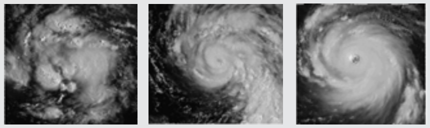

Evidence of Strong Updrafts in Tropical Cyclones using Combined Satellite, Lightning, and High-Altitude Aircraft Observations

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Daniel J. Cecil❖

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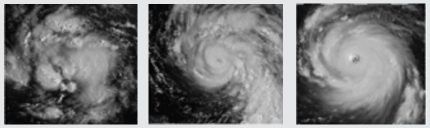
❖ NASA Marshall Space Flight Center, Huntsville, AL

Naval Research Laboratory, Monterey, CA

★ National Aeronautics and Space Administration-Goddard Space Flight Center, Greenbelt, MD

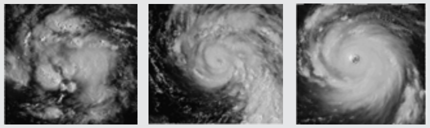


Introduction/Motivation

- Being able to identify/observe regions of strong active TC convection and trends in a time-continuous mode can have many applications (possible TC structure/intensity change and genesis forecasting, tropical aviation applications, NWP parameterizations and validation, etc.).

- Satellites are the natural platform to address this investigation, but the observations need careful interpretation and tailoring to extract reliable metrics/proxies of TC convective updraft velocities.

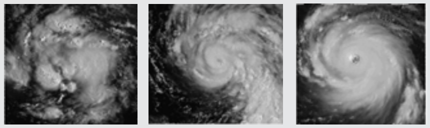
- One specific application (the focus of this presentation) is hazard avoidance for the NASA Global Hawk (GH) flying missions for the Hurricane and Severe Storm Sentinel (HS3) field project.



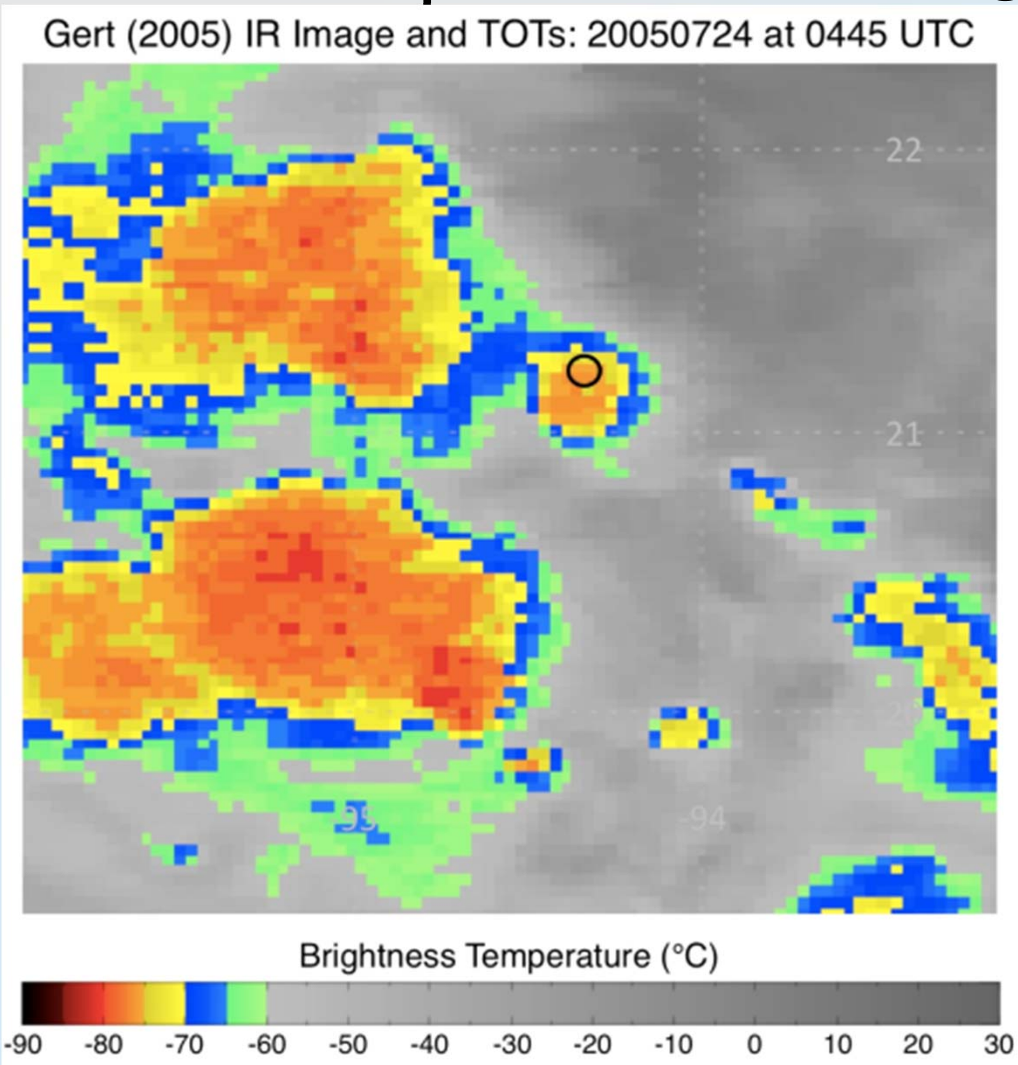
Introduction/Motivation

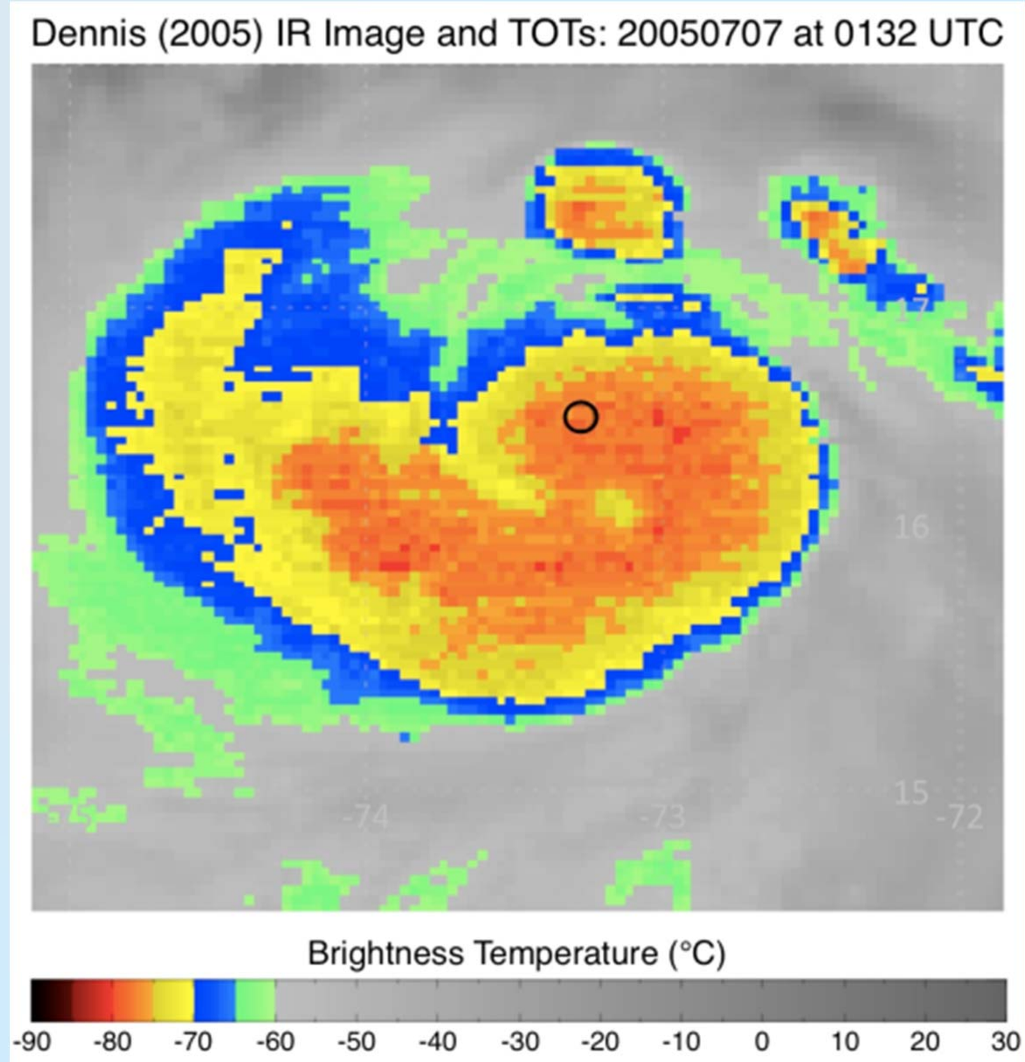
- Primary objective: Avoid significant high-altitude turbulence caused by strong convective TC updrafts.
- Original GH storm over-flight rules to avoid such hazards:
  1) Aircraft should maintain at least 10000 ft. vertical separation from convective cloud tops that are below FL500 with reported lightning.
  2) No over-flight of cumulus-type tops higher than FL500.
- However, these rules also mean that many potentially good HS3 science missions could be unnecessarily constrained, especially when investigating TC core regions.

Can we identify regions of strong updrafts that could potentially cause over-storm turbulence while at the same time allowing the Global Hawk to investigate TC core regions?



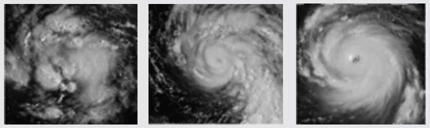
Can simple enhanced-IR satellite imagery do the trick?





One of these tropical cyclones has an updraft (circled), identified by ER-2 Doppler Radar, of ~19 m s^{-1}. The other has a ~10 m s^{-1} updraft.

Can you identify which TC has the much stronger updraft?



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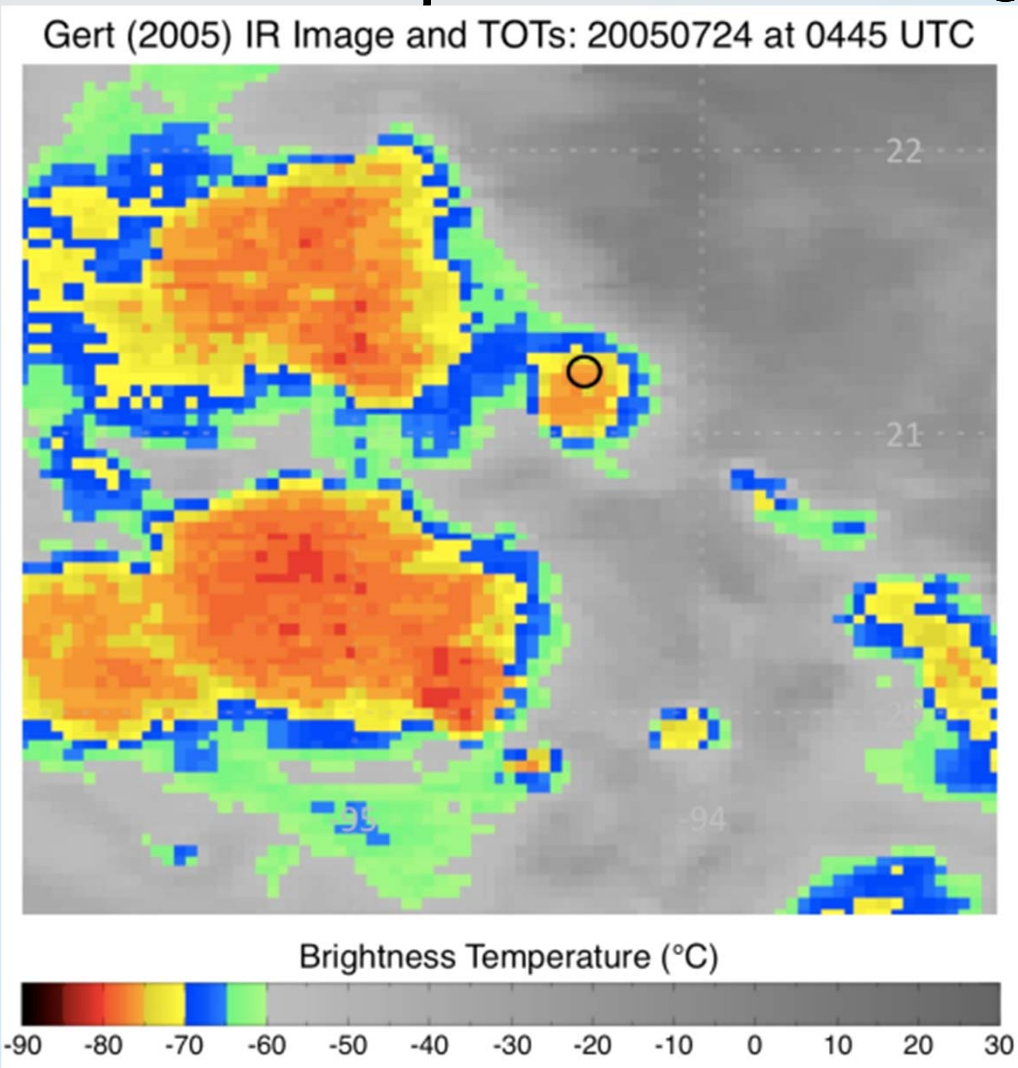
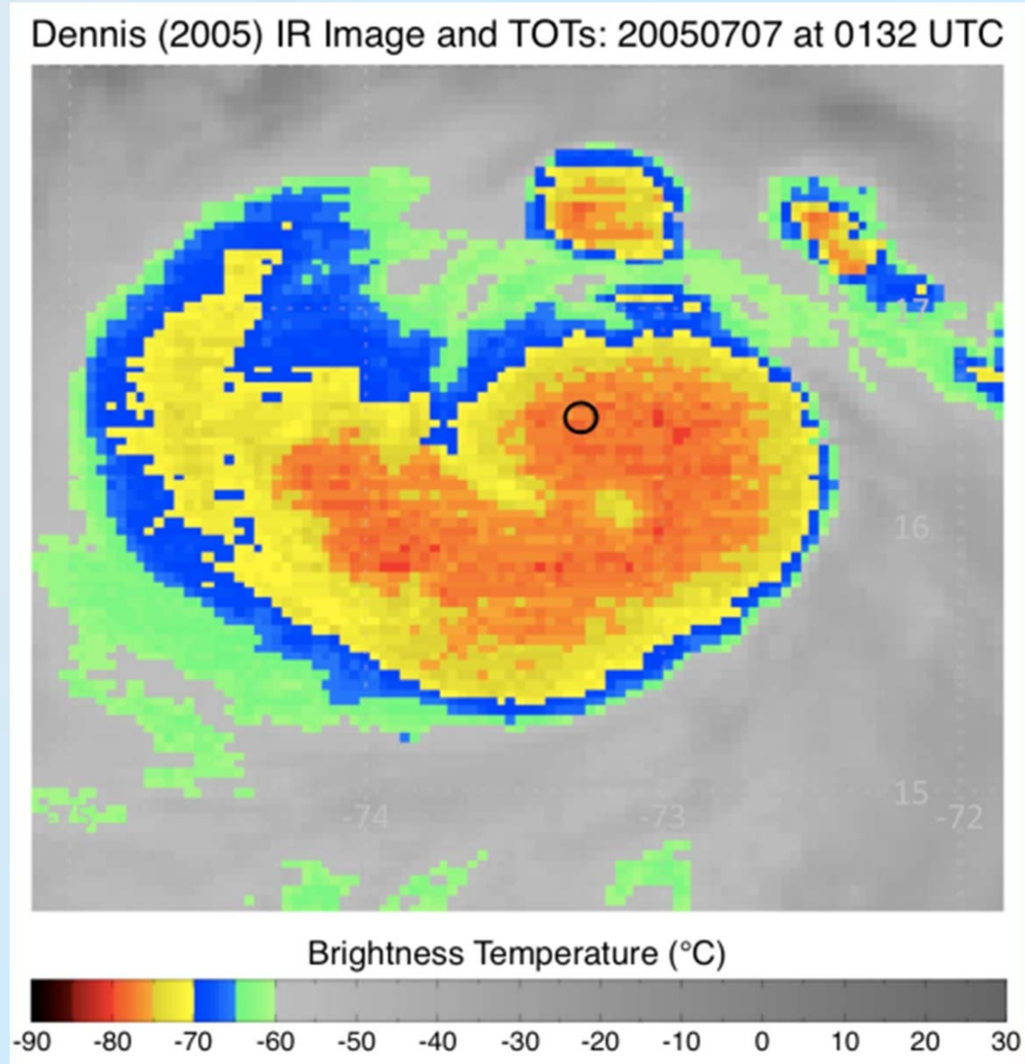
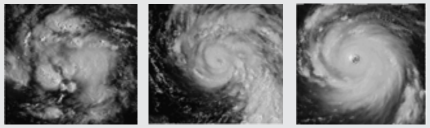




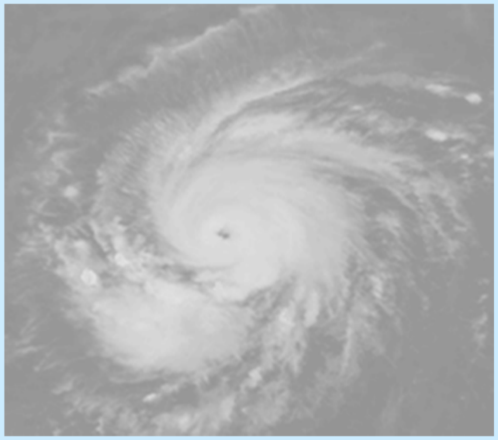
One of these tropical cyclones has an updraft (circled), identified by ER-2 Doppler Radar, of ~19 m s^{-1}. The other has a ~10 m s^{-1} updraft.

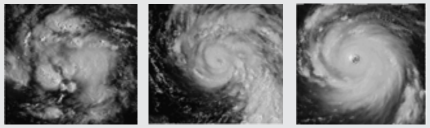
Can you identify which TC has the much stronger updraft? **Uh, no…**



Diagnostic Toolbox

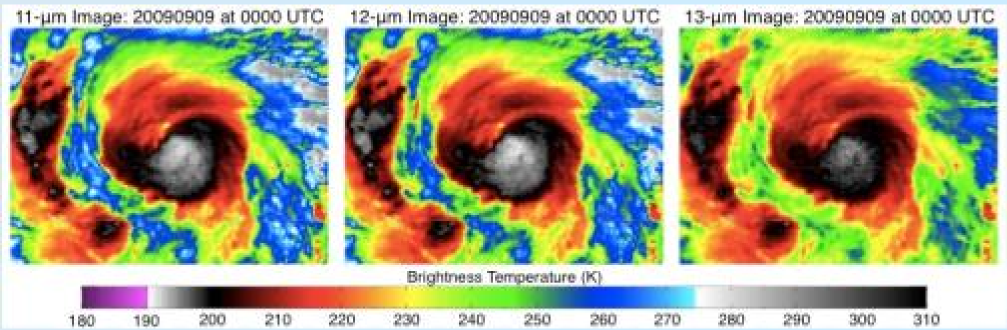
- **Satellite-Based IR Cloud Heights**
- **Satellite-Based Tropical Overshooting Tops**
- **Ground-based Lightning Network Data**



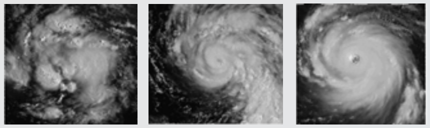


Diagnostic Tool #1: ABI Cloud Height Algorithm (ACHA)

- Being developed for the GOES-R Advanced Baseline Imager (ABI) by NESDIS.
- Employs the 11, 12 and 13.3 μm (Meteosat) or 6.7, 11 and 13.3 μm (GOES) LW-IR bands, and a radiative transfer model to estimate cloud heights and properties. Can operate night and day.



Identify cloud-top brightness temperature, cloud emissivity, and optical depth information for each satellite pixel.



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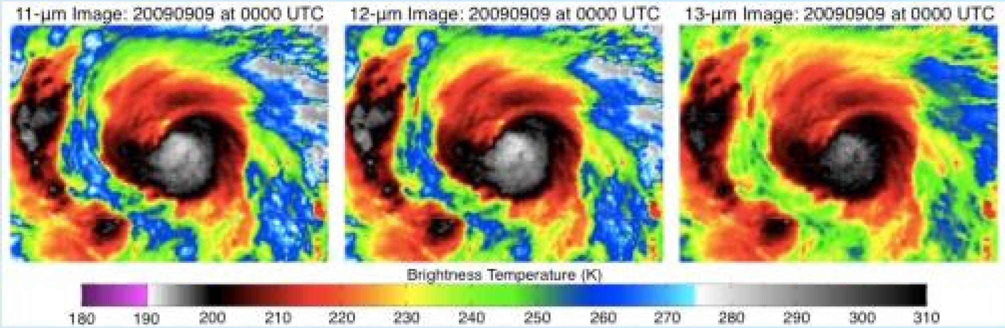
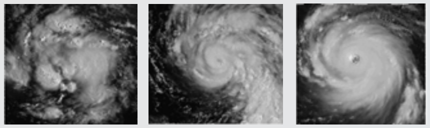


Identify cloud-top brightness temperature, cloud emissivity, and optical depth information for each satellite pixel.

↓

Calculate the cloud-top temperature from the above variables.

Cloud-top Temperature = …



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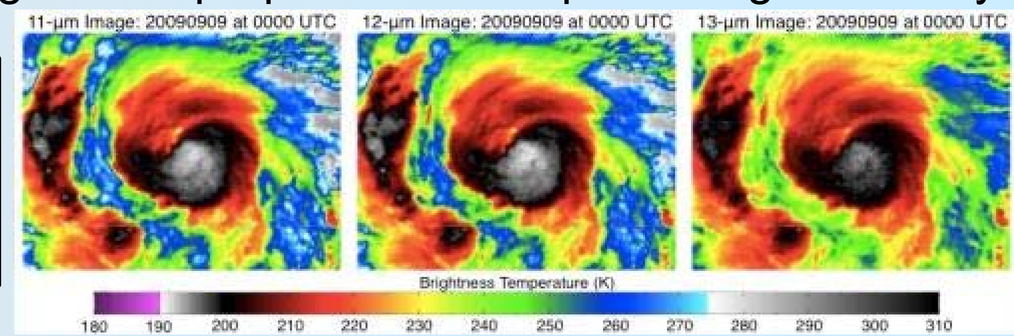

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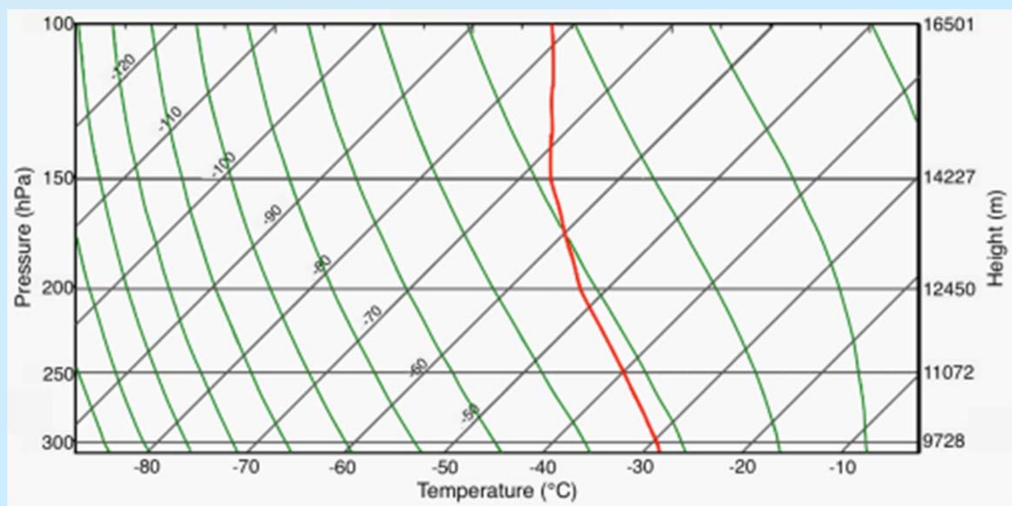
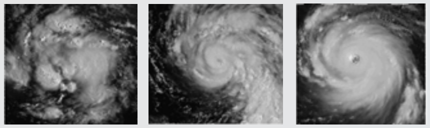
Calculate the cloud-top temperature from the above variables.

Cloud-top Temperature = …

↓

Compare the cloud-top temperature to a collocated temperature profile provided by Numerical Weather Prediction data (e.g. GFS model) to derive estimated cloud-top height and cloud-top pressure.





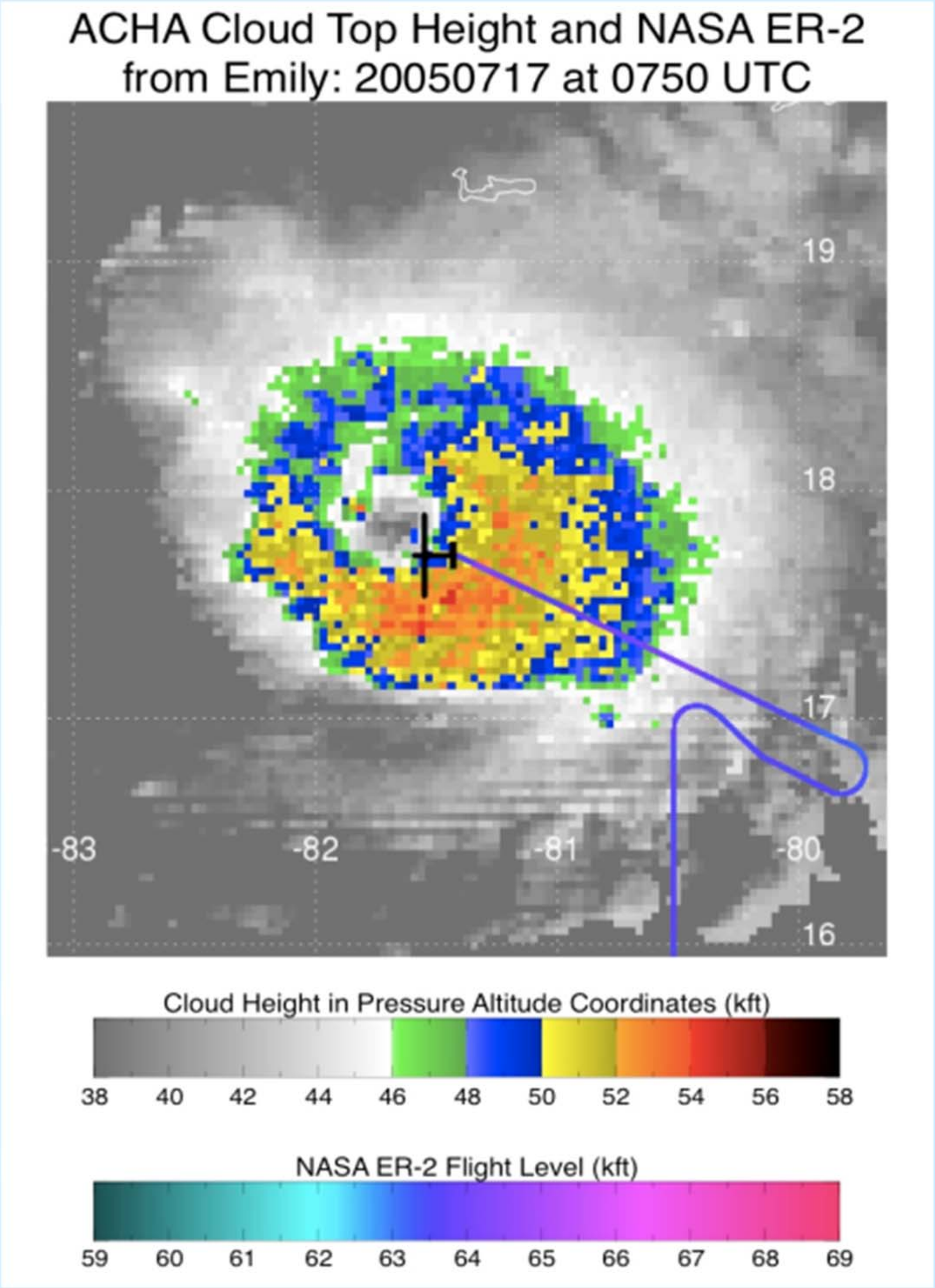
Usefulness of ACHA

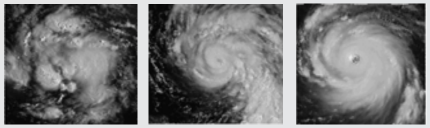
ACHA can effectively estimate the heights of deep convection.

1) Higher/deeper clouds can potentially be associated with stronger TC updrafts.
2) Can use the ACHA cloud top heights to estimate the clearance an aircraft will need during over-flight of TC core.

See Poster P47 for further details

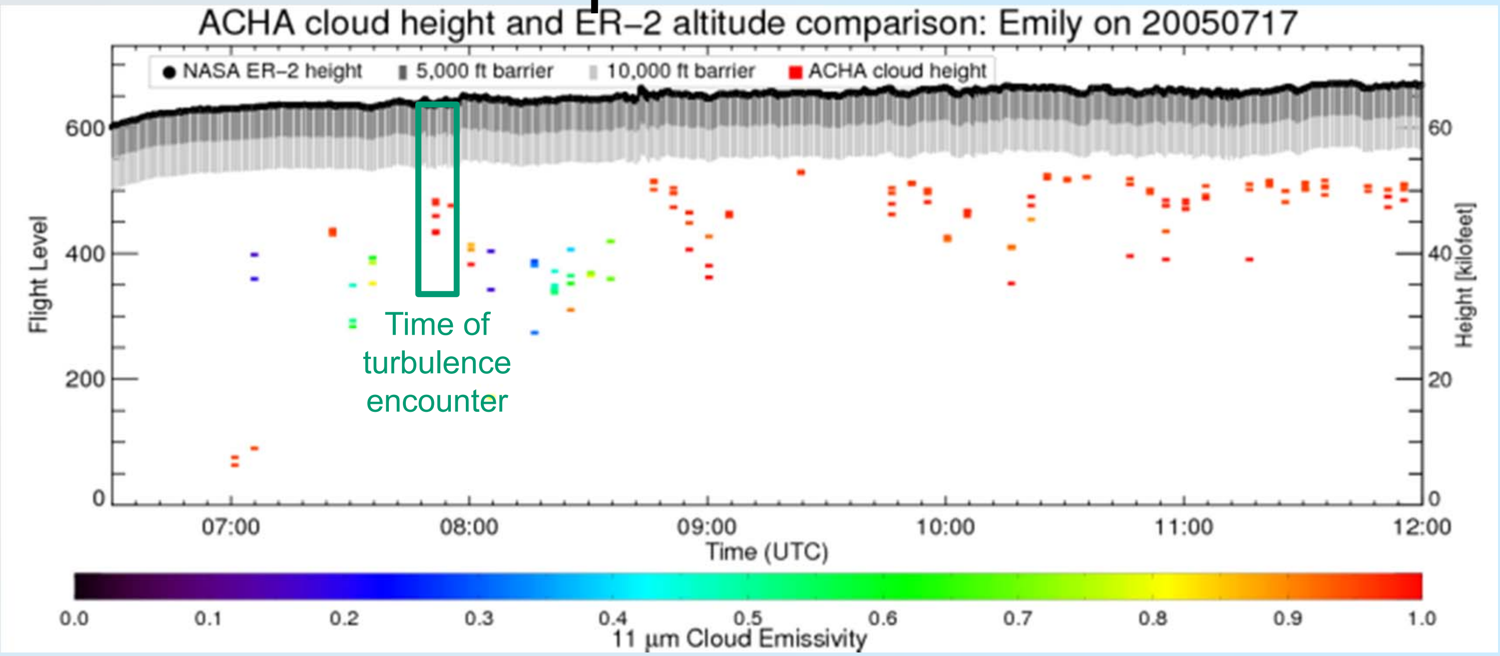
Example to right: NASA ER-2 is about to encounter severe turbulence when flying over a ~23.5 m s^{-1} updraft during TC Emily (2005). This case was the basis for the subsequent Global Hawk flight rules.

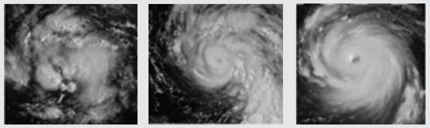




However, enhanced IR, or even ACHA, alone is not sufficient to reliably deduce strong updrafts!

At the time of the ER-2 encounter, with turbulence, it had about 12,000 ft. clearance over the ACHA-estimated cloud top heights.





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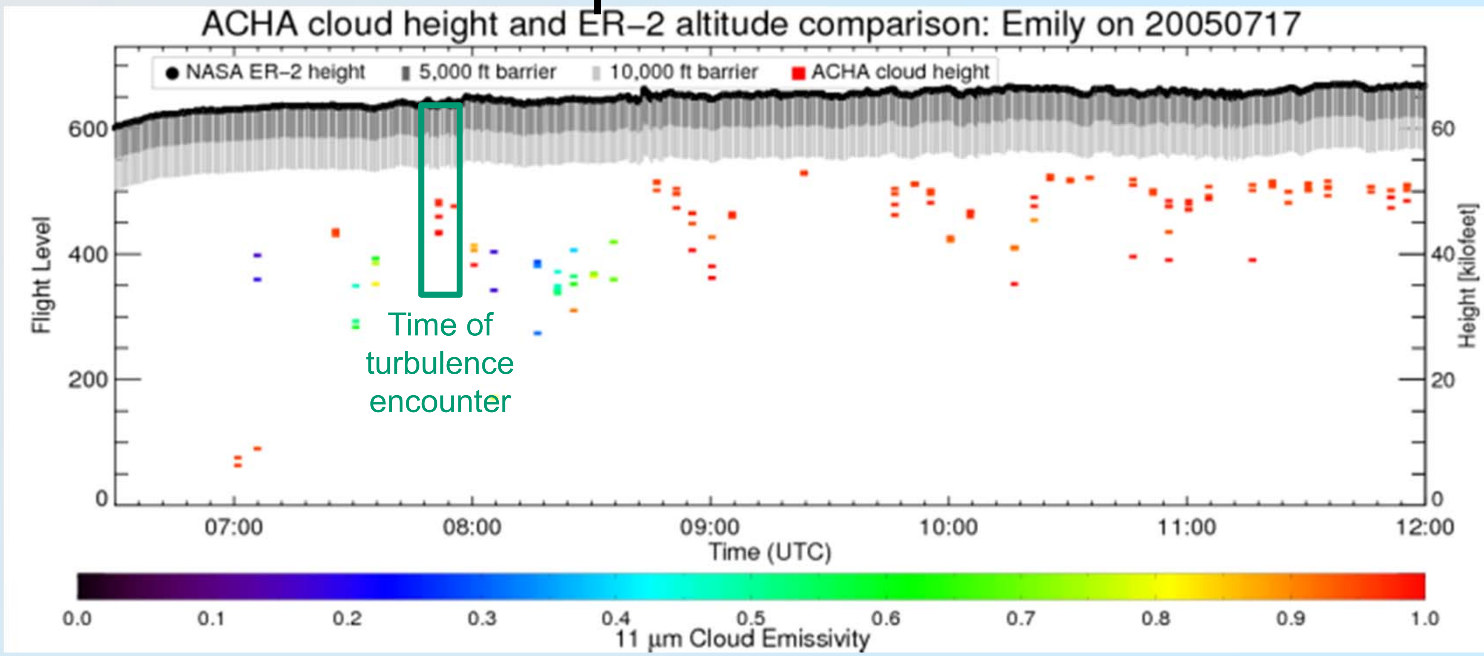
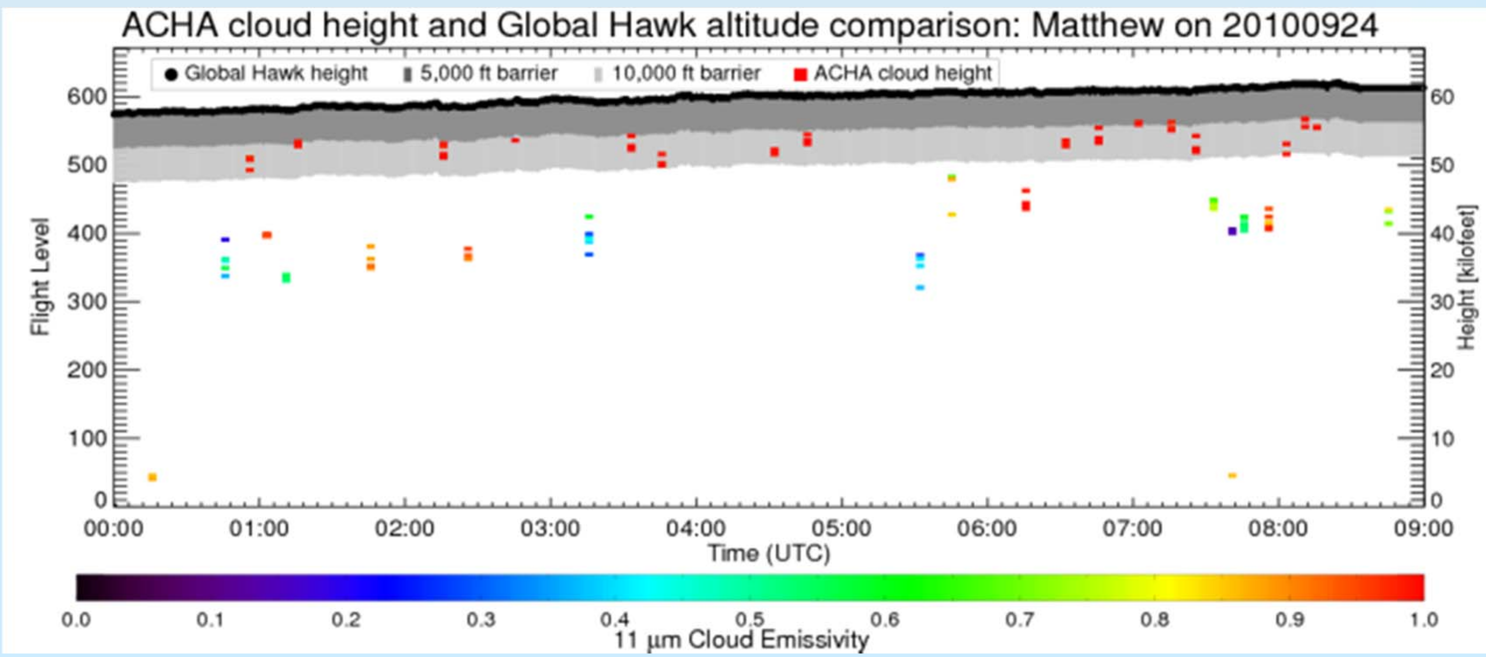
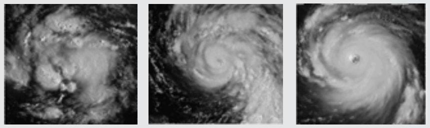




On the other hand, the GH flew closer to higher cloud tops of TC Matthew in 2010, but did not record significant turbulence.



Diagnostic Tool #2: Tropical Overshooting Top (TOT) Detection Algorithm

Employing routinely-available geostationary satellite imagery, find relative minima in the 11 μm (IR) brightness temperature (BT) field colder than 215 K.

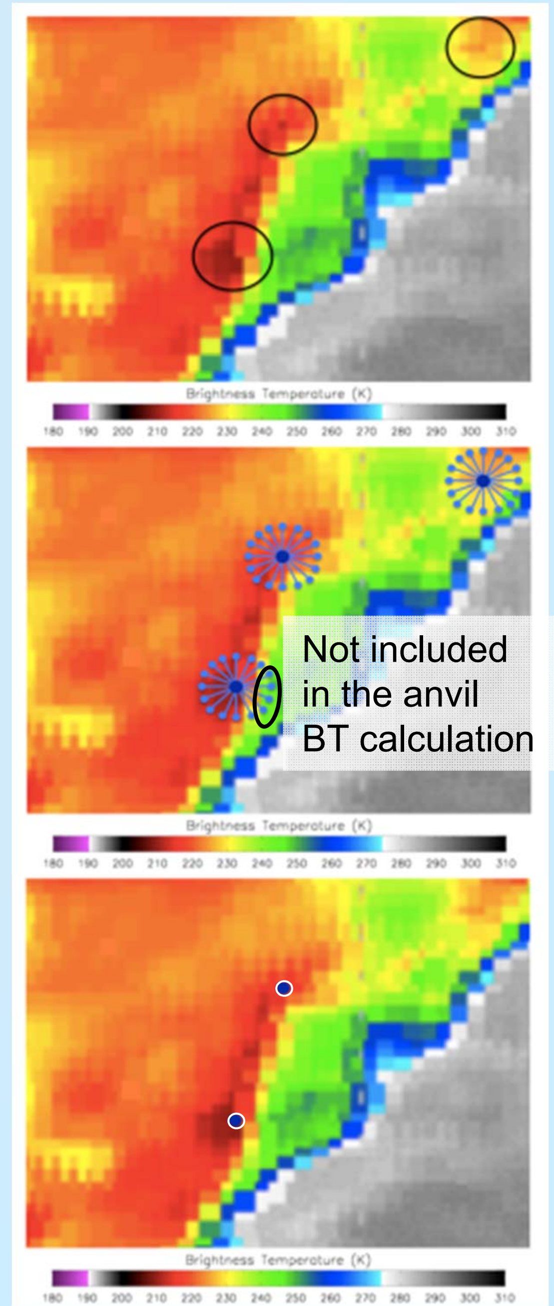
↓

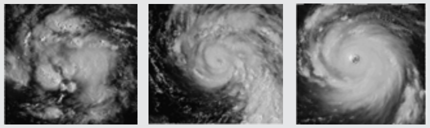
Sample the surrounding anvil at an ~8 km radius in 16 radial directions.
At least 9-of-16 anvil cloud pixels must be colder than 225 K.
Compute the mean BT of these pixels.

↓

Cloud pixel minima at least 9 K colder than the surrounding anvil (BTD ≥ 9) are flagged as a tropical overshooting top (TOT).

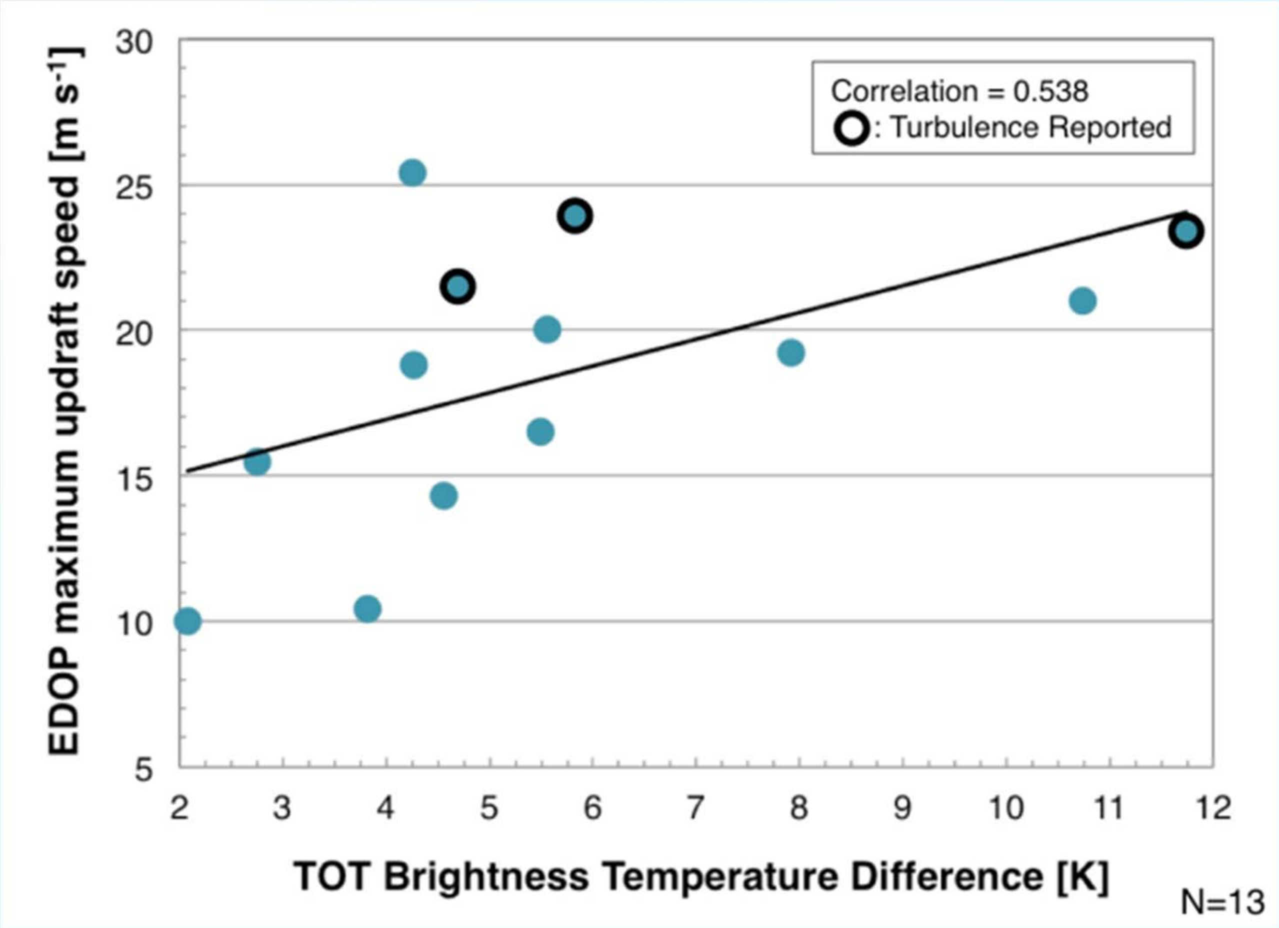
Cloud pixel minima with a BTD ≥ 4.5 K and BTD < 9 K can also be flagged as TOTs.



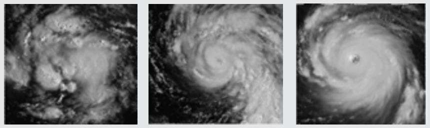


Can TOTs be utilized as a proxy for potential strong updrafts?

Comparison of TOT magnitudes to ER-2 Doppler Radar (EDOP) measured updraft speeds (from Heymsfield et al. (2010)).



A moderate correlation is found, but with observed differences up to 8 m/sec. Also, convective clouds below a cirrus anvil will not be detected.



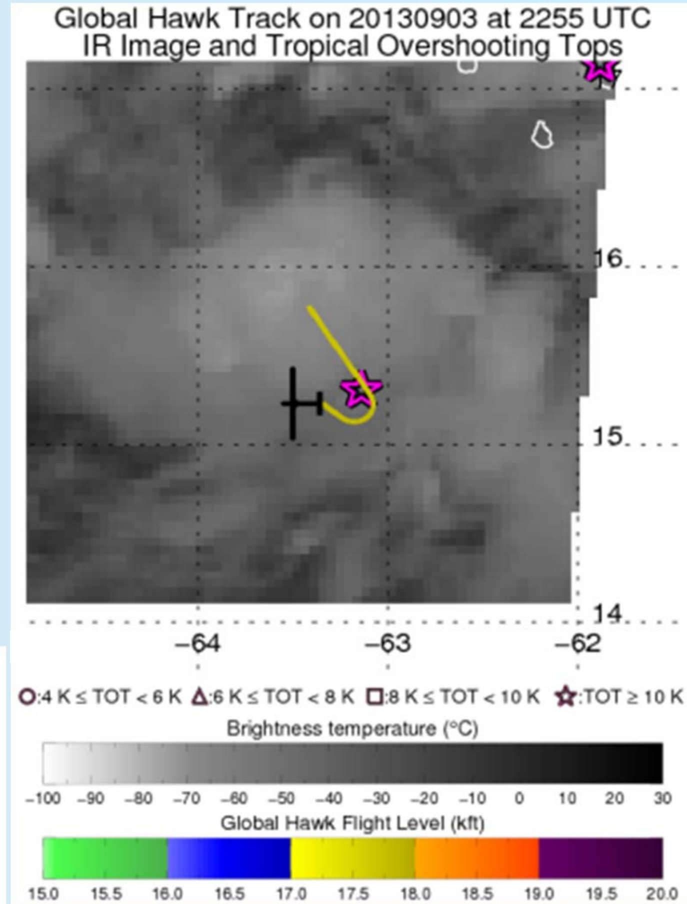
Detection using Microwave Sources?

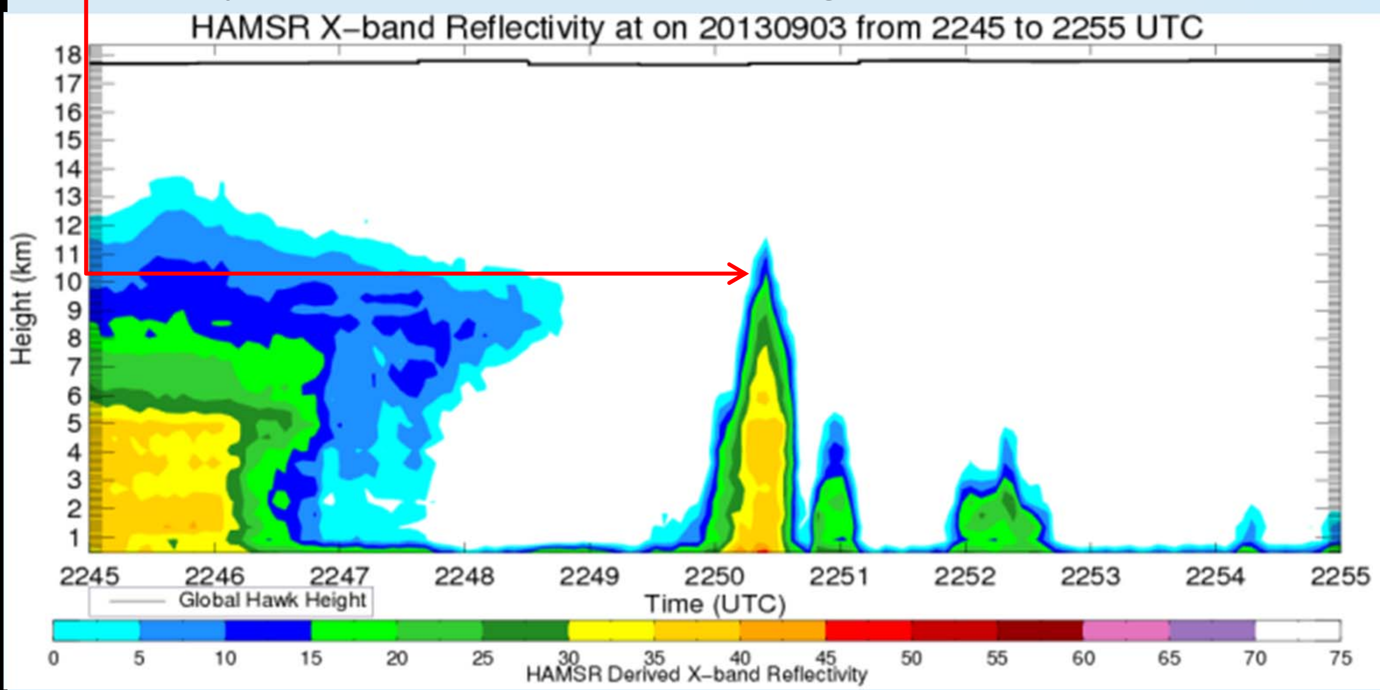
Global Hawk flies right over the top of a developing TOT in pre-TC Gabrielle in 2013 (figure at right).

- TOT appears just after the GH over-flight in the 2255 UTC GOES satellite scan.

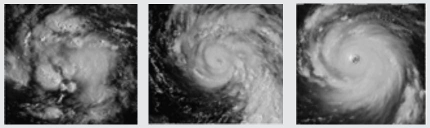
High Altitude MMIC Sounding Radiometer (HAMSR) onboard the GH identifies a narrow band of high reflectivity extending to ~11.5 km at the location of the TOT.

- Likely associated with strong convective updraft.

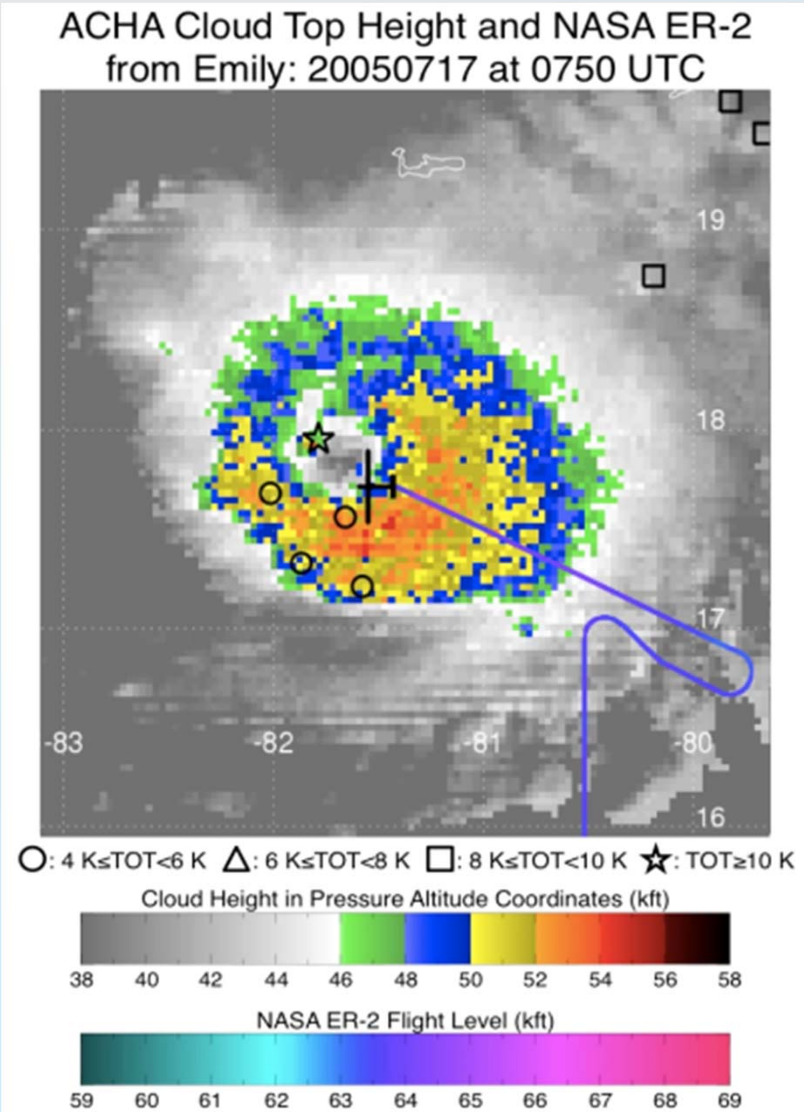




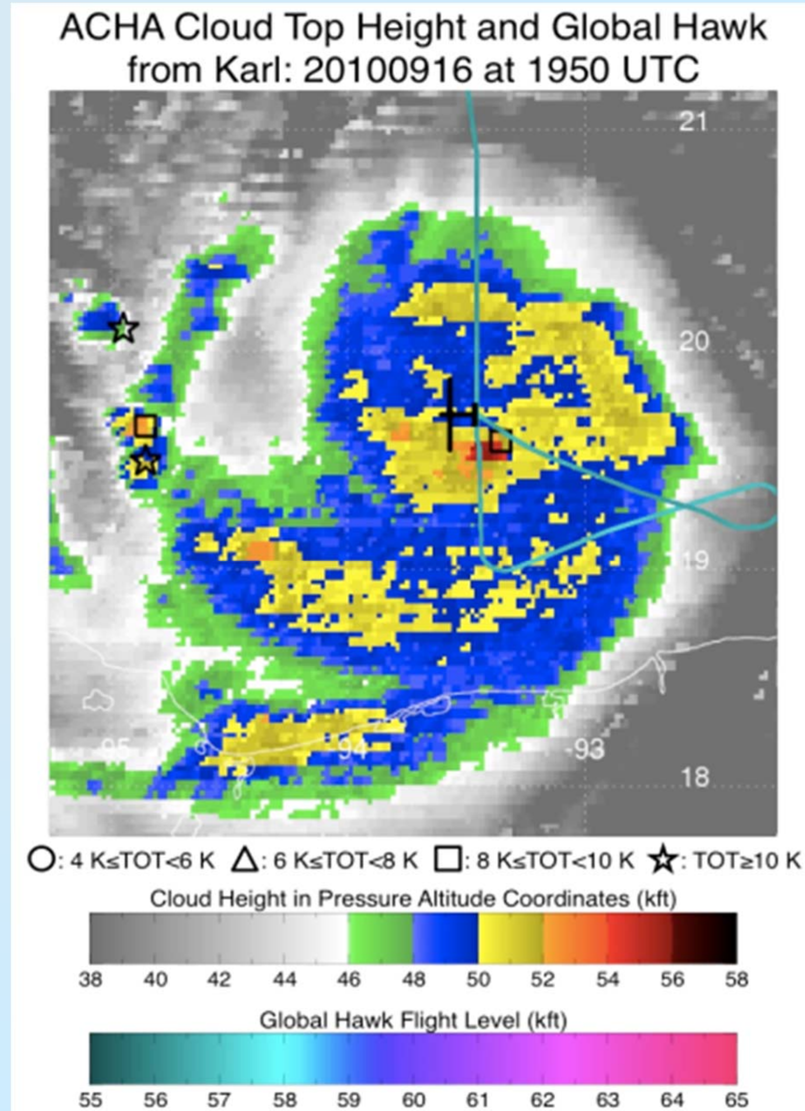
Potential for using satellite microwave observations for cal/val, but data latency would prohibit real time use



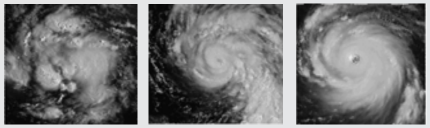
But can TOTs alone distinguish turbulence induced by strong updrafts?



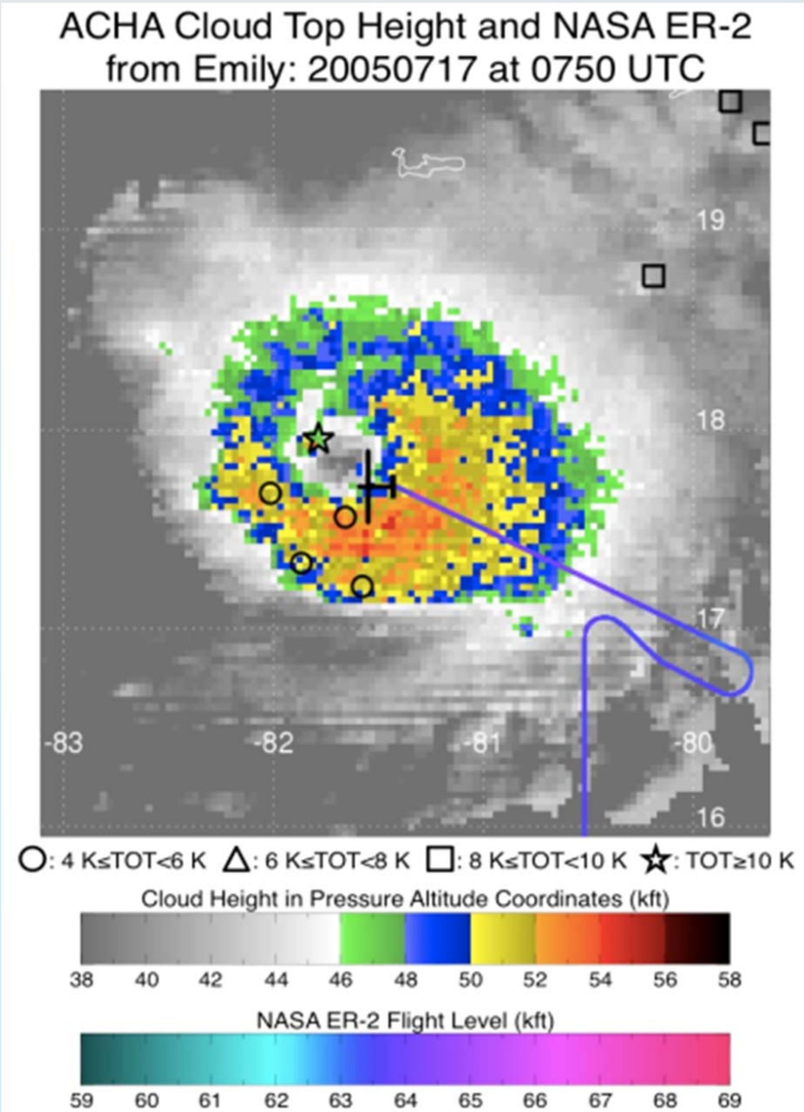
The NASA ER-2 overflies an ~23.5 m s^{-1} updraft and experiences severe turbulence.



The GH overflies an ~21.0 m s^{-1} updraft (based on TOT BTD) and experiences no turbulence.



But can TOTs <u>alone</u> distinguish turbulence induced by strong updrafts? Um, no..



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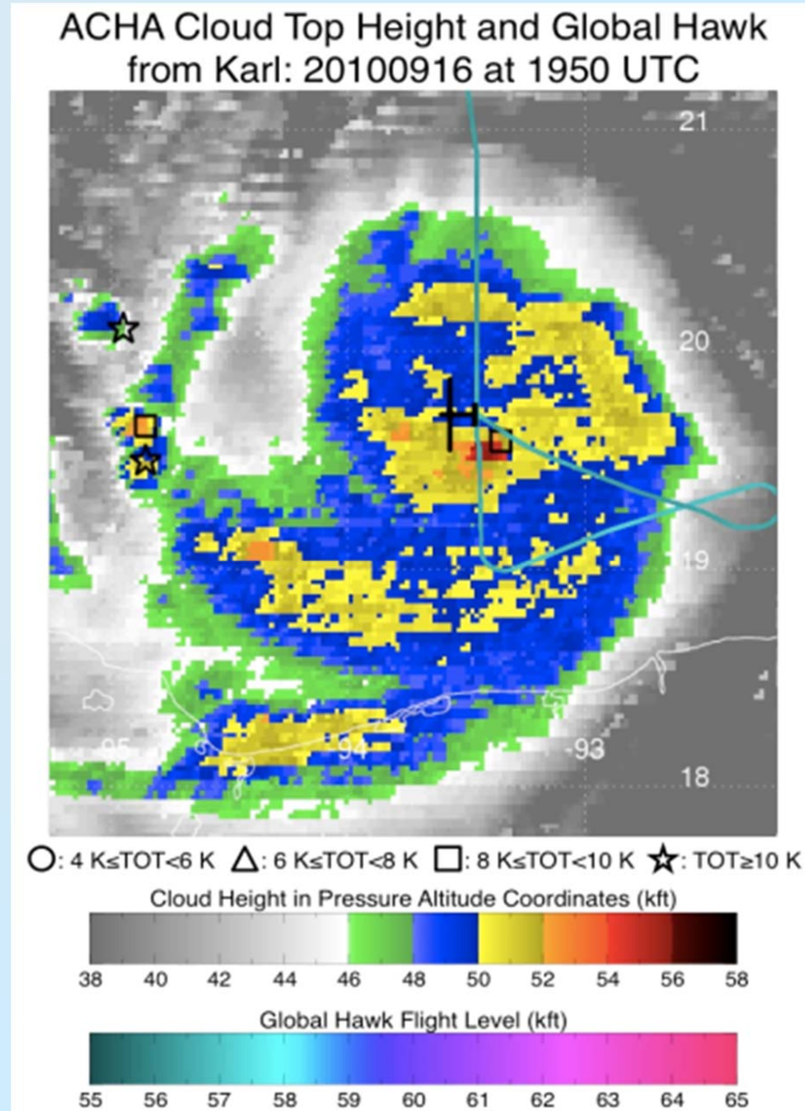

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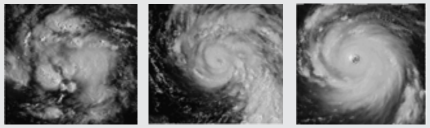
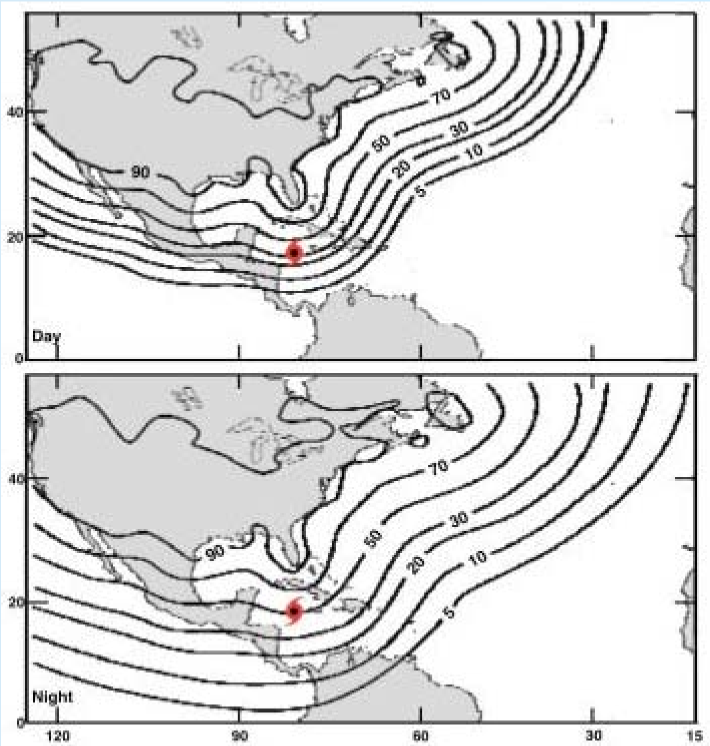


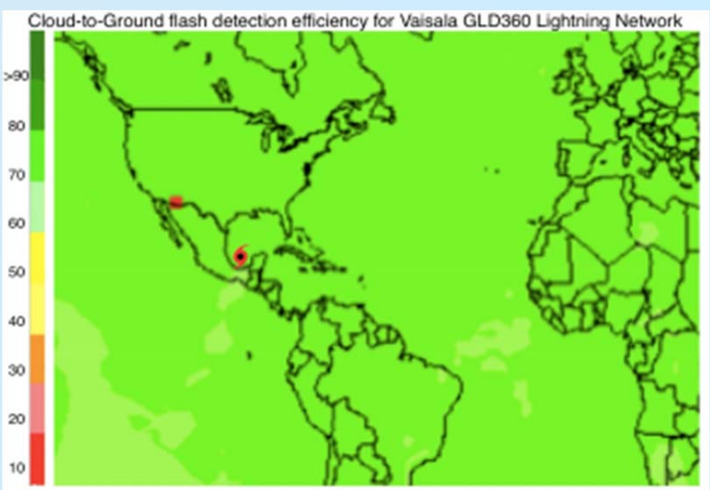
Diagnostic Tool #3: Lightning Data

1) Vaisala VLF long-range detection network (available for TC Emily)
   - 30-50% Detection Efficiency in the region of Emily, depending on day versus night
   - Median flash location accuracy of 8 (10) km for daytime (nighttime)

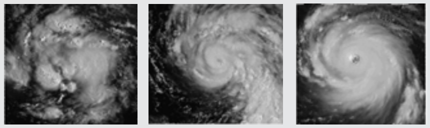


Adapted from Cummins et al. (2008).

2) Vaisala GLD360 (used for TC Karl)
   - ~70% Cloud-to-Ground Flash Detection. Efficiency in the region of Karl
   - Median flash location accuracy between 5 and 10 km



From *Vaisala Global Lightning Dataset* (2009)



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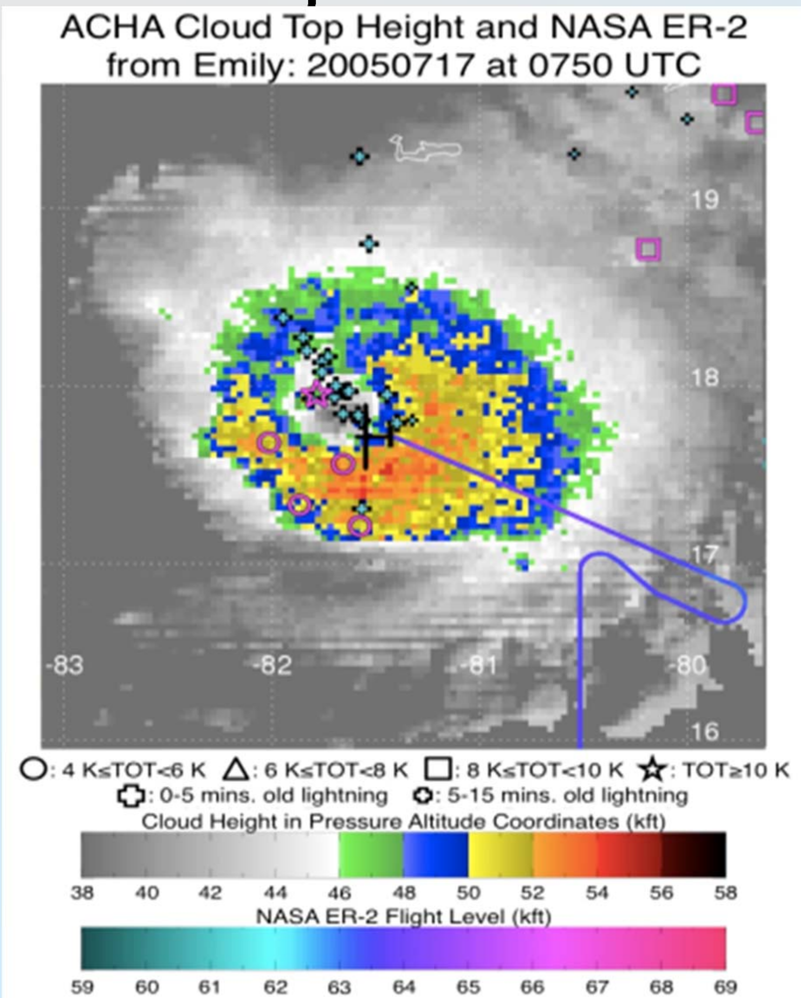
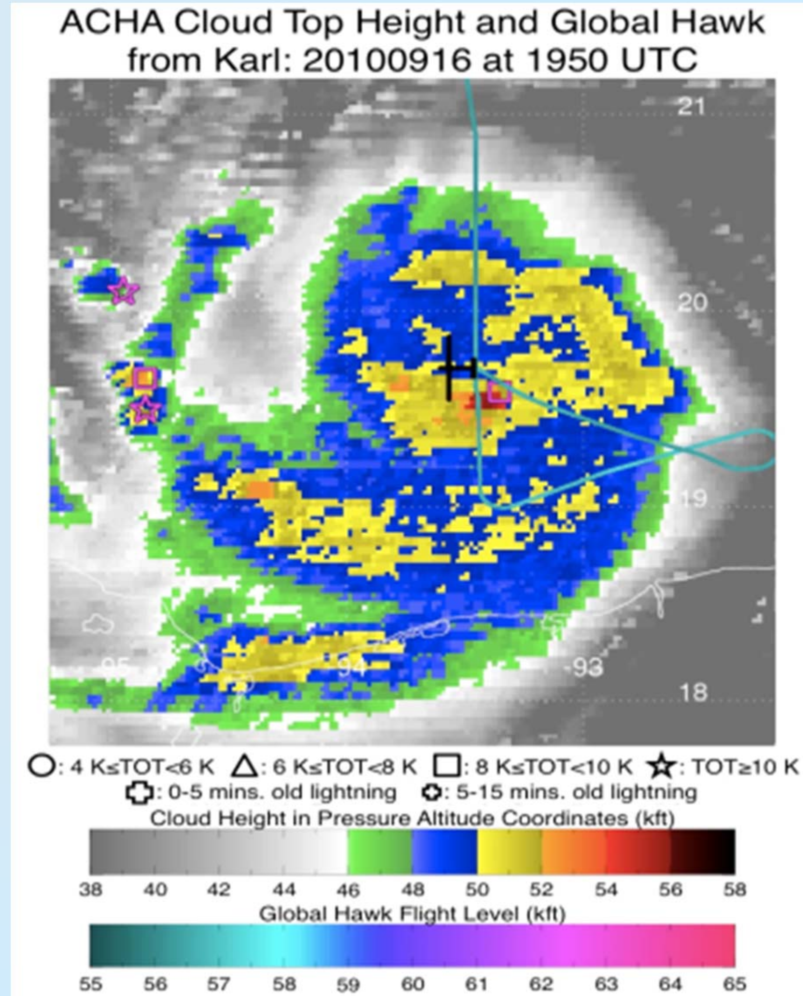
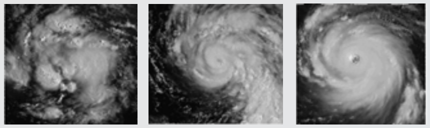




Multiple lightning strikes associated with the turbulence-causing TOT in TC Emily, despite the lower detection efficiency (Also noted by Cecil et al. (2010)).

No observed lightning strikes are associated with the non-turbulence-causing TOT in TC Karl, even with the relatively higher detection efficiency.

But can lightning alone deduce local turbulence?



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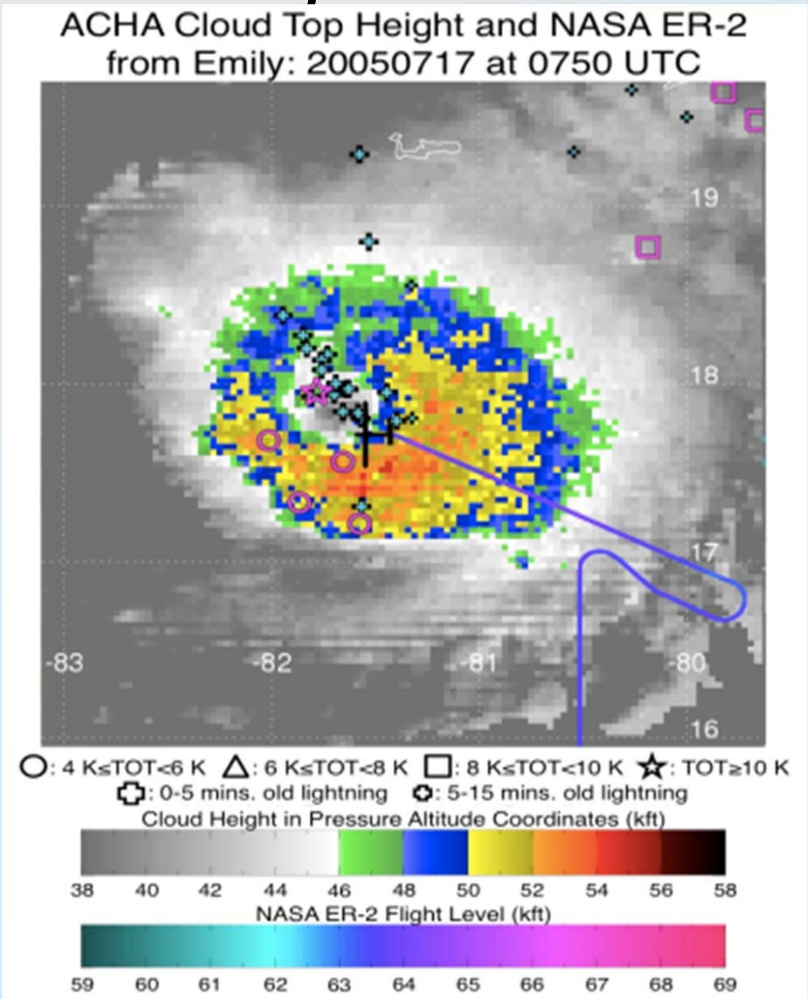

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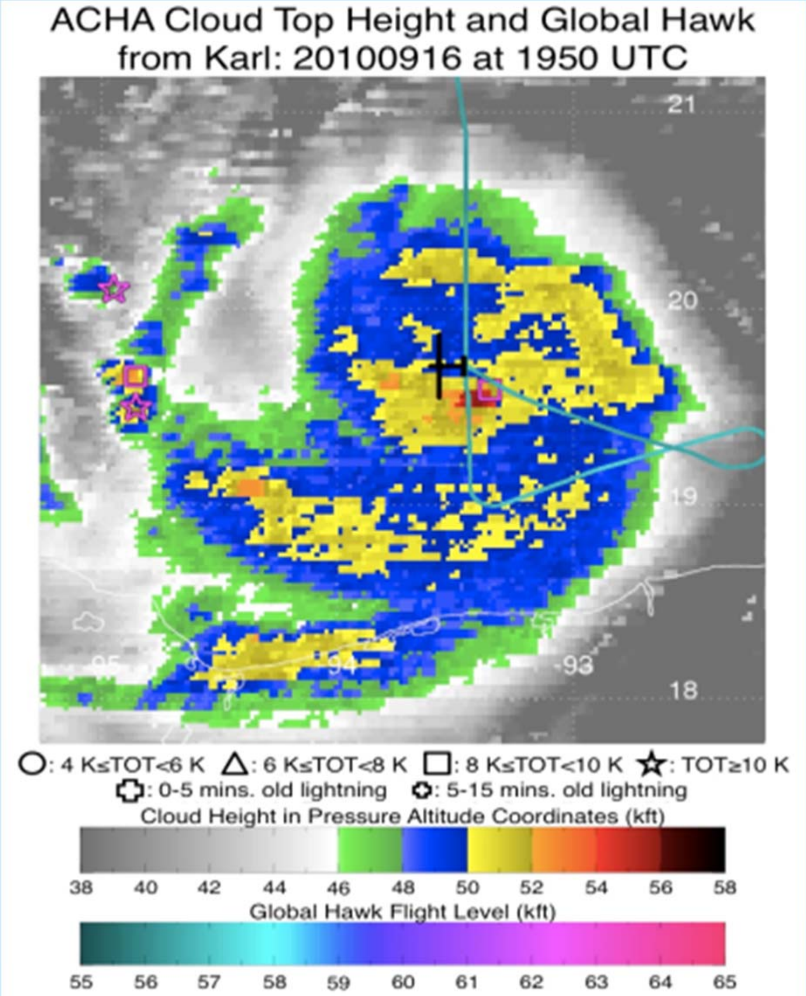
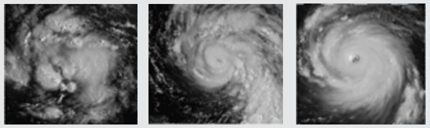


No observed lightning strikes are associated with the non-turbulence-causing TOT in TC Karl, even with the relatively higher detection efficiency.

But can lightning alone deduce local turbulence? No, again…

- Current oceanic lightning detection is sub-optimal, but…
- GOES-R (launch in 2016) will have a lightning mapper



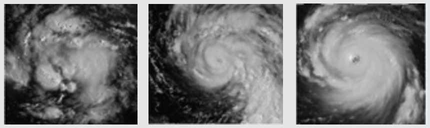
Conclusions

Using a **combination** of satellite-based image analysis tools and lightning data, we are able to identify convective signatures of locally strong updrafts in TCs which could potentially lead to turbulence:

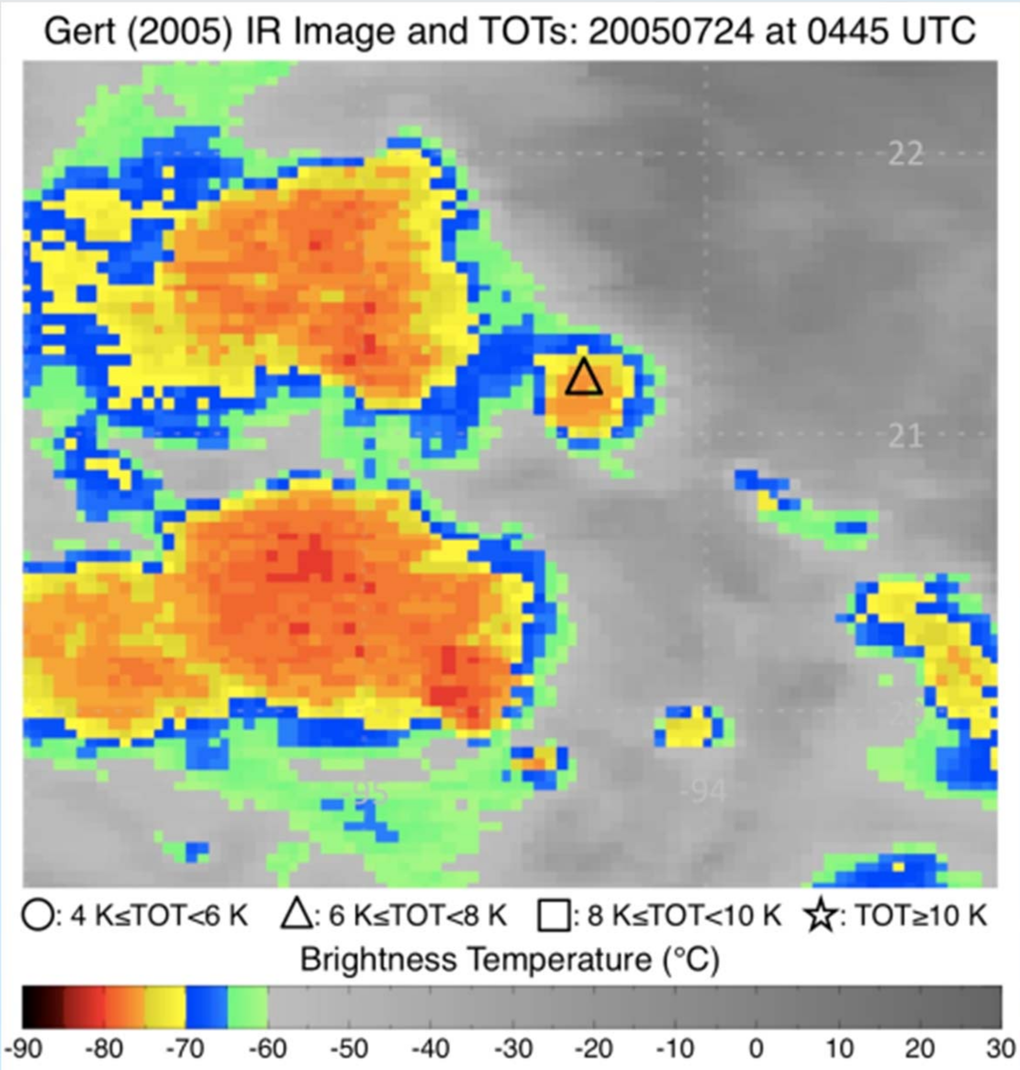
- ABI Cloud Height Algorithm (ACHA) can reliably estimate the heights of the deep/cold convective clouds.
- Tropical Overshooting Top (TOT) magnitude can be a proxy for associated strong updraft potential.
- Lightning frequency can further distinguish potential turbulence-causing updrafts.

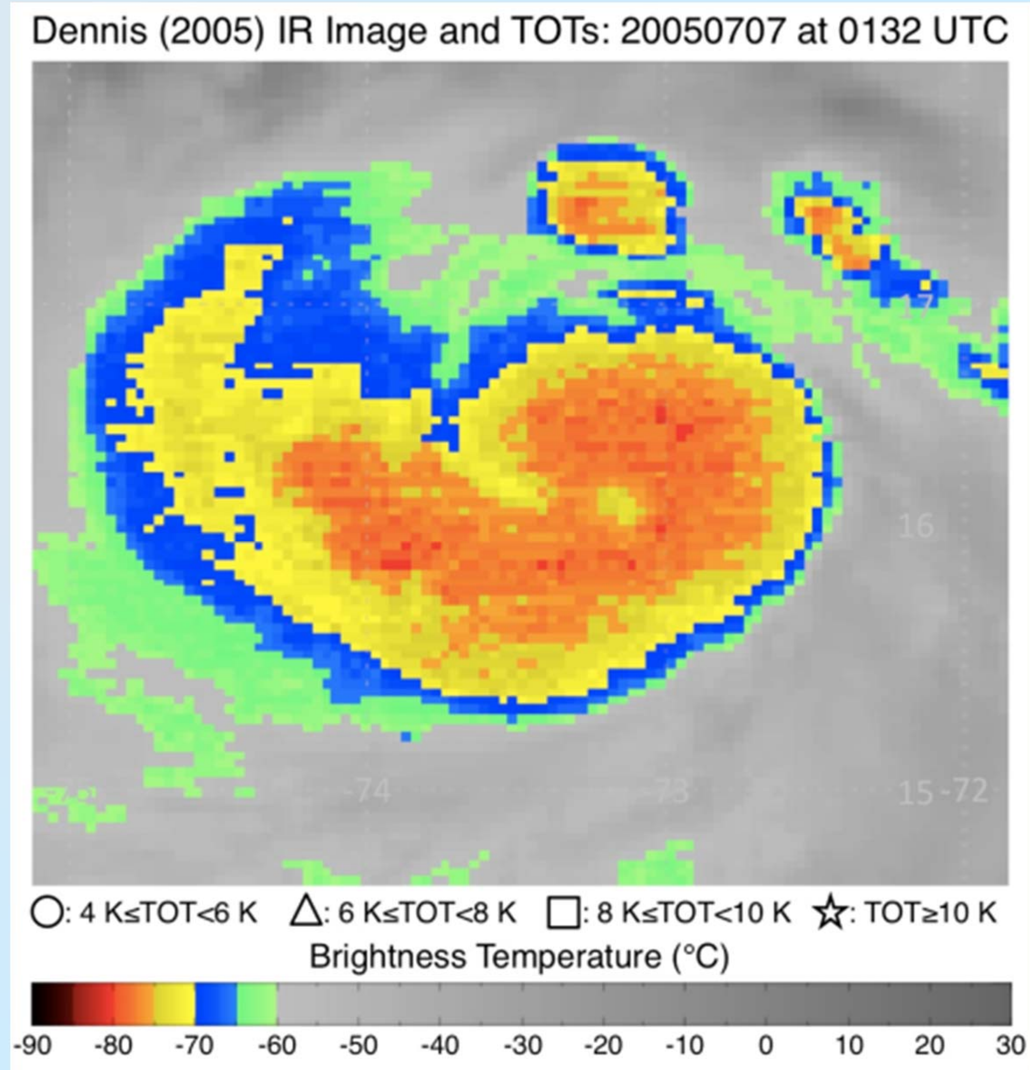
Result: New Global Hawk over-flight rules:

- Regions of cold cloud tops that have not exhibited the aforementioned indicators of intense convection are acceptable for over-flights within 5000 ft. of cloud tops.
- Convective regions with indicators of persistent lightning and/or strong TOTs should be avoided at all times (fly around).



Questions?





Gert (left) had the strongest ER-2 Doppler Radar identified updraft.