Understanding convectively-induced turbulence hazards using high-resolution models

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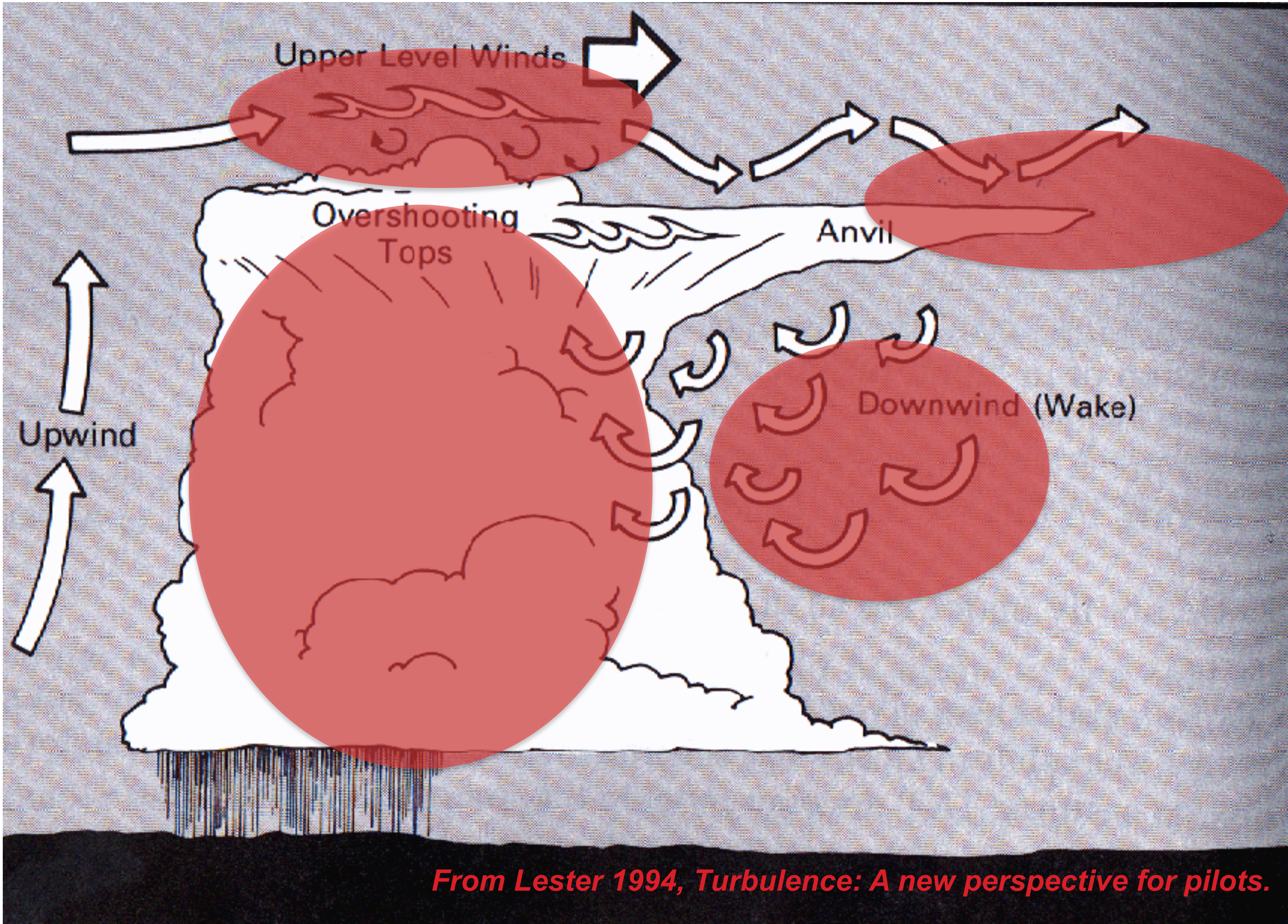
THE UNIVERSITY OF MELBOURNE

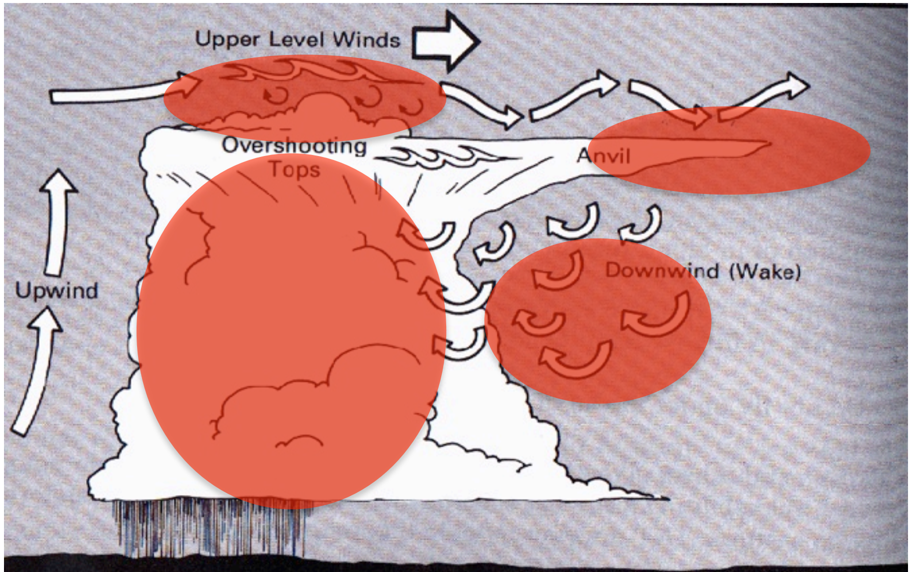
HIWC Workshop – 9 Nov 2015
Bureau of Meteorology, Melbourne

Known regions of turbulence near thunderstorms



From Lester 1994, Turbulence: A new perspective for pilots.

INTRODUCTION / MOTIVATION



From Lester 1994, Turbulence: A new perspective for pilots

Turbulence generated by thunderstorms is a hazard for aviation

- Incomplete understanding of processes leading to out-of-cloud turbulence
- Incomplete in situ characterization of in-cloud turbulence due to hazards, sampling and intermittency issues
- Modelling studies have examined turbulence occurrence but relative intensity of turbulence in and around cloud is difficult to quantify
- It is a challenging observational and modelling problem due to scales involved.

Aviation turbulence types..

CAT (Clear-air turbulence): Any turbulence not associated with convective clouds. [Can include sources such as mountain waves, jet streams, upper-fronts, etc.]

CIT (Convectively-induced turbulence): Turbulence associated with convective clouds.

In-cloud CIT: Turbulence occurring within cloudy air associated with convective storms. (Is avoidable using visual and radar guidance)

Near-cloud turbulence (NCT): Turbulence that has convective origin (CIT) but occurs outside of cloud. (Is responsible for unexpected encounters as it is normally invisible).

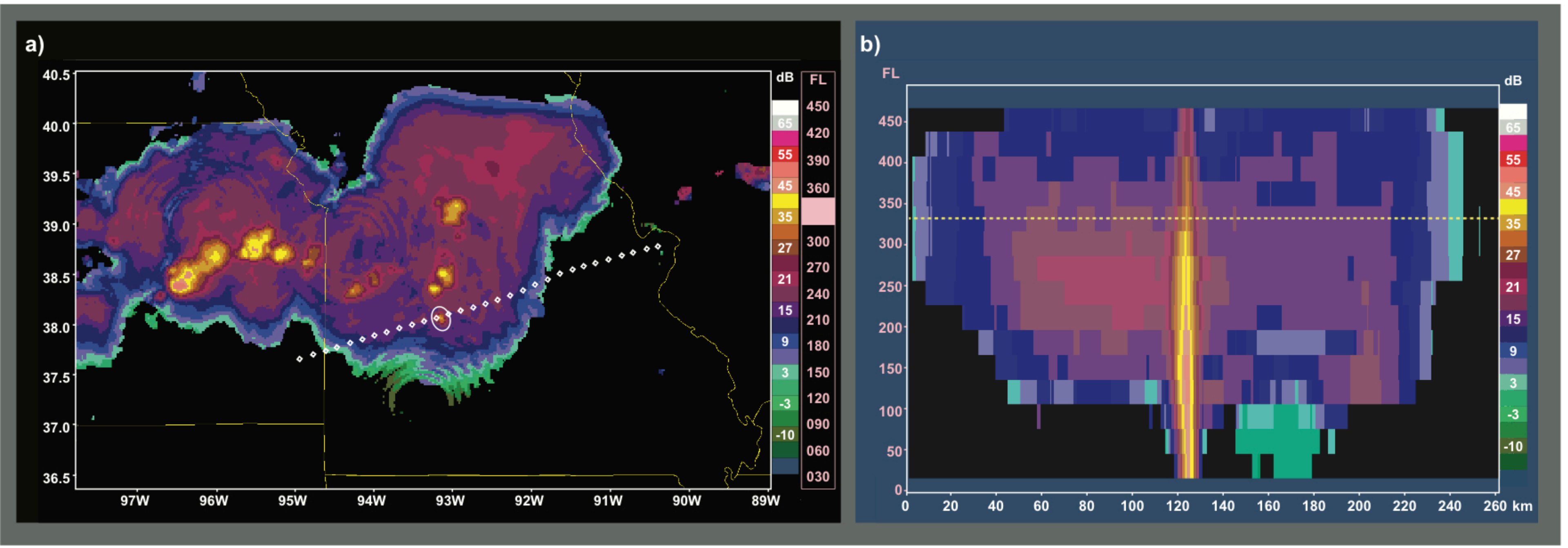
FAA guidelines (FAA Aeronautical Information Manual, Chapter 7 – Thunderstorm flying):

- "Avoid by at least 20nm [laterally] any thunderstorm identified as severe. This is especially true under the anvil of a large cumulonimbus"

Recent research along with anecdotal evidence has shown these guideline to sometimes be inadequate

20 July 2010 - 21 Injuries: in-cloud turbulence

Commercial passenger aircraft flying from Washington DC to LAX penetrated growing updraft embedded within mesoscale convective system.



10 Injuries: possible out-of-cloud CIT near Indonesia

Herald Sun
Stories start here.

V Australia Melbourne flight affected by food poisoning and turbulence

Shannon Deery | Herald Sun | February 01, 2011 7:44am | 58 comments

A+ A− Share

UPDATE 10.15am: A MOTHER-of-three was forced to hold her children down in their seats to stop them flying around the cabin of a Melbourne- bound V Australia flight when it hit turbulence.

Ambulance crews were called to attend the arrival of flight VA20 from Phuket in Thailand as it landed at Tullamarine at 7.40am, with a number of passengers suffering injuries.

Michelle Baghdassarian, who was travelling with her three small children, said it was the scariest flight she had been on.

Shelley Read and her partner Graeme Ogden from Toolama,

ATSB Report:

- Seatbelt sign off during event
- "There was no indication of precipitation in the immediate vicinity. The crew observed some weather returns indicating areas of heavy precipitation on their weather radar to both the north and south of their flight path, although these were over 40 NM (74 km) away."

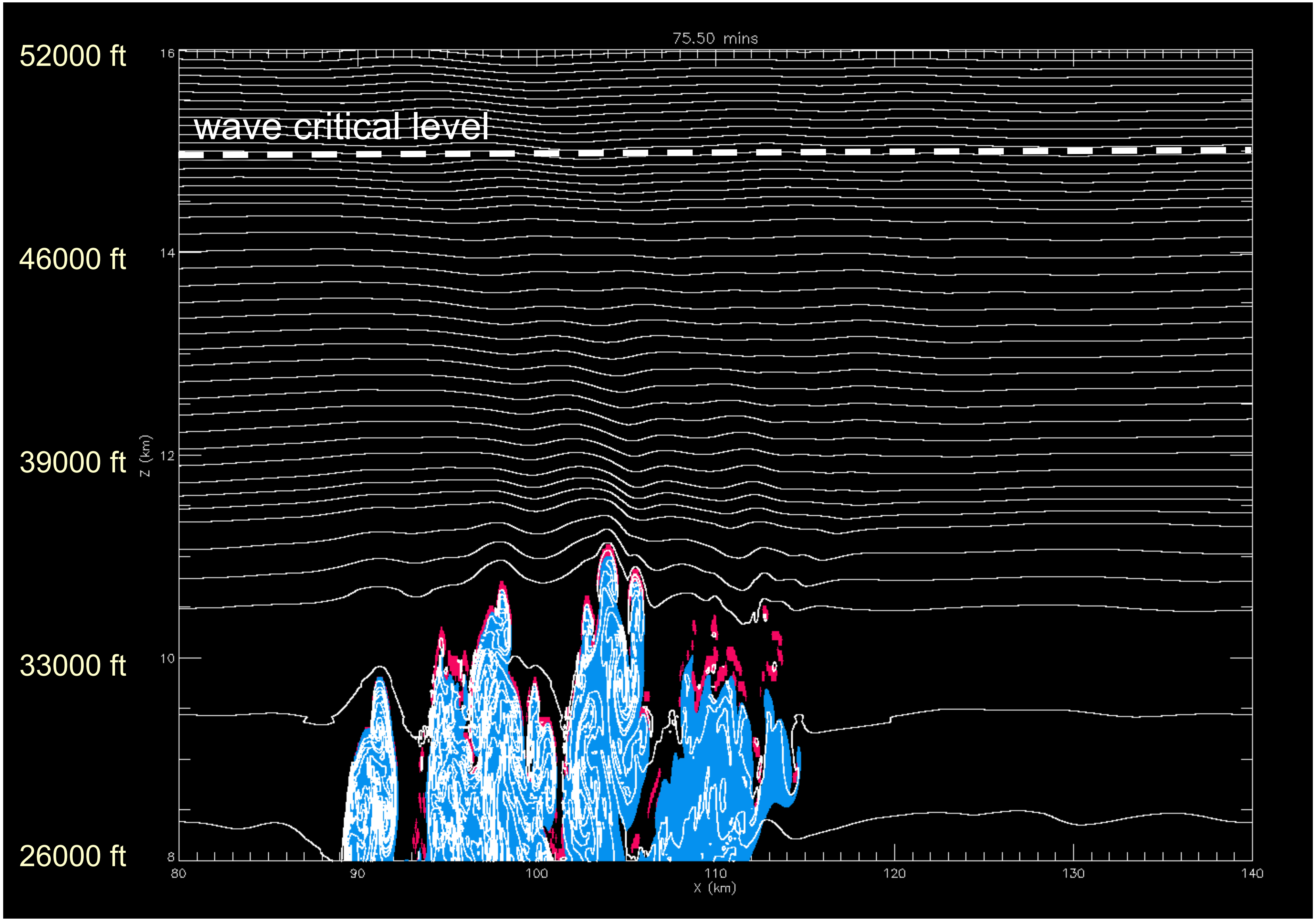
RECENT ADVANCES IN THE UNDERSTANDING OF NEAR-CLOUD TURBULENCE

BY TODD P. LANE, ROBERT D. SHARMAN, STANLEY B. TRIER, ROBERT G. FOVELL, AND JOHN K. WILLIAMS

Advances in numerical modeling and new observations are providing valuable information about turbulence near thunderstorms and are paving the way for the development of new turbulence avoidance and forecasting strategies for the aviation industry.

Bulletin of the American Meteorological Society, 2012.

2D simulation: Gravity Waves and turbulence above convection

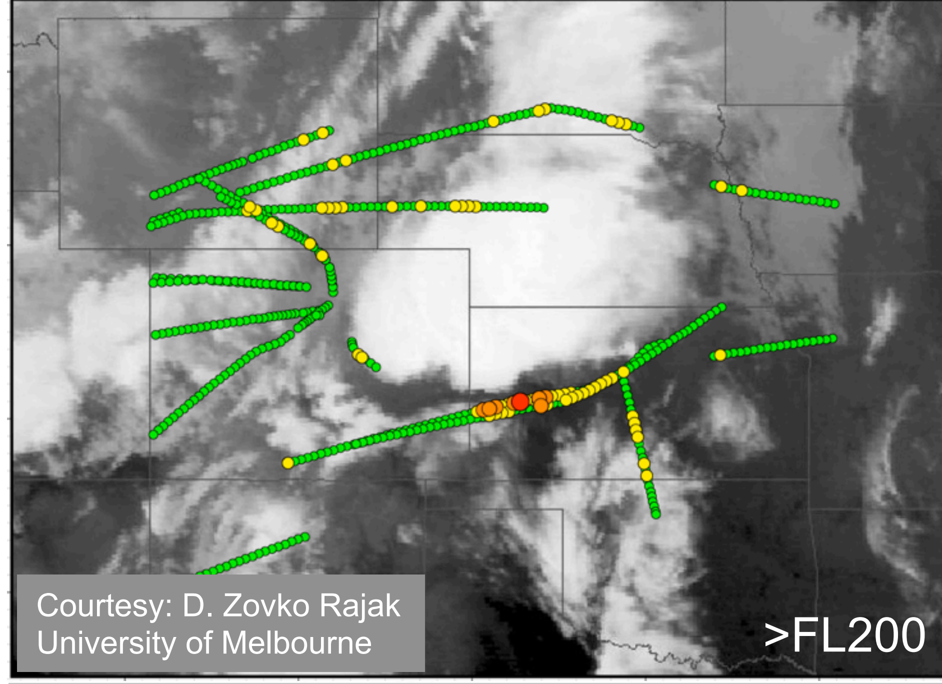


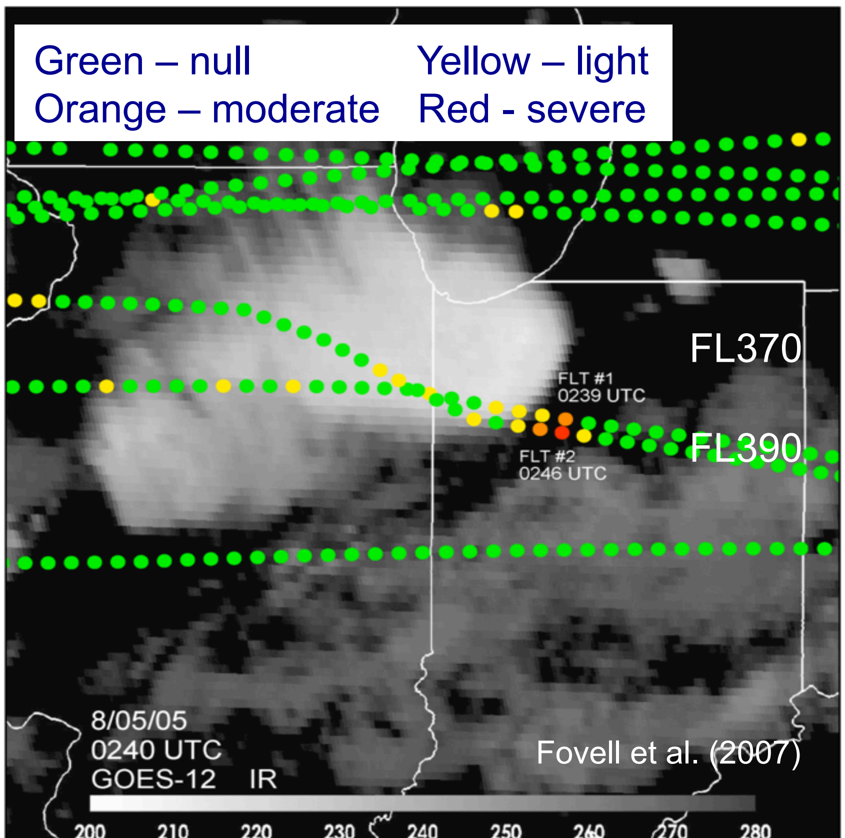
2-D simulation (50-m grid spacing) showing cloud (blue), potential temperature, and statically unstable air (red) – See Lane et al. (2003, *J. Atmos. Sci.*)

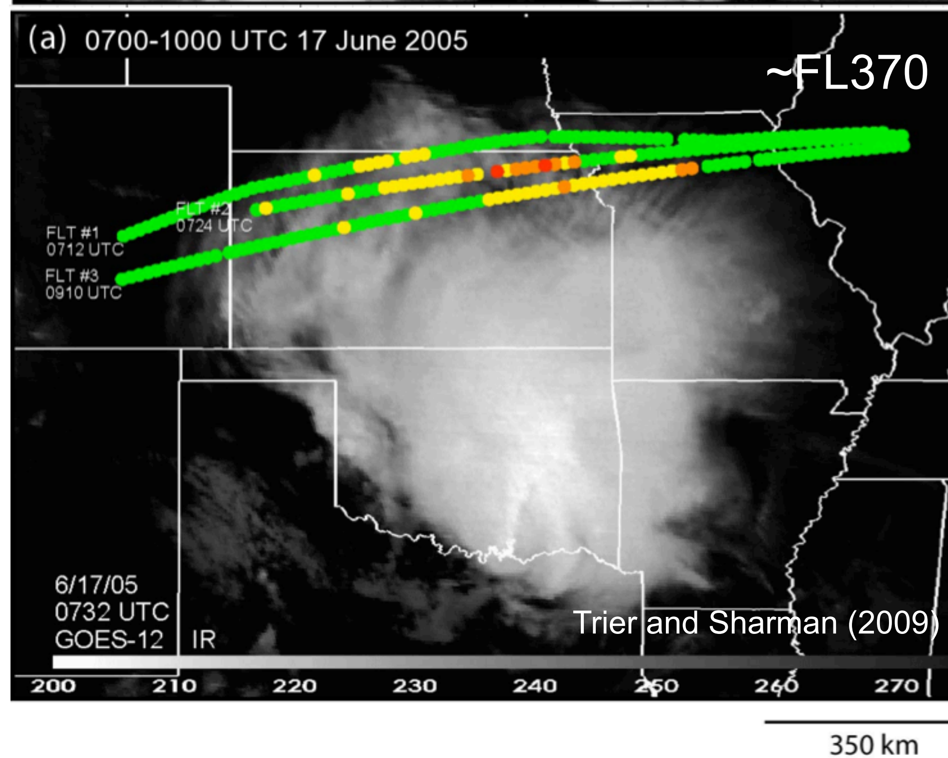
Turbulence adjacent to convection.

Case after case of upper-level turbulence in clear-air (or within thin cirrus) adjacent to thunderstorms as revealed by automated data from commercial aircraft.

Mechanisms related to enhanced shears and gravity waves in storm outlow







OUTSTANDING QUESTIONS / CHALLENGES

What is the relative intensity of turbulence inside and outside of cloud?

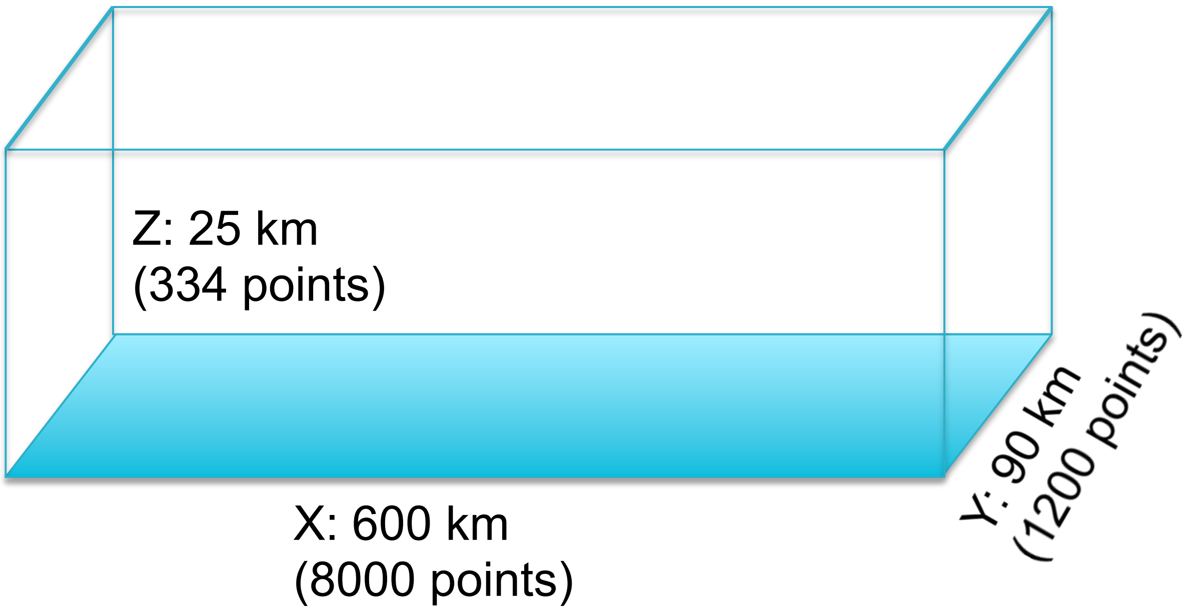
What is the character of the turbulence, including its intermittency?

What are the key dynamical processes that generate the turbulence?

APPROACH

Large-eddy simulations to characterize turbulence from idealized squall lines

- 75m grid spacing: resolves start of inertial range and scales of motion that influence large aircraft (scales < ~2 km)



CM1 (G. Bryan's model)

$\Delta x = \Delta y = \Delta z = 75$ m

Weisman-Klemp sounding

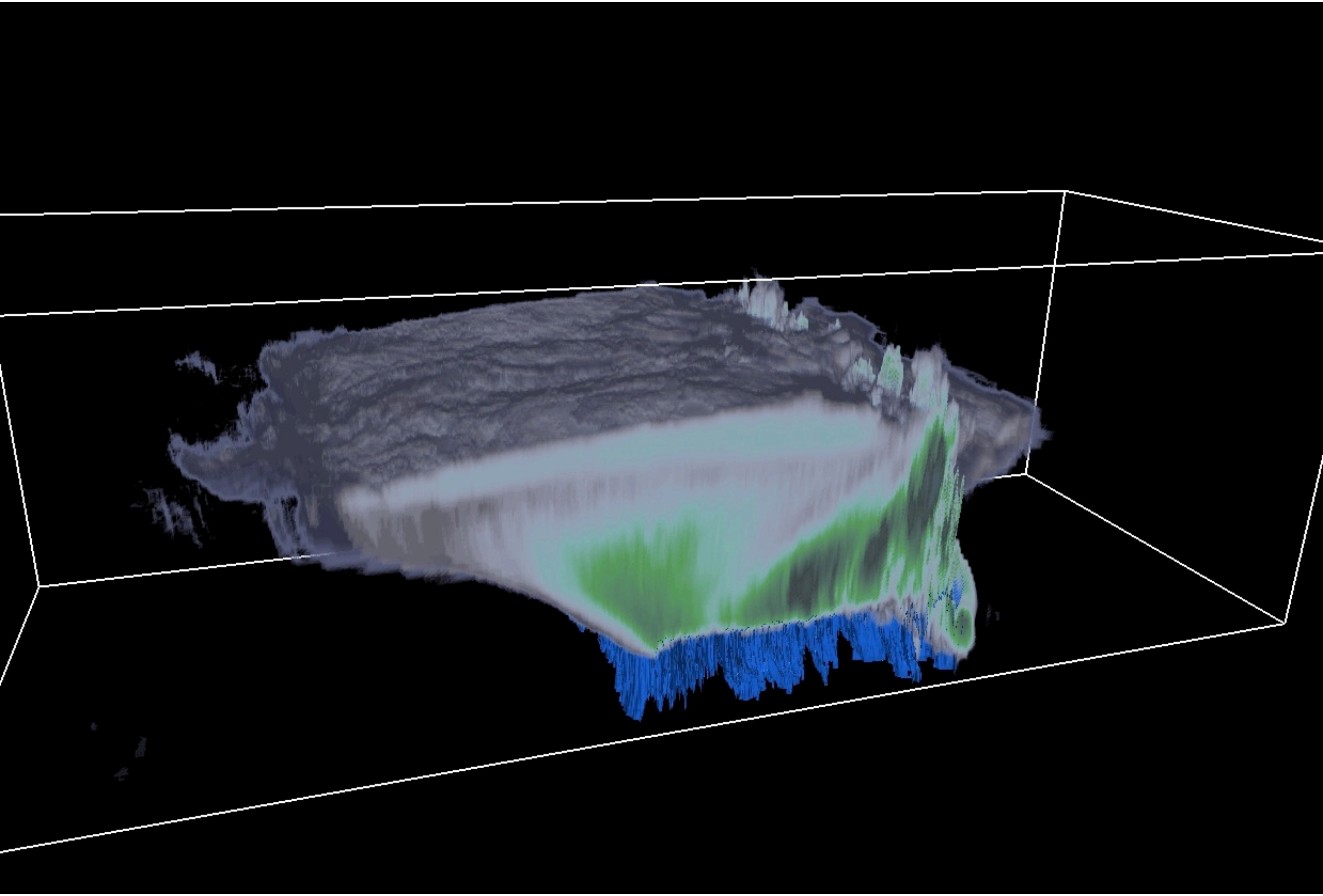
Initialized with line thermal

No background shear above 2.5 km

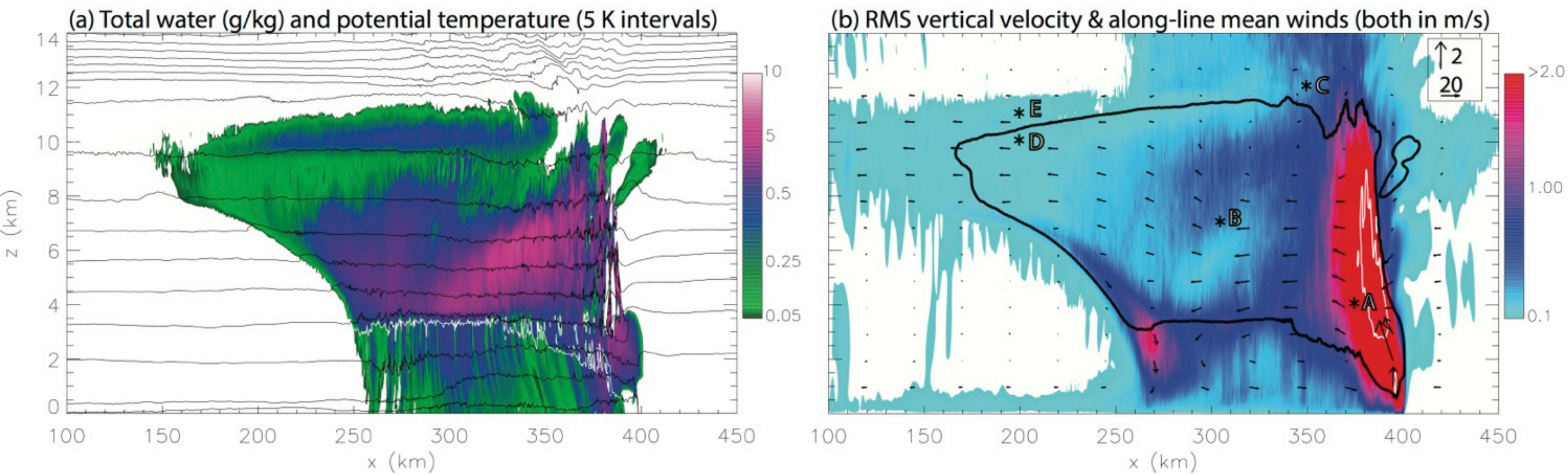
[periodic in y-direction]
[Lin et al. microphysics]
[9 km deep sponge]
[1.5 order TKE]

Lane, T.P., and R.D. Sharman. 2014. Intensity of thunderstorm-generated turbulence revealed by large-eddy simulation. *Geophysical Research Letters.*

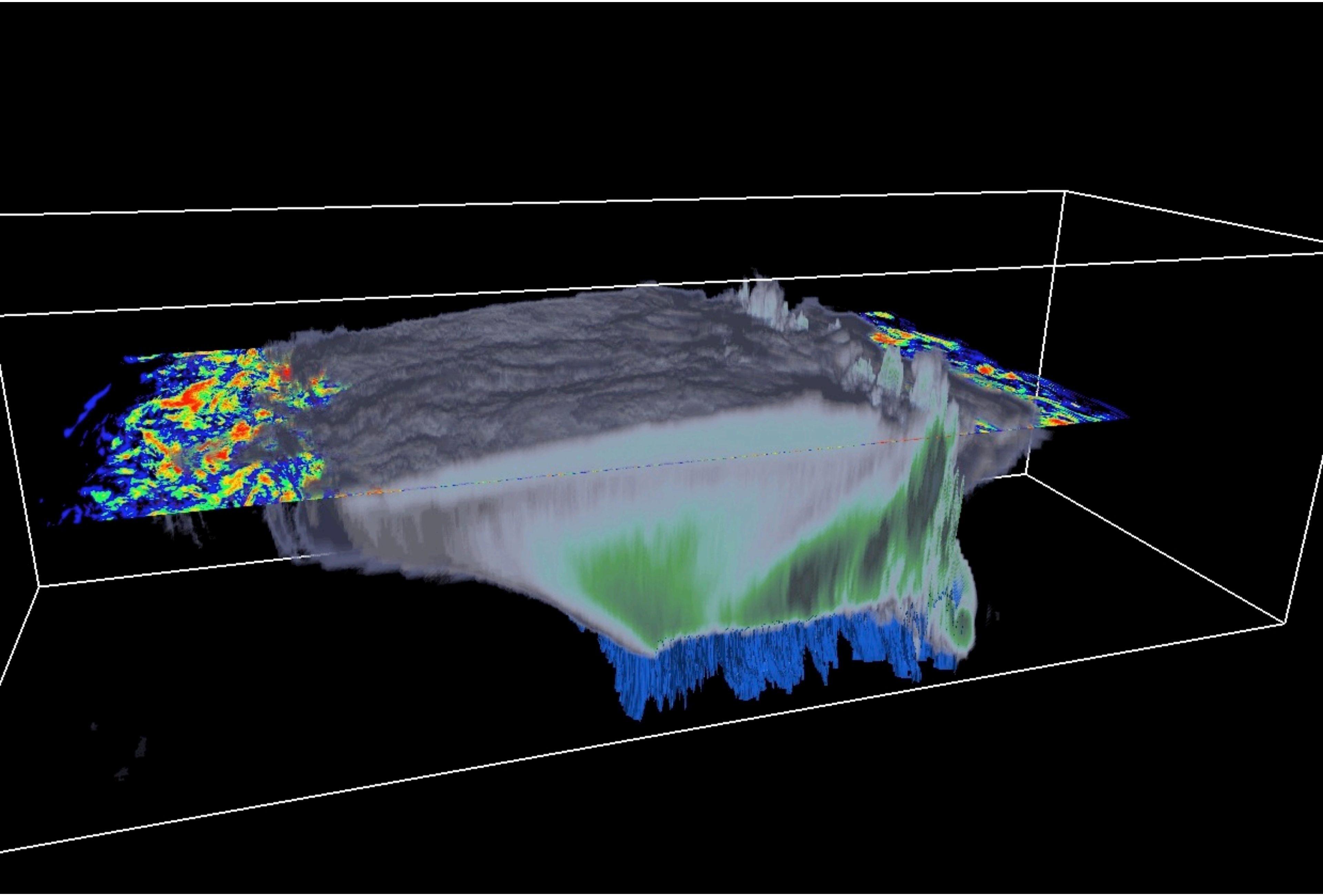
RESULTS: 3D Structure (cloud)



RESULTS: Along-line structure



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



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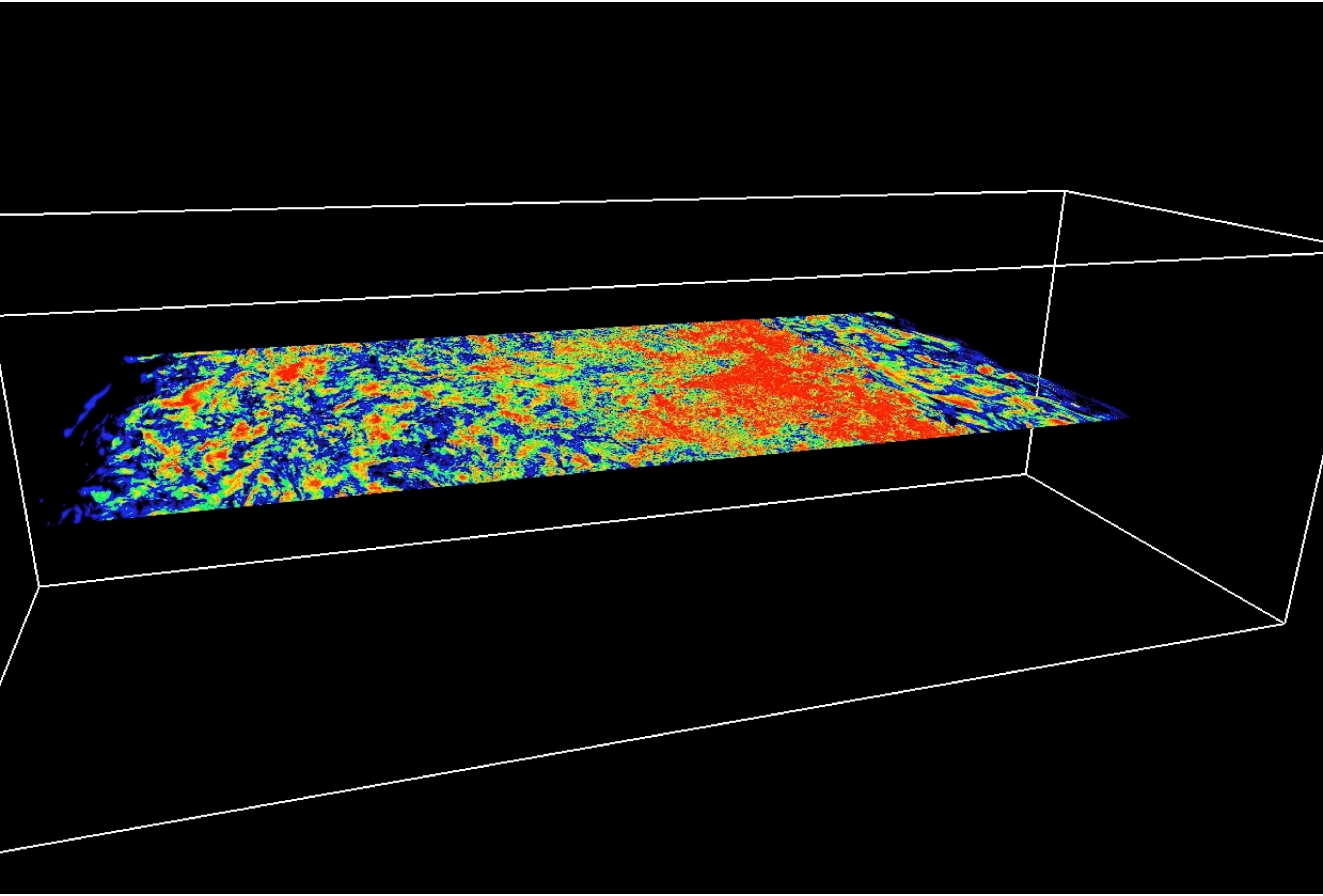
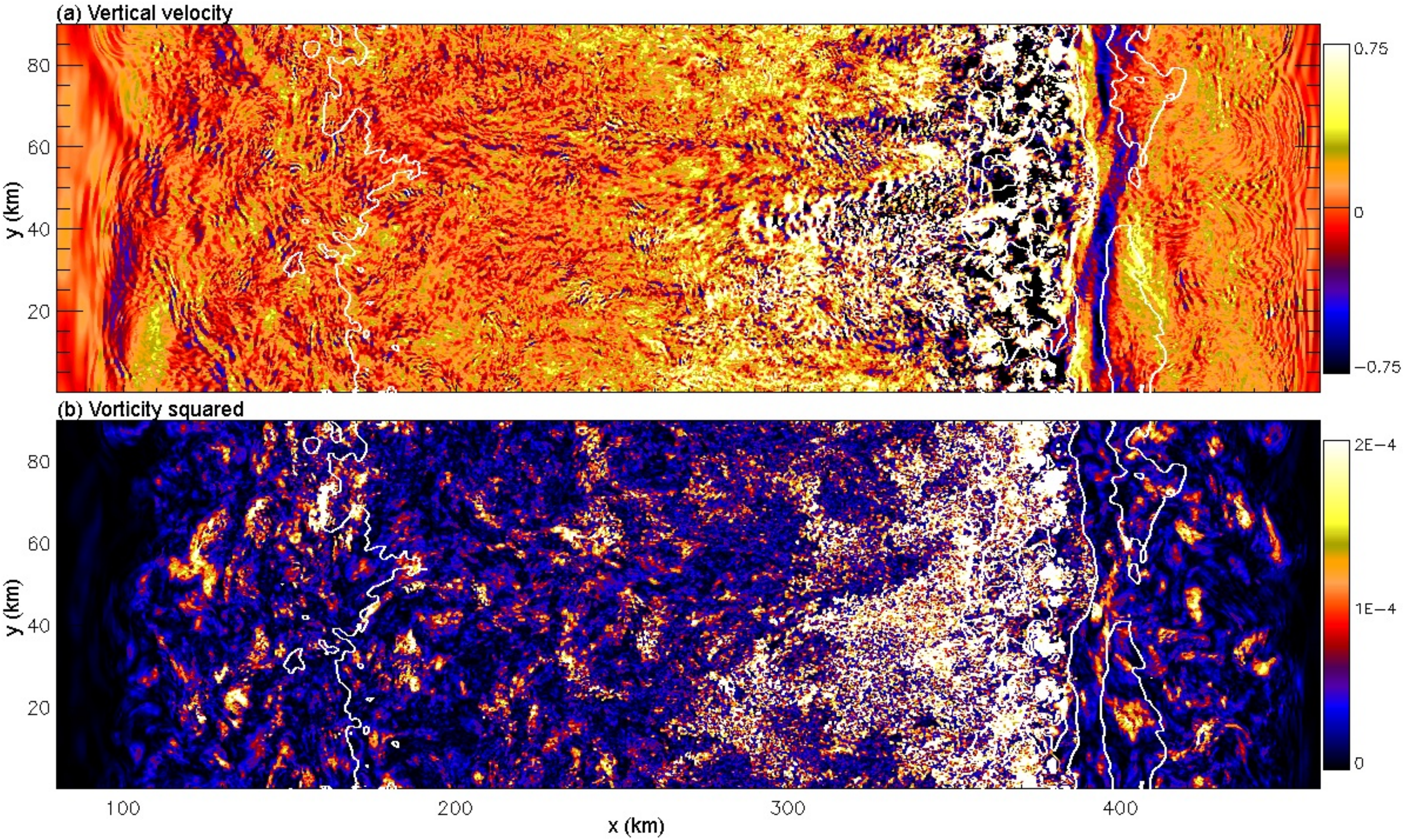


RESULTS: 10-km vertical velocity ($m\ s^{-1}$) and vorticity^2 (s^{-2})



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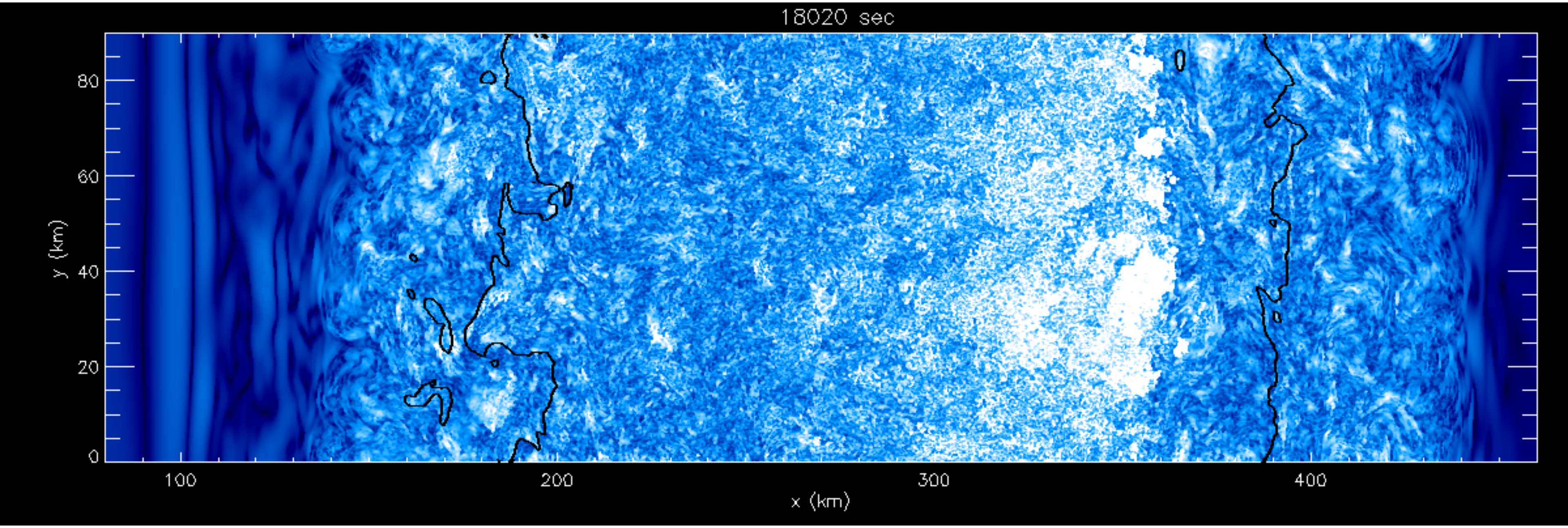
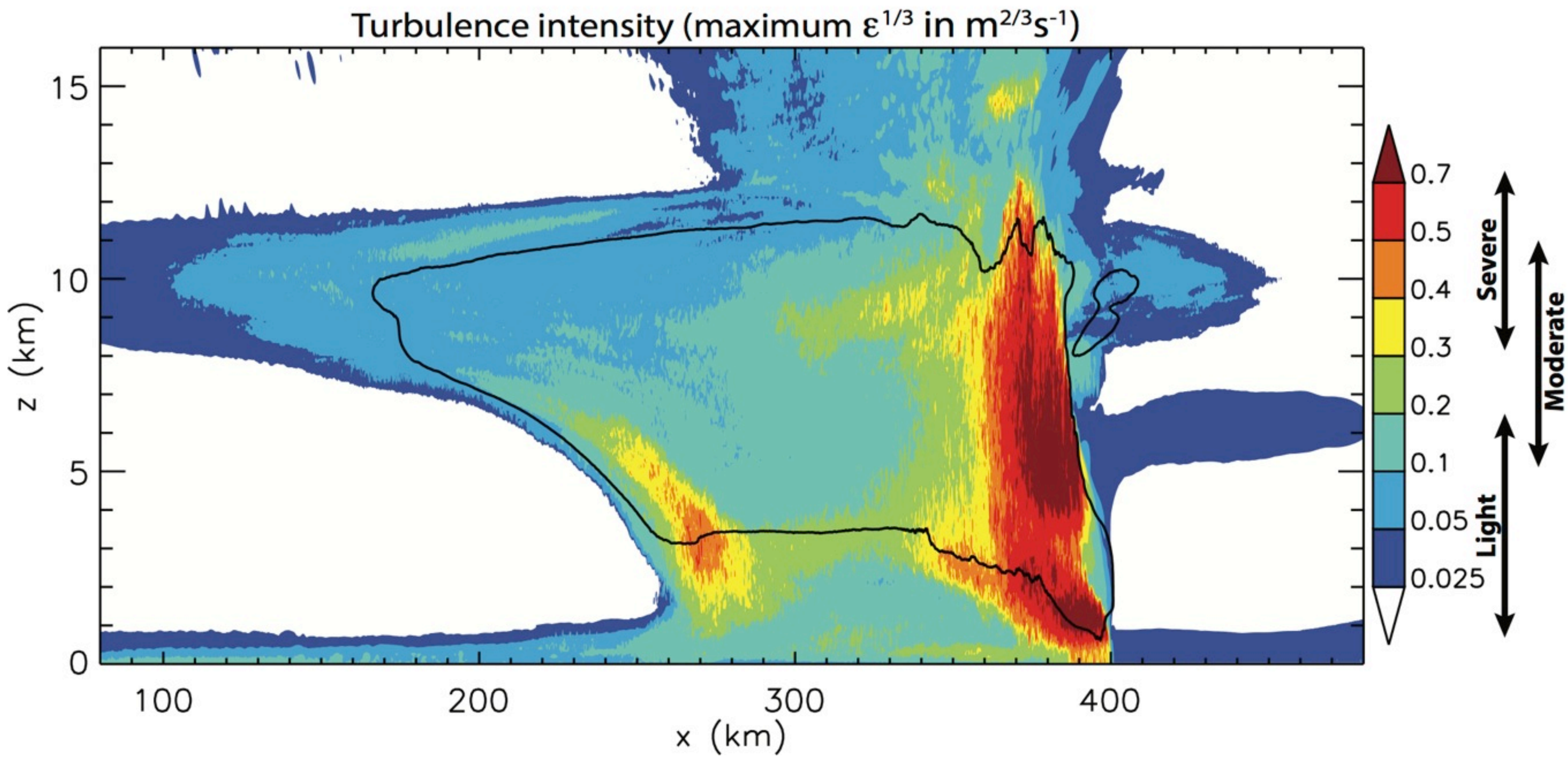


RESULTS: Turbulence intensity



- Using the relation for the transverse component: $|\hat{u}|^2={}^4/_3 C\varepsilon^{2/3}k^{-5/3}$, C=0.5
- Calculated in the same way as commercial aircraft: estimate $\varepsilon^{1/3}$ along overlapping short (9 km long) segments in y-direction.

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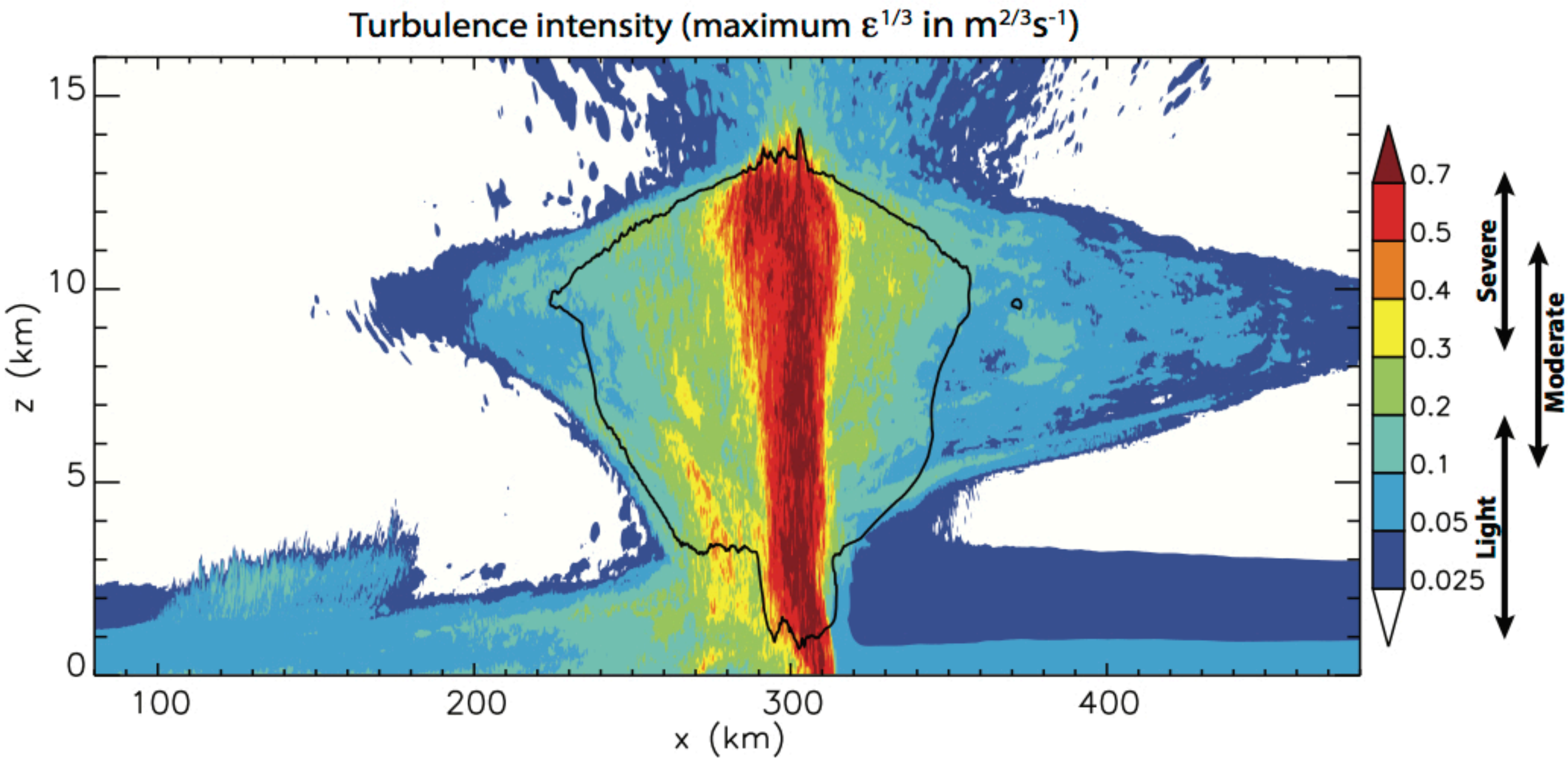

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SUMMARY

- Turbulence occurs:
  - Above cloud due to nonlinear gravity wave processes
  - In shallow layer above and below anvil due to Kelvin-Helmholtz instability
  - In laterally asymmetric distribution in outflow region.
  - At severe / extreme levels in convective cores.
- Most focus on aviation turbulence has been on midlatitude cases – many opportunities to study turbulence in tropical systems.
- In need of in situ observations of updraft penetrations and anvil regions to evaluate model simulations. HIWC data?