon-20: 180 m/s
- 45-s averages of aircraft data (used 1-s data previously)
- Aircraft and satellite obs within 10 minutes
- TWC > 0.01 g m^{-3} considered in-cloud threshold

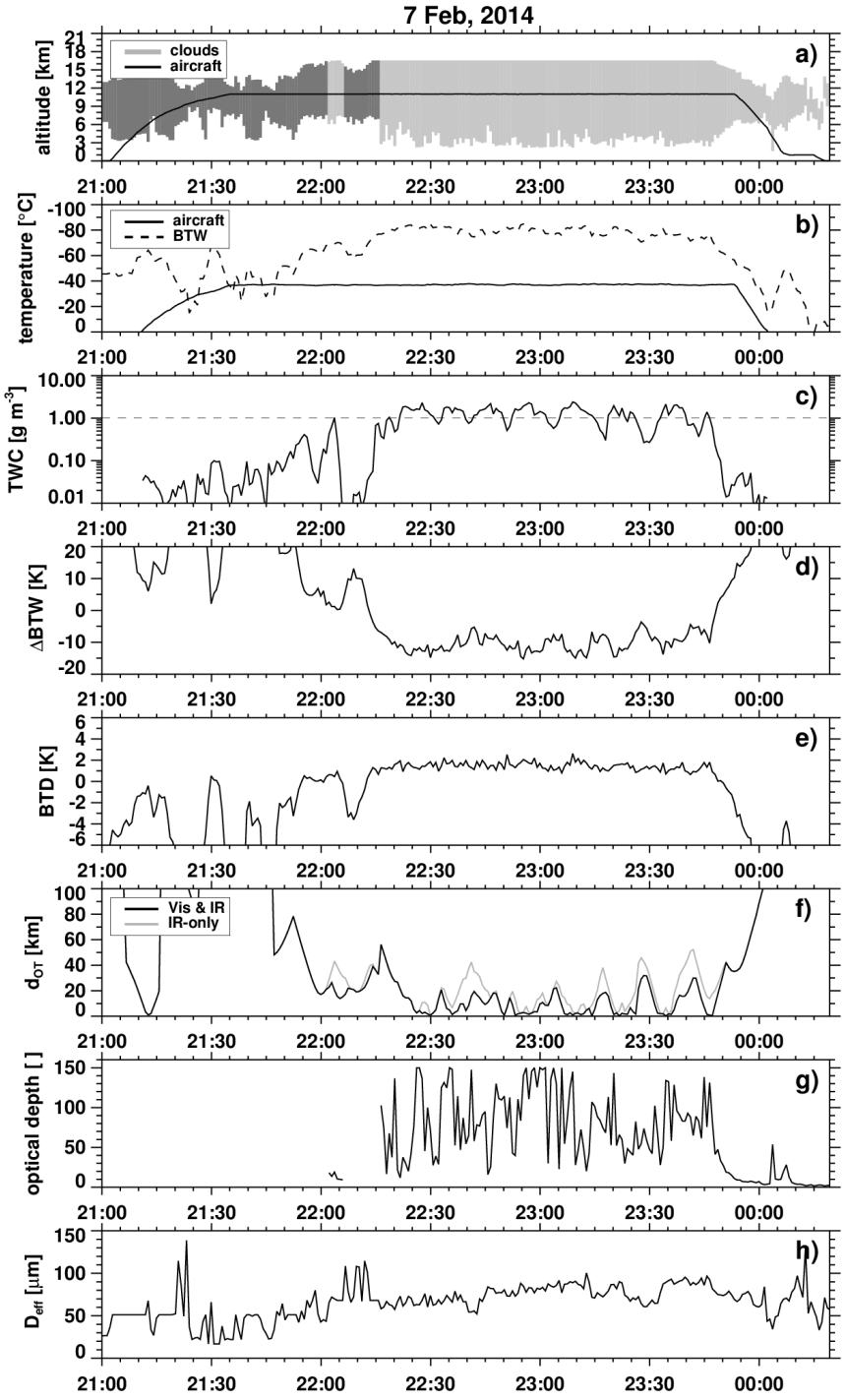
IKP2 total water content TWC [g m^{-3}], 45-s averages

negative ΔBTW indicate cloud tops colder than the mean anvil temp in the region

distance from Falcon's position to nearest overshooting top or textured feature

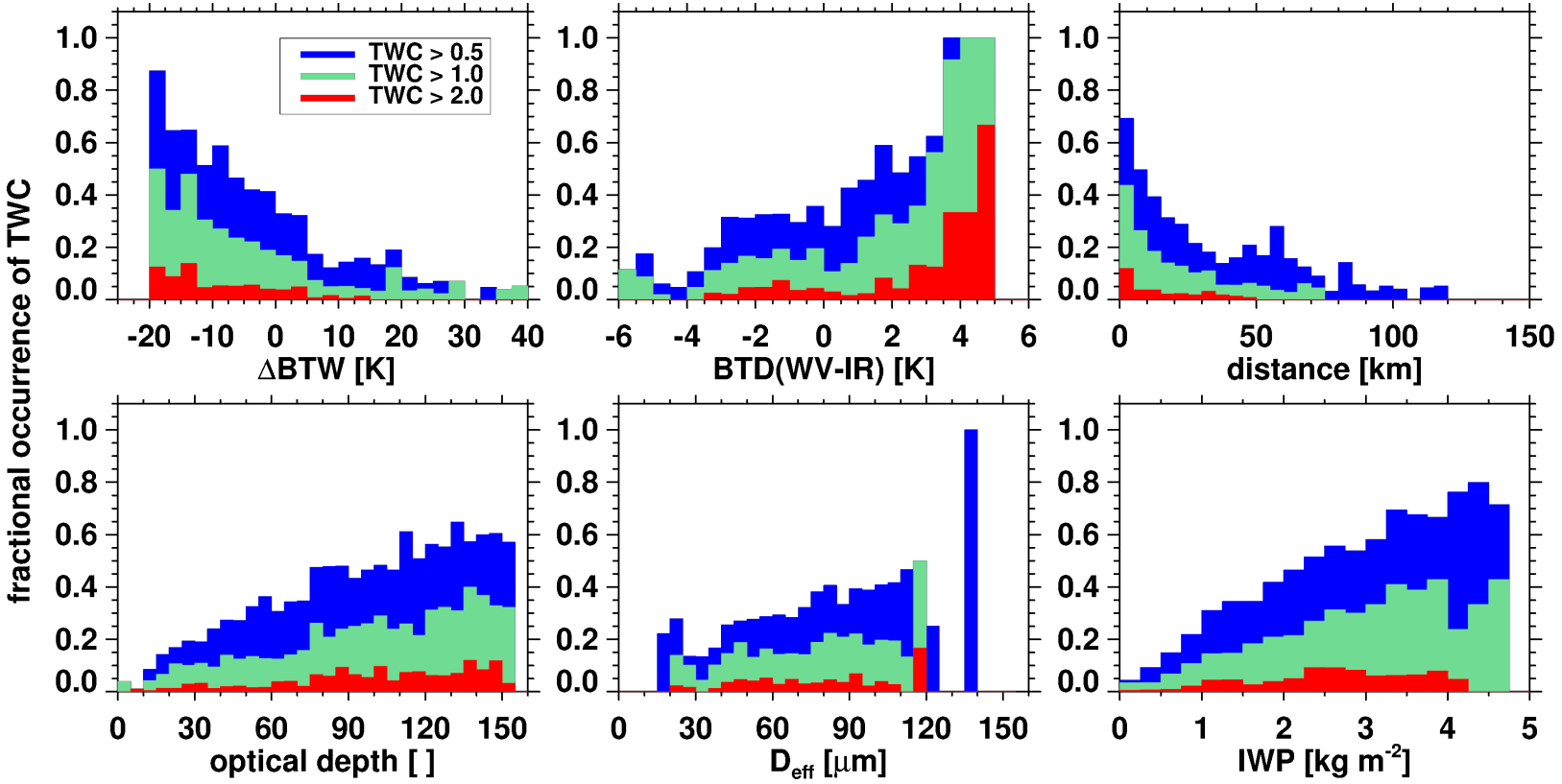
COD > 30 indicative of convective clouds

variations in particle size don't seem correlated with TWC



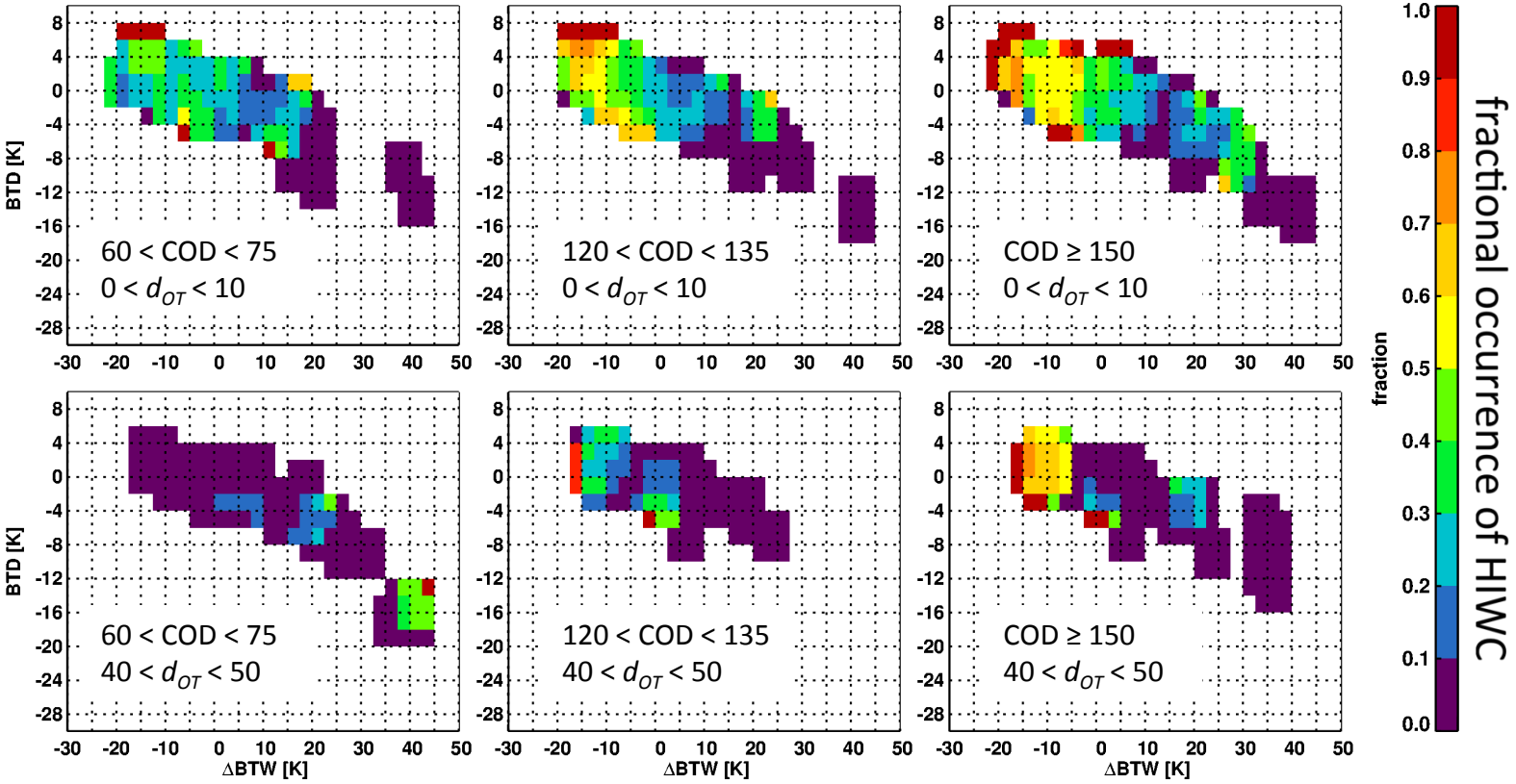
Cloud Properties Coincident with HIWC

- Examined fractional occurrence of TWC with different satellite observations/retrievals
- TWC occurrence changes significantly with all parameters shown except D_{eff}
- Trends for TWC > 2 g m^{-3} (red) much weaker
- 70% of matches within 5 km of OTs had TWC > 0.5 g m^{-3}
- Most high TWC located within 50 km of OTs
- Sustained TWC > 2 g m^{-3} relatively rare
- No single satellite observation indicates certainty of HIWC
- Correlation among the different parameters, i.e., not independent
- How about joint distributions of several parameters?



Cloud Properties Coincident with HIWC

- HIWC defined hereafter as TWC > 1 g m^{-3}
- 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 (proximity to convective center where HIWC might be actively produced)
- Used 66% of matched dataset to derive statistics and develop algorithm
- Multi-dimensional analysis of fractional occurrence distribution enhances product
  - Use distributions as a look-up table of HIWC fractional occurrence



HIWC Probability (PHIWC) Estimation

- Define HIWC as TWC > 1 g m^{-3}
  - 83rd percentile of 45-s TWC averages
  - Peak values are larger

- Use different methods depending on solar illumination conditions
  - COD and VIS texture detection unavailable at night

- Daytime method (Visible + IR info)
  - PHIWC = PHIWC(ΔBTW, BTD, d_{OT}, COD)
  - Use "background" value for d_{OT} > 50 km; PHIWC = PHIWC(ΔBTW, BTD, COD)

- Nighttime method (IR-only info)
  - PHIWC = PHIWC(ΔBTW, BTD, d_{OT})
  - Use "background" value for d_{OT} > 50 km; PHIWC = PHIWC(ΔBTW, BTD)
  - COD retrievals limited to < 6
  - No cloud texture information from visible channel – OT proximity computed for IR-only detections

- Spatial smoothing performed to reduce noise

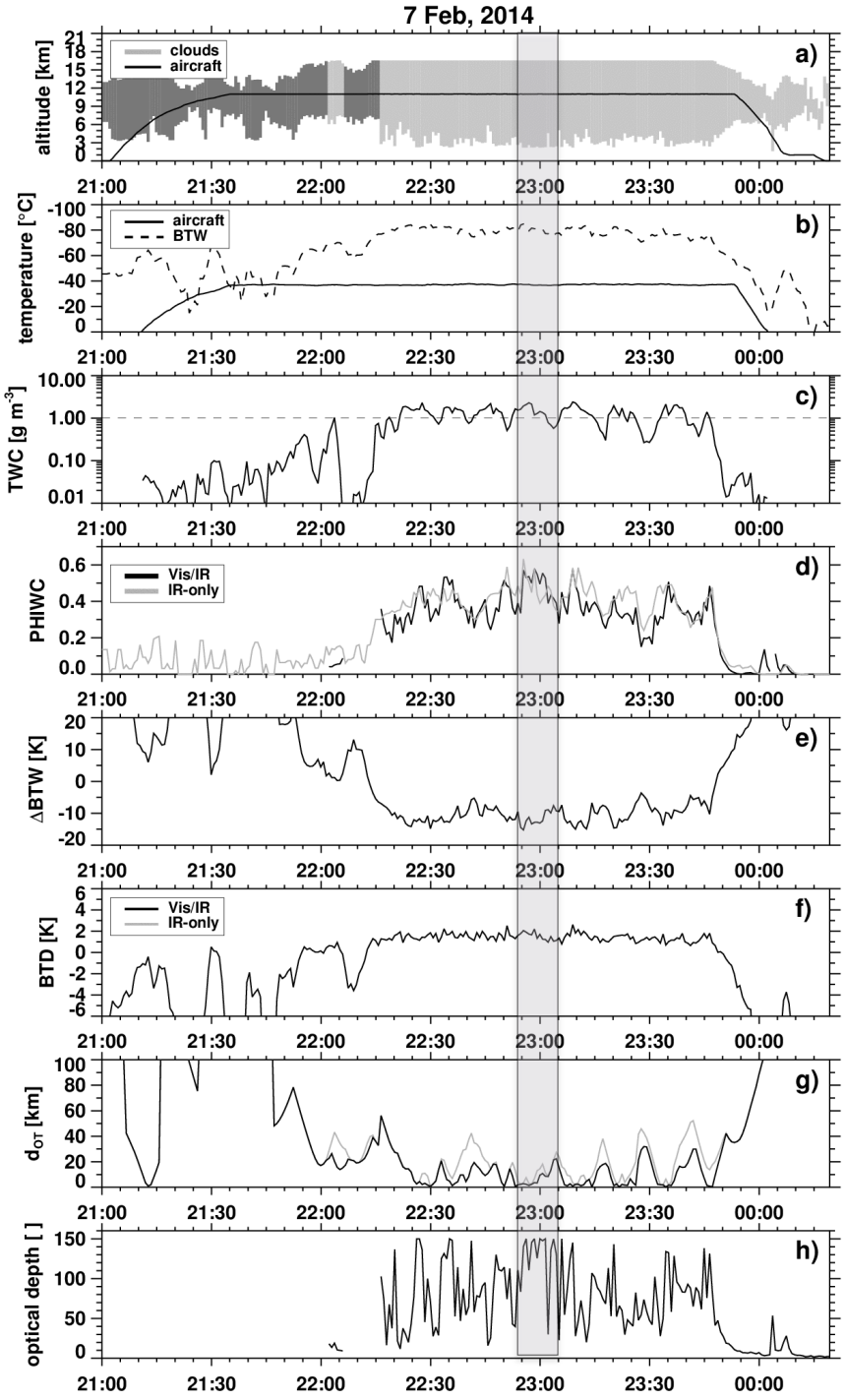
Collocated Aircraft/Satellite Observations

- 7 Feb, 2014 (Darwin flight 16)
- HIWC probability (PHIWC) shown in panel d)

TWC < 1 for first third of flight, then > 1 for the remainder

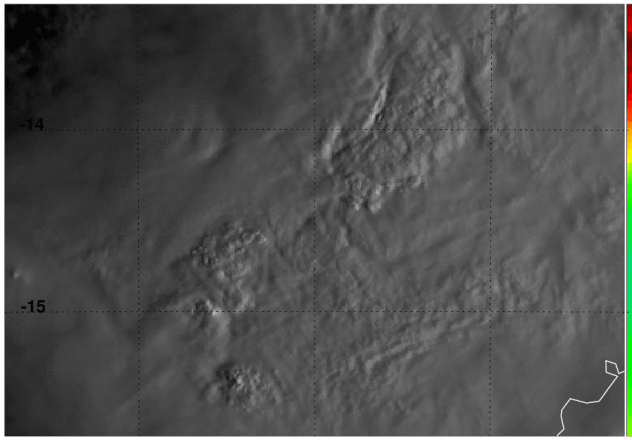
Vis/IR & IR-only PHIWC give consistent results. IR-only gives somewhat larger values

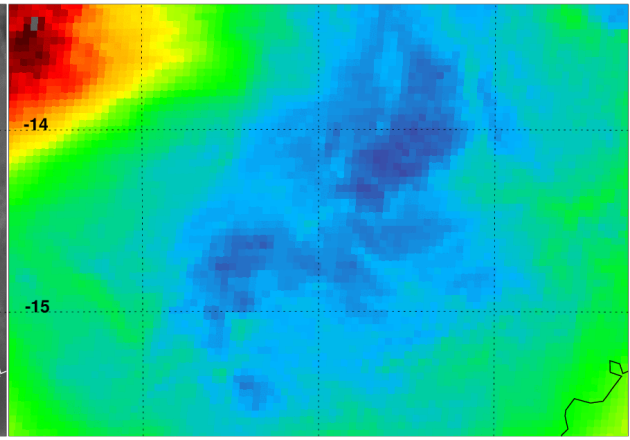
TWC peaks correspond to close proximity to detected OTs/texture



HIWC Probability Case Study

- 7 Feb, 2014, 2259 UTC (Darwin flight 16)
- TWC > 1 correspond to PHIWC > 0.5

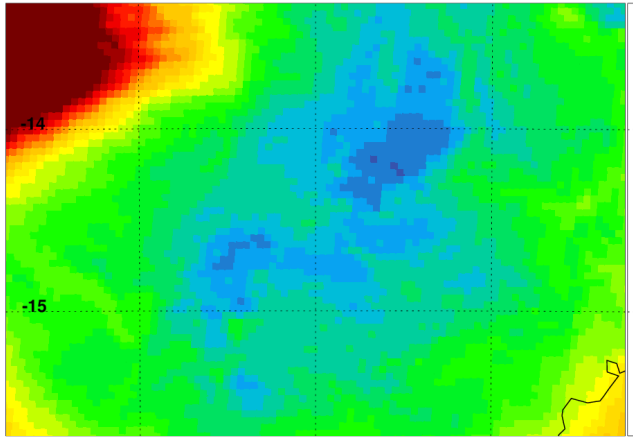


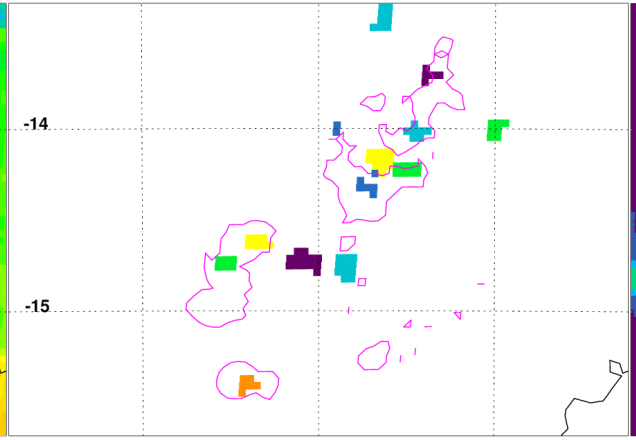


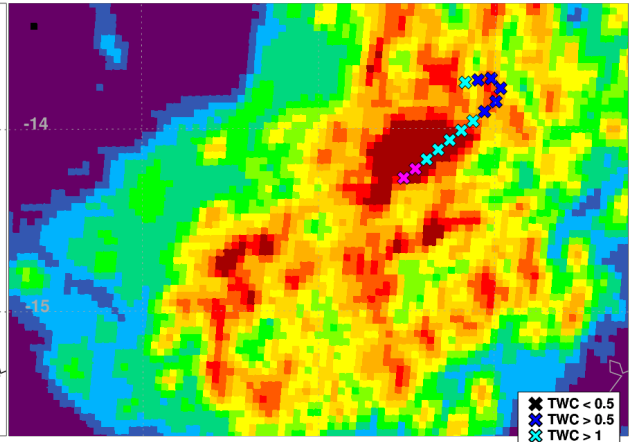
2014-02-07 2259 UTC

BTW [K]

180 200 220 240 260 280 300 320







ΔBTW [K]

-20 -10 0 10 20 30 40

OT Probability

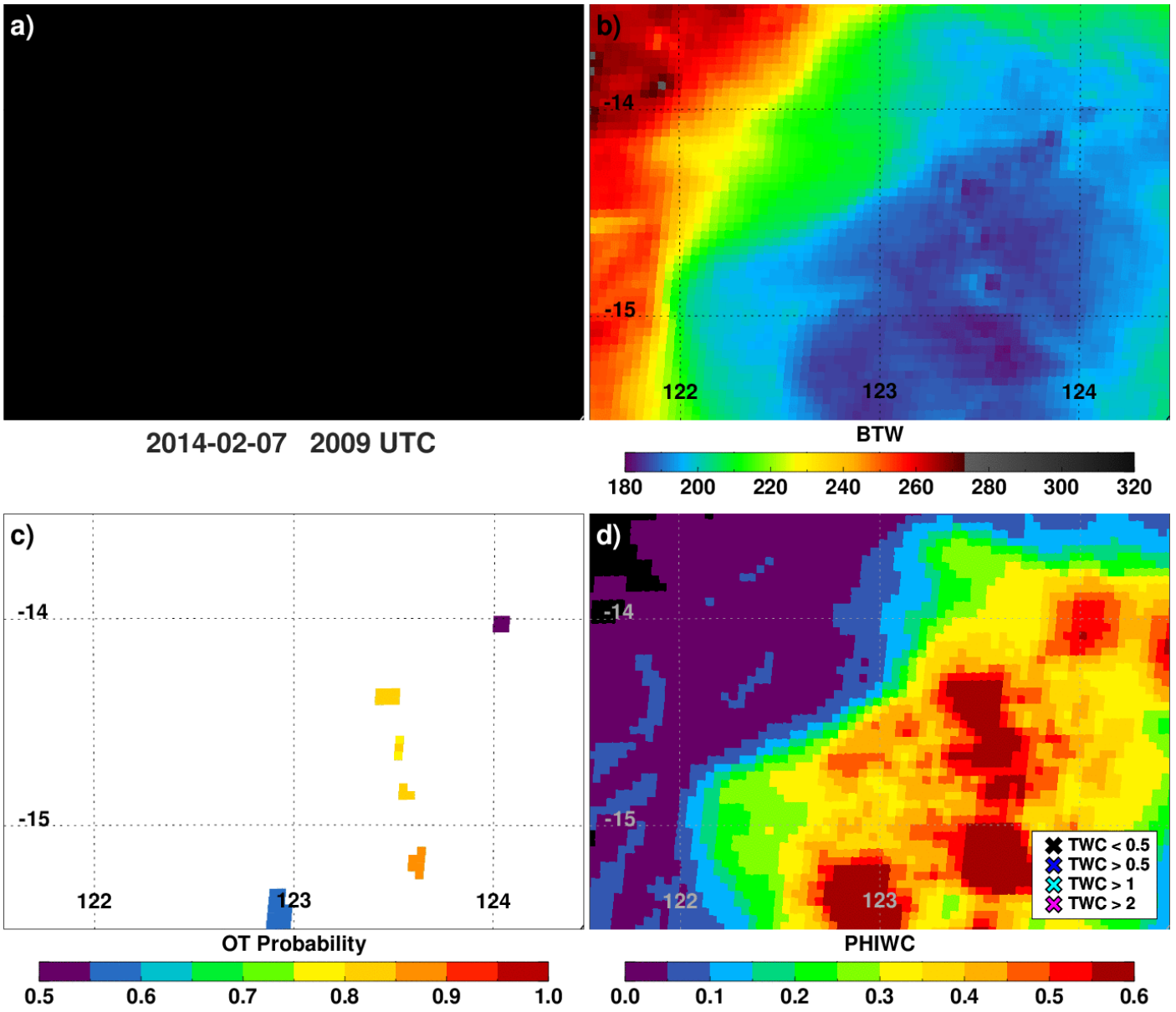
0.5 0.6 0.7 0.8 0.9 1.0

HIWC probability

0.0 0.1 0.2 0.3 0.4 0.5 0.6

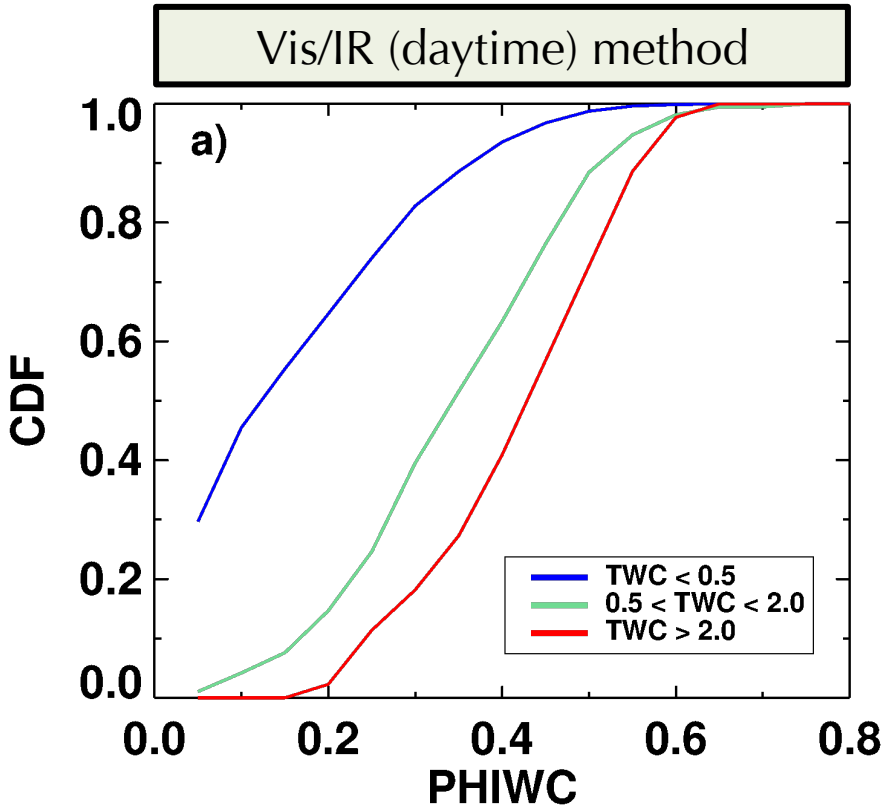
HIWC Probability Animation

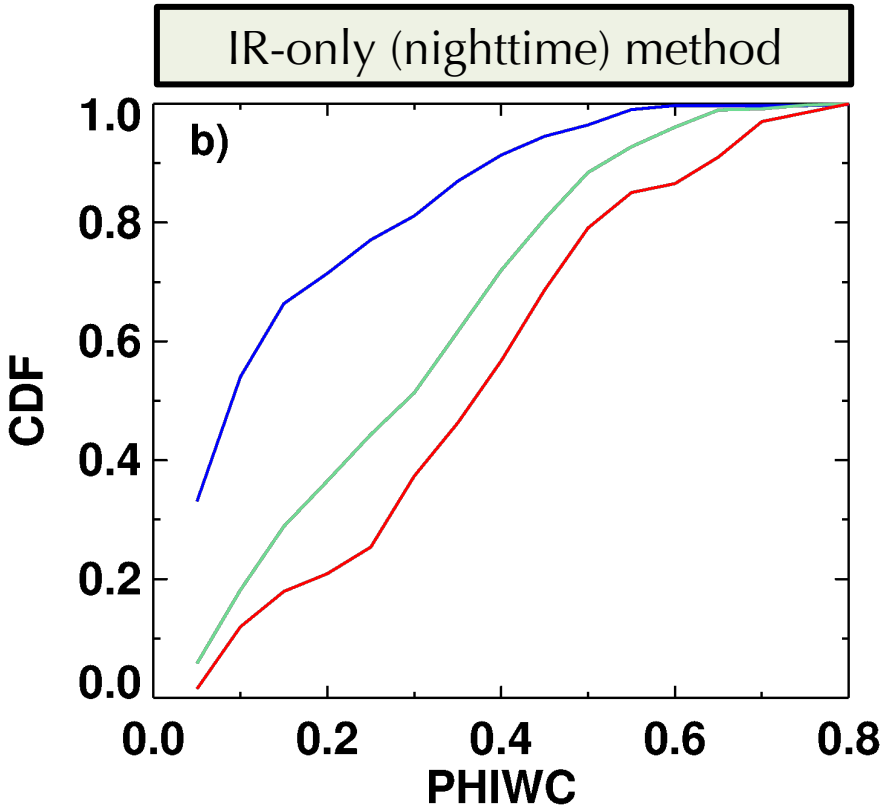
7 Feb, 2014; 2009 – 2349 UTC (Darwin flight 16)



HIWC Probability Verification/Validation

- 34% of Darwin/Cayenne dataset reserved for validation
- PHIWC CDFs for low (blue), moderate-high (green), and extreme TWC (red)
- PHIWC for extreme TWC (red) clearly greater than lower TWC values (blue)
- TWC < 0.5 g m^{-3} tend to have much lower PHIWC than TWC > 0.5 (blue vs. green and red curves)
- 90% of TWC < 0.5 g m^{-3} have PHIWC < 0.4
- 50% of TWC > 2 have PHIWC > 0.4





Summary

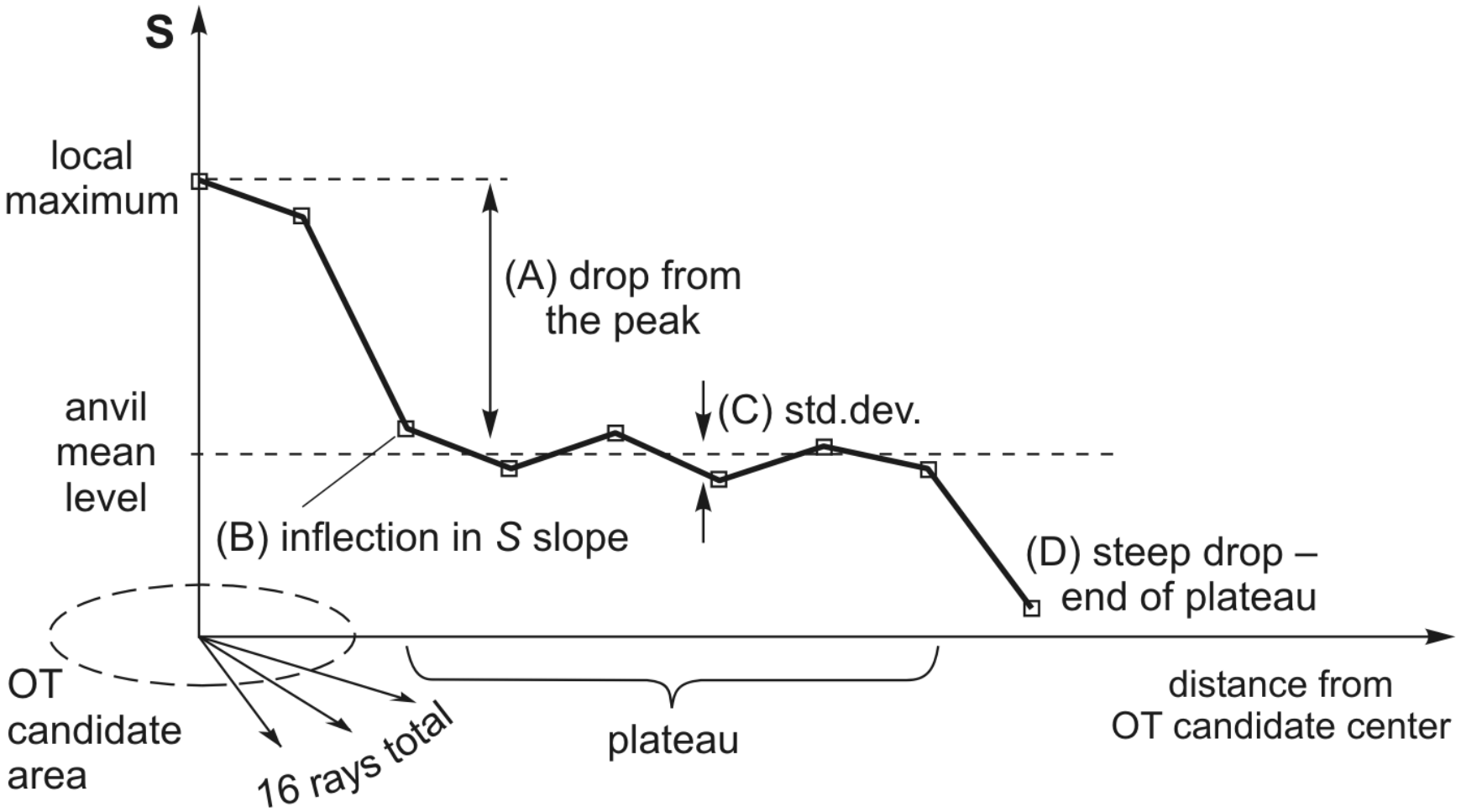
- Significant enhancements to LaRC satellite-based HIWC diagnostic product
  - OT products integrated into development of PHIWC product rather than applied after model development; helps isolate only the most active and intense parts of storms
  - Provides smoother field than previous version
  - HIWC closely related to OTs, but PHIWC algorithm not completely dependent on any one parameter
  - Daytime (Vis/IR) and nighttime (IR-only) methods
  - Given sample sizes, the differences are small
  - Transition from IR-only to Vis/IR algorithm is fairly smooth
  - Nighttime CWP method may aid IR-only approach

Future Work

- Update with new Cayenne IKP2 dataset
- Submit publication to JAOT in July/August
- Further validation with Florida dataset planned soon
  - Flights days with 1-minute GOES-14 imagery very valuable
- Implement prototype PHIWC product on near-real-time GEOSat cloud analysis domains
- Compare with RASTA and CloudSat
  - Use passive profiling technique to estimate altitudes of HIWC?

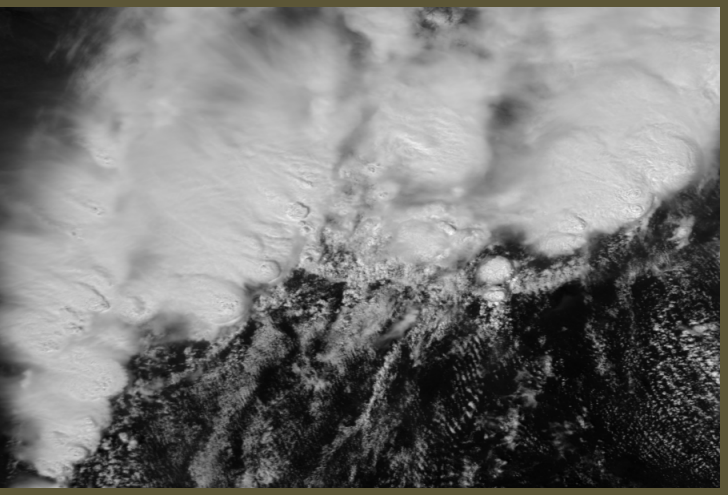
Extra/Backup Slides

IR-Based OT Pattern Recognition Analysis

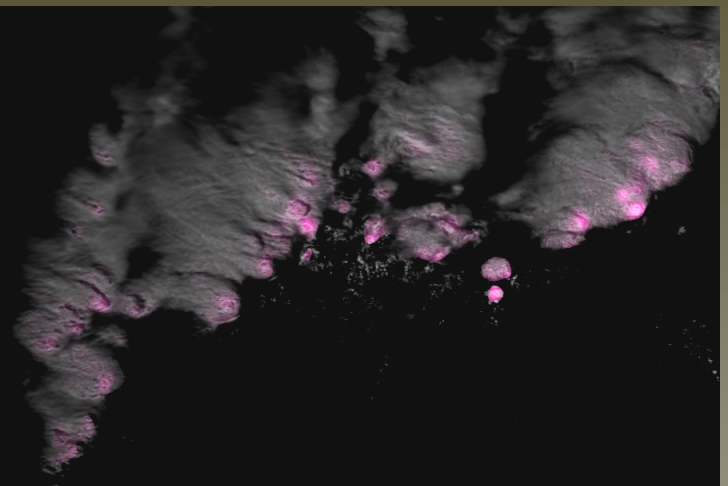


Visible Channel Pattern Recognition

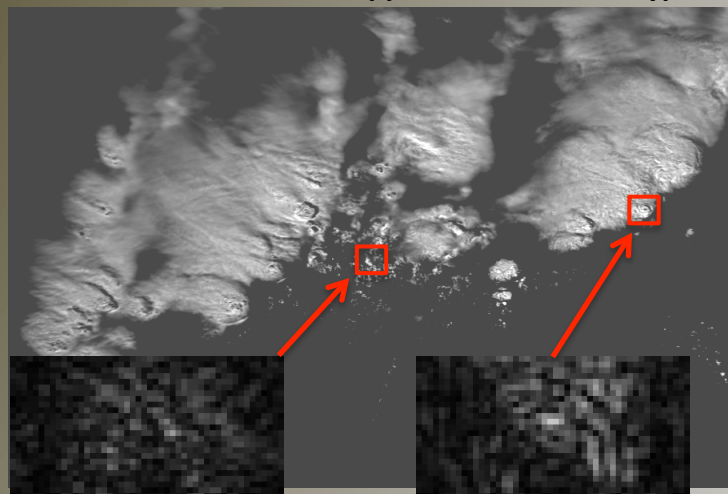
Input MODIS 1 km Visible Image

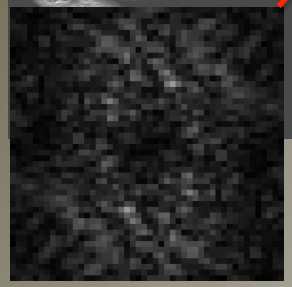


Final OT Candidate Regions
Based on Visible Analysis



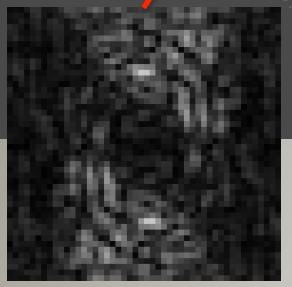
Non-linear Brightness Correction to Highlight Convective Clouds and Suppress Other Cloud Types





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