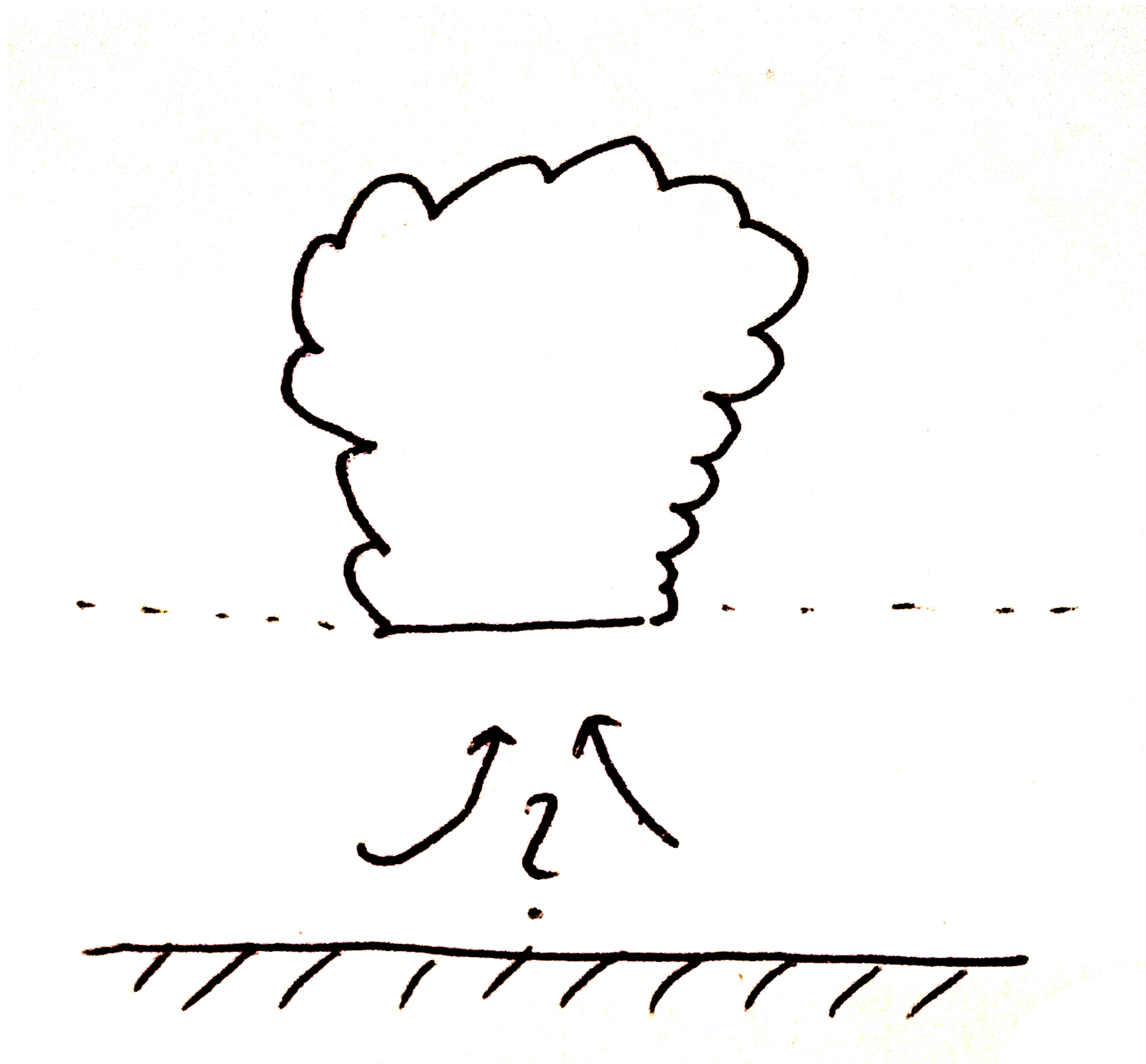
UNIVERSITY OF LEEDS

Studying cool structures of the boundary layer - and other things

Leif Denby, University of Leeds

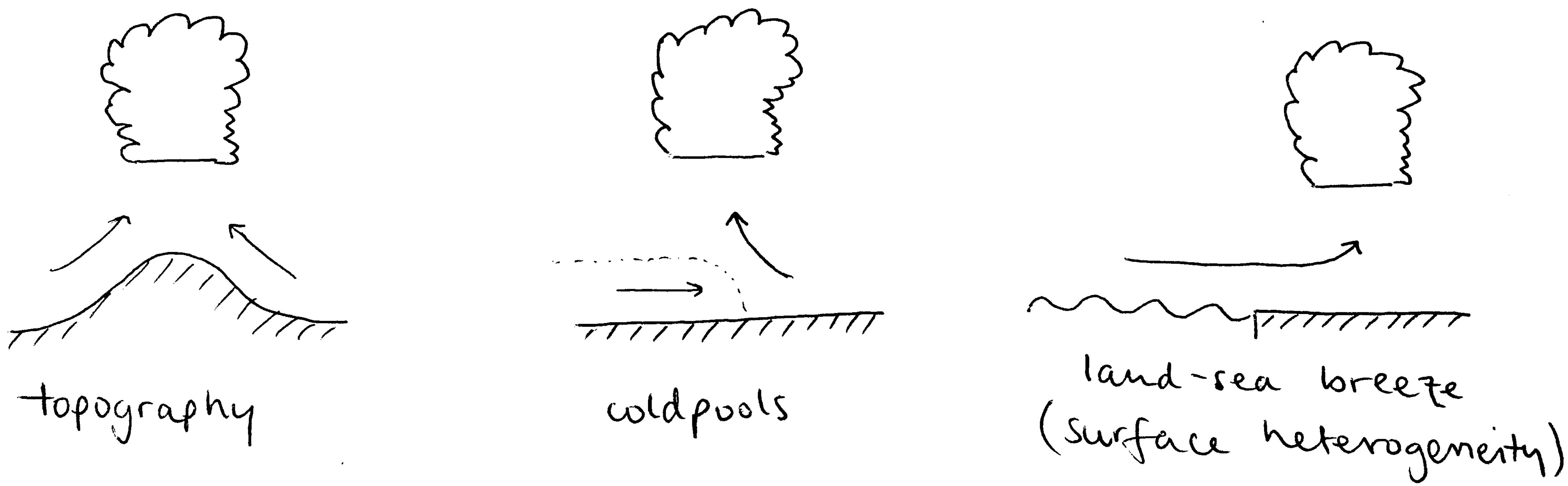
28/5/2018, ParaCon Plenary, Reading University

Aim



Aim

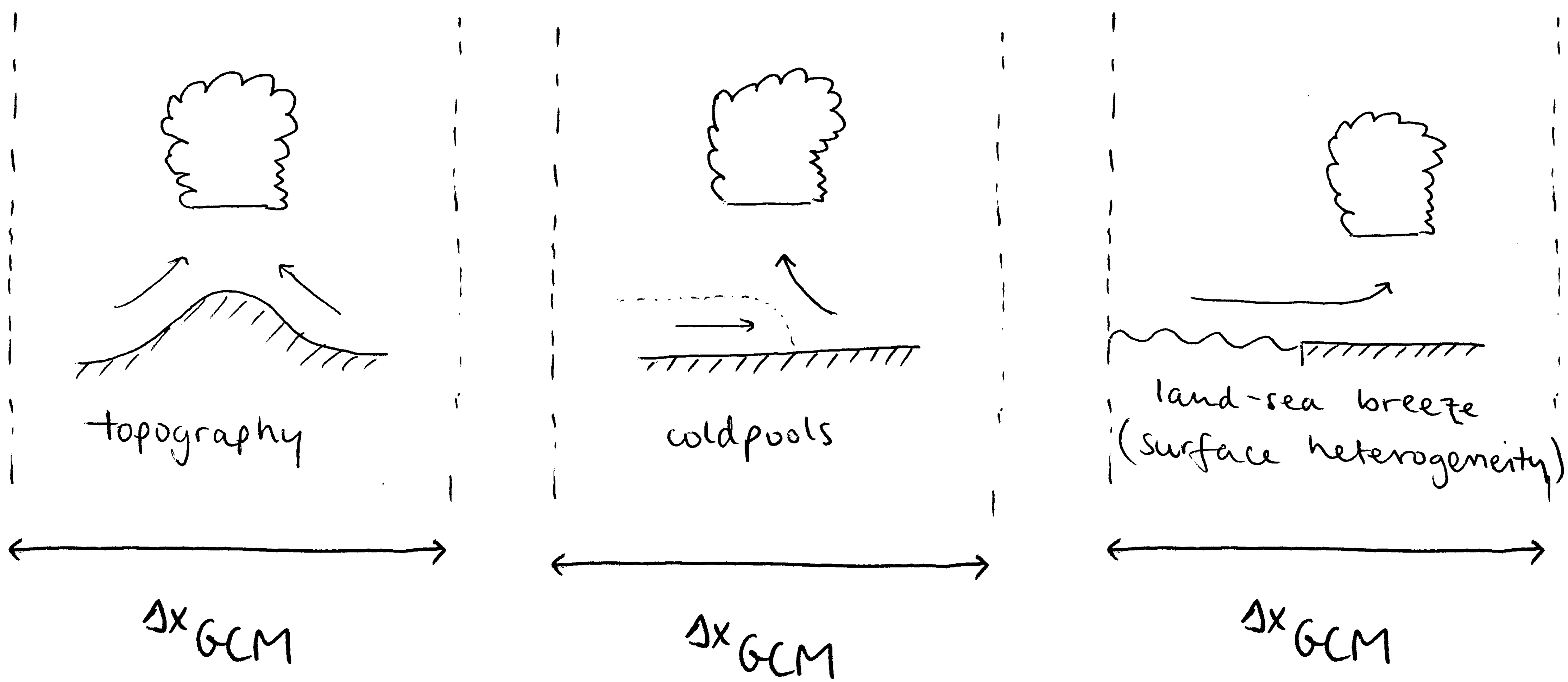
- Describe statistics of boundary layer relevant to triggering convection and the sensitivity to presence of different phenomena



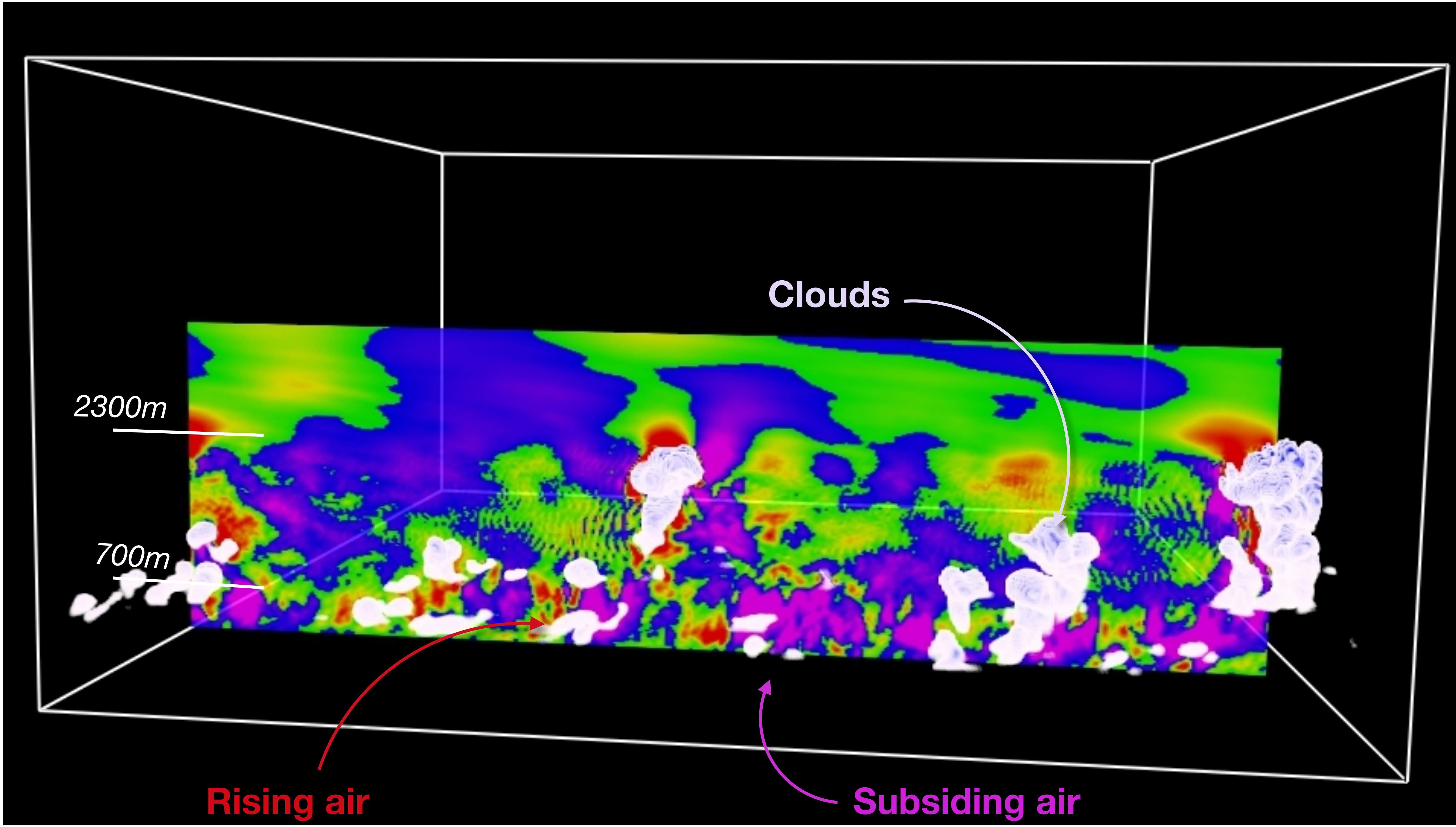
- *"What are the length-scales and magnitudes of perturbations which trigger convection?"*

Why?

- GCMs have too coarse resolution to fully represent convection (O(km))
  - ➡ Trigger (and evolution) of convection must be parameterised
  - ➡ These *sub-grid* features are known to be critical in predicting formation of convection



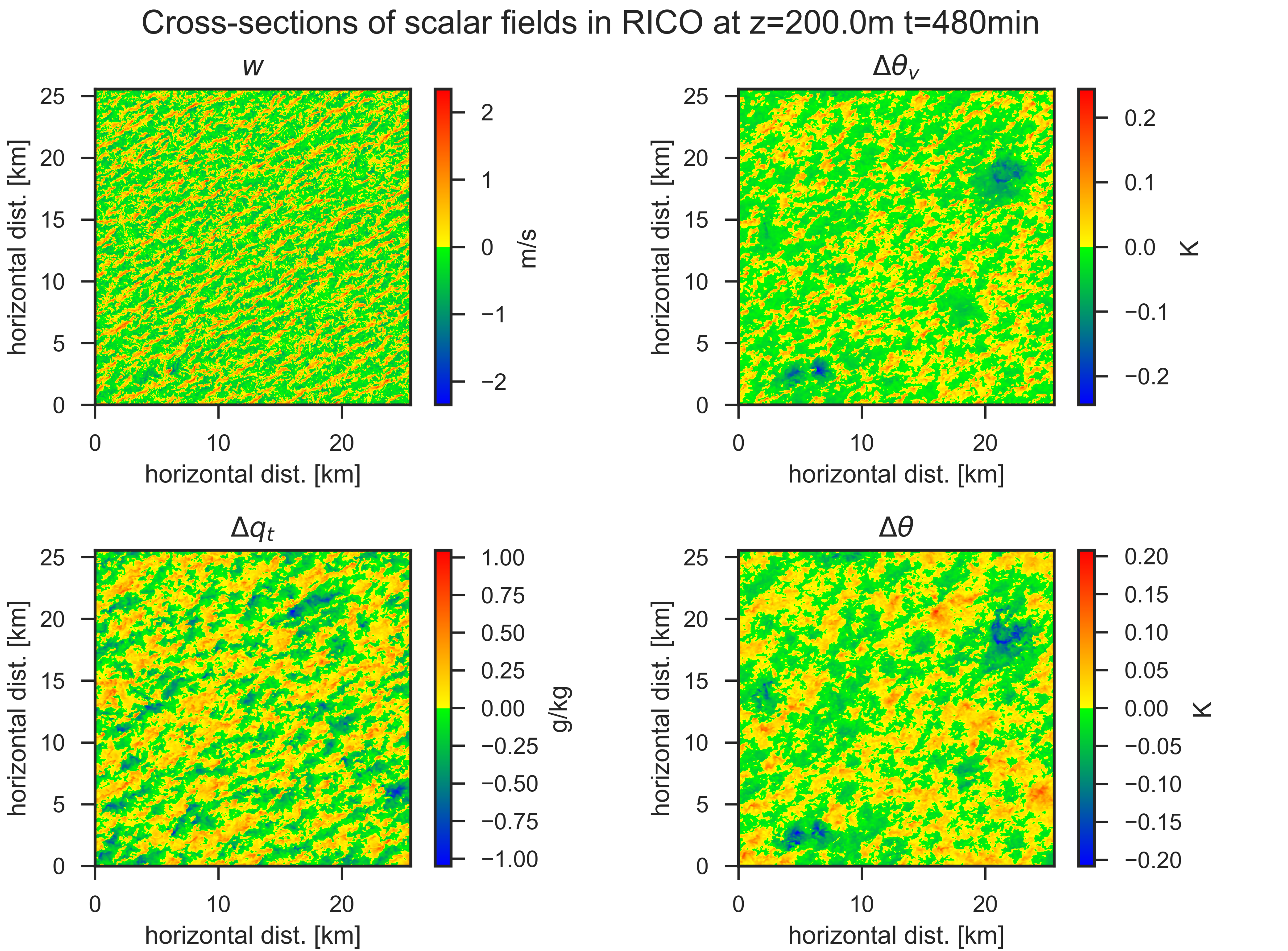
What are the length-scales of variability?



Δx=25m Large-Eddy Simulation, RICO test-case

Rendered with VAPOR

What are the length-scales of variability?



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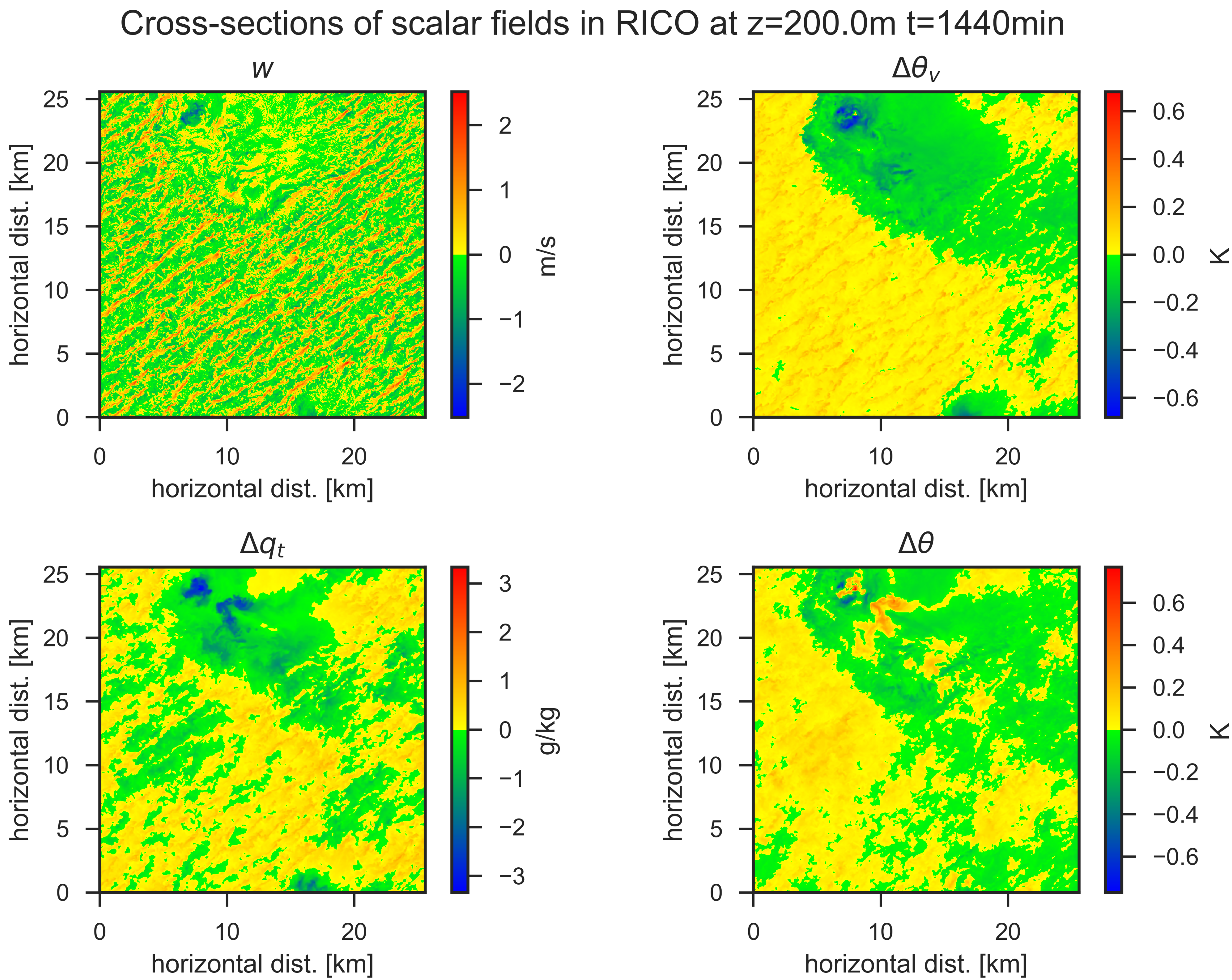


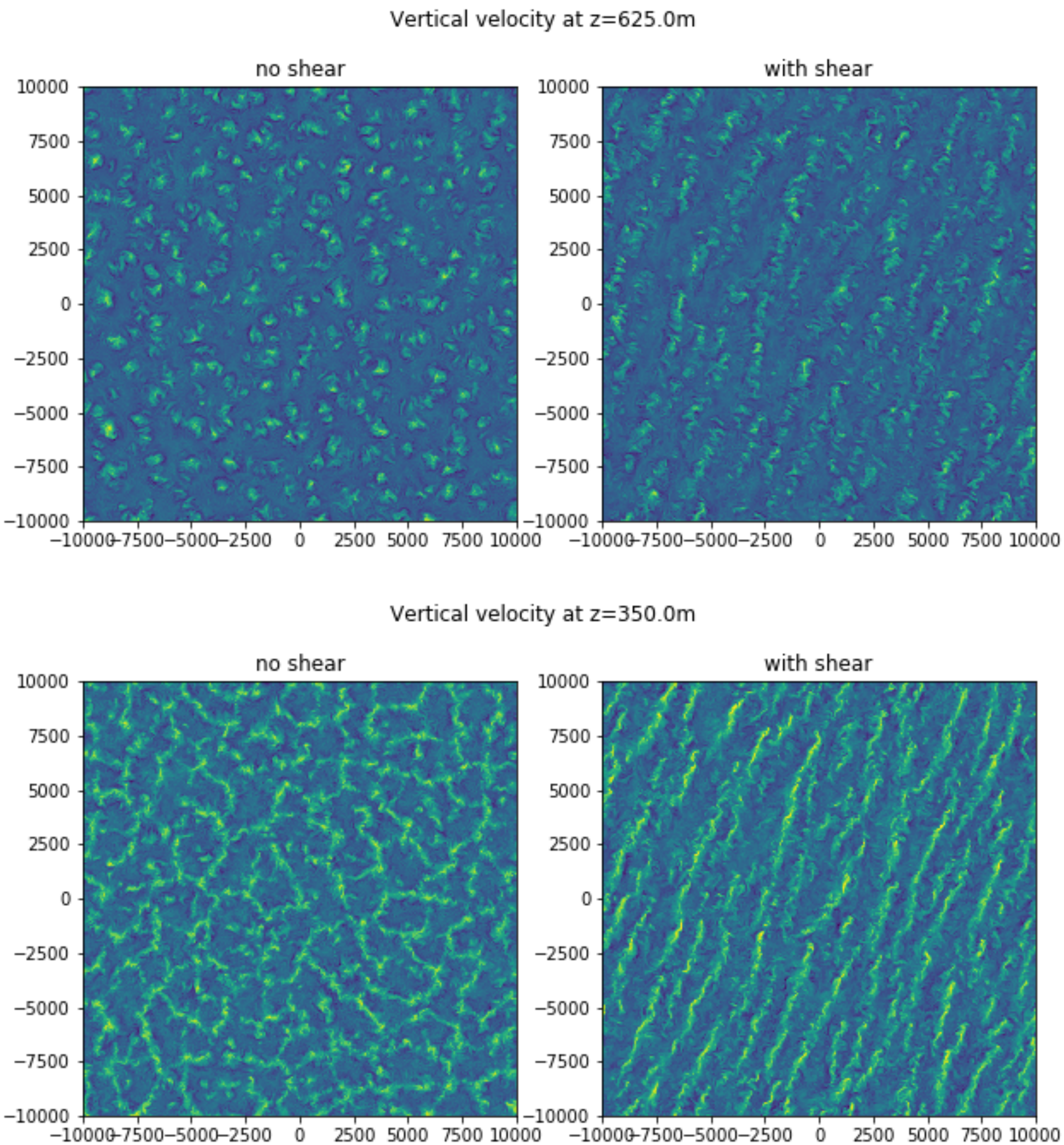
3 topics today

1. Recap of tools developed - in context of sheared vs non-sheared “RICO” simulations

2. Analysis of coherent structures when coldpool is present

3. Topographic triggering of convection test-case development

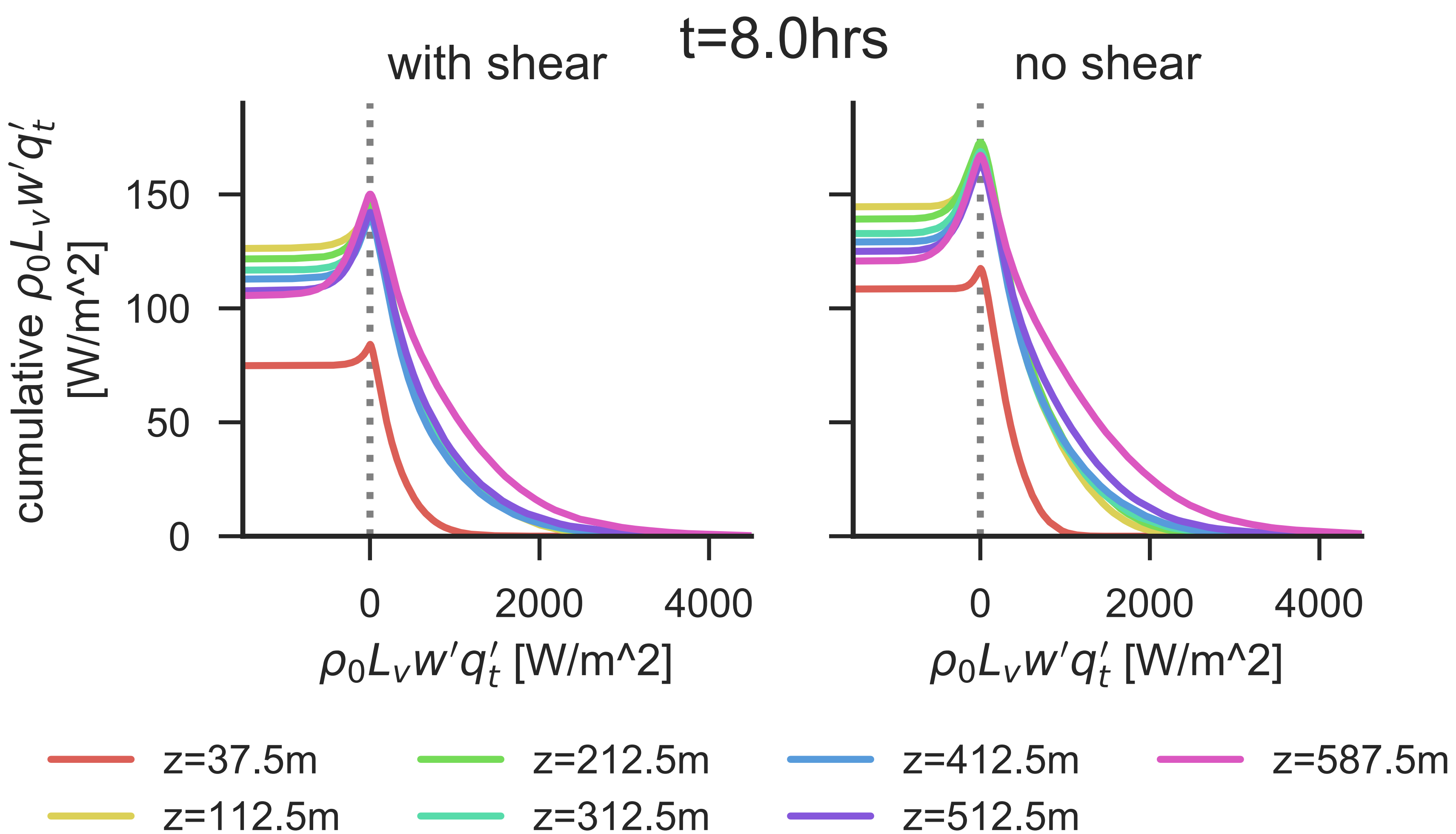
shear/no-shear RICO simulations



- Fixed fluxes (F_S=150W/m^2, F_l=7.0W/m^2)
- Convective cells instead of rolls in boundary layer
- In shear convection appears at ends of rolls?
- Without shear at nodes of cells?

1: cumulative contributions to vertical flux

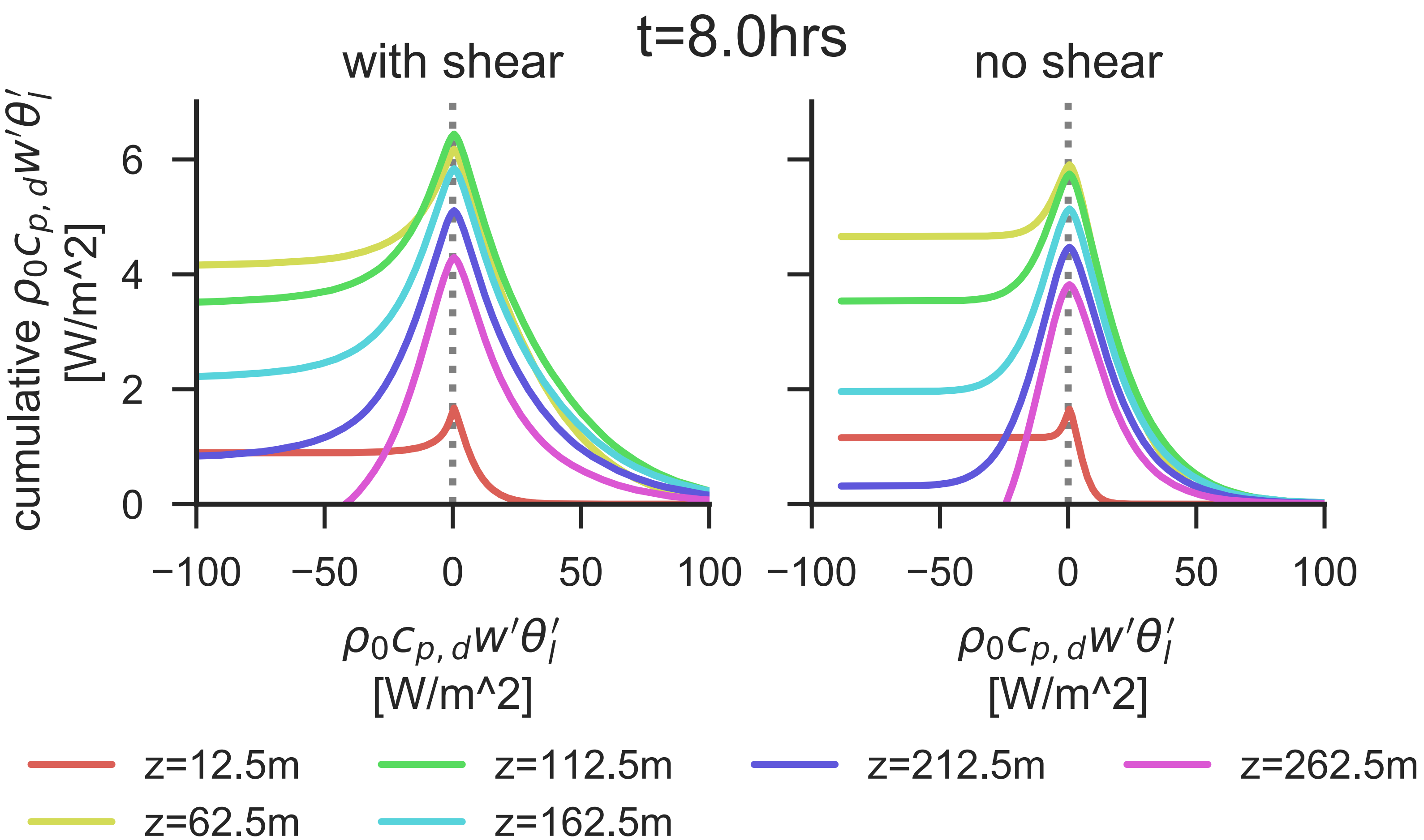
which values of vertical flux contribute the most to the horizontal mean flux?



- in bulk of boundary (100m < z < 500m) distribution unchanged with height
- at around 900W/m^2 ~ 0.6m/s kg/kg see largest change in contribution to total flux

1: cumulative contributions to vertical flux

which values of vertical flux contribute the most to the horizontal mean flux?



- sensible heat flux contribution small compared to latent
- distribution changes with height, might change with different Bowen ratio?

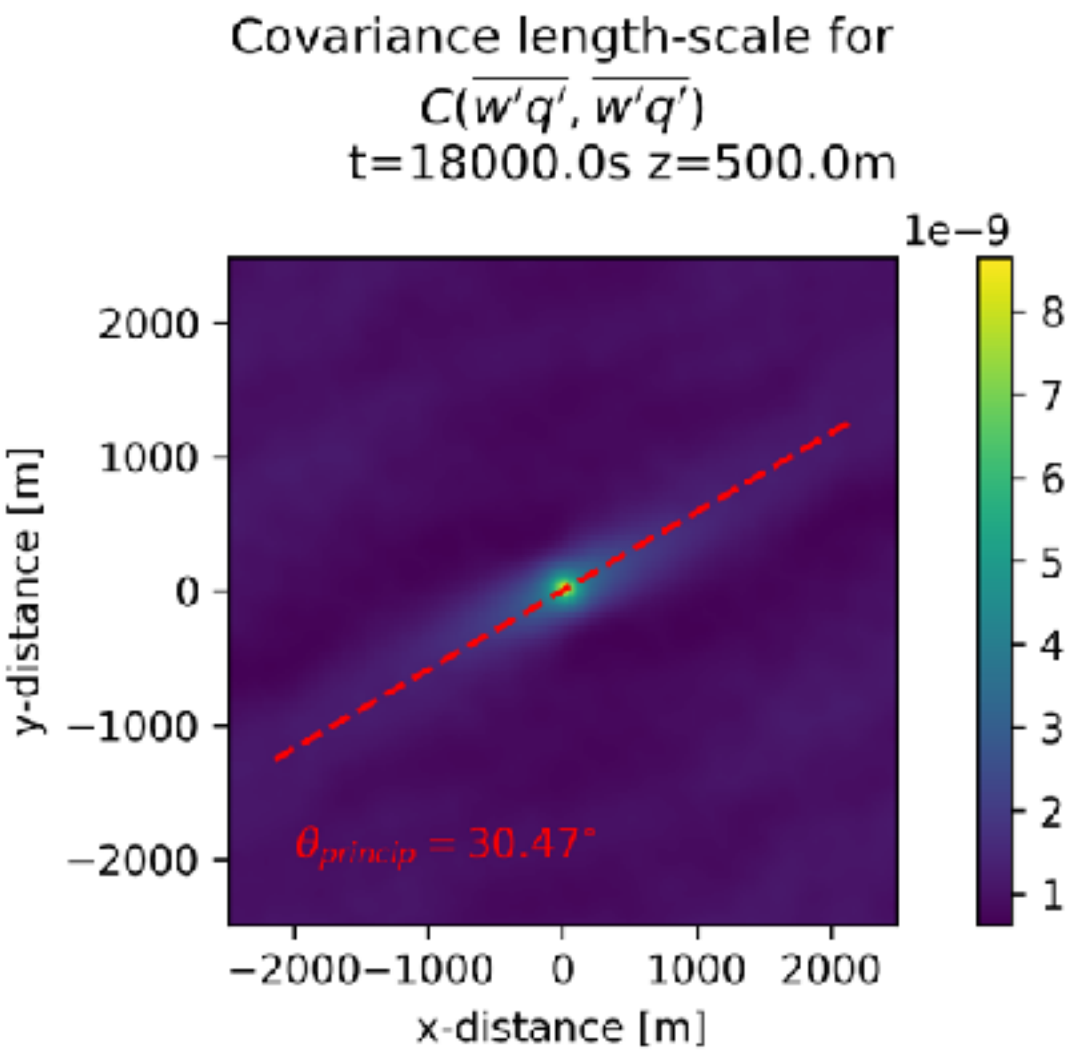
Use of cumulants to study characteristic scales

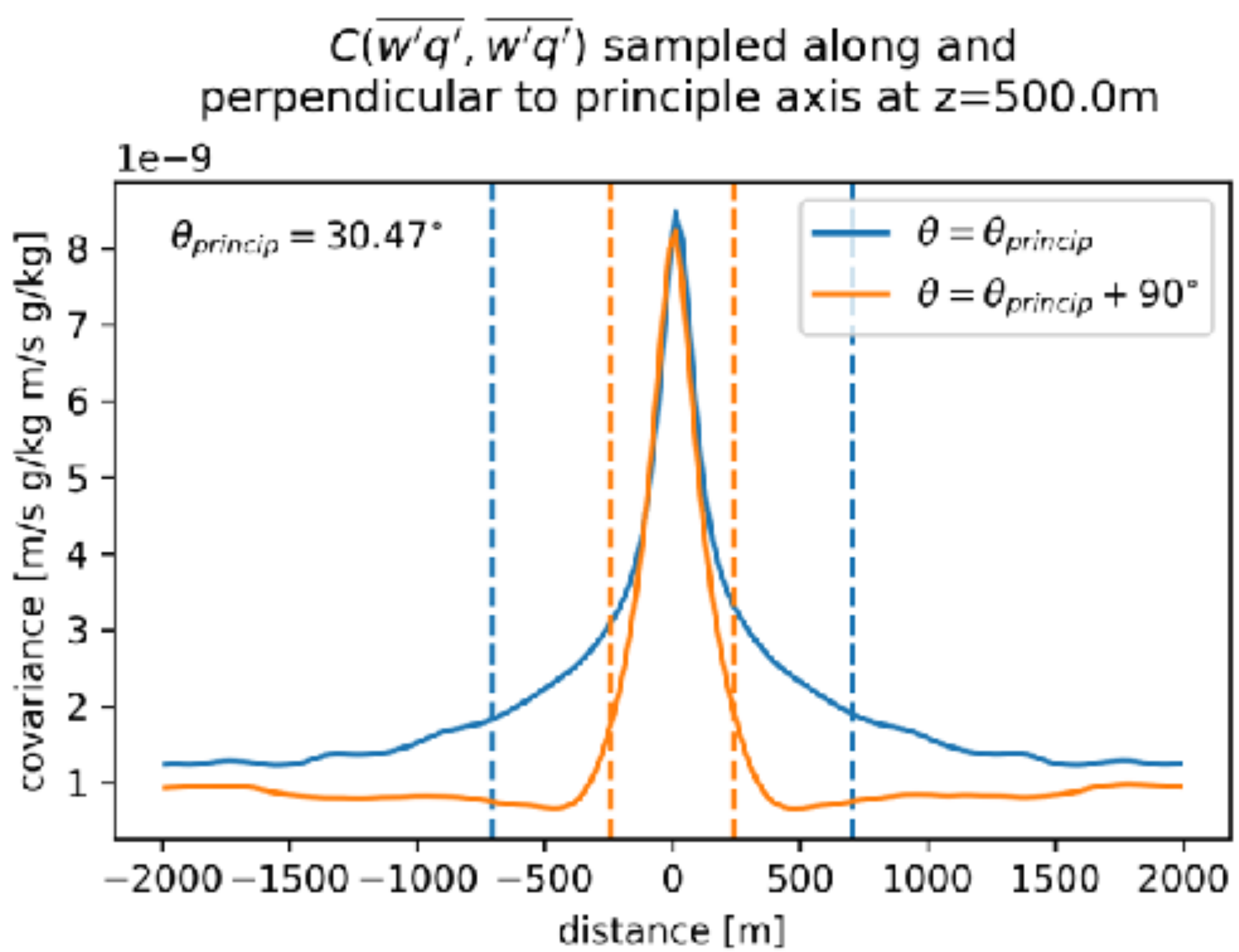
- Two-point correlation of two scalar fields (ϕ and ψ), here taken at same height (z) for both fields

$$c_{\phi\psi}(\xi, \mu, z) = \frac{1}{L_x L_y} \int_0^{L_x} \int_0^{L_y} \phi'(x, y, z)\psi'(x + \xi, y + \nu, z) dx dy$$

- Measures how correlation with distance (in xy-plane) of scalar fields
- Used by Tobias and Marston 2016 to identify principle length-scales in 3D cuvette flow

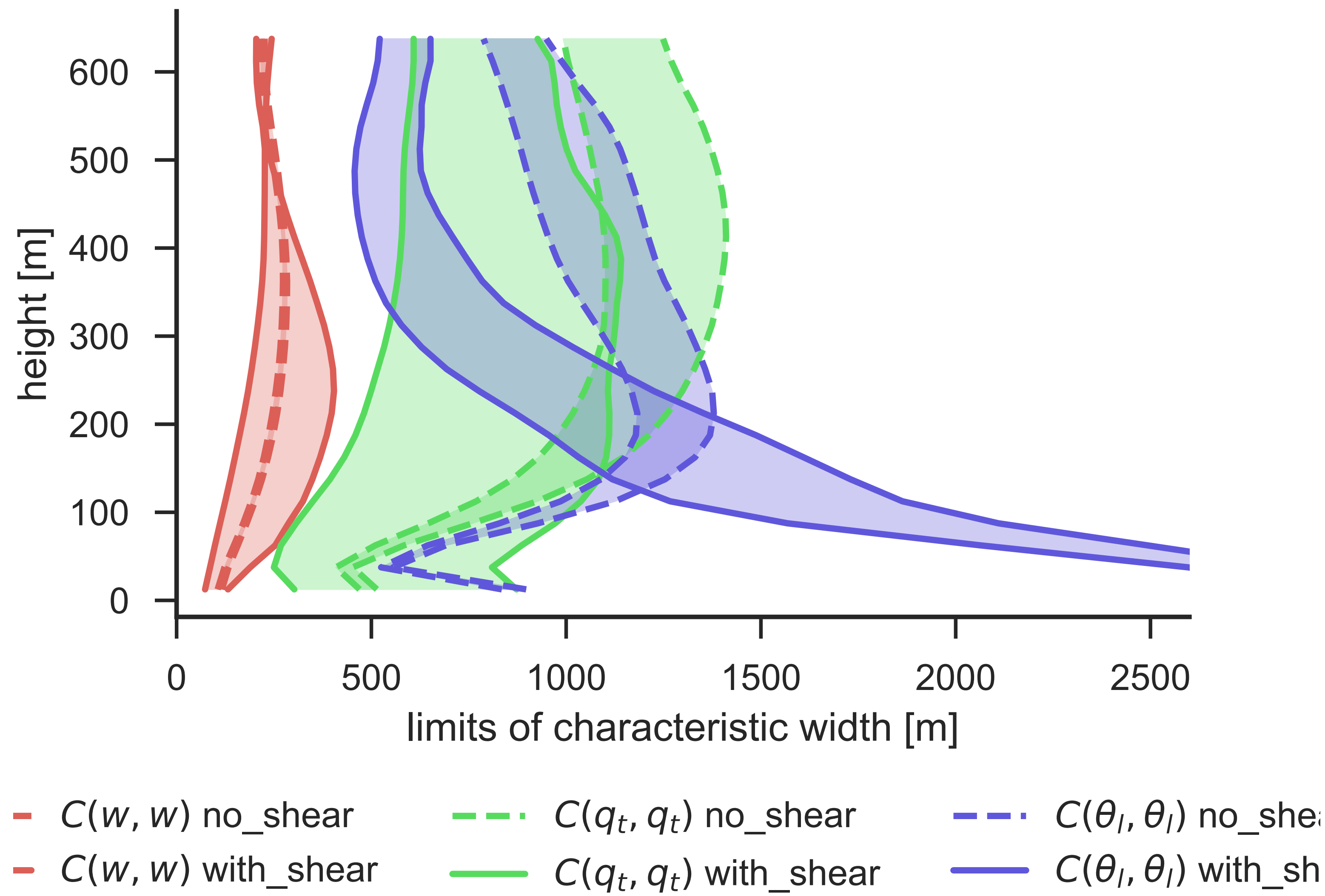
Use of cumulants to study characteristic scales





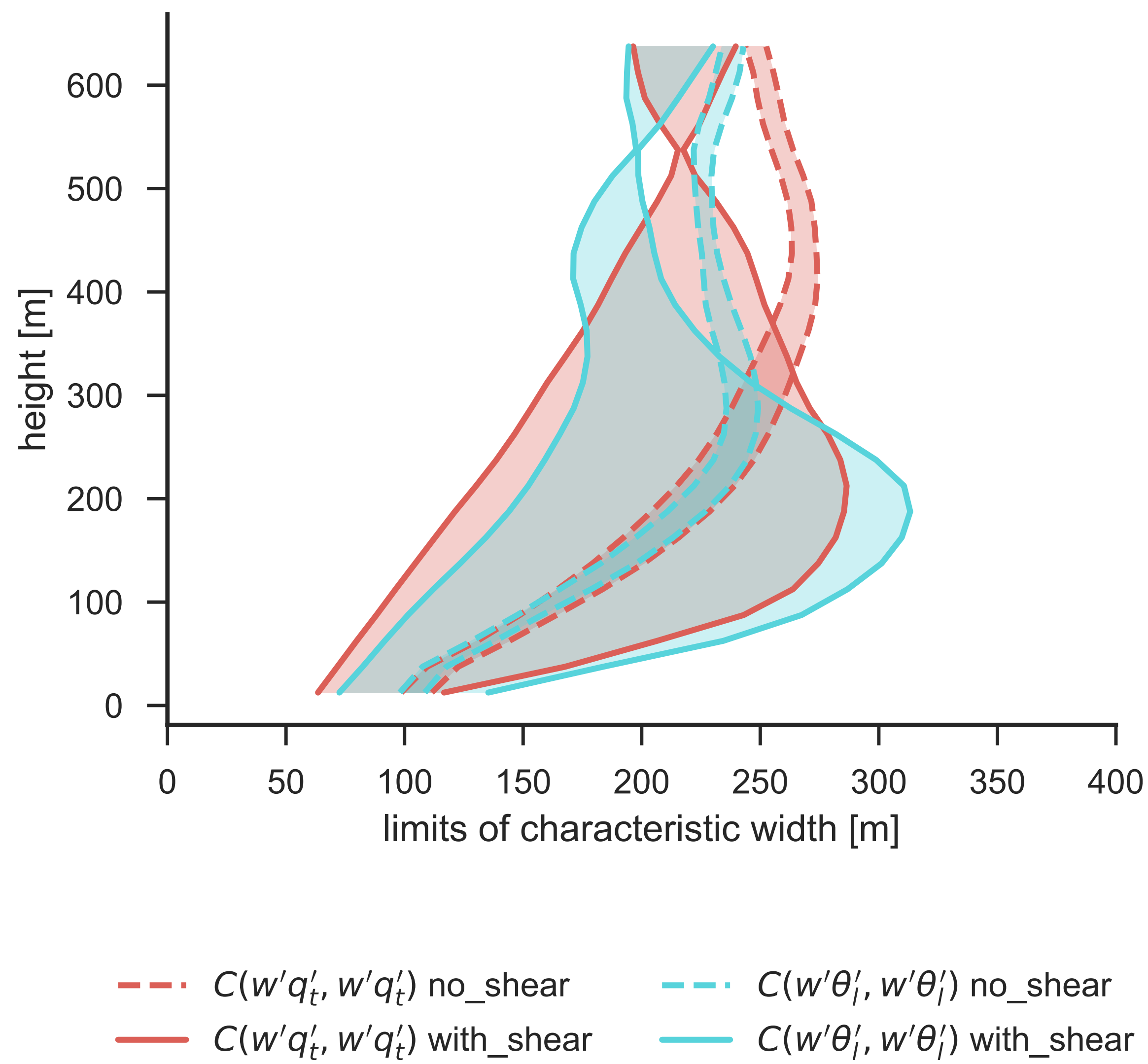
- Principle axis identified from principle axis of moment of inertia tensor

Characteristic length-scales of scalar fields



- scalar fields vary over different length-scales
- wind shear generally causes elongation of structures, although temperature appears organised by shear? (sensible heat flux small though, see later)

Characteristic length-scales of vertical flux fields



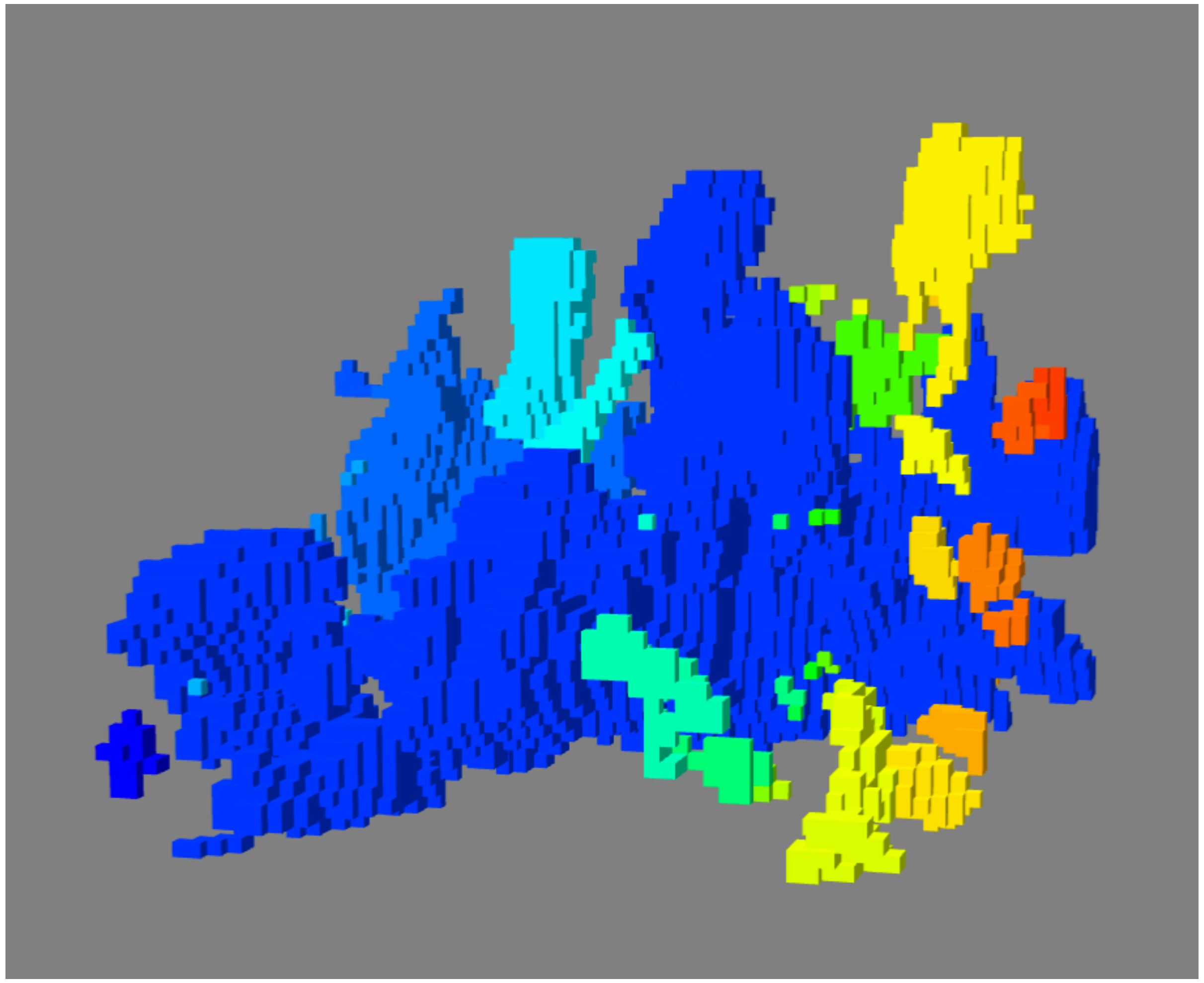
- moisture (latent) and (sensible) heat flux similar length-scale till ~300m.
- shear causes elongation of coherent structures

3. Identifying individual triggering objects

- Identify (and later, track in time) boundary layer structures which cause convection to trigger

  ➡ Developing cloud-tracking code with Steven Boeing

- Use to partition distributions of variability by individual objects (of specific size, volume, shape, etc)



Buoyant elements defined by w > 0.5m/s
in boundary layer of RICO simulation at t=480min

➡ Investigating using object topology as means of classification (Contour-tree analysis by Hamish Carr, Leeds)

What are characteristic sizes of objects in the boundary layer?

- Use Minkowski functionals to compute characteristic length-scales

$$V_0 = V = \int dV$$
$$V_1 = \frac{A}{6} = \frac{1}{6}\int dS$$
$$V_2 = \frac{H}{3\pi} = -\frac{1}{6\pi}\int dS \nabla \cdot \hat{n}$$
$$\left(V_3 = \frac{1}{4\pi}\int (\kappa_1 \kappa_2) dS \right)$$

$$\Rightarrow$$

$$L = \frac{3V_2}{4V_3}$$
$$W = \frac{2V_1}{\pi V_2}$$
$$T = \frac{V_0}{2V_1}$$

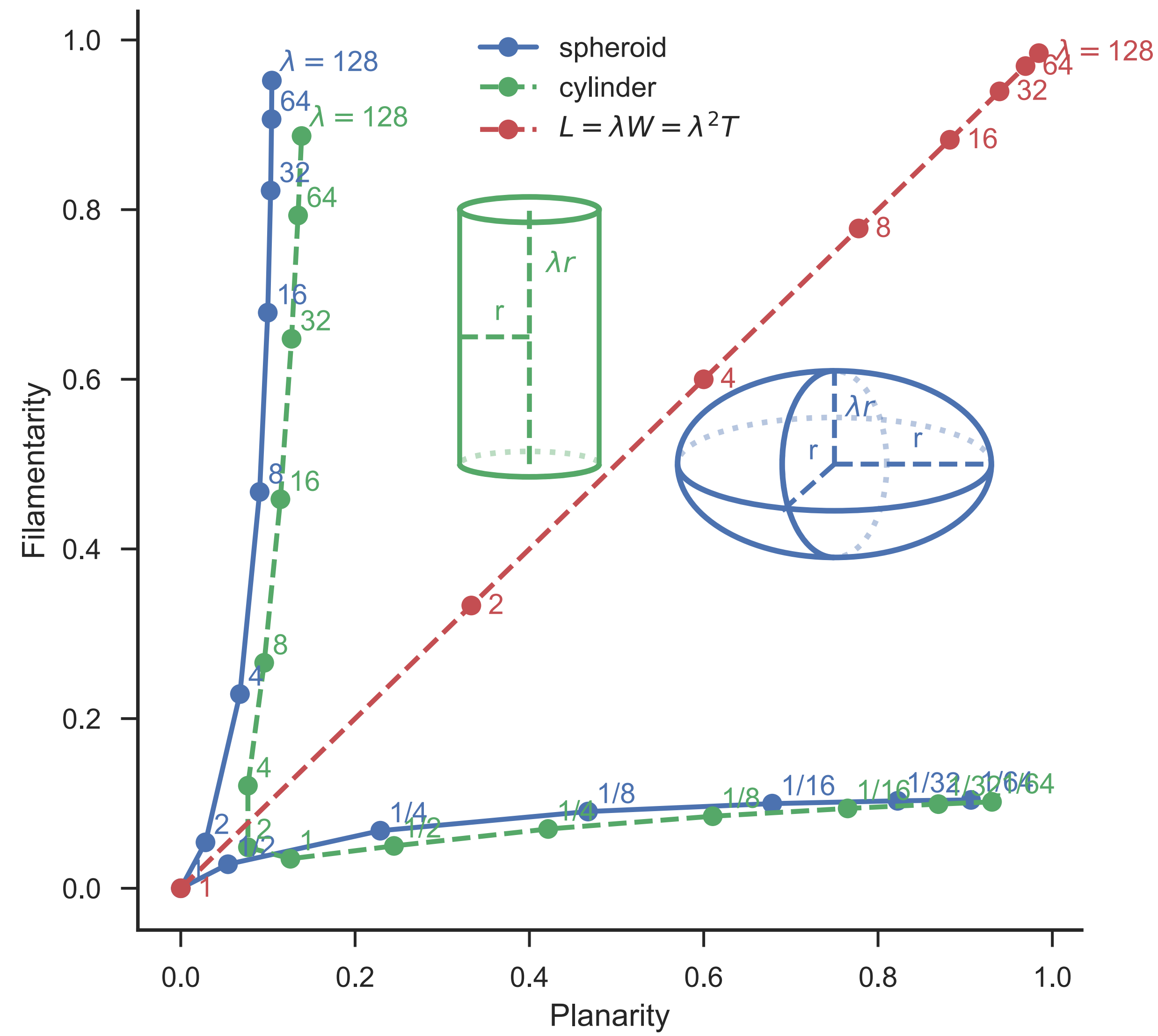
$L \geq W \geq T$ *by construction*

V: volume, A: area, H: mean curvature, κ_1 and κ_2 intrinsic local curvature ($\nabla \cdot \hat{n} = \kappa_1 + \kappa_2$)

What is shape of objects in the boundary layer?

Calculate the planarity (P) and filamentary (F) from Minkowski functional length-scales

$$P = \frac{W - T}{W + T}, F = \frac{L - W}{L + W}$$



➡️ Measures how pencil or disc-like an object is

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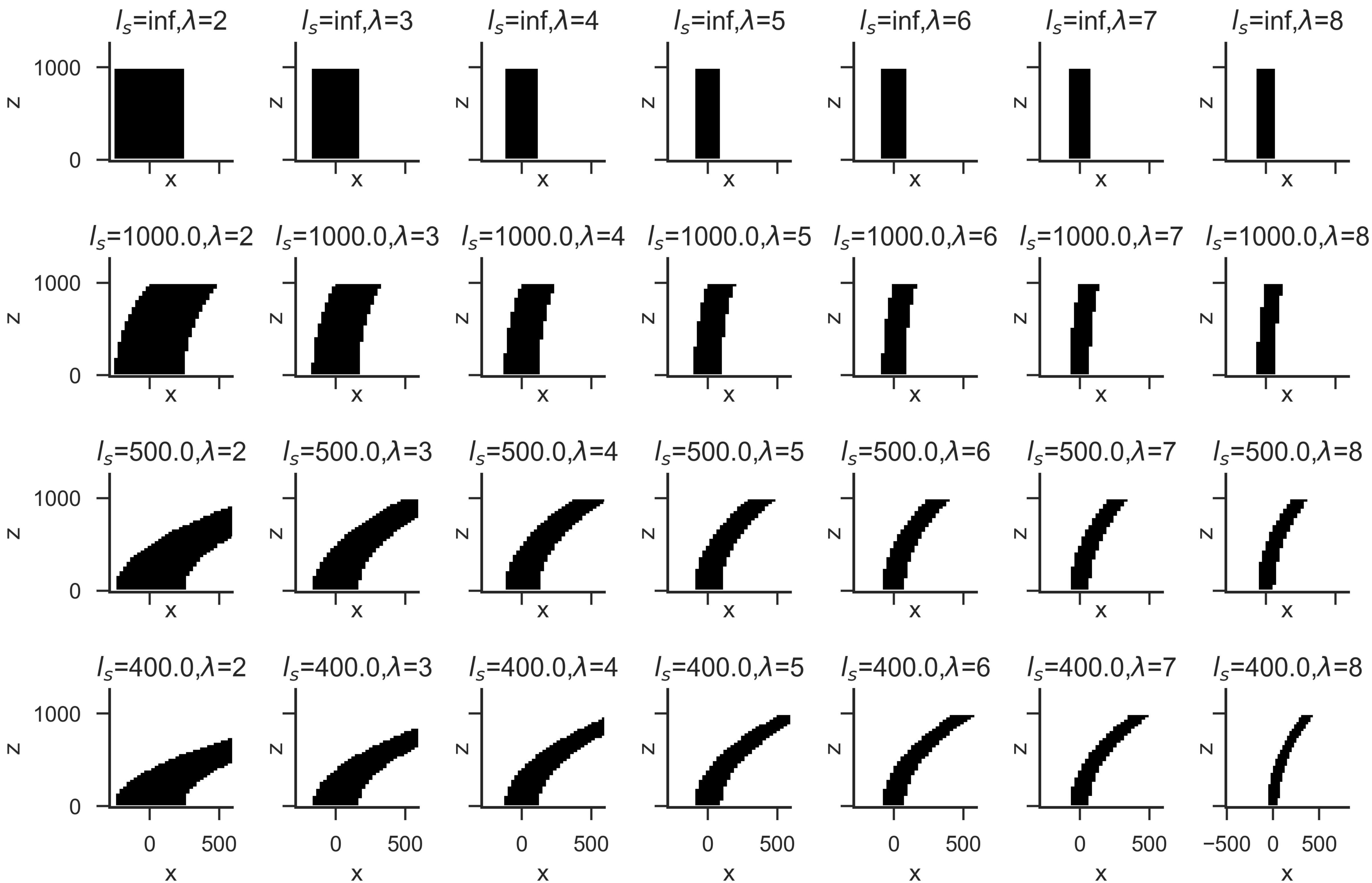

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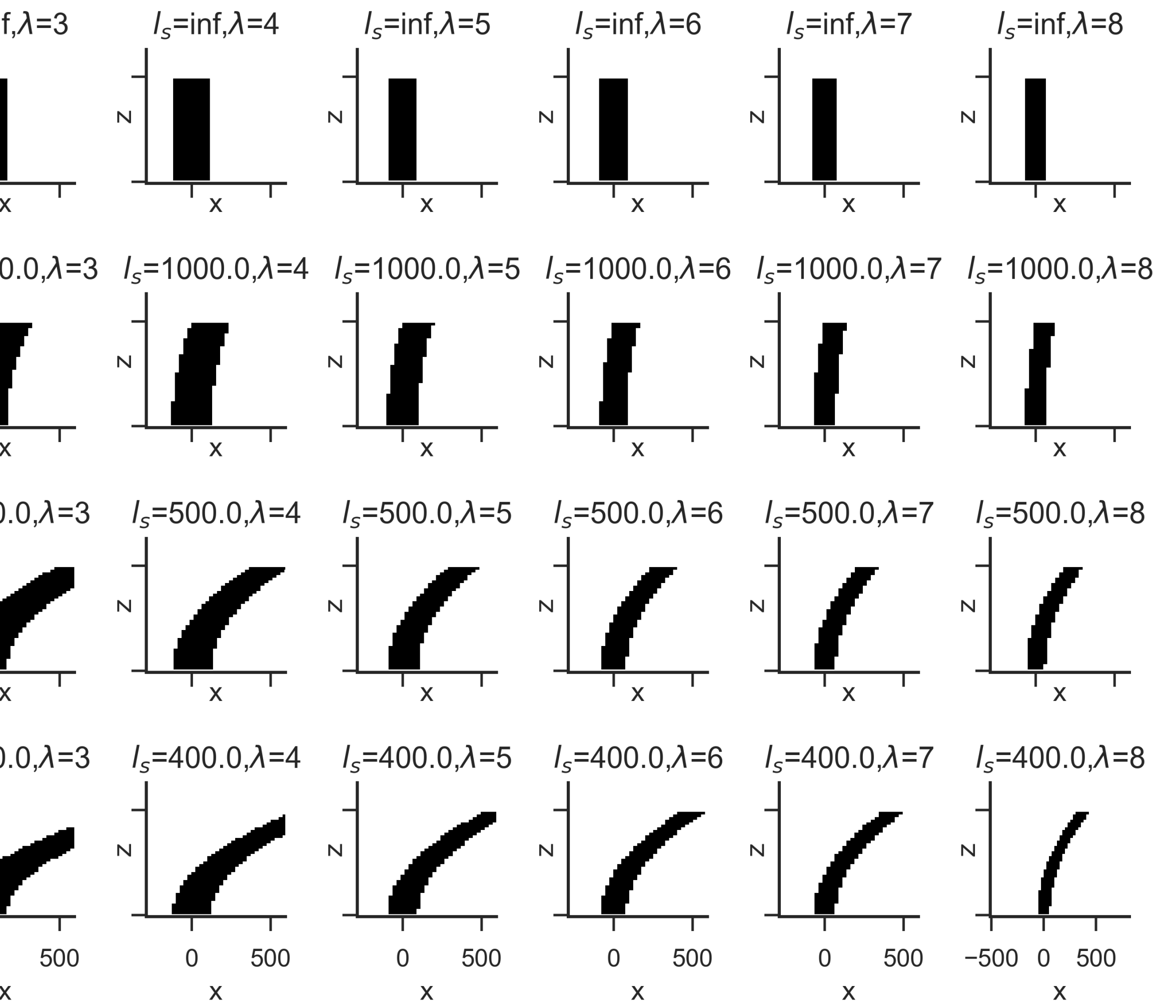

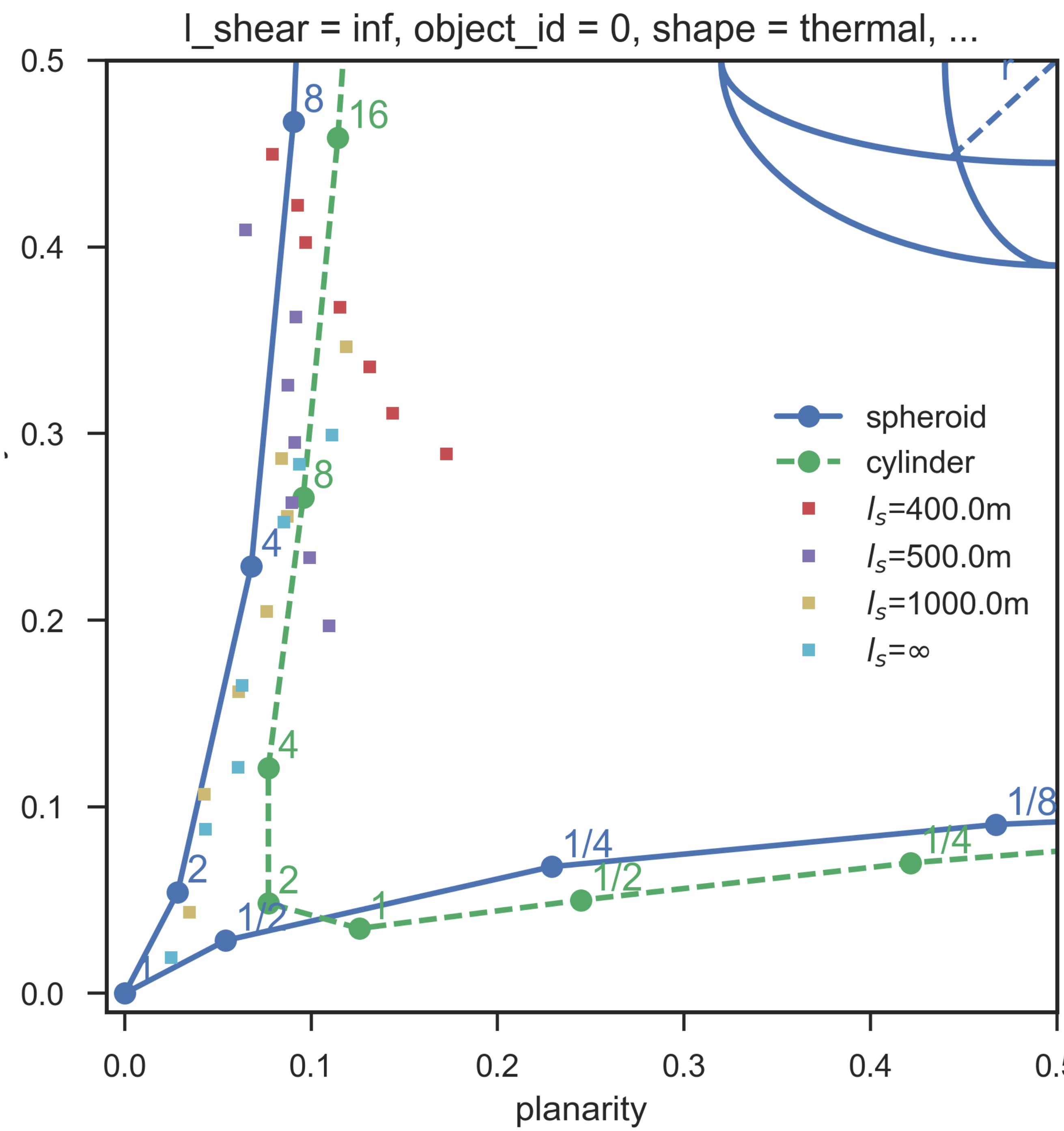

Generally have filamentarity < 0.5 and planarity < 0.2

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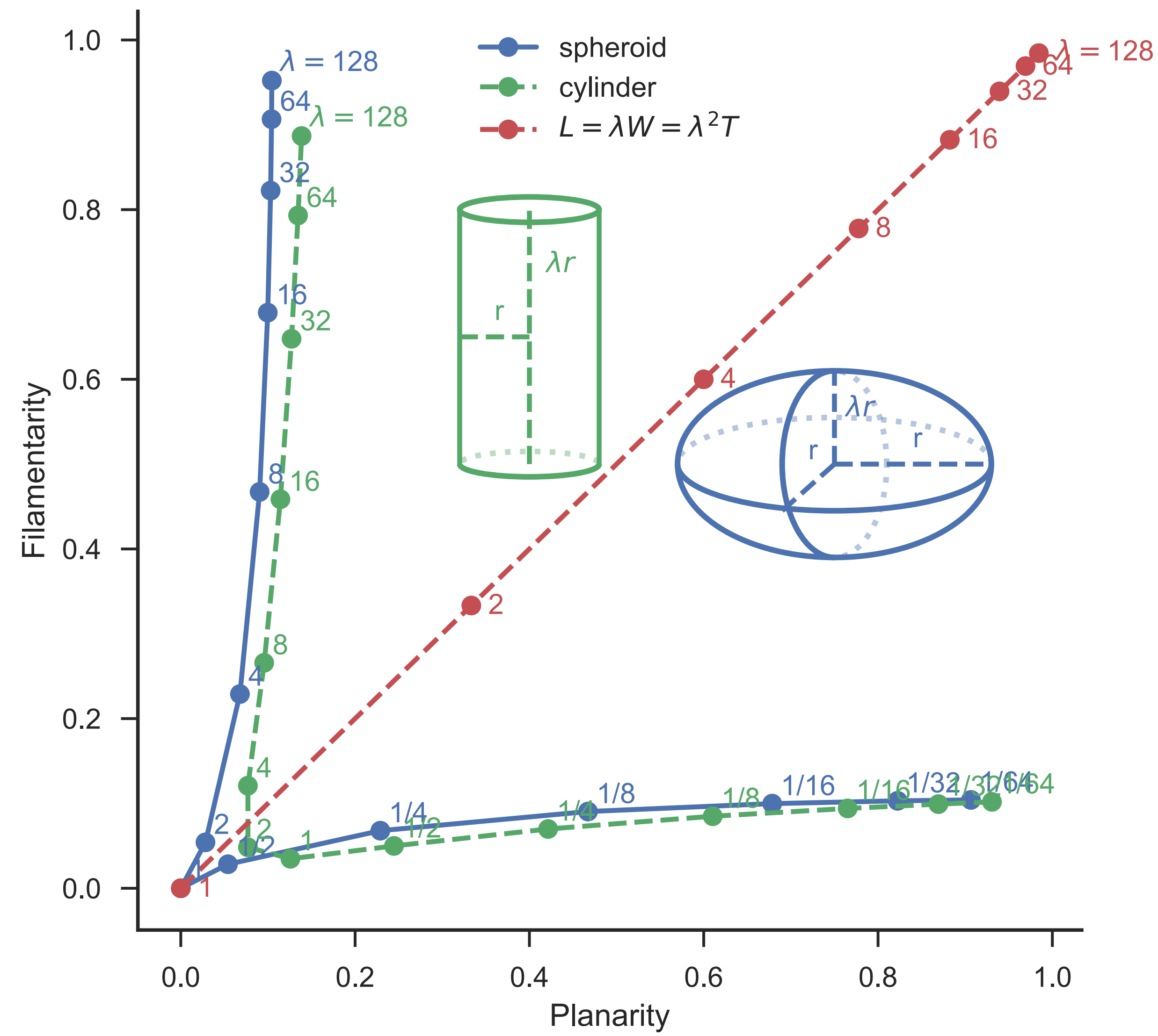
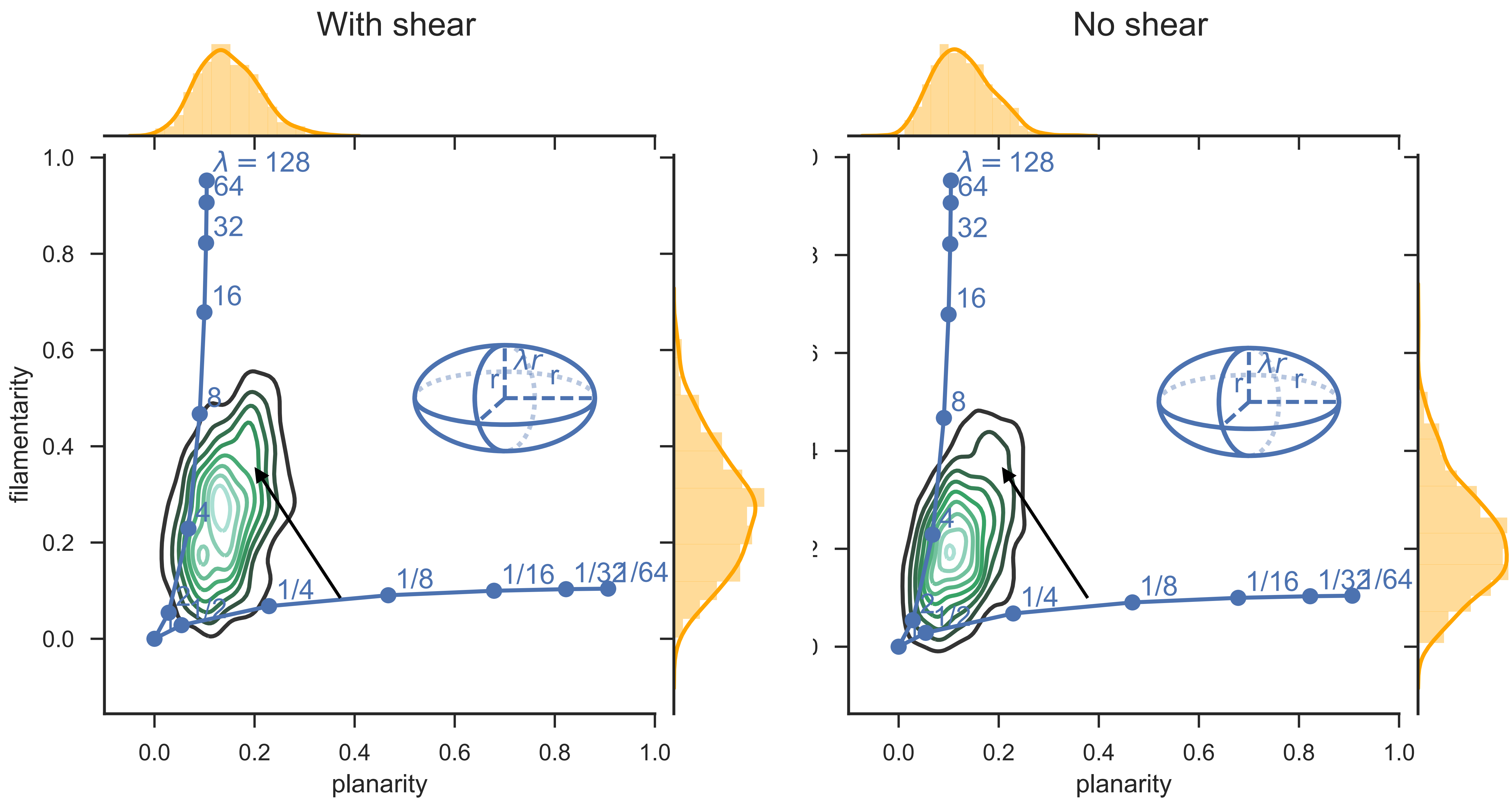


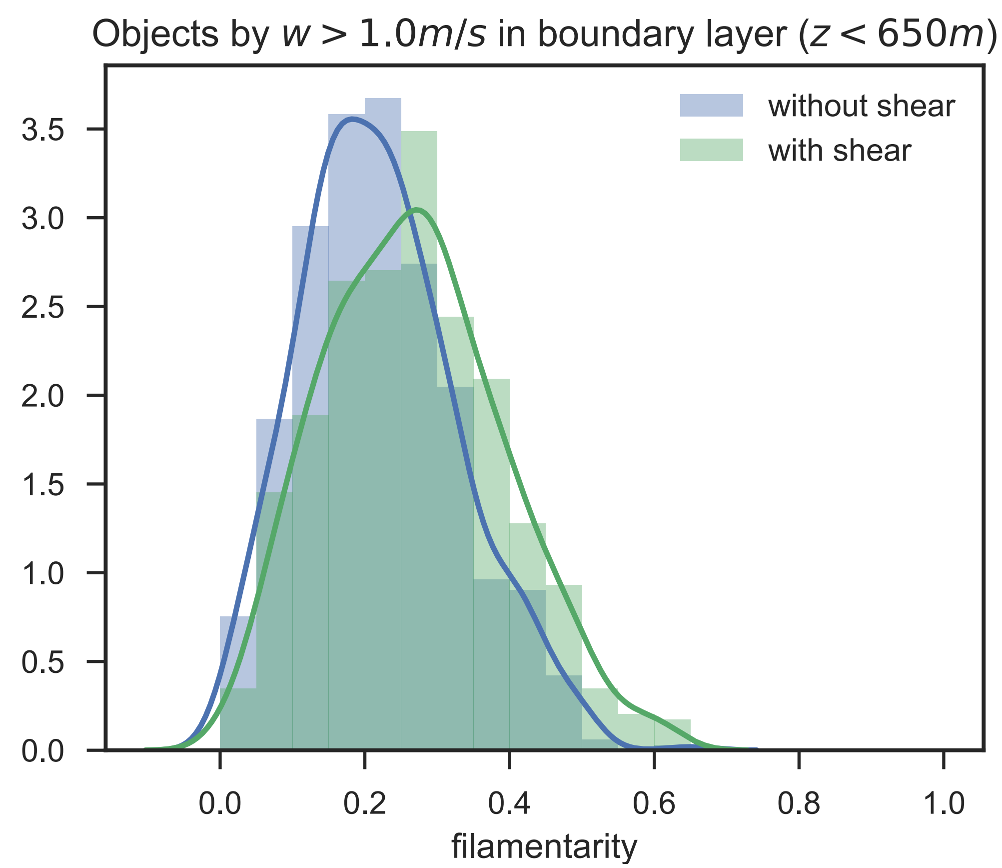
$$P = \frac{W - T}{W + T}, F = \frac{L - W}{L + W}$$

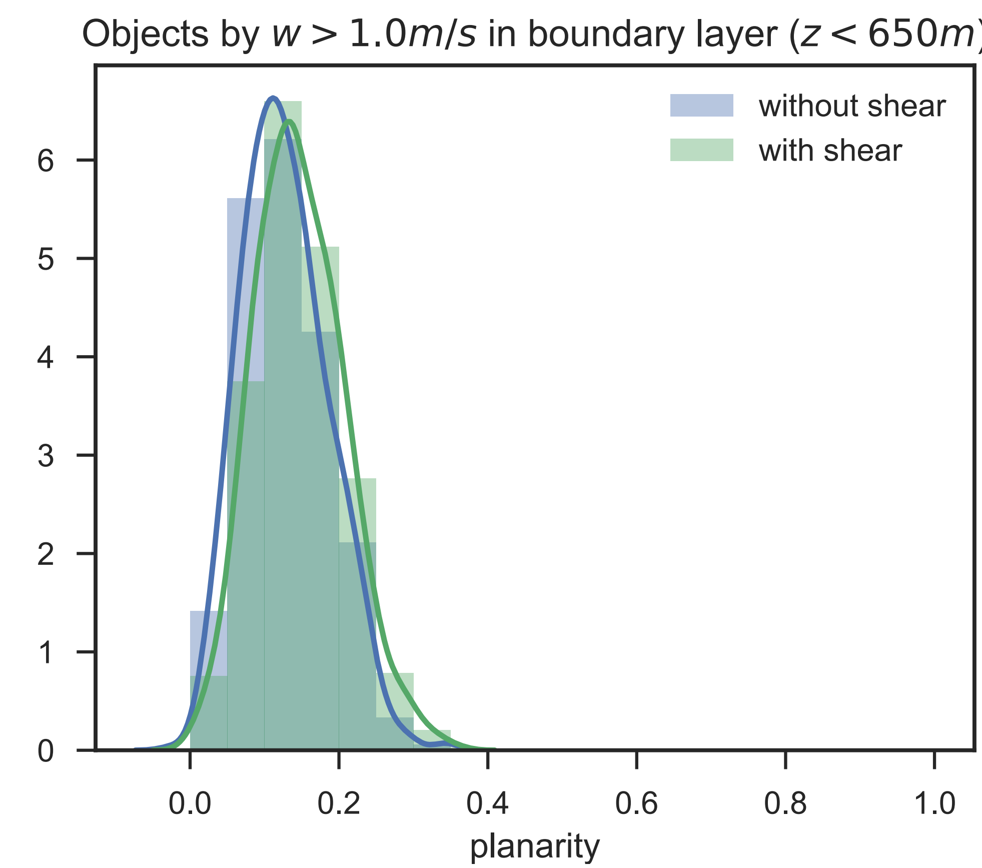
➡️ Measures how pencil or disc-like an object is

Shear's effect on topology



Shear/no-shear affect on topology





- ➡️ Shear appears to elongate boundary layer thermals, more elongated and more planar

Three coldpool questions

1. Do coldpools alter the bulk statistics in the boundary layer?

2. Spatial (horizontal) variation in coherent length-scales?

   - different length-scales within, outside or near coldpool edge?

3. Time variation of coherent length-scales?

   - does formation of coldpools affect coherence outside of them?

One coldpool question

1. ~~Do coldpools alter the bulk statistics in the boundary layer?~~

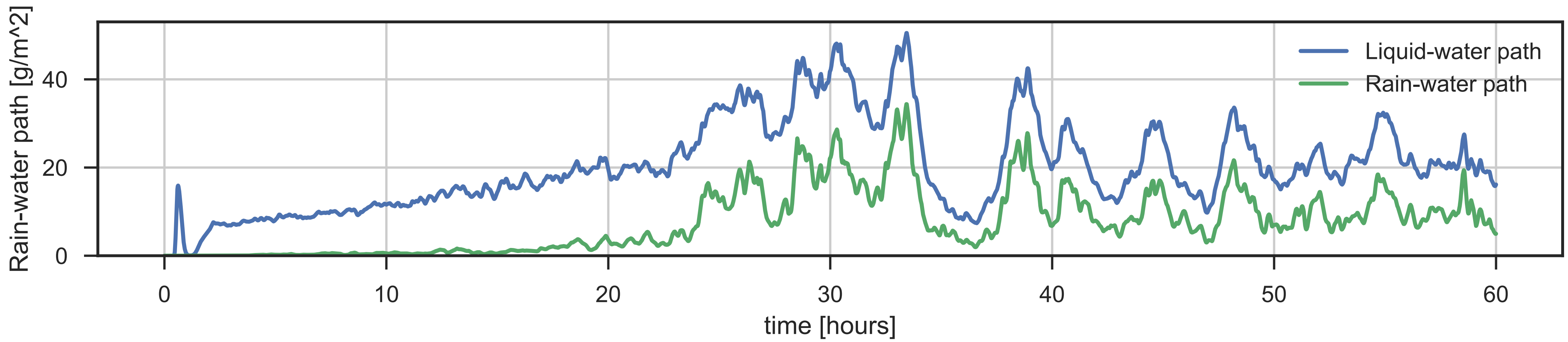
2. Spatial (horizontal) variation in coherent length-scales?

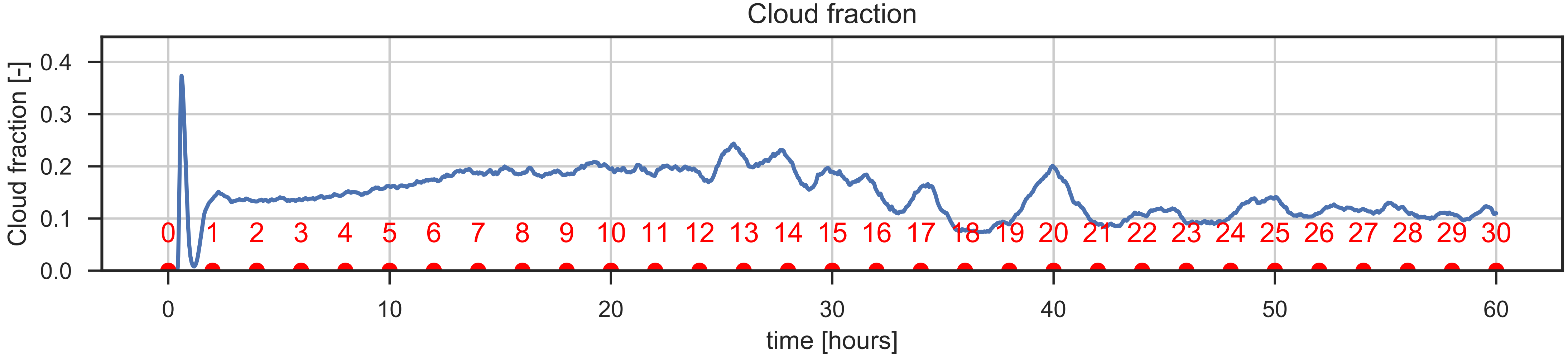
    - different length-scales within, outside or near coldpool edge?

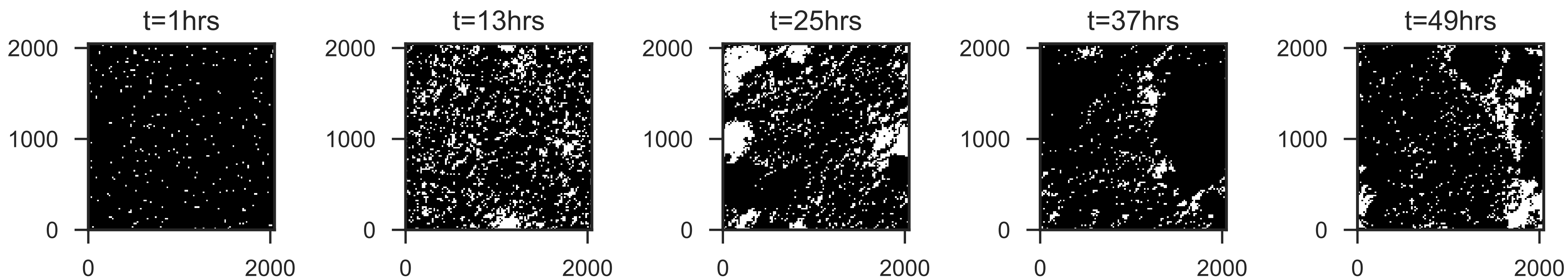
3. Time variation of coherent length-scales?

    - does formation of coldpools affect coherence outside of them?

RICO: overview

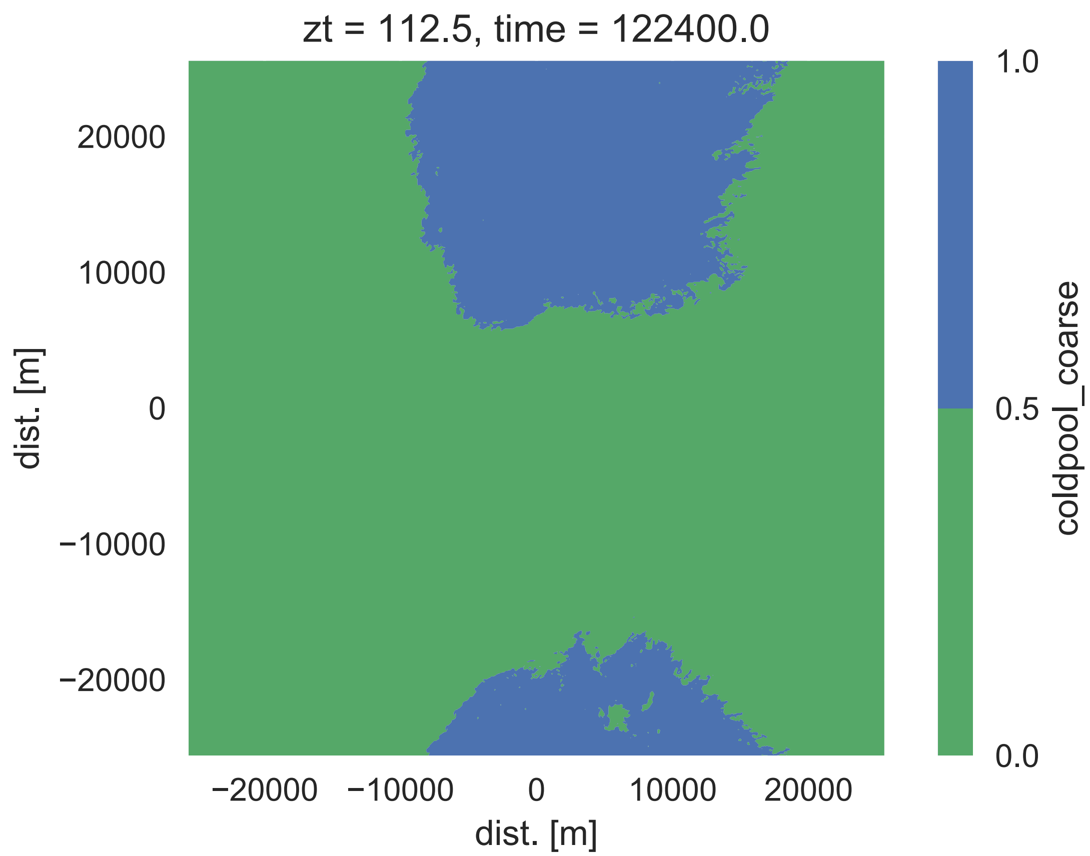


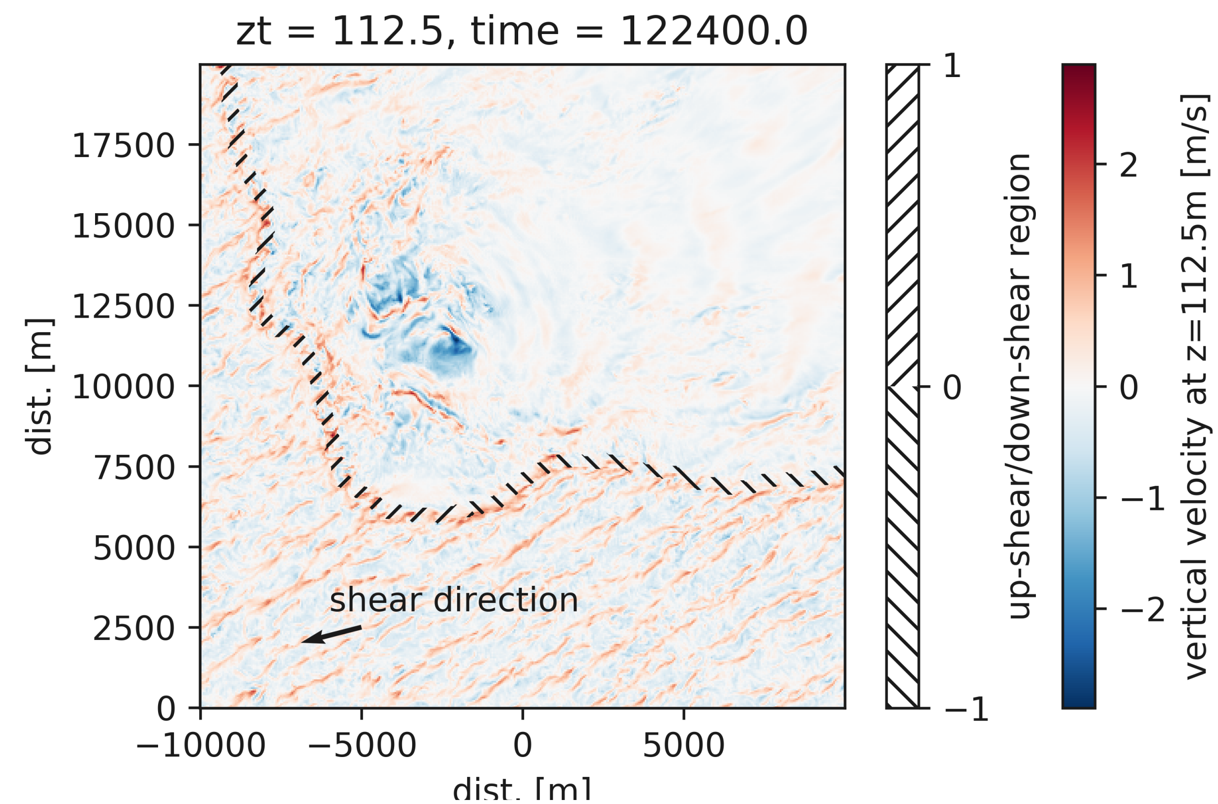




Domain decomposition

Identifying interesting regions to study



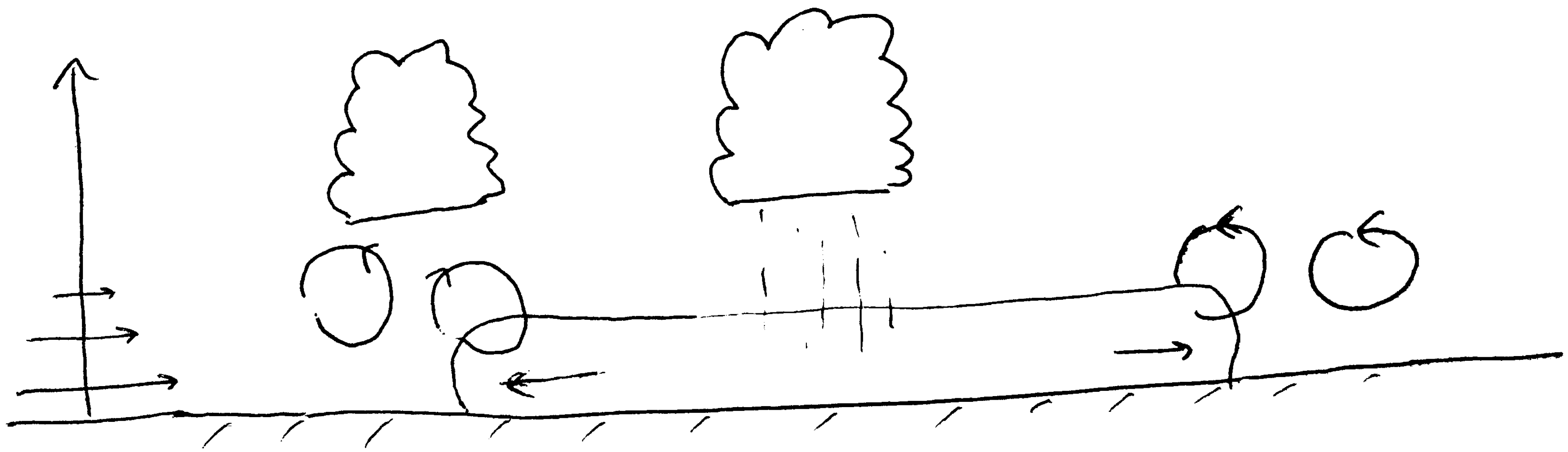


Using density anomoly ($\theta_v' < -0.1K$) to define coldpool region

Using mean direction of ambient shear and coldpool edge orientation to identify up-shear/down-shear edge

RKW-theory (precipitating clouds)

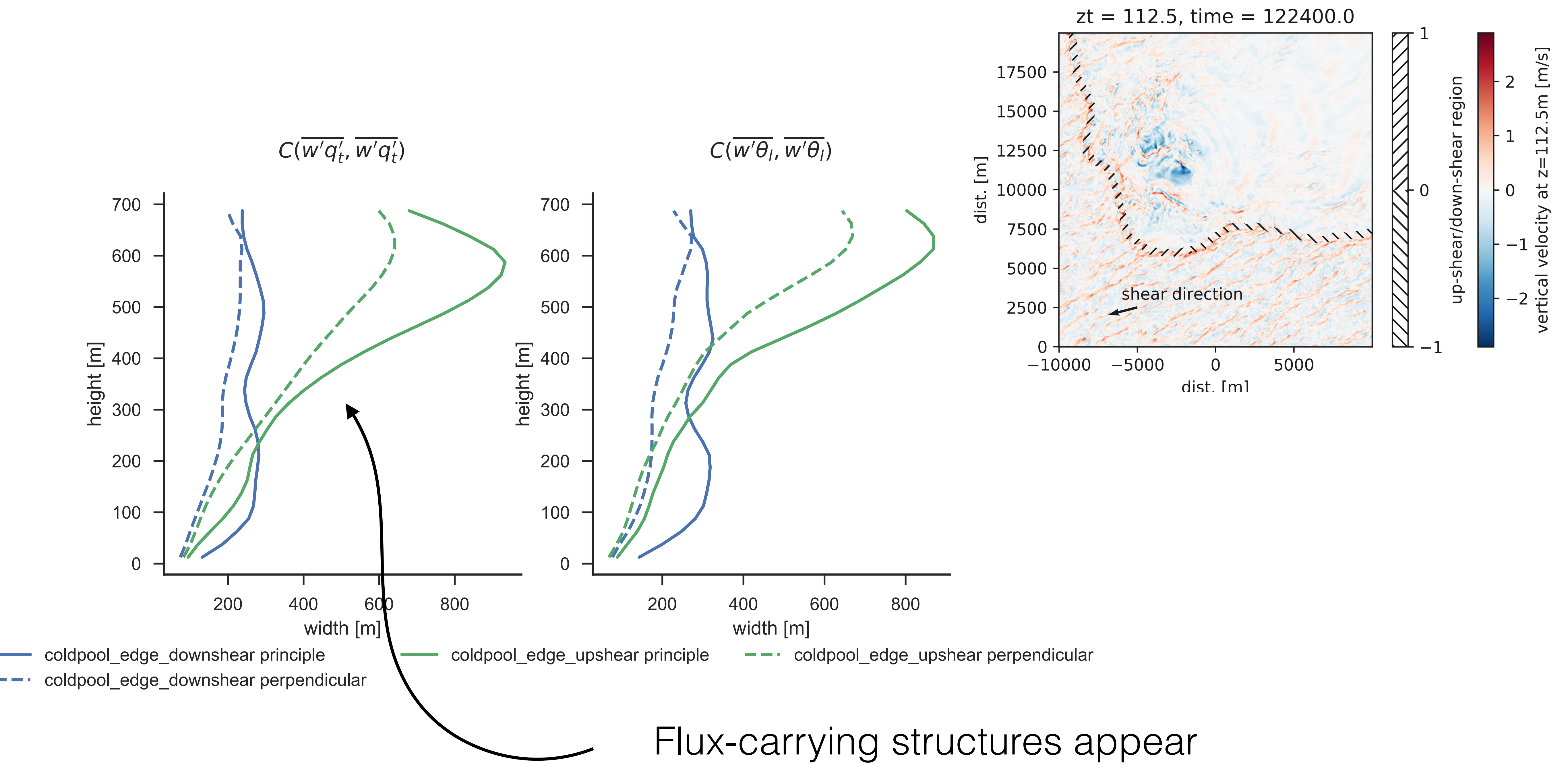
Rotunno, Klemp & Weisman 1980s



- Evaporation of rain creates density current
- At edge of spreading current (gust front) air is lifted, inducing local vorticity
- When combined with shear of opposite vorticity convection is more strongly forced, can trigger new clouds or self-reinforce existing (super-cells)

Coherence length

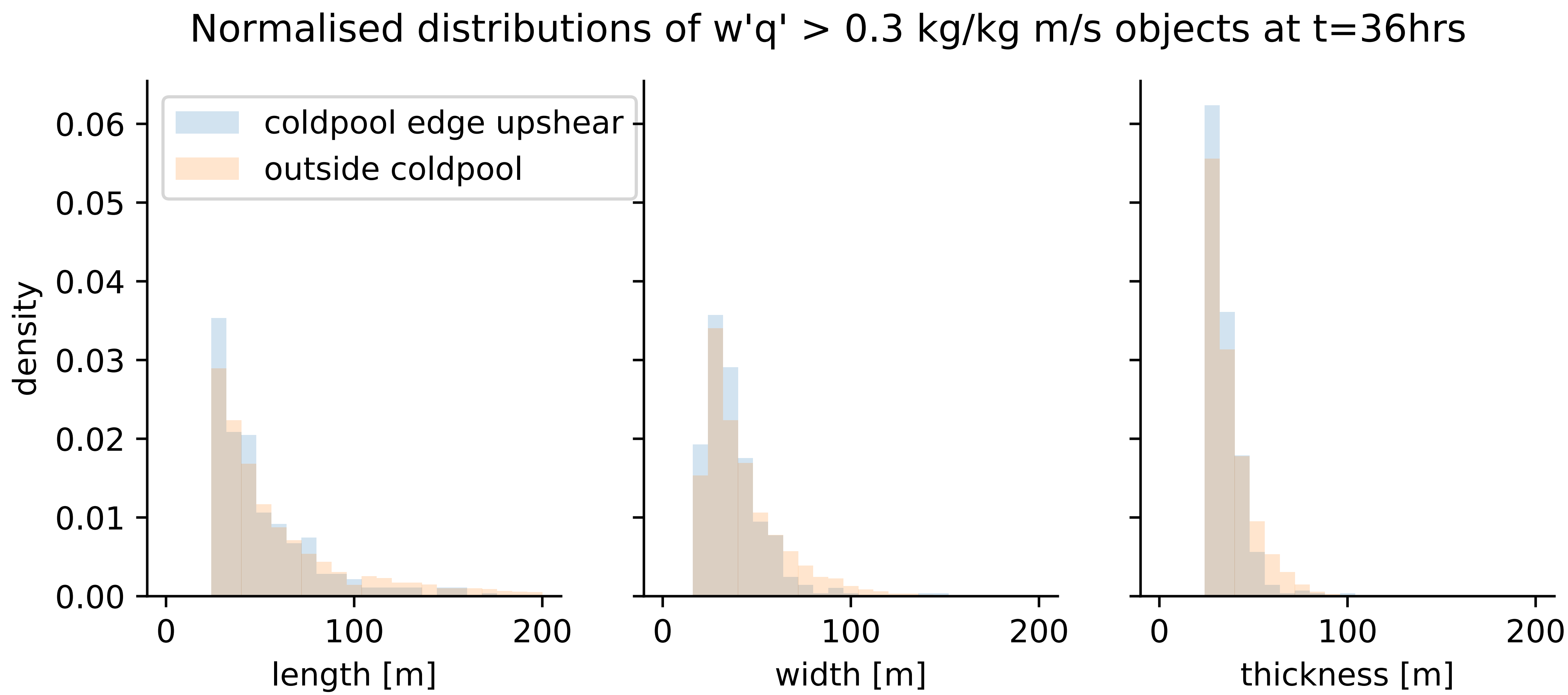
Upshear and downshear coldpool edge



Flux-carrying structures appear larger than in bulk of domain

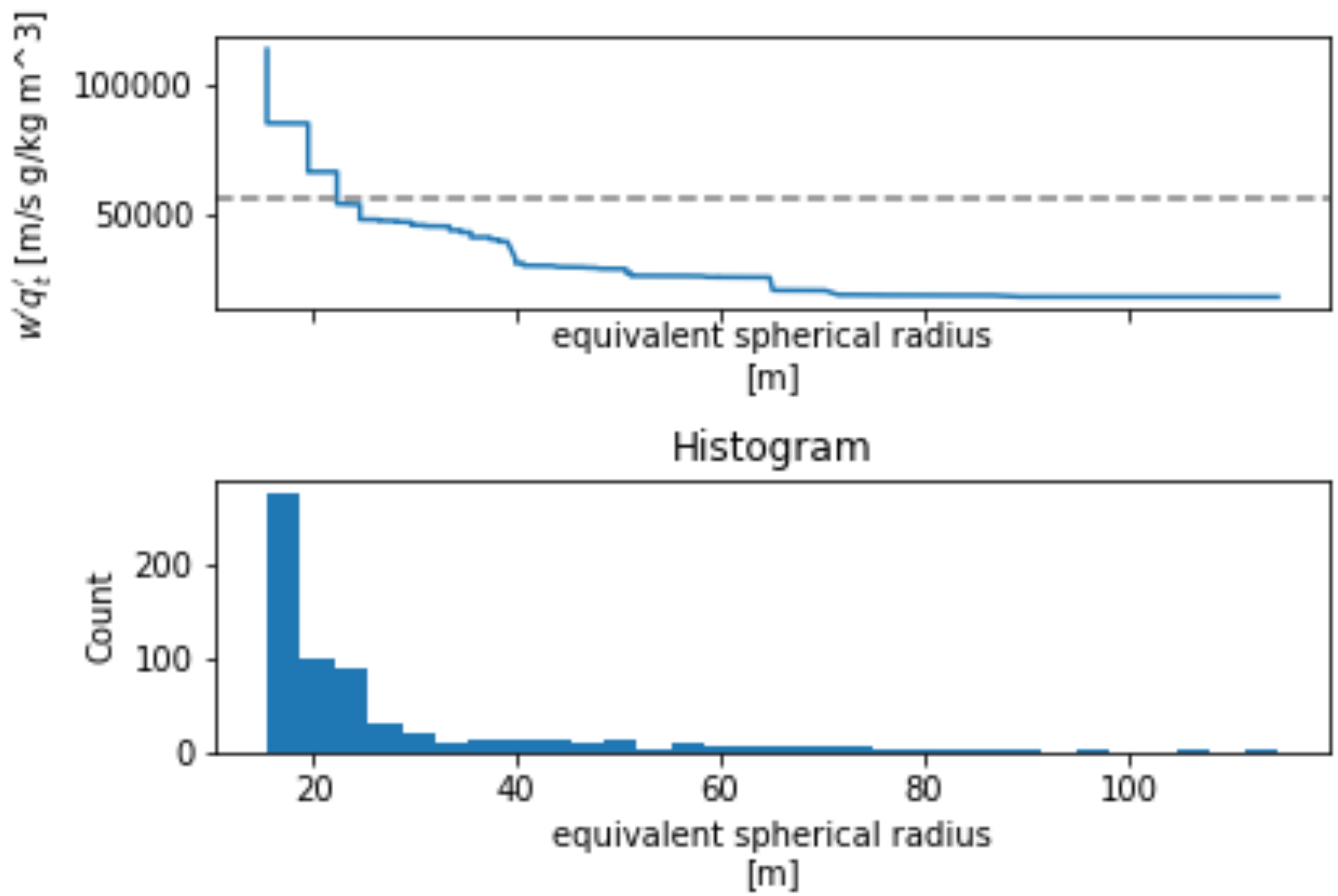
What are the characteristic length-scales of boundary layer structures?

Minkowski functionals of individual objects



- Objects in up-shear edge are longer, wider and thicker than in bulk of domain

But…

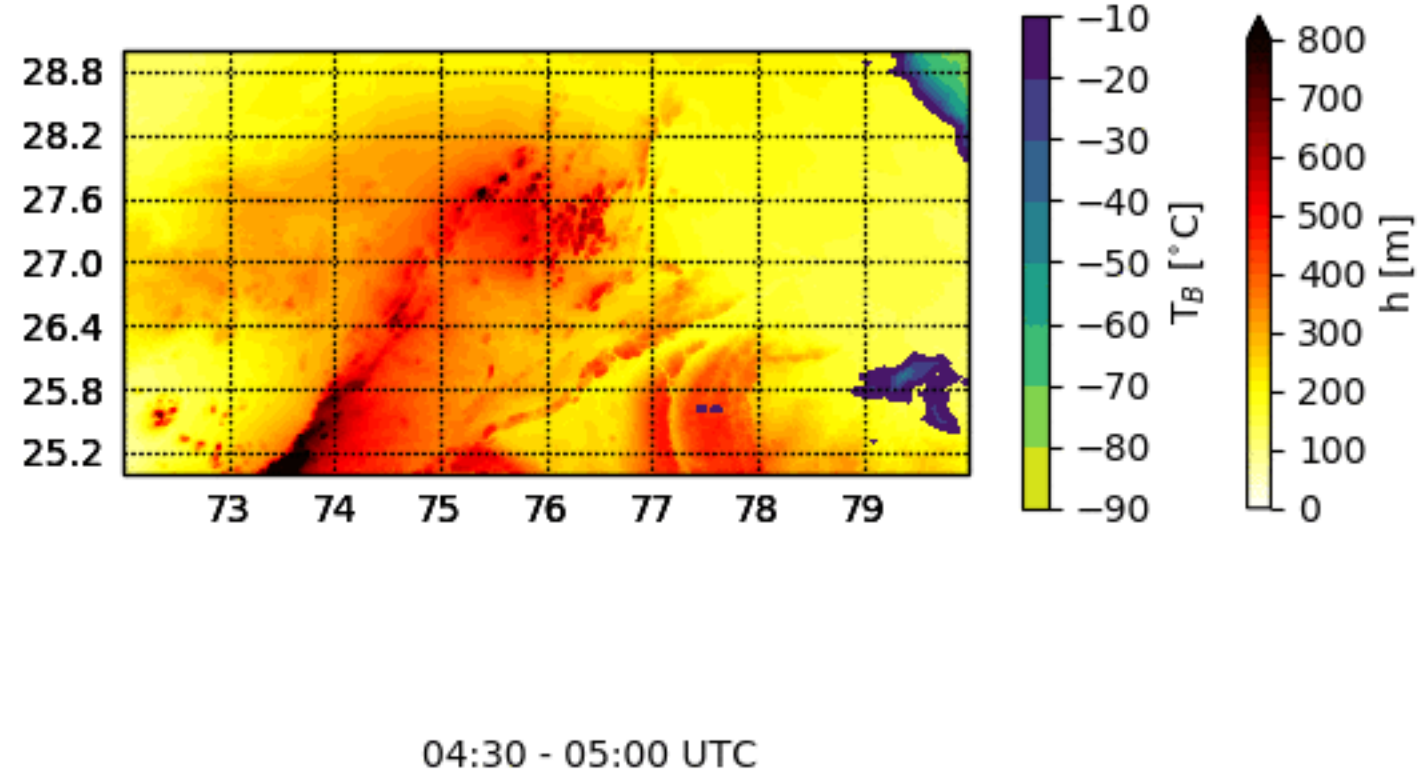


- Smaller objects contribute significantly to total flux
  => Need to identify objects that *trigger* convection

Ongoing: orographic triggering test case

- Based off 30th June 2016 INCOMPASS flight B968 near Lucknow, India

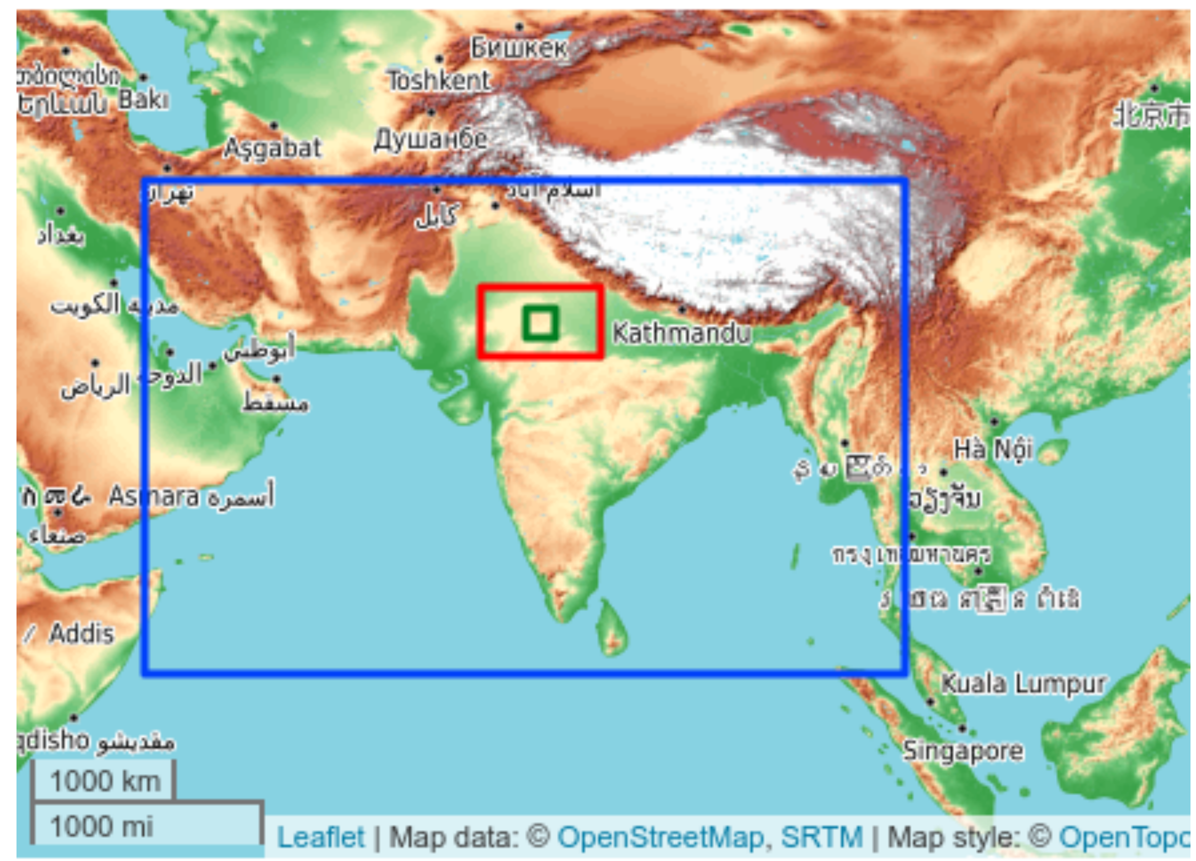
- Convection develops from midday over shallow (~300m) topography



EUMETSAT brightness temperature, Emma Barton (CEH)

Ongoing: orographic triggering test case

- Using MetOffice Unified Model because MONC/UCLALES can't represent topography
- Setup being developed by Chris Dearden (CEMAC Leeds), currently have running:
    - Four-level nest with n320 global and dx=200m inner most nest
- Still to resolve:
    - Soil-moisture initiation, stochastic sampling, feasible domain size



Ongoing: identifying objects which trigger clouds

Methods being developed:

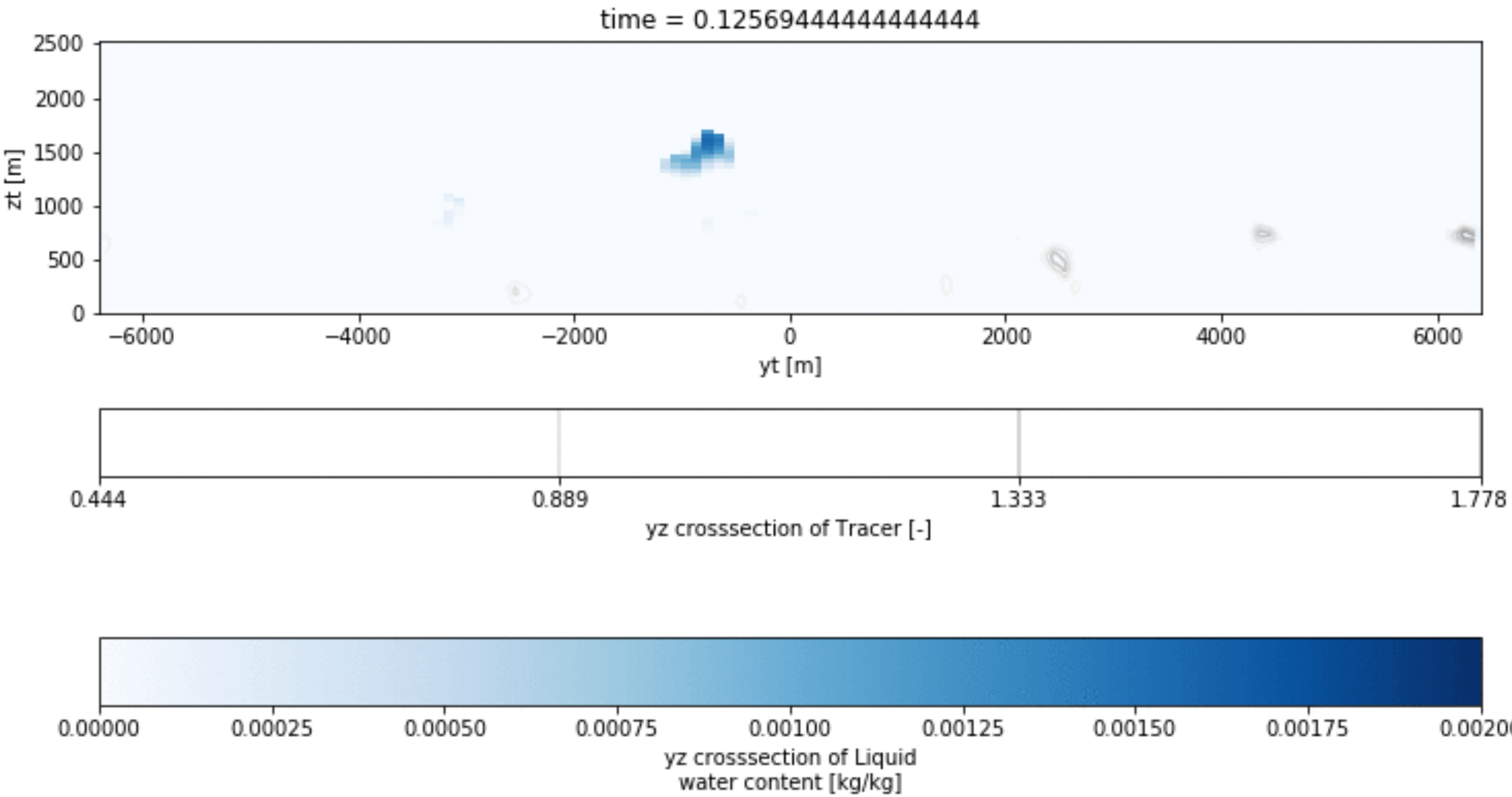
1. Rank objects by likelihood of overcoming CIN (e.g. by kinetic energy + potential energy)

2. Track boundary layer thermals using Couvreux “radioactive tracer”, use existing cloud-tracking code

3. Use Lagrangian particles and their intersection with boundary-layer objects and clouds

Planning to have results from all three by December plenary!

Time-evolution of radioactive tracer in coarse (dx=100m) RICO



Thank you!

Questions?