The GENESIS of convective organisation

Leif Denby, University of Leeds

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Workshop on Understanding Convective Self-organisation
Aim
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- 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 ($O(\text{km})$)
  - 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?

Cross-sections of scalar fields in RICO at $z=200.0m$ $t=480$min

- $w$
- $\Delta\theta_v$
- $\Delta q_t$
- $\Delta\theta$
What are the length-scales of variability?

Cross-sections of scalar fields in RICO at $z=200.0\,\text{m} \, t=1440\,\text{min}$

- $w$
- $\Delta \theta_v$
- $\Delta q_t$
- $\Delta \theta$
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:

... 

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 $\alpha \Delta \theta_v$
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?
Domain decomposition

Identifying interesting regions to study

Using density anomaly ($\theta_\nu < -0.1K$) to define coldpool region

Using mean direction of ambient shear and coldpool edge orientation to identify up-shear/down-shear edge
Bulk statistics
Cumulative distributions of moist and heat fluxes
Bulk statistics

Outside coldpool and up-shear coldpool edge

Cumulative distribution in rico_gcss/rico_gcss.tn18 with 'outside coldpool using -0.1K theta_v limit' mask

t=122400.0s

Cumulative distribution in rico_gcss/rico_gcss.tn18 with 'coldpool edge in upshear direction' mask

t=122400.0s
Bulk statistics
Before and after convective organisation

Cumulative distribution in rico_gcss/rico_gcss.tn10 with 'outside coldpool using -0.1K theta_v limit' mask

Cumulative distribution in rico_gcss/rico_gcss.tn14 with 'outside coldpool using -0.1K theta_v limit' mask

Cumulative distribution in rico_gcss/rico_gcss.tn18 with 'outside coldpool using -0.1K theta_v limit' mask

No organisation
Isolated coldpools
Convection arc
Use of cumulants to study characteristic scales

- Two-point correlation of two scalar fields ($\phi$ and $\psi$), here taken at same height ($z$) for both fields

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

- 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
Coherence length
Inside and outside coldpool

C(q_flux, q_flux)
C(t_flux, t_flux)

- **coldpool_coarse principle**
- **coldpool_coarse perpendicular**
- **not_coldpool_coarse principle**
- **not_coldpool_coarse perpendicular**
- **full domain principle**
- **full domain perpendicular**

zt = 112.5, time = 122400.0
Coherence length

Upshear and downshear coldpool edge
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)

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

Buoyant elements defined by $w > 0.5\text{m/s}$ in boundary layer of RICO simulation at $t=480\text{min}$
What are characteristic sizes of objects in the boundary layer?

• Use Minkowski functionals to compute characteristic length-scales

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

\[ L = \frac{3V_2}{4V_3}, \quad W = \frac{2V_1}{\pi V_2}, \quad T = \frac{V_0}{2V_1} \]

\[ L \geq W \geq T \quad \text{by construction} \]

V: volume, A: area, H: mean curvature, \( \kappa_1 \) and \( \kappa_2 \) intrinsic local curvature (\( \nabla \cdot \hat{n} = \kappa_1 + \kappa_2 \))
What are the characteristic length-scales of boundary layer structures?

Normalised distributions of \( w'q' > 0.3 \text{ kg/kg m/s} \) objects at \( t=36\text{hrs} \)

- **coldpool edge upshear**
- **outside coldpool**

![Distributions of w'q' objects](image-url)
What is shape of objects in the boundary layer?

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

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

Measures how pencil or disc-like an object is
What is shape of objects in the boundary layer?
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)