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Characteristics of moist boundary-layer structures

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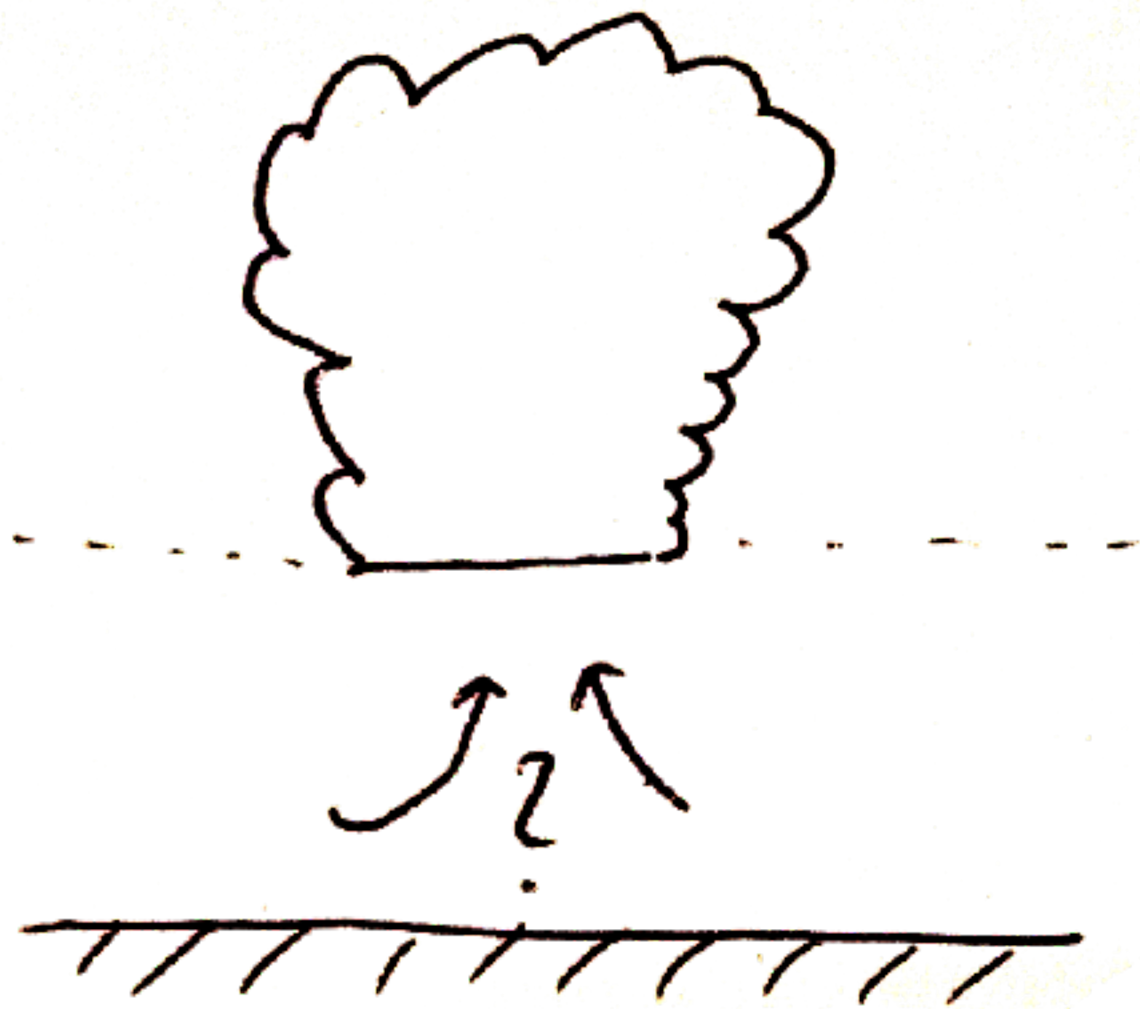
Mini-symposium on boundary-layer convection coupling, 5/3/2018 Leeds

Overview

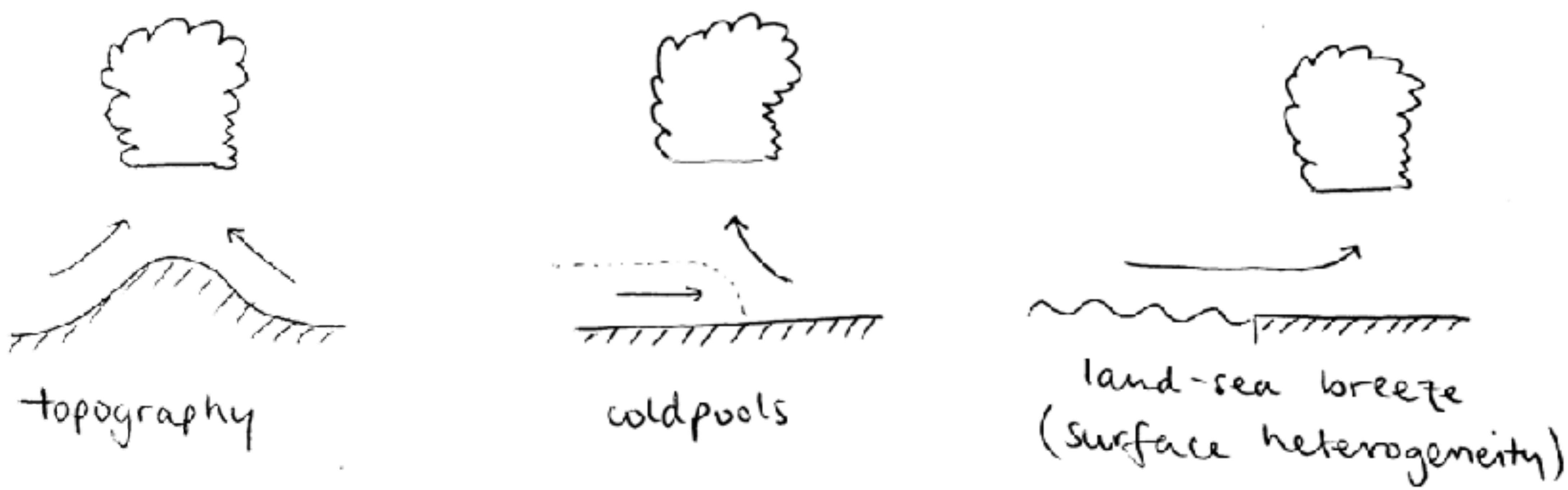
- Motivation
  - Coupling of boundary-layer structures to convection
- Simulations
  - Shear vs non-shear
  - RICO distributed vs organised convection
- Analysis results
  - Analysis hierarchy
  - Variation of horizontal size of boundary-layer structures using cumulants
  - Distribution of object sizes using Minchovski functionals
- Next steps
  - Exploring method of defining coherent objects using Lagrangian particle tracking
  - More simulation setups, diurnal cycle and transition to deep convection

Aim



Aim

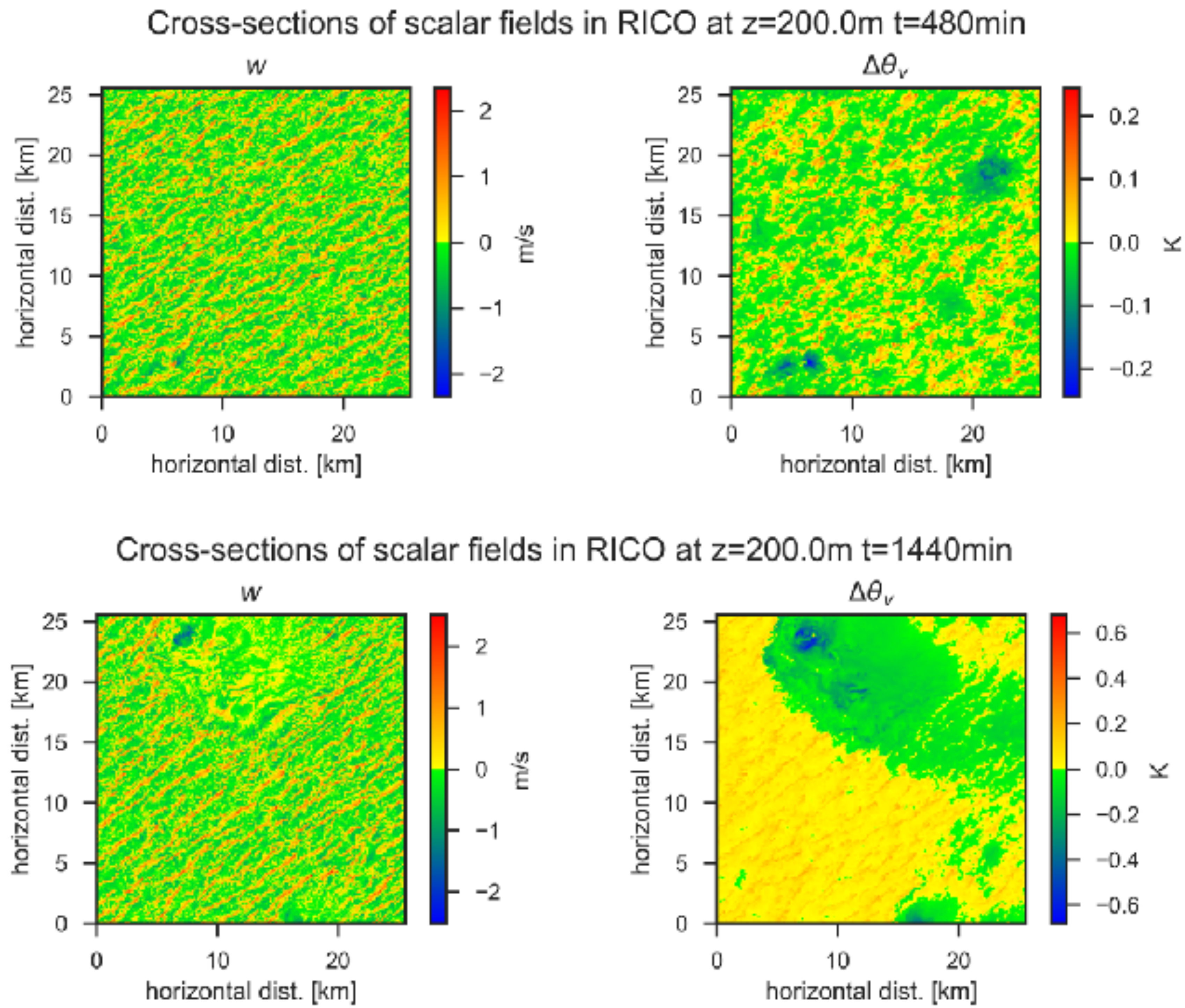
- Describe statistics of boundary layer relevant to triggering convection and the sensitivity to presence of different phenomena



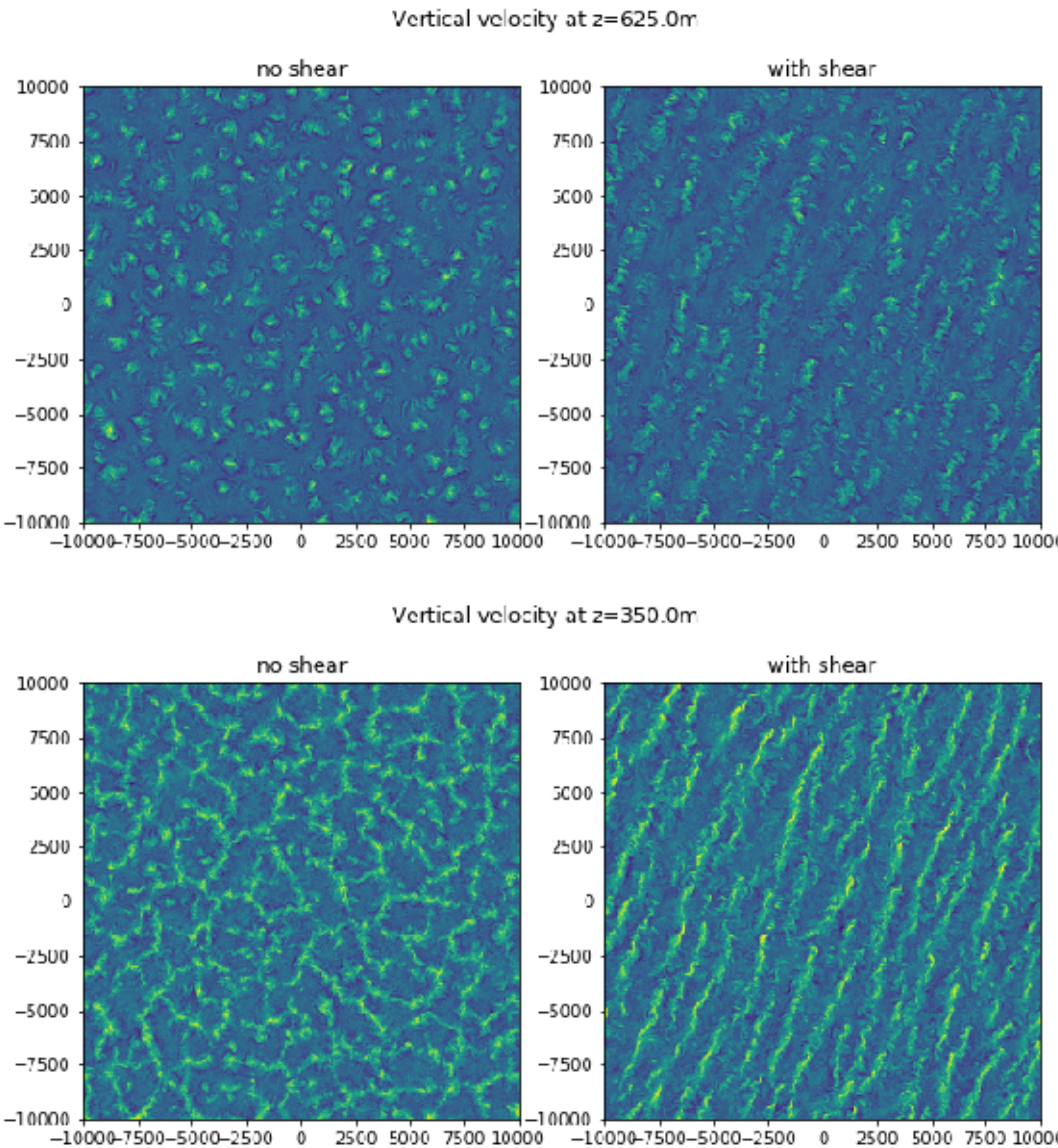
- *"What are the length-scales and magnitudes of perturbations which trigger convection?"*

Organised convection in RICO simulations

- Over time convection organises
- How does this alter triggering of new convective cells? Are individual boundary-layer structures still triggering individual clouds?

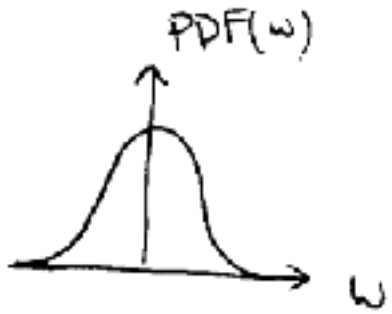


shear/no-shear RICO simulations

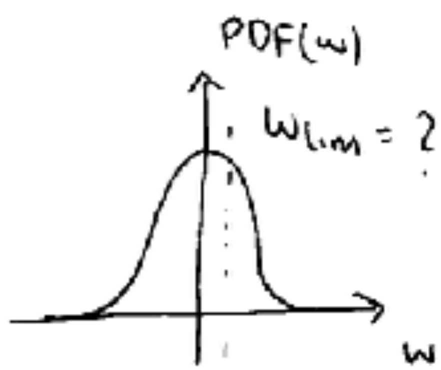


- Fixed fluxes (F_s=150W/m^2, F_l=7.0W/m^2)
- Convective cells instead of rolls in boundary layer
- In shear convection appears at ends of rolls?
- Without shear at nodes of cells?

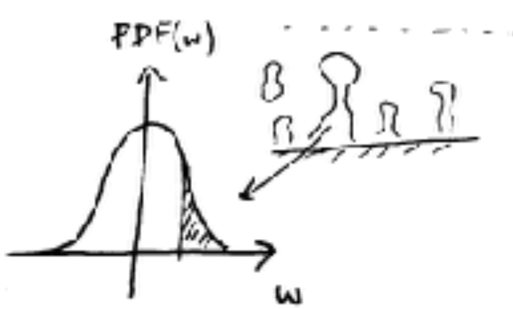
Hierarchy of analysis



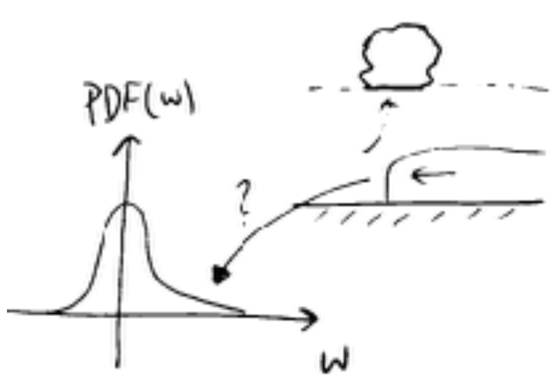
a) Vertical profiles of horizontally integrated properties, e.g. PDFs of scalars (without identifying triggering updrafts)



b) Vertical profiles of identified updraft regions (e.g. *two-fluid* partitioning)

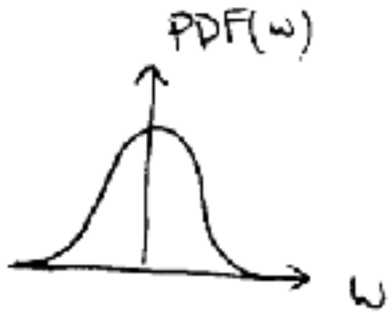


c) Object-based decomposition of horizontal variability



d) Identify cause of change in vertical profiles and new scalar quantities which parameterise change

Hierarchy of analysis



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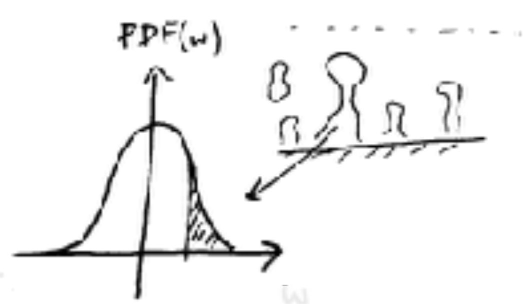

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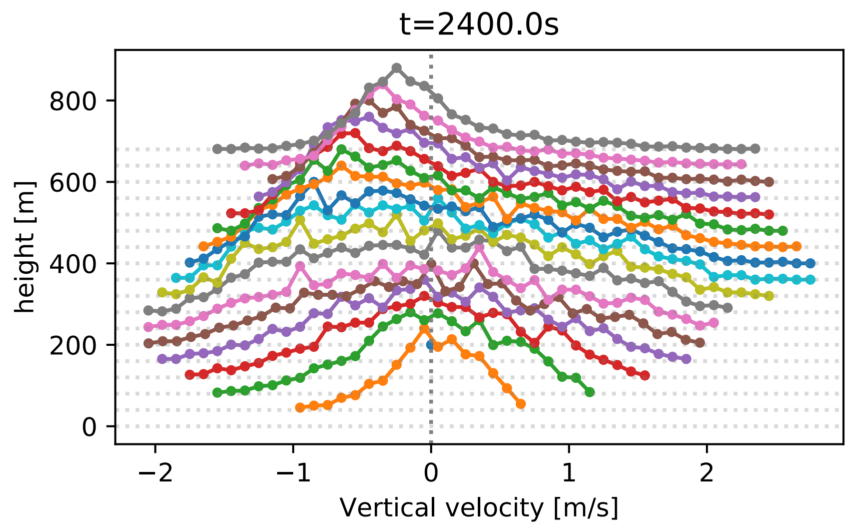
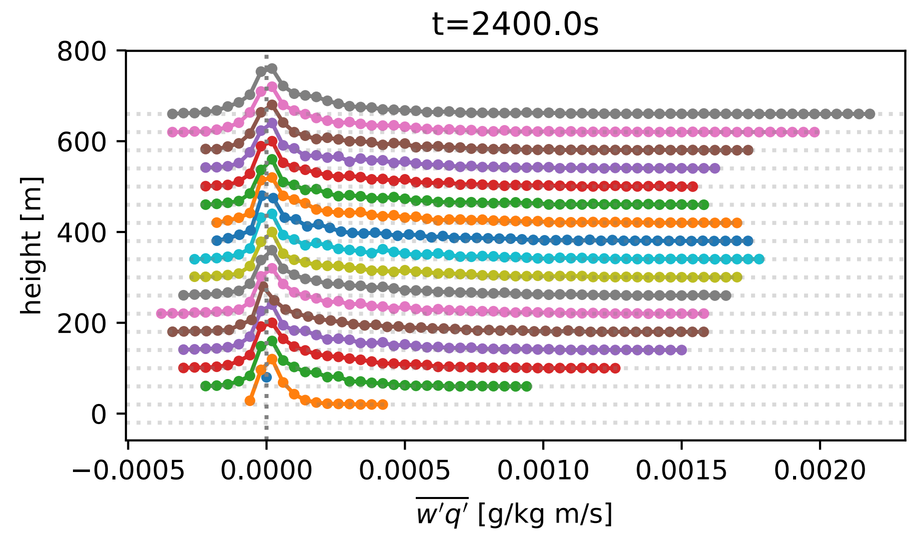
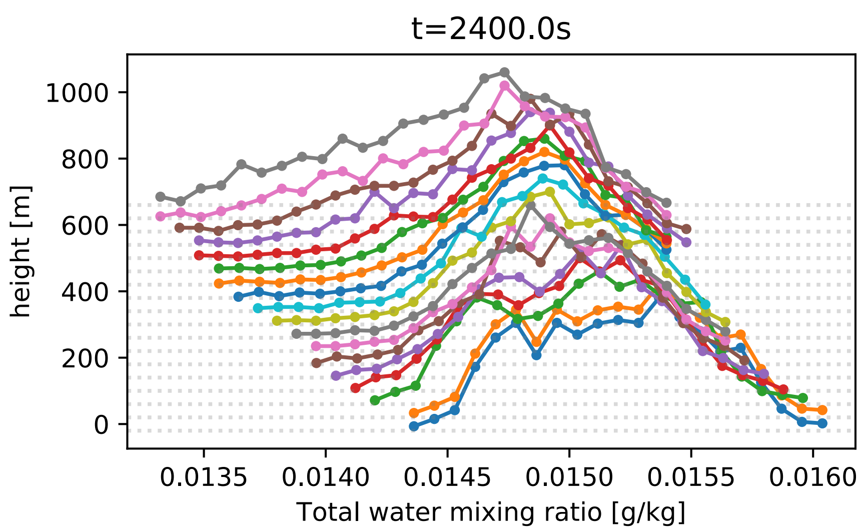
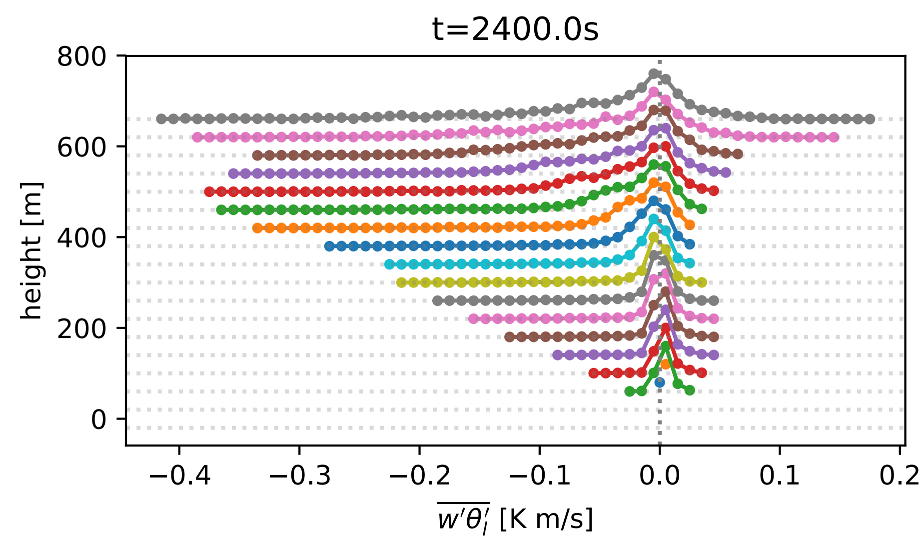
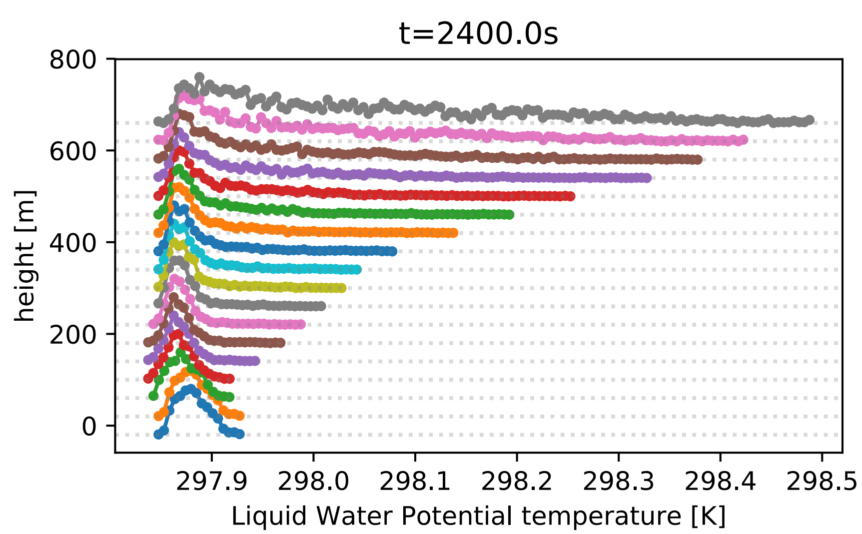
Bulk statistics in boundary-layer











Histograms of horizontal cross-section of full domain, offset by height at which histogram is performed

Bulk statistics in boundary-layer

Pros:

✅ Can easily see qualitative changes, e.g.

- ✅ Largest vertical velocities in middle of boundary-layer
- ✅ See drop in largest heat flux at ~400m
- ✅ Moisture distribution changes shape as well as being offset towards lower values (entrainment not working equally on all concentrations of moisture?)

✅ Easy to compute

✅ Conclusions not affected by choice of how fluid is partitioned

Cons:

🚫 No spatial information retained, size and shape of buoyant regions not available

🚫 No partitioning of fluid makes analysis hard, e.g.

- 🚫 how is subsiding air affecting distributions?
- 🚫 how do the properties of air that trigger convection vary?

🚫 Not directly related to convection scheme, need to know what air triggered convection

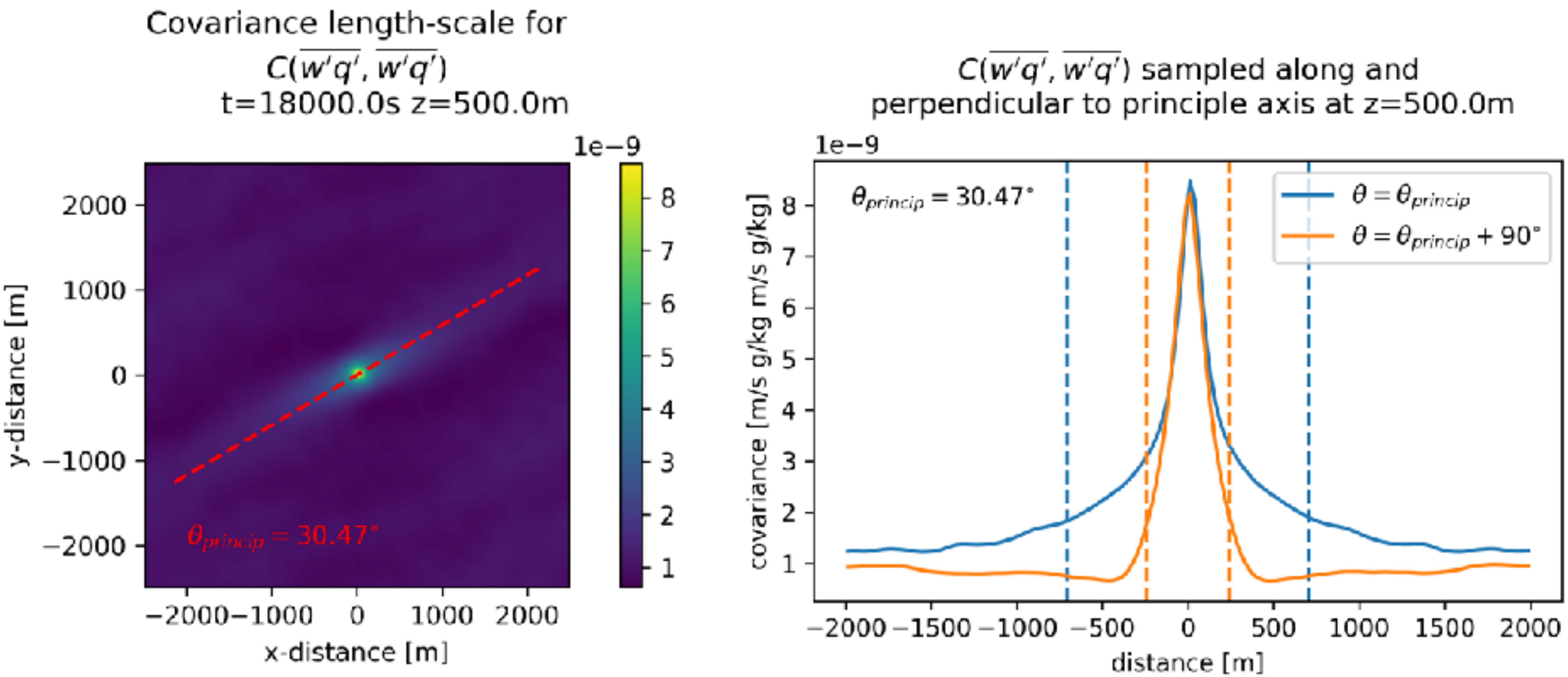
Use of cumulants to study characteristic scales

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

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

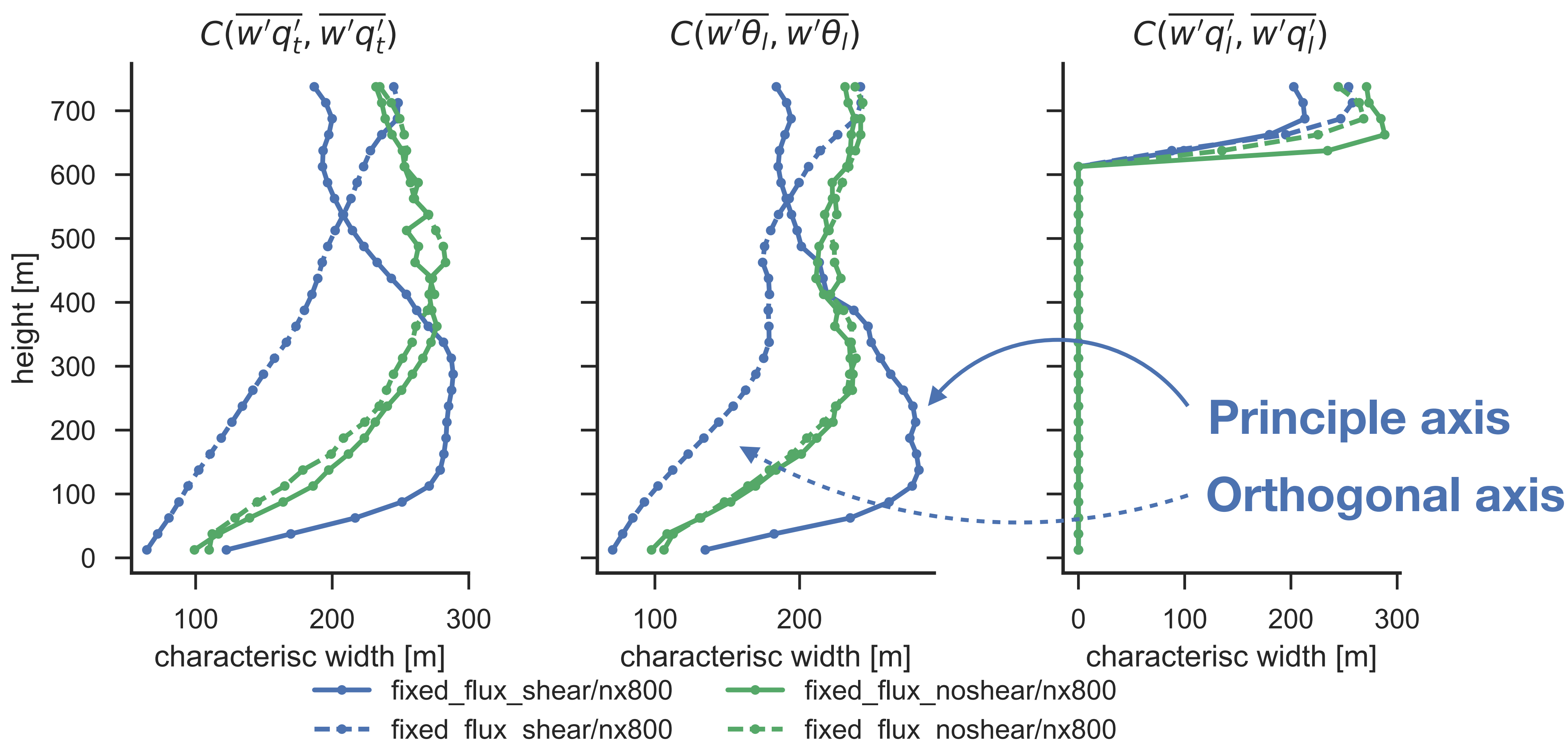
- Measures how correlation with distance (in xy-plane) of scalar fields
- Used by Tobias and Marston 2016 to identify principle length-scales in 3D cuvette flow

Use of cumulants to study characteristic scales



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

Use of cumulants to study characteristic scales



- Wind-shear causes horizontal elongation of regions which transport vertical flux
- Imprints on size of clouds produced

Use of cumulants to study characteristic scales

Pros:

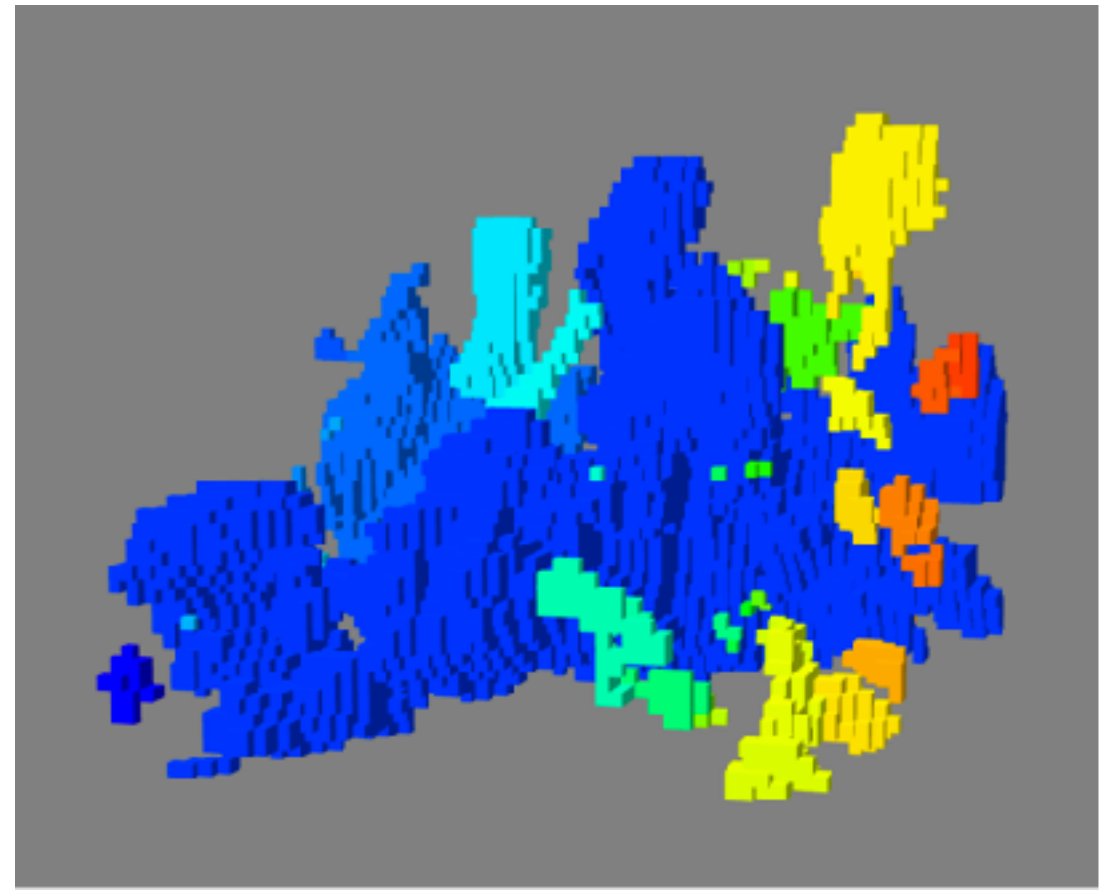
- ✅ Measures spatial coherence of regions of vertical flux *without* having to define objects
- ✅ Produces characteristic length-scales (principle and orthogonal)
  - ✅ Directly relevant to *bulk-plume convection schemes*

Cons:

- 🚫 No partitioning of fluid makes analysis hard, e.g.
  - 🚫 Regions of subsiding air will also be coherent, how does this affect cumulant?
  - 🚫 All buoyant boundary-layer thermals/plumes combined into one measure of coherence, but maybe their individual spatial scale is important? E.g. for *spectral convection schemes*
  - 🚫 No measure of spatial distribution of boundary-layer objects, may be important as convection organises?

Characteristic scales of objects using Minkowski functionals

- 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

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

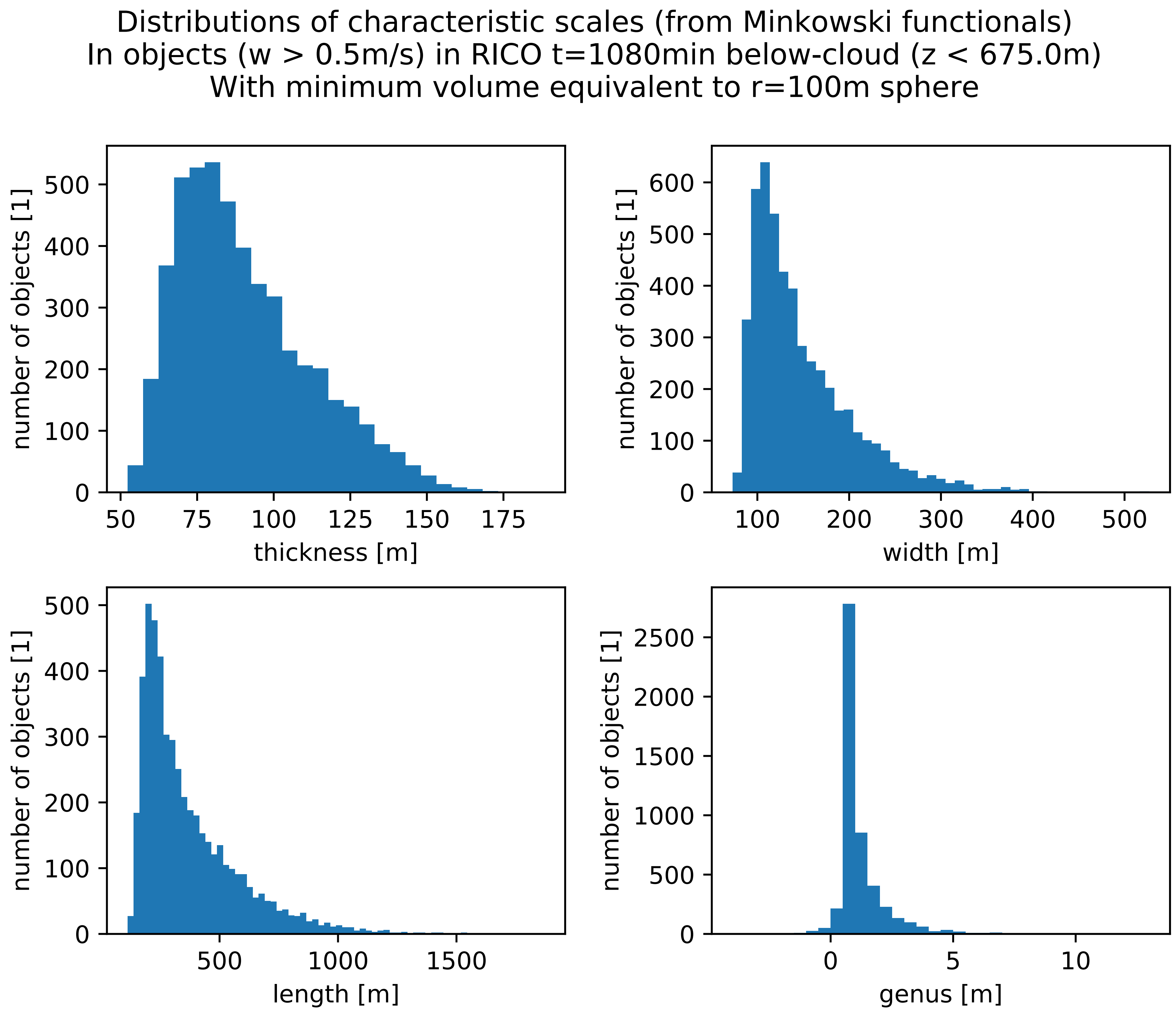
$$\Rightarrow$$

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

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

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

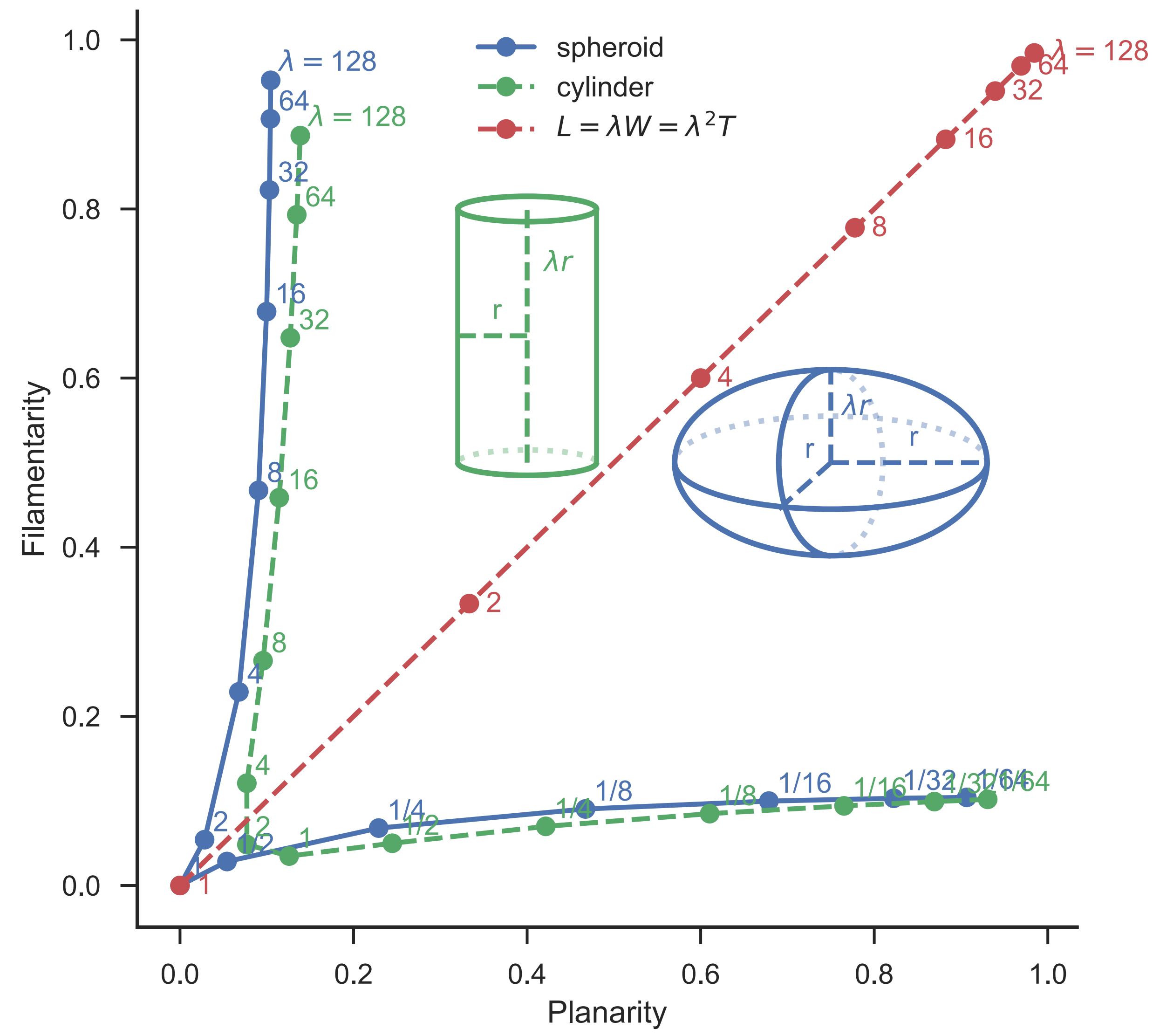
What are the characteristic length-scales of boundary layer structures?



What is shape of objects in the boundary layer?

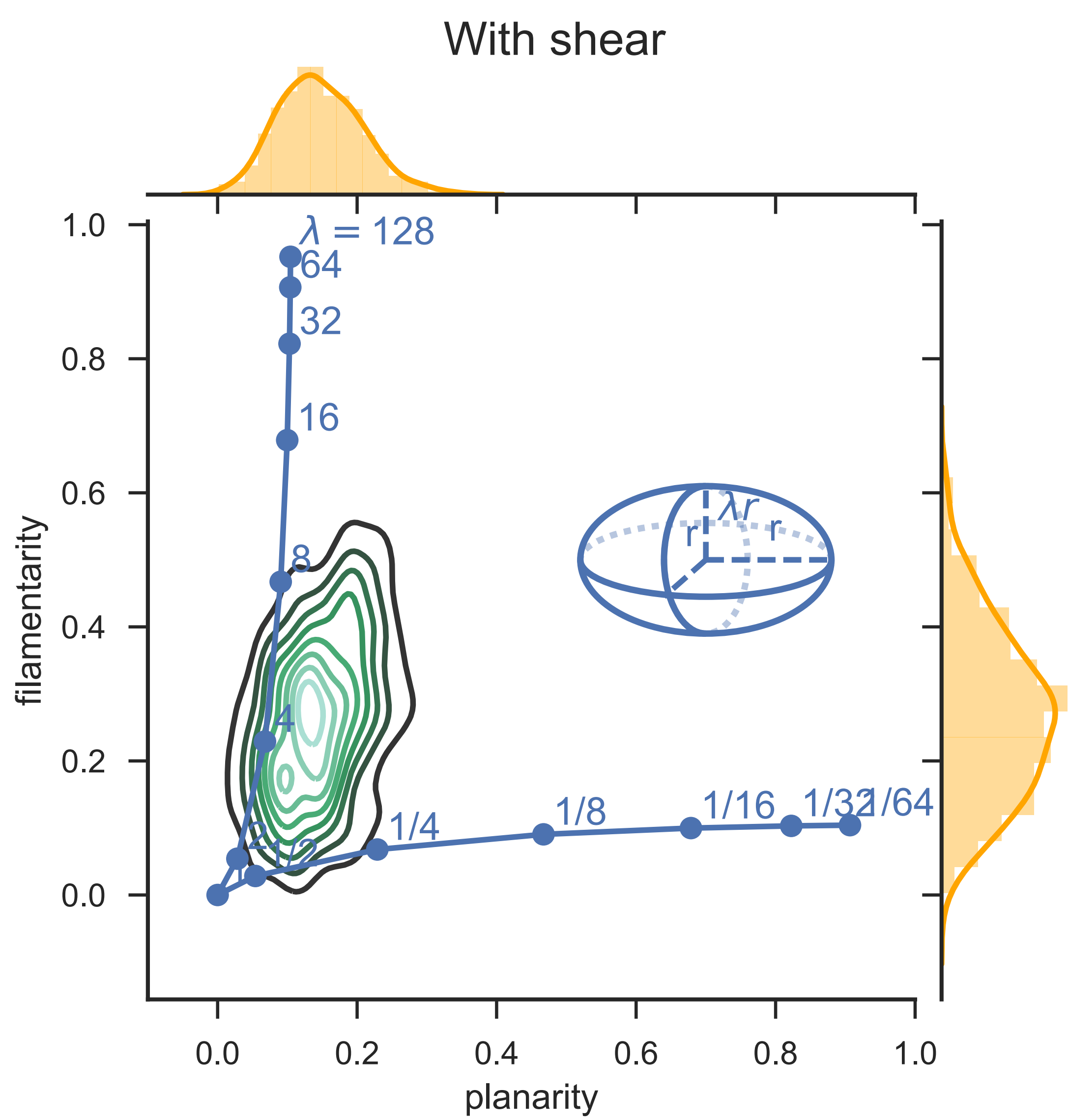
Calculate the planarity (P) and filamentary (F) from Minkowski functional length-scales

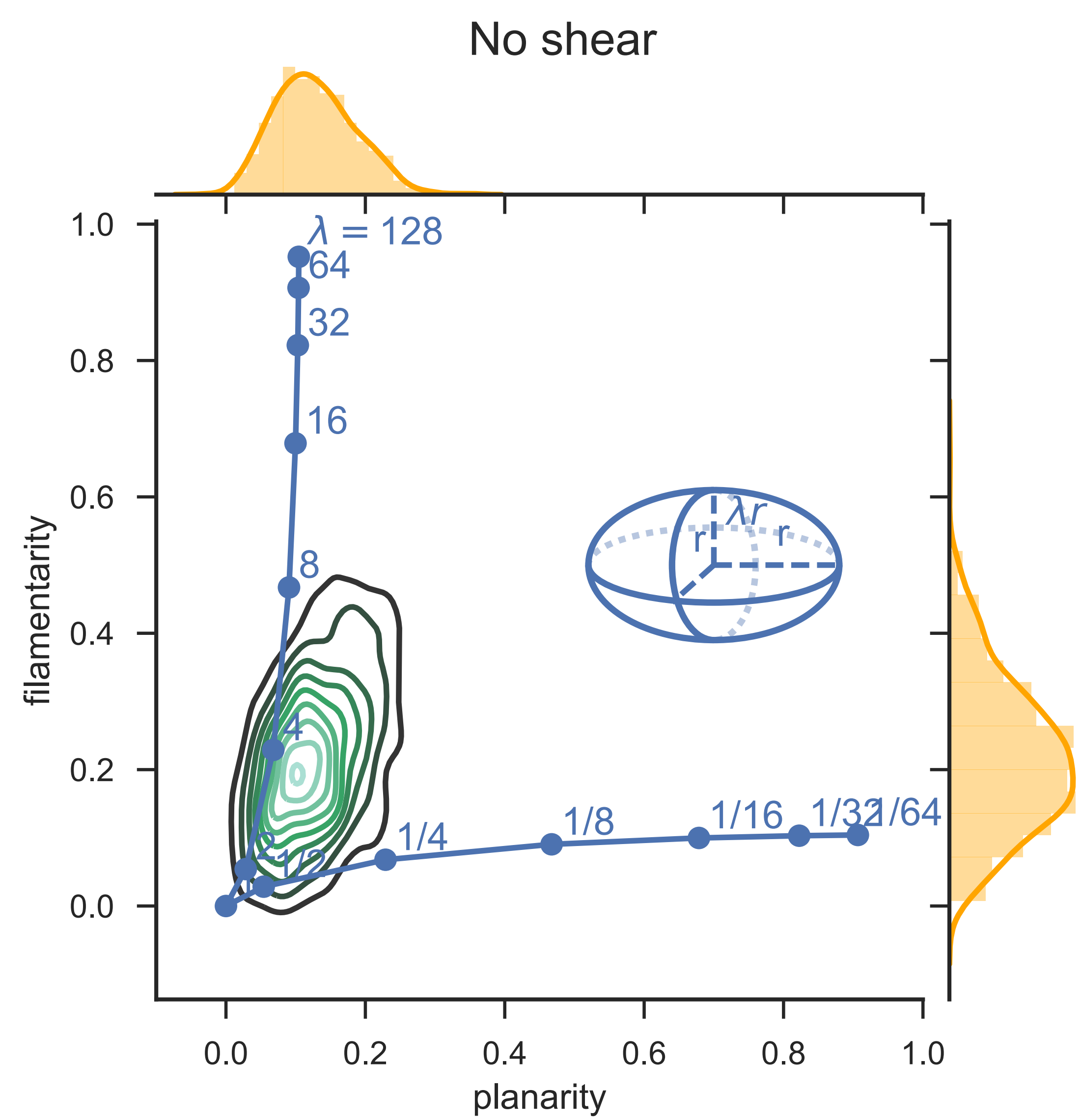
$$P = \frac{W - T}{W + T}, F = \frac{L - W}{L + W}$$



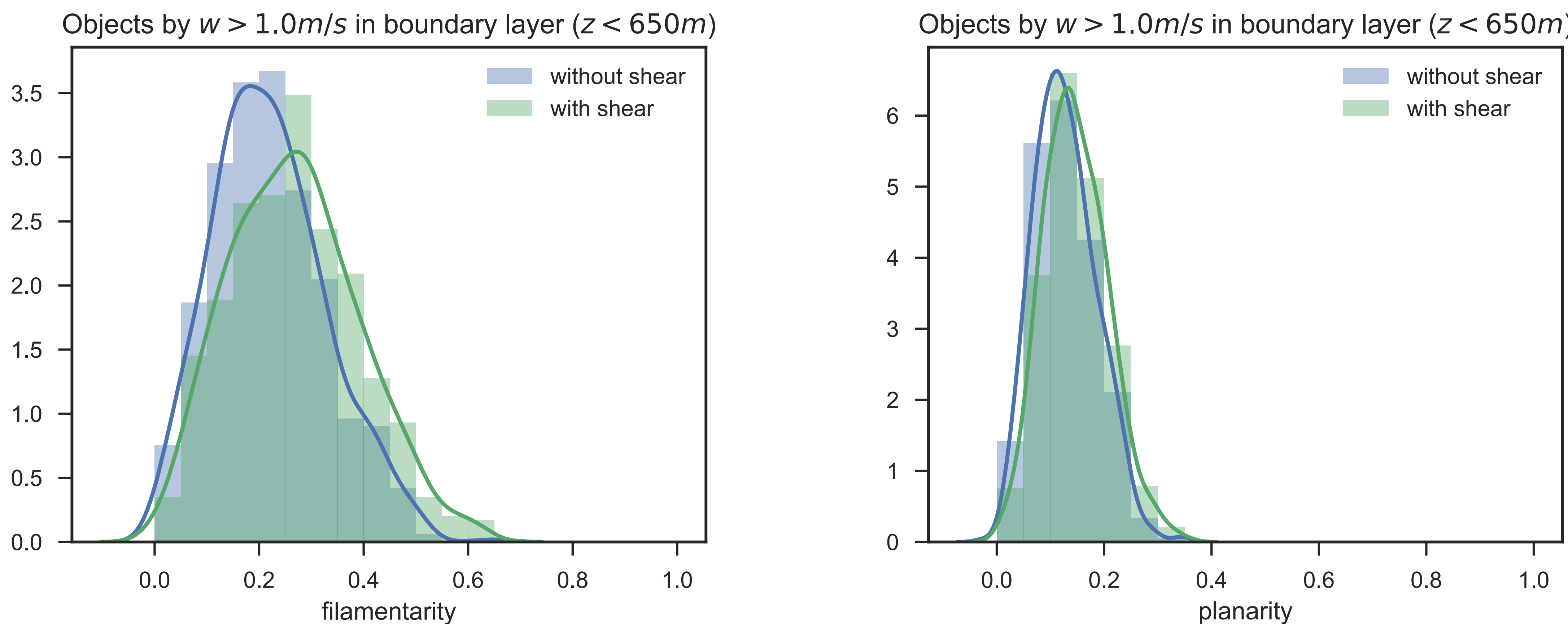
➡️ Measures how pencil or disc-like an object is

Shear/no-shear affect on topology





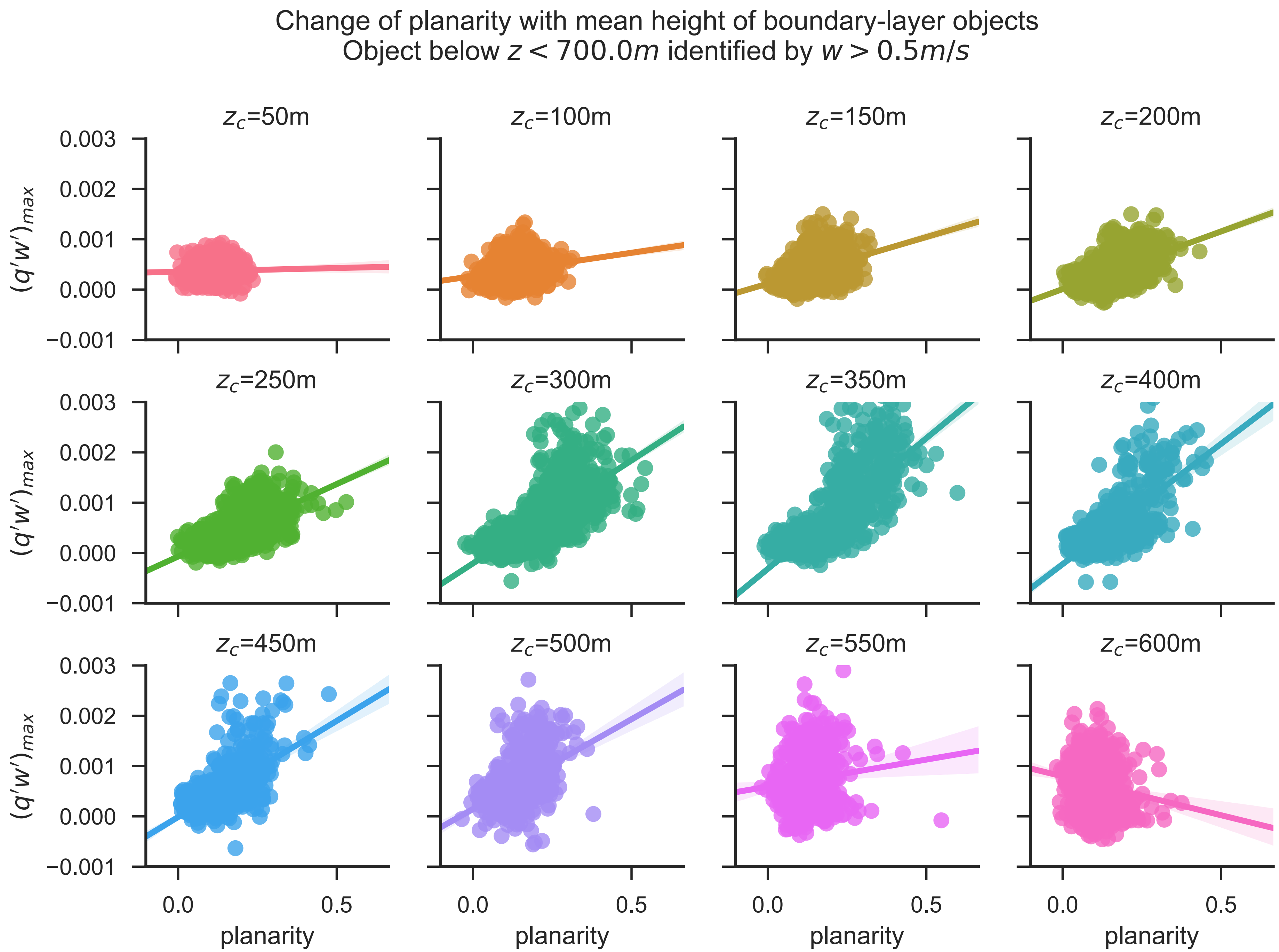
Shear/no-shear affect on topology



➡️ Shear appears to elongate boundary layer thermals

- Does this correlate with properties of triggering thermals?

What are the shapes of objects which carry most moisture flux?



➡️ Objects with largest vertical moisture flux become more planar towards boundary layer centre

Use of cumulants to study characteristic scales

Pros:

✅ Decomposition into objects make it possible to quantify scales of rising thermals/plumes in boundary-layer, answer questions like

- ✅ Are spectral decompositions of the boundary layer transport reasonable?
- ✅ Which scales transport most of vertical flux?
- ✅ Do spatial scales in boundary layer affect spatial scales of convection?

✅ Dynamics of boundary layer evolution in time can be studied through more quantitative measures, e.g. spatial scale, orientation, spatial distribution of boundary layer coherence

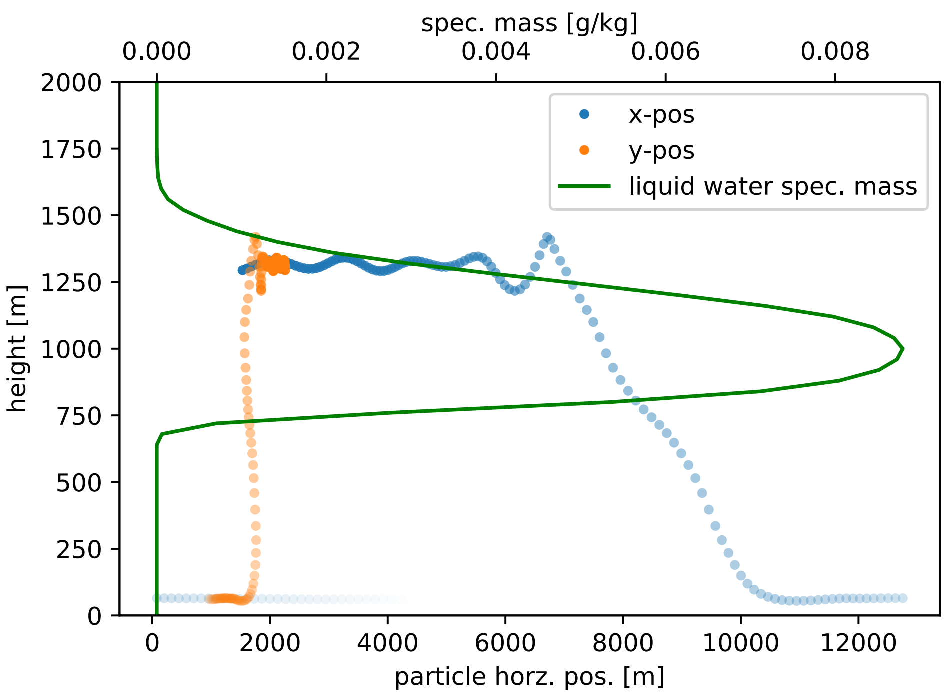
Cons:

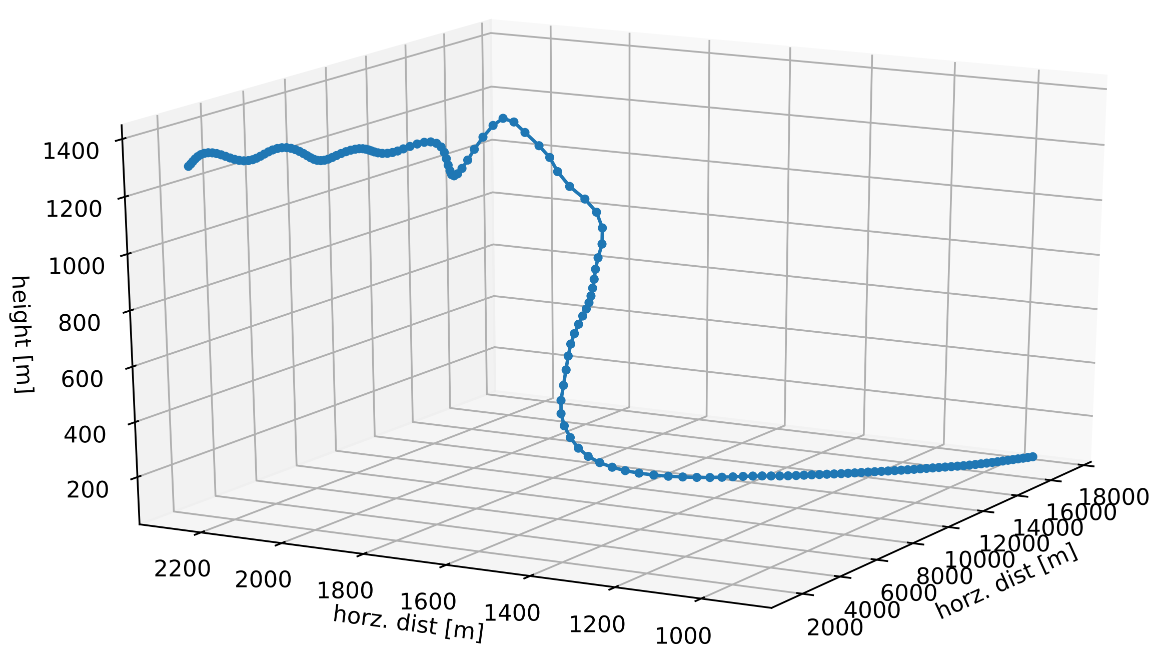
🚫 Sensitive to exactly *how* objects are defined, unclear currently what most appropriate definition would be

🚫 Does not identify which objects actually trigger convection, needed for convection scheme

Next steps

- Identify triggering air using Lagrangian particles
  - Use to identify appropriate criteria for defining triggering objects





- Analyse simulations with temporal evolution (diurnal cycle and transition to deep convection)