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Total Lightning in a Multi-Sensor Approach to the Detection and Forecasting of Convectively Induced Turbulence (CIT)

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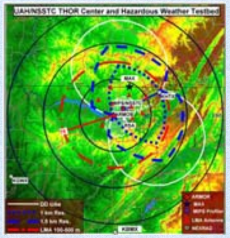
Goals and Approach

Objective: Investigate the potential for GOES-R multi-sensor detection and short-term forecasting of turbulence and other aviation hazards associated with rapidly growing and mature convective cells.

Approach: Utilize Advanced Baseline Imager (ABI) proxy cloud top cooling and overshooting top (OT) detection and Geostationary Lightning Mapper (GLM) proxy total lightning flash rates for diagnosis of storm intensity and growth rate

NASA MSFC Northern Alabama LMA (NA-LMA) sensors, Hytop (KHTX) Weather Surveillance Radar – 1988 Doppler (WSR-88D) and UAHuntsville radars



- GLM proxy total lightning data are obtained from the VHF-based Lightning Mapping Arrays (LMAs) over Alabama (see Figure to right for network diagram), Florida, Oklahoma and Washington DC
- Cloud top cooling and overshooting top detection are obtained from Geostationary Operational Environmental Satellite (GOES) observations over the LMA operational domains (< 150 km from LMA center)
- Turbulence occurrence is determined objectively using eddy dissipation rate (EDR) data from the NCAR turbulence algorithm applied to commercial aircraft navigation data over the LMA domains

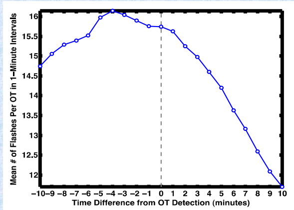
Co-Evolution of NA-LMA Total Lightning and GOES Overshooting Cloud Top Detections

- An overshooting cloud top (OT) implies the presence of an updraft of sufficient strength to penetrate through the equilibrium level and into the lower stratosphere
- Given the presence of a strong updraft within the OT region, one would expect there to be some correlation between lightning flash rate and OT detections, but this relationship has never been rigorously quantified

Lightning Trends Near OT Detections

- The number of Northern Alabama Lightning Mapping Array (NA-LMA) flash detections within 15 km and +/- 10 mins of GOES-12/13 OT detections have been analyzed at 1 min intervals for 1606 OT events occurring across 37 days. Each day featured 40+ OT detections within 100 km of Huntsville, AL
  - *For an OT to be detected within GOES IR imagery, the height difference between the OT and surrounding anvil must be > 1 km (> 6 K, Bedka et al. (JAMC, 2010))*
  - *All GOES imagery (RSO + operational scans) from these 37 days were processed within the GOES-R OT detection algorithm. The exact time a given GOES pixel was scanned (i.e. not the nominal image timestamp) is used as the center of the 20 min time window. Parallax correction was done using a constant 14 km height*
- The results show that the maximum flash rate most often occurs shortly before the time of OT detection. Lightning flashes peak 0-4 minutes before OT detection due to accelerating convective updrafts that later produce a detectable OT signature in GOES IR imagery

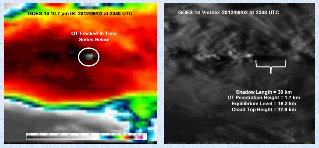
Mean Number Of NA-LMA Flashes Per OT At 1-Minute Intervals Before, During, and After 1606 GOES-12/13 OT Detections

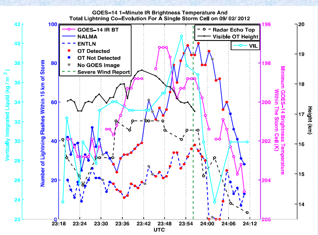


OT – Lightning Co-Evolution Within 1-Minute GOES-14 SRSO Data

- Total lightning flash detections from NA-LMA and Earth Networks Total Lightning Network (ENTLN) were monitored at 1-min intervals within 15 km of the center of an OT-producing storm cell south of Huntsville, AL. OTs were detected by the GOES-R algorithm for 30 consecutive GOES scans, though an OT was evident in visible imagery prior to 2333 UTC. The length of the OT-induced shadow in visible imagery was used to compute OT penetration height, which was added to the equilibrium level (16.2 km) to derive a cloud top height. Radar VIL and enhanced echo top height were analyzed from the Huntsville and Birmingham, AL WSR-88D.

Analysis of GOES OT Detection, IR Temperature, and NA-LMA Flash Co-Evolution Using GOES-14 1-Minute Super Rapid Scan Data





GENERAL FINDINGS

1) Lightning activity began to increase in association with IR cloud top cooling and an increase in echo top height. The NA-LMA and ENLTN lightning time trends follow each other quite well though there is a significant difference in flash counts between the two detection systems.

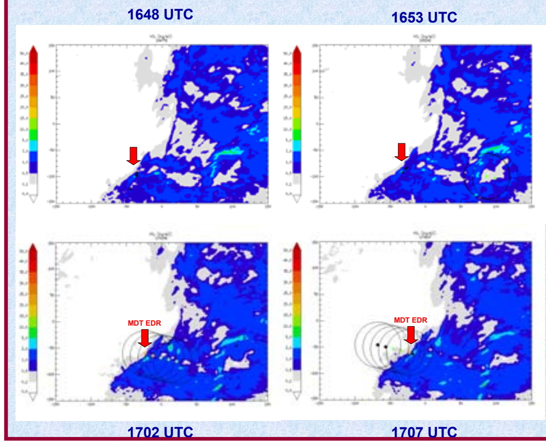
2) Echo top and visible-shadow based cloud top heights are well correlated.

3) Lightning maximized near time of a severe wind report at 2356 UTC. The minimum IR BT (maximum VIL) preceded the maximum flash rate by ~7 (3) minutes, though a secondary maximum in echo top and IR BT occurred at time of severe wind.

4) Rapid increase and maximum in VIL is physically correlated to subsequent increase and peak in flash rate due to non-inductive charging and strong downdraft and surface severe wind due to precipitation loading and melting in collapsing cell.

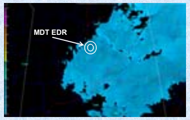
5) The times when OTs were first detected corresponded with the beginning of a significant increase in lightning activity and VIL. Although detection of continuous OTs for extended period did not clearly indicate a particular time of significant weather, the combined presence of continuous OTs, high/increasing VIL and high/increasing flash rate may be indicative of impending high impact weather and may improve the forecaster's situational awareness.

Case Study of Moderate Turbulence: January 24, 2010

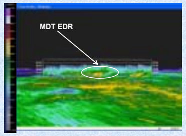


Horizontal maps of the KHTX vertically integrated liquid (VIL, kg m^{-2}, color shaded as shown). Distance in km relative to the center of the NA-LMA network. Each individual NA-LMA flash origin location is shown by a small "+" symbol. The NCAR EDR turbulence values are shown at the aircraft location by a diamond symbol (black: no turbulence; green: light; yellow-orange: moderate; red: severe). EDR reports are plotted 2 minutes before and 3 minutes after the radar time. A 20 mile (32.2 km) range ring around the aircraft location is shown to highlight storms in the vicinity.

- As seen in KHTX VIL (*left*), storm tops (*below left*) and vertical reflectivity structure (*below right*), relatively weak convection over the Tennessee Valley
- Little-to-no lightning across domain consistent with low VIL but some cells are notable for very low flash rate (< 1 min^{-1})
- Flight arrives in area at 1653 UTC and is moving from southeast to northwest
- Although VIL is weak, cell in path of flight (red arrow) is one of three cells producing lightning prior to its passage (*left*)
- Moderate EDR reported as aircraft flies over (or very nearby) lightning producing cell (1703-1707 UTC) (*left*)
- NA-LMA data indicate the cell is charged and may be stronger than what is obvious from radar alone (e.g., VIL, vertical reflectivity structure)
- Cell in question is 1 of 3 in NA-LMA domain producing any lightning just prior and during moderate EDR reports (thunderstorms easily avoidable with NA-LMA/GLM proxy)



KHTX radar echo tops

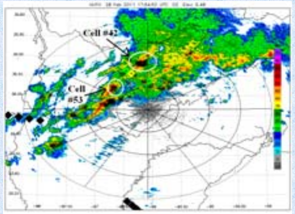


Vertical cross-section of KHTX reflectivity (dBZ)

Echo tops below 25,000-30,000 feet in vicinity of EDR/CIT.

Cell intensity just sufficient for marginal lightning production. But GLM proxy clearly shows cell is a thunderstorm (i.e., CIT threat) 25 minutes before arrival of flight that experienced MDT CIT.

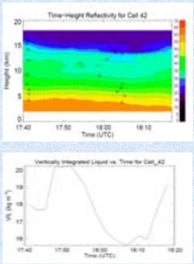
WDSS-II Tracked Moderate Turbulence Case Study: February 28, 2011



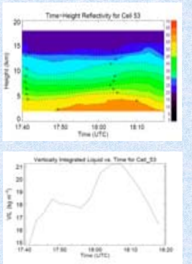
Lowest elevation angle scan from KHTX (Hytop, AL) at 17:54 UTC showing moderate turbulence EDR (yellow diamond) as flight tries to go between two robust lightning producing cells. These cells were tracked in WDSS-II to ascertain convective properties. NALMA flash origin points from +/- 3 minutes of scan time are shown as black asterisks.

We utilized the WDSS-II w2segmotion algorithm to track reflectivity at 5 kilometers (-10 C) for this case. Cells were tracked from ~17:40-18:20 UTC. We then used storm centroid data to interrogate two cells: cell #53 (south of aircraft track) and cell #42 (north of aircraft track) near the time of the MDT turbulence (17:50 UTC)

Cell # 42 (Time-Height) Reflectivity and VIL Plots



Cell # 53 (Time-Height) Reflectivity and VIL Plots

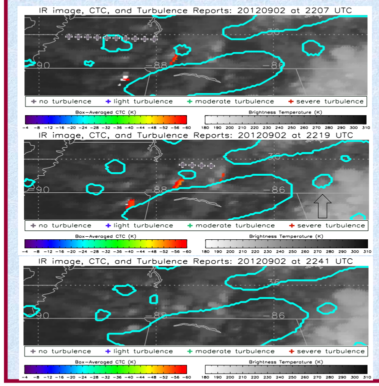


Presence of lightning in small cells under the flight path suggests these cells are a greater turbulence threat than radar alone would indicate and should thus be avoided by aircraft.

Cell #42 shows a relatively steady-state vertical reflectivity structure with a trend towards decreased intensity after 18 UTC. A distinct increase in VIL is apparent right around the time of the MDT turbulence suggesting that cell #42 may be responsible for the MDT report.

Cell #53 is increasing in strength at the time of the MDT turbulence report with a peak in both vertical reflectivity and VIL between 18:00 and 18:10 UTC.

Using Object Tracking to Identify Cloud Properties Associated with Turbulence

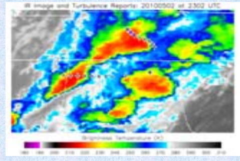


We can use the Warning Decision Support System -- Integrated Information (WDSS-II) to objectively track clouds that have the potential of CIT. An example of this tracking from Sept 2 is shown at left.

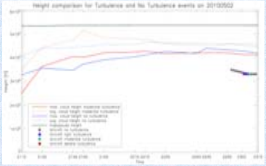
Cloud Top Cooling (CTC) can be detected in growing object (arrow in middle image). A rapidly developing updraft associated with CTC is a potential cause of CIT. For more information on CTC and CIT, see poster P.265.

Example with manual object tracking: May 2, 2010

Using WDSS-II, manually tracked the 2 cells through which aircraft flew through to identify potential cloud properties that caused turbulence.



Example of display to identify cloud properties potentially associated with aircraft turbulence.



Both aircraft flew into the storm system, as evident by the cloud heights being higher than the flight height. Neither cloud cluster appears to be growing from IR.