Turbulence Mixing and the study of Clouds

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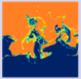
Venturefest 2012, Oxford

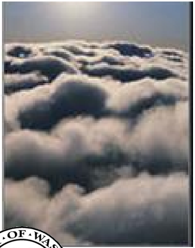


William Turner, “Study of Clouds”, about 1830
(Tate Gallery, London)

Motivation: Cloud entrainment

Isolated cumulous:
Entrainment throughout the cloud depth: from above, sides and at the base.
Effects of gravity vary

Stratocumulous:
Entrainment mainly from the top



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Field Data

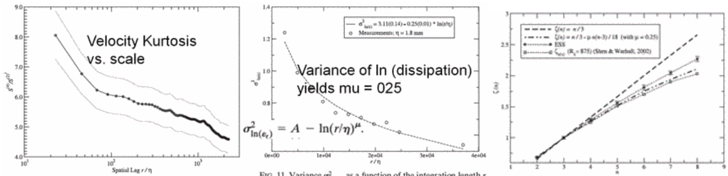

FIG. 10. Kurtosis function $K = S^{(4)}/(S^{(2)})^2$ as a function of the normalized lag r/η. The dotted lines indicate a ±10% range for the statistical sampling uncertainty (see text for more details).

FIG. 11. Variance $\sigma^2_{\ln(\epsilon_r)}$ as a function of the integration length r normalized with the Kolmogorov length $\eta \approx 1.8$ mm. An integral length scale of $L \approx 100$ m limits $r/\eta < L/\eta \approx 5 \times 10^4$. A logarithmic fit (dashed line) yields an intermittency exponent $\mu = 0.25$ with a standard error of 0.01.

FIG. 9. The scaling exponents $\zeta(n)'$ of the structure functions, as plotted via ESS theory in Fig. 8. Theoretical values for K41 and for K62 with an intermittency factor of $\mu = 0.25$ are shown for reference, together with data derived from wind-tunnel experiments by

All turbulence measurements in a stratocumulous are consistent with laboratory experiments

(data from Siebert at al., 2009)

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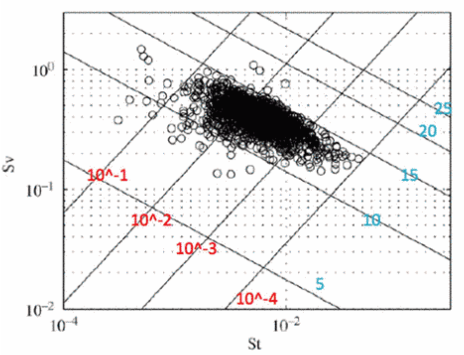
Field Data

Small Cumulous

Settling parameter vs. Stokes number



Upward diagonals:
dissipation rate [m^2/s^3]
Downward diagonals:

droplet diameters [μm]

N.B: these are averaged values

$$Sv = \frac{\nu_t}{\nu_\eta} = \frac{St}{Fr}, \quad St \approx d^2\varepsilon^{1/2} \text{ and } Sv \approx d^2\varepsilon^{-1/4}$$

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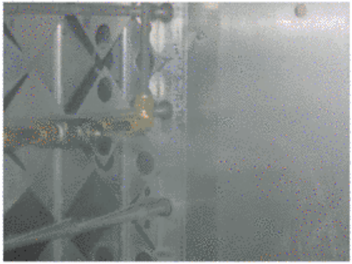
Laboratory experiments

Settling particle velocity enhancement/reduction in turbulence with gravity

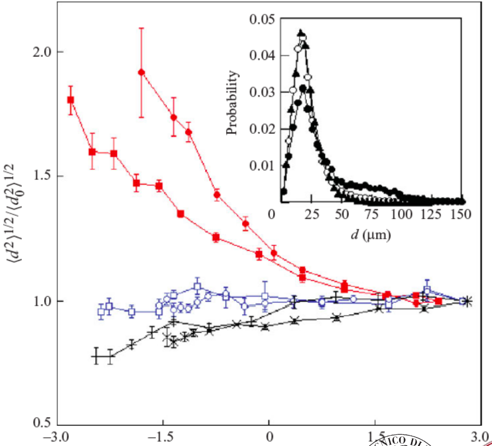


Alesida et al, JFM 468 (2002)
Davila - Hunt, JFM 440 (2001)
Kawanasi-Shiozaki, J.Hydr.Eng. 134 (2008)
Lazaro-Lasheras, Phys.Fluids 1 (1989)
Murray JGR 75 (1970)
Nielsen, J.Sed.Petr. 35 (1993)
Tooby et al, JGR 82 (1977)
Wang - Maxey JFM 256 (1993)
...

Acceleration of inertial particles: Bodenschatz, Xu, Mordant, Ayyalasomayajula, Qureshi, ...

Clustering: Shaw, collins, Bec, Vassilicos, Hunt

Particle diameter effect



Red : g+

Blue : g_0

Black : g-

Squares: TT interface,

Circles: TN interface

Inset: particle size distribution

No gravity ⇒ small & large particles transported the same way

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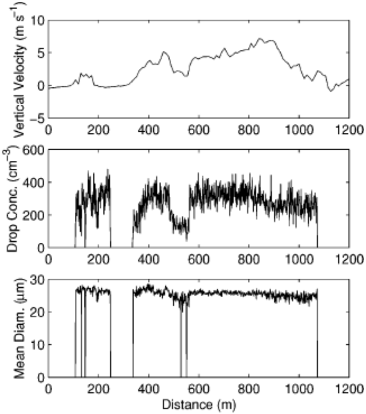
Shear



from Shaw, ARFM 35 (2003)

Real clouds:
sharp interfaces
and shear

Shear is important!

What can simulations tell

http://www.polito.it/philofluid

Entrainment

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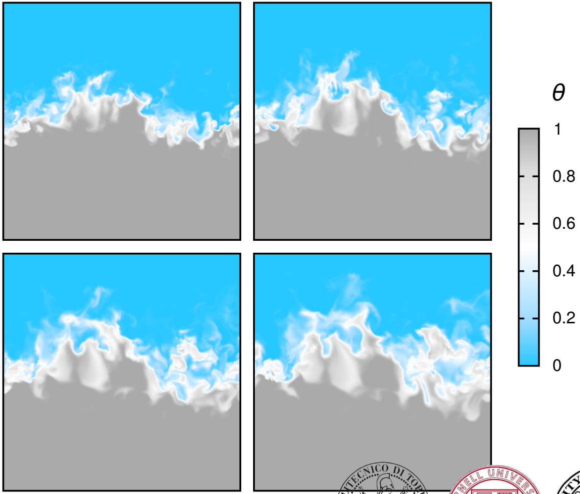
Entrainment -Interface



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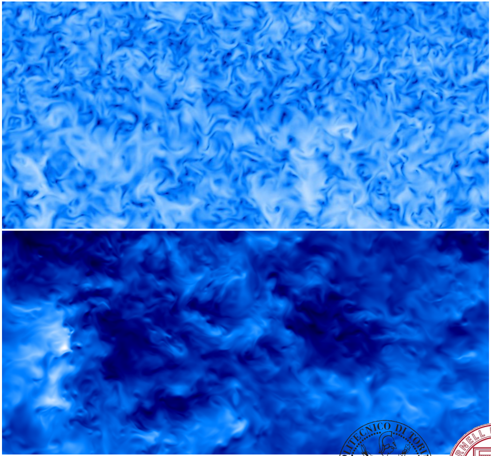
Entrainment

Energy/velocity field:



John Constable, "Study of Clouds", about 1820
(University of Oxford, Ashmolean museum)

Conclusions

- gravity is very important in droplet distribution
- mixing is affected by large scales
- we are beginning to understand the mechanics of entrainment, *but* need to know more about:
  – evaporation
  – shear
  – convection
- rain making must understand droplet distribution *and* how it changes with time
- global warming $\Leftrightarrow$ droplet size distribution (absorbtion/reflection of light)

Interdisciplinary holistic approach is necessary!