



Some examples of the use of LES to develop parametrizations at the Met Office

Adrian Lock plus many colleagues



What is LES?

- High resolution (<50m) 3D atmospheric model
- Aims to resolve the turbulent eddies responsible for the bulk of the transport
 - the subgrid turbulence parametrization only dissipates energy locally
 - If LES is well-resolved, this should be reliable



Parametrization development strategy

- Use LES to
 - understand key processes
 - test sensitivity to individual parameters
 - use detailed diagnostics from LES to evaluate single column models
 - develop and quantify empirical relationships
- Important to know how far to trust the LES
 - Use model intercomparisons and comparison with observations (eg GCSS)



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Example 1

To investigate moisture sensitivity of cumulus convection



Moisture sensitivity of cumulus convection

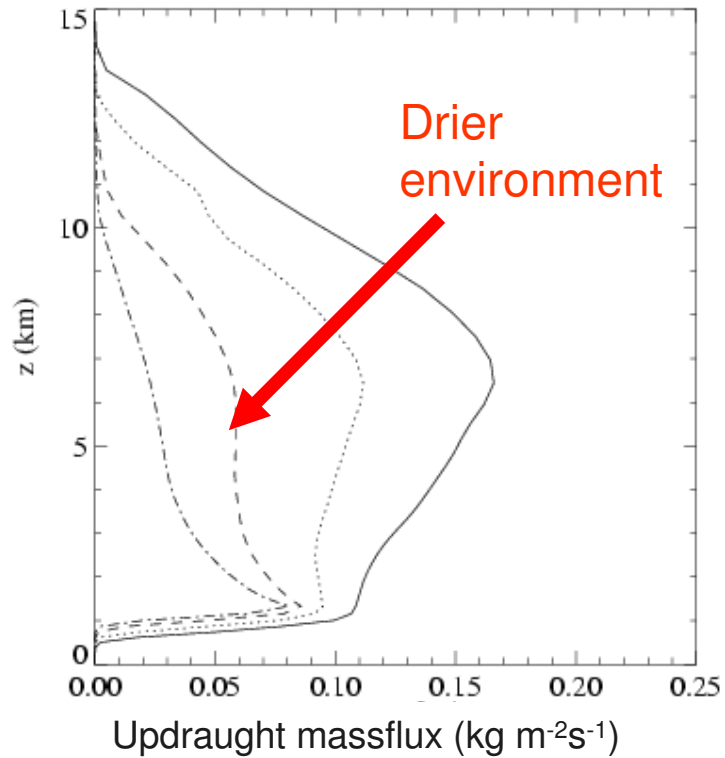
EUROCS, Derbyshire et al (2004)

- Plenty of circumstantial evidence for a dependence but poorly quantified
- Important to be well modelled by a parametrization
- Idealized CRM/SCM comparison
 - Forcing specified as relaxation of horizontal mean to target profiles (U , T , q)
 - 4 separate simulations with different target humidities
 - Run to quasi-equilibrium

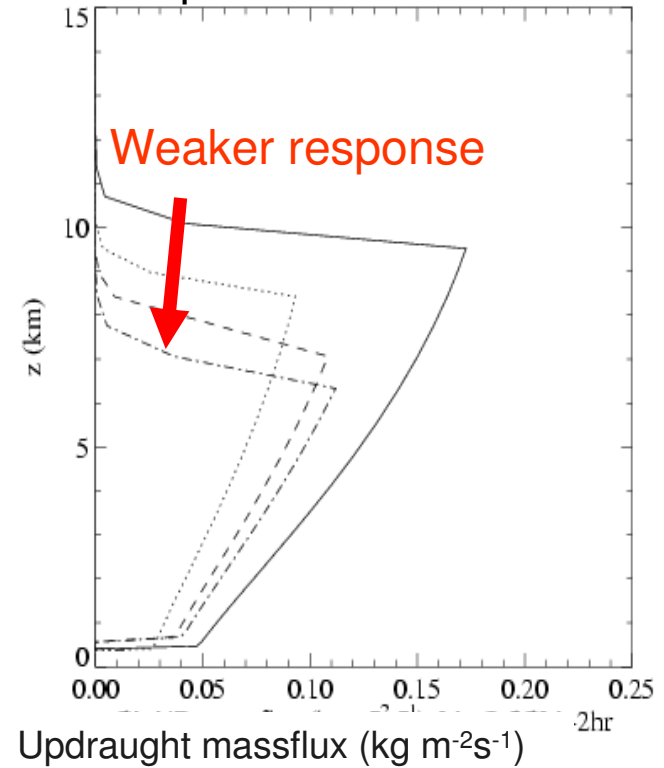


Sensitivity to free-tropospheric moisture (relative humidities 25%, 50%, 70%, 90%; $z > 2\text{km}$)

Similar vertical mass transports from two CRM



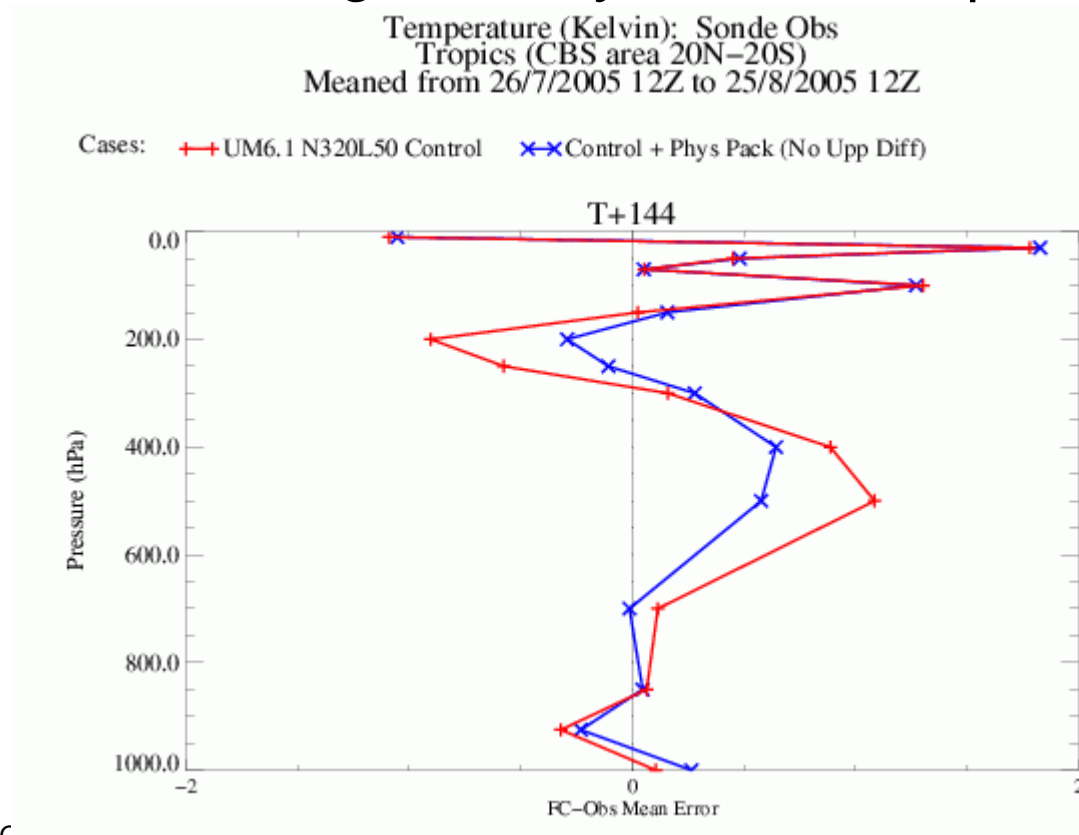
SCM using a plume-based cumulus parametrization





Impact of adaptive detrainment

- This evidence inspired changes to the Met Office massflux scheme (Maidens, Derbyshire)
- Implementation significantly reduced tropical T biases:





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Example 2

Identify scaling parameters for shallow cumulus

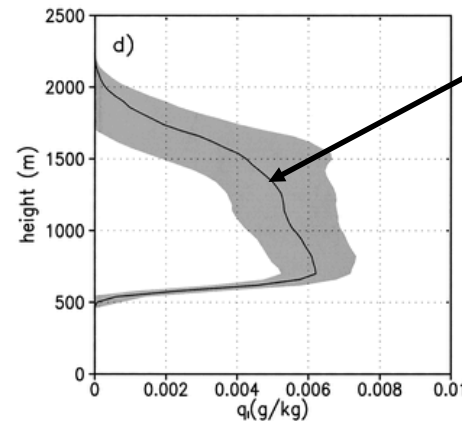
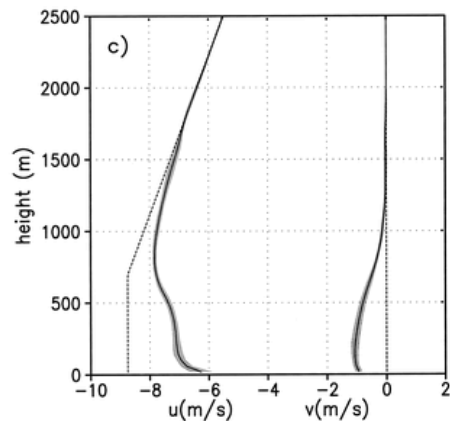
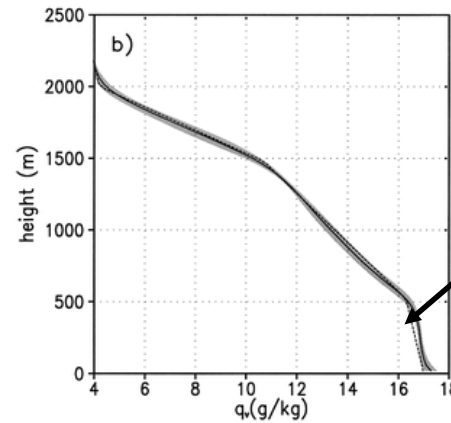
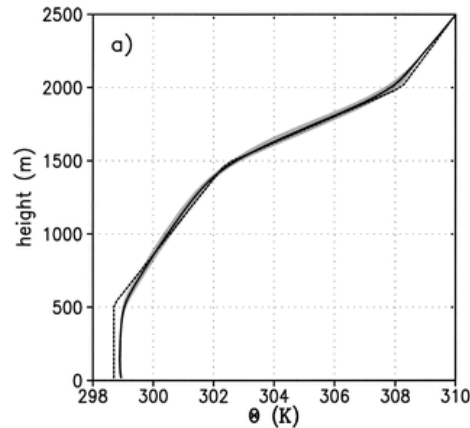


Scaling parameters for shallow cumulus

Grant, Brown and Lock

Trust LEM in this regime

- GCSS observations-based case study (Siebesma et al, 2003)
- Excellent agreement between 10 different LEM





Scaling parameters for shallow cumulus

Grant, Brown and Lock

- Trust LEM in this regime
 - GCSS observations-based case study (Siebesma et al, 2003)
 - Excellent agreement between 10 different LEM
- Explore parameter space
 - Vary forcing and initial profiles
- Use physical and dimensional arguments to scale important aspects of the cloud transports
 - Eg. TKE (turbulence kinetic energy) budget



Scaling parameters for shallow cumulus

Grant, Brown and Lock

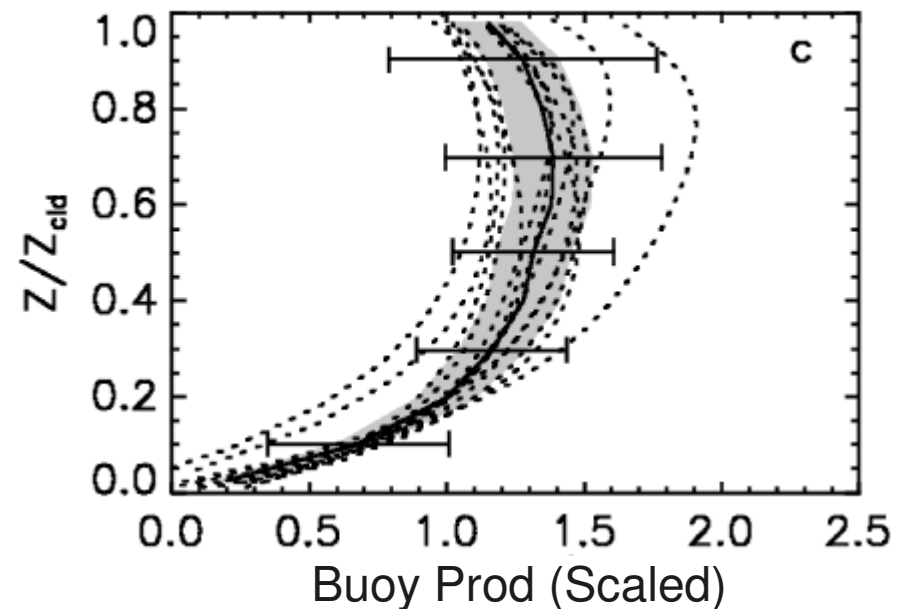
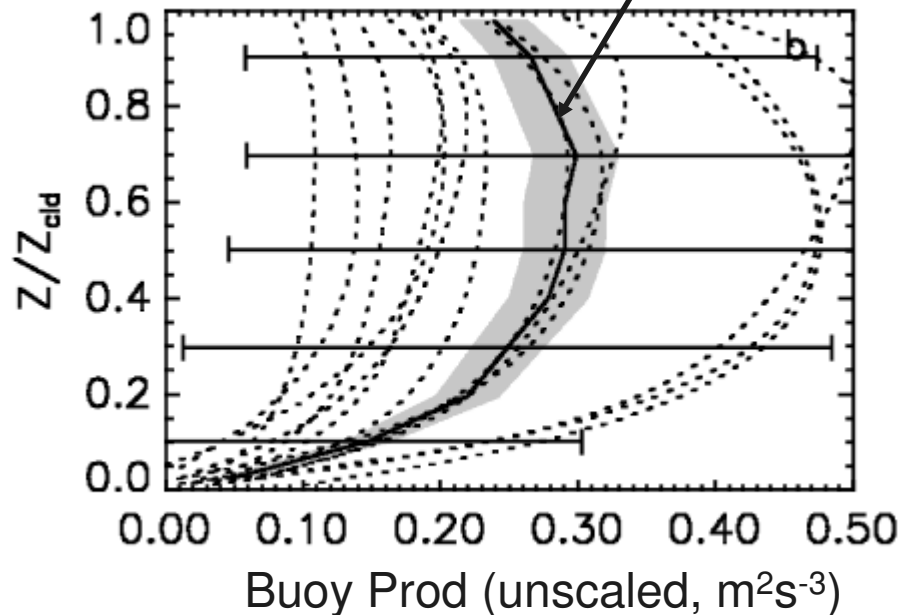
- Simulations demonstrate a large variation in buoyancy production of TKE
- Most of this variance can be explained by a dimensional combination of key parameters

- Surface fluxes, CAPE, layer depths

■ Estimate of sampling error

↔ 2 Std deviations

Mean





Scaling parameters for shallow cumulus

Grant, Brown and Lock

- Use this and similar scaling parameters to improve existing parametrizations...
 - Scale cumulus cloud cover, cloud-base massflux and entrainment rate in Met Office UM shallow cumulus massflux scheme
 - Scale cumulus cloud cover, buoyancy production and non-gradient flux terms in a “1.5 order” closure (Lock and Mailhot, 2006)
- ...and currently developing a new “turbulence-based” scheme for cumulus convection



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Example 3

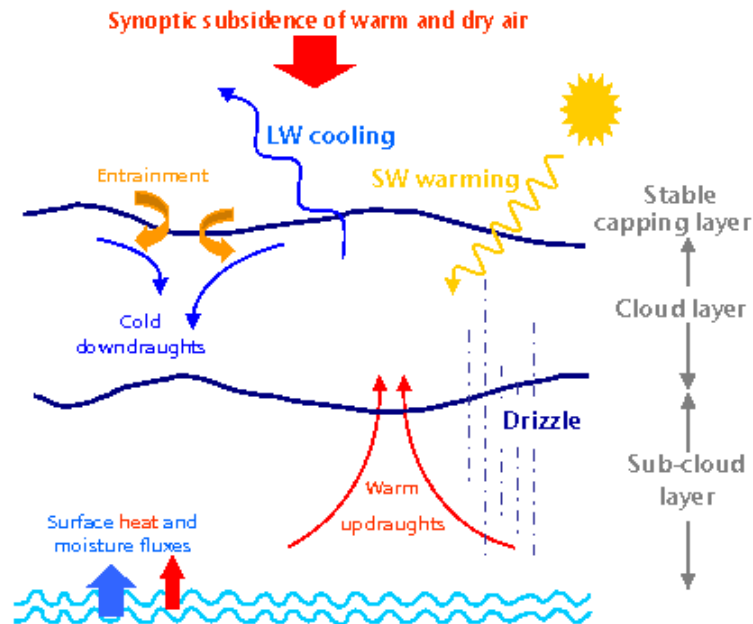
Parametrization of cloud-top entrainment in stratocumulus



Stratocumulus intercomparisons

- Stratocumulus was the first cloud type examined by the GCSS Boundary Layer Cloud working group:
 - 1994: NE Pacific stratocumulus, based on FIRE I
 - Moeng et al (1996)
 - Large spread in results
 - Leading order problems with saturation mixing ratio calculation, radiative transfer
- Back to the drawing board!
 - 1995: Smoke cloud, ~ lab experiment
 - Bretherton et al (1999)
 - Much better agreement between LES
 - Quantified minimal resolution needed to believe LES entrainment rate
 - Spawned several extensive studies of parameter space (van Zanten et al 1999, Moeng et al 1999, Lock and MacVean 1999, Lock 1998)

Factors controlling entrainment



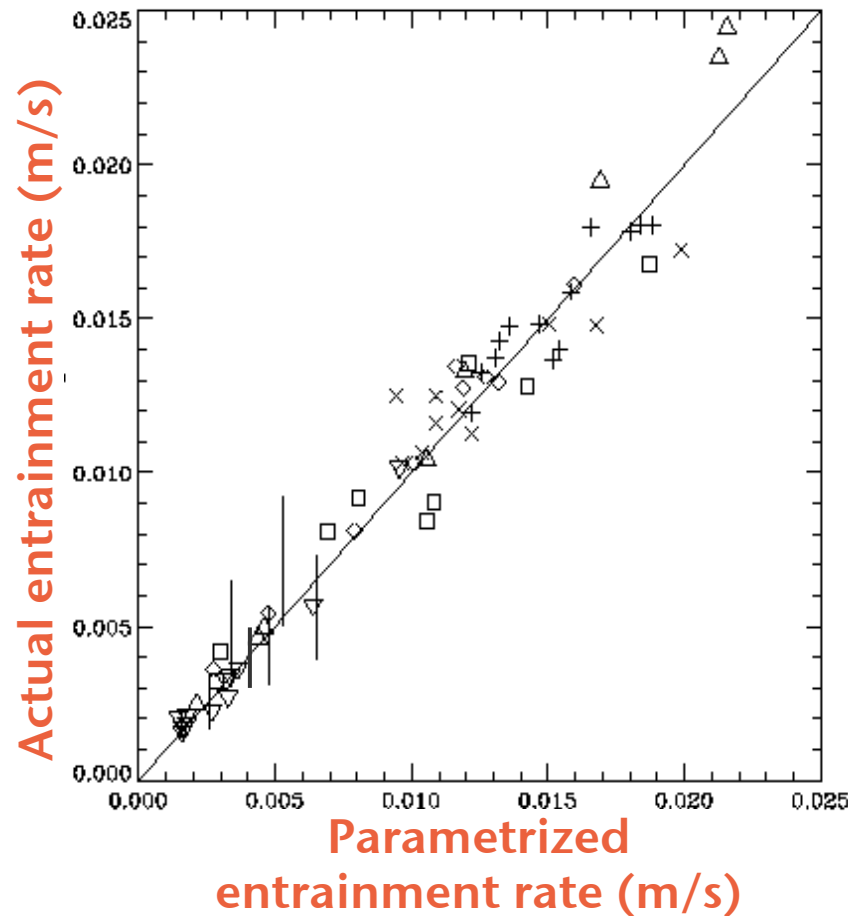
- Surface buoyancy flux
- Differential radiative cooling between top and interior of cloud
- Evaporative cooling at cloud top
- Shear
- Inversion strength

Perform specially designed series of LES to investigate parameter dependence:

- dry boundary layers with varying surface flux and shear
- smoke clouds with varying radiation
- water clouds with varying inversion jumps in T and q



Comparison of Lock (1998) entrainment parametrization with LES and observations



LES

Cloud free:

Δ = surface heated

Smoke clouds:

∇ = radiatively cooled

\square = surf heat + rad cool

Water clouds:

\times = rad cool (no b.r.)

$+$ = rad cool + buoy rev

\diamond = buoyancy reversal only

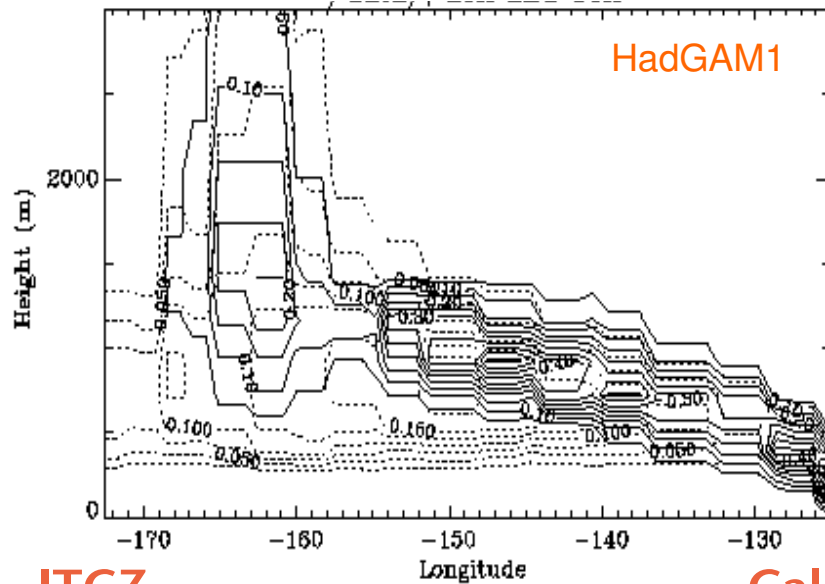
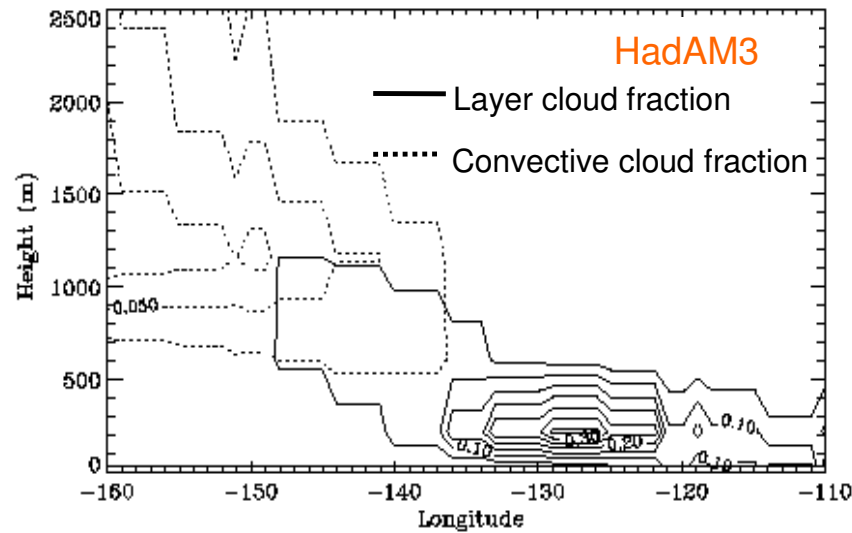
Observations

$|$ = Nicholls & Leighton, 1986;
Price, 1999; Stevens et al 2003



Met Office GCM cloud fractions

EUROCS cross-section – 1998 JJA mean



- HadGAM1 has a more realistic boundary layer structure
 - Eg. Riehl et al (1951) schematic based on weather ship observations:

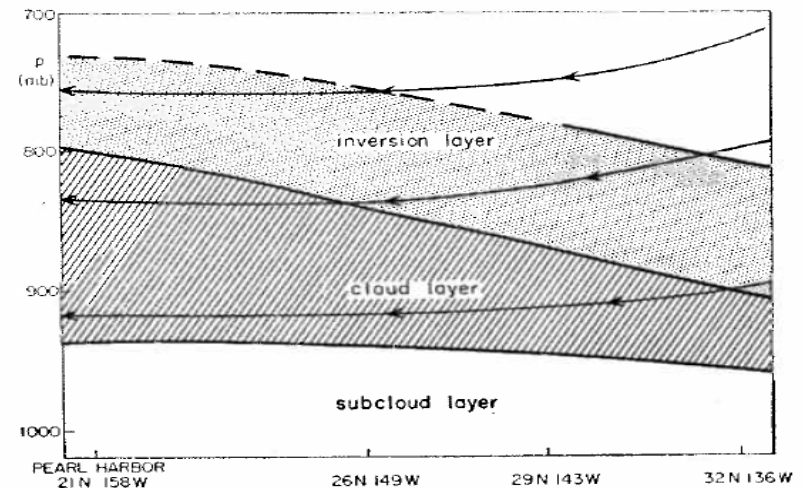


Figure 8. Illustrating the four layers of the trade-wind zone in relation to sample air trajectories.



Caveat to example 3!

Problems with using LES to derive parametrizations of cloud-top entrainment in stratocumulus



Constraining LES of stratocumulus

- Can you believe an entrainment rate derived from LES?
- One of the aims of DYCOMS II (2001) was to constrain LES
 - Lagrangian experiment (so no uncertain horizontal advection forcing needed)
 - Nocturnal, non-precipitating (so simple)
 - Observations ~steady for 6 hours
 - 5 independent measures of the entrainment rate

Stevens et al (2003):

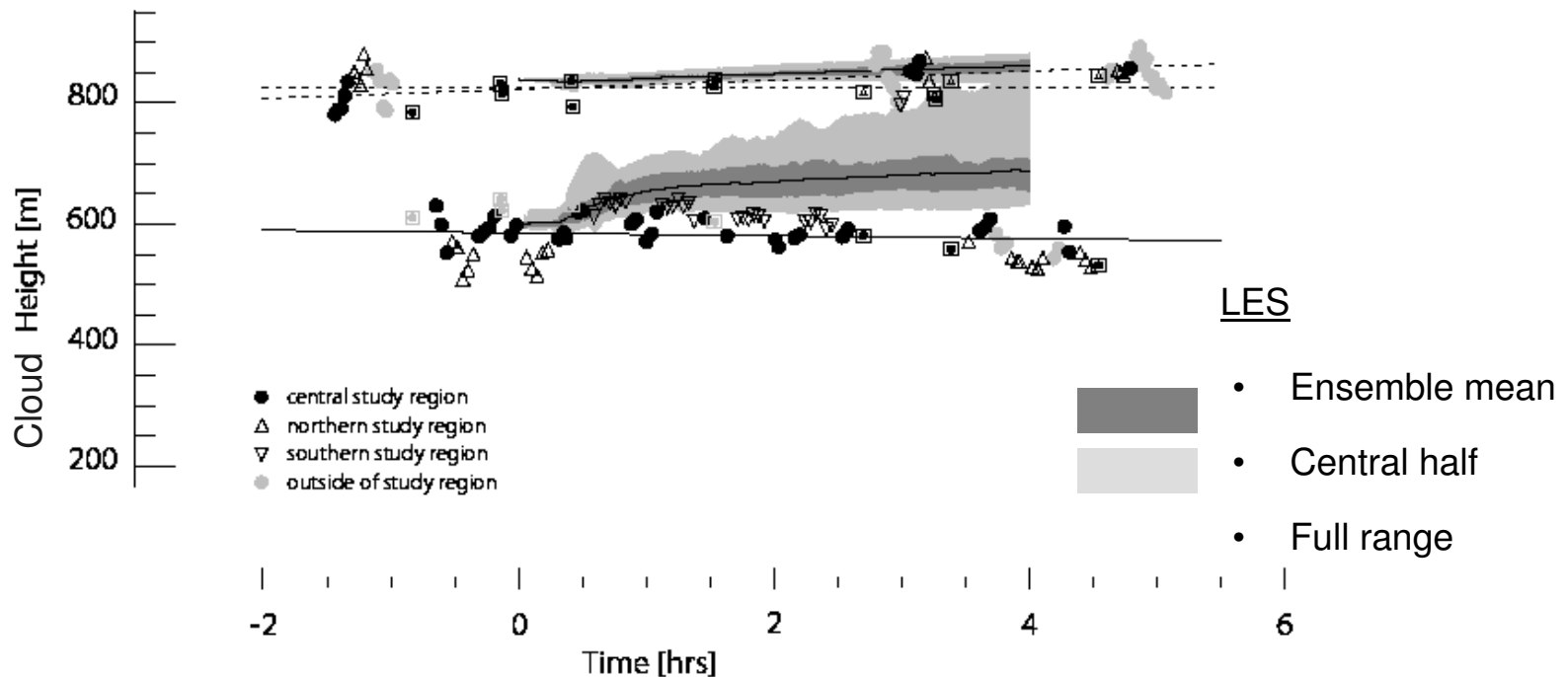
Table 2. ENTRAINMENT VELOCITY ESTIMATES

Method	Estimate [cm s^{-1}]
q_t budget	0.31 ± 0.08
s_l budget	0.47 ± 0.08
q_t cloud-top flux	0.39 ± 0.07
O_3 cloud-top flux	0.27 ± 0.09
DMS cloud-top flux	0.48 ± 0.11
Weighted Average	0.38 ± 0.04

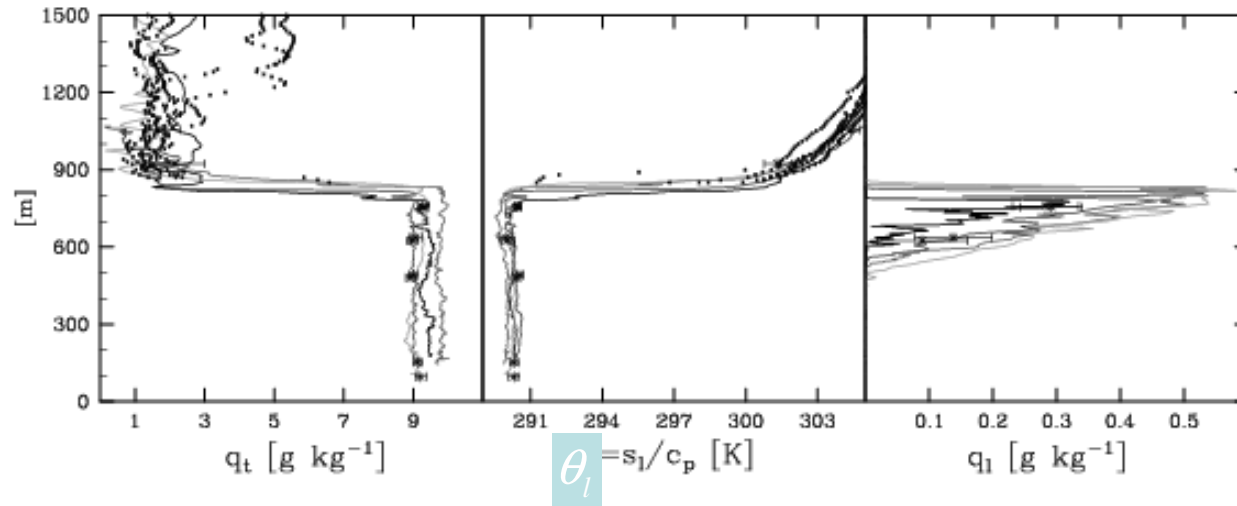


LES intercomparison results

- GCSS BL cloud working group case: DYCOMS II, flight RF01
- General excessive drying of cloud layer by most LES
 - Entrained air is very dry so overestimate of entrainment leads to excessive cloud evaporation and so rise in cloud base
 - Can't blame “uncertain forcing” because there is none!



Observed profiles from RF01



Stevens et al
(QJ,2003)

- Inversions capping typical stratocumulus clouds are very strong and sharp, making accurate modelling by LES very hard
 - Bretherton et al (1999) estimate of required resolution $\sim 3\text{m}$ for RF01
- So, *LES-derived entrainment rates should be treated with caution*
- Several groups exploring LES with grids $< 1\text{m}$
 - Increases issues of representation of droplet evaporation and mixing

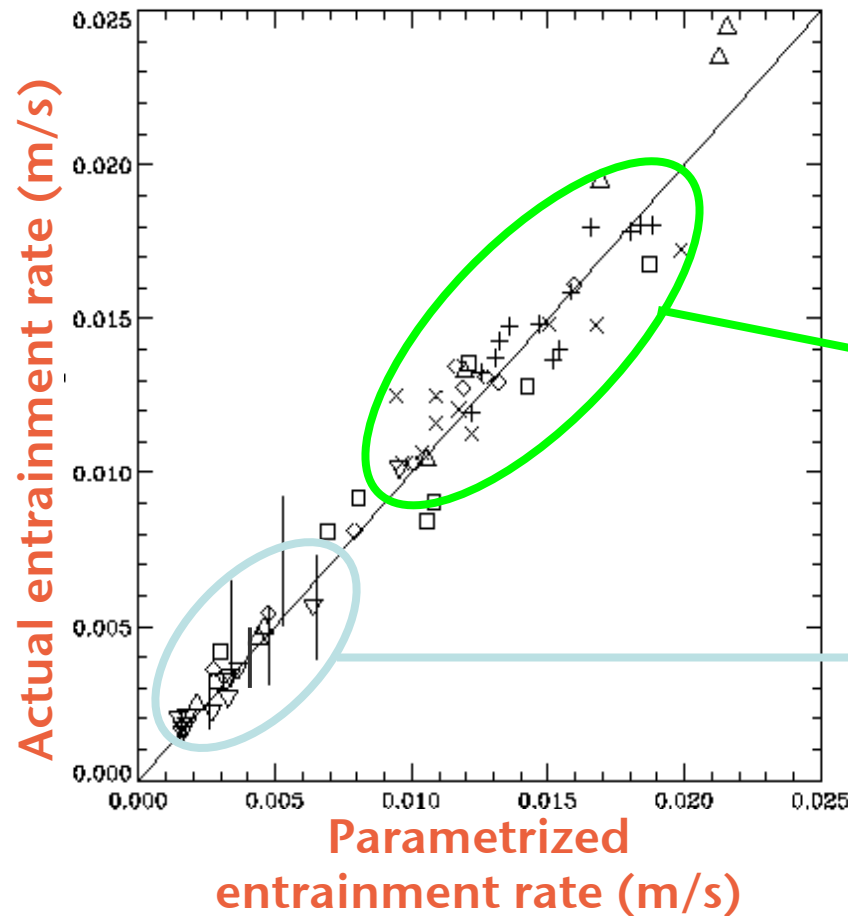


How do LES-derived entrainment parametrizations compare?

- Stevens (2002) compared entrainment parametrizations in the literature, some derived from LES, some from observations
- Very significant variability
- Lock (1998) was ~2 times weaker than the others
- Maximum inversion strength in Lock (1998) was only 2K
 - Completely unrealistic (eg. RF01 ~ 10K)
 - But resolution required ~ 15m, according to Bretherton et al (1999)
 - So numerically robust



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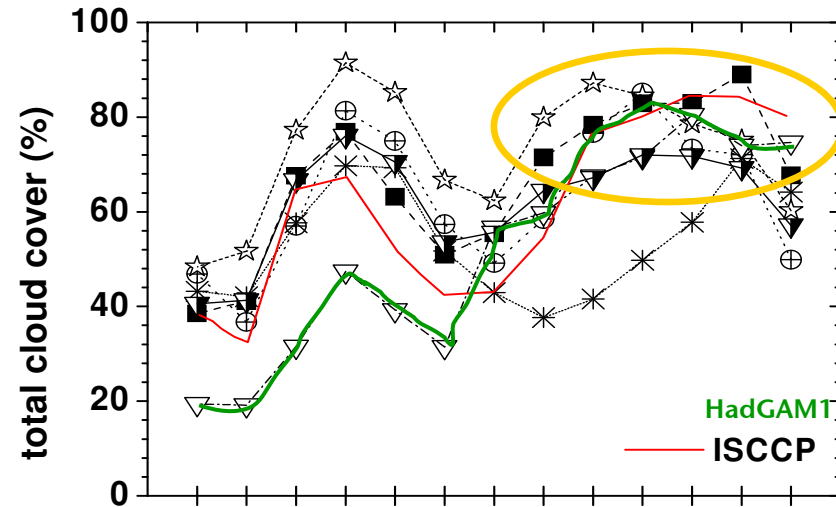
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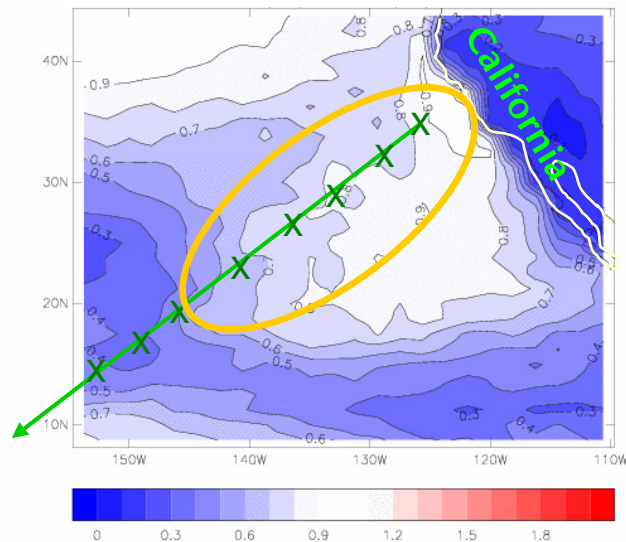
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GCM stratocumulus representation (EUROCS, Siebesma et al 2004)

- GCMs, data from JJA 1998
- Cross-section from California to central Pacific
- HadGAM1 stratocumulus quite good
- Sensitivity tests to the entrainment rate parametrization tend to show detriment

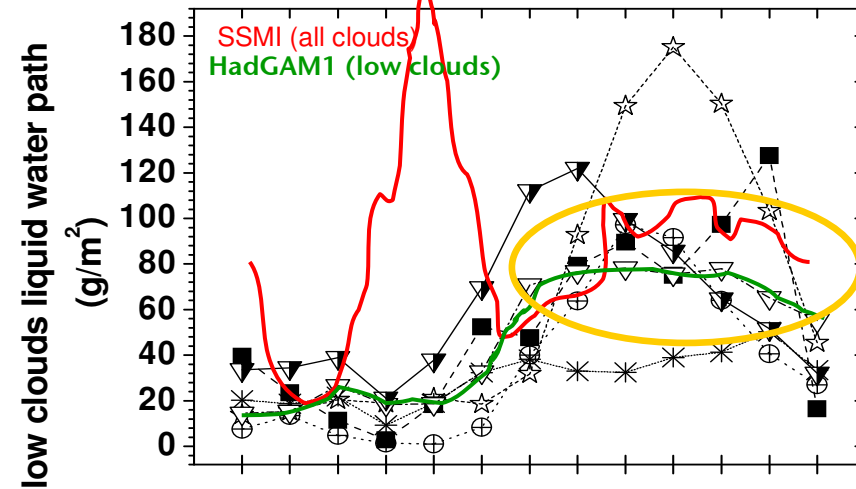


HadGAM1 total cloud cover



Central Pacific

California





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Summary

- LES models have played a crucial role in developing parametrizations for NWP and climate models at the Met Office
- They provide:
 - Ability to explore parameter space
 - Detailed diagnostics for evaluating parametrization performance
 - Interpretation of in-situ (fine scale) observations
- To support parametrization progress, LES need to be:
 - Better than current SCMs (but not necessarily perfect!)
 - Validated against observations
- Need to allow for LES limitations in experimental design or when quantifying confidence in results
- Experience with LES in research mode directly informs the next generation of operational forecast models (e.g. 1.5km resolution UK)



GCSS BL Clouds Current activities

Stratocu-Cu transitions

- Stratocu-Cu transition cases
 - Just released (June)
 - Two separate tracks:
 - 1st ASTEX Lagrangian: “standard” intercomparison against aircraft observations – **Stephan de Roode**
 - Composite cases, based on trajectories, reanalysis and satellite data – **Irina Sandu**
 - 3 transition simulations: median, slow and fast
 - Can the same LES/SCM represent not just a single case in detail (ASTEX) but also the observed variability?
 - First workshop in September at EUCLIPSE meeting
 - See <http://appconv.metoffice.com/blclouds> for details



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Questions

Thank you