# New Developments in the Graphical Turbulence Guidance (GTG) Forecasting System

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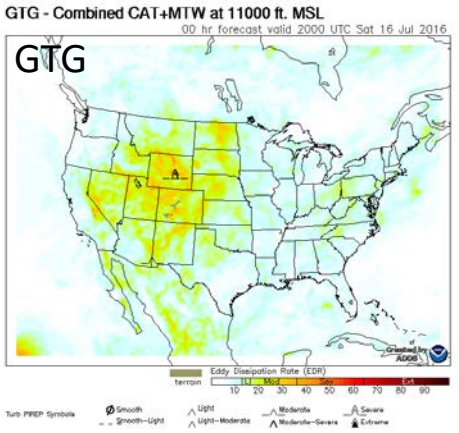
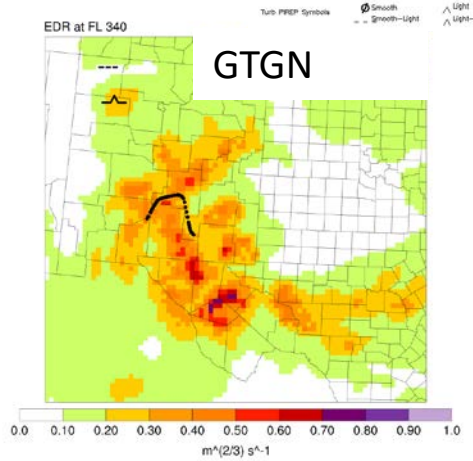
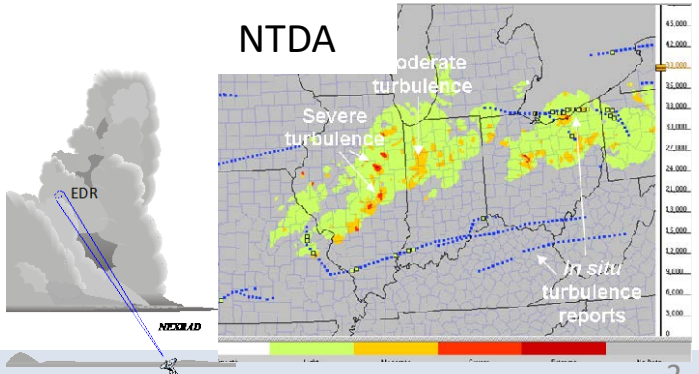
# Goals & Products

## Work Areas

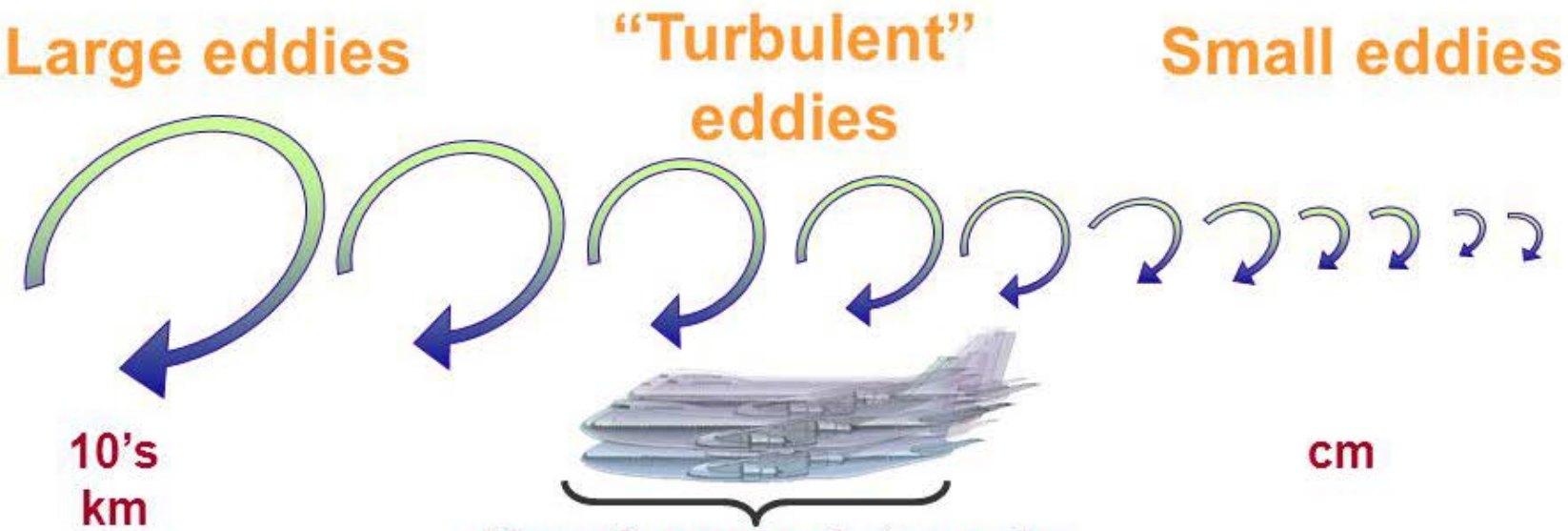
- Develop forecast products for strategic avoidance (GTG)
- Develop nowcast products for tactical avoidance (GTGN)
- Develop more and improved observations
- Support transition to operations (e.g. NCEP, AWC) of products and global harmonization of global turbulence forecasts
- All products estimate a turbulence intensity metric termed “EDR” (energy or eddy dissipation rate$^{1/3}$)



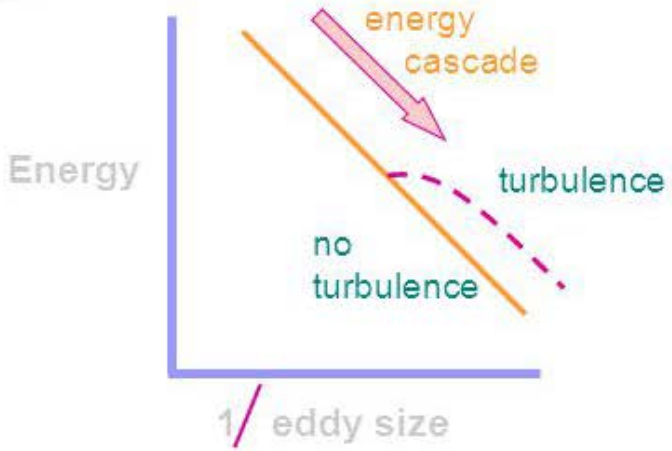



# Turbulence Scales and Model Forecasts







# Graphical Turbulence Guidance

- Forecast system is called the Graphical Turbulence Guidance (GTG)*
  - Can be based on various models (RAP, GFS, UK-Met etc.)
  - Currently adapting it to HRRR, FV3
- Assumes large scale model resolved turbulence sources linked to aircraft scale turbulence
- Computes suite of turbulence diagnostics for MWT, CAT and LLT
- **Currently adding in-cloud CIT diagnosis based on HRRR**
- GTG = MAX of ensemble weighted mean:

$$CAT = W_1D_1 + W_2D_2 + W_3D_3 + \ldots.$$

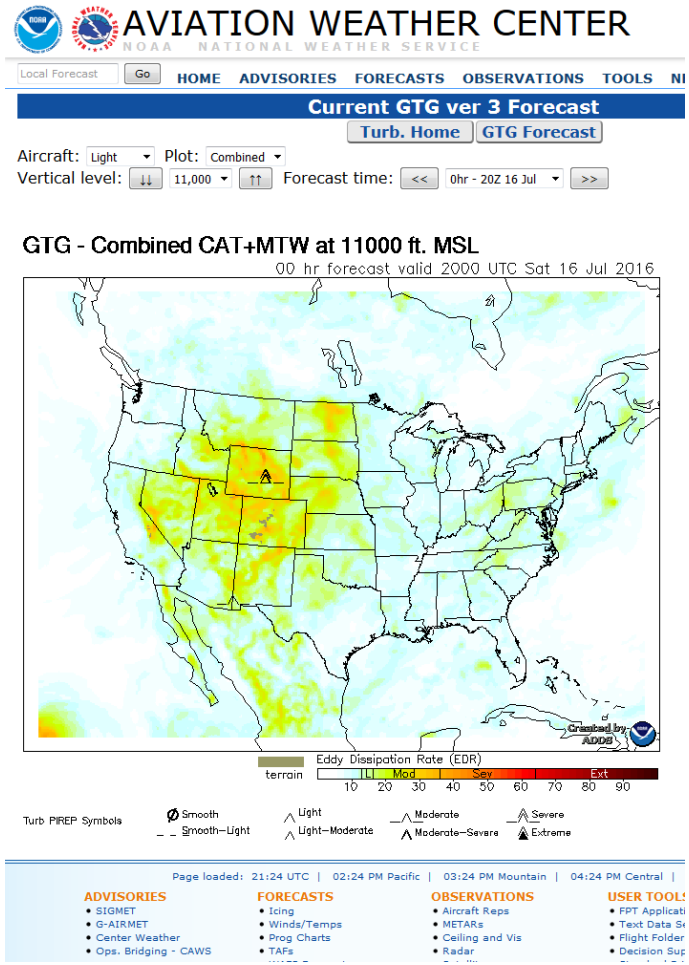
$$MWT = W_1D_1 + W_2D_2 + W_3D_3 + \ldots.$$

$$LLT = W_1D_1 + W_2D_2 + W_3D_3 + \ldots.$$

$$CIT = W_1D_1 + W_2D_2 + W_3D_3 + \ldots.$$

***GTG=MAX(CAT, MWT, LLT, CIT)***

- Outputs Eddy Dissipation Rate (EDR) for low, mid and high levels



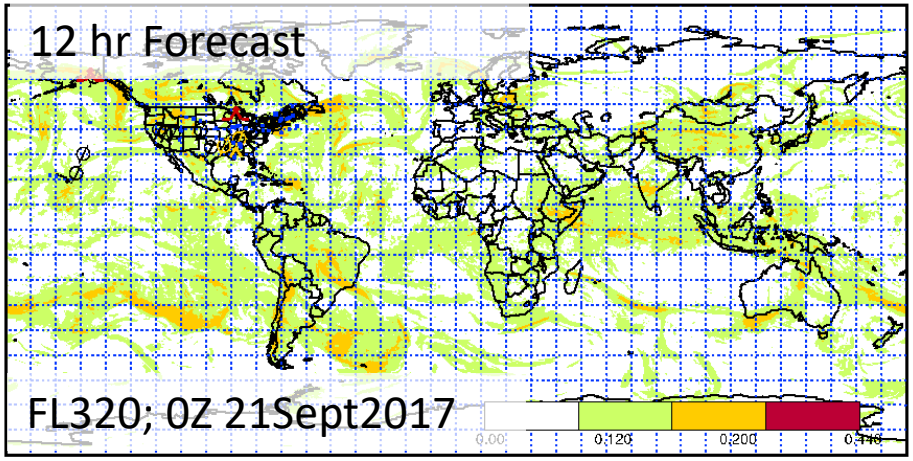

*Sharman et al. *Weather & Forecasting* 2006
Sharman and Pearson, *J Appl Met Climate*, 2017
Pearson and Sharman, *J Appl Met Climate*, 2017

# Graphical Turbulence Guidance Enhancements

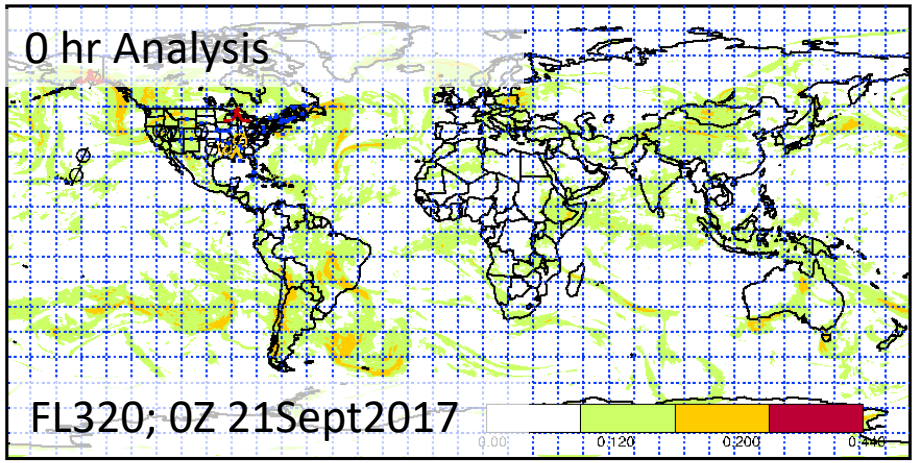
- Made code base changes of the global GTG (GTG-G) to run on FV3 model in NCEP UPP infrastructure and include UKMO NWP model to support WAFS.

- Collaboration with Jung-Hoon Kim at AWC on probabilistic GTG-G

GTG NCEP FV3 global model

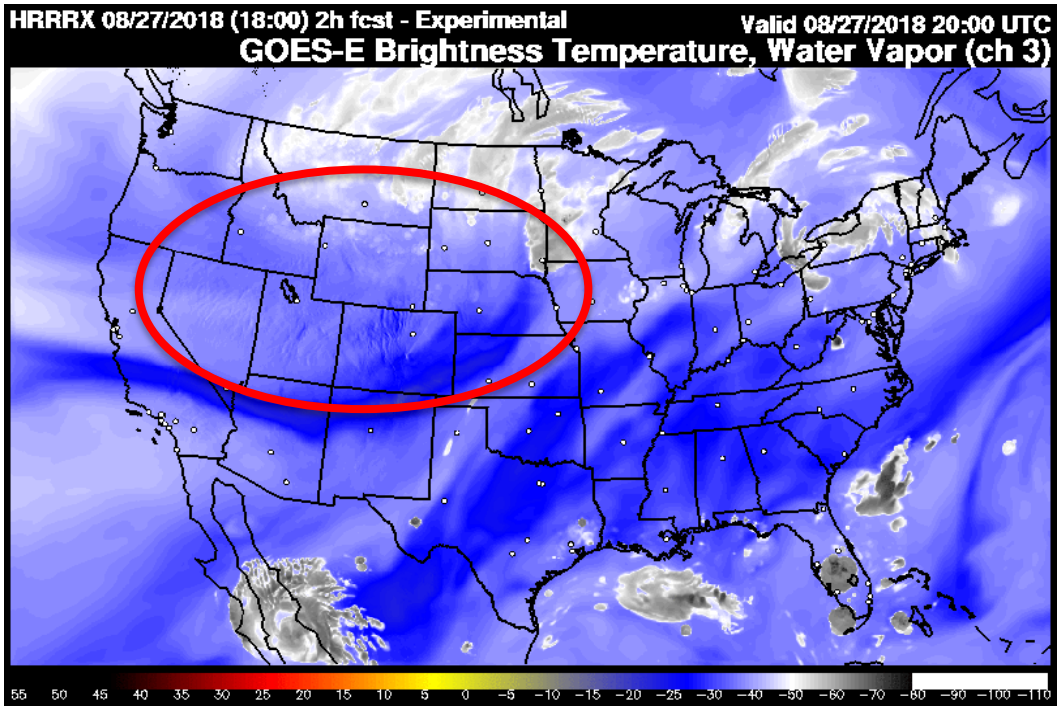


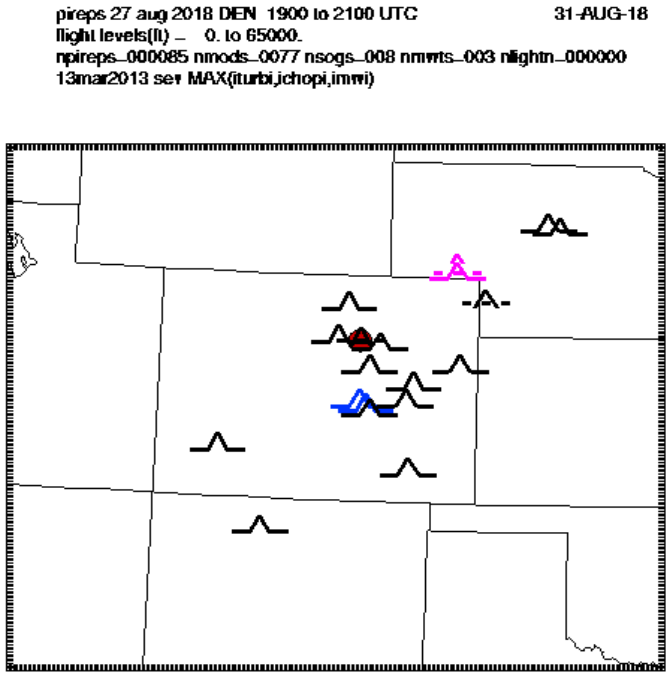

GTG UKMO global model



# Graphical Turbulence Guidance Enhancements

- Upgrading to new GTG CONUS version that is based on HRRR:
  - Improved low level (LLT)
  - Adding convectively induced turbulence (CIT) capability
  - Adaptation/calibration of CAT & MWT to HRRR

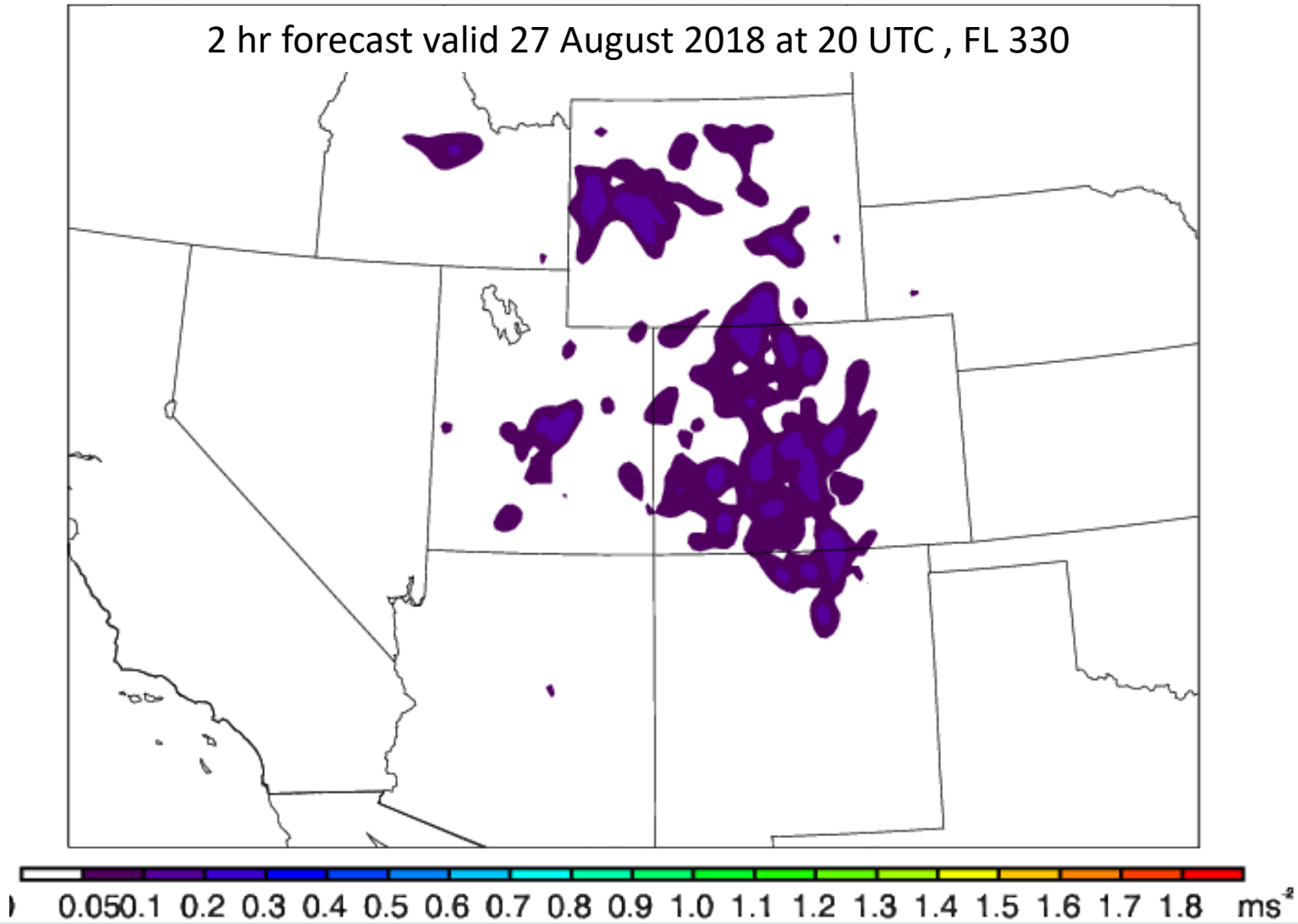



MWT Example, 27 August 2018 at 20 UTC

# Graphical Turbulence Guidance Enhancements

## HRRR versus RAP MWT index: $d_s$ x|DIV|

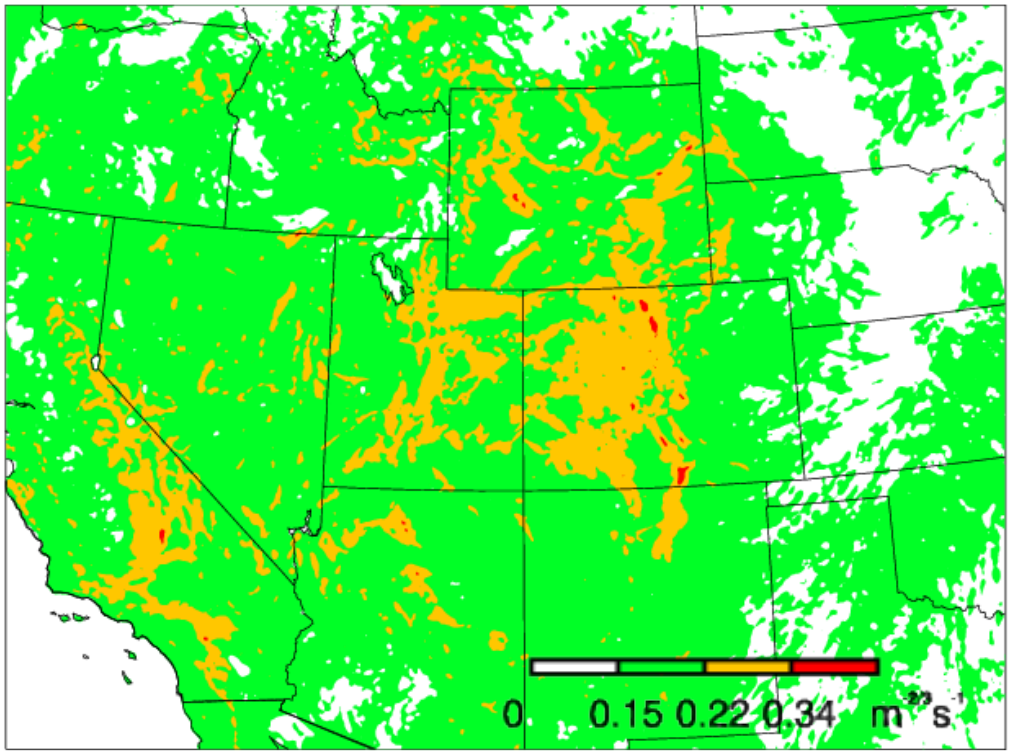


# Graphical Turbulence Guidance Enhancements

- Improved low level turbulence (LLT) diagnosis for HRRR compared to RAP (see Domingo Muñoz-Esparza talk)

GTG HRRR - LLT Example, 2hr forecast

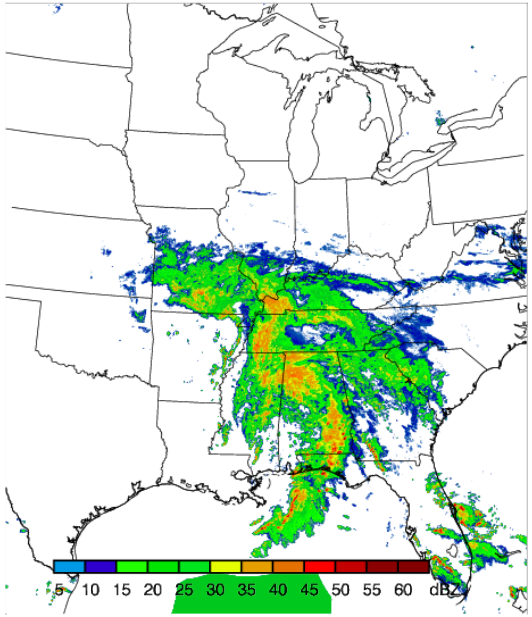
27 August 2018 at 20 UTC, z~1km



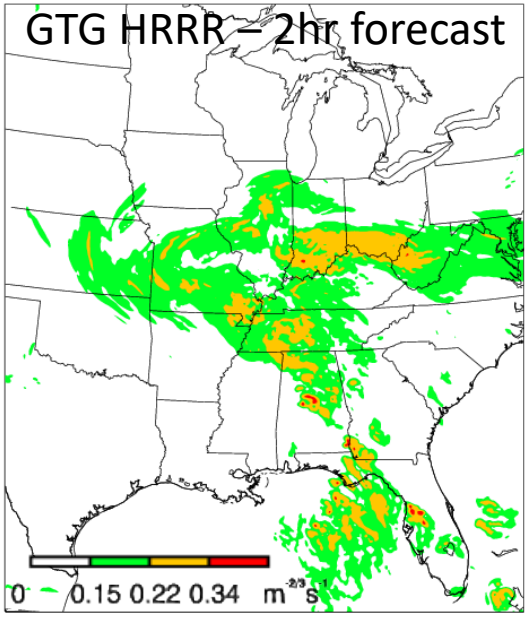
# Graphical Turbulence Guidance Enhancements

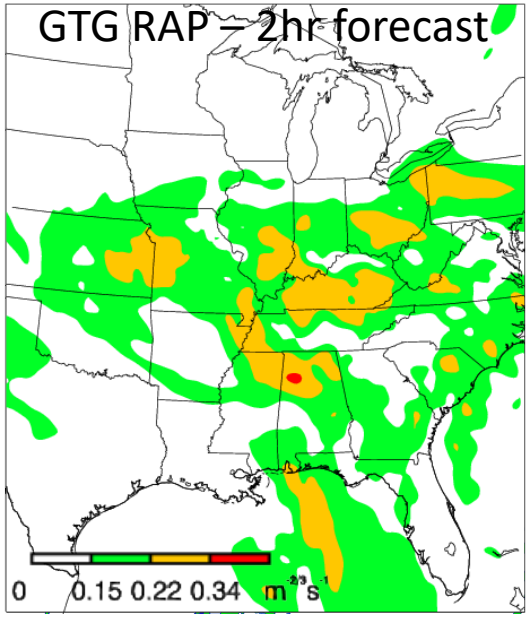
- Higher HRRR grid resolution resolves convection better

NSSL Radar Reflectivity Mosaic




23 April 2018 at 20 UTC, FL 330

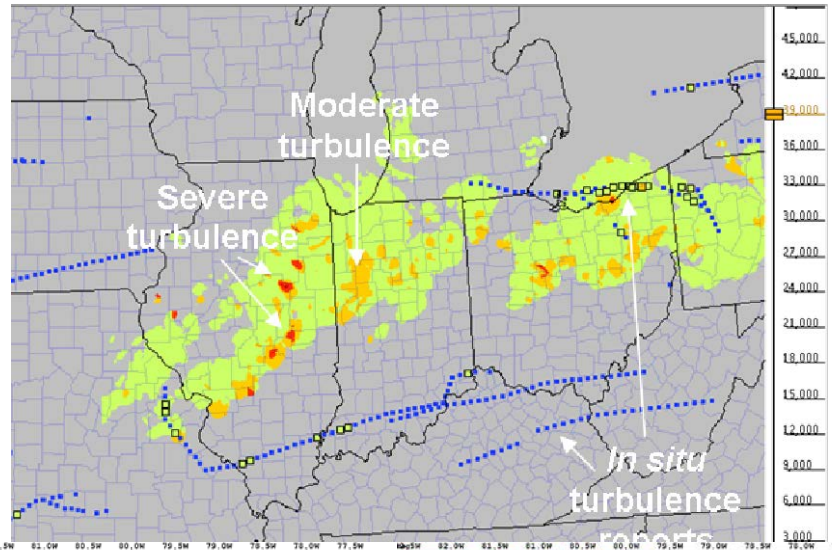


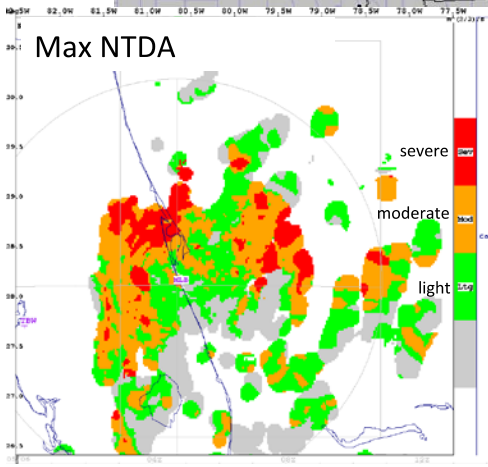



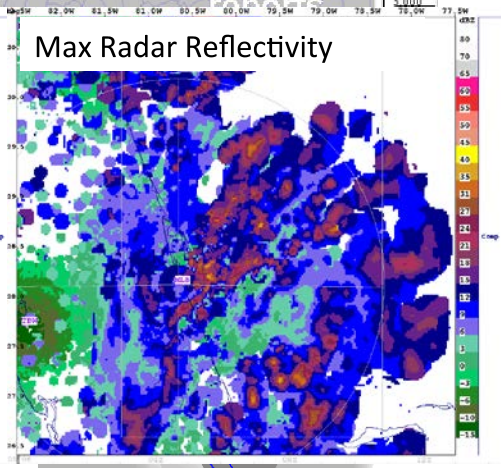

- Adding CIT parameterization:
  - Identified CIT diagnostics
  - Calibrate diagnostics based on NTDA EDR and in-situ EDR, combined them to ensemble weighted mean in-cloud CIT field
  - GTG output contains MAX EDR of MWT,CAT,LLT & CIT

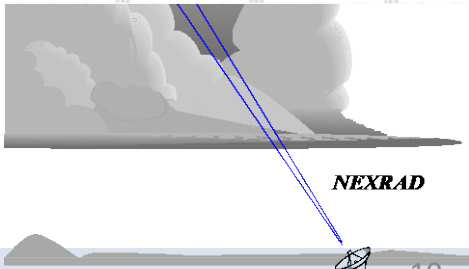
# NEXRAD/NCAR Turbulence Detection Algorithm

- Reflectivity (dBZ) is NOT a reliable indicator of turbulence location
  - Airspace outside high-echo regions may be turbulent
  - Convective turbulence can be small-scale and evolve quickly
- NTDA makes use of NEXRAD radar measured spectrum width
  - Undergoes significant data quality control
  - Converts radar measurements into EDR (Williams et al. 2016)
  - Verified with in situ turbulence measurements and Pireps
- NTDA produces 3D mosaic of EDR and confidence:
  - 5 minute update rate
  - 2 km horizontal x 3,000 ft vertical resolution



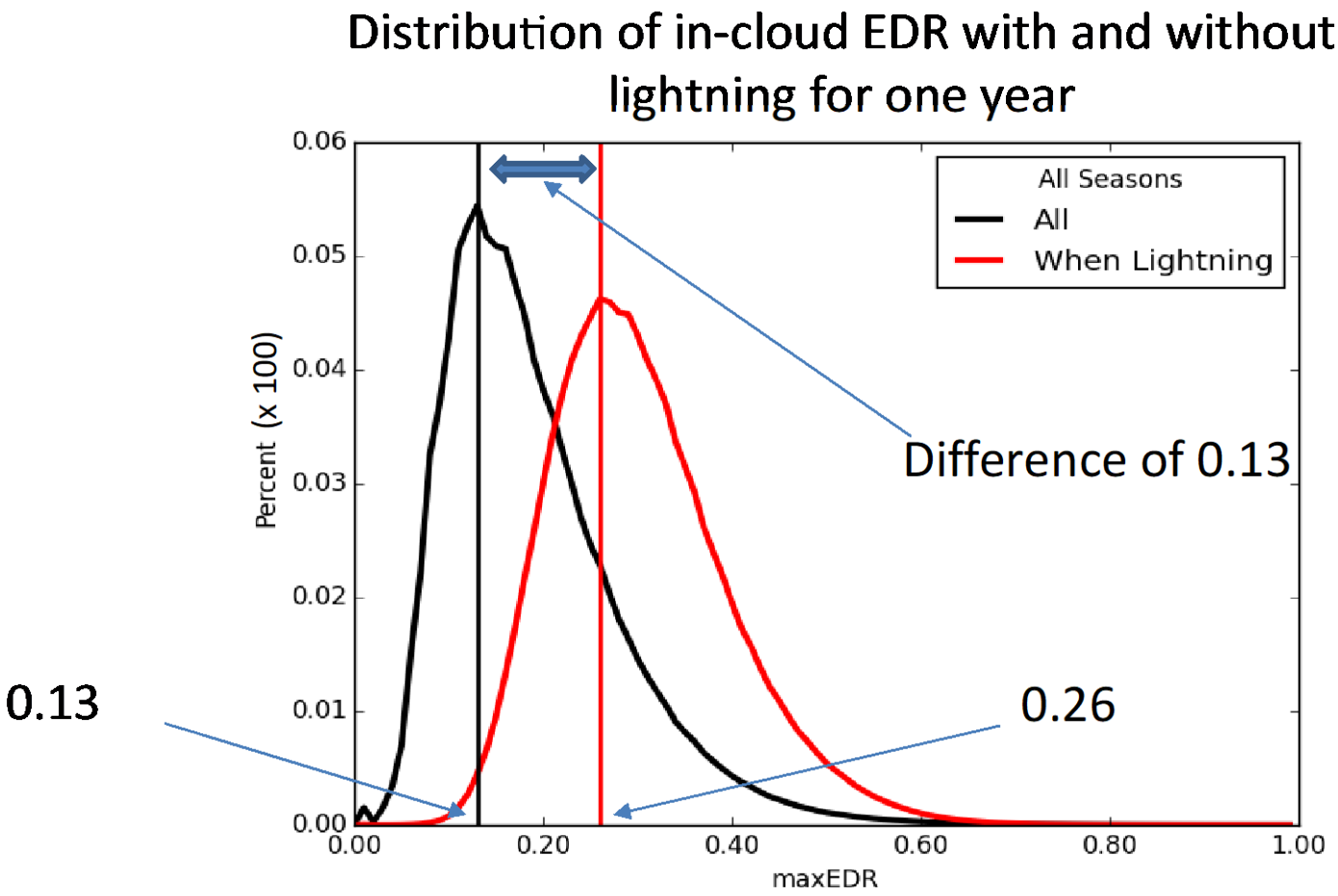



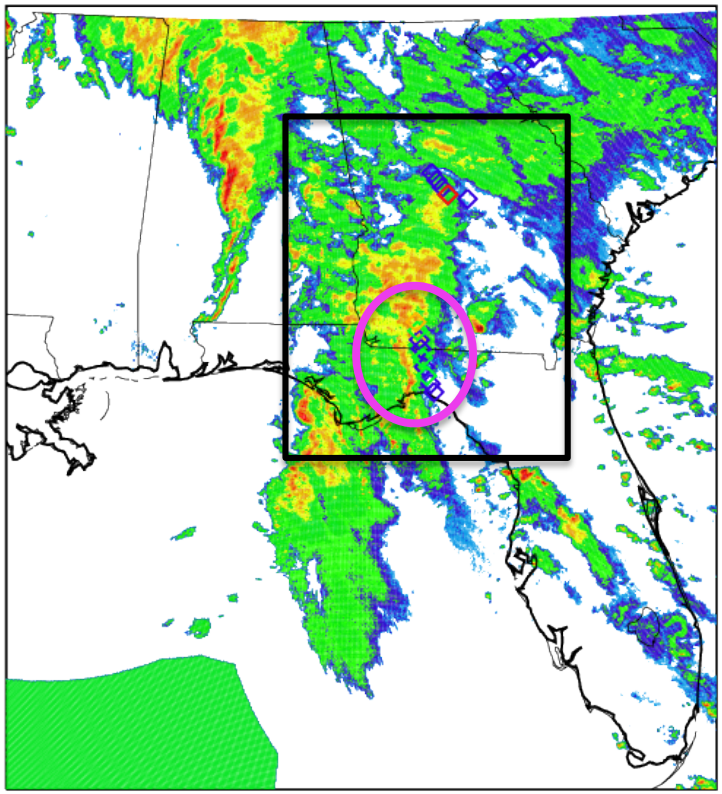
# In-Cloud EDR Distribution

- In-situ EDR versus NTDA EDR based on data from 2015-2016
- Peak of in-cloud EDR distribution shifts to higher EDR
- Distribution of EDR in thunderstorms shifts to even higher EDR

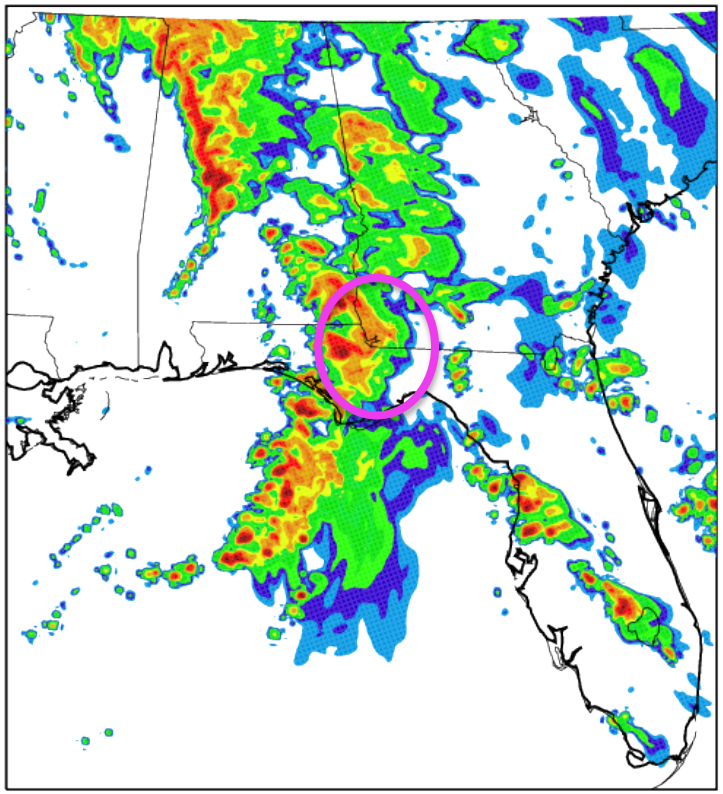


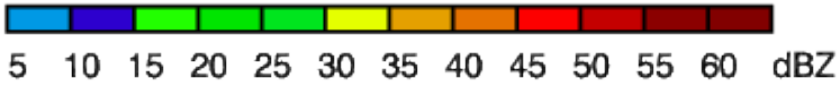
# Case Study of in cloud CIT Forecast 23 April 2018, 1 UTC

NSSL Radar Reflectivity Mosaic



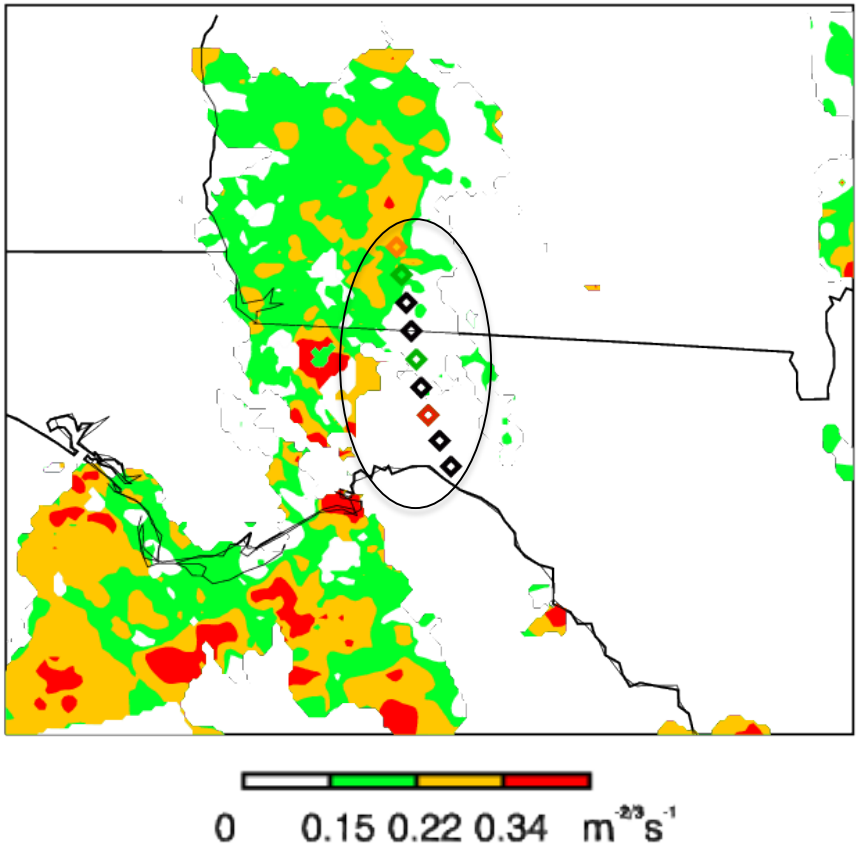
HRRR Radar Reflectivity 2 hr forecast



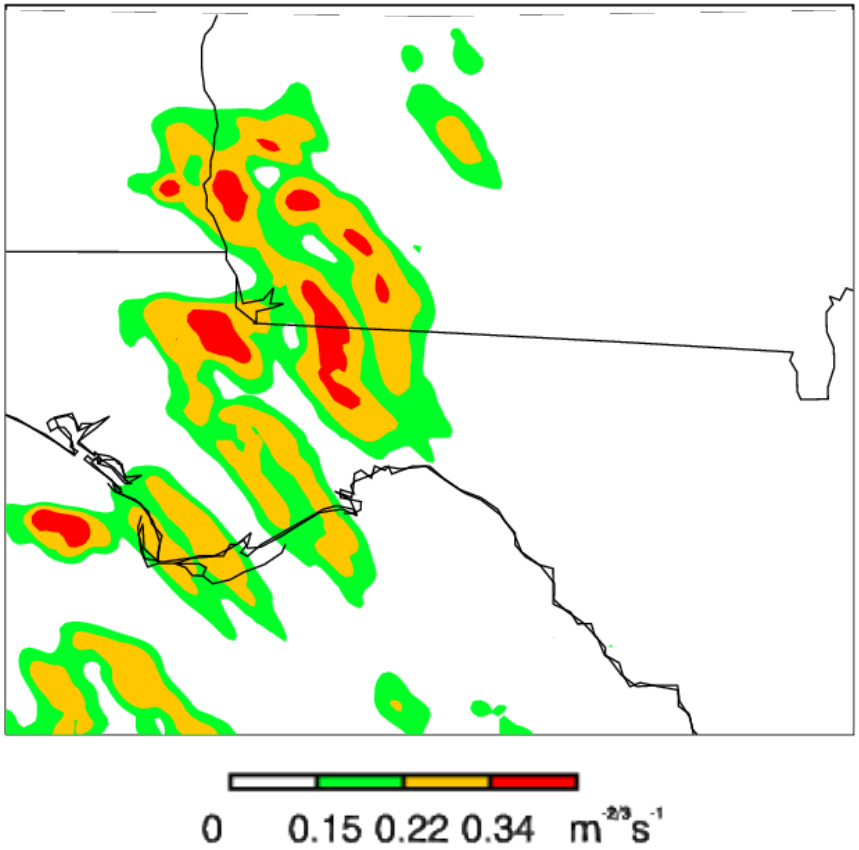


# Case Study of in cloud CIT Forecast
# 23 April 2018, 1 UTC

Max. NTDA EDR and in-situ EDR, FL 330

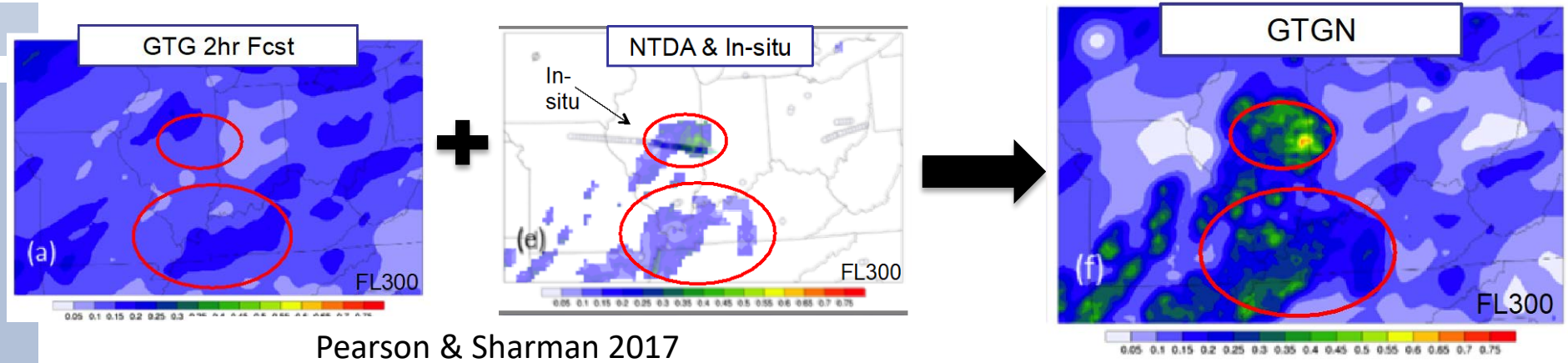



GTG CIT max. EDR, FL 330



# Graphical Turbulence Guidance Nowcast (GTGN)

- Provides short-term forecasts of turbulence
- Uses GTG short-term forecasts nudged with most recent observations to provide 15-min updates of EDR on 3 dimensional grid
- Includes convective turbulence observations (NTDA)
- Includes in situ observations of EDR from airlines
- Currently in demo/evaluation phase and transitioned to operations (AWC, AWDE, DAL)




Pearson & Sharman 2017

# GTG and GTGN Deployment Schedule

| Version | Capabilities | Op. date*/enter QA |
|---|---|---|
| GTG1 | Upper levels<br>RUC20 | 3/2003* |
| GTG2 | Improved GTG1<br>+Mid levels<br>+Uses UAL in situ | 2/11/2010* |
| GTG2.5 | 13 km WRFRAP cutout grid<br>+VWA insitu (UAL+DAL) | 5/1/2012* |
| GTG3.0 | 13 km RAP conus grids<br>Provides EDR<br>+ MWT<br>+ all levels (0-FL450)<br>+1-18 hrs | 10/20/2015* |
| GTG-G | FV3 + UKMET (merge at AWC)<br>0-36 hrs<br>Upper-levels only | August 2018<br>(FY2019*) |
| GTGN | 15-min updates, in-cloud CIT | FY2020* |
| GTG4 | Improved GTG3<br>+ HRRR 3-km grid<br>+ CIT forecasts<br>+ improved LLT forecasts | FY2019<br>(FY2020*) |
| GTGN2 | Adapted to HRRR | FY2021 |
| GTG5 | Upgrade to FV3-HRRR | FY2022? |
| GTG6 | Improved GTG5<br>+Ensembles/Probabilistic forecasts | FY2022/2023? |

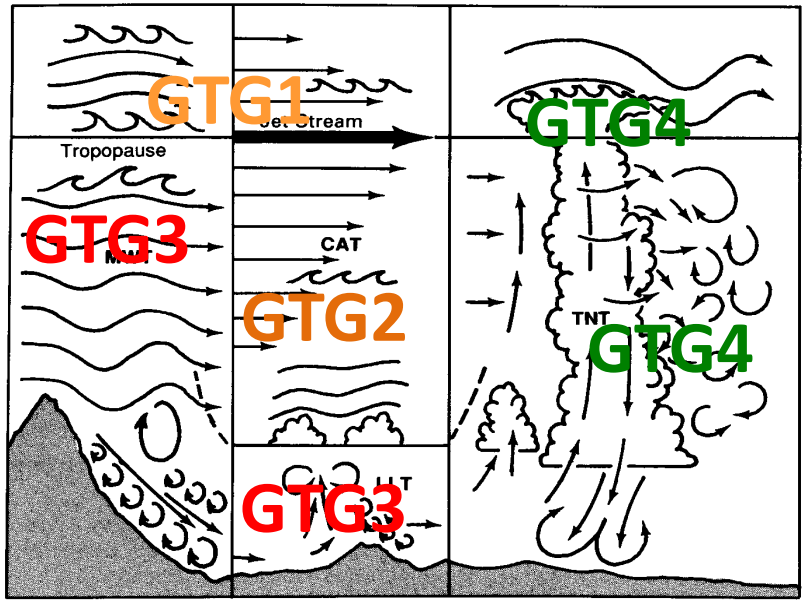



**Figure 1-16. Aviation turbulence classifications. This figure is a pictorial summary of the turbulence-producing phenomena that may occur in each turbulence classification.**

Source: P. Lester, "Turbulence – A new perspective for pilots," Jeppesen, 1994

# Thank you!

# Questions?

This research is in response to requirements and funding by the Federal Aviation Administration (FA
The views expressed are those of the authors and do not necessarily represent the official policy
position of the FAA.