Characteristics of convectively induced turbulence determined from tropical and midlatitude simulations

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BLUE WATERS
SUSTAINED PETASCALE COMPUTING

UND School of Graduate Studies
University of North Dakota

UND Atmospheric Sciences

I use Blue Waters to

simulate thunderstorms at high resolution to study turbulence prediction for aviation operations in the midlatitudes and tropics

Federal Aviation Administration

Turbulence scales: 10-1000 m

Motivation

- Global air travel is predicted to increase at a rate of 5% over the next 5 years

More planes in the sky

Courtesy of A. Karboski

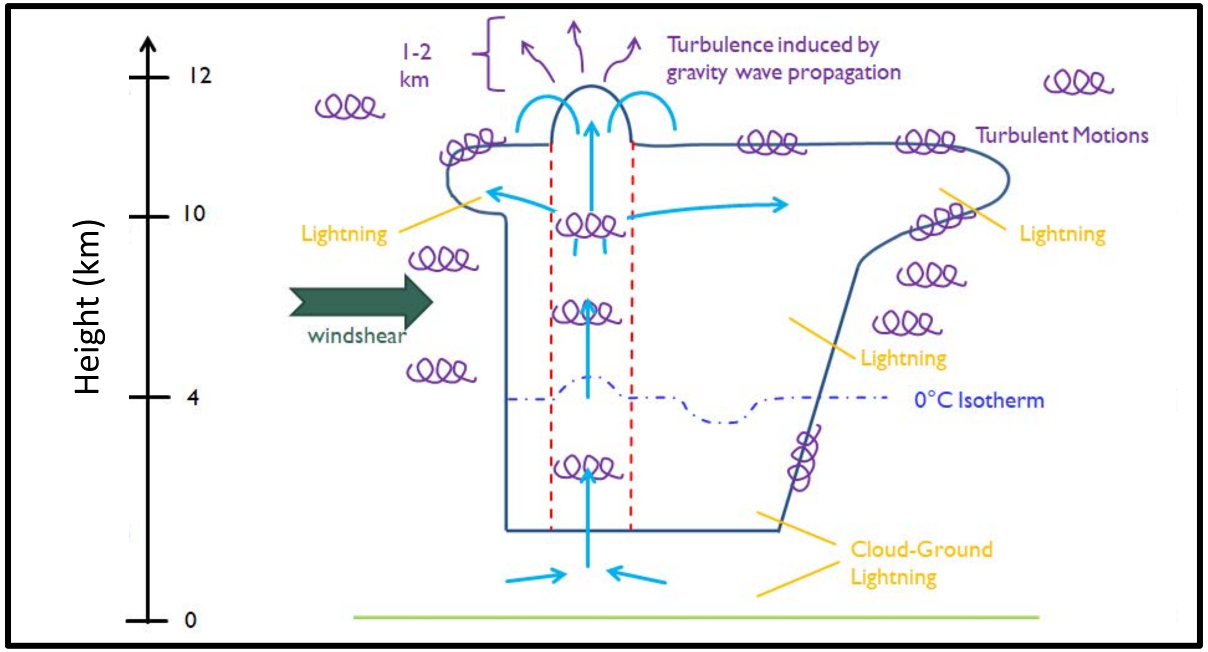
- 65% of weather related incidents are caused by turbulence
- Delays, structural damage, injuries to passengers and crew, instrumentation failure
  - 500 passengers and crew injured between 2002-2016

Increase safety and efficiency

Statista (2018); Sharman and Trier (2018); FAA (2017); Ball et al. (2010)

Sources of CIT

- Out-of-cloud convectively induced turbulence (CIT)



- 1-5 km above convection
- > 100 km away

3) Convectively generated gravity waves that propagate and break above convection (need high resolution to replicate)

Sharman and Trier (2018); Zovko-Rajak and Lane (2014); Lane and Sharman (2014); Lane et al. (2012); Lane et al. (2003); Pantley and Lester (1990); USAF (1982)

FAA Thunderstorm Guidelines

- Limitations
  - Convectively induced turbulence (CIT) can occur farther away than 20 mi
  - Vertical avoidance threshold has been disregarded
  - Regulations are solely based on continental midlatitude convection
  - U.S. aviation operations in the tropics abide by the same guidelines
  - Developing convection turbulence hazards are not addressed by FAA guidelines

Make steps towards improving FAA Thunderstorm guidelines

FAA (2017)

Methodology

- 6 simulations of CIT using the Weather Research and Forecasting (WRF) model v3.7
  - **500-m** horizontal grid spacing, **350-m** vertical grid spacing, 10 minute output
  - Initialized with ERA-Interim
- Turbulence diagnostics
  - Eddy dissipation rate and structure functions
  - Static stability, vertical wind shear, vertical velocity
- Developing convection verses mature convection

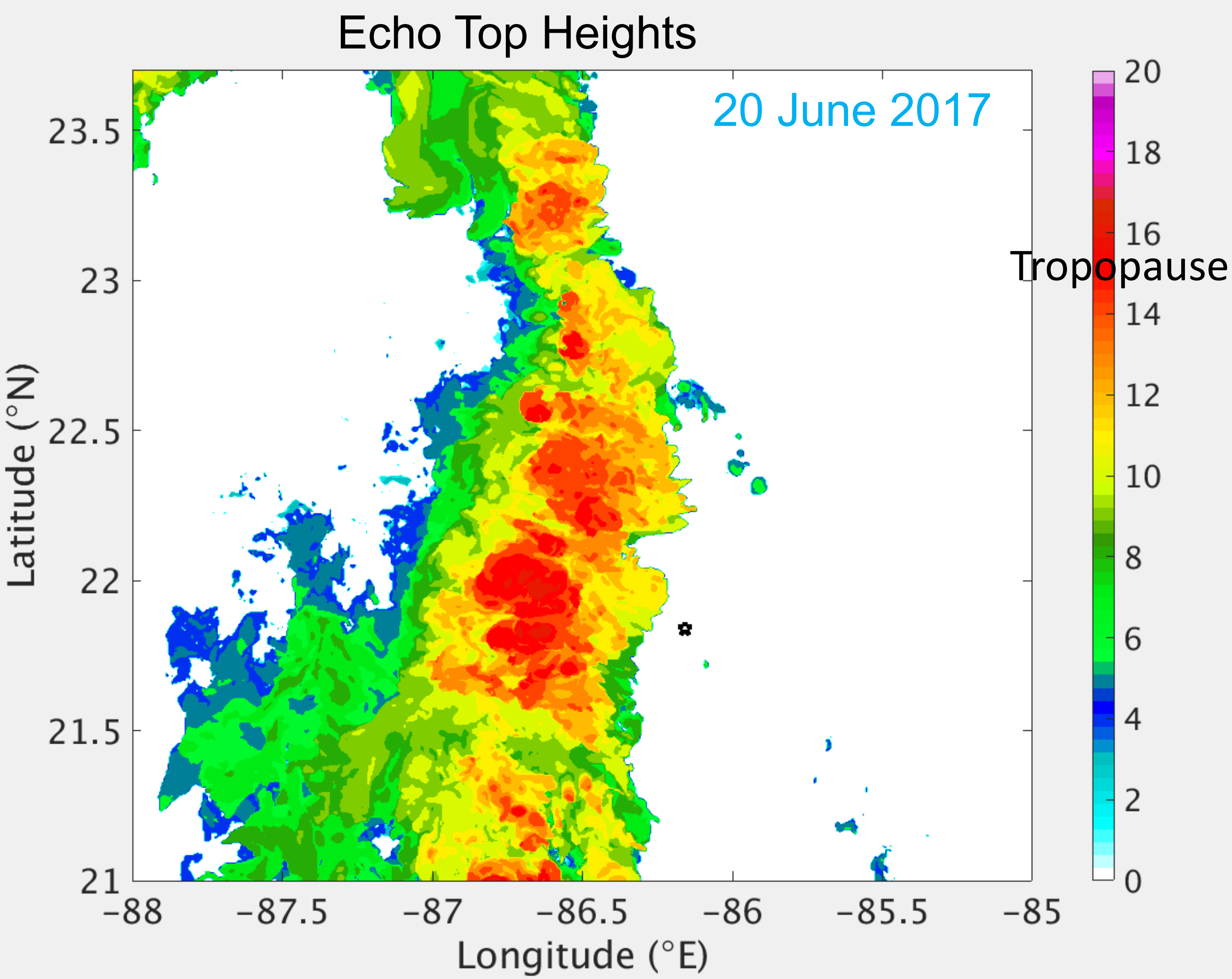
- Large domains to capture the evolution of synoptic and mesoscale features at 10 minute output

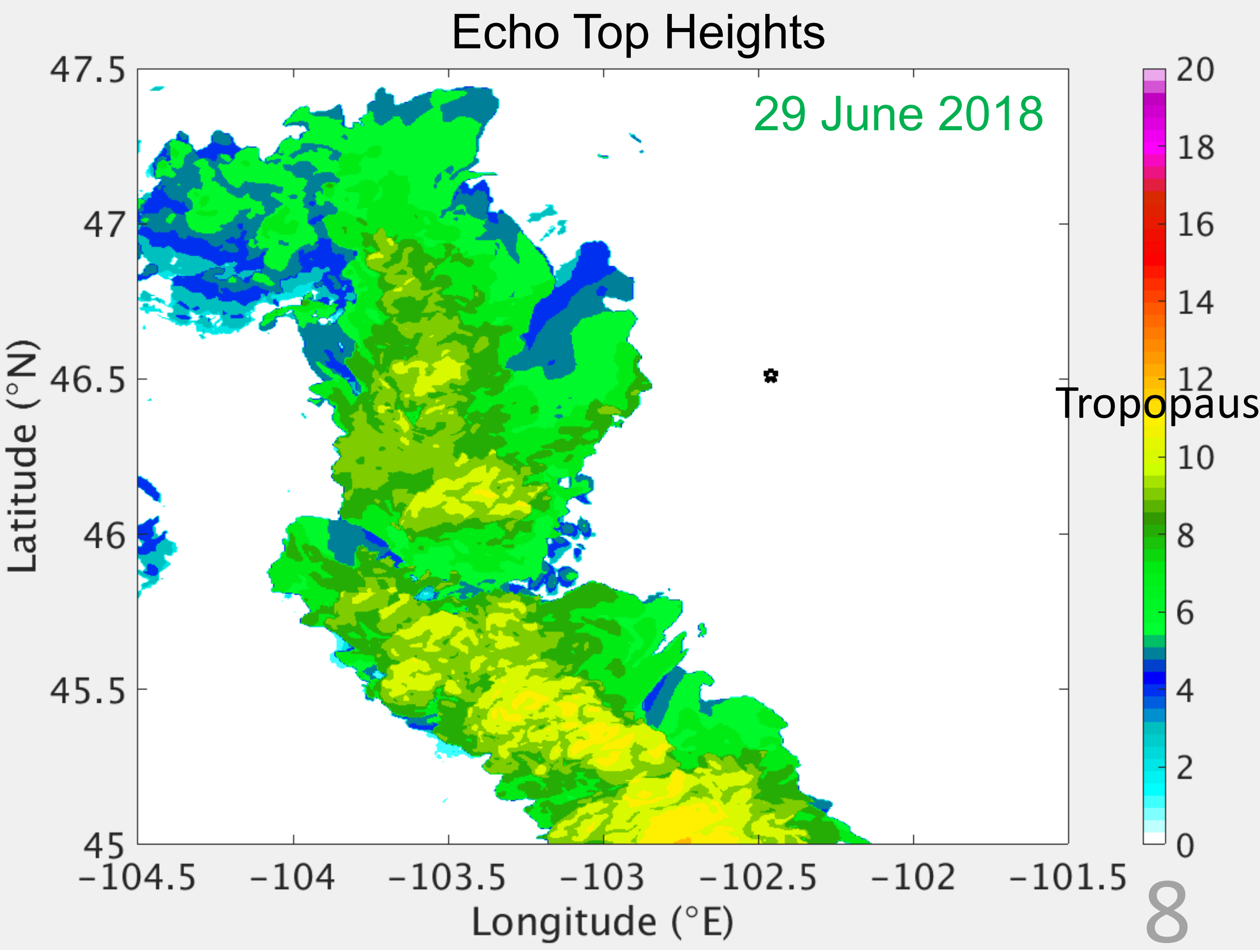
Methodology

Case Day	Location	Probable Cause	# of Grid Points	Cores	Time Step	Run Time/6 hr Sim. Time
03 Aug 2009	Dominican Republic	Flew through a convective updraft	109,024,542	2048	9 sec	~12 hrs
10 Jul 1997	North Dakota	Flew over developing convective updraft	25,714,260	2048	3 sec	~4 hrs
27 Dec 2014	Java Sea	Navigating around severe convection	93,758,148	1024	6 sec	~22 hrs
04 Jun 2018	New Mexico	Flew through a hail core	54,960,192	1024	6 sec	~13 hrs
20 Jun 2017	Gulf of Mexico	Flew between two lines of developing convection	57,629,880	2048	6 sec	~14 hrs
29 Jun 2018	North Dakota	Flew north of severe convection	50,118,750	2048	9 sec	~7 hrs

Results

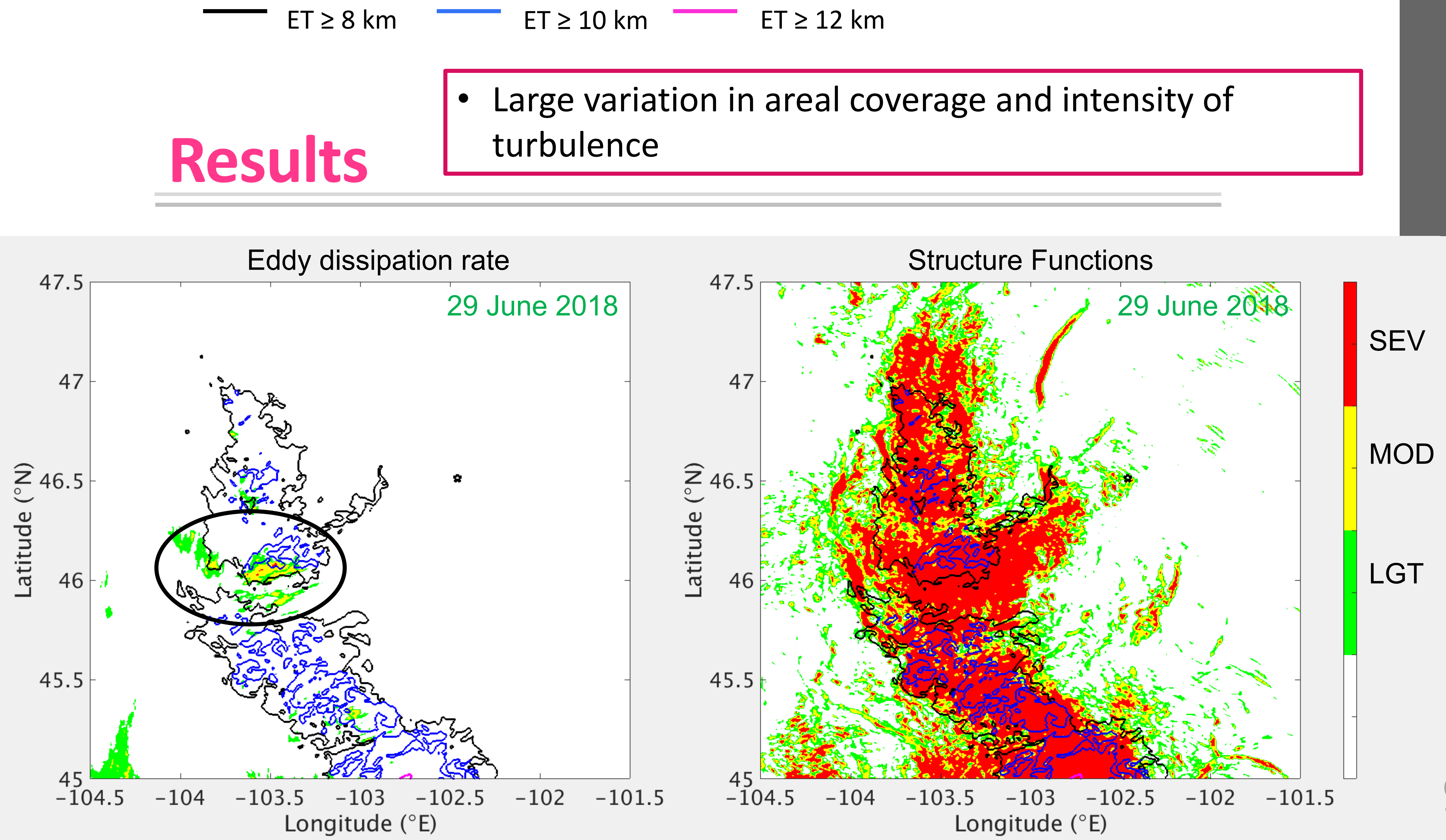
- Small scale features of convection
- Convective depth is related to gravity wave generation





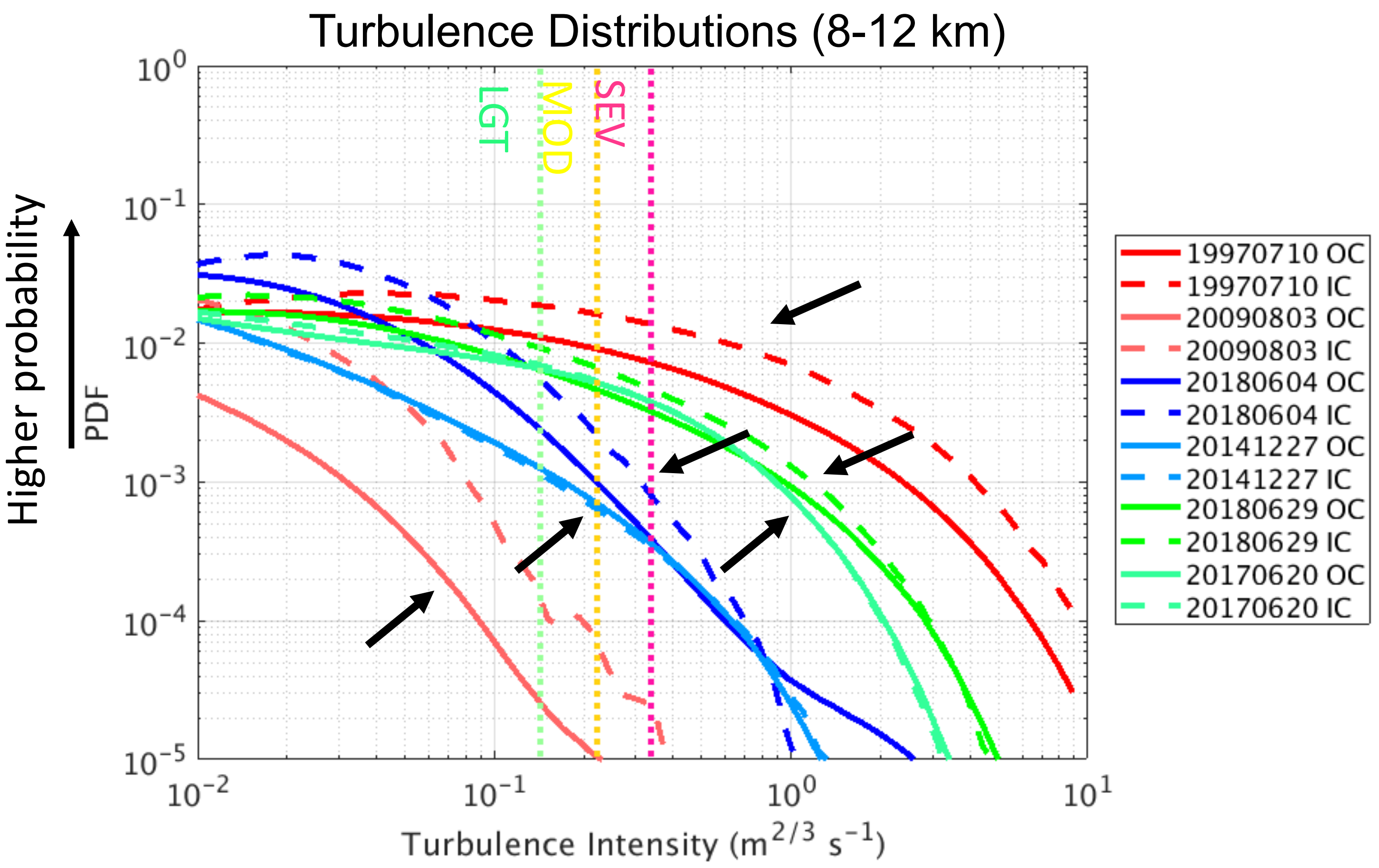
Results

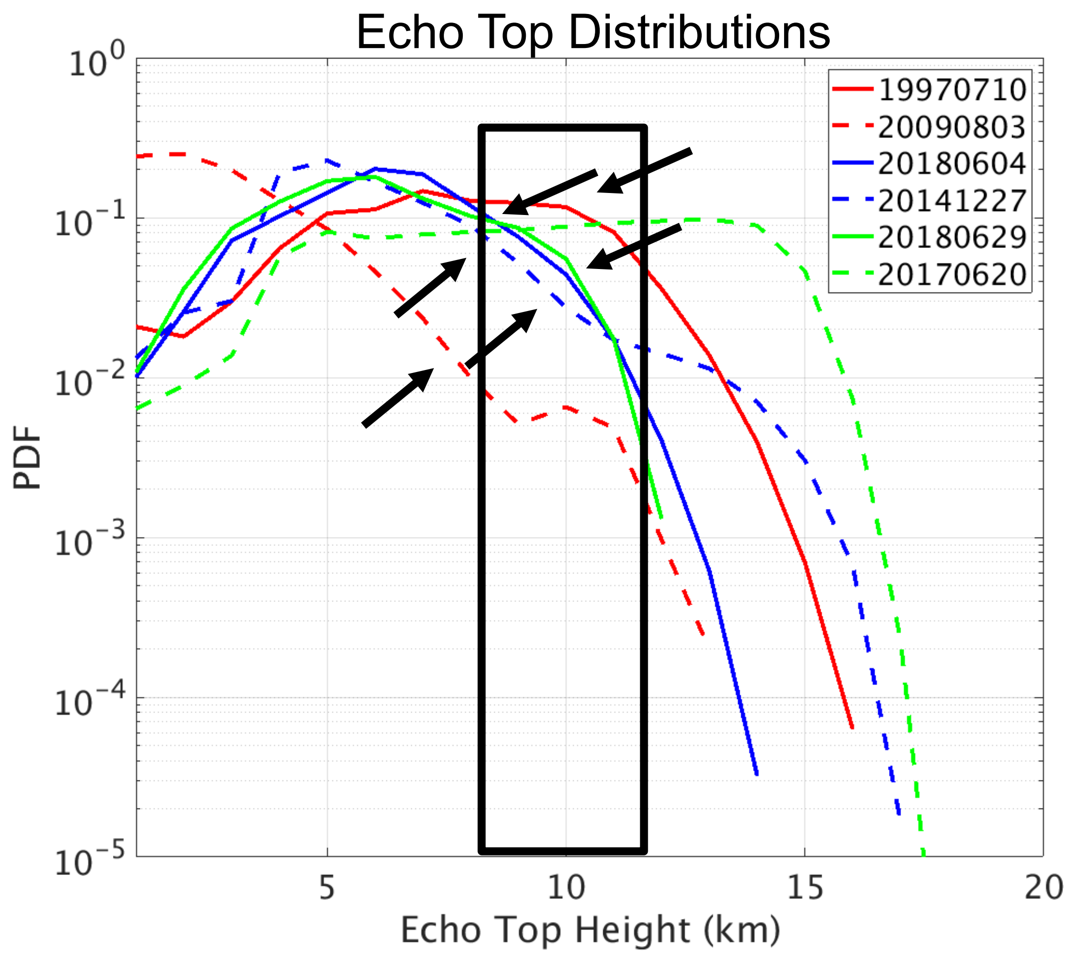
- Large variation in areal coverage and intensity of turbulence



Out-of-cloud (OC)
In-cloud (IC)

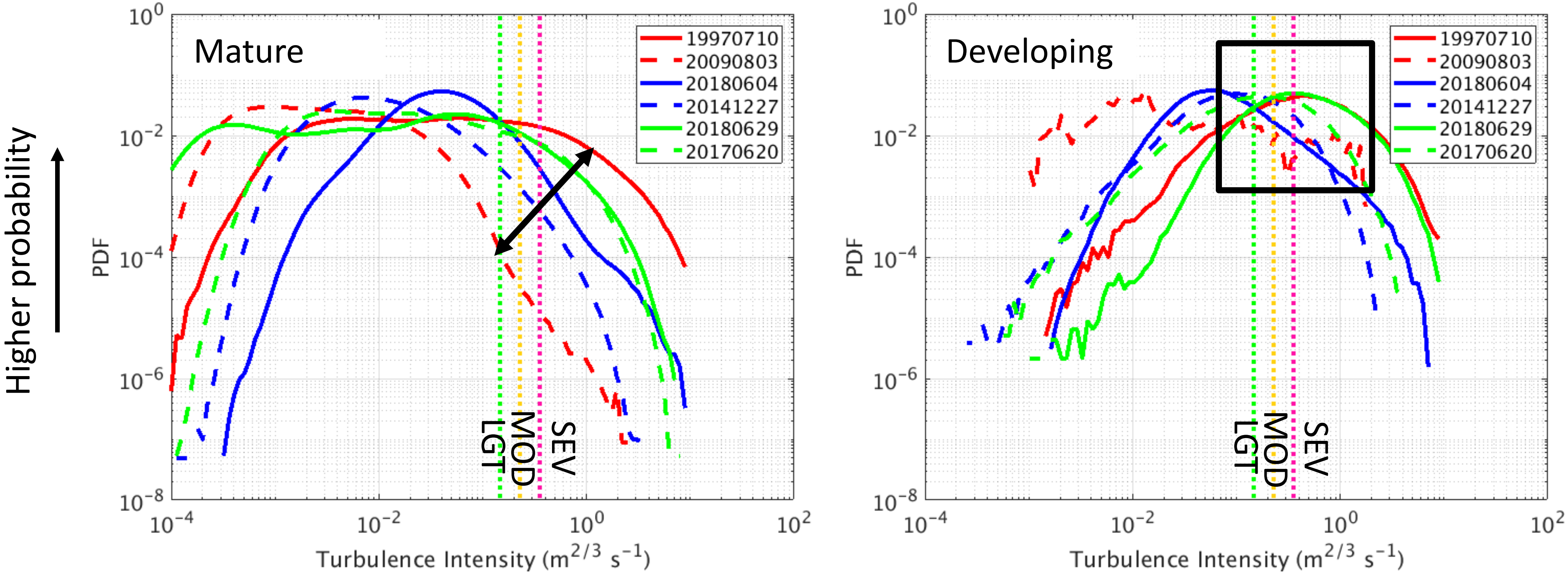
Results





Midlatitude continental cases
Tropical oceanic cases

Results

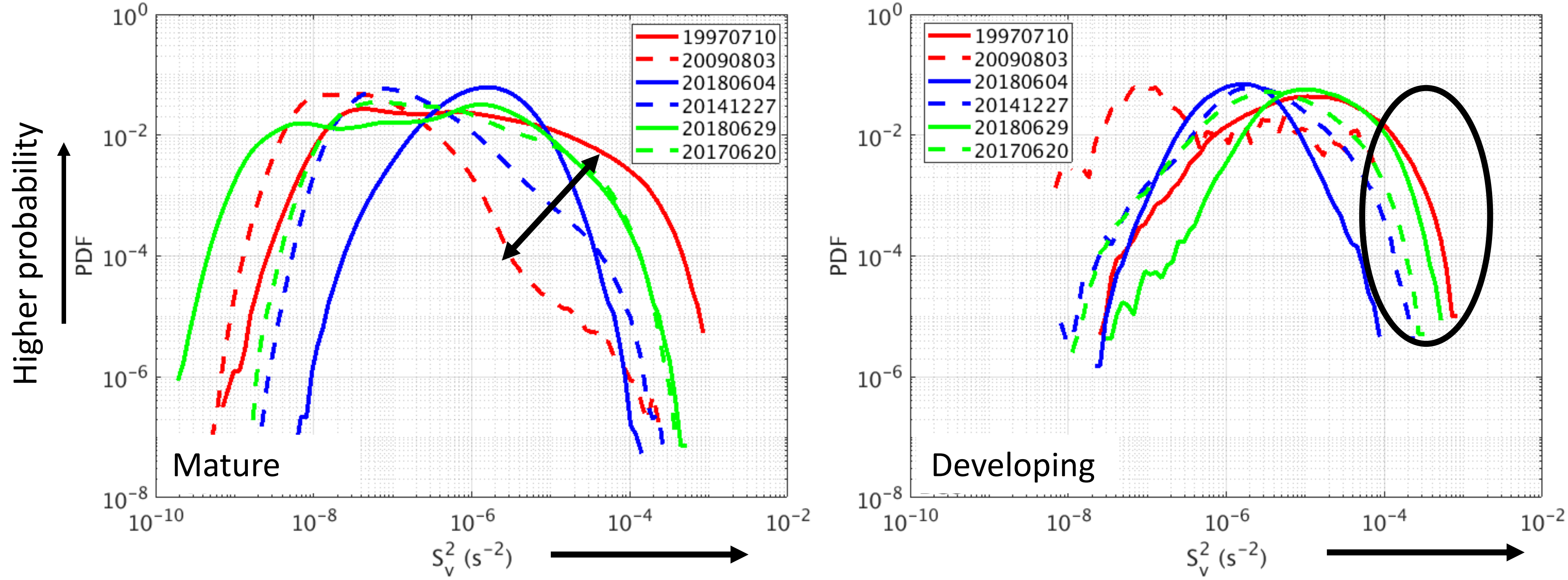


- Turbulence distributions near mature convection vs developing convection
  - Likelihood of stronger turbulence increases near developing COs
  - Tropical turbulence distributions are influenced most by convective stage

Midlatitude continental cases

Tropical oceanic cases

Results



- Vertical wind shear distributions near mature convection vs developing convection
  - Vertical wind shear increases near developing convection for both regions
  - Vertical wind shear is influenced by storm type

Broader Impacts

- FAA Thunderstorm Guidelines
  - Development of guidelines that are region, storm stage, and storm type specific, directional preference
- Limitations of turbulence diagnostics in tropical regimes
- Computational expenses needed to predict turbulence at high resolution
- Need many more simulations to create statistical data base to influence policy change at government level

Conclusions

- Blue Waters was utilized to make high resolution simulations of thunderstorms for six turbulence encounters
- Various turbulence diagnostics were calculated and compared
- Turbulence near developing convection and mature convection was compared
- Environmental stability and vertical wind shear were analyzed near convection
- More research is needed to investigate turbulence near developing convection in the tropics

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