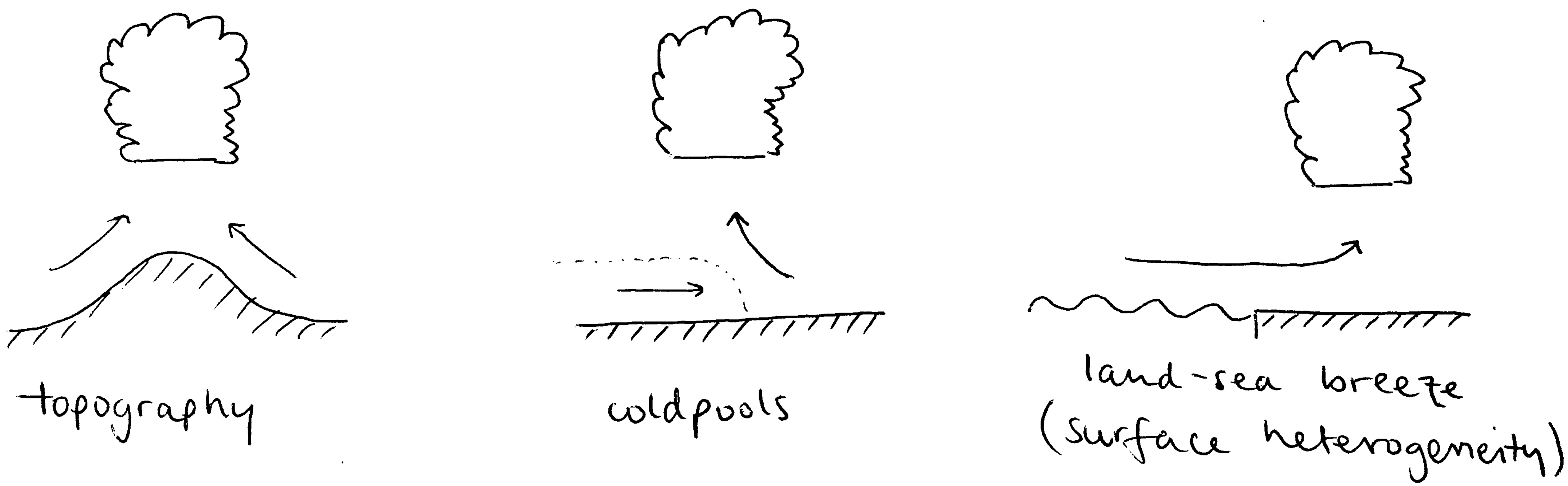
Aim

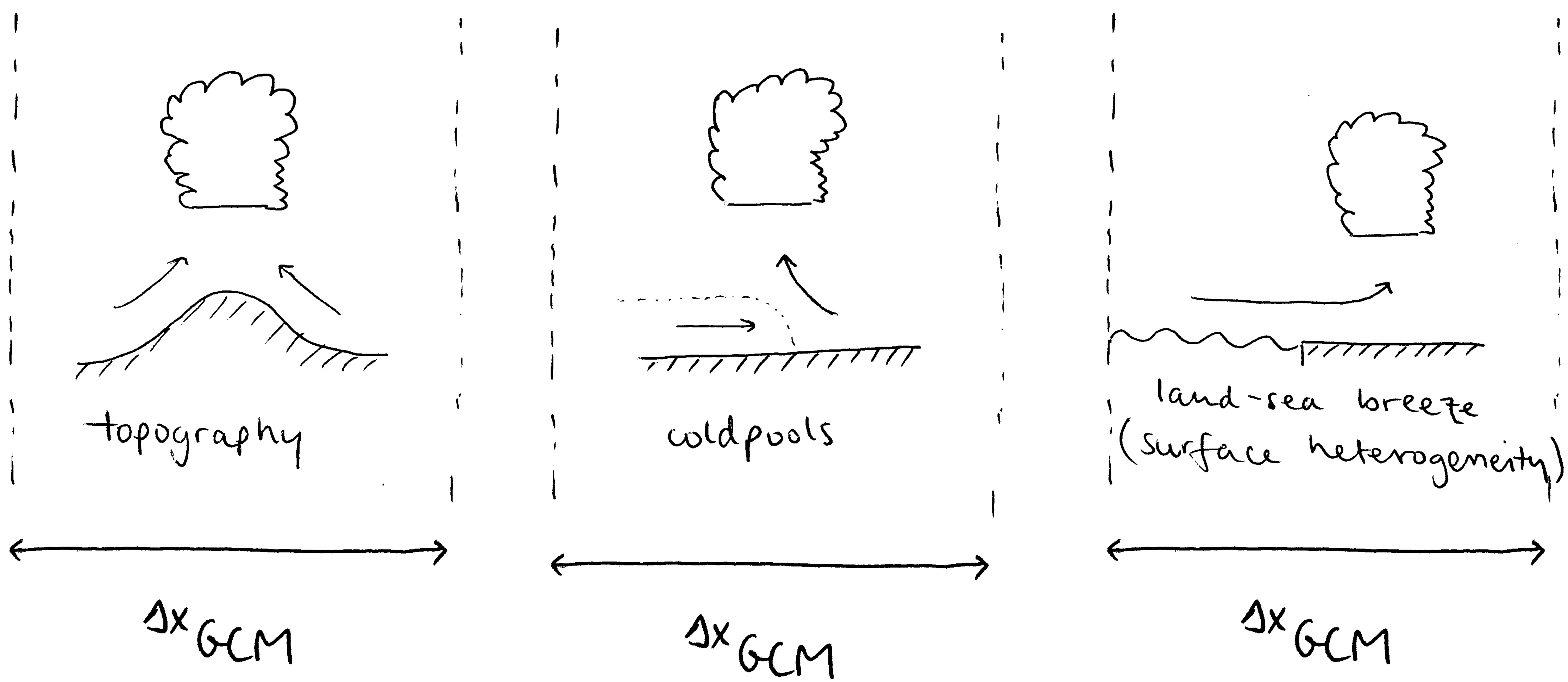
- Describe statistics of boundary layer relevant to triggering convection and the sensitivity to presence of different phenomena



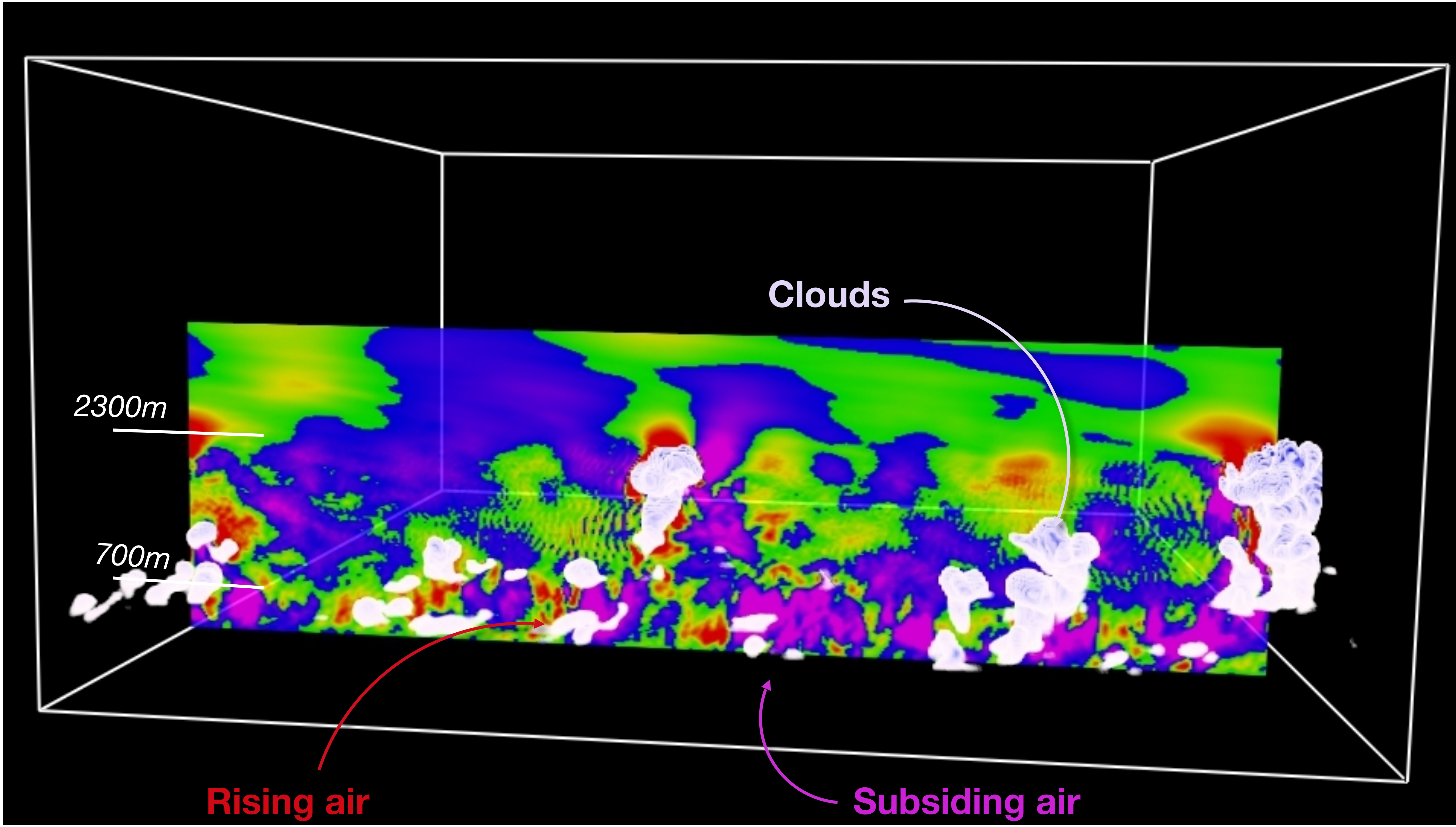
- *"What are the length-scales and magnitudes of perturbations which trigger convection?"*

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



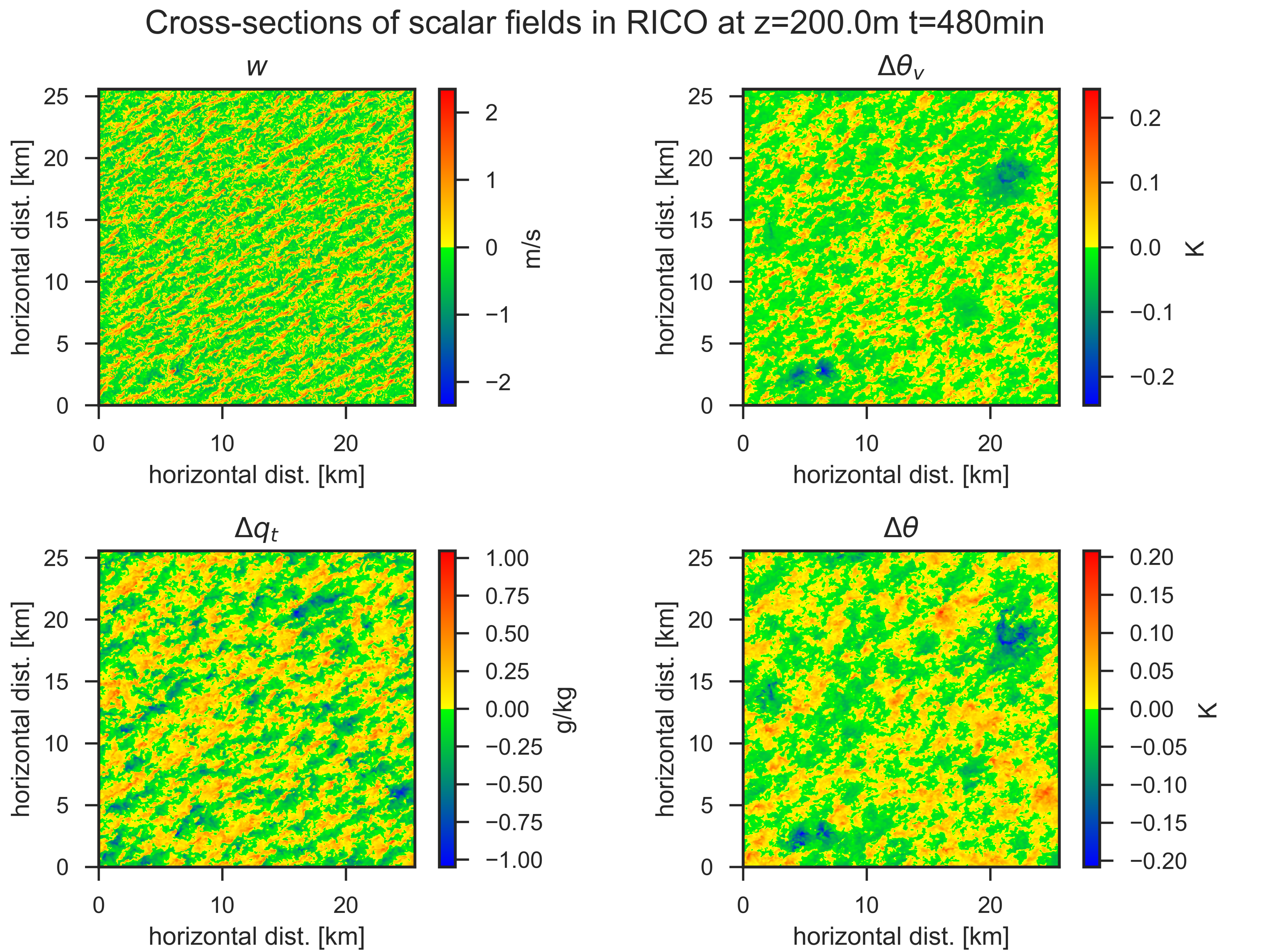
What are the length-scales of variability?



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

Rendered with VAPOR

What are the length-scales of variability?



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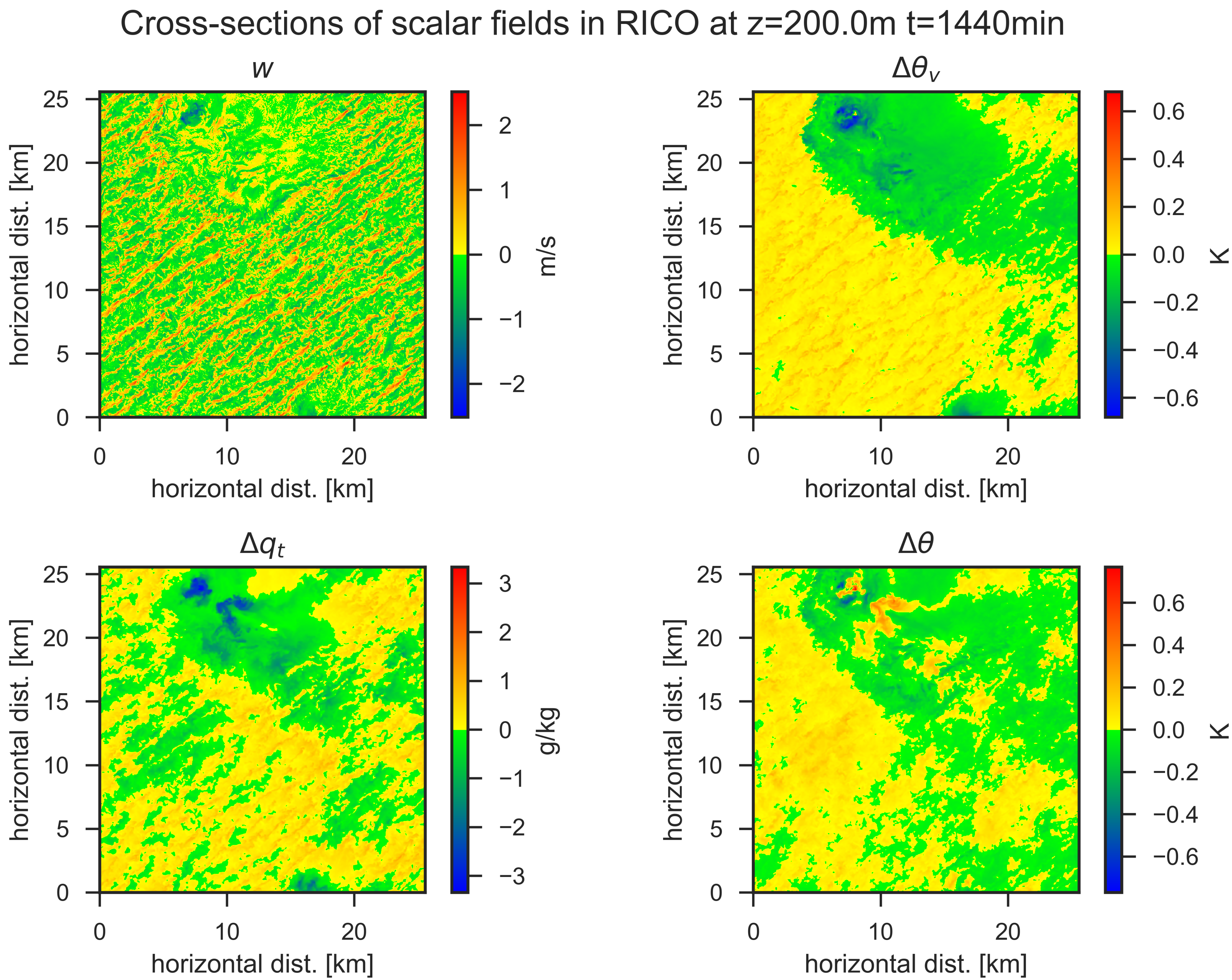
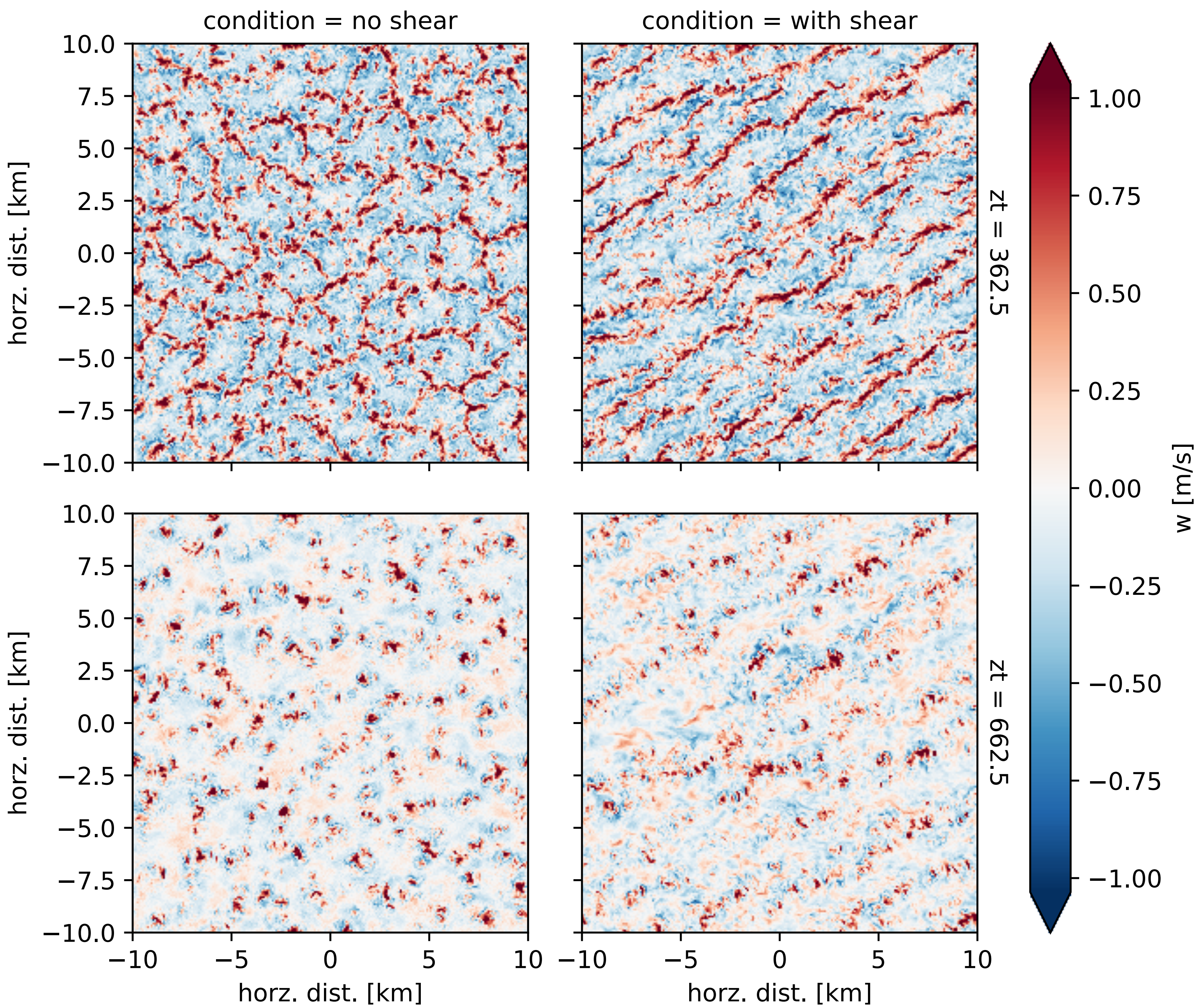
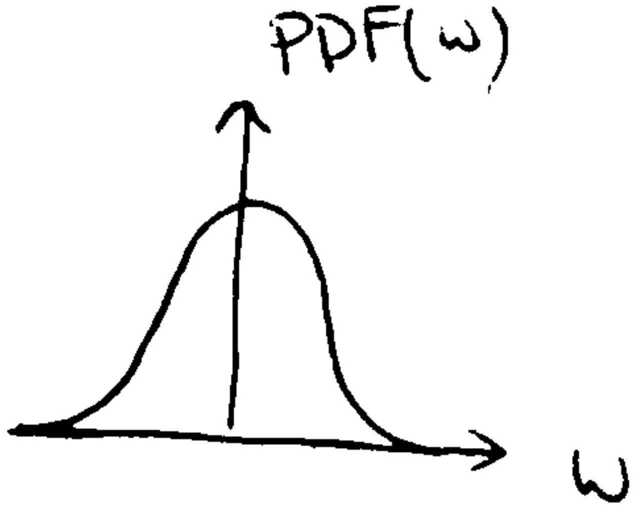


Example: shear/no-shear RICO-like simulations



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

Researching things relevant to convective parameterisation

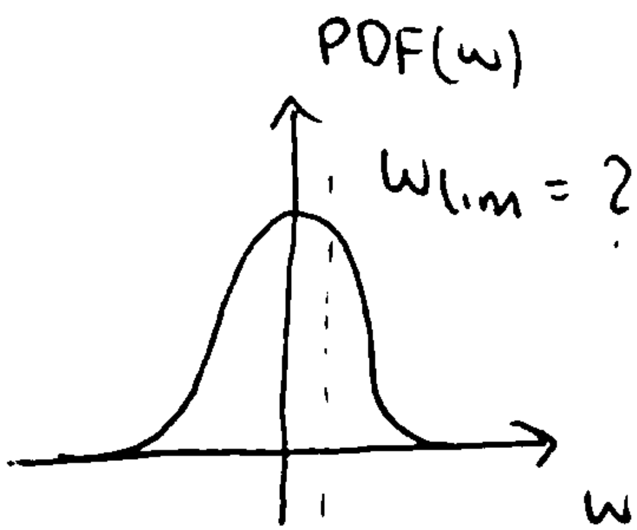


Hierarchy of analysis:

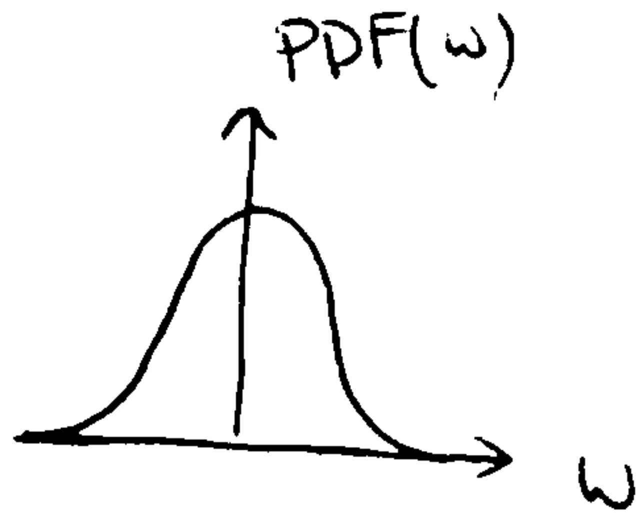
a) Vertical profiles of horizontally integrated properties, e.g. PDFs of scalars (without identifying triggering updrafts)

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

- Is there an optimal partitioning of fluid between updrafts/environment?
- Interested in total BL vertical transport or only thermals which trigger convection?



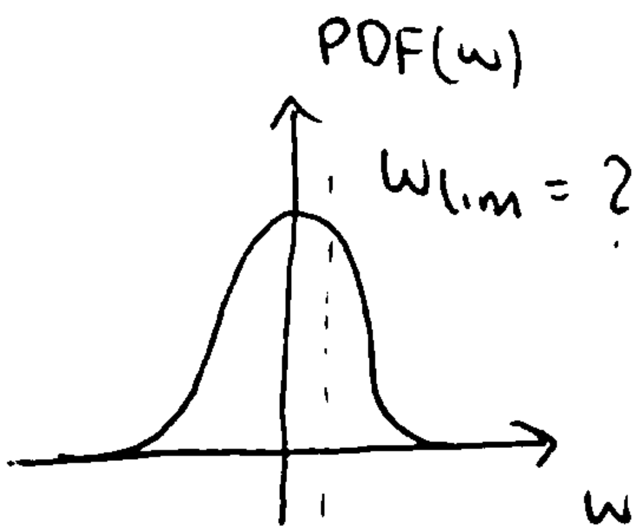
Researching things relevant to convective parameterisation



Hierarchy of analysis:

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

tools ready!



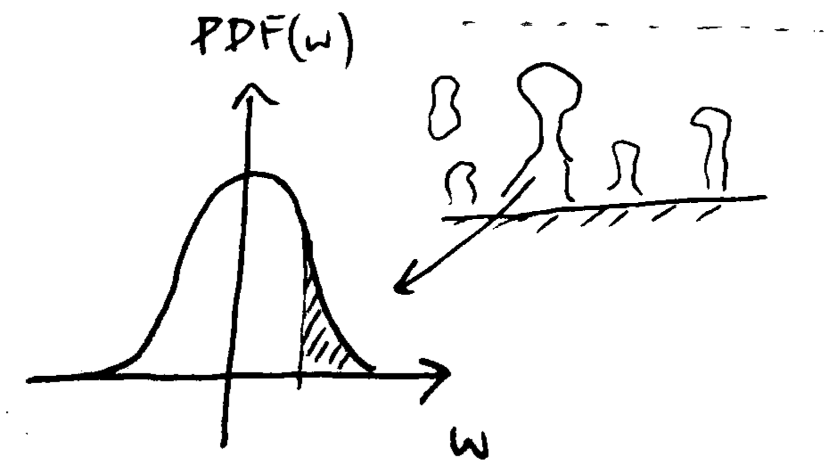
b) Vertical profiles of identified updraft regions (e.g. *two-fluid* partitioning)

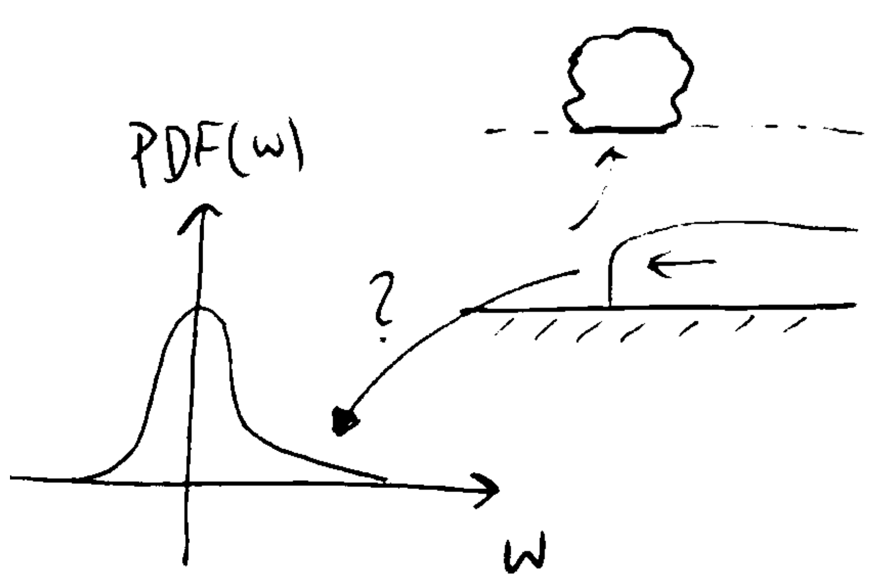
- Is there an optimal partitioning of fluid between updrafts/environment?
- Interested in total BL vertical transport or only thermals which trigger convection?

I think so

Found method to identify these

Researching things relevant to convective parameterisation





Hierarchy of analysis:

…

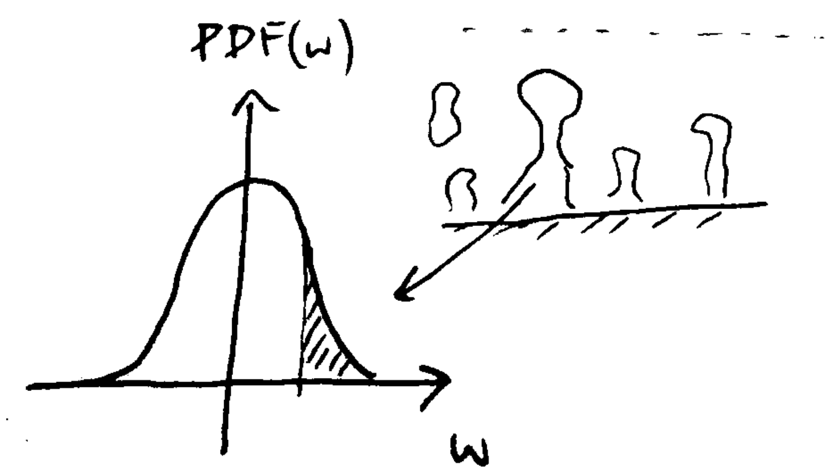
c) Object-based decomposition of horizontal variability

- e.g. reconstruct PDFs using only *N-largest* objects, construct *object size* vs *scalar perturbation* PDFs or identify triggering objects

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

- e.g. *the presence of a cold pool with magnitude* $\Delta\theta_v$ *modifies the skewness of the PDF(w) by* $\alpha\Delta\theta_v$

Researching things relevant to convective parameterisation



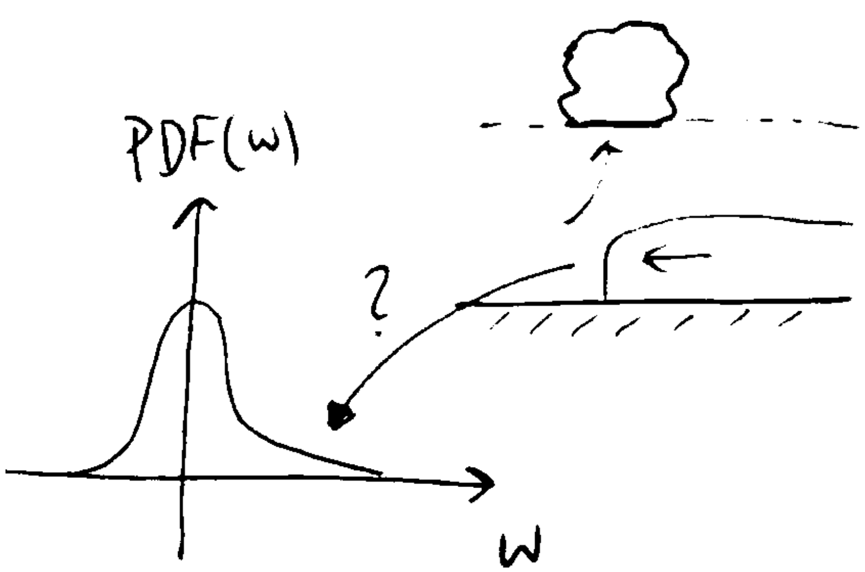
Hierarchy of analysis:

…

c) Object-based decomposition of horizontal variability

- e.g. reconstruct PDFs using only *N-largest* objects, construct *object size* vs *scalar perturbation* PDFs or identify triggering objects

some interesting results!



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- e.g. *the presence of a cold pool with magnitude* $\Delta\theta_v$ *modifies the skewness of the PDF(w) by* $\alpha\Delta\theta_v$

Ongoing

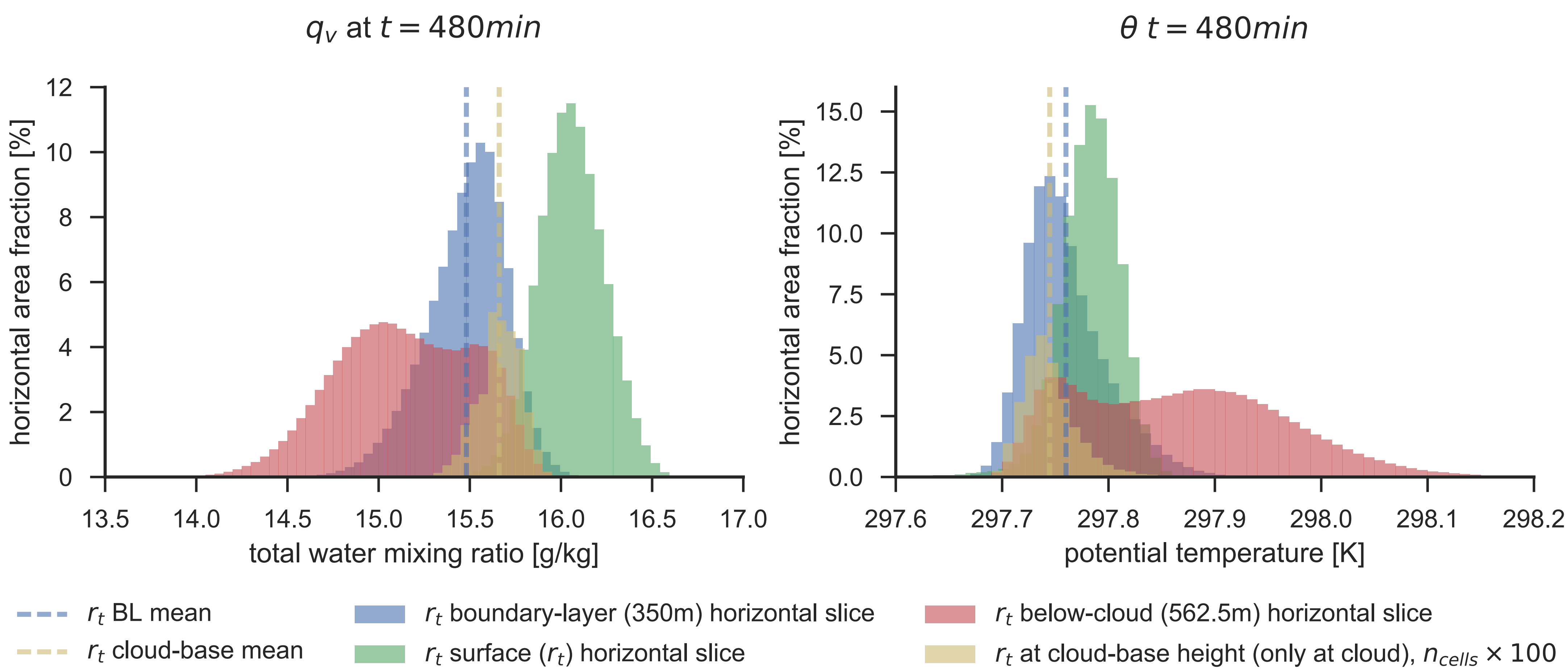
2 topics today

1. Statistical properties of *bulk* boundary layer and cloud-feeding air

    i. Joint-distributions and characteristic length-scales in boundary-layer

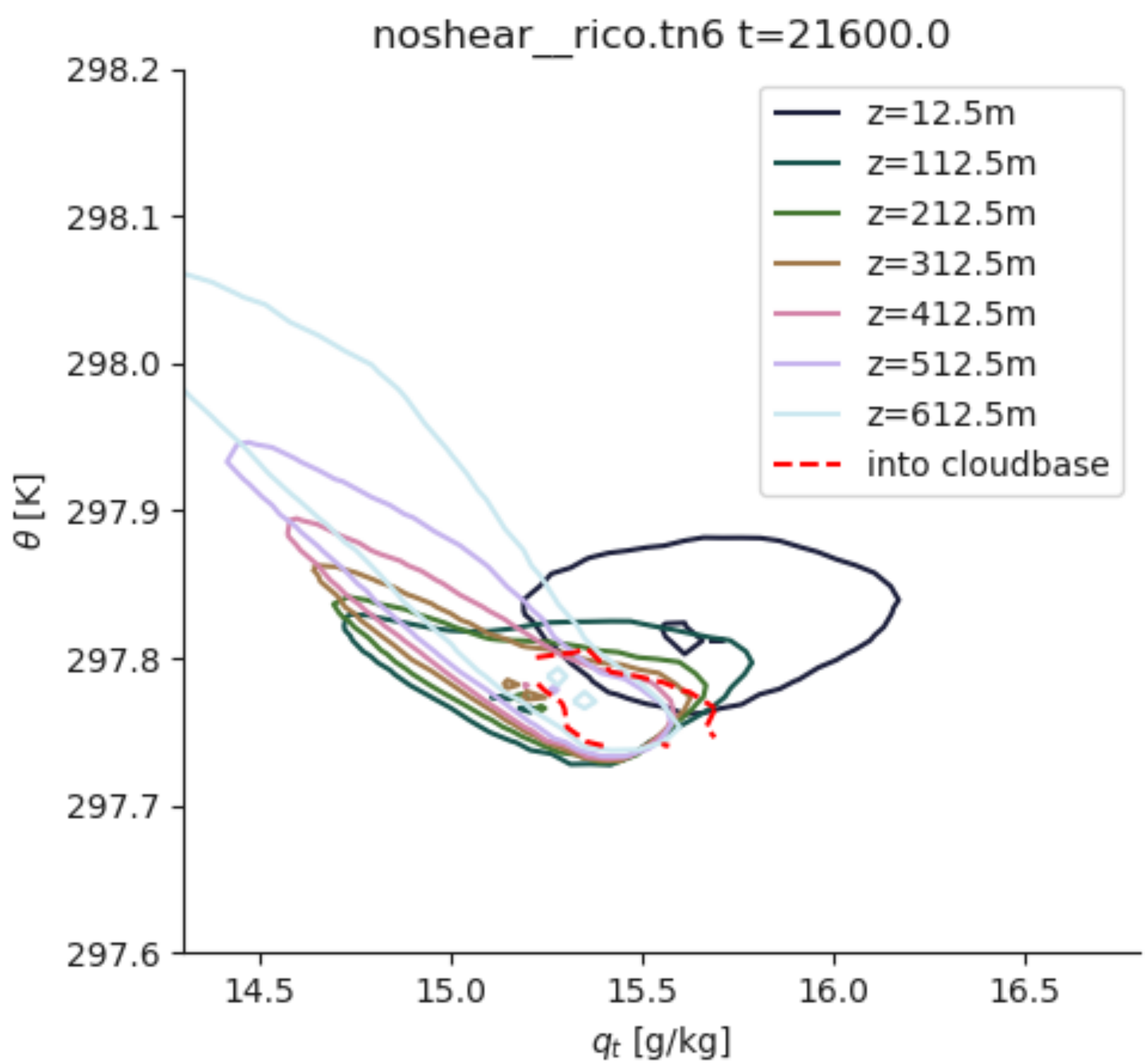
2. Statistical properties of *individual* boundary-layer objects

1. Distributions of moisture and temperature (at interesting heights)



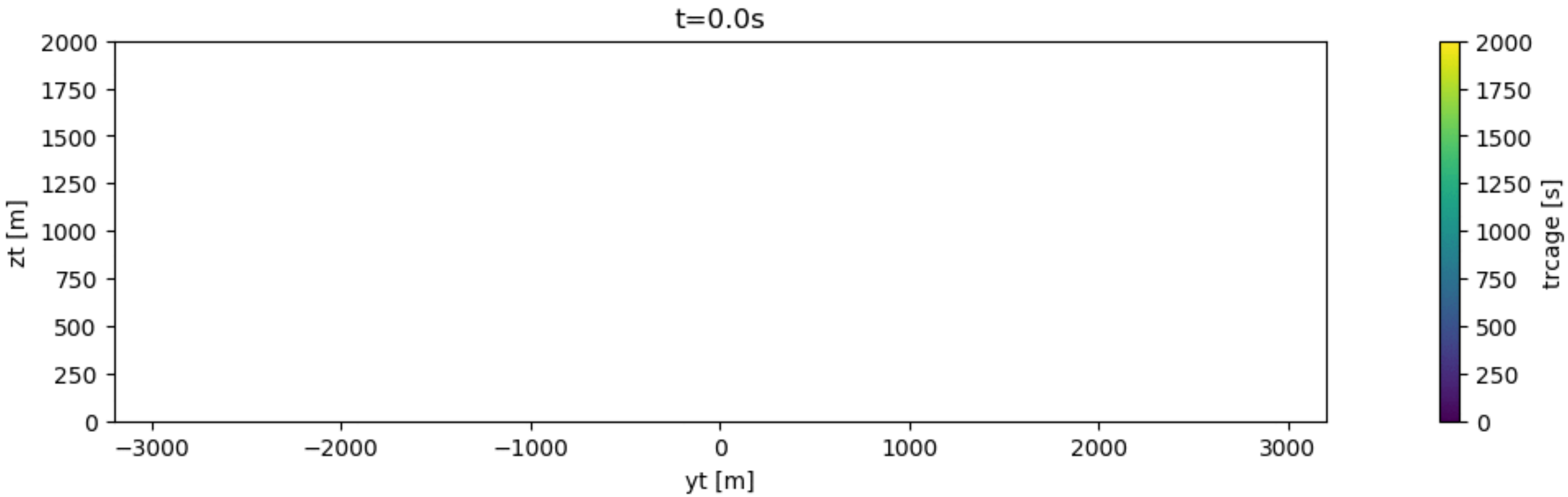
- Air that reaches cloud-level appears to be moister and colder than boundary layer characteristic values
- But *what are the joint distributions (and their height variation)?*

How does water vapour and temperature correlate in the boundary layer?



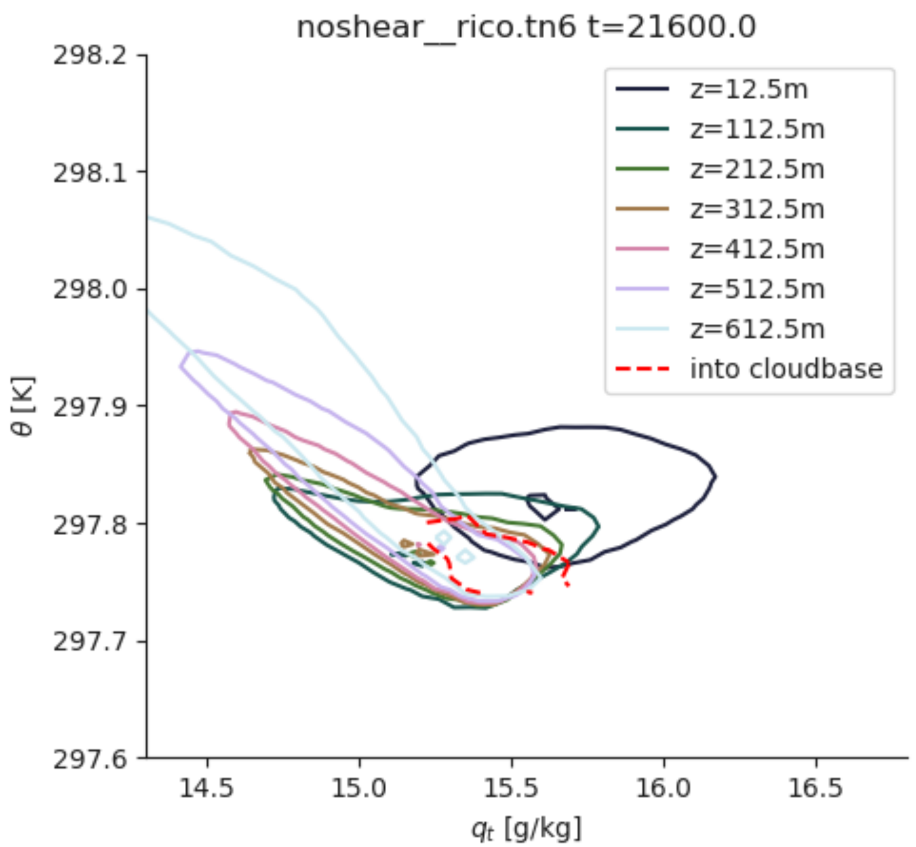
- Inner and outer contour at each height contain regions with top 5% and top 90% concentration of points respectively ("garlic plot")
- Red contour: air Δx below tracked clouds within 3min of appearance => air entering clouds
- How can we *isolate the air that enters clouds*?

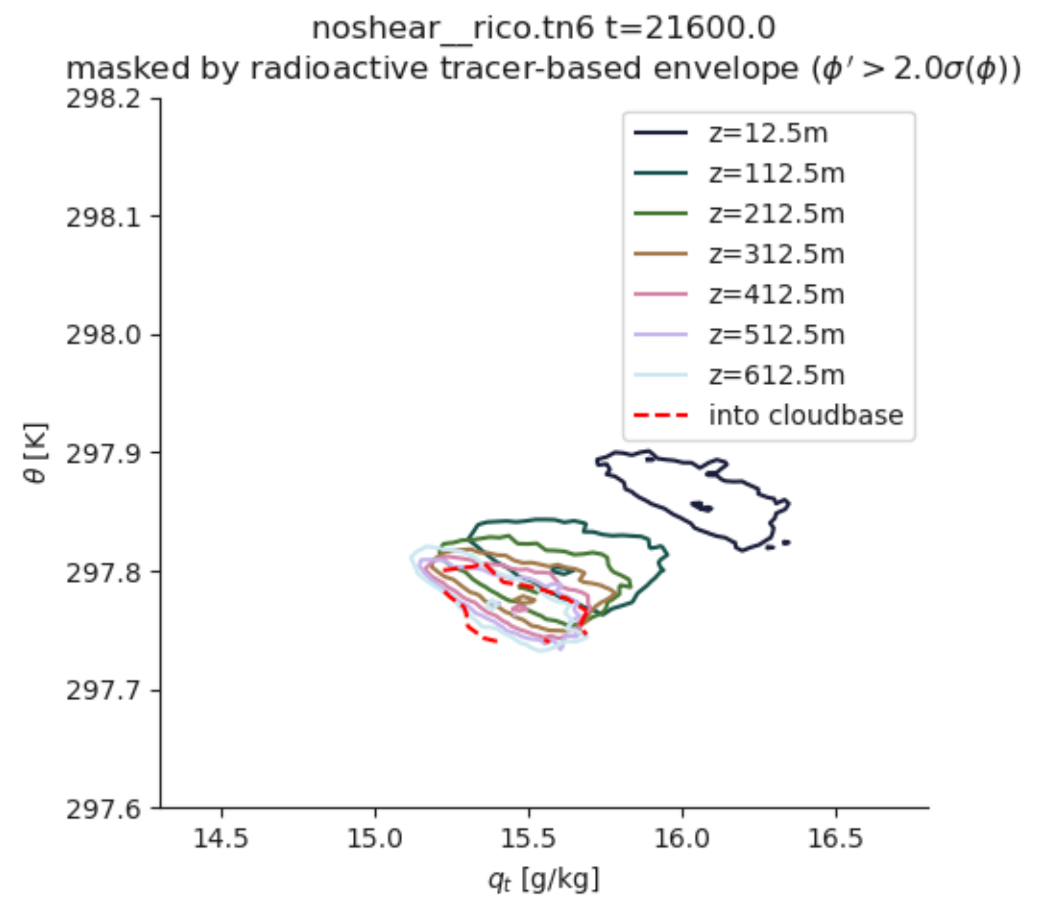
Boundary layer thermals marked with radioactive tracer



- Two tracers (ϕ_1, ϕ_2) with different half-life (τ_1=10min, τ_2=15min) released from surface
- Time since release: $t_{age} = \tau_1 \tau_2 \log(\phi_1/\phi_2)/(\tau_1-\tau_2)$
- Thermal edge defined using deviation from std. div. in horizontal slice: $\phi'(x,y,z) > \sigma(\phi(z))$ (as in Couvreux et al 2010)

Radioactive tracer picks out air entering clouds

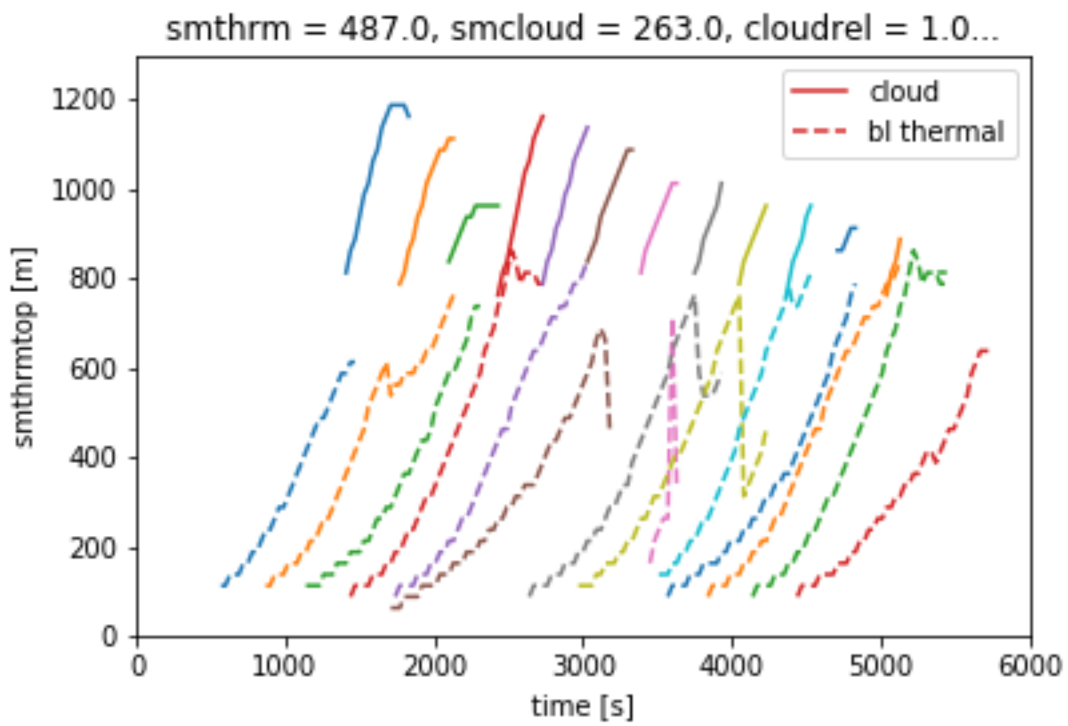




- We can now identify the air that enters clouds and looks at its properties
- In this case the mean and distribution appears translated with height => should be easy to parameterise

(we can also track them…)

Updated cloud-tracking code by Heus 2008 to track thermals, and clouds, and interaction between them



Height of top of individual clouds and thermals that each cloud was triggered by

- Both thermals and clouds are tracked separately (using rad. tracer and liquid water)
- Can study properties of air triggering specific clouds
- Currently ~60% clouds have triggering thermals identified. Another trigger mechanism? Investigating cut-offs in tracking

…but that is part of object-based analysis, discussed later

1.b. Characteristic length-scales of boundary-layer structures

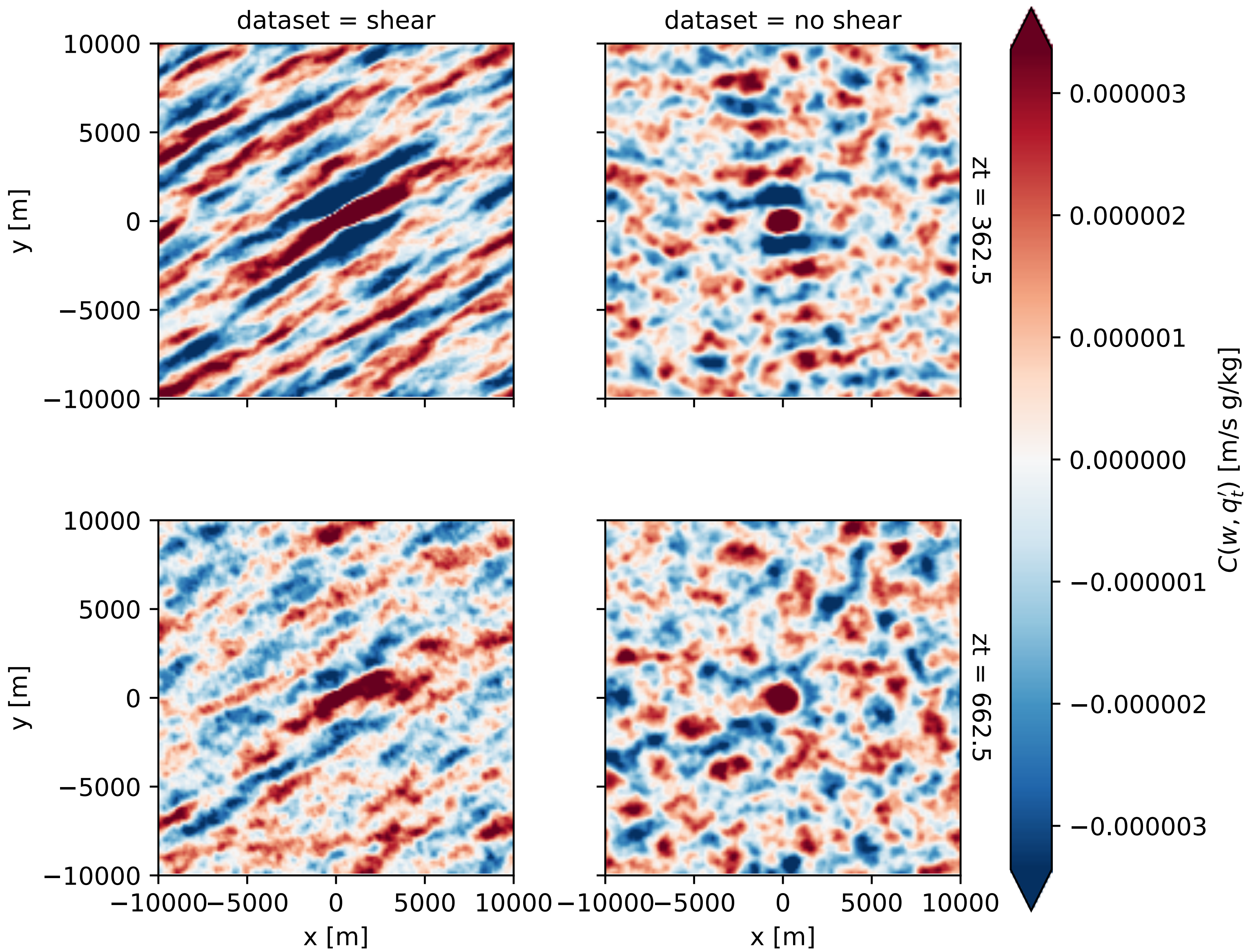
- Two-point correlation of two scalar fields (ϕ and ψ), here taken at same height (z) for both fields

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

- Measures how correlation with distance (in xy-plane) of scalar fields

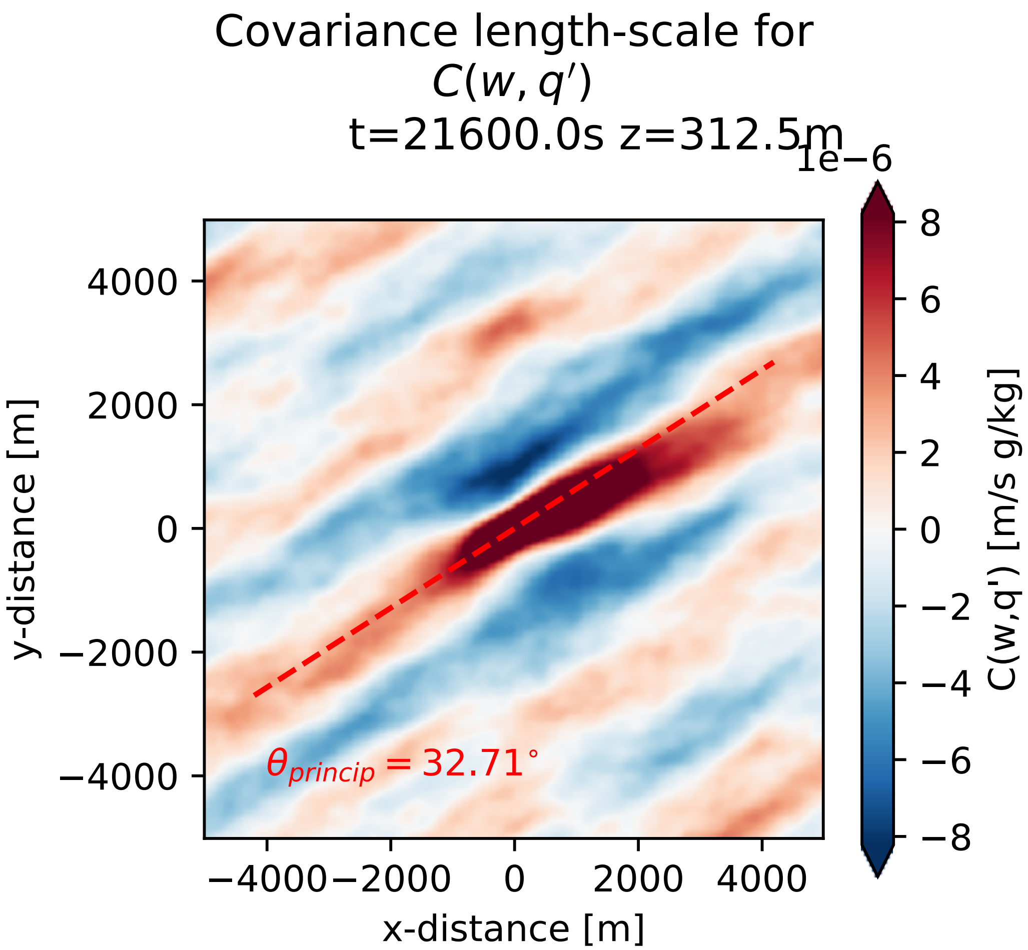
- Used by Tobias and Marston 2016 to identify principle length-scales diffusive transport in 3D Couette flow

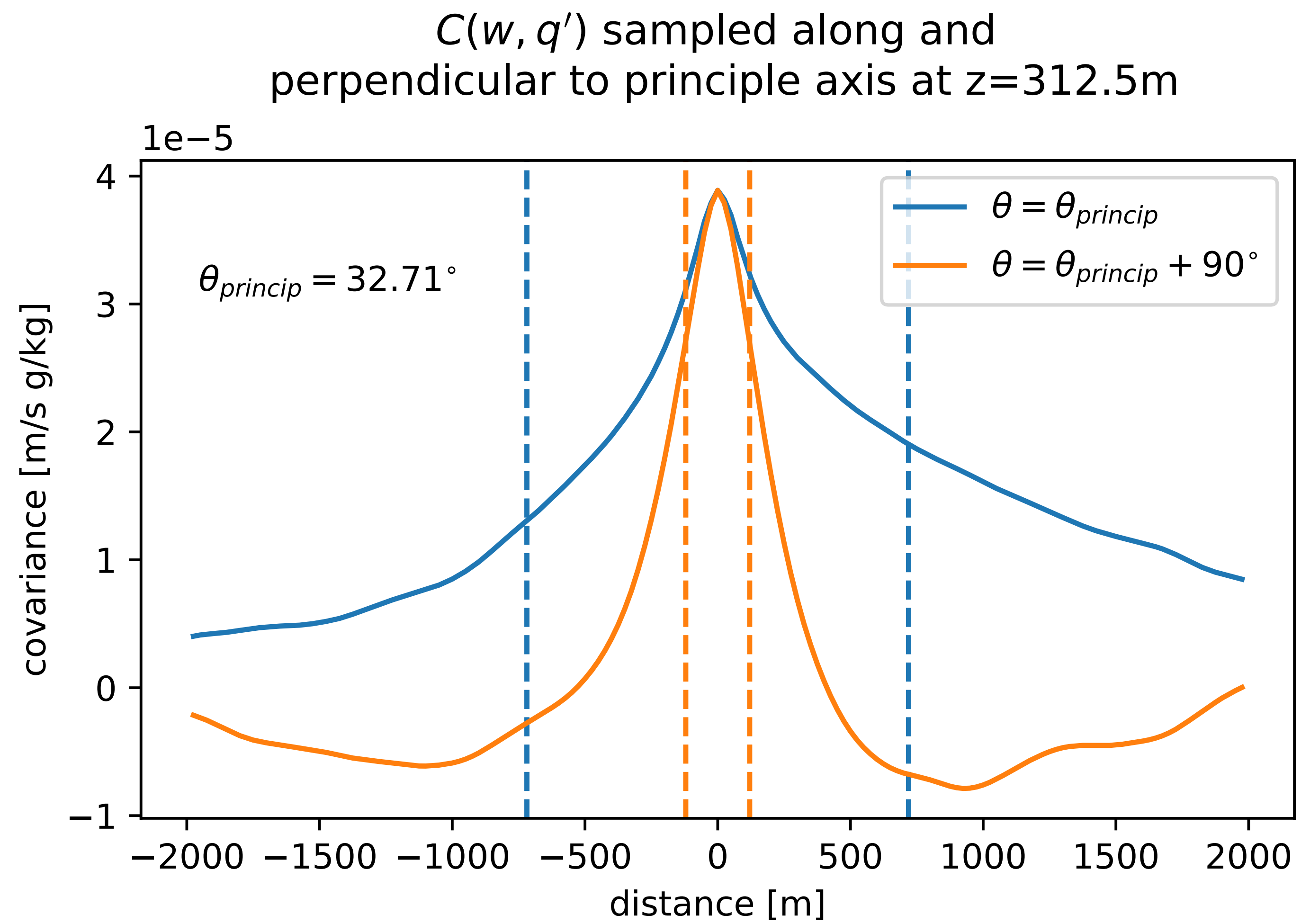
Use of cumulants to study characteristic scales



- With shear coherence is increased in direction of shear
    - Coherence stronger in mid boundary-layer than at cloud-base
- Non-sheared case *does* show coherence length-scale, characteristic scale of convective cells?
    - Similar scale to cross-shear coherence length-scale?

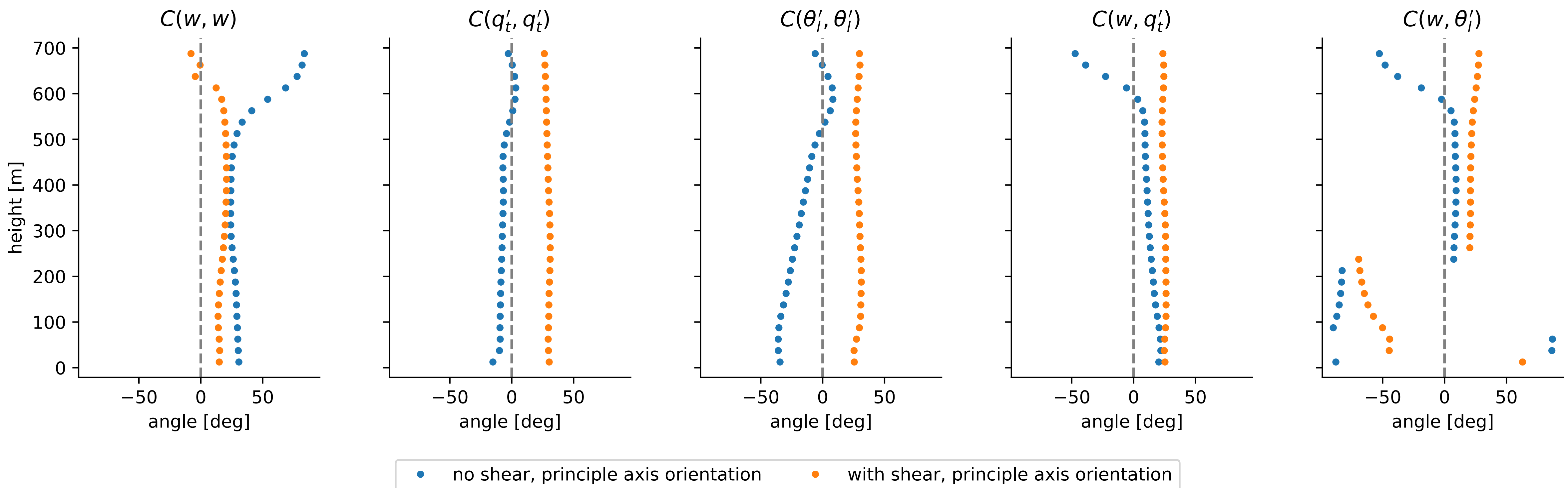
Use of cumulants to study characteristic scales





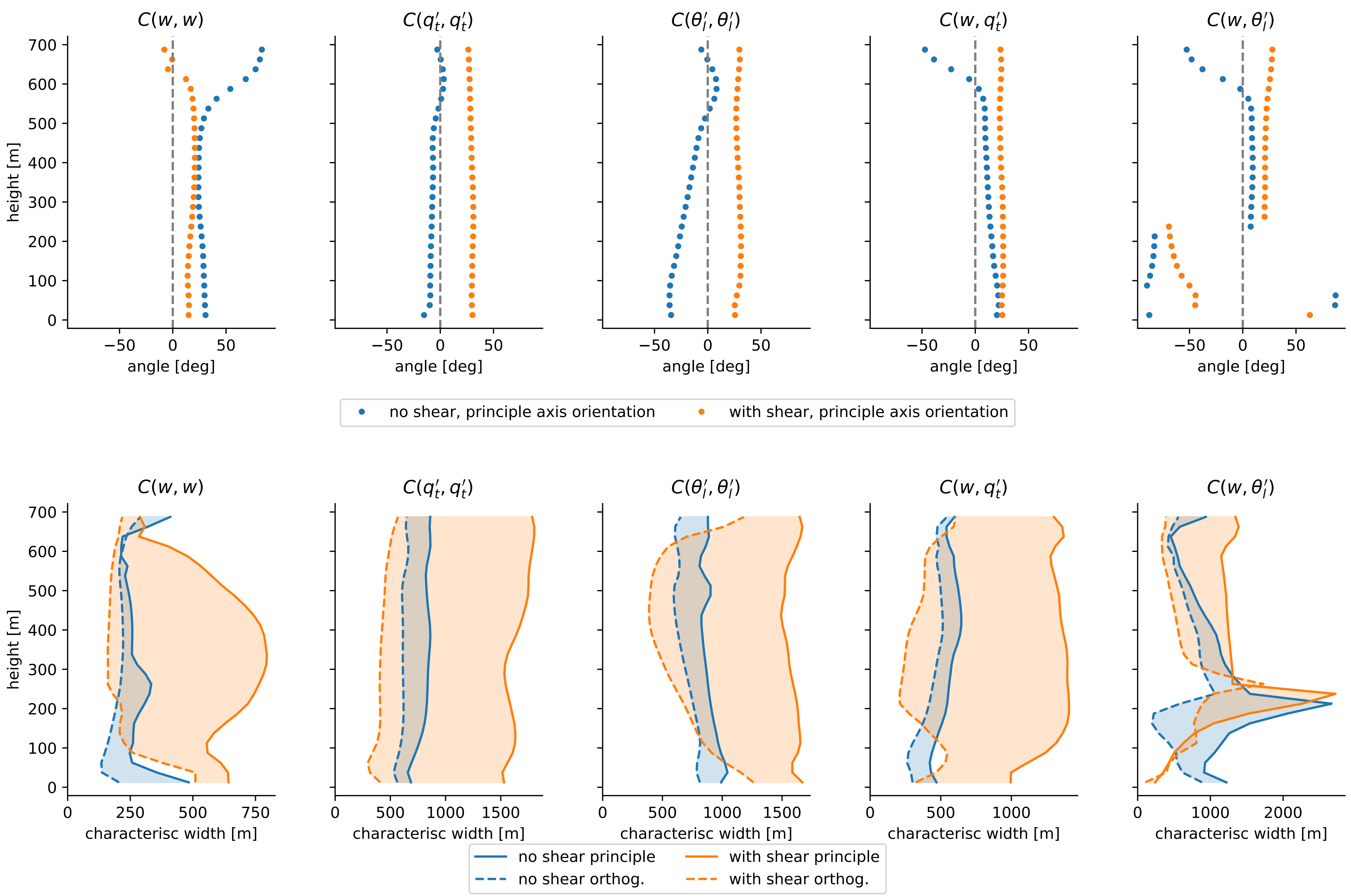
- Direction of strongest coherence from principle axis of moment of inertia tensor
- Coherence length-scale calculated as moment of covariance

Characteristic length-scales of vertical flux fields



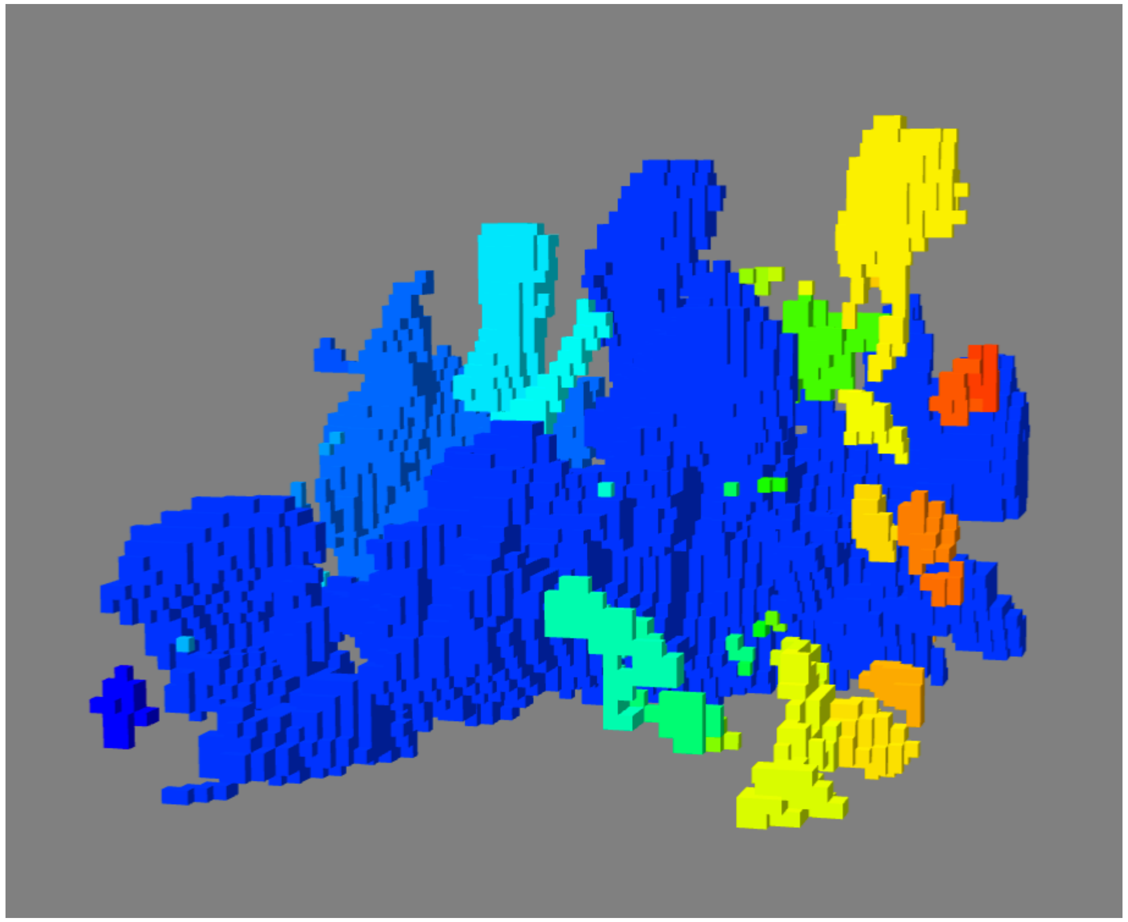
- With shear all fields but heat-flux (θ_l) are oriented in same direction
    - Twist in vertical velocity angle at cloud-base?
- Without shear different fields have different orientation, but appears quite stable (smooth change) with height
- Heat-flux is small in simulation (over ocean => buoyancy from moisture flux, not heat flux), so probably little anisotropy

Characteristic length-scales of vertical flux fields



2. Object-based analysis
Identifying individual objects

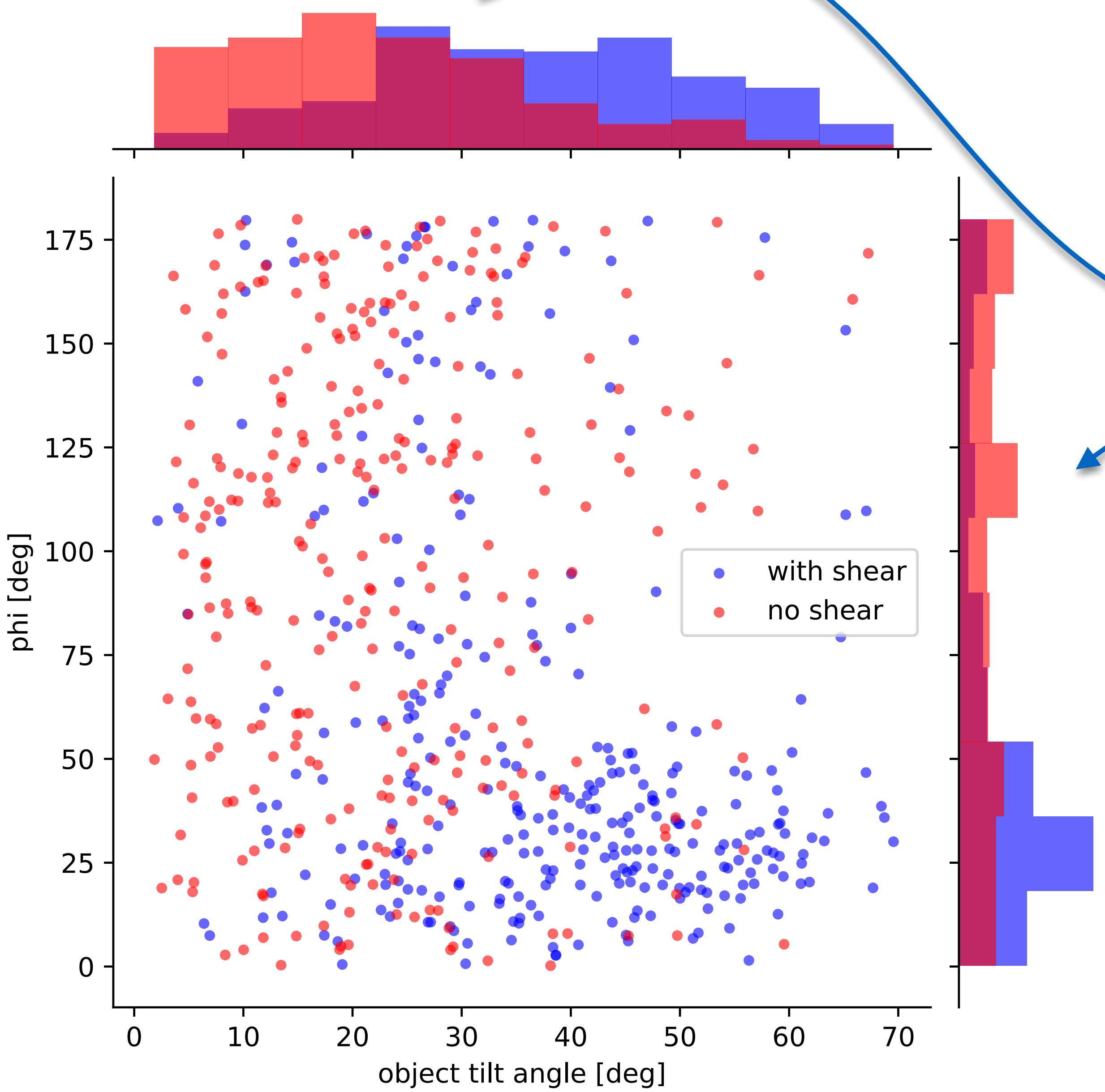
- Identify (and later, track in time) boundary layer structures which cause convection to trigger
- Use to partition distributions of variability by individual objects (of specific size, volume, shape, etc)



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 and fiber-surfaces analysis with Hamish Carr and PhD student, Leeds

Are the objects oriented with cumulant direction?



Yes! ~30°

- Although objects in non-sheared environment appear titled no correlation with orientation
- Shear tilts objects in direction of shear

- Tilt and orientation calculate from slope of center-of-mass in every height inside object

What are characteristic sizes of objects in the boundary layer?

- Use Minkowski functionals to compute characteristic length-scales

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

$$\Rightarrow$$

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

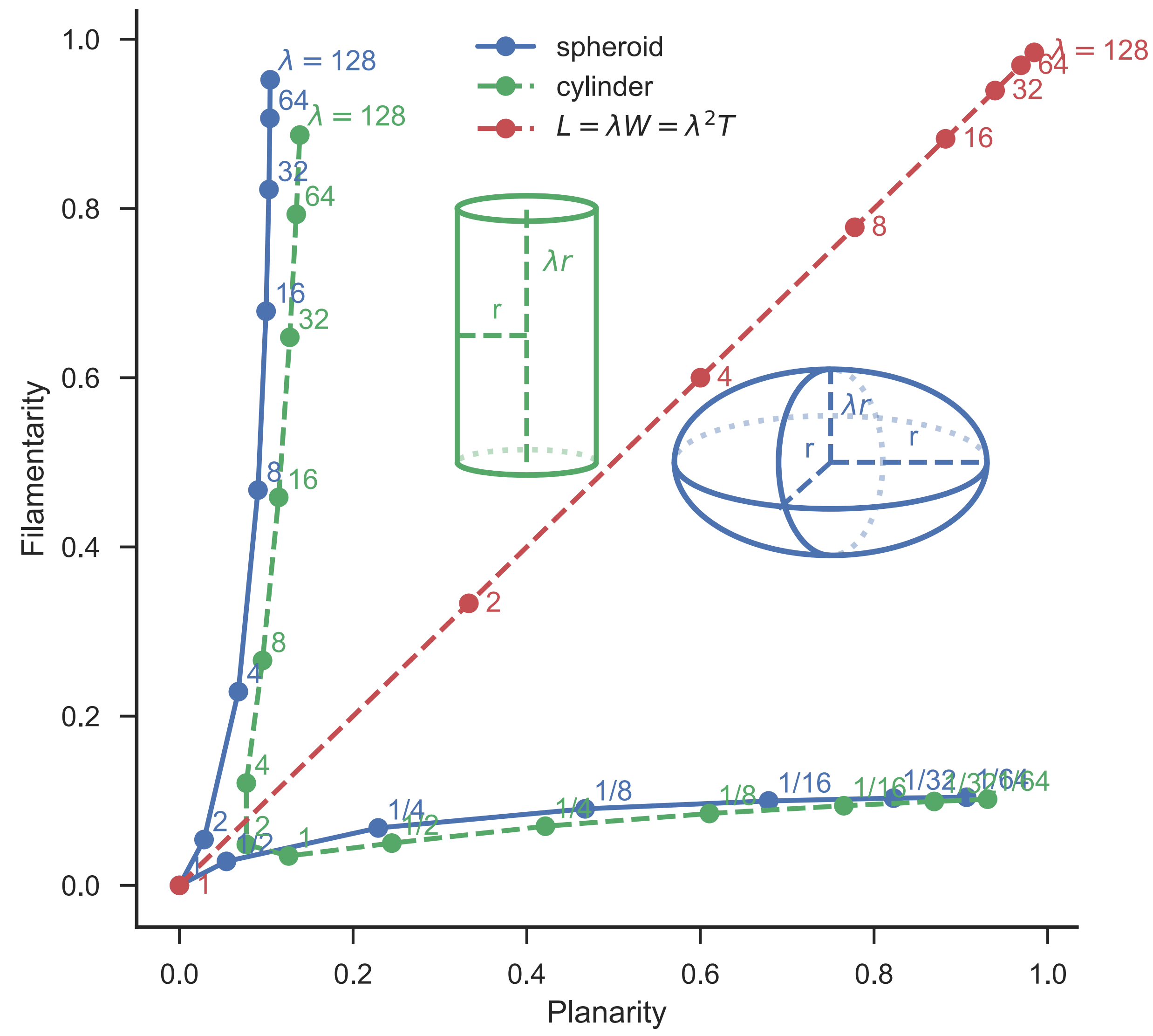
$L \geq W \geq T$ *by construction*

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

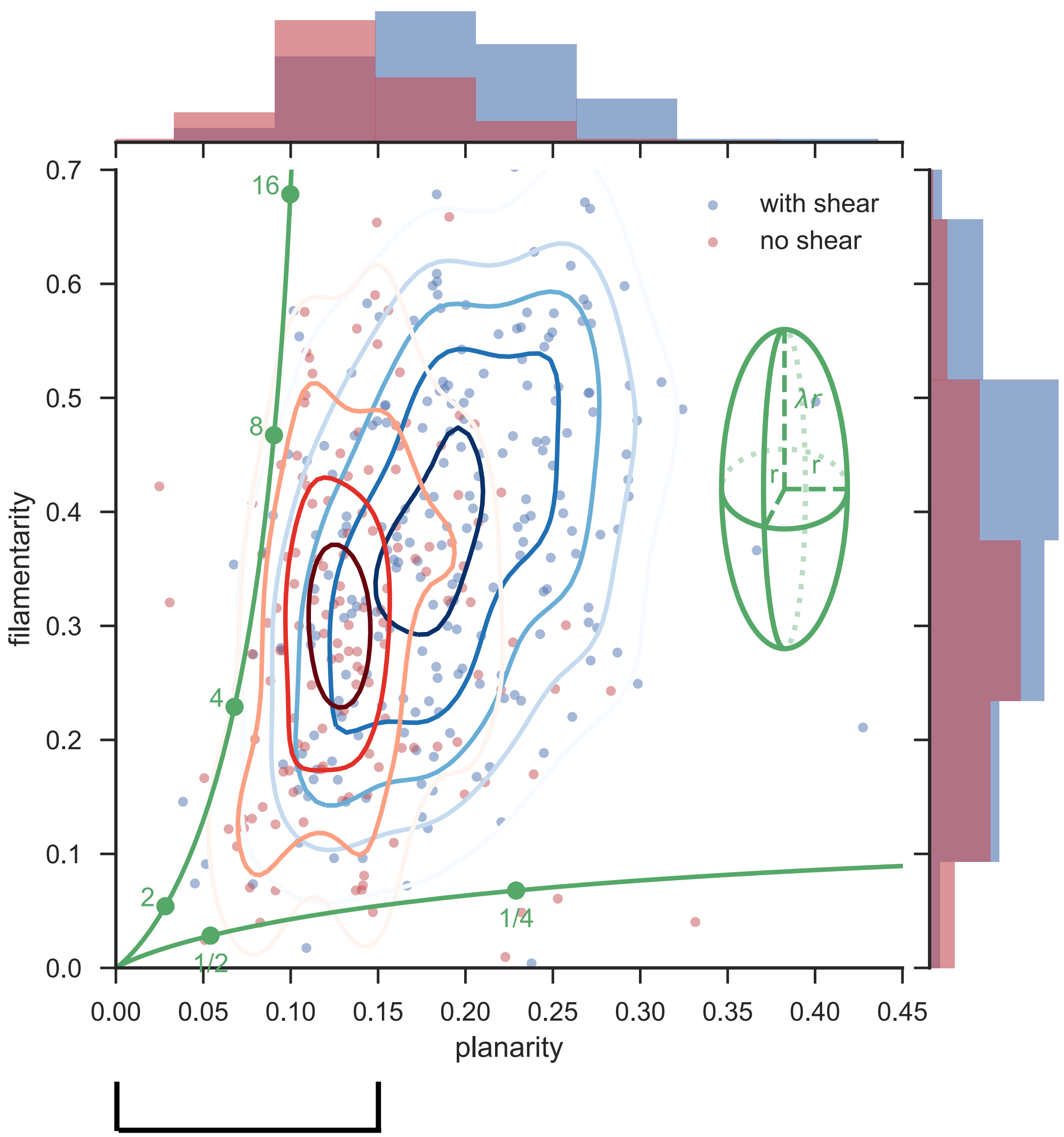
$$P = \frac{W - T}{W + T}, F = \frac{L - W}{L + W}$$



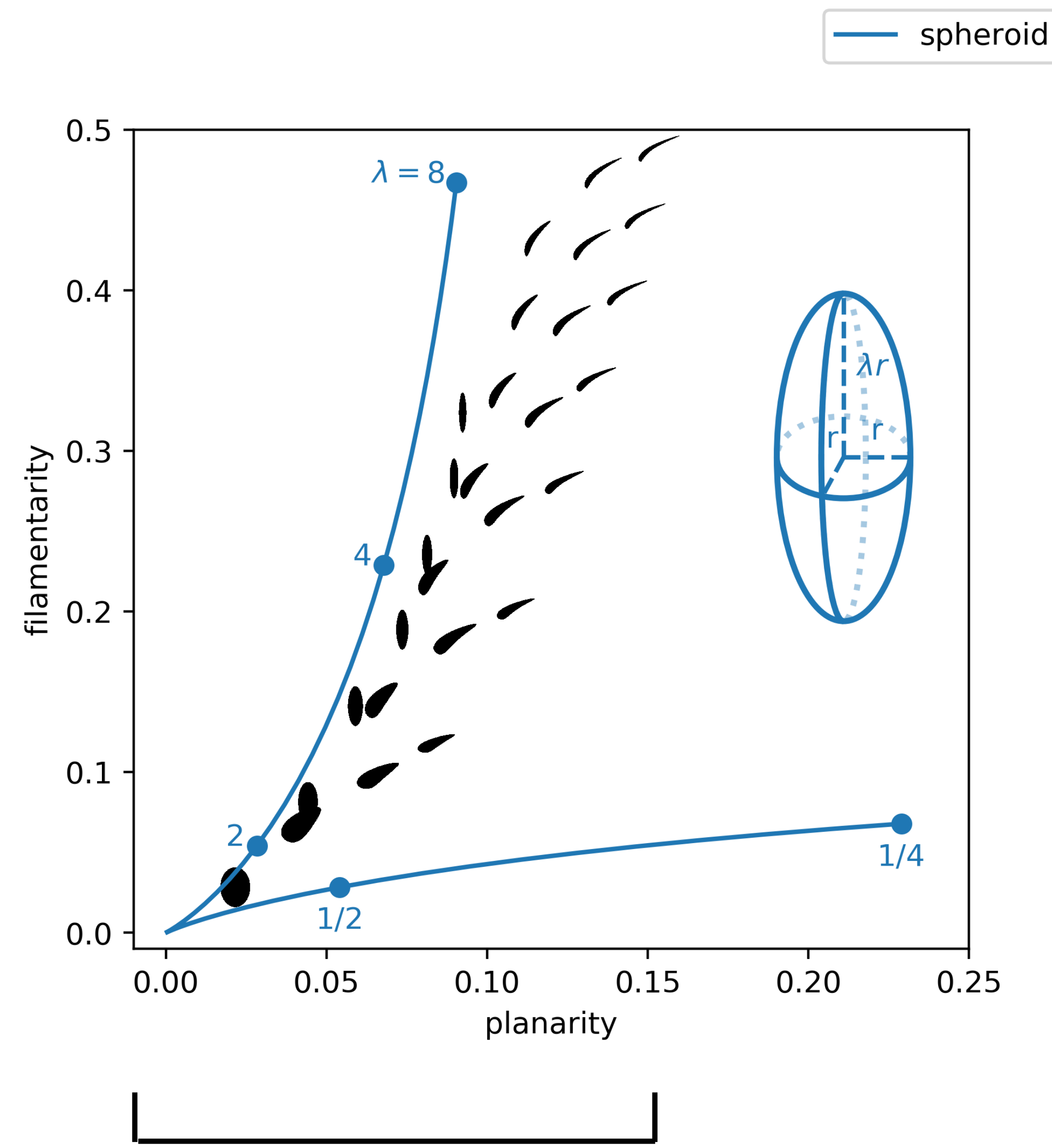
➡ Measures how pencil or disc-like an object is

What is shape of objects in the boundary layer?

objects in LES

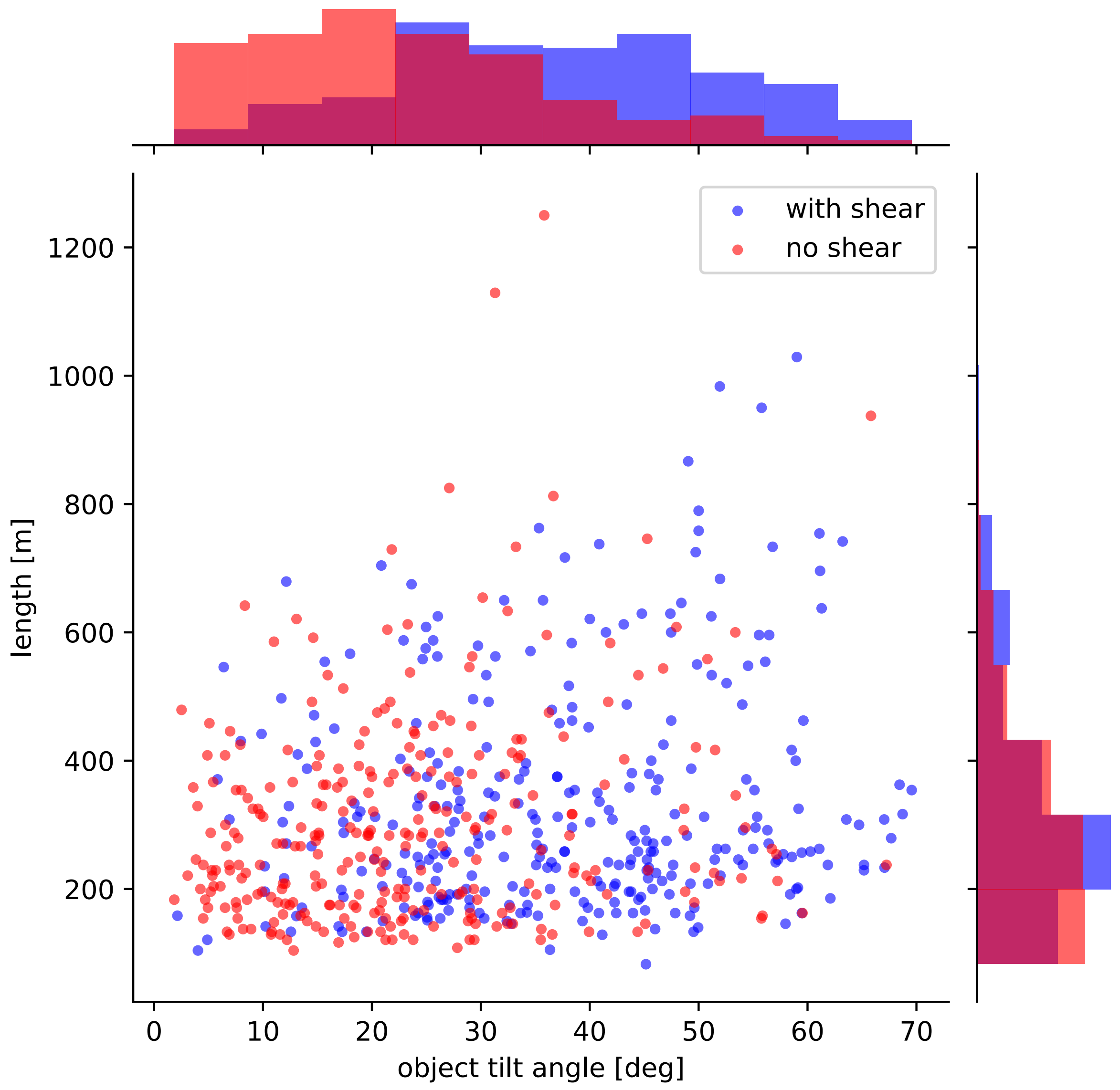


synthetic objects



➡ Shear causes structures to become longer and wider by ~30% and ~50% respectively

Does object tilt correlate with length?



➡ Doesn’t appear to be a large effect, but maybe obscured by large number of small objects

Next steps

Papers being written

1. Demonstration of cumulants and Minkowski functionals as means to quantify bulk and object-based properties of atmospheric fluids with coherent structures

2. Investigation of the effect of changing Bowen-ratio on properties coherent structures in the boundary layer

Ongoing work:

I. Developing topography test-case to do parameter study (bulk surface moisture flux and topography height)

II. Setting up/finding cases with deeper convection and diurnal cycle

III. Developing predictive model for properties of boundary-layer coherent structures

Thank you!

Questions?