Studies of convectively induced turbulence

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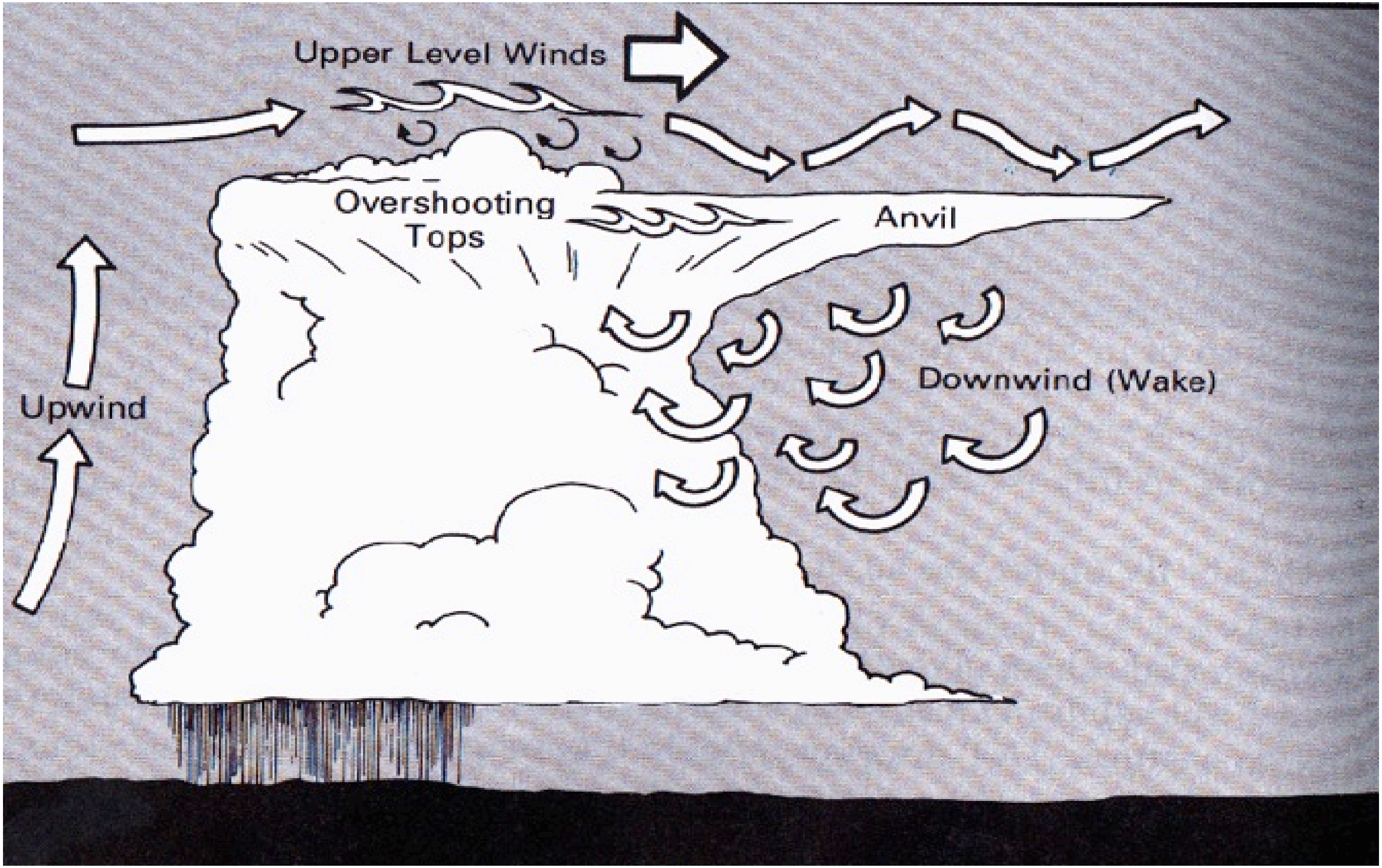
Turbulence Impact Mitigation Workshop V3. McLean VA 5-6 Sep 18

INTRODUCTION / MOTIVATION



From Lester 1994, Turbulence: A new perspective for pilots

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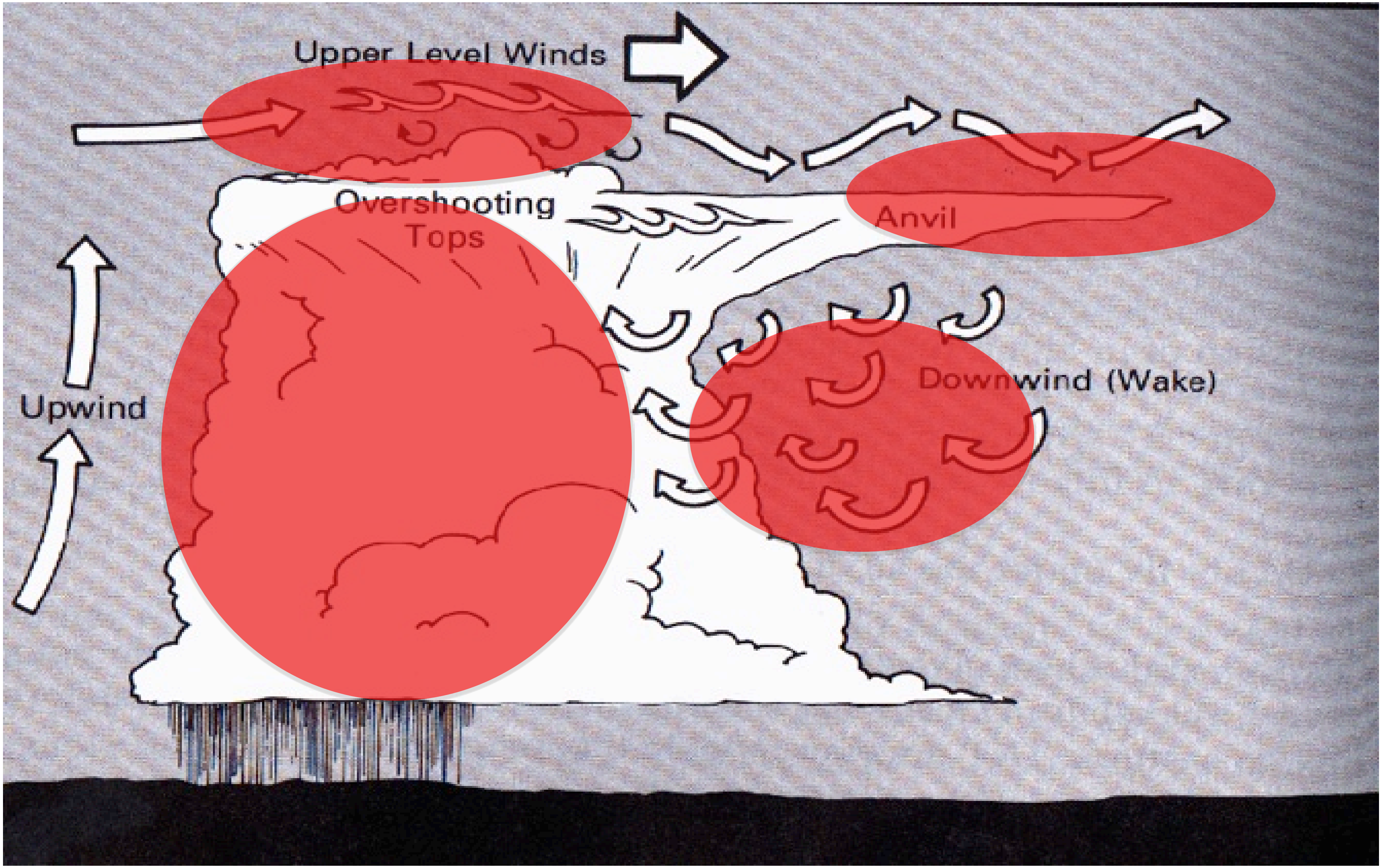

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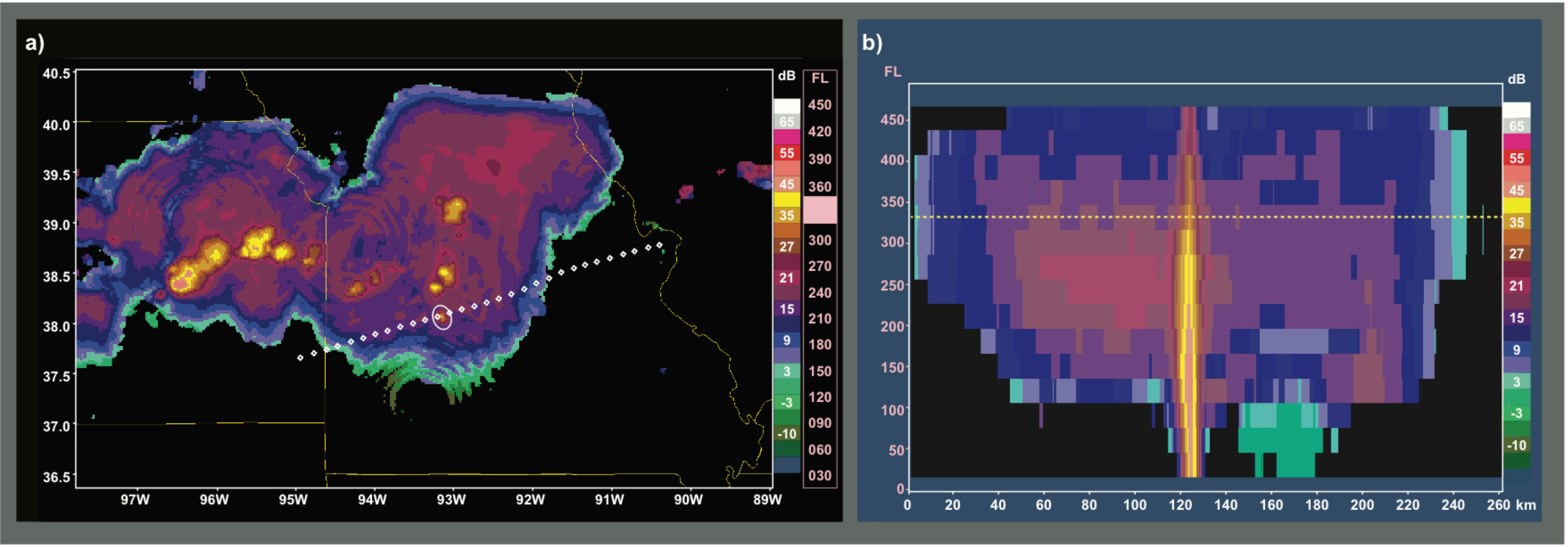
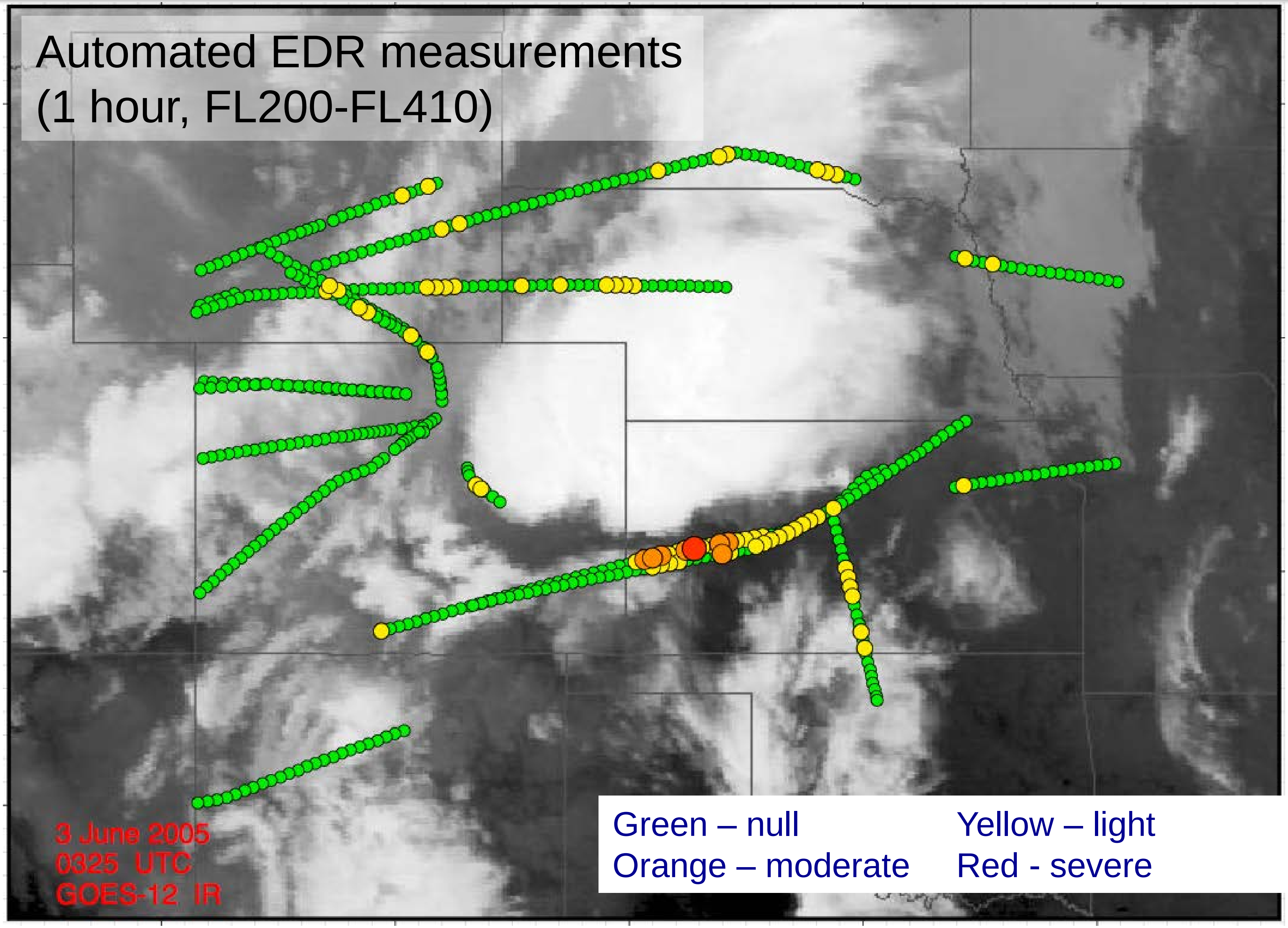
Example cases of convectively induced turbulence (CIT)

21 injuries over Missouri: in-cloud CIT



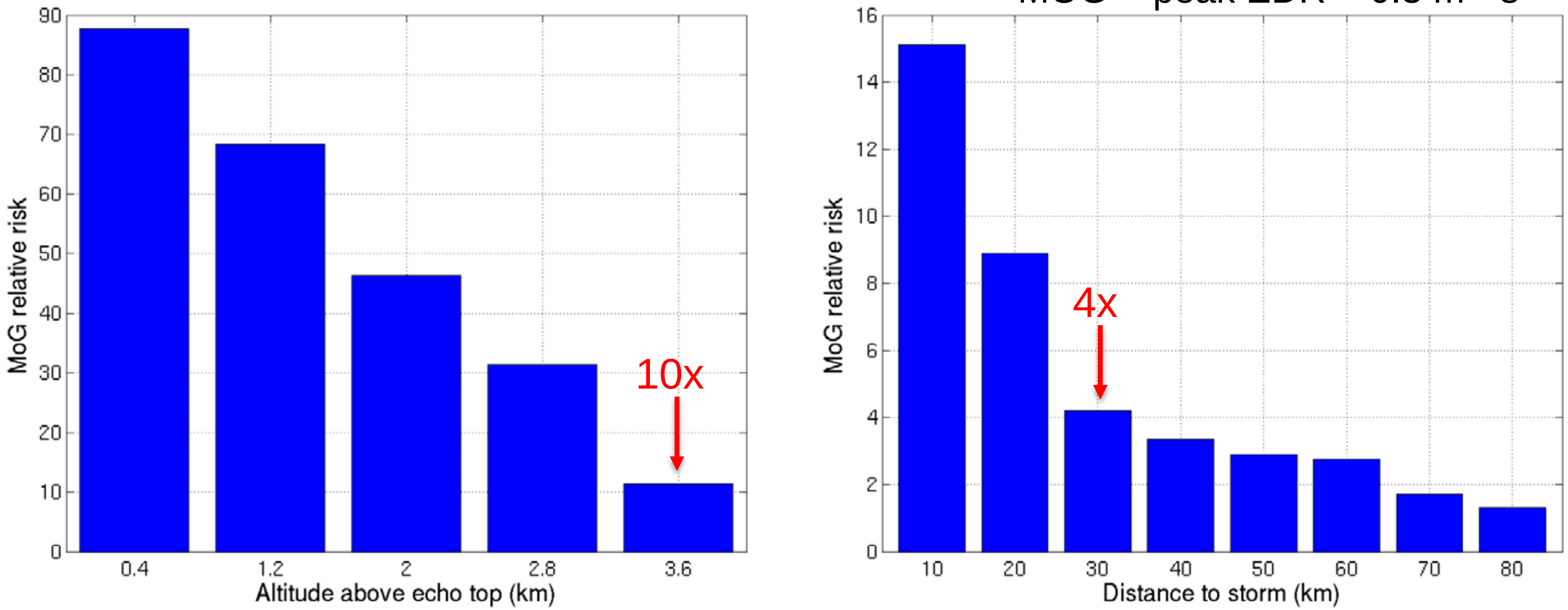
20 July 2010, Washington DC to LAX

Example cases of convectively induced turbulence (CIT)



Risk of Moderate-or-Greater (MOG) turbulence relative to storms

MOG = peak EDR > 0.3 $m^{2/3}s^{-1}$



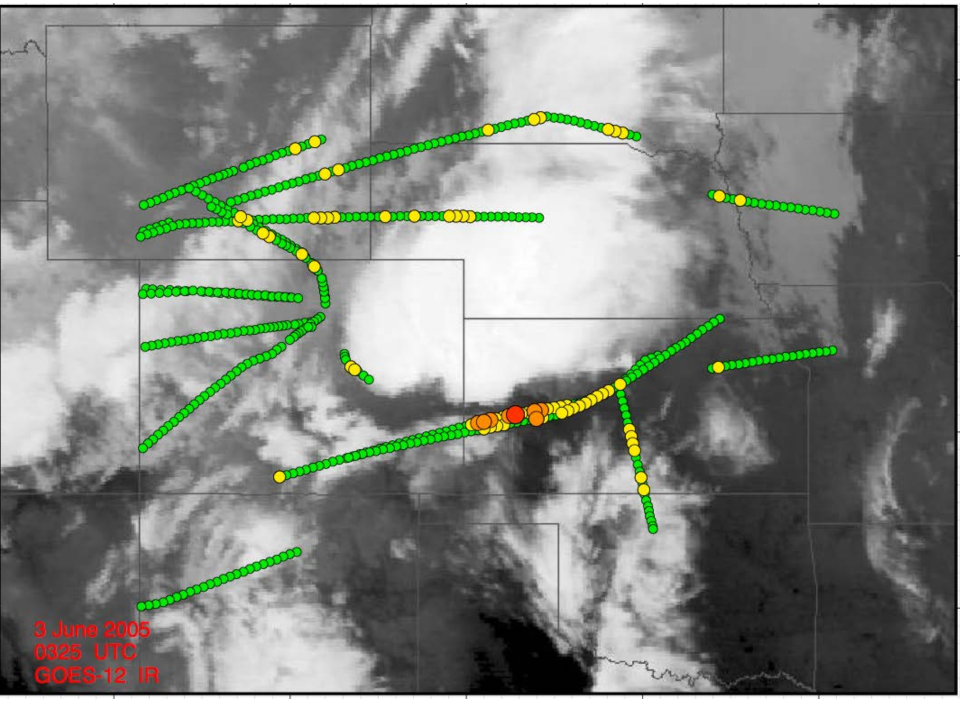
EDR-derived measurements over the USA compared to NEXRAD derived cloud boundaries

- > 7 million peak EDR reports for 2004 - 2005 warm seasons (May-Oct) between 25-42,000 ft.
- ‘Relative risk’ refers to background occurrence (0.03% of all reports are MOG).
    - E.g., relative risk of 10 means that MOG is 10x more likely to occur at that location
- Significantly enhanced risk (10x) at 12,000 ft (3.6 km) above cloud
- MOG 4x more likely at ~20 miles (30 km) from storm – c.f. FAA guidelines
- 50 % of MOG reports are within 100 km of storms

Analysis by John Williams - from Lane et al. (2012, BAMS)

HIGH-RESOLUTION SIMULATIONS TO UNDERSTAND GENERATION

Observations



Severe report at:

- 0319 UTC
- 38,000 ft (=11.9 km above sea level)
- ~31 miles (50 km) from cloud boundary

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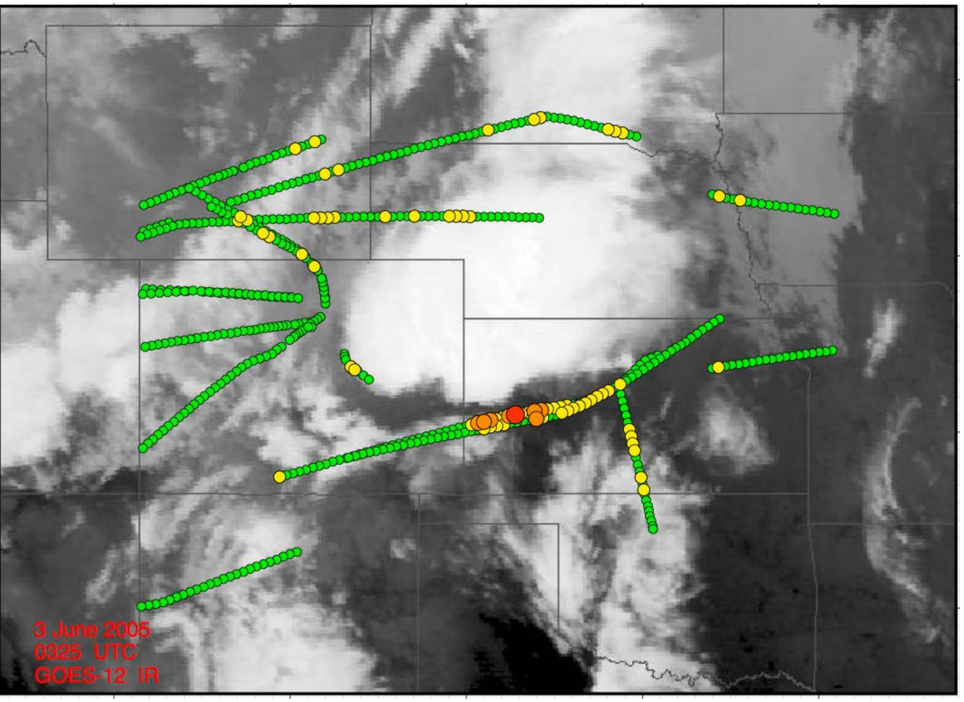

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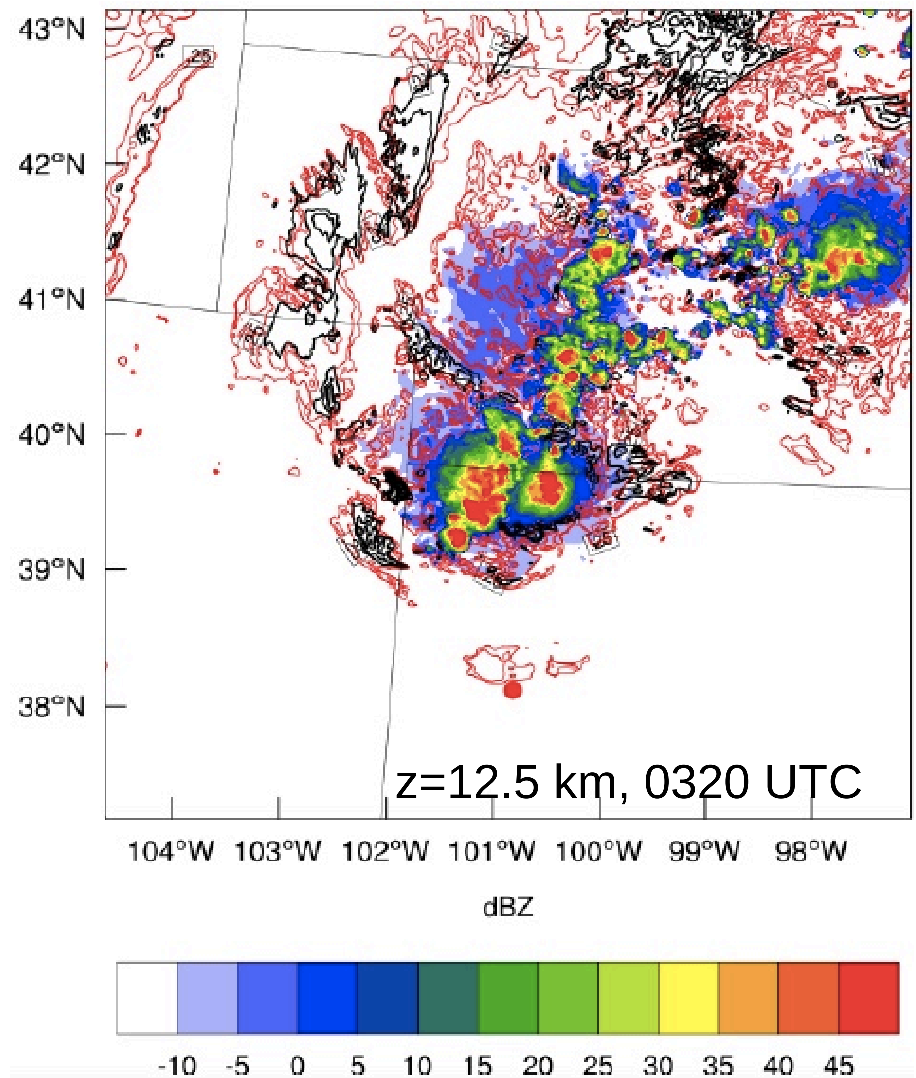
1.1 km resolution simulation (WRF)

Radar reflectivity (colors)
Turbulence Kinetic Energy (red lines)
Low Richardson number (black lines)



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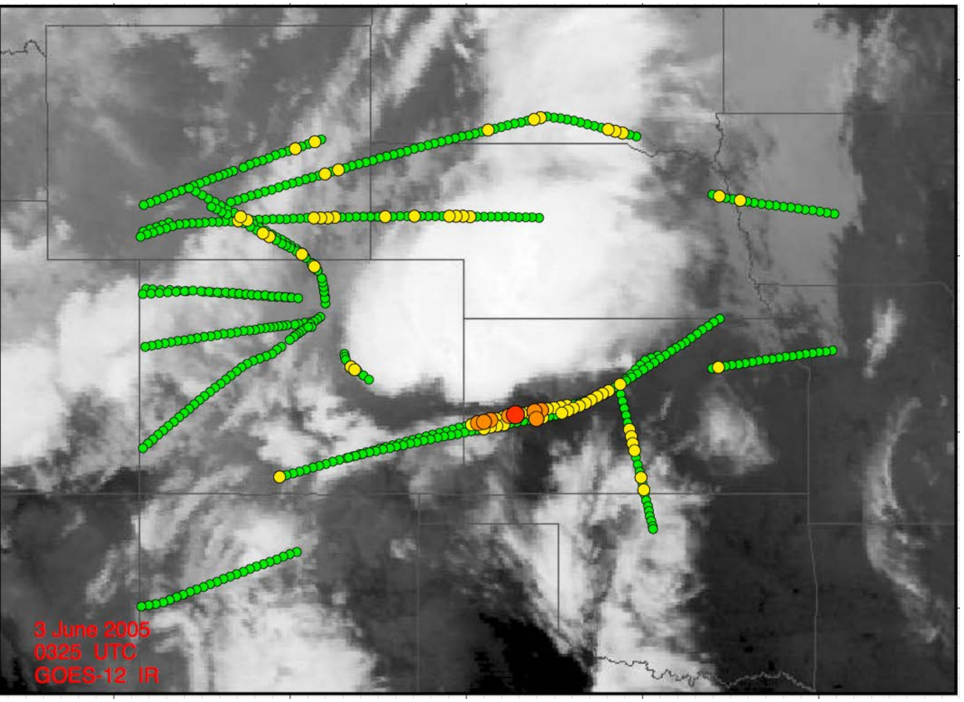

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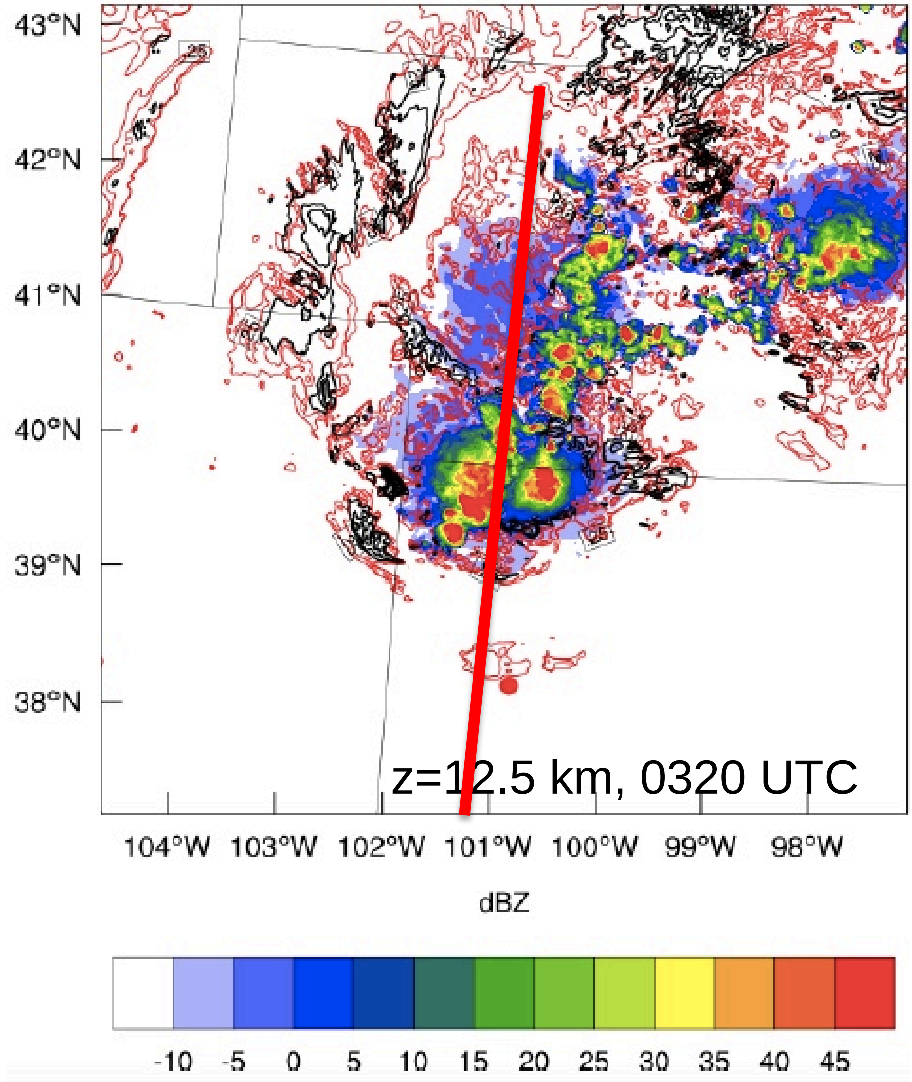

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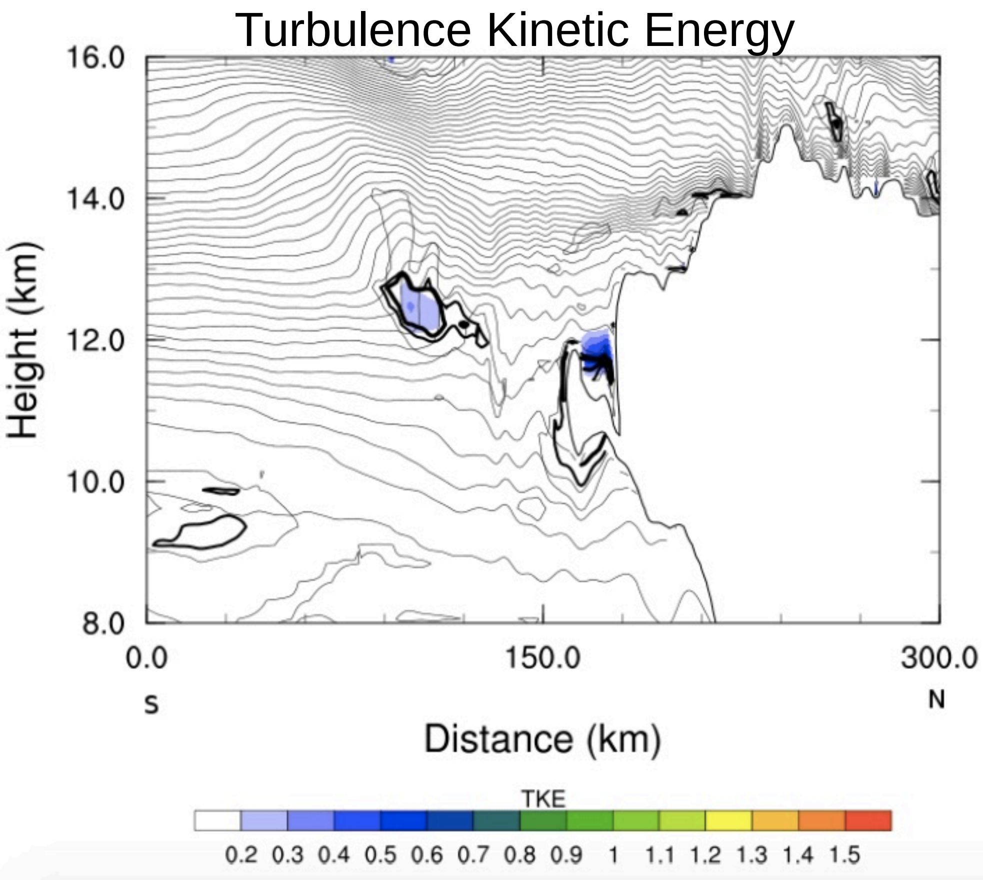
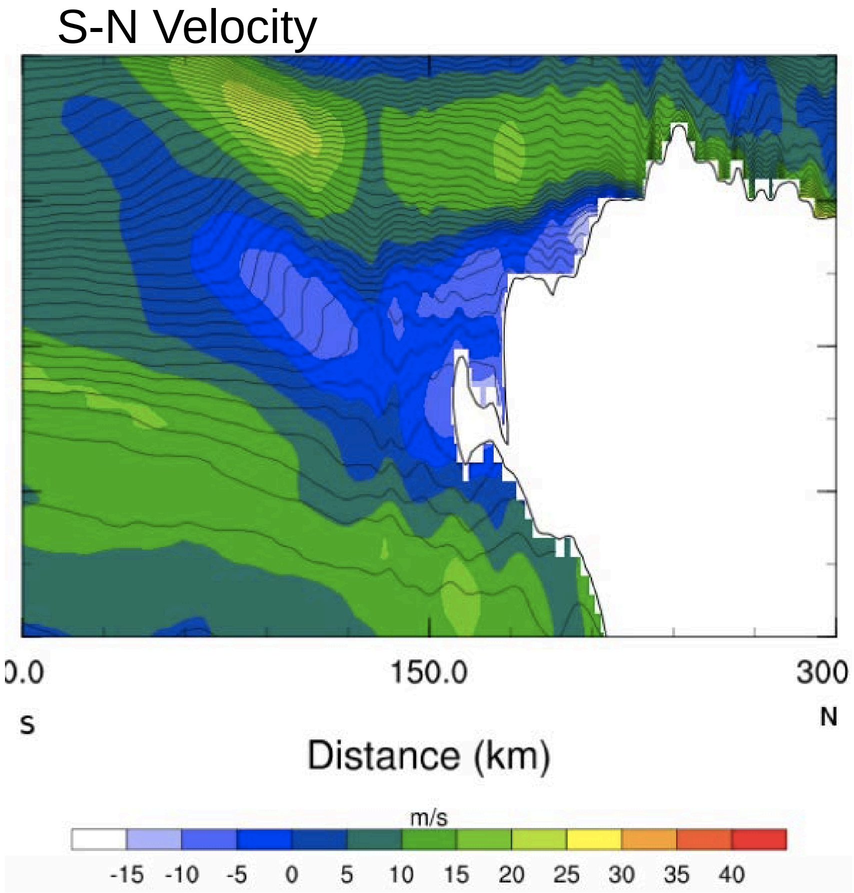


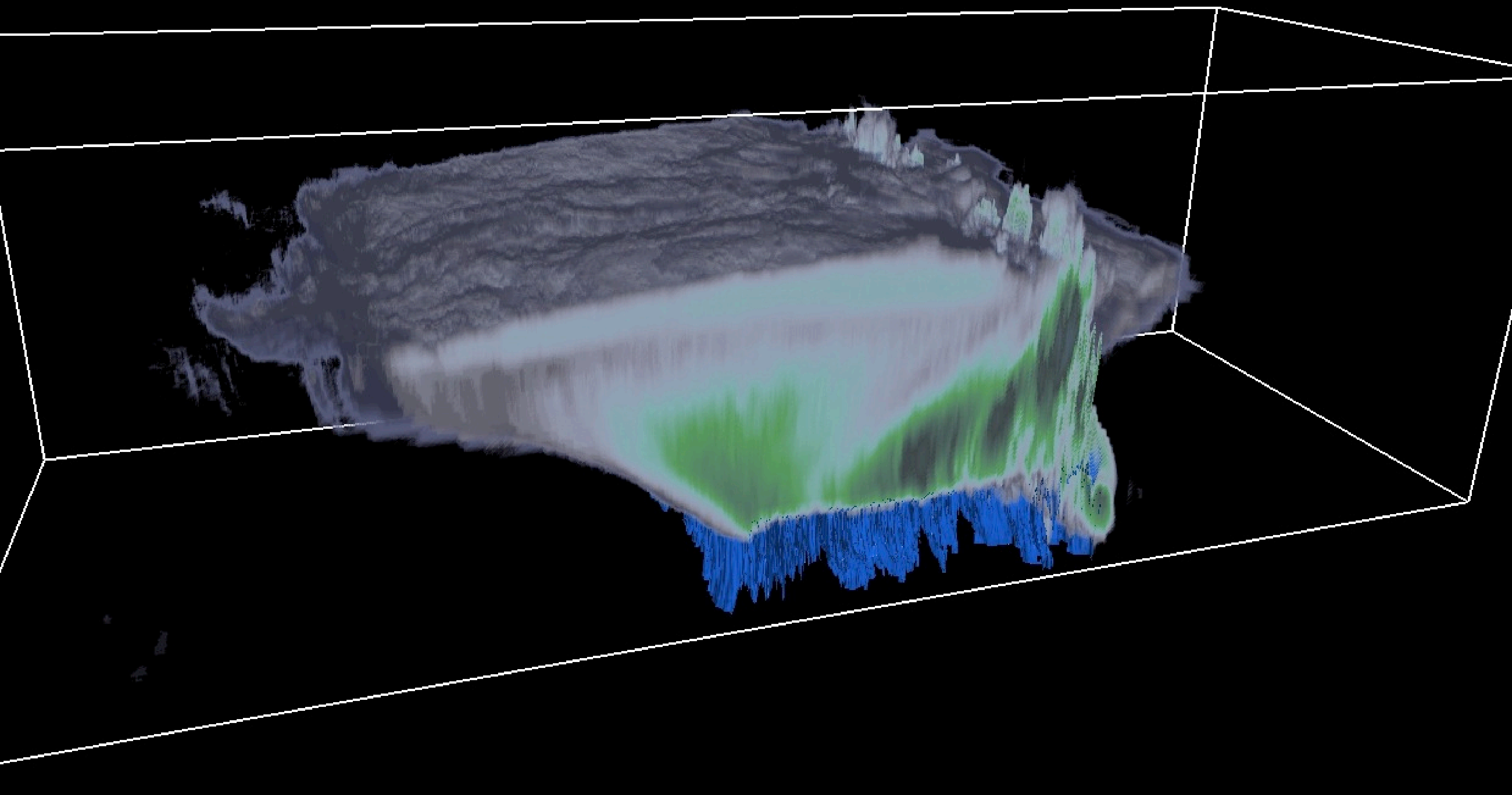


- Localized (and transient) turbulence at about 30-50 miles (50-80 km) from storm
- Related to wave processes (local wave breaking)

- Simulations represent occurrence reasonably well, but unable to provide good measures of intensity due to resolution

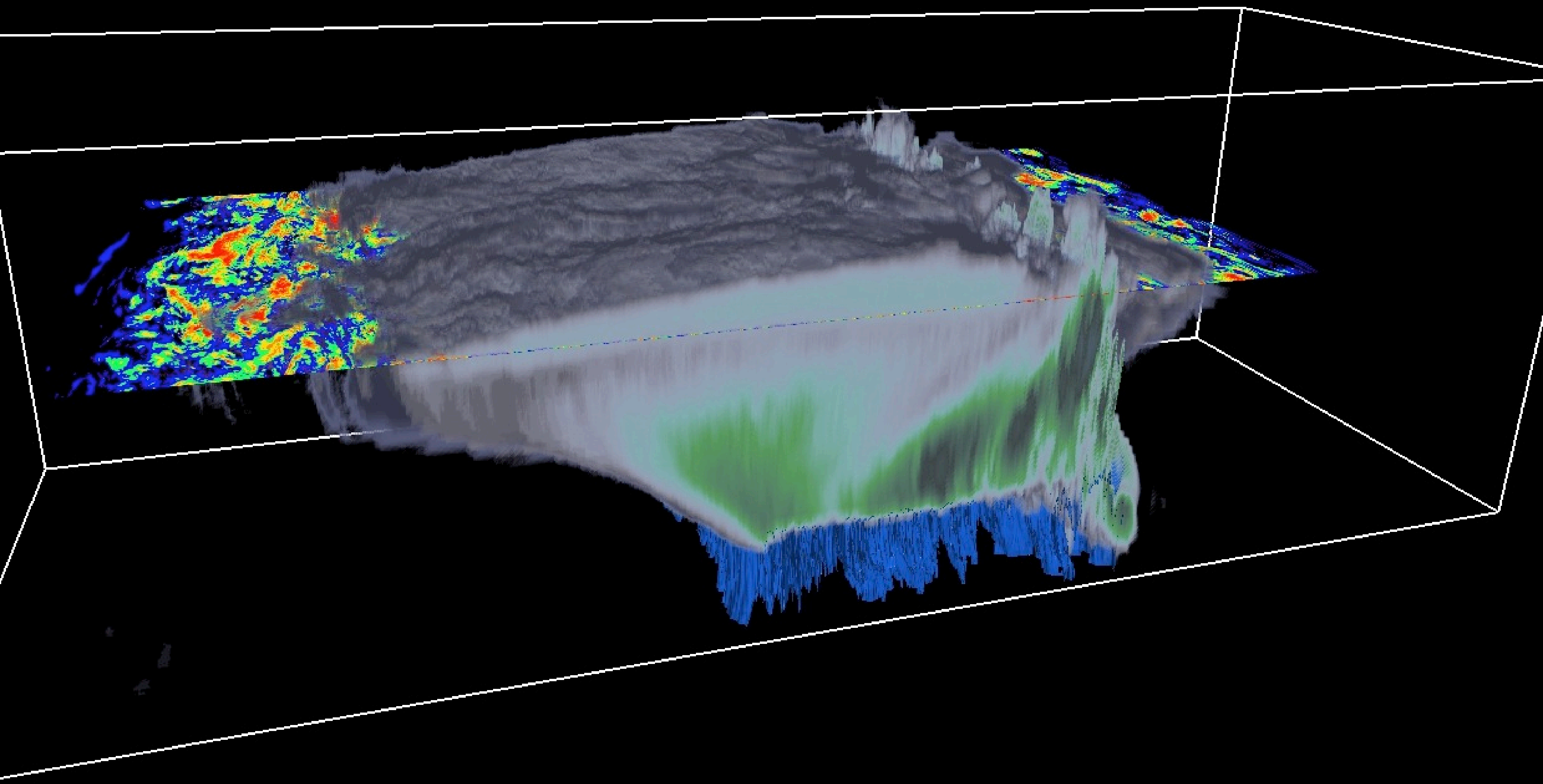
Idealized simulations to characterize intensity

Large-eddy simulations (75 m grid spacing) can resolve turbulence



Idealized simulations to characterize intensity

RESULTS: 3D Structure (cloud & 10-km vorticity)



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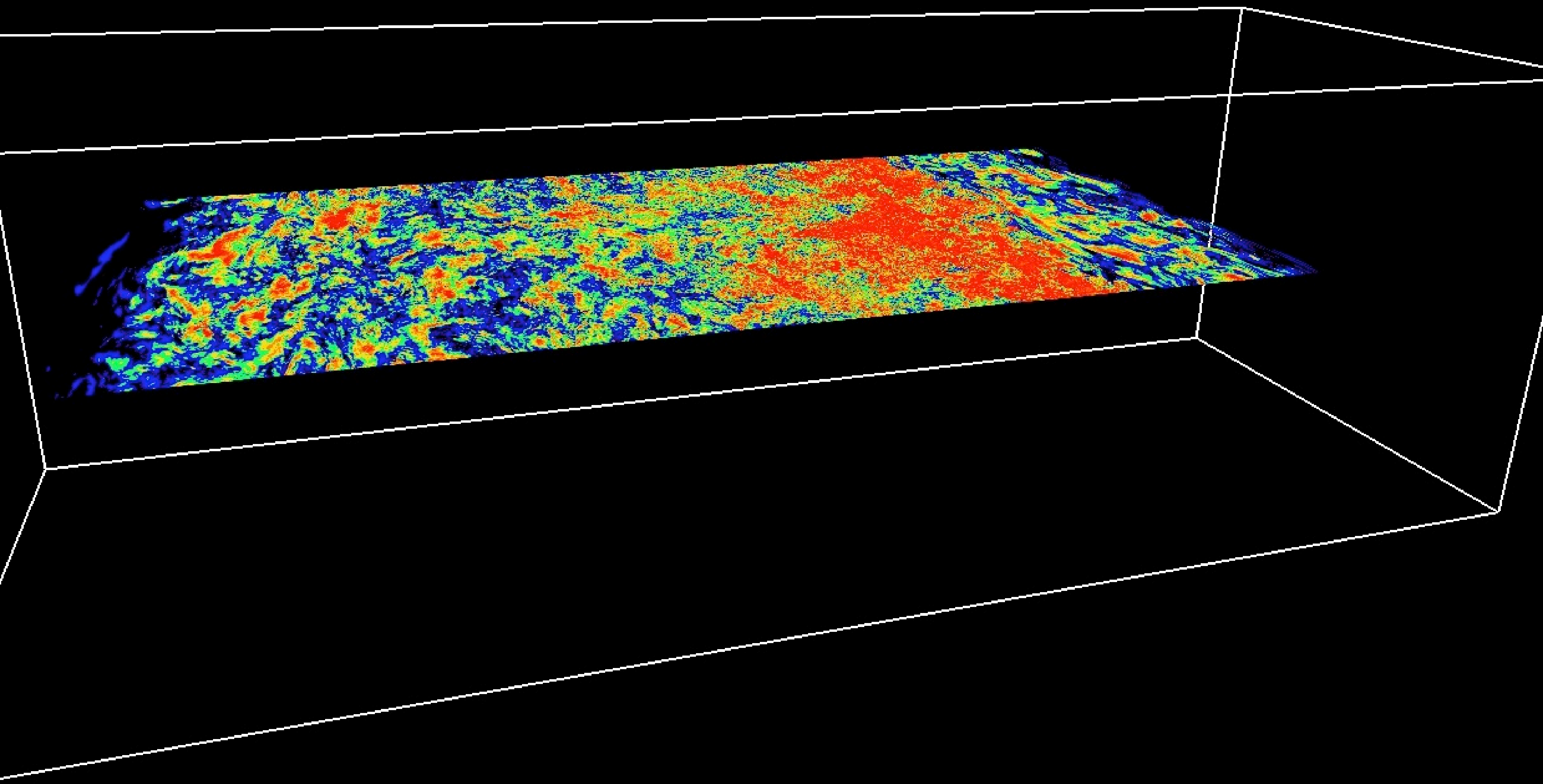
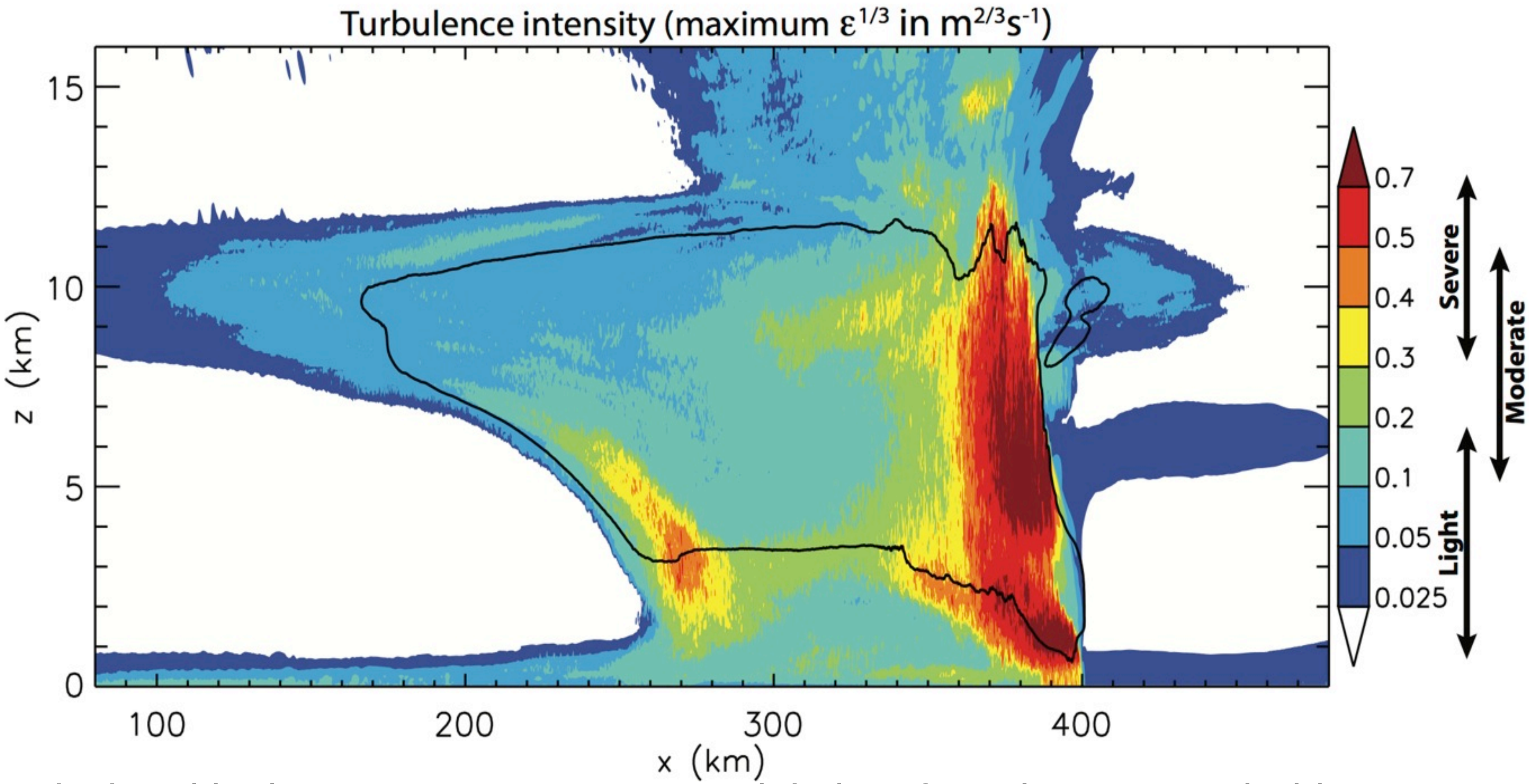


Idealized simulation to characterize intensity (squall line)

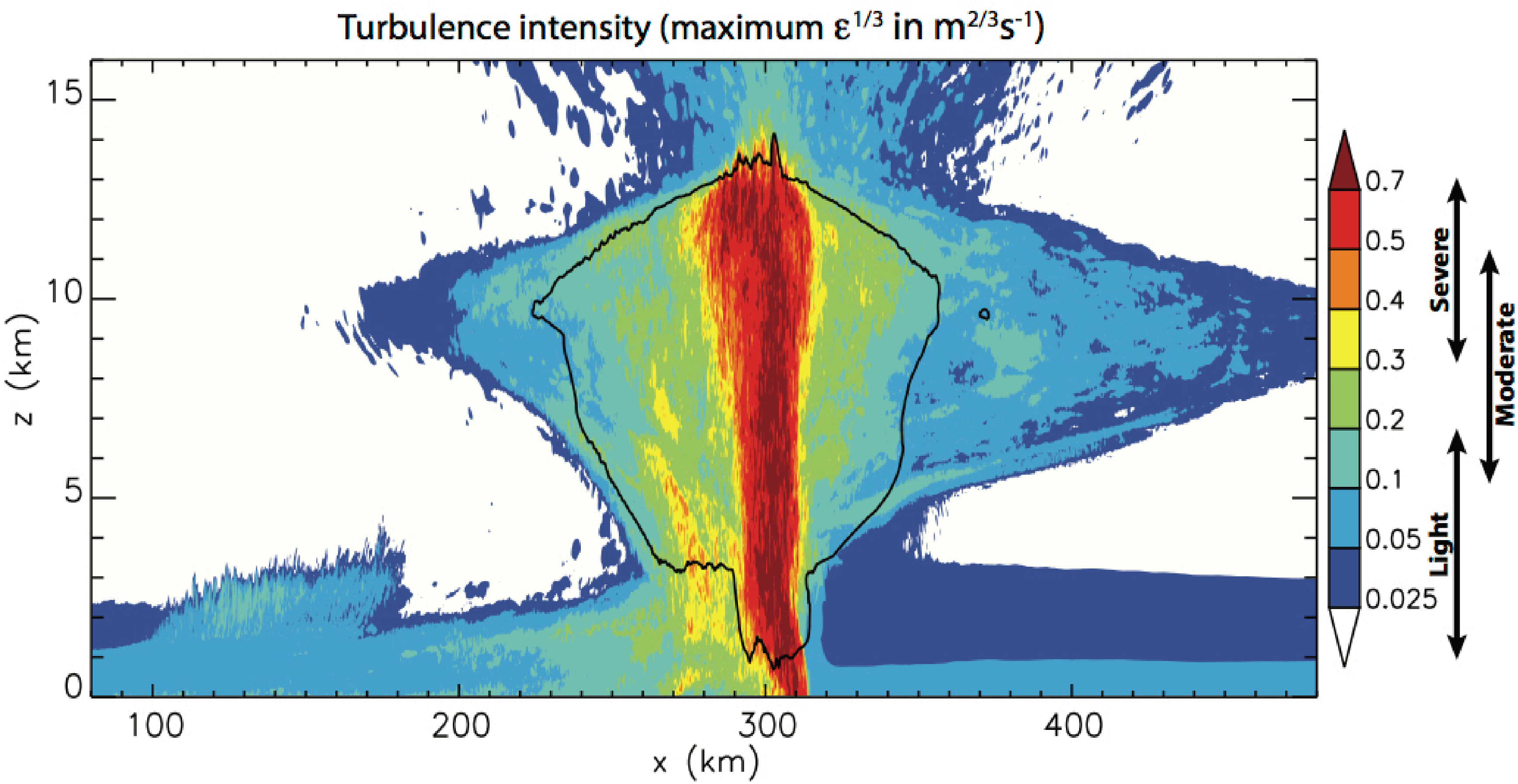


- Calculated in the same way as commercial aircraft: estimate EDR (Eddy Dissipation Rate, $\varepsilon^{1/3}$) along overlapping short (9 km long) segments in y-direction.

- Corresponding subjective intensity determined from comparisons to PIREPS (Sharman et al. 2014)

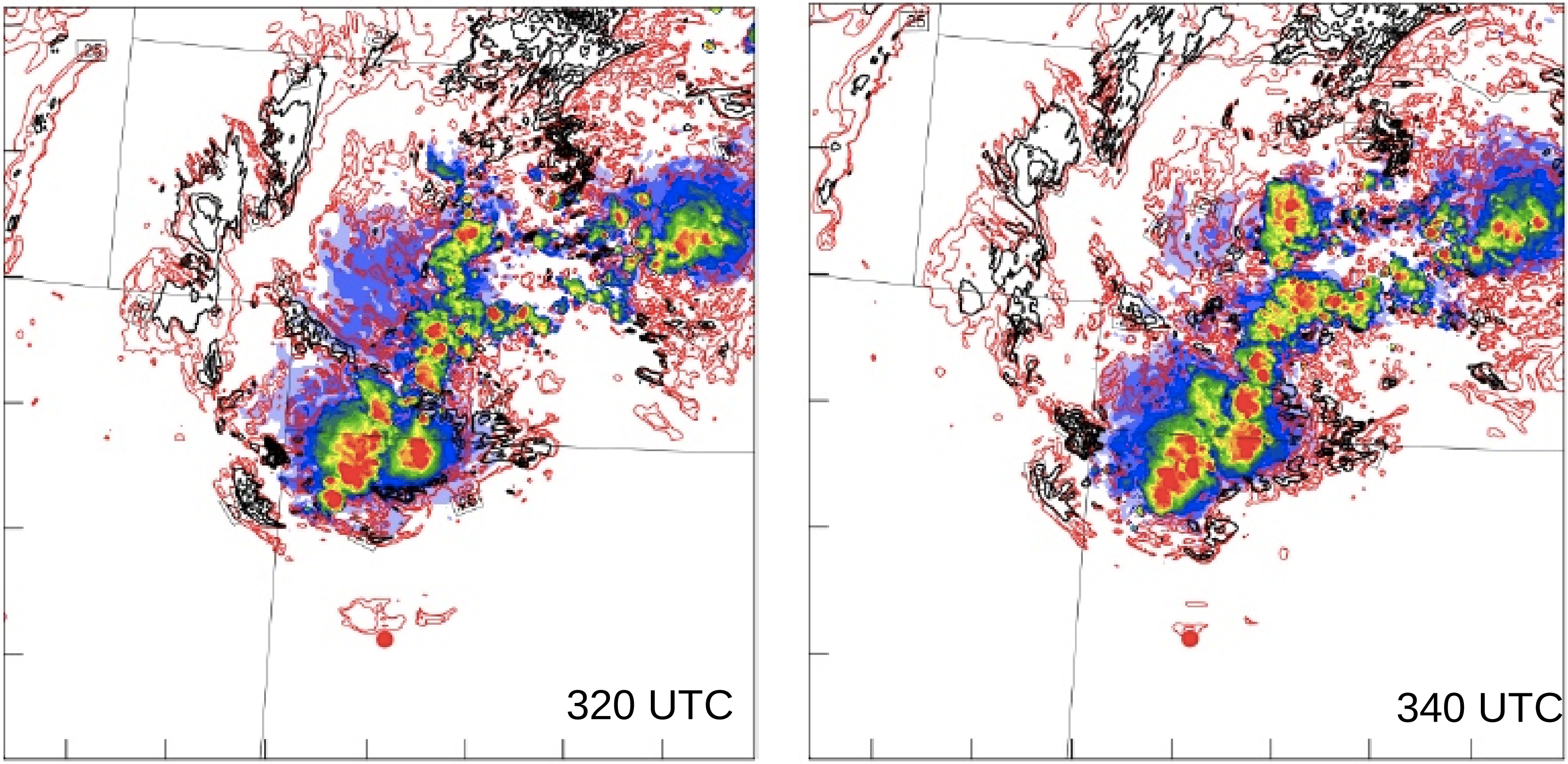
from Lane and Sharman (2014, GRL)

Idealized simulation to characterize intensity (upright storm)



- Upright storm has broader turbulence extent ahead of storm
- **Storm characteristics matter** in determining risk of turbulence relative to cloud boundary – related to upper outflow of storm (among other things)

The way forward? Prediction with high-resolution NWP



- Moist convection and turbulence both suffer from low predictability
- Ensemble approaches essential to capture uncertainty in both convection and turbulence

- Complicated implementation into air traffic operations due to highly detailed spatial structures and intermittency

SUMMARY

- There is an enhanced risk of turbulence that extends significant distances above and around convective storms
- Significant progress has been made in recent years to better understand the mechanisms of turbulence around clouds
  - Wave processes, enhanced wind shear, sensitivity to storm type, etc.
- High-resolution weather prediction is capable of identifying specific regions of enhanced turbulence likelihood
- How can these advances be best utilized to improve avoidance methods to reduce turbulence encounters? E.g.,
  - Improved guidelines for tactical avoidance
  - Diagnosis (for nowcasting) of risk based on theory, models, and remote sensing
  - High-resolution Numerical Weather Prediction