Comparison of Convectively-Induced Turbulence Response Using Prescribed Latent Heating Versus Full Model Physics

Katelyn Barber[1], Claudia Stephan[2], and Gretchen Mullendore[1]

1. University of North Dakota

2. National Centre for Atmospheric Science

17th Annual WRF Users' Workshop

Boulder, CO 2016

Supported by a grant from the Northrop Grumman Corporation and by North Dakota EPSCOR through NSF Grant #IIA-1355466

Motivation

- Convectively-induced turbulence (CIT)
  - Aviation hazard that can cause moderate to severe structural damage to aircraft
- Model resolution dependence
  - Influences turbulence magnitude
  - Coarse operational models cannot resolve CIT processes
  - High resolution models are needed for CIT forecasting
    - Computationally expensive and time consuming
- Can CIT forecasting be improved without need for large time and computational allowances?

Methodology

- Stephan and Alexander (2015) developed a method to model convectively-generated gravity waves based on precipitation fields
  - Successfully verified against upper stratospheric waves
  - Can this method be applied to the troposphere for CIT?

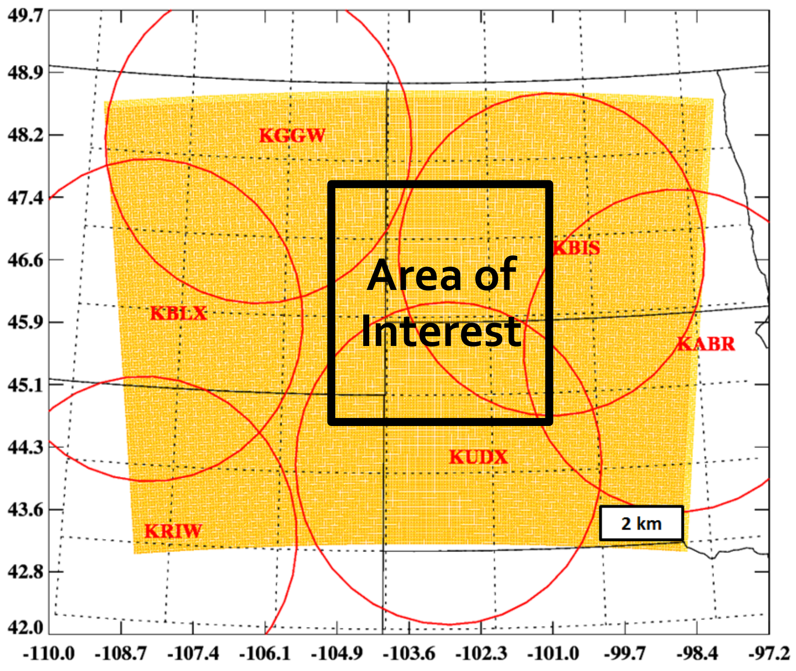
1. *Evaluate CIT using Stephan and Alexander (2015) method on historical cases of CIT
    - 10 July 1997
  - Compared to high resolution simulations ("truth") and "operational-scale" model simulations
2. Application of technique in nowcasting environment

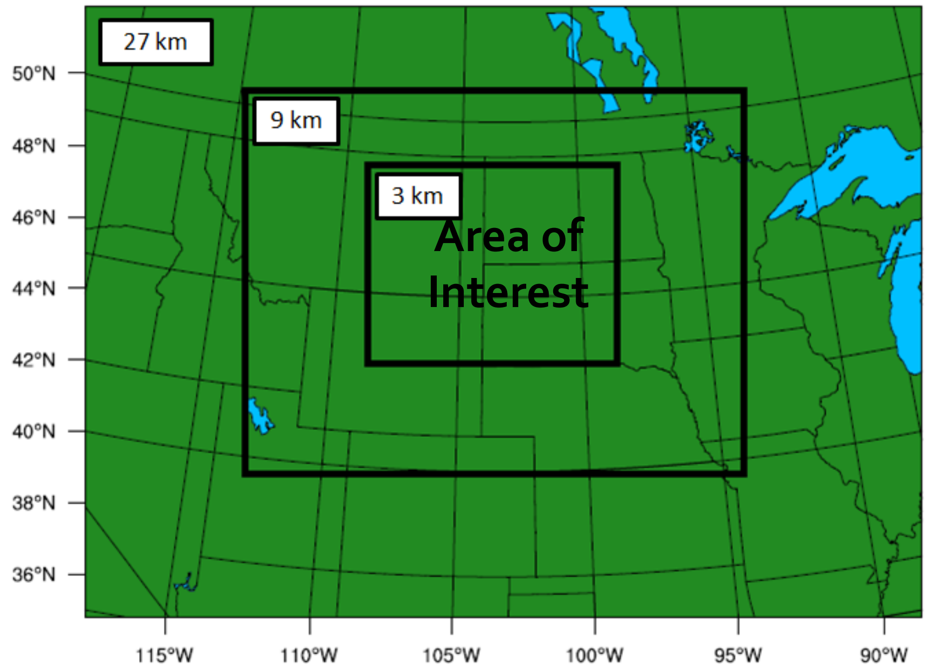
* Today's presentation

Methodology- Stephan and Alexander (2015)

- Substitution of model microphysics scheme with a latent heating field in a dry WRF-Ideal simulation
  - 10 minutes radar-derived precipitation data (Storm Total Rainfall Accumulation Product)
    - Radar data within domain are interpolated in space and time to create mosaic
  - Heating algorithm creates vertical heating/cooling profiles
    - Relationship between precipitation data and known microphysics tendencies
    - Evaluated every 10 minutes
  - Algorithm is only implemented in grid cells where precipitation rate exceeds 1.0 mm per 10 minutes
    - Stephan and Alexander (2014) found this threshold to be a good definition of a convective pixel
- WRF-Ideal run with no cumulus, microphysics, radiation, surface, and planetary boundary layer schemes

Methodology: Simulations





Model	Number of Domains	Horizontal Resolution	Vertical Levels	Model Top	Damping Layer
WRF-Ideal	1	2 km	101	~ 35 km	10 km
WRF Full Physics	3	4.5, 1.5 km, 500 m	100	~ 31 km	10 km
	3	27, 9 , 3 km	91	~31 km	10 km

Stephan and Alexander Method

“High Resolution”

“Operational-Scale”

Case Overview

- 10 July 1997
  - Well documented and investigated (Lane et al. 2003; Lane and Sharman 2006; Lane and Sharman 2008)
  - Commercial aircraft experienced severe turbulence near Dickinson, North Dakota
    - Out of cloud turbulence
    - Aircraft was maneuvering between scattered thunderstorms and passed over a maturing deep convective cloud
      - Cell had overshot into the tropopause near the location of the aircraft (~ 11 km)

Turbulence Intensity Calculation

- Eddy dissipation rate: Turbulence metric popular with aviation
  - Is not dependent on aircraft size, type, or speed (Poellot and Grainger 1991; Emanuel et al. 2013)

- $EDR = (TKE^{3/2}/L)^{1/3}$ ($m^{2/3}$ s^{-1})
  - TKE: Turbulent kinetic energy (m^2 s^{-2})
    - Predicted subgrid-scale TKE by diagnosing gradient Richardson number (Janijć 2002)
  - L: Length scale (m)
    - 336 m (Ahmad and Proctor 2012)

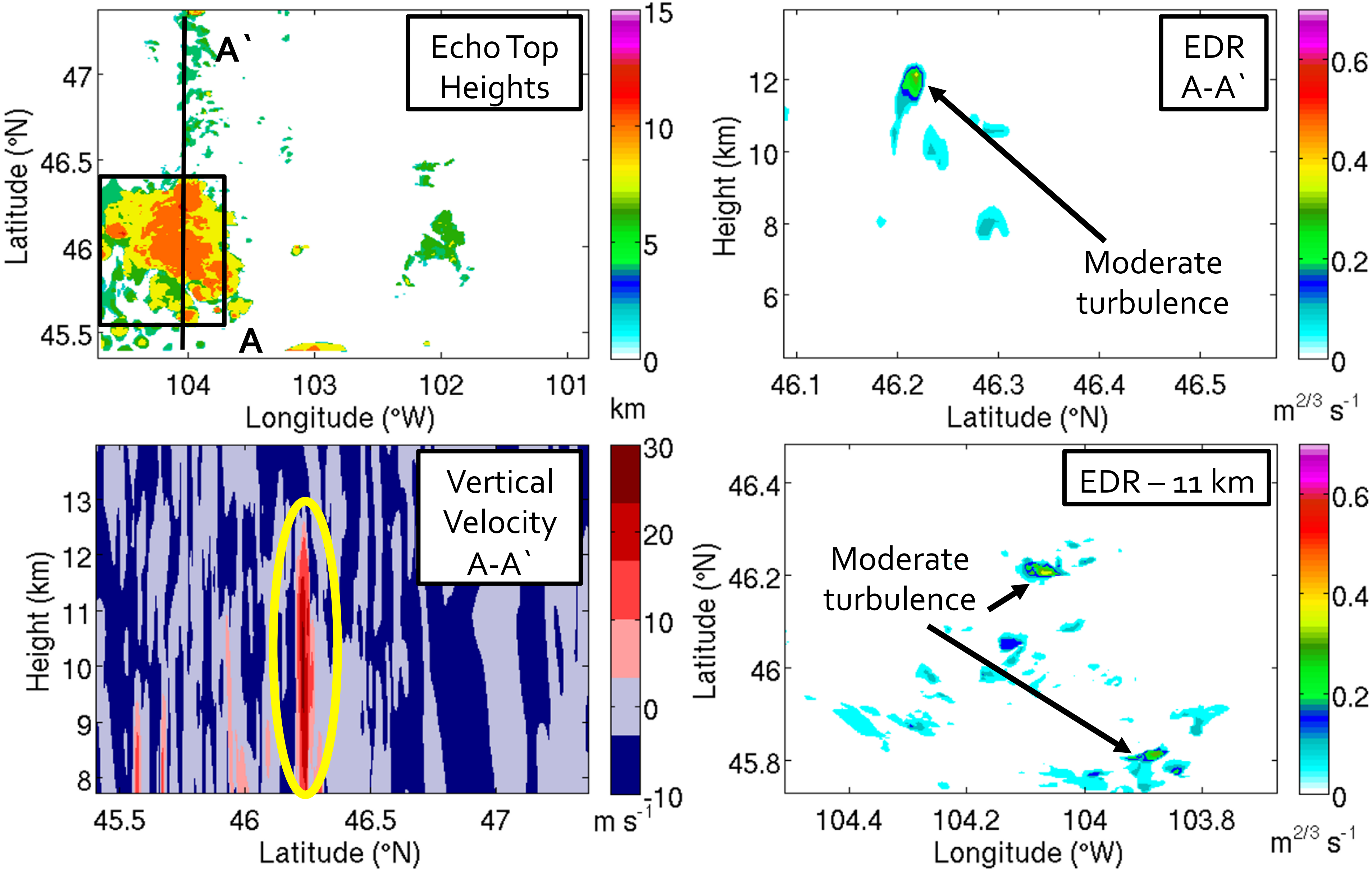
Turbulence Intensity	EDR ($m^{2/3}$ s^{-1})
Light	0.1-0.3
Moderate	0.3-0.5
Severe	0.5-0.7
Extreme	> 0.7

(Lane et al. 2012)

Results: High Resolution

WRF-Full Physics (500 m) 21:40 UTC

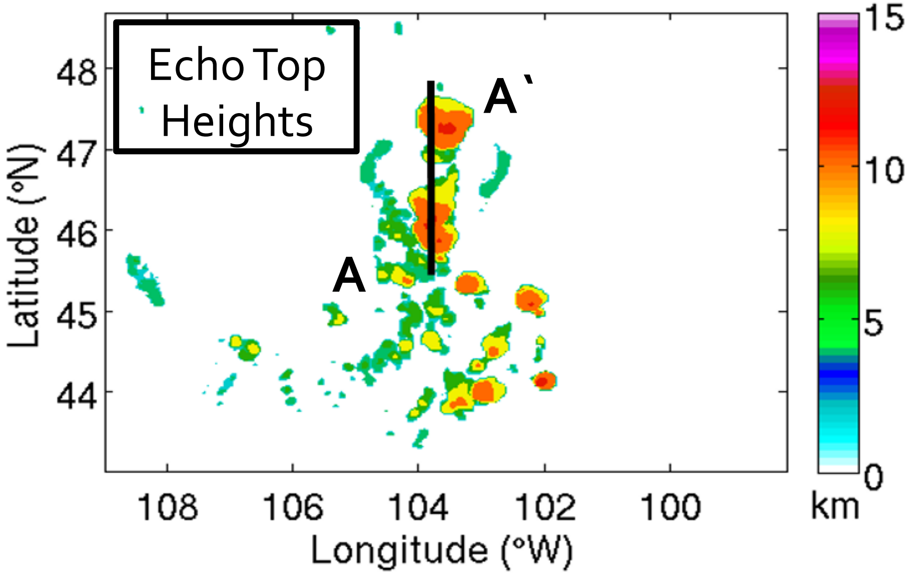
- Moderate turbulence near 12.1 km
  - In cloud
- Limited light turbulence near convection
- Aircraft would have experienced moderate turbulence if flying near 11 km
  - Avoid turbulence by increasing flight level to above 13 km
  - Lateral avoidance of 25 nm would suffice

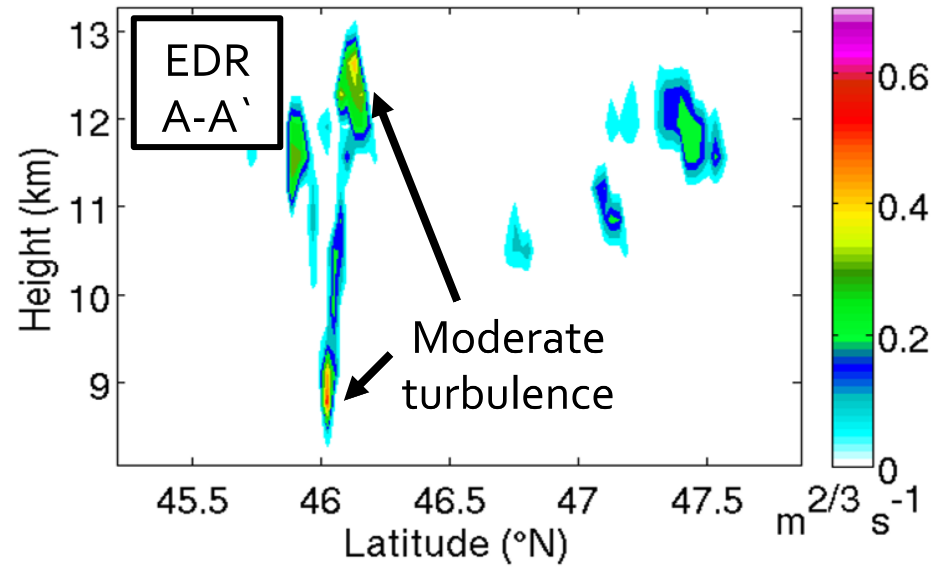


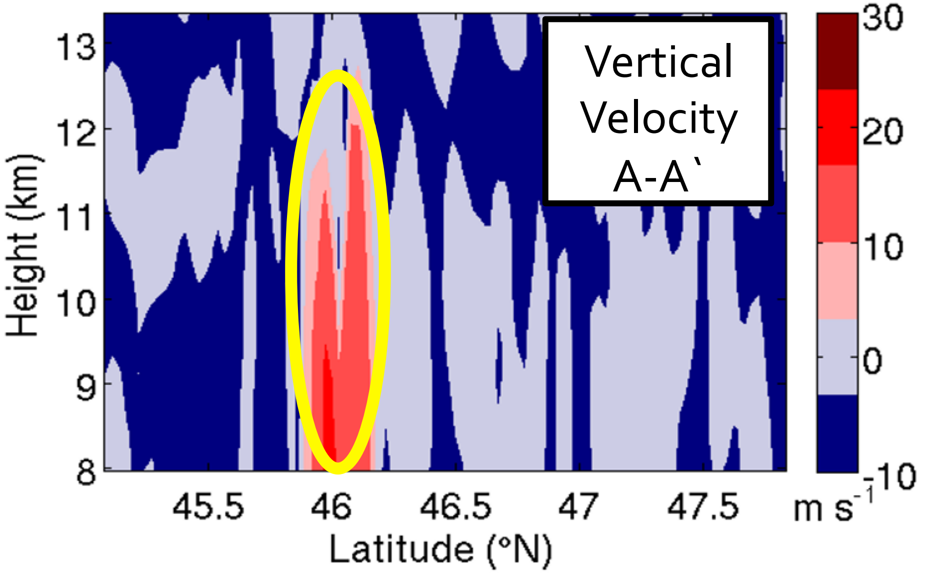
Results: Operational-Scale Hindcast

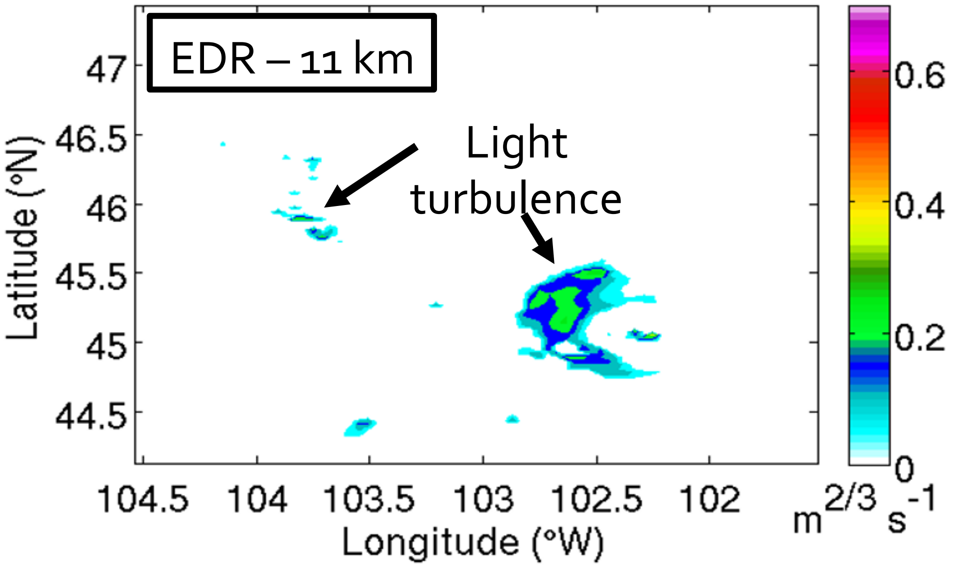
WRF-Full Physics (3km) 21:40 UTC

- Moderate turbulence near 9 and 12.5 km
    - In cloud
- Limited light turbulence near convection
- Aircraft would have experienced turbulence if flying near 11 km
    - Avoid turbulence by increasing flight level to above 13 km
    - Lateral avoidance of 25 nm would suffice





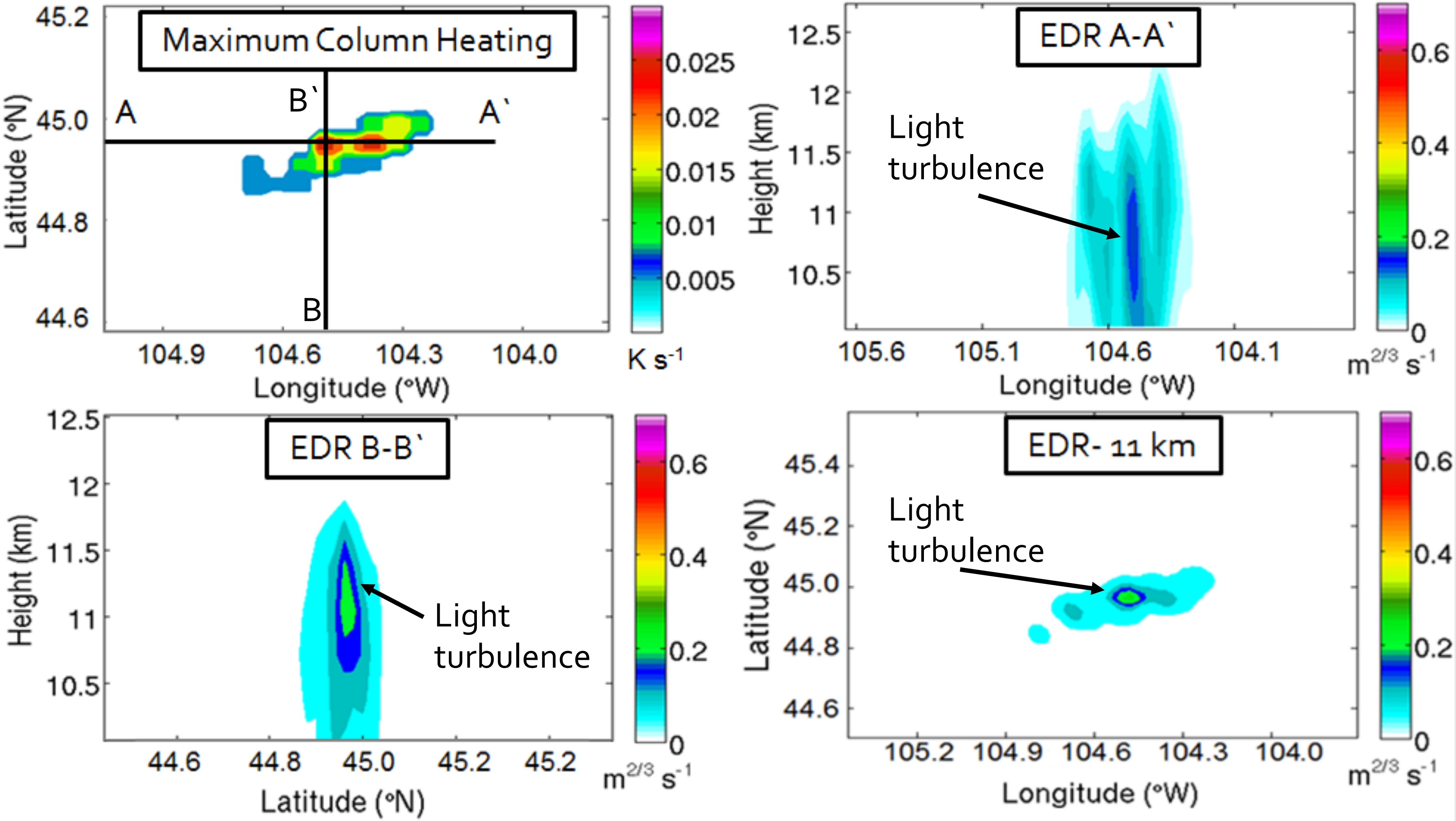




*Echo top heights are shown at 22 UTC

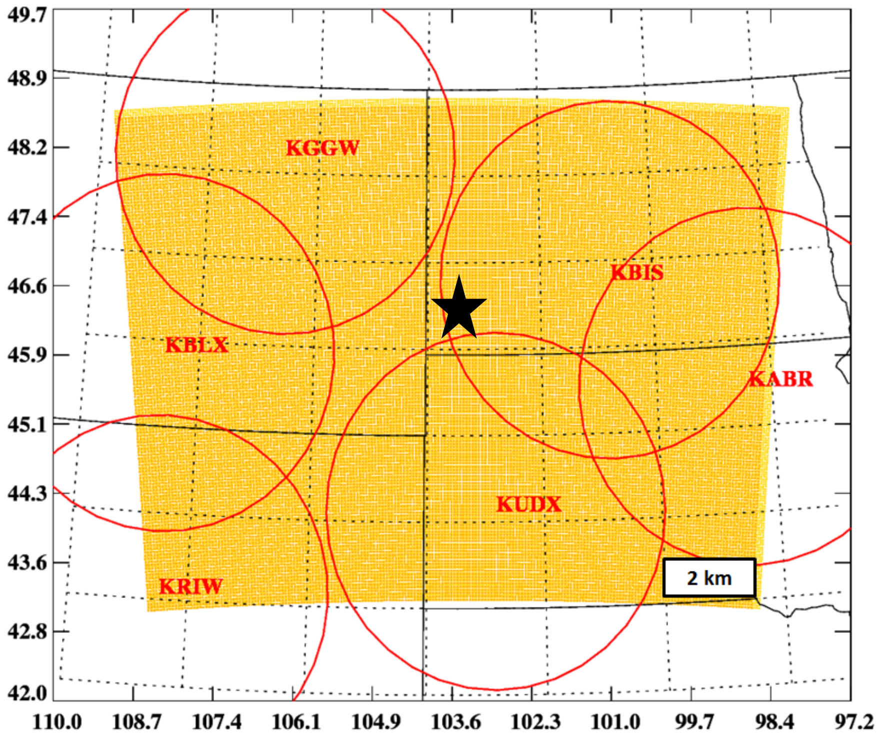
Results: Stephan and Alexander Method

- Light turbulence up to 11.7 km
    - In cloud
    - Limited turbulence above convection
    - Limited areal coverage
- Aircraft flying at 11 km would have experienced light turbulence
    - Avoid turbulence by increasing flight level or circumnavigating area



Discussion: Stephan and Alexander Method

- Turbulence intensity identified is weaker than observations showed
- Actual event took place where only one radar covers area
  - Radar gaps
  - Influence on the simulation
- Increase in observations→ more information to generate latent heating profiles
  - Resolution of radar data
  - Accuracy of radar-derived precipitation amounts
- Investigation of other historical CIT cases where more radars are in use
- Simplified heating profiles



Conclusions

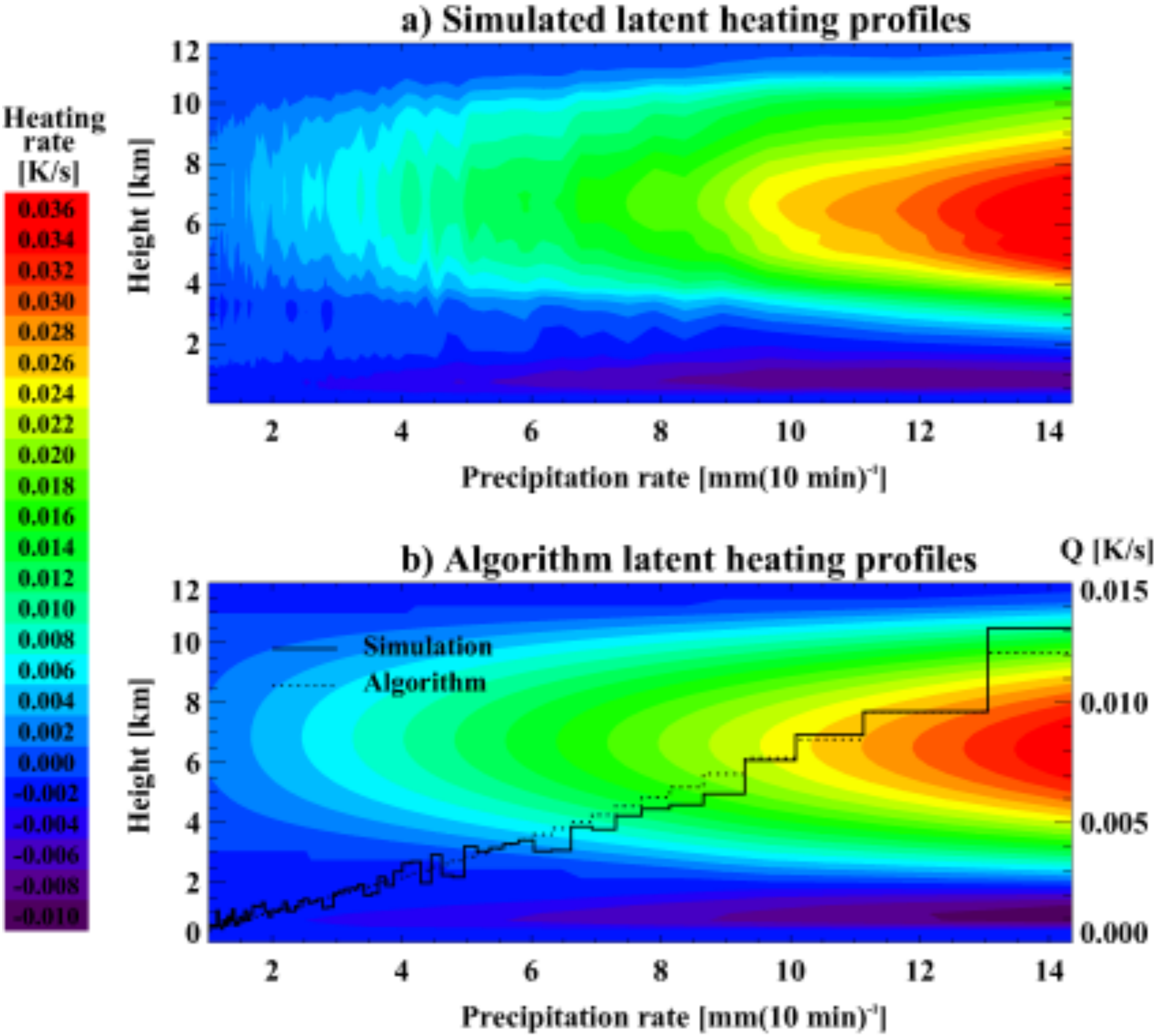
- High resolution and operational-scale simulations produced moderate intensity turbulence
  - "Operational-scale" simulation uses 91 vertical levels and physics settings shown to improve turbulence forecasting
    - Results if "operational-scale" simulation uses more common model physics and set up (Future work)
- Stephan and Alexander (2015) method only produced light turbulence at time of aircraft incident
  - Radar coverage limitations
  - Simplified heating profiles
  - More cases needed to validate new technique against more traditional approaches of forecasting CIT
  - Method has been successful in gravity wave identification in the upper troposphere and stratosphere in previous studies

References

- Ahmad, N. N., and F. H. Proctor, 2011: Large eddy simulations of severe convection induced turbulence. *AIAA*, 2011-3201.
- Emanuel, M., J. Sherry, S. Catapano, L. Cornman, and P. Robinson, 2013: In situ performance standard for eddy dissipation rate. Preprint and Recording, *16th Conf. Aviation, Range, and Aerospace Meteor.*, Austin, TX, Amer. Meteor. Soc., 11.3.
- Federal Aviation Administration, 2012: FAA aeronautical information manual. Chapter 7. [Available online at www.aa.gov/air_traffic/publications/atpubs/aim/].
- Golding, W. L., 2000: Turbulence and its impact on commercial aviation. *J. Aviation/Aerospace Edu. & Res.*, 11.2.
- Janjić, Z. I., 2002: Nonsingular implementation of the Mellor-Yamada level 2.5 scheme in the NCEP Meso model. NCEP Office Note No. 437, 61 pp.
- Lane, T. P., R. D. Sharman, T. L. Clark, and H. M. Hsu, 2003: An investigation of turbulence generation mechanisms above deep convection. *J. Atmos. Sci.*, **60**, 1297-1321.
- Lane, T. P., and R. D. Sharman, 2006: Gravity wave breaking, secondary wave generation, and mixing above deep convection in a three-dimensional cloud model. *Geophys. Res. Lett.*, **33**, L23813.
- Lane, T. P., and R. D. Sharman, 2008: Some influences of background flow conditions on the generation of turbulence due to gravity wave breaking above deep convection. *J. Appl. Meteor. Climatol.*, **47**, 2777-2796.
- Lane, T. P., R. D. Sharman, S. B. Trier, R. G. Fovell, and J. K. Williams, 2012: Recent advances in the understanding of near cloud turbulence. *Bull. Amer. Meteor. Soc.*, **93**, 499-515.
- Poellot, M. R., and C. A., Grainger, 1991: A comparison of several airborne measures of turbulence. Preprint, *4th International Conference of the Aviation Weather Systems*, Amer. Meteor. Soc., Paris, France.
- Stephan, C., and M. J. Alexander, 2015: Realistic simulations of atmospheric gravity waves over the continental U.S. using precipitation radar data. *J. Adv. Model. Earth Syst.*, **7**, 823-835.

Extra Slides

- RRTM, Dudhia, Kain Fritsch, Noah Land Surface model, MYJ, WDM6, ETA similarity
- Claudia's 2014 paper did not find much difference when using different microphysics schemes to make heating algoritm
  - Did not critically affect gravity wave momentum flux spectra
  - Chose Morrison
- Claudia uses MERRA data to initialize her run
- A half sine profile, which is considered representative for convective rainfall [*Shige et al*., 2004], was chosen for the shape of the vertical heating distribution. The amplitude of the profiles was determined by the column-integrated heating which in turn was calculated from the observed precipitation
- Our heating algorithm is based on the heating profiles generated by a full-physics WRF model and therefore inherently includes advection, ice-phase processes, or evaporation



a) Simulated latent heating profiles
b) Algorithm latent heating profiles
Heating rate [K/s]
0.036
0.034
0.032
0.030
0.028
0.026
0.024
0.022
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
-0.002
-0.004
-0.006
-0.008
-0.010
Height [km]
Precipitation rate [mm(10 min)-1]
Q [K/s]
Simulation
Algorithm

Results: WRF-Ideal Radar-Derived Latent Heat 23:20 UTC

- Moderate turbulence above 12 km
  - In cloud (12-13 km)
- Light turbulence up to 15 km above convection
  - Out of cloud
- Severe turbulence at 13 km
  - Out of cloud
  - West of cell
- Aircraft would have experienced turbulence if attempted to fly over cell
  - Lateral avoidance more than 25 nm would be needed