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

Georgios Efstathiou, John Thuburn and Bob Beare

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

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

Local (Small scale) Turbulence

Non-local (Coherent) Structures

Coherent (Fluid 2)

Small scale (Fluid 1)
Diagnosing coherent structures

Large Eddy Simulations (Met Office LEM)

- Quasi-steady CBL ($Q_H = 240 \, \text{W m}^{-2}, \, z_* \approx 1000 \, \text{m}$)
  - $\Delta x = 25 \, \text{m}, \, \Delta z = 10 \, \text{m}$

- Southern Great Plains ARM site (Shallow Cu – 21/6/1997)
  - $\Delta x = 50 \, \text{m}, \, \Delta z = 20 \, \text{m}$

\[
\frac{\partial c}{\partial t} = \frac{c}{\tau}
\]

"Radioactive" tracer emitted from the surface ($\tau = 15 \, \text{min}$)

Method

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

\[
c'(x, y, z) > m \, \max\{s_c(z), s_{c_{\text{min}}}(z)\} \quad \& \quad w(x, y, z) > 0
\]

   with $m = 1$

2. Optimise vertical turbulent tracer transfer - Maximise Resolved $f_2$ (OPTH$_2$)
2.3 Optimisation of the Vertical Scalar Transfer

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

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

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

\[
H_2 = \sigma_2(w_2 - \overline{w})(c_2 - \overline{c})
\]
Optimisation of vertical turbulent transfer

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

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

\[z/z_* = 0.5\]
Optimisation of vertical turbulent transfer

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

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

\[
\frac{z}{z_*} = 0.5
\]
Results (CBL)

Area Fraction

\[ \frac{z}{z^*} = 5\% \]

\[ \sigma_2 \]

[Graph showing area fraction with markers for TRACER and OPTH2]

[Graphs showing TRACER and OPTH2 with X (m) and Z (m) axes, and color scale]
Results (CBL)

Heat Flux Decomposition

Sub-filter f1

Resolved f1

Sub-filter f2

Resolved f2

Vertical Velocity

\[ \frac{z}{z_*} \]

\[ \frac{w}{w_*} \]

\[ \frac{1}{w_*} \]

\[ \frac{1}{w_*} \]
Results (CBL)

Quadrant Analysis

Similar area fraction – Different heat flux mechanisms
ARM case – Preliminary Results (1330 LT)

Area Fraction

- TRACER
- Cloud
- OPT2H₂

Fluid 2, Clouds, TRACER, OPTH₂
ARM case – Preliminary Results

Liquid water fluxes

- Resolved f2
- Resolved f1
- Sub-filter f2
- Sub-filter f1
- Total LES

TRACER

OPTH$_2$
Conclusions

• Optimisation is able to produce coherent structures
  • No assumption about the shape of the JFD
  • No \textit{a priori} sampling criteria
  • Physically based:
    
    Thermals are very efficient transferring scalars

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

\textit{Asai and Kashara (1967) found max KE and heat transport at } \sigma \approx 0.2 - 0.3 \textit{. “This may be interpreted to mean that cumulus clouds are formed in hurricanes to carry heat upwards with the most efficient rate.”}
Conclusions

- Optimisation is able to produce coherent structures
  - No assumption about the shape of the JFD
  - No \textit{a priori} sampling criteria
  - Physically based:
    - OPT increases Resolved $f_2 +$ Resolved $f_1$ - Less to be parametrized
    - Differences between OPT and TRACER ($m = 1$) are small
    - Non-local transfer is dominated by Resolved $f_2$ - local by Sub-filter $f_1$
    - Preliminary results show ability of OPT to capture cloud structures

Asai and Kashara (1967) found max KE and heat transport at $\sigma \sim 0.2 - 0.3$

Thermals are very efficient transferring scalars

Is there an objective way to diagnose coherent motion?

Vertical Velocity Distribution

![Graph showing vertical velocity distribution with different curves labeled as $w>0$, TRACER, $p_w = 5\%$, and OPTH$_2$. The x-axis represents $\max[w]$ (m s$^{-1}$) and the y-axis represents particles.]