Aviation Turbulence Nowcasting

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Nowcasting Turbulence Approach for Aviation

- Tactical guidance of turbulence hazards for aviation
- Challenge: Turbulence rare event and not well measured
- Turbulence nowcasting
  - Make use of short term numerical model analysis or forecasts
  - Make use of available observations of turbulence and derived turbulence estimates

Turbulence Observations

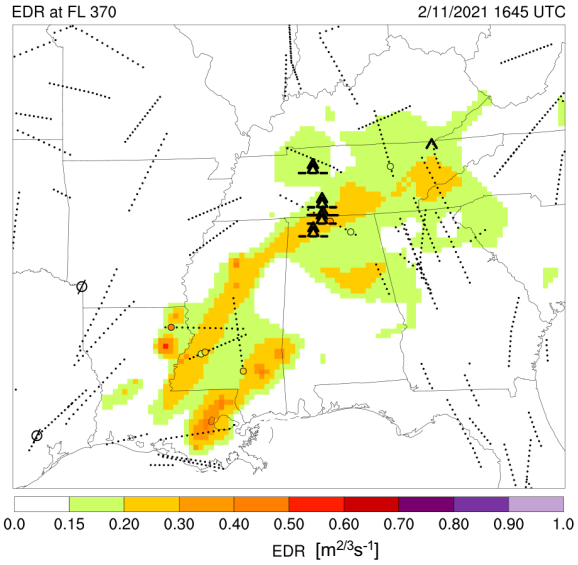
Airborne Turbulence Observations

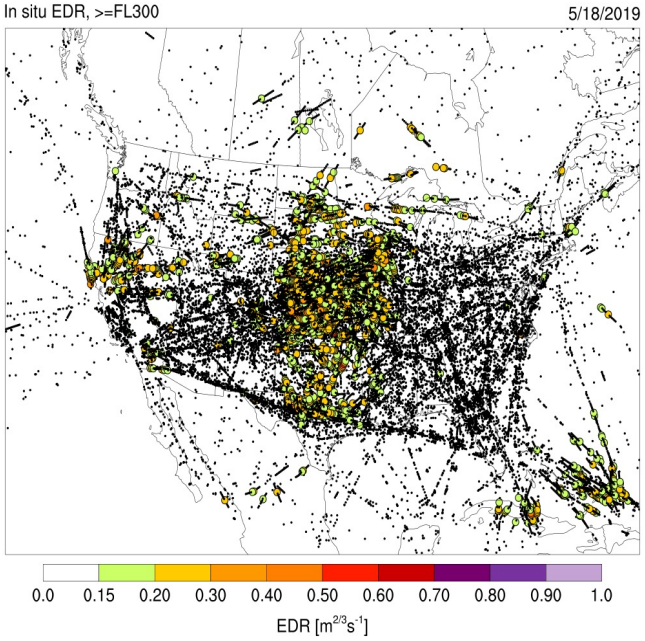
Pilot Reports of Turbulence (PIREPs):

- Subjective, aircraft-dependent Pilot's assessment of the level of turbulence, null to extreme
- PIREP intensity converted to EDR using a parabolic equation based on the type of reporting aircraft

In situ EDR reports:

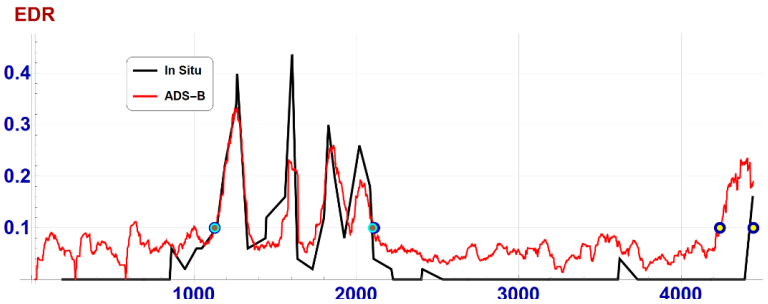
- Automated, aircraft independent measure of turbulence
- Available now on Boeing and Airbus aircraft
- Algorithm calculates peak and mean EDR every minute of flight (0-1 scale)
- Reports include time and position information of aircraft from onboard avionics
- Include much more precise time and position information than PIREPs.





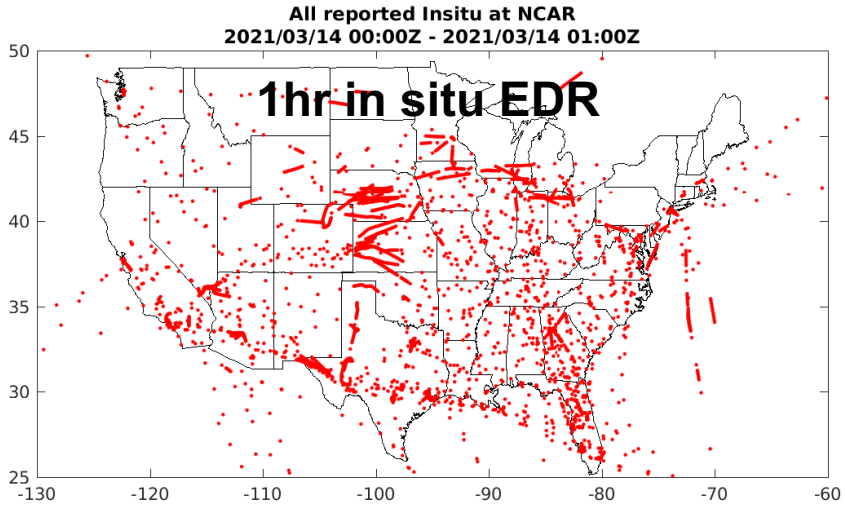
Airborne Turbulence Observations

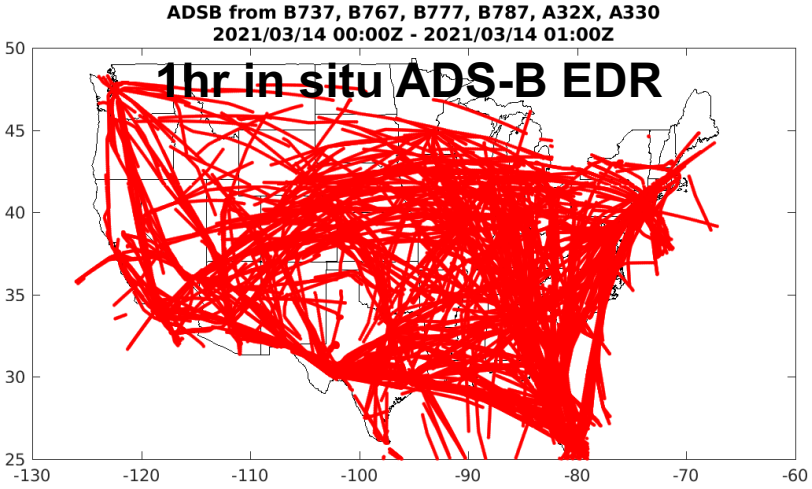
- ADS-B (Automatic Dependent Surveillance- Broadcast
  - Must convert to EDR
  - Challenging due to low sampling rate (~1Hz) and data quantization (e.g. ~0.3 m/s vertical rate)
  - High density ~150,000 as of June 2022
  - No downlink costs
  - Current research area at NCAR (L. Cornman PI)



Sample insitu-ADSB comparison
Courtesy L. Cornman
UCAR Confidential and Proprietary

ADS-B coverage

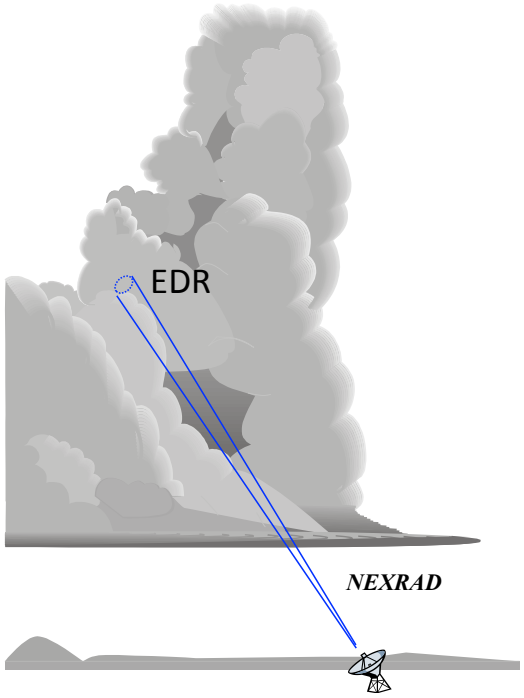


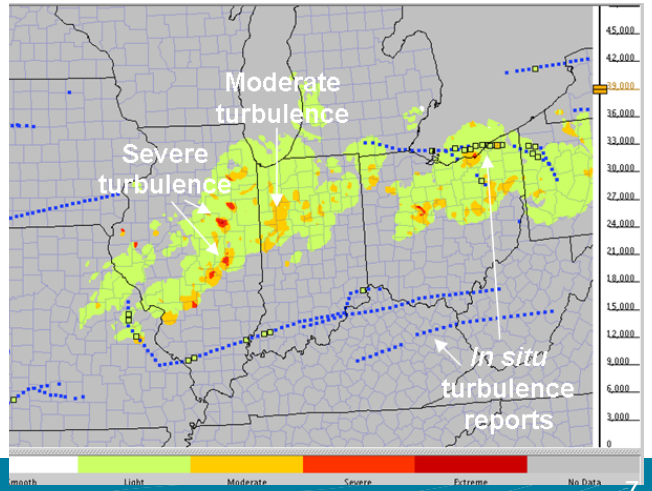


Turbulence Inside Clouds and Precipitation

NEXRAD/NCAR Turbulence Detection Algorithm (NTDA)

- Compute turbulence measure “Eddy dissipation rate (EDR, $m^{2/3}\ s^{-1}$)” from radar spectrum width
- NEXRAD/NCAR Turbulence Detection Algorithm (NTDA, Williams and Meymaris, 2016)
  - Uses radar spectrum width from ~140 radars in US
  - Includes spectrum width measurement quality assessment (SNR, clutter/RFI contamination etc.) and range dependent scaling function for EDR estimate
  - Merges radar data to produce 3D grids of EDR and “confidence” every 5 min
  - Grids: 2 km horizontal x 3,000 ft vertical resolution
  - Verified with in-situ EDR aircraft data from research and commercial aircraft & Pireps



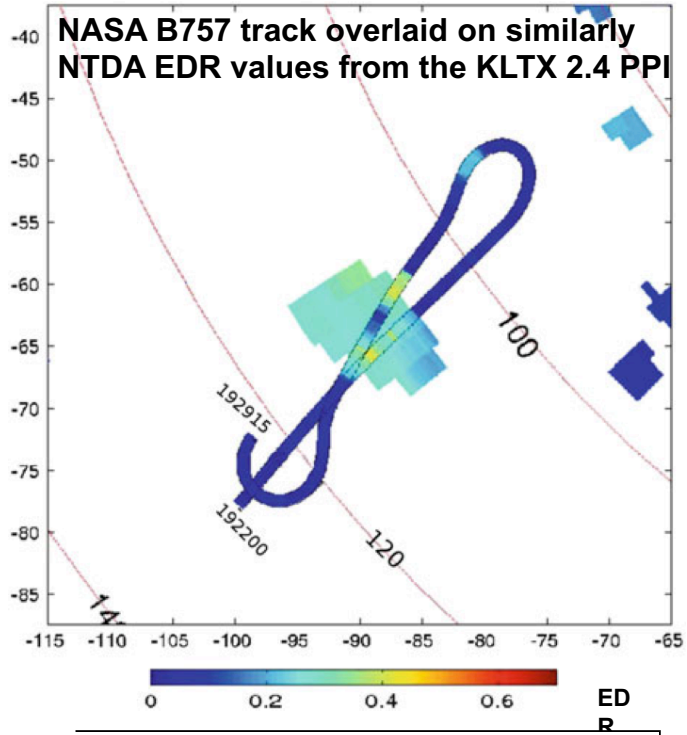


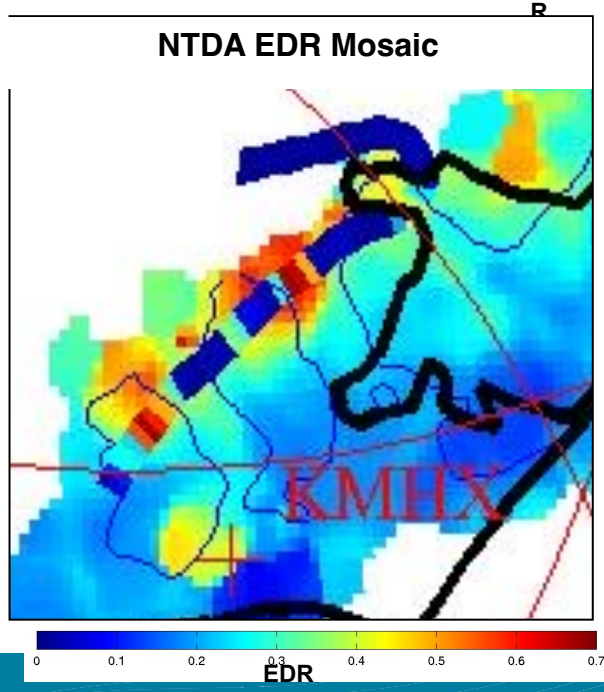
Verification

NASA B-757 Flight Tests

- 11 flights in and around thunderstorms over the south-eastern US
- High-rate aircraft data used to compute EDR along flight track
- Results compared to NTDA EDR mosaic computed from nearby NEXRADs

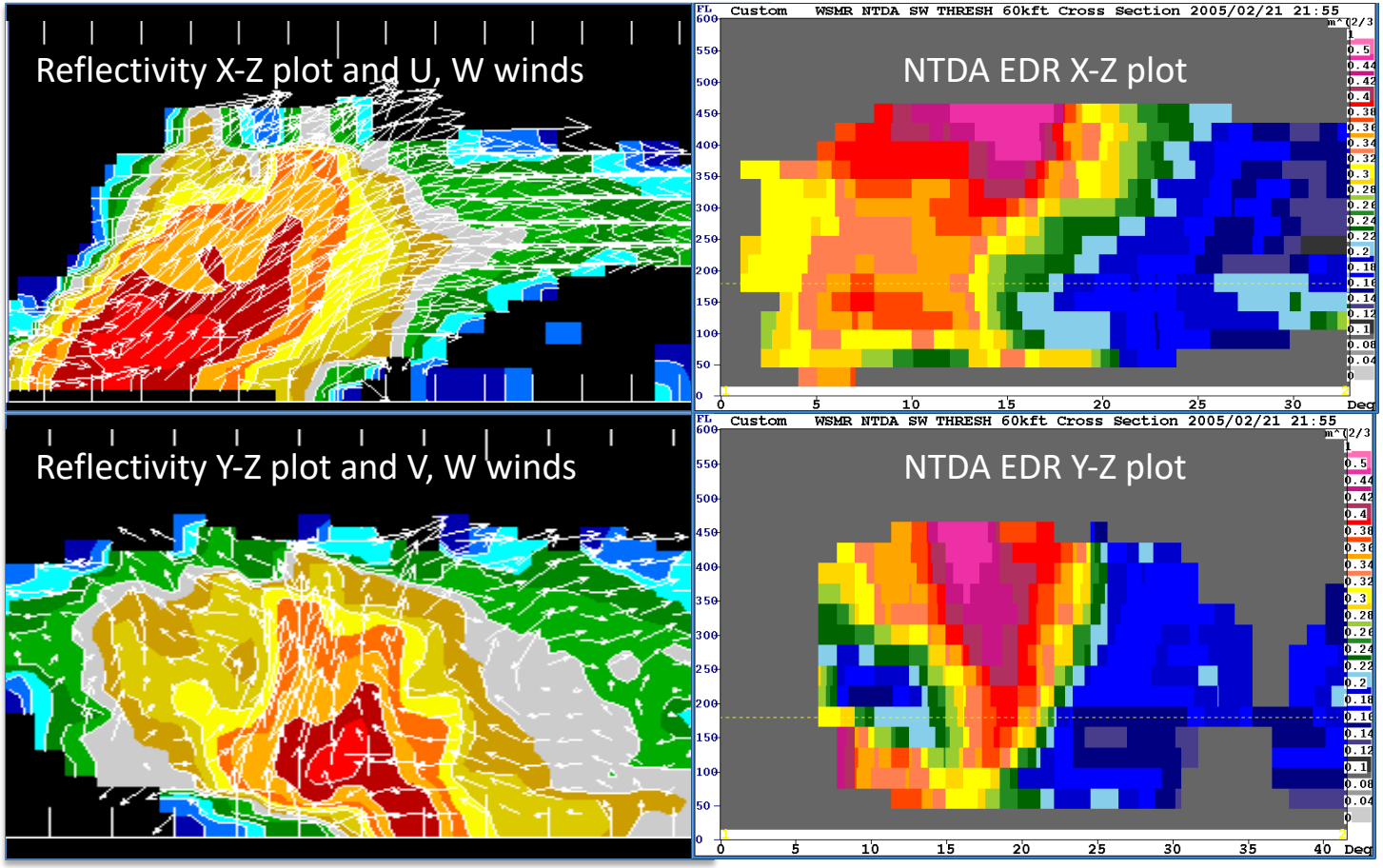
The NASA Langley B-757 aircraft





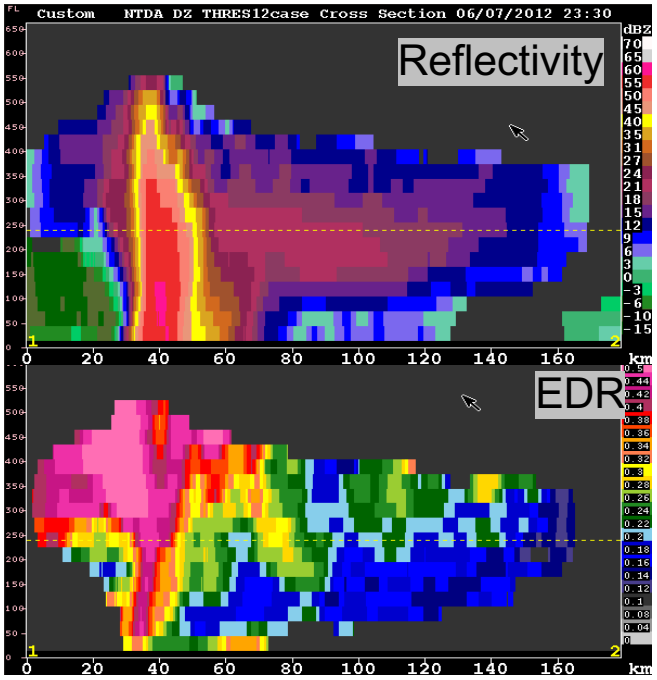
Thunderstorm Wind Field and Turbulence

Example: 21 Feb 2005, Huntsville, AL dual-Doppler analysis



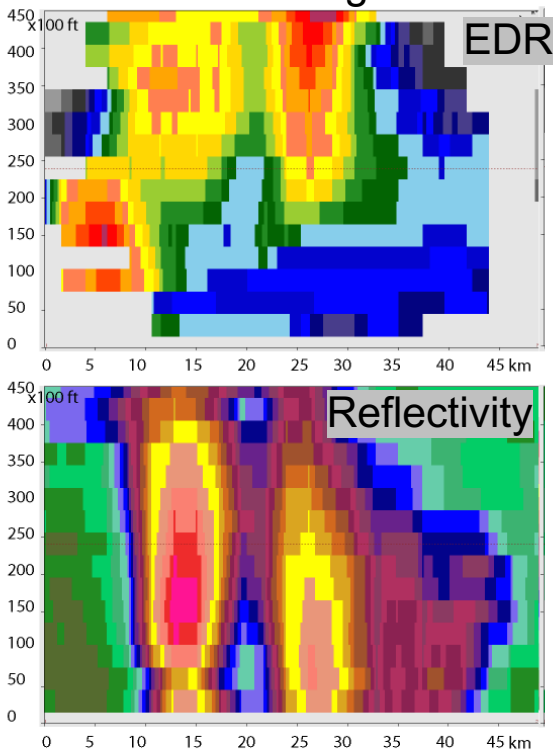
Turbulence Characteristics by Storm Type

Colorado Supercell Storm

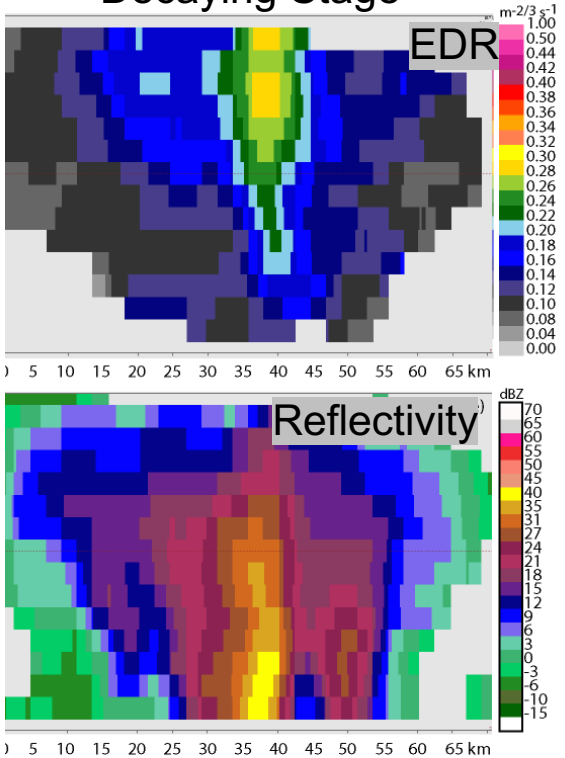


New Mexico Single Cell Storm

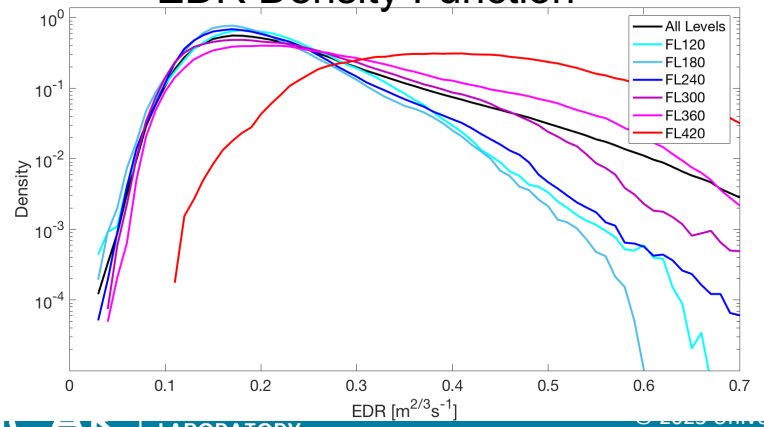
Mature Stage



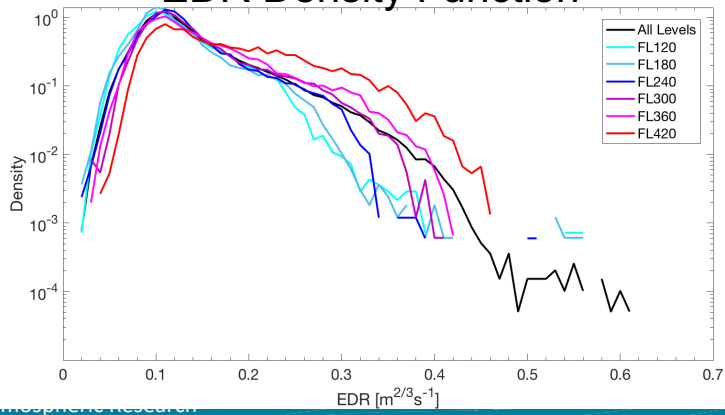
Decaying Stage



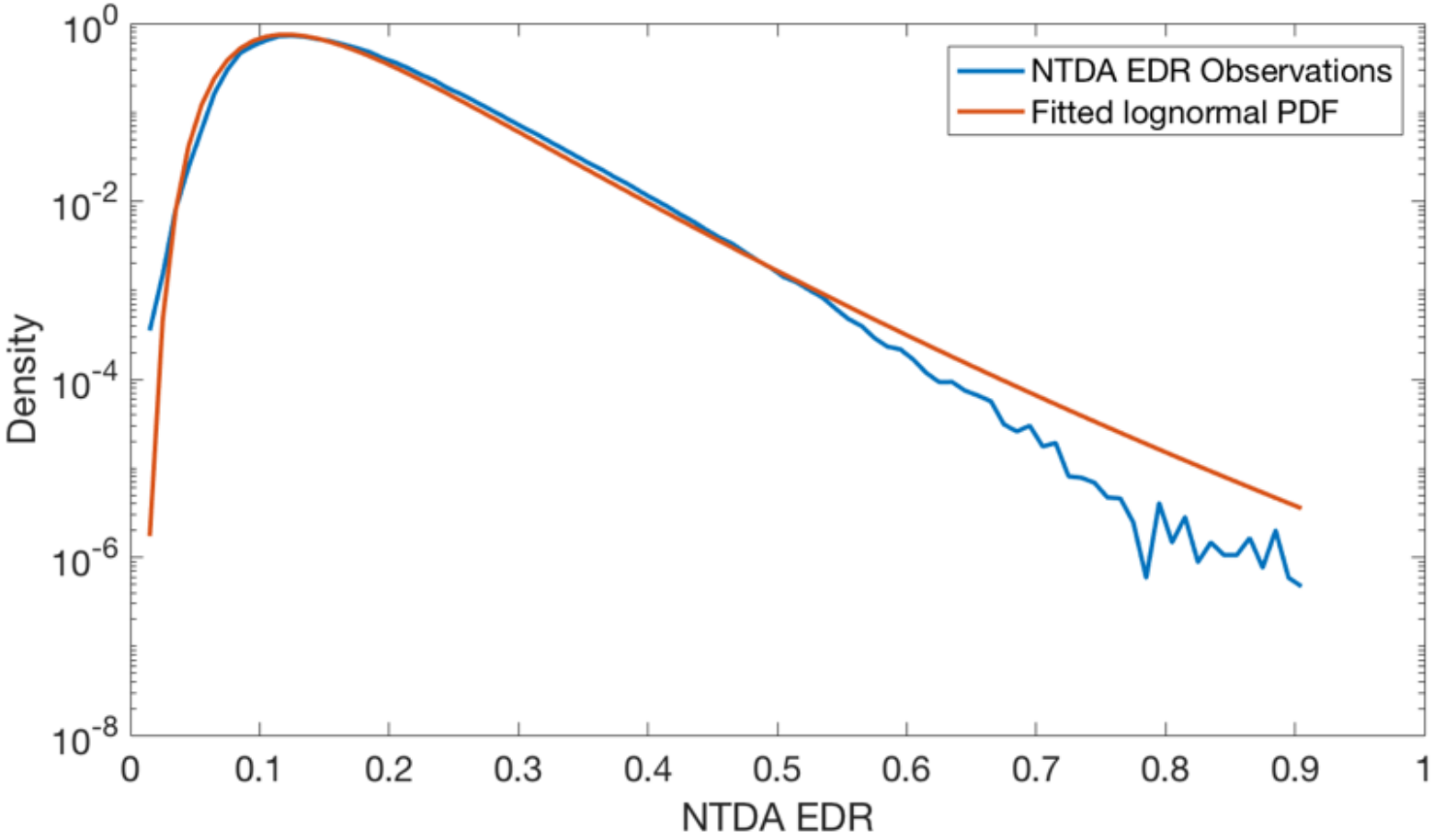
EDR Density Function



EDR Density Function

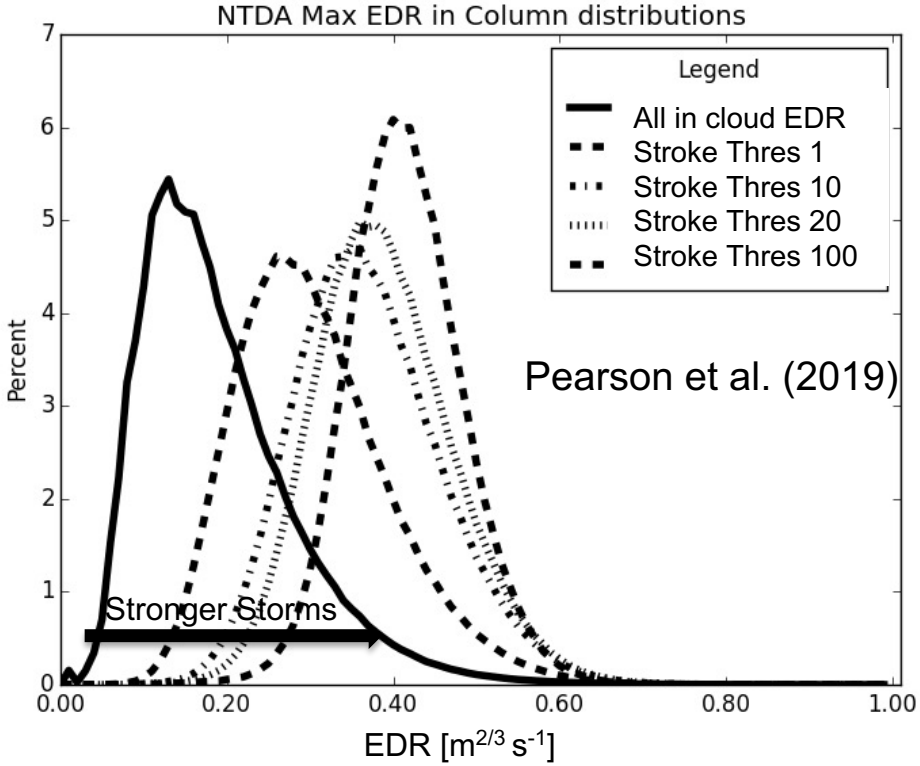


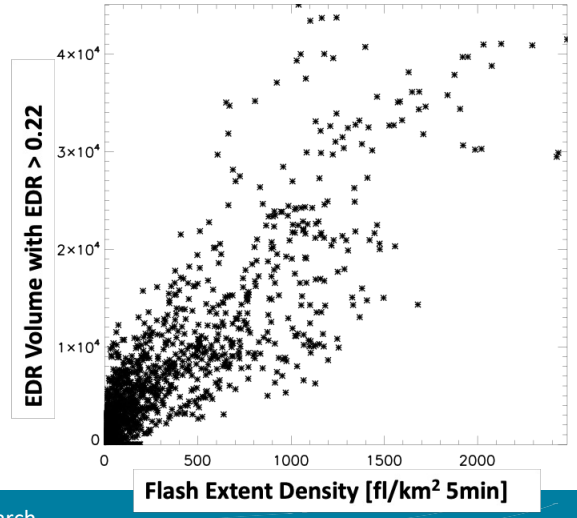
NTDA EDR PDF and fitted lognormal PDF from 1 year climatology



Lightning and Turbulence

- Can lightning information be used to provide turbulence inferences?
- Large updraft volumes of higher updraft speeds are capable of producing more hydrometeors in the mixed ice phase and likely greater shears and more intense convective turbulence
- NTDA EDR distributions conditioned on lightning information
- Scatterplots of EDR volume and flash extent densities





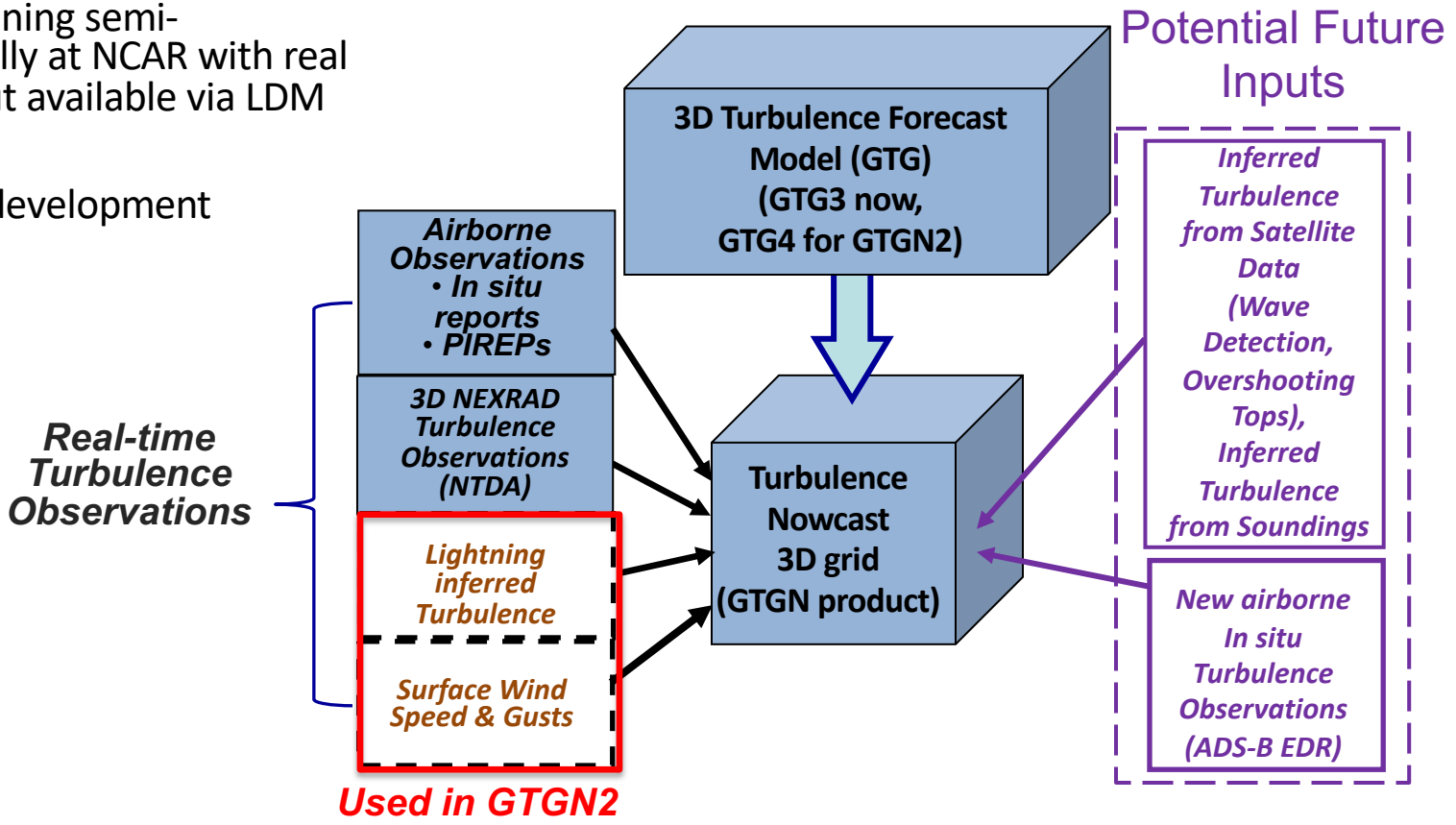
Turbulence Nowcasts
GTGN

GTG-Nowcast (GTGN) Overview

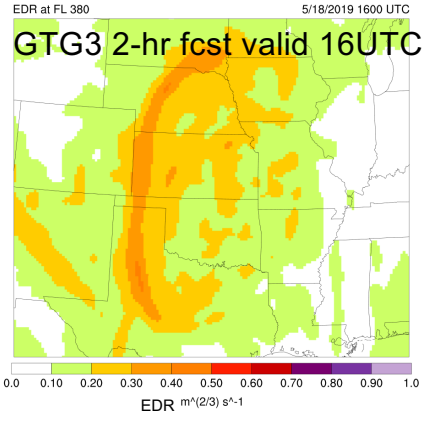
- Nowcast – tactical turbulence avoidance product
  - Rapid update cycle of 15 minutes, valid for next 15 minutes
  - 3D grid over CONUS domain; all altitudes every 1000 ft
- Uses GTG output grid as a basis for the GTGN nowcast
  - Most recent GTG forecast valid closest to nowcast valid time
- Observation-centric
  - Nudges turbulence forecasts to be more consistent with recent turbulence observations
  - Uses both airborne and ground based observations
- All sources of turbulence are represented
  - Low-level, clear-air, mountain wave, and in- and near-cloud turbulence
- Outputs 3D grid of EDR ($\varepsilon^{1/3}$ $m^{2/3}$ / s)
  - Eddy Dissipation Rate (EDR) is an atmospheric, aircraft independent, turbulence metric
  - Same output grid as GTG

Graphical Turbulence Guidance Nowcast (GTGN) Overview: Aviation Nowcast System

- GTGN1 running semi-operationally at NCAR with real time output available via LDM
- GTGN2 in development



GTGN1 Overview:
Example 18 May 2019 at 16UTC, FL380



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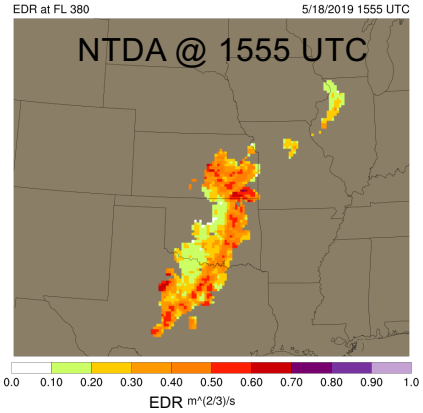

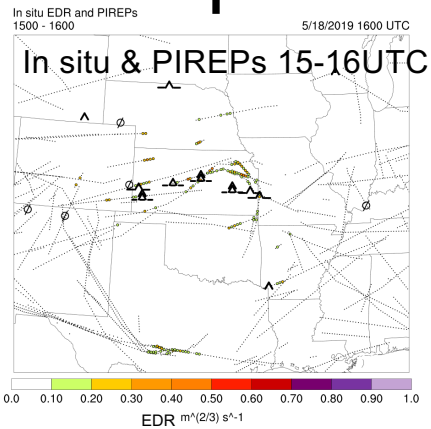

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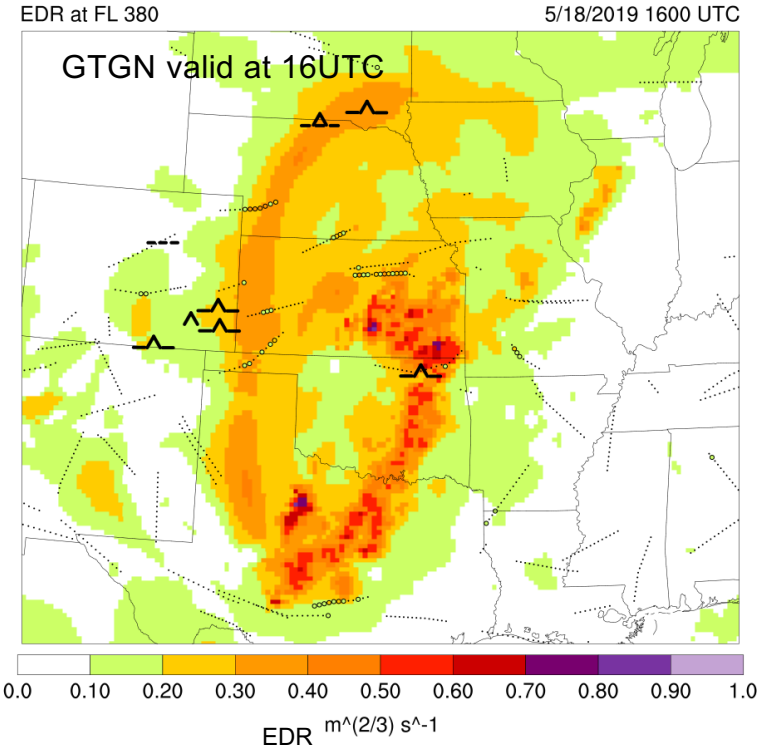
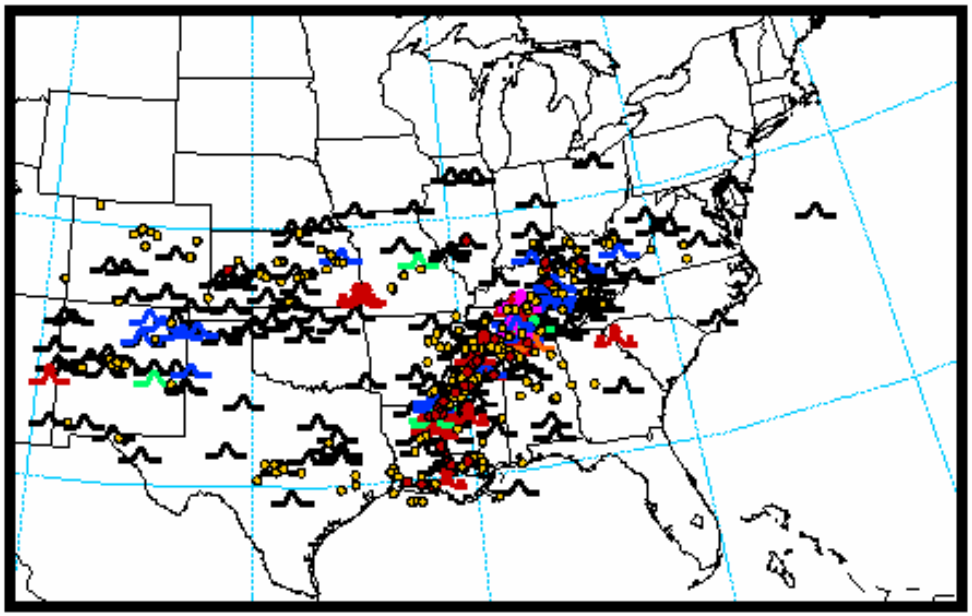


Verification Obs 1600-1615

GTGN Example: 11 February 2022

- Widespread and long lived turbulence throughout the day
- Above 20k feet shown:
  - Lots of Mod, Severe PIREPs
    - Including several wave reports (blue, pink)
    - Including many clear-air reports (green, orange)
  - EDR reports shown EDR >= 0.22
    - 0.22-0.34 (moderate) in yellow
    - 0.34-1 (severe) in red



Wave - blue (lgt to mod), pink (sev);
CAT – green (lgt to mod), orange (sev)

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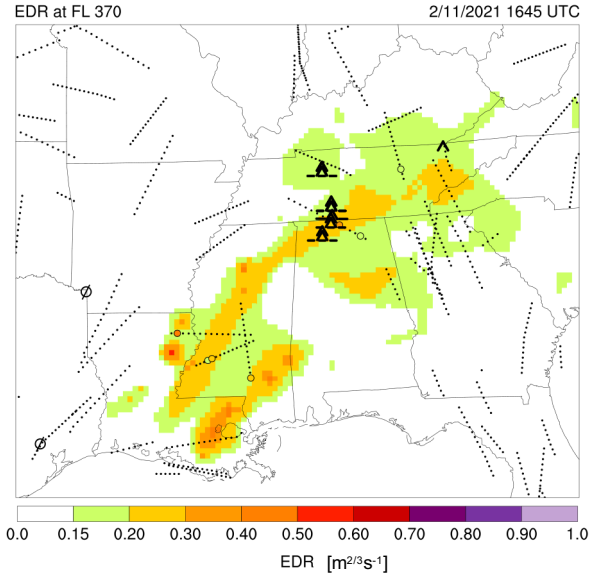
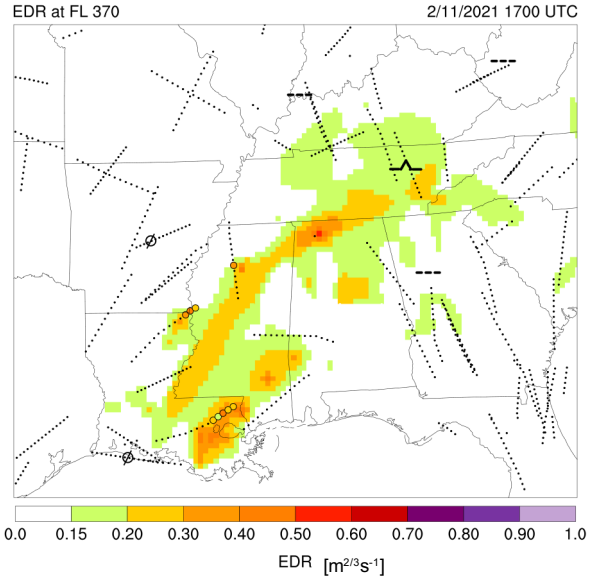
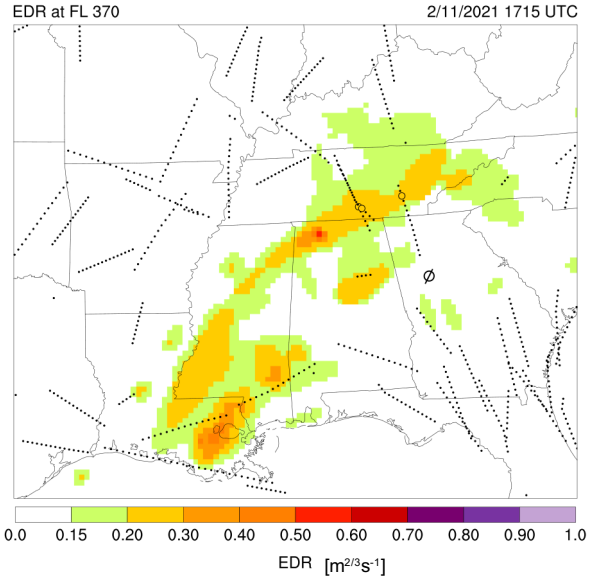
11 Feb 2021 Case Analysis: GTGN at FL370, 1645 – 1715 UTC

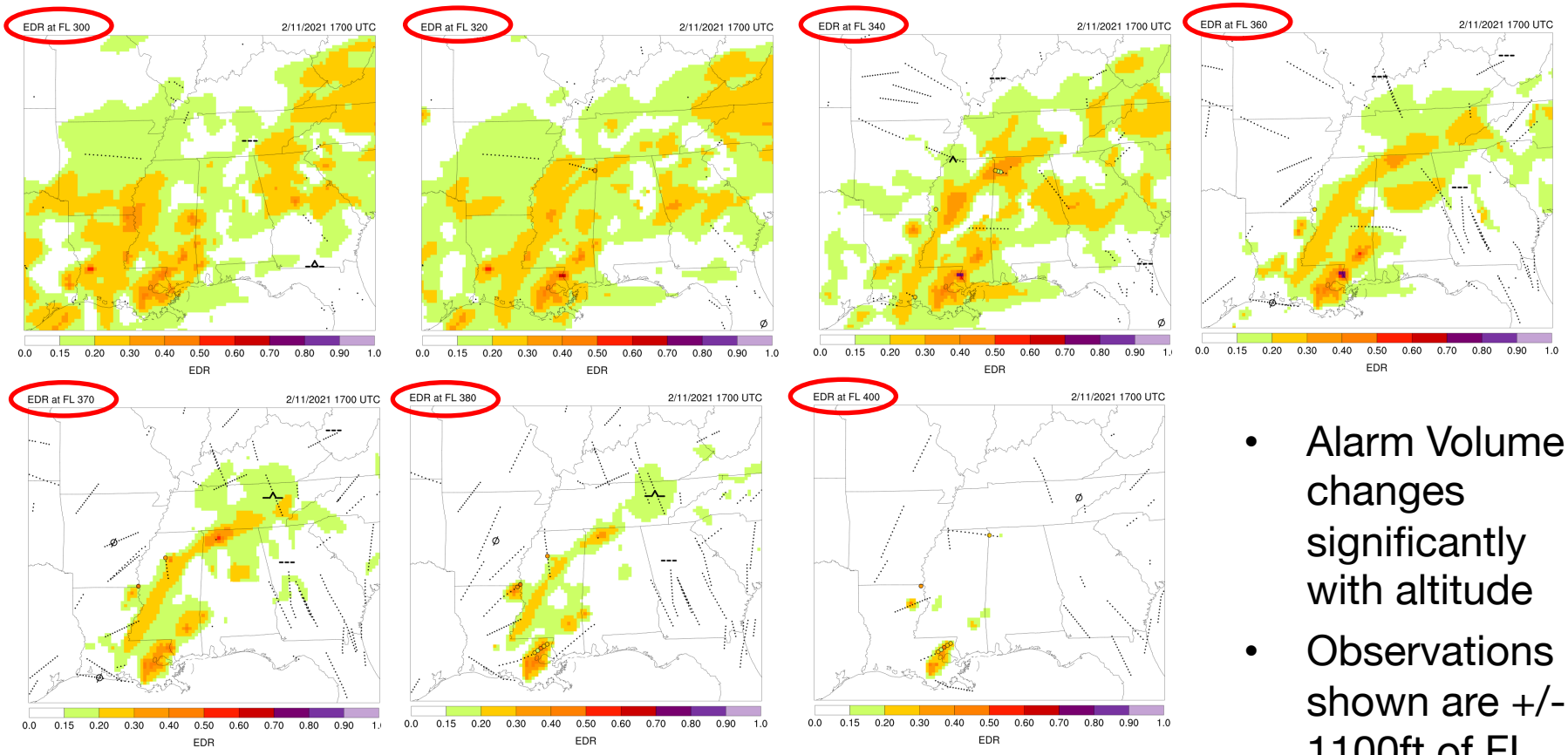






- GTGN real time output at 1645, 1700, 1715 UTC, FL370. Observations from 1645 – 1730 shown in 15 minute valid ranges +/- 2100 ft around FL370 for the 3 plots
- GTGN shows areas of MOG turbulence corresponding to the precise locations of several Mod and Mod-Sev PIREPs, as well as numerous elevated in situ EDR reports in LA, MS and TN over this time window.
- Null in situ EDR reports around these events are in areas GTGN shows as null to light turbulence.
- These times show skill in correctly identifying narrow regions of MOG turbulence and adjacent null turbulence.

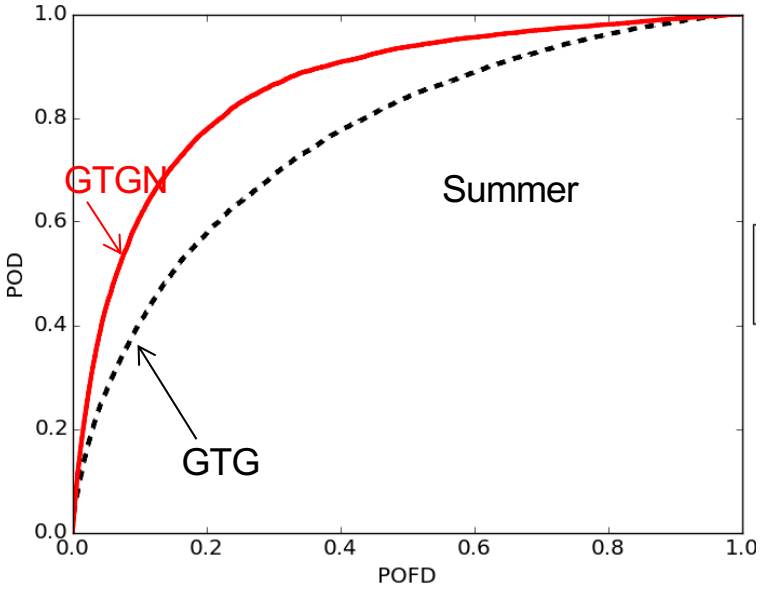
11 Feb 2021 Case Analysis: GTGN at 1700 UTC, FL300 – FL400

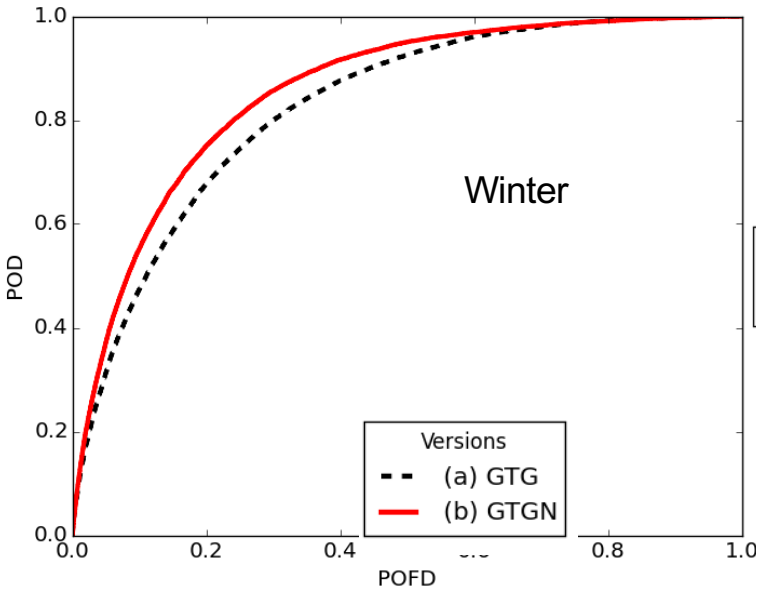


- Alarm Volume changes significantly with altitude
- Observations shown are +/- 1100ft of FL

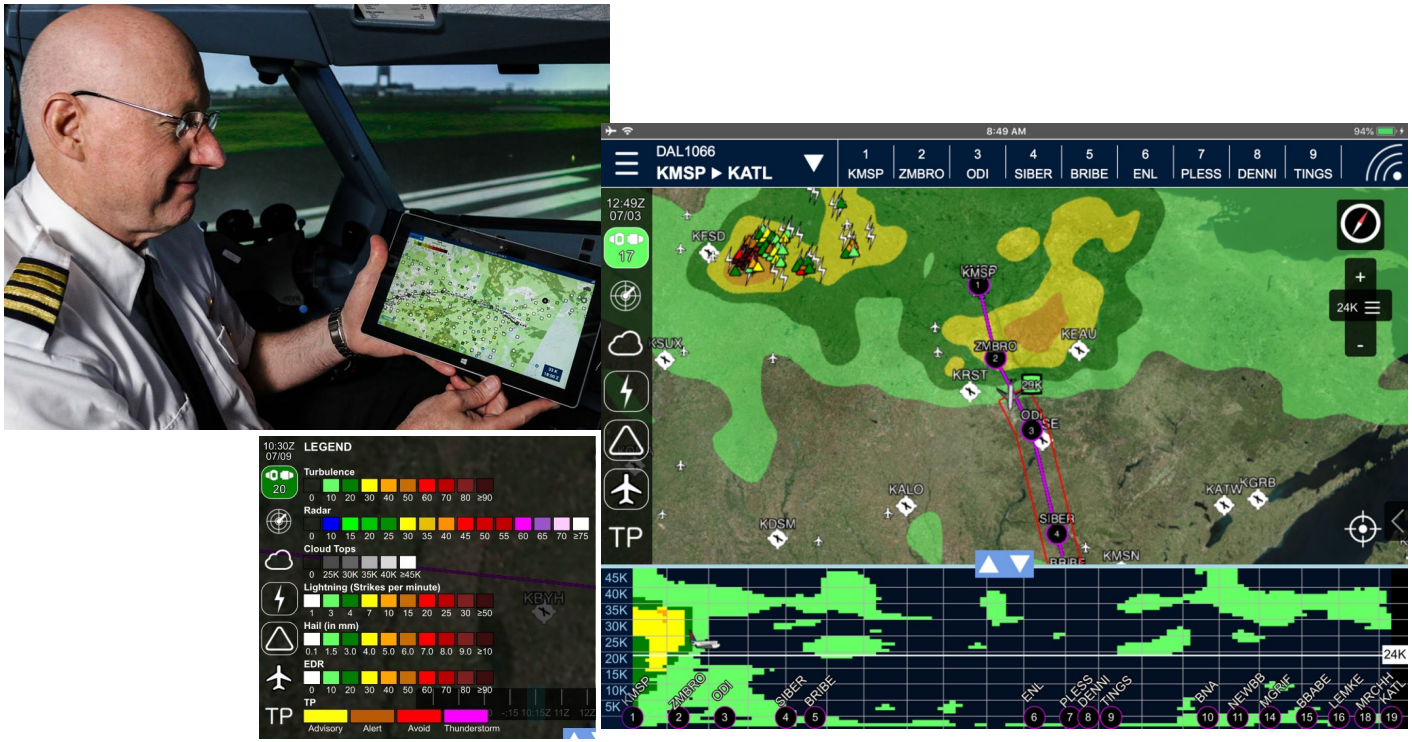
GTGN Evaluation

- Evaluation: ROC curve comparison of GTG versus GTGN for **summer and winter months**





GTGN Evaluation from Delta Airlines and FAA



GTGN displayed via App on Tablet for use in the cockpit

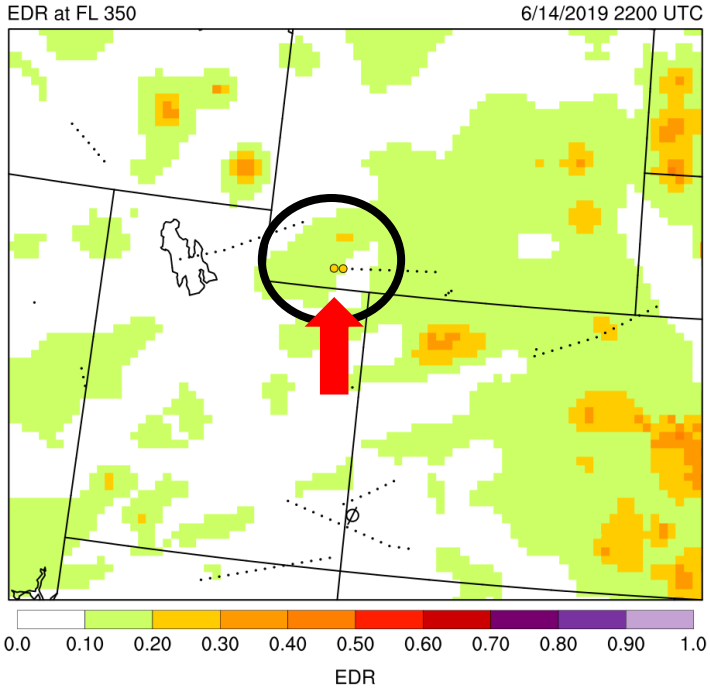
Courtesy Delta Airlines

GTGN2: Addition of Lightning Under Development

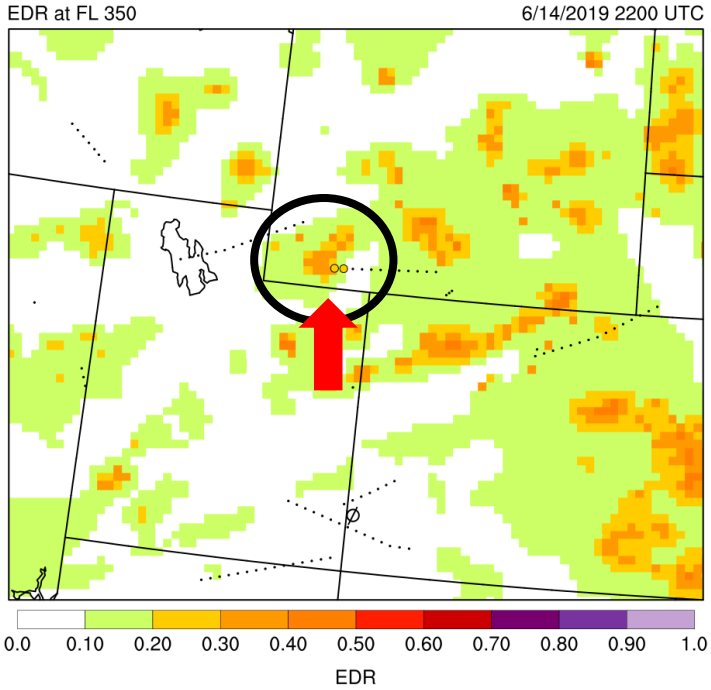
- Lightning Observations are available:
  - over CONUS to fill in where NTDA has sparse coverage
  - Over oceans and globally allowing for a GTGN with CIT over expanded domains

GTGN2: Addition of Lightning Under Development

Improves nowcast of turbulence in the mountainous western US where Radar coverage is limited



GTGN 1.0



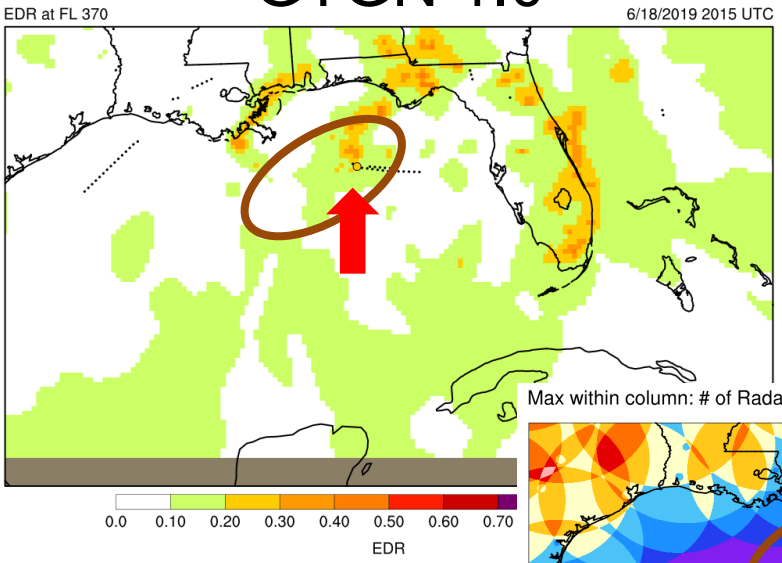
GTGN with Lightning

With next 15 minutes of in situ & PIREP observations

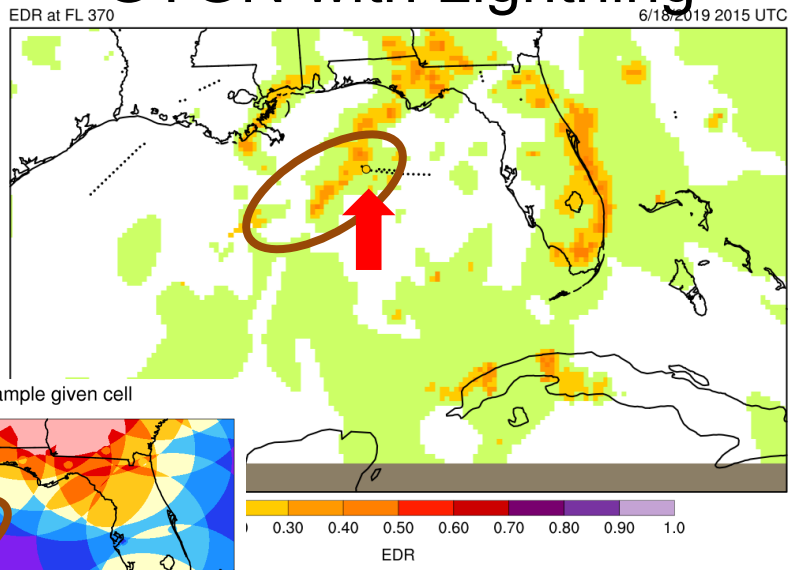
GTGN2: Addition of Lightning Under Development

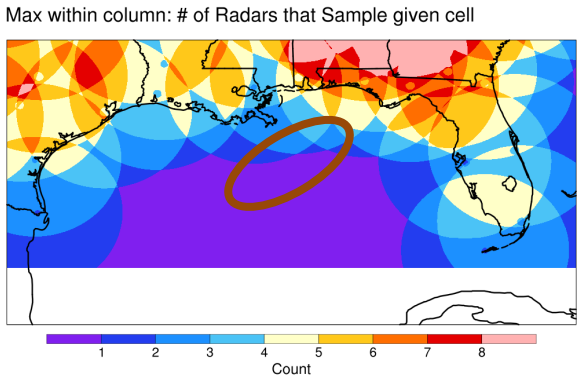
Improves nowcast of turbulence Oceanic Regions without RADAR coverage

GTGN 1.0

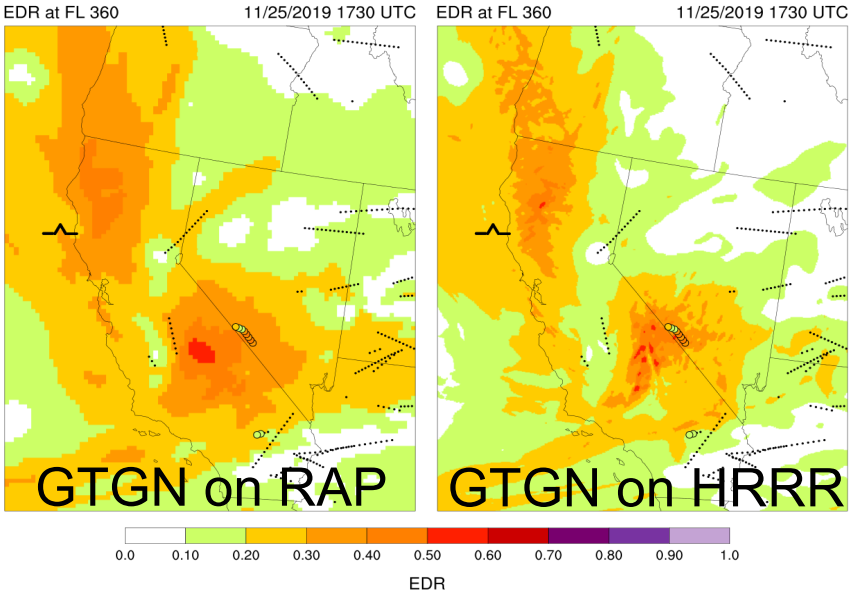


GTGN with Lightning

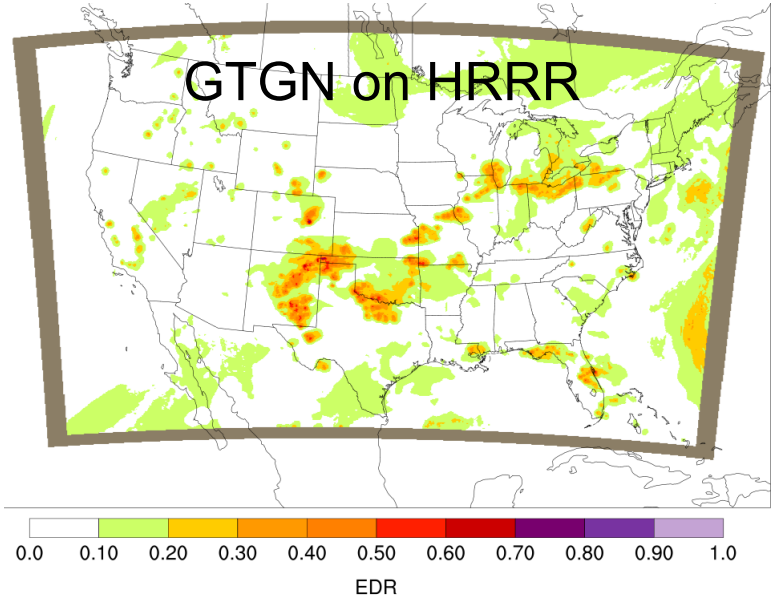




GTGN2: 3-km GTG Input Under Development



- GTGN inputs all on 3-km GTG output domain
- GTG CIT forecast



- Provides:
  - More detail in turbulence features
  - Less volume MOG forecast
  - CIT forecast