How should we represent convective genesis?

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Aim

- Characterise coherent boundary-layer structures which cause the formation of moist-convective updrafts (i.e. convective clouds).
  - What are the spatial scales of dry updrafts? Horizontal aspect ratio? Spatial distribution (spatial separation)?
  - What influences these characteristics? I.e. how do these characteristics change with the boundary layer state?
  - How do specific phenomena related to moist convection (shallow/deep convection, squall lines, coldpools, etc) affect these?
  - Does the topology of these coherent structures influence their dynamical behaviour? Can the topology be used as a means of classification (instead of isosurfaces)?

So as to

- Identify which physical variables are most important to represent convective trigger, which variables carry memory.
- Provide convective scheme with joint distributions (e.g. $P(q_t, \theta_l, w)$) of cloud-base conditions

Simulation setup

Preliminary results: **Multiple ($O(10^4)$) interacting clouds triggered through surface-fluxes and large-scale forcing** in large domain ($50km \times 50km$) LES ($\Delta x = 25m$)

- Radiative-Convective Equilibrium precipitating marine shallow cumulus based on RICO measuring campaign
- Using UCLA-LES (Stevens et al. 2005)
- Individual clouds identified with cloud-tracking algorithm (Heus and Seifert 2013)

For future simulations: **large-domain simulations capturing phenomena of interest**

- will be performed using MONC LES (Brown et al. 2015)
- all literature, case descriptions, scientific motiviation, initial and boundary conditions collected **in one central place**: `https://github.com/leifdenby/moistconvection`
- identify which phenomena are present in different test-cases. Lack of studies which focus on **surface heterogeneity** and **cold-pools**.

"Name" of test case	Transient forcing	cloud-type	precip.	coldpools	land/ ocean	surface heterogeneity
RICO	✗	ShCu	✓	✓	ocean	✗
BOMEX	✗	ShCu	✗	✗?	ocean	✗
ARM SGP (Brown et al 2002)	✓ (diurnal)	ShCu	✗	?	land	✗
ARM SGP (Cerderwall et al 2000)	✓ (diurnal, 1month)	Deep Cu	✓	?	land	✗
TOGA-COARE (Petch 2007)	✓	Deep Cu (transition)	✓	?	ocean	✗
TRMM-LBA (Grabowski 2003)	✓ (no day->night)	Deep Cu (transition)	✓	?	land	✗
TOGA-COARE (Redelsperger et al 2000)	✓	squall line	✓	?	land	✗
...						

Figure 1: Overview of test-cases based observational field campaigns

Analysis methods

Cumulant analysis

In Tobias and Marston 2016 cumulants (which are a higher-order generalisation of covariance) was applied to identify the principle length-scales of coherent structures in 3D Couette flow. For example computing the second cumulant for velocity at two different heights (z_1 and z_2) is given by

$$c_{uu}(\xi, \mu, z_1, z_2) = \frac{1}{L_x L_y} \int_0^{L_x} \int_0^{L_y} u'(x, y, z_1) u'(x+\xi, y+\nu, z_2) dx dy.$$

It is the intention in this to work to apply the same method of analysis to identify the dominant modes in the convective boundary layer.

Topological analysis

Contour tree analysis

- represent nestedness of isolines (in 2D) and isosurfaces (in 3D) through a 2D graph (the "contour-tree")
- nodes are saddle-points in the data
- height axis in contour-tree represents iso-value
- vertices are isolines/isosurface for a given iso-value

Graph represents topology of objects. Aim is to develop method of classification of coherent updrafts based on this representation.

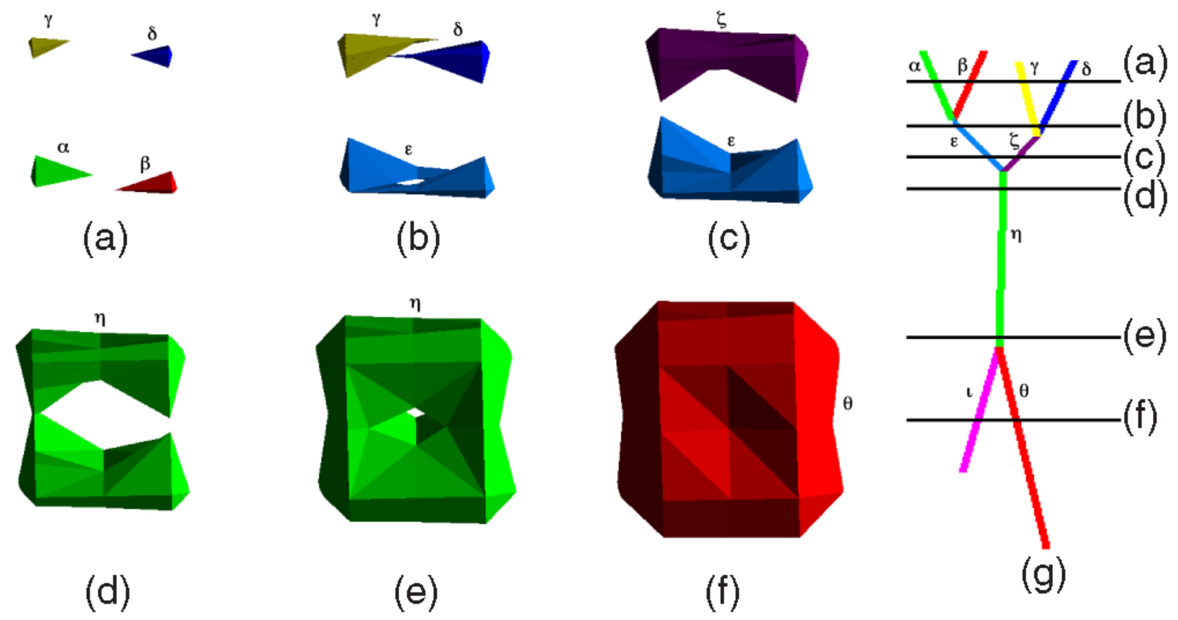

Figure 2: Six examples of isosurfaces for different iso-values for 3D scalar field (left) and its corresponding contour-tree (right). At each iso-surface value the number vertices represents the isosurfaces present. From Heine et al. 2011

Topological measures

In Zhdankin et al. 2014 the energy dissipation in magnetohydrodynamic turbulence was studied by computing Minkowski functionals of structures identified by isosurfaces of current density. It was found that the majority of transport was done by long thin filaments and thus this method may be used identify the conherent structures which carry the most transport of a given scalar, and similarly will be used to identify the coherent structures in the convective boundary layer which provide transport of moisture and heat to trigger convective clouds.
The first three Minkowski functionals in 3D are

$V_0 = V = \int dV,$

$V_1 = \frac{A}{6} = \frac{1}{6} \int dS,$

$V_2 = \frac{H}{3\pi} = -\frac{1}{6\pi} \int dS \nabla \cdot \hat{n},$

representing the volume, surface area and curvature respectively.

From these a the characteris *length*, *witdth* and *thickness* (saying whether the object more like a *sphere*, *stick* or a *pancake*) can be calculated as

$L_m = \frac{3V_2}{4}, W_m = \frac{2V_1}{\pi V_2}, T_m = \frac{V_0}{2V_1},$

where the normalization is so that all measures correspond to the radius when applied to a sphere.

(Preliminary) results

Below-cloud perturbations from LES

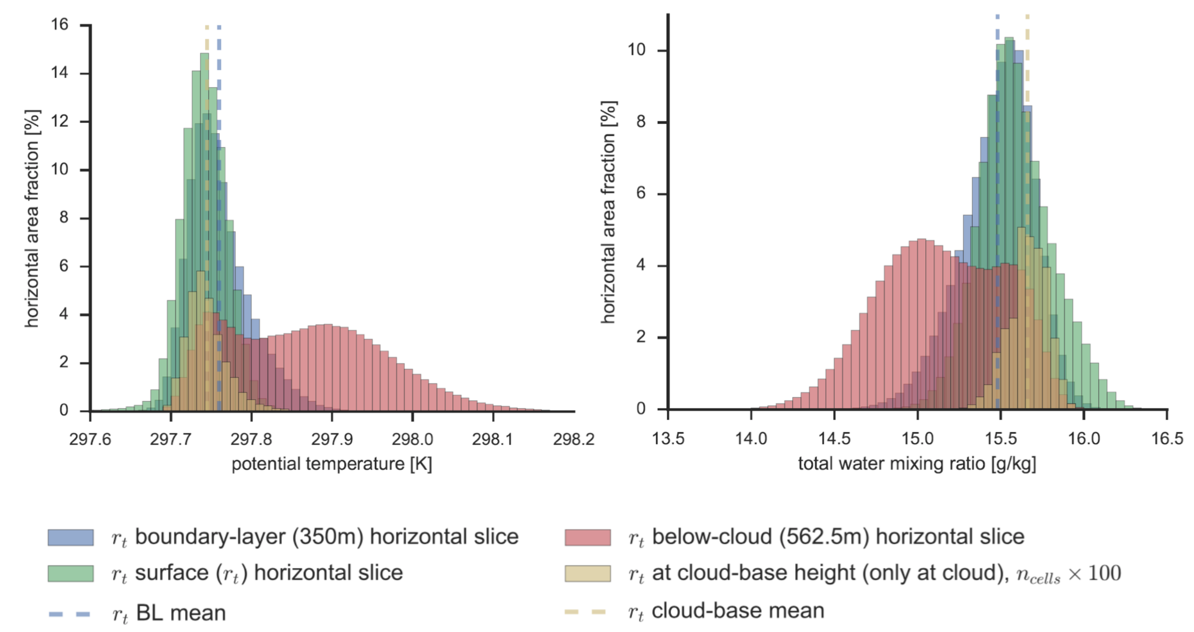

Figure 3: Distributions of total water and potential temperature in characteristic heights in boundary layer and at cloud-base extracted from 3D LES. Bimodal distribution at cloud-base made of cold and moist updrafts likely originating from surface, mean value at cloud-base colder than boundary-layer mean.

2D cumulant analysis

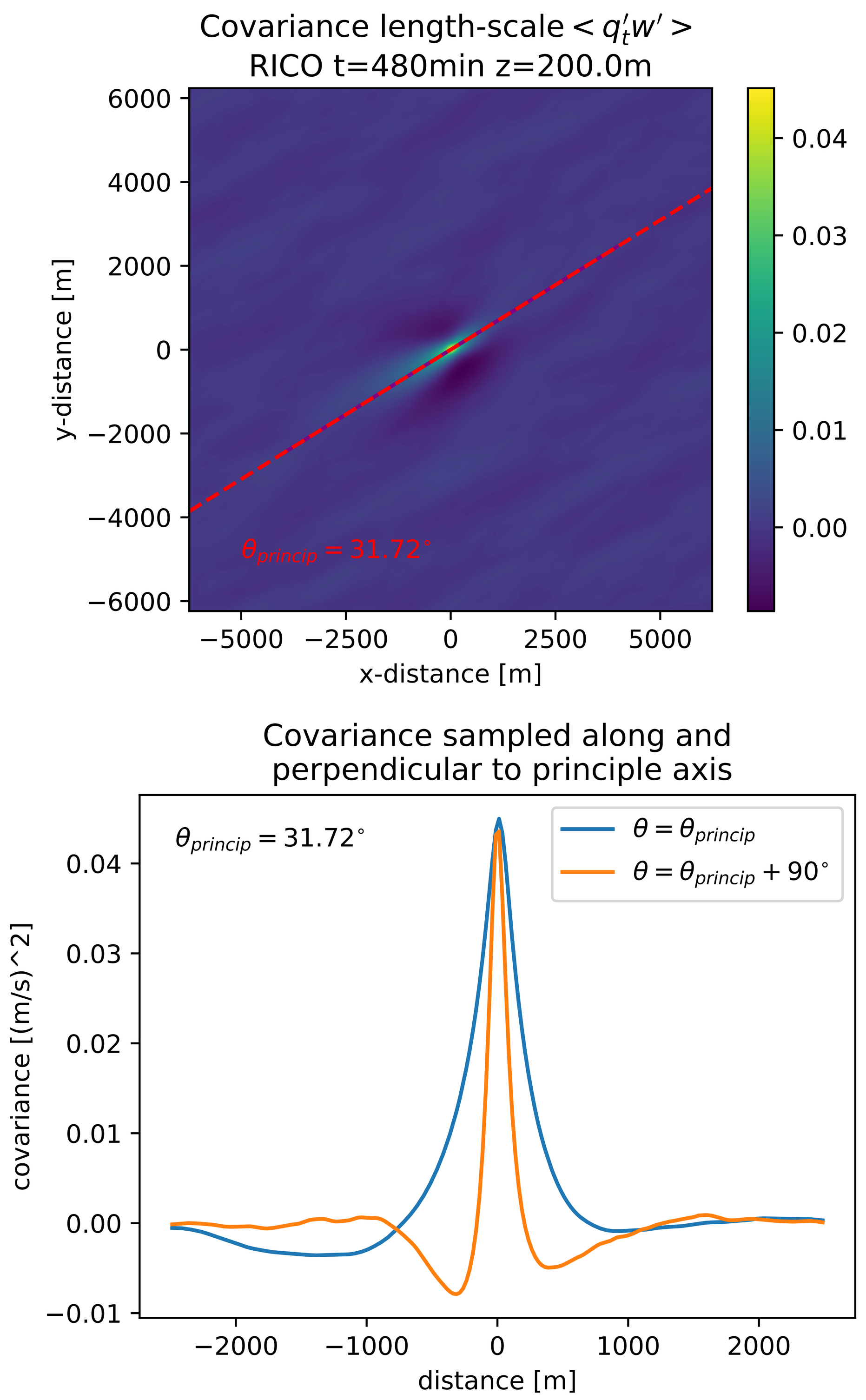

Figure 4: 2nd cumulant shows distances over which vertical velocity and total water vary together, it shows vertical transport of moisture and through the distribution over distances gives a characteristic width of updrafts. Characteristic width extended in cross-wind direction due to formation of rolls.

(Preliminary) results, continued

Volume and area distribution of updrafts

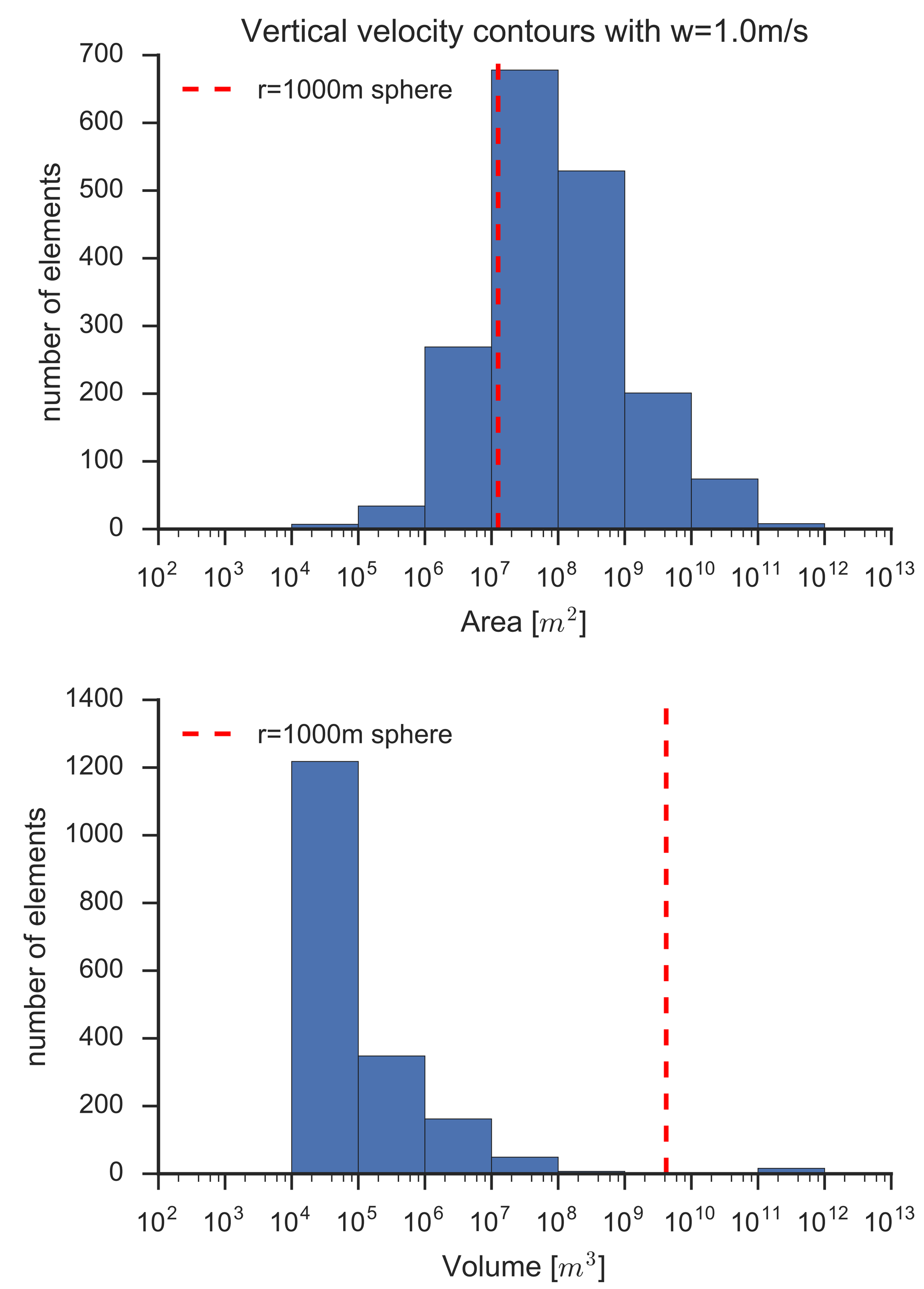

Figure 5: Distribution of surface area (top) and volume (bottom) of objects identified by iso-surface of $w = 1.0m/s$ with same measures for a sphere with $r = 1000m$ plotted for reference. The distance to the spherical shape indicates that the updraft elements are more elongated than spherical as expected.

Future work

- Design and run simulations which feature convective phenomena of interest
- Extract joint distributions of $P(w, q_t, \theta_l)$ at cloud-base and as function of height to study boundary layer structure in presence of different phenomena.
- Investigate connection between dry thermal properties and topology of thermals
- Identify which physical variables control characteristics of boundary layer thermals in presence of different convective phenomena
- Develop parameterisation which produces prediction of distribution of thermal size as well as physical properties at cloud base

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