IDENTIFYING COHERENT STRUCTURES BY OPTIMISING A TWO-FLUID REPRESENTATION OF SHALLOW CONVECTION

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ParaCon - CoDyPhy

Motivation

- Diagnose
  - the partitioning of the flow into coherent structures and their environment
  - the characteristics of coherent structures vs their environment
- Understand
  - the turbulent transfer of heat and moisture in the BL and cloud layer
  - the coupling of the BL with evolving Cu

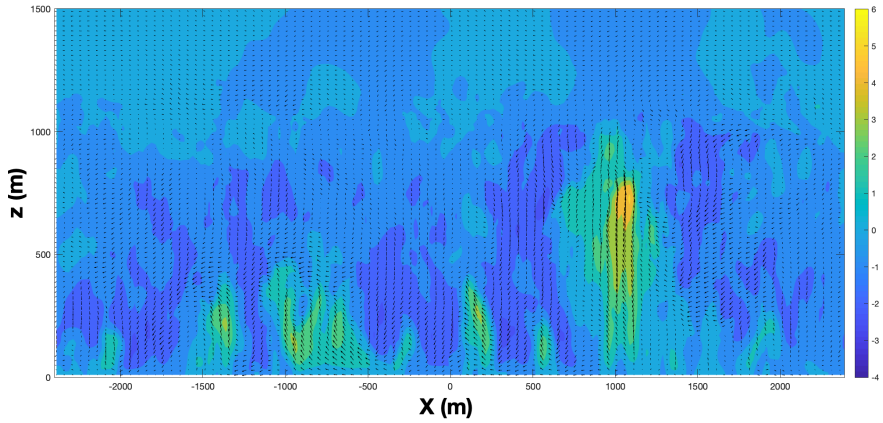
- Diagnostics to drive a multi-fluid simulation of shallow convection

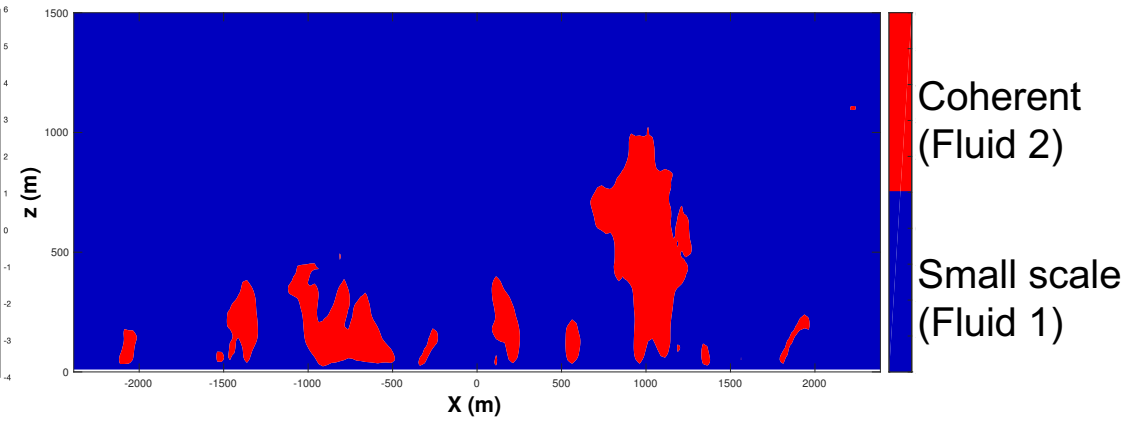
Partition the flow

$$\overline{w'\theta'} = -K\frac{\partial\overline{\theta}}{\partial z} + \overline{w'\theta'}_{NL}$$

Local
(Small scale)
Turbulence

Non-local
(Coherent)
Structures





Diagnosing coherent structures

Large Eddy Simulations (Met Office LEM)

- Quasi-steady CBL (Q_H = 240 W m^{-2} , z_* ≈ 1000 m)
  - Δx = 25 m, Δz = 10 m
- Southern Great Plains ARM site (Shallow Cu – 21/6/1997)
  - Δx = 50 m, Δz = 20 m

$$\frac{\partial c}{\partial t} = \frac{c}{\tau}$$

”Radioactive” tracer emitted from the surface (τ = 15 min)

Method

1. Tracer threshold method (TRACER) (Couvreux et al., 2010)

$$c'(x,y,z) > m \max[s_c(z), s_{cmin}(z)] \;\; \& \;\; w(x,y,z) > 0$$

with m = 1

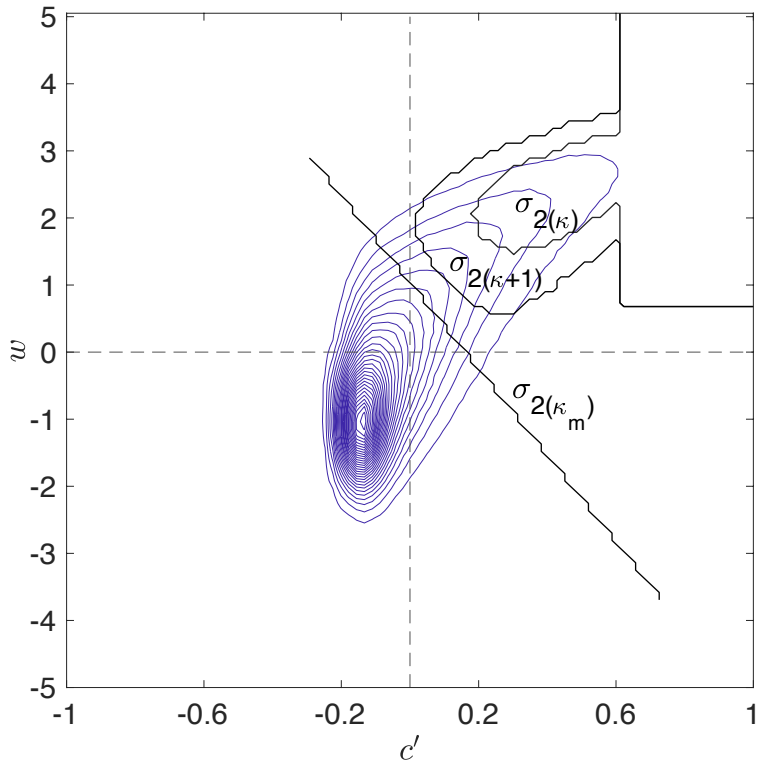
2. Optimise vertical turbulent tracer transfer - Maximise Resolved f2 ($OPTH_2$)

Optimisation of vertical turbulent transfer

- Decompose the flow: fluid 2 (Coherent structures) fluid 1 (Environment)

$$\overline{w'c'} = \underbrace{\boxed{\sigma_1(w_1-\overline{w})(c_1-\overline{c})}}_{\text{Resolved f1}} + \underbrace{\boxed{\sigma_2(w_2-\overline{w})(c_2-\overline{c})}}_{\text{Resolved f2}} + \underbrace{\boxed{\sigma_1\overline{w'c'}^1}}_{\text{Sub f1}} + \underbrace{\boxed{\sigma_2\overline{w'c'}^2}}_{\text{Sub f2}}$$

- No assumption about the shape of the JFD
- No arbitrary sampling criteria
- Less to be parametrized



$w'c'$ JFD at z

$\sigma_{2(\kappa_m)}$

Maximises

$$H_2 = \sigma_2(w_2-\overline{w})(c_2-\overline{c})$$

Optimisation of vertical turbulent transfer

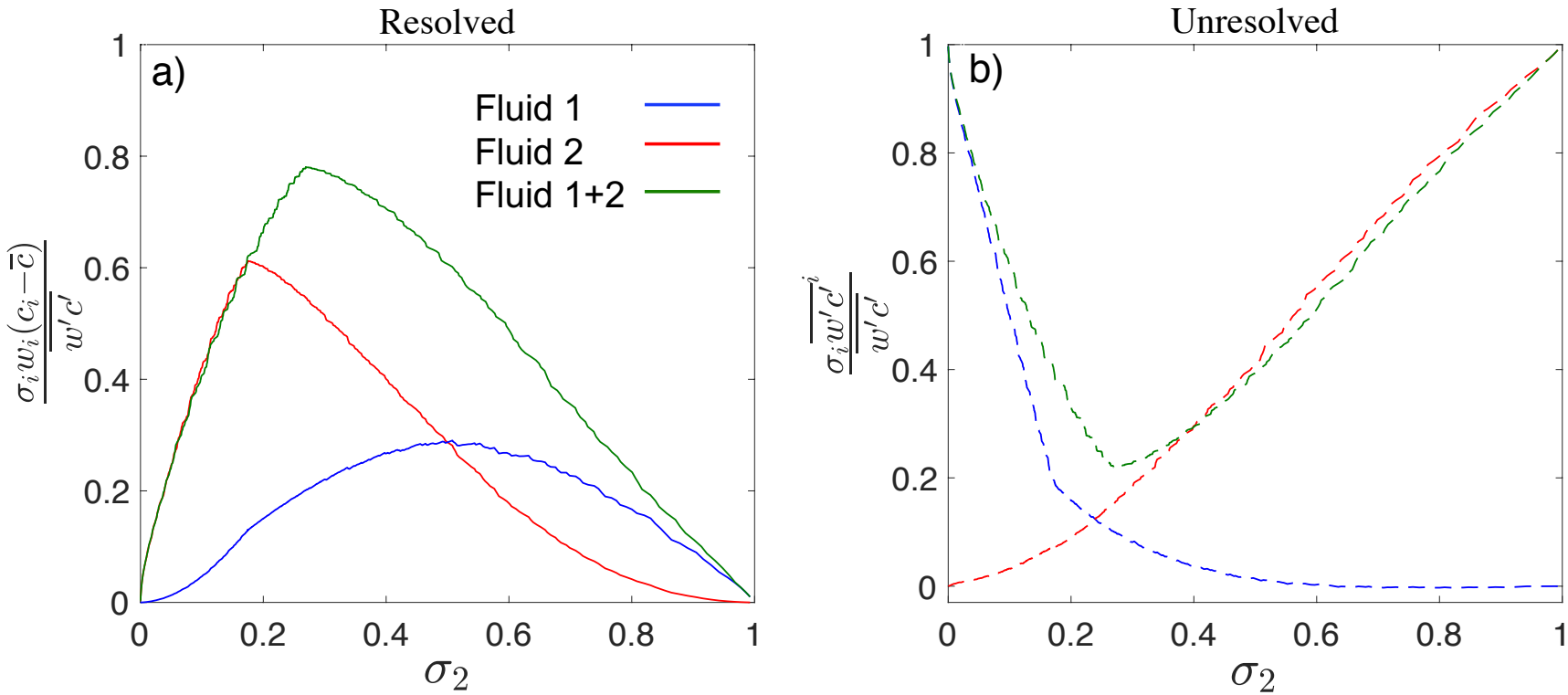
- Partition the flow: fluid 2 (Coherent structures) fluid 1 (Environment)

Resolved — Sub-filter

fluid 1 — fluid 2 — fluid 1 — fluid 2

$$\overline{w'c'} = \sigma_1(w_1-\overline{w})(c_1-\overline{c}) + \sigma_2(w_2-\overline{w})(c_2-\overline{c}) + \sigma_1\overline{w'c'}^1 + \sigma_2\overline{w'c'}^2$$

$z/z_* = 0.5$



Optimisation of vertical turbulent transfer

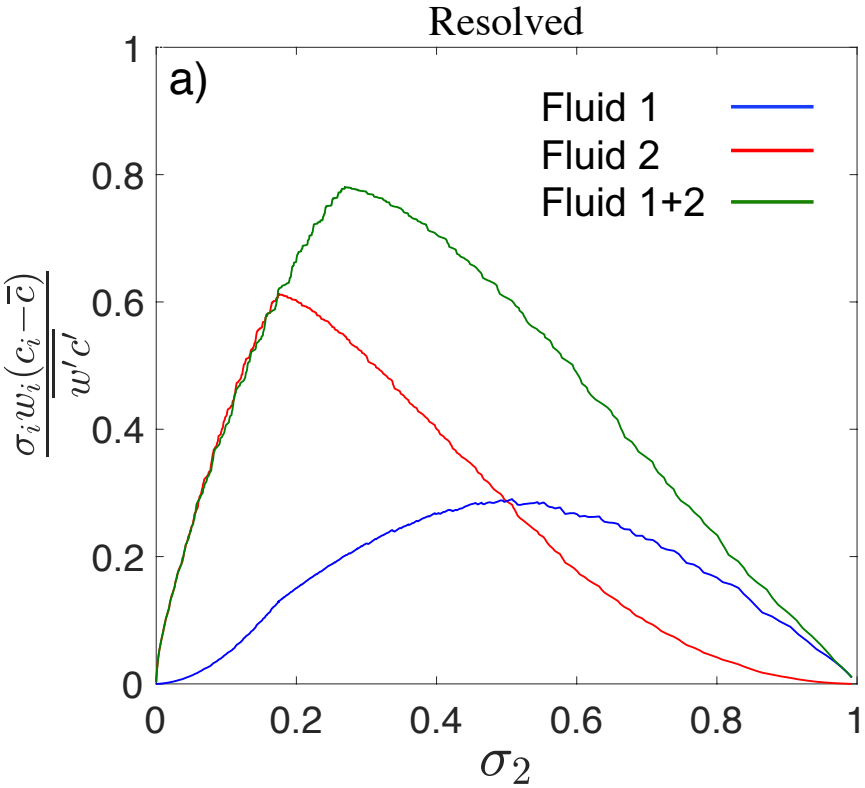
- Partition the flow: fluid 2 (Coherent structures) fluid 1 (Environment)

Resolved

fluid 1 fluid 2

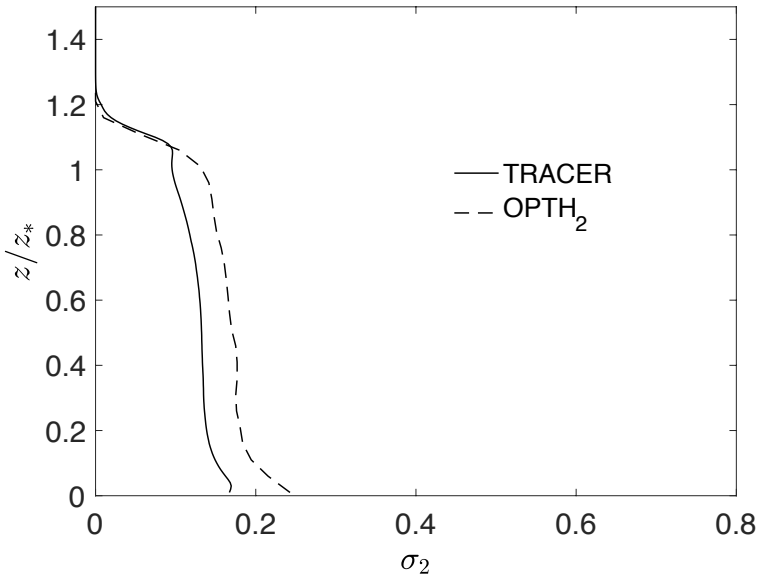
$$\overline{w'c'} = \sigma_1(w_1 - \overline{w})(c_1 - \overline{c}) + \sigma_2(w_2 - \overline{w})(c_2 - \overline{c})$$

$z/z_* = 0.5$



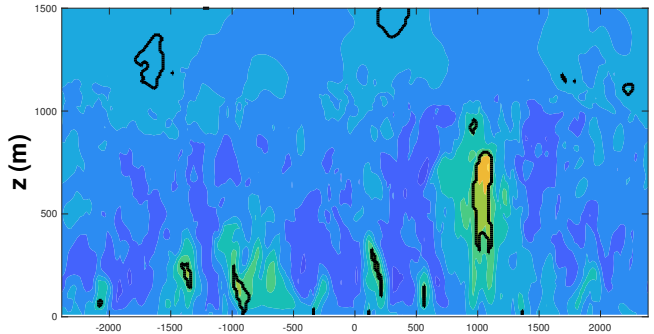
Results (CBL)

Area Fraction

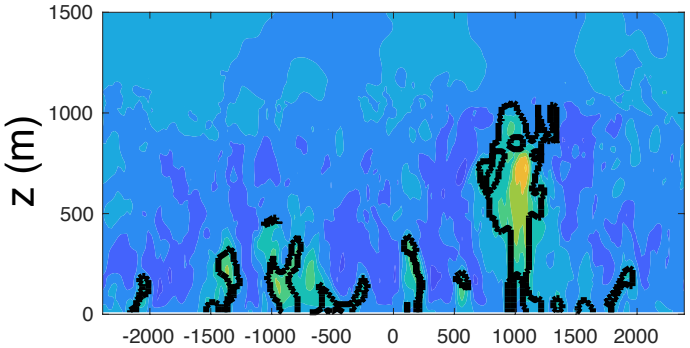


$p_w = 5\%$

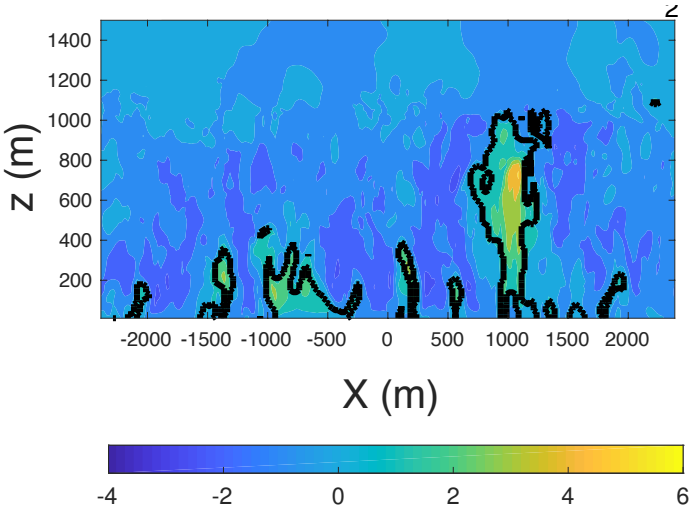
Fluid 2



TRACER

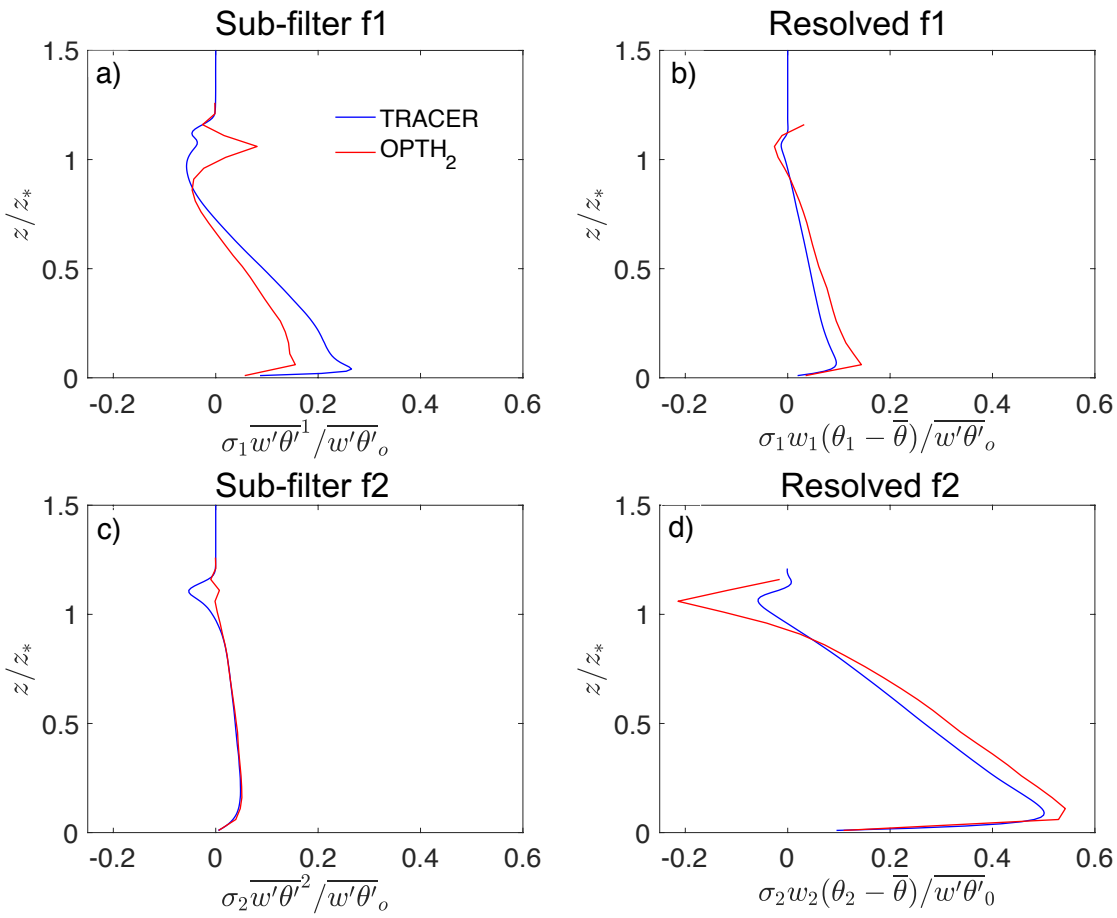


OPTH$_2$

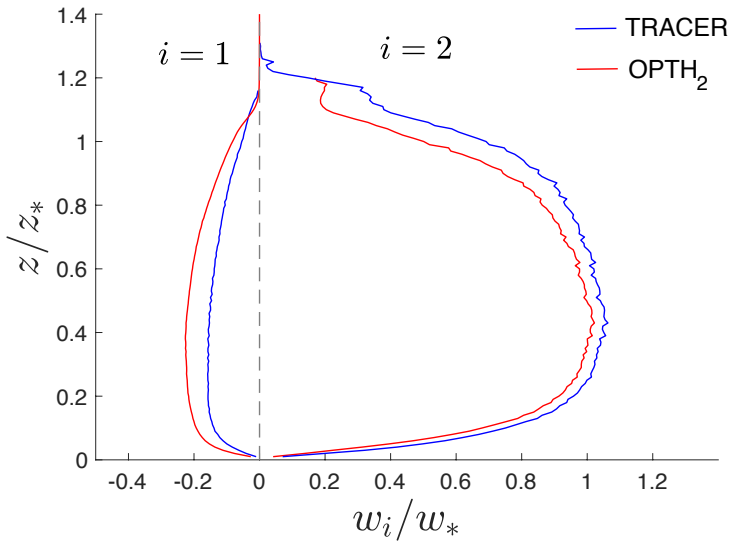


Results (CBL)

Heat Flux Decomposition

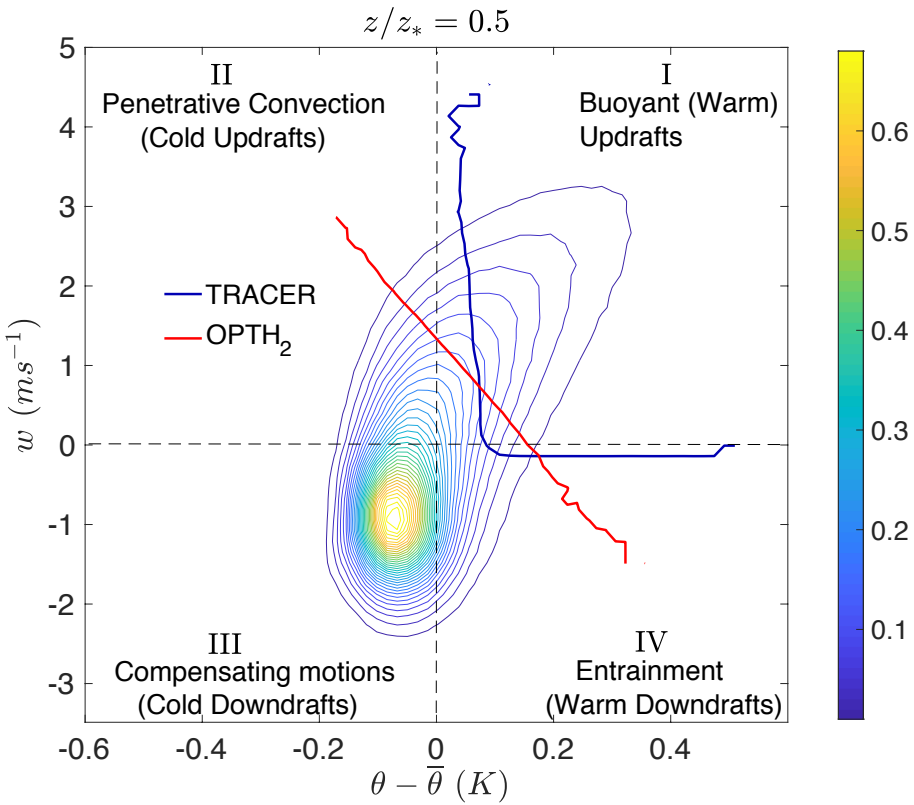


Vertical Velocity



Results (CBL)

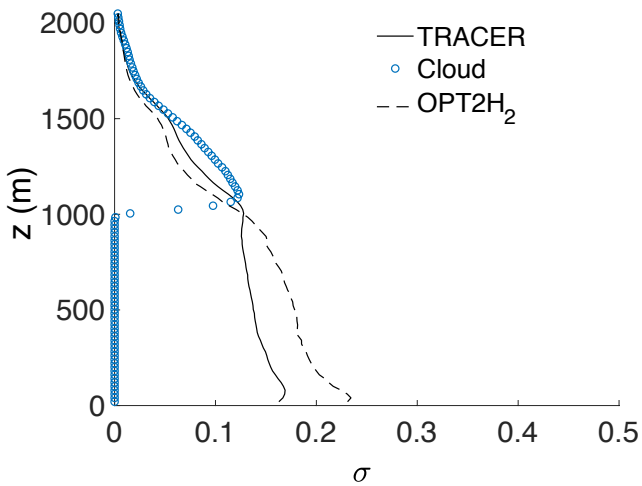
Quadrant Analysis

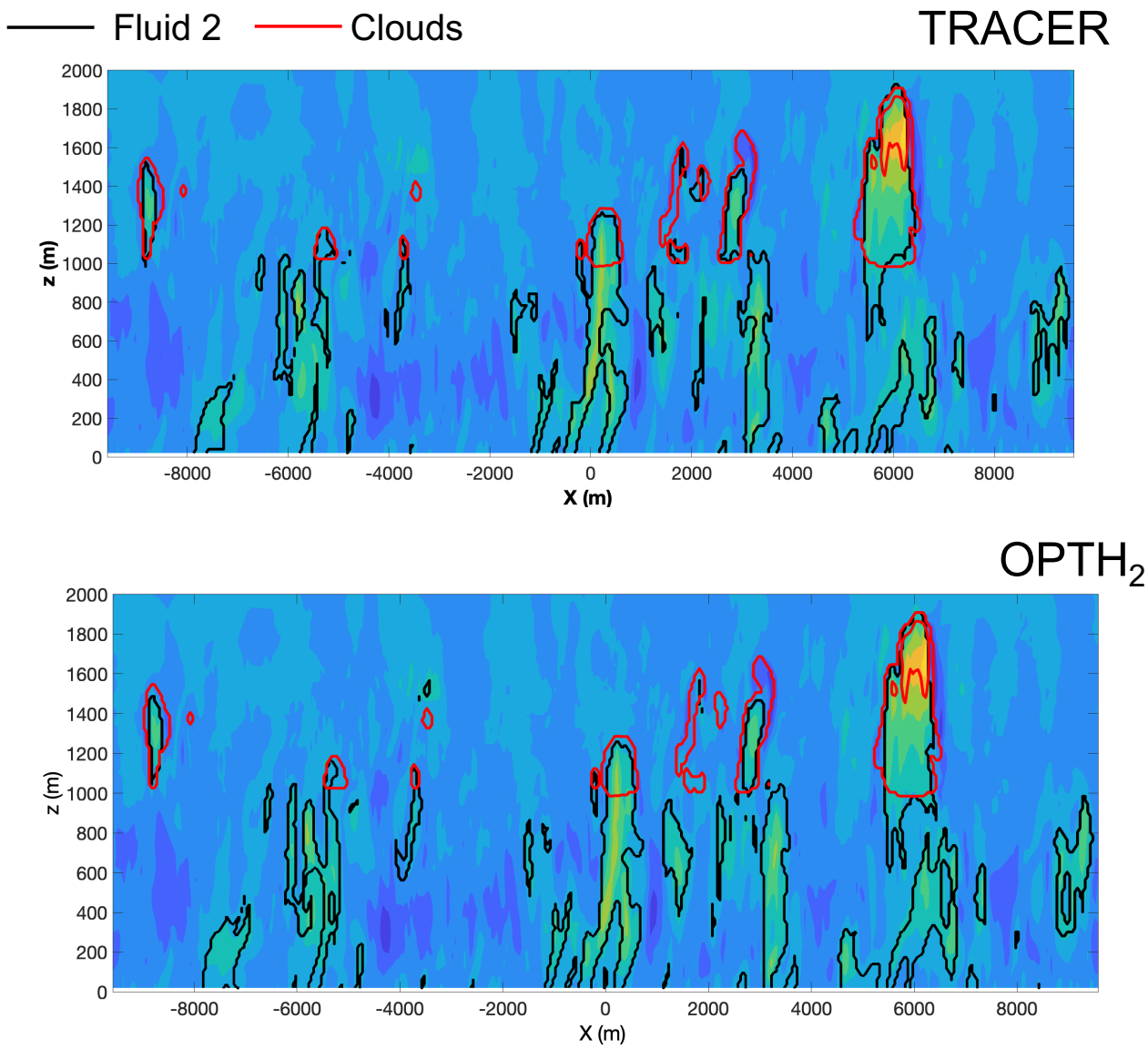


Similar area fraction – Different heat flux mechanisms

ARM case – Preliminary Results (1330 LT)

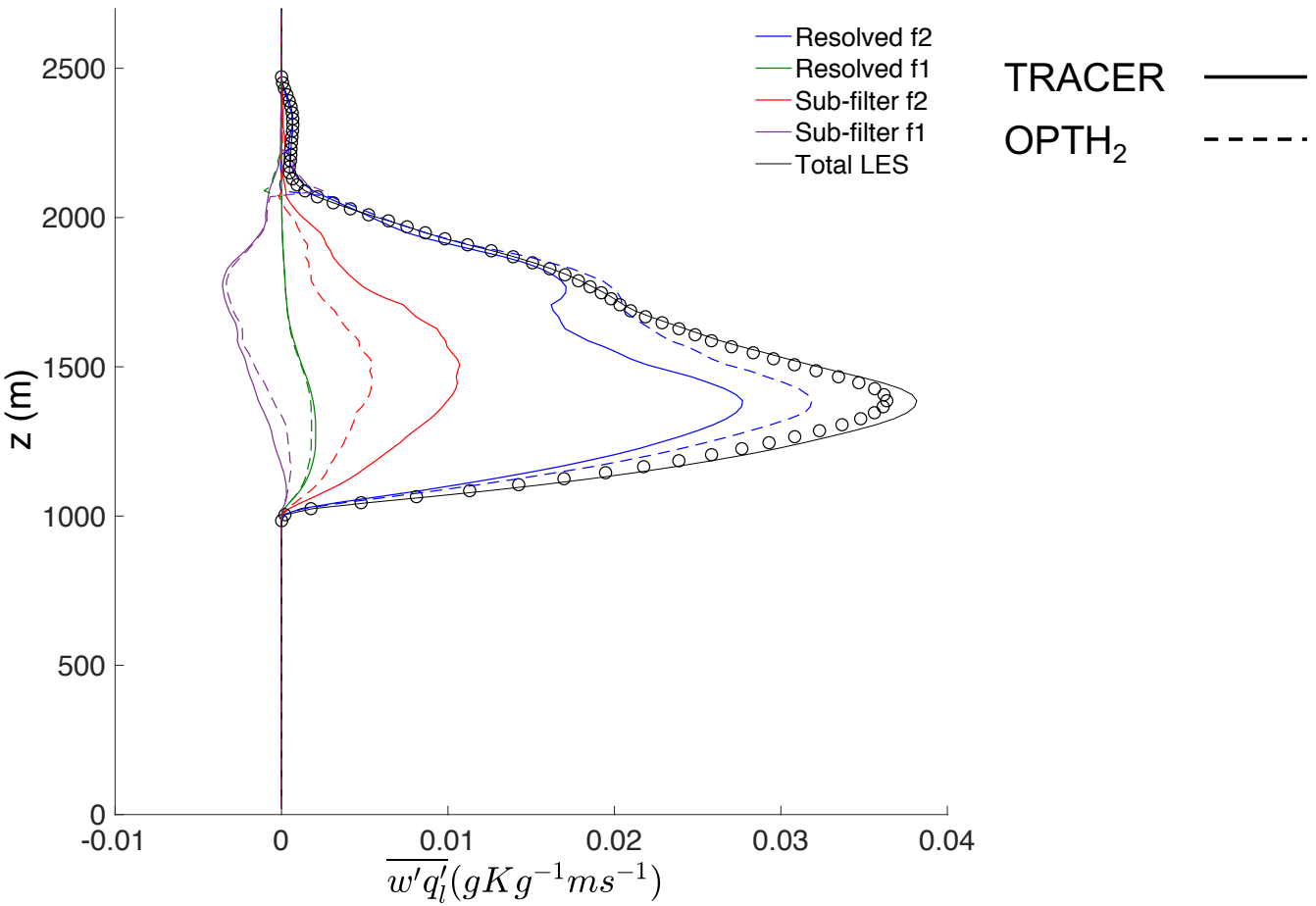
Area Fraction





ARM case – Preliminary Results

Liquid water fluxes



Conclusions

- Optimisation is able to produce coherent structures
  - No assumption about the shape of the JFD
  - No *a priori* sampling criteria
  - Physically based:

Asai and Kashara (1967) found max KE and heat transport at σ ~ 0.2 - 0.3

Thermals are very efficient transferring scalars

per cent". This may be interpreted to mean that cumulus clouds are formed in hurricanes to carry heat upwards with the most efficient rate."

  - OPT increases Resolved f2 + Resolved f1- Less to be parametrized

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  - OPT increases Resolved f2 + Resolved f1- Less to be parametrized
- Differences between OPT and TRACER (m = 1) are small
- Non-local transfer is dominated by Resolved f2 - local by Sub-filter f1
- Preliminary results show ability of OPT to capture cloud structures

Is there an objective way to diagnose coherent motion?

Efstathiou GA, Thuburn J and RJ Beare (2019) Diagnosing coherent structures in the convective boundary layer by optimizing their vertical turbulent scalar transfer. *Boundary-Layer Meteorology*, provisionally accepted.

Vertical Velocity Distribution