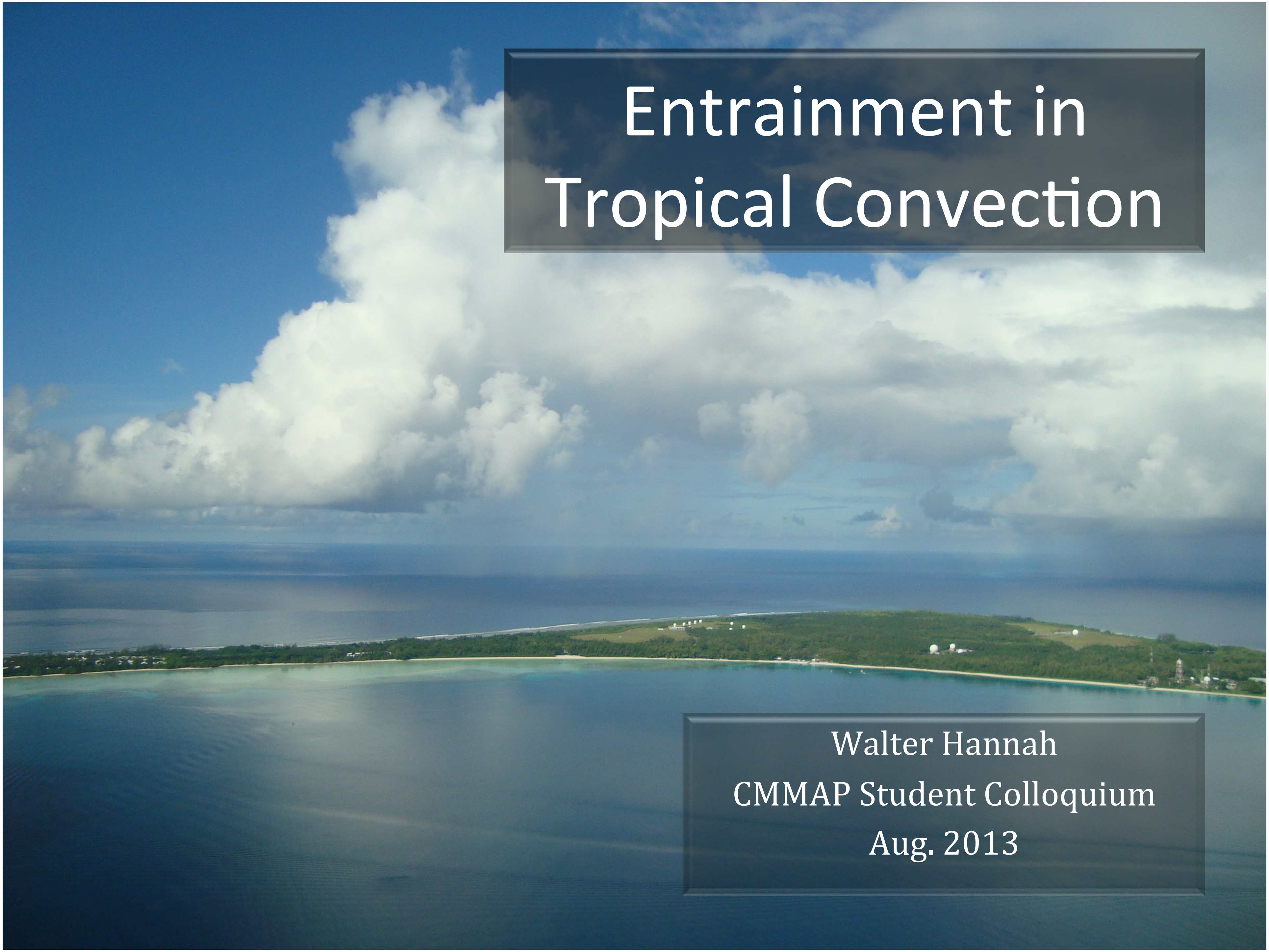
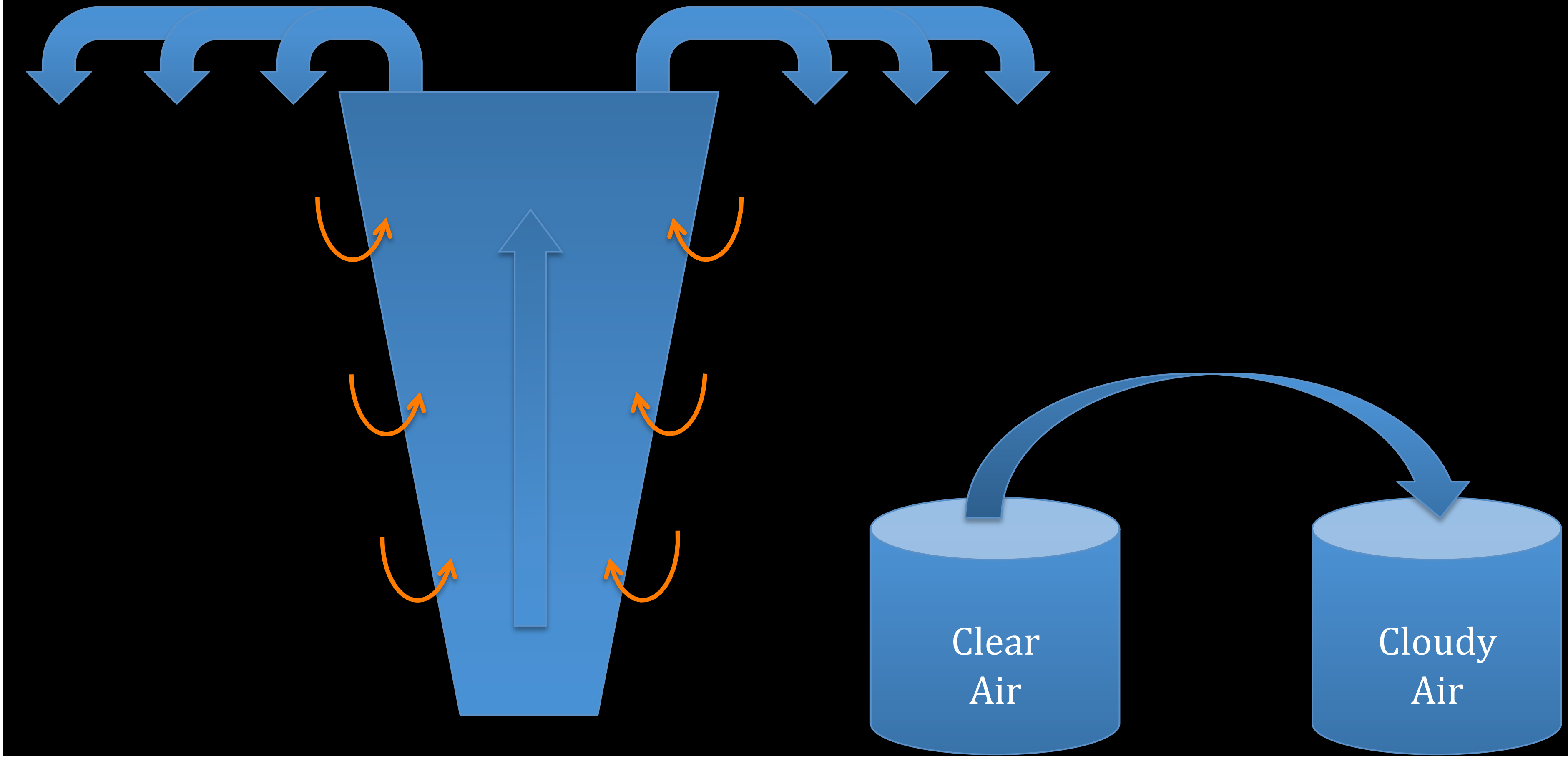


Entrainment in Tropical Convection

Walter Hannah
CMMAP Student Colloquium
Aug. 2013

Entrainment

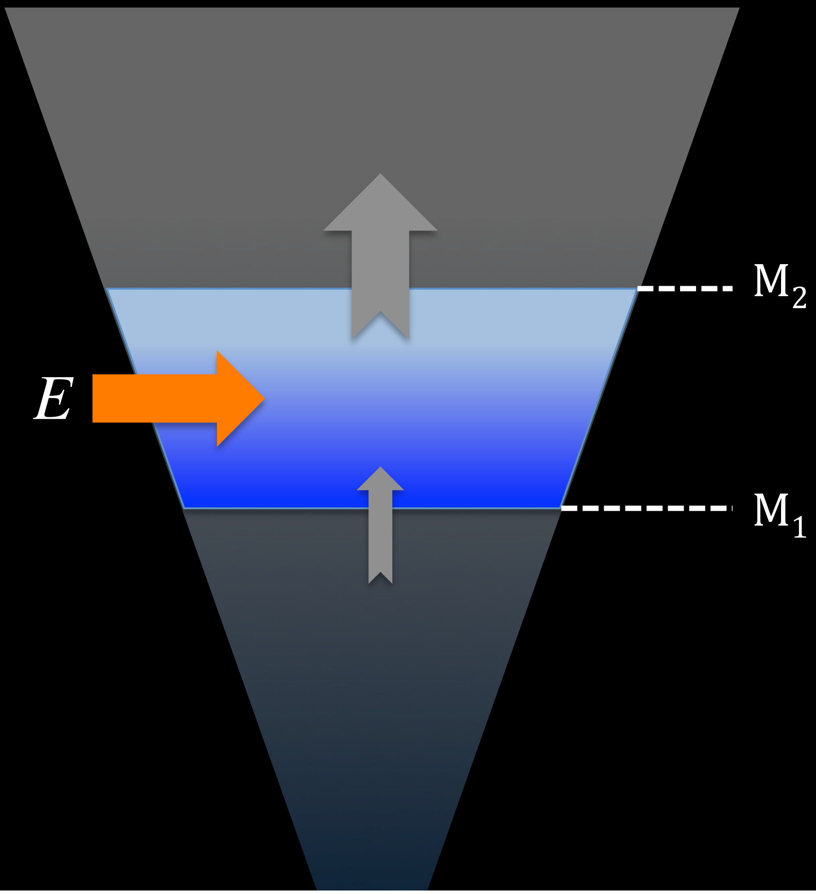
en•train (*v.)* – to transform "non-cloudy" air into "cloudy" air



Entrainment

For the simplest plume model, ignoring detrainment, the change in mass flux with height can be used to define entrainment

Total Entrainment	$E = \frac{dM}{dz}$
Fractional Entrainment	$\varepsilon = \frac{1}{M}\frac{dM}{dz}$



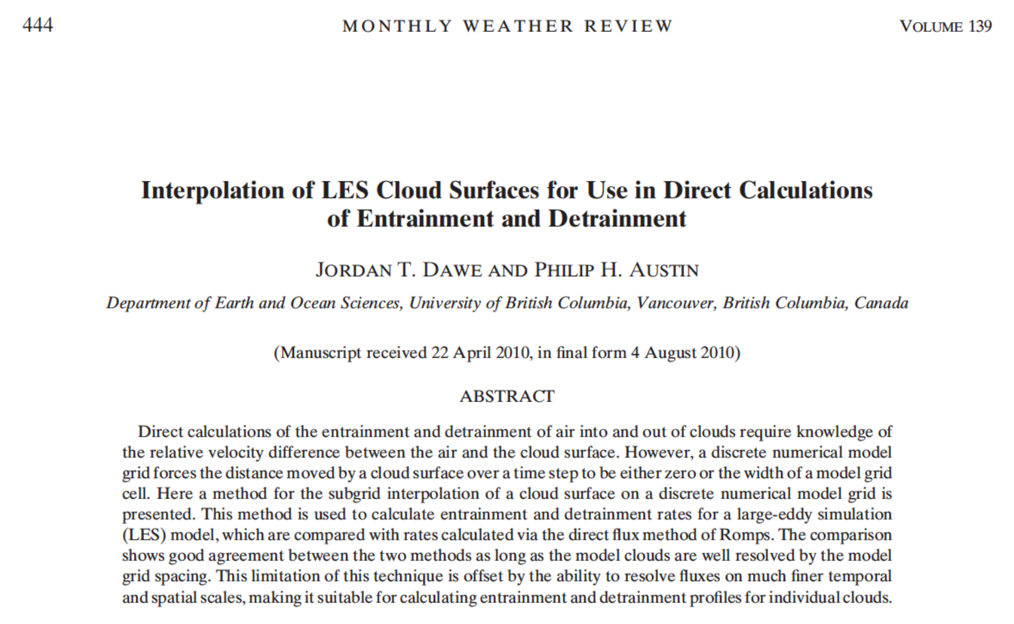
Direct Measurement

There are many methods to estimate E or ε in observations and cloud resolving models

A new method that directly measures entrainment in high resolution models has been introduced:

J. Dawes and P. Austin (2011)

D. Romps (2010)



Interpolation of LES Cloud Surfaces for Use in Direct Calculations of Entrainment and Detrainment

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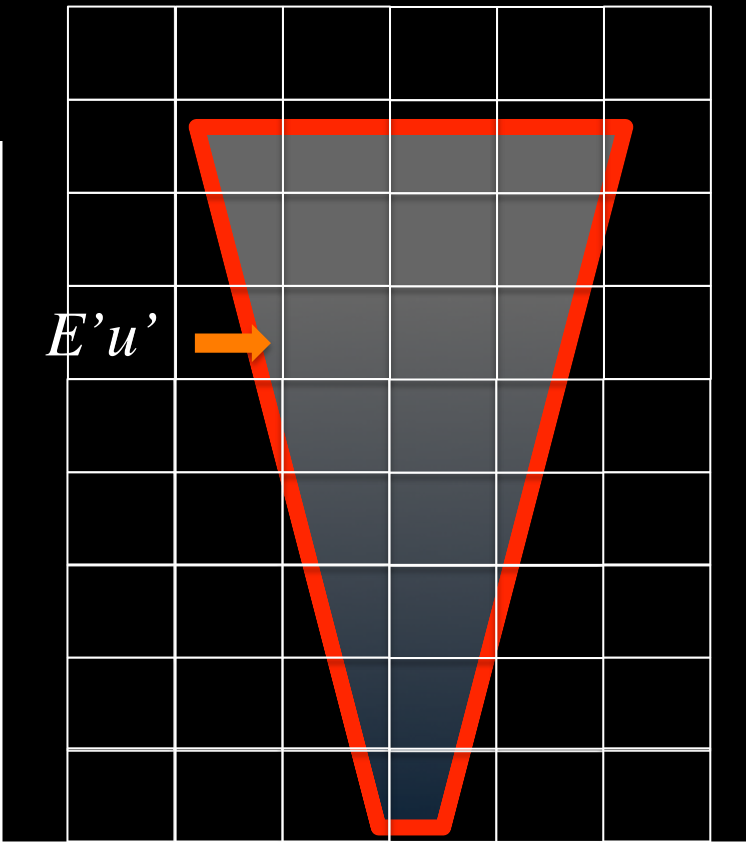
Department of Earth and Ocean Sciences, University of British Columbia, Vancouver, British Columbia, Canada

(Manuscript received 22 April 2010, in final form 4 August 2010)

ABSTRACT

Direct calculations of the entrainment and detrainment of air into and out of clouds require knowledge of the relative velocity difference between the air and the cloud surface. However, a discrete numerical model grid forces the distance moved by a cloud surface over a time step to be either zero or the width of a model grid cell. Here a method for the subgrid interpolation of a cloud surface on a discrete numerical model grid is presented. This method is used to calculate entrainment and detrainment rates for a large-eddy simulation (LES) model, which are compared with rates calculated via the direct flux method of Romps. The comparison shows good agreement between the two methods as long as the model clouds are well resolved by the model grid spacing. This limitation of this technique is offset by the ability to resolve fluxes on much finer temporal and spatial scales, making it suitable for calculating entrainment and detrainment profiles for individual clouds.



Experiment

Using this new method we would like to find out more about entrainment to guide future convective scheme development

So let’s try to answer a few questions:

- Is entrainment fundamentally different in organized convection?
  (Mapes and Neale 2011)
  - How does shear affect entrainment?
- Does environmental humidity cause less fractional entrainment?
  (Bechtold et al. 2008)

J. Adv. Model. Earth Syst., **Vol. 3**, Art. M06004, 20 pp.

JAMES
JOURNAL OF ADVANCES IN MODELING EARTH SYSTEMS

Parameterizing Convective Organization to Escape the Entrainment Dilemma

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Revised, JAMES February 2011

Lateral mixing parameters in buoyancy-driven deep convection schemes are among the most sensitive and important unknowns in atmosphere models. Unfortunately, there is not a true optimum value for plume mixing rate, but rather a dilemma or tradeoff: Excessive dilution of updrafts leads to unstable stratification bias in the mean state, while inadequate dilution allows deep convection to occur too easily, causing poor space and time distributions and variability. In this too-small parameter space, compromises are made based on competing metrics of model performance. We attempt to escape this “entrainment dilemma” by making bulk plume parameters (chiefly entrainment rate) depend on a new prognostic variable (“organization,” *org*) meant to reflect the rectified effects of subgrid-scale structure in meteorological fields. We test an *org* scheme in the Community Atmosphere Model (CAM5) with a new unified shallow-deep convection scheme (UW-ens, a 2-plume version of the University of Washington scheme). Since buoyant ascent involves natural selection, subgrid structure makes convection systematically deeper and stronger than the pure unorganized case: plumes of average (or randomly sampled) air rising in the average environment. To reflect this, *org* is nonnegative, but we leave it dimensionless. A time scale characterizes its behavior (here ~3 h for a 2° model). Currently its source is rain evaporation, but other sources can be added easily. We also let *org* be horizontally transported by advection, as a mass-weighted mean over the convecting layer. Linear

mth above the mean
ability of overlap in a
been implemented in
as a time-lagged but
dilemma, since fully
while the pioneering
scale variability.

DOI:10.1029/2011MS000042

ıass flux is used to compute a
es in the large-scale governing
ume model is a sturdy classic.
based on Bretherton et al. 2004)
d detrainment of an assumed
on buoyancy sorting principles,
n for the plume core which can
l activation processes.
model is sometimes called a
t represents the bulk or aggreg-
nble of convective elements or

be addressed.
Marine and Atmospheric Sciences
Rickenbacker Causeway, Miami, FL

QUARTERLY JOURNAL OF THE ROYAL METEOROLOGICAL SOCIETY
Q. J. R. Meteorol. Soc. **134**: 1337–1351 (2008)
Published online in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/qj.289

RMetS
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Advances in simulating atmospheric variability with the ECMWF model: From synoptic to decadal time-scales

Peter Bechtold,* Martin Köhler, Thomas Jung, Francisco Doblas-Reyes, Martin Leutbecher, Mark J. Rodwell, Frederic Vitart and Gianpaolo Balsamo
European Centre for Medium-Range Weather Forecasts, Reading, UK

ABSTRACT: Advances in simulating atmospheric variability with the ECMWF model are presented that stem from revisions of the convection and diffusion parametrizations. The revisions concern in particular the introduction of a variable convective adjustment time-scale, a convective entrainment rate proportional to the environmental relative humidity, as well as free tropospheric diffusion coefficients for heat and momentum based on Monin–Obukhov functional dependencies.

The forecasting system is evaluated against analyses and observations using high-resolution medium-range deterministic and ensemble forecasts, monthly and seasonal integrations, and decadal integrations with coupled atmosphere-ocean models. The results show a significantly higher and more realistic level of model activity in terms of the amplitude of tropical and extratropical mesoscale, synoptic and planetary perturbations. Importantly, with the higher variability and reduced bias not only the probabilistic scores are improved, but also the midlatitude deterministic scores in the short and medium ranges. Furthermore, for the first time the model is able to represent a realistic spectrum of convectively coupled equatorial Kelvin and Rossby waves, and maintains a realistic amplitude of the Madden–Julian oscillation (MJO) during monthly forecasts. However, the propagation speed of the MJO is slower than observed. The higher tropical tropospheric wave activity also results in better stratospheric temperatures and winds through the deposition of momentum.

The partitioning between convective and resolved precipitation is unaffected by the model changes with roughly 62% of the total global precipitation being of the convective type. Finally, the changes in convection and diffusion parametrizations resulted in a larger spread of the ensemble forecasts, which allowed the amplitude of the initial perturbations in the ensemble prediction system to decrease by 30%. Copyright © 2008 Royal Meteorological Society

KEY WORDS atmospheric variability; model climate; tropical waves; convection; vertical diffusion; numerical weather prediction

Received 28 February 2008; Revised 16 June 2008; Accepted 18 June 2008

1. Introduction

Forecasting the state of the atmosphere involves the prediction of a slowly evolving mean equilibrium state (also referred to as the climate) and the temporal and spatial variations about this state. Predicting the amplitude and phase of the planetary, synoptic and mesoscale perturbations in a deterministic and ensemble prediction system (EPS) is a challenging task.

The main physical processes that lead to the generation of kinetic energy in the atmosphere are the differential radiative heating and the convective heating (Haimberger and Hantel, 2000; Steinheimer *et al.*, 2008). Latent heat release in deep convection excites among others equatorial Rossby, Kelvin and mixed Rossby-gravity waves. It has been demonstrated in numerous modelling studies (Slingo *et al.*, 1994; Scinocca and McFarlane, 2004; Lin *et al.*, 2008) that the simulation of these waves in global models is very sensitive to the type of convective parametrization employed. Typically in these studies the simulated tropical variability increases with increasing resolved precipitation at the expense of the parametrized precipitation. An inadequate representation of the convective forcing and the associated equatorial waves has numerous consequences as errors project on the wavenumber 1 and 2 Madden–Julian oscillation (MJO) as well as on the stratospheric meteorology like the quasi-biennial oscillation (QBO) since these waves propagate upward and interact with the mean flow (Ricciardulli and Garcia, 2000; Horinouchi *et al.*, 2003). These errors even affect midlatitude meteorology through interaction with the midlatitude Rossby waves. In contrast to convection parametrization schemes, explicit models of deep convection tend to excite a larger and more realistic spectrum of waves. However these models are very expensive numerically, and either still have problems in representing a good mean atmospheric state (Khairoutdinov *et al.*, 2005), or are mainly run on an aqua-planet (Nasumo *et al.*, 2007) or on limited domains (Shutts, 2007), and therefore are not applicable yet to global numerical weather prediction.

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E-mail: peter.bechtold@ecmwf.int

Experiment Setup

Δx = 500 m

72 km^2 domain

Initialized with tropical mean sounding

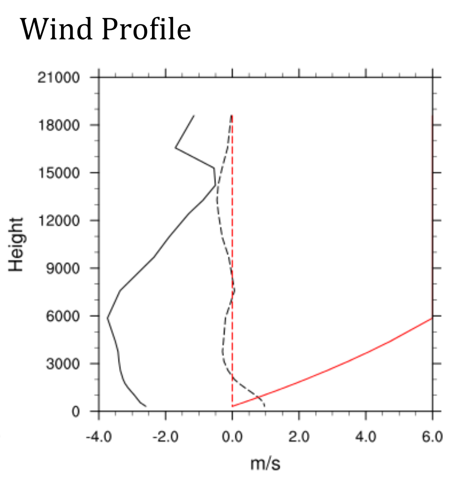
warm/wet bubble was also added:

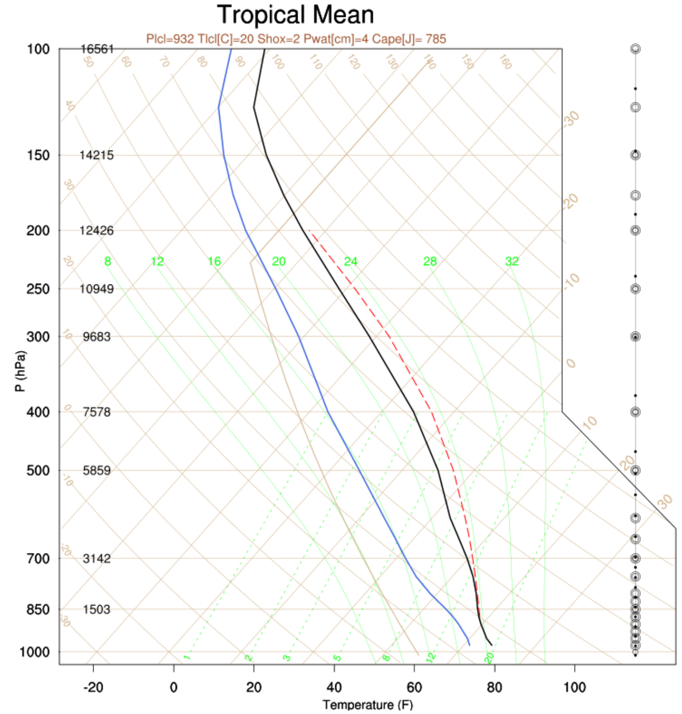
dT = 1 K

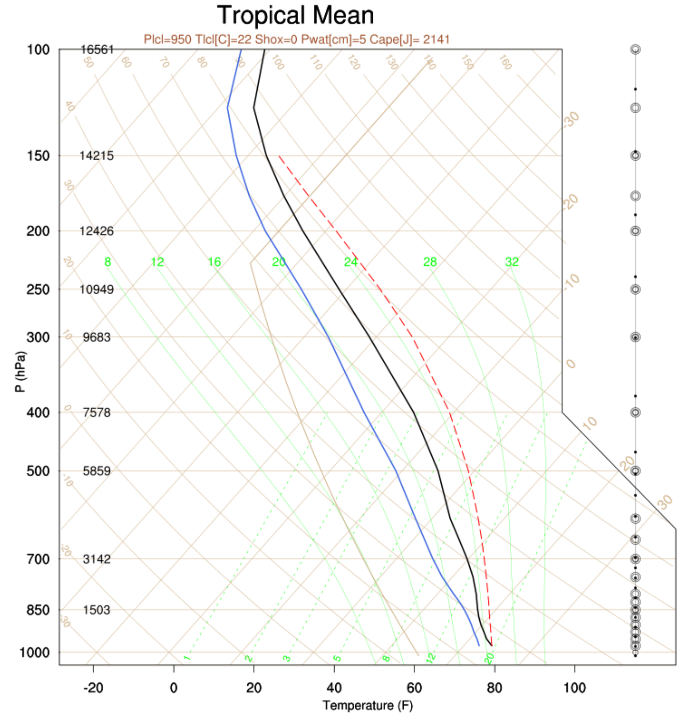
dq = 3 g/kg

X rad = 4 / 8 / 12 km

Z rad = 2 km


Wind Profile


Tropical Mean
Plcl=932 Tlcl[C]=20 Shox=2 Pwat[cm]=4 Cape[J]= 785

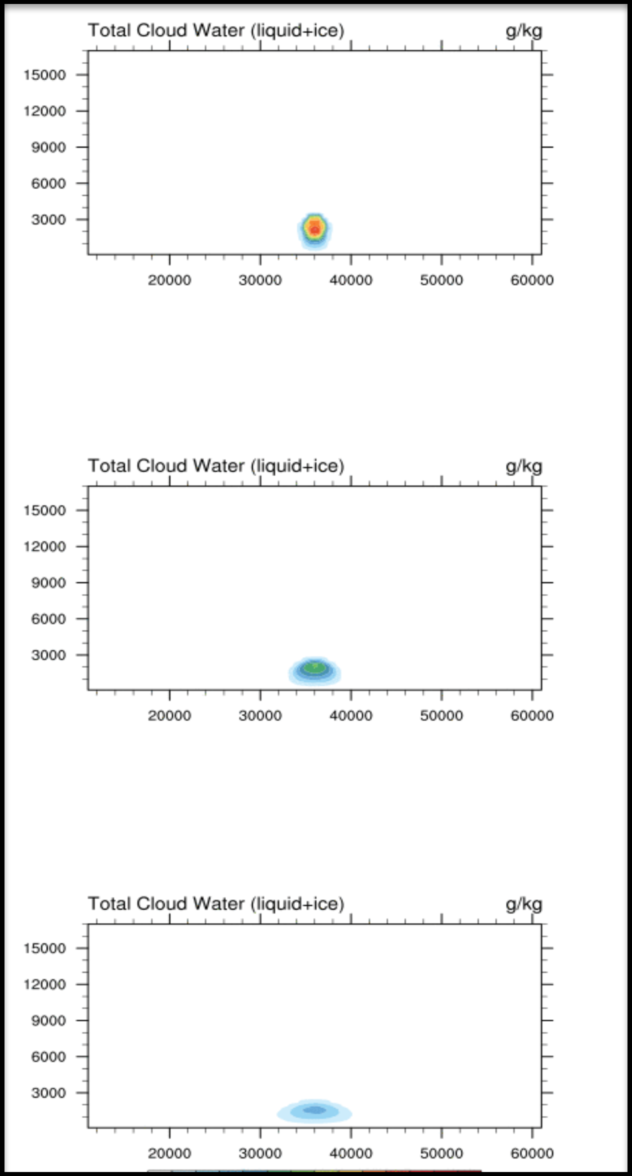

Tropical Mean
Plcl=950 Tlcl[C]=22 Shox=0 Pwat[cm]=5 Cape[J]= 2141

Initial Radius

4 km

8 km

12 km



Control

Higher Humidity

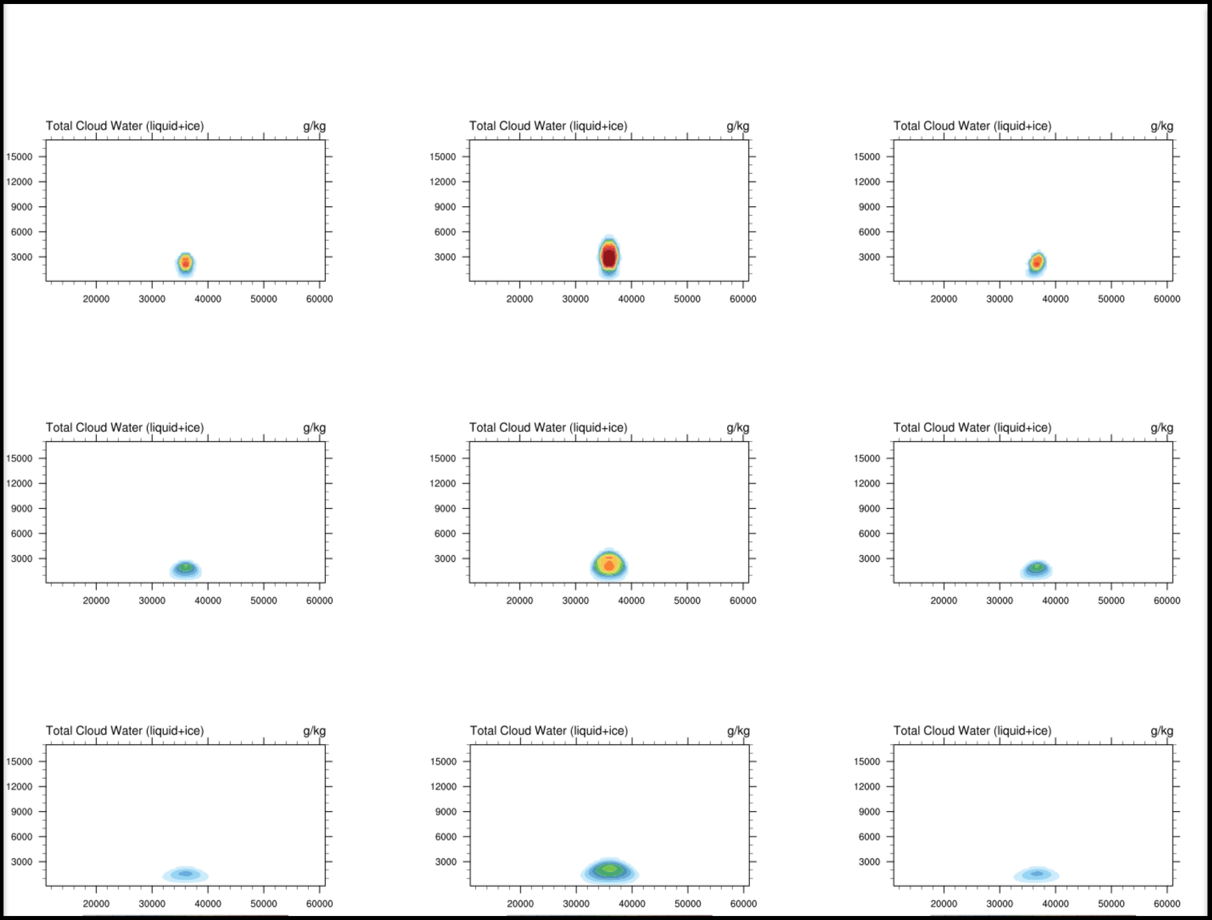
w/ Shear

Initial Radius

4 km

8 km

12 km



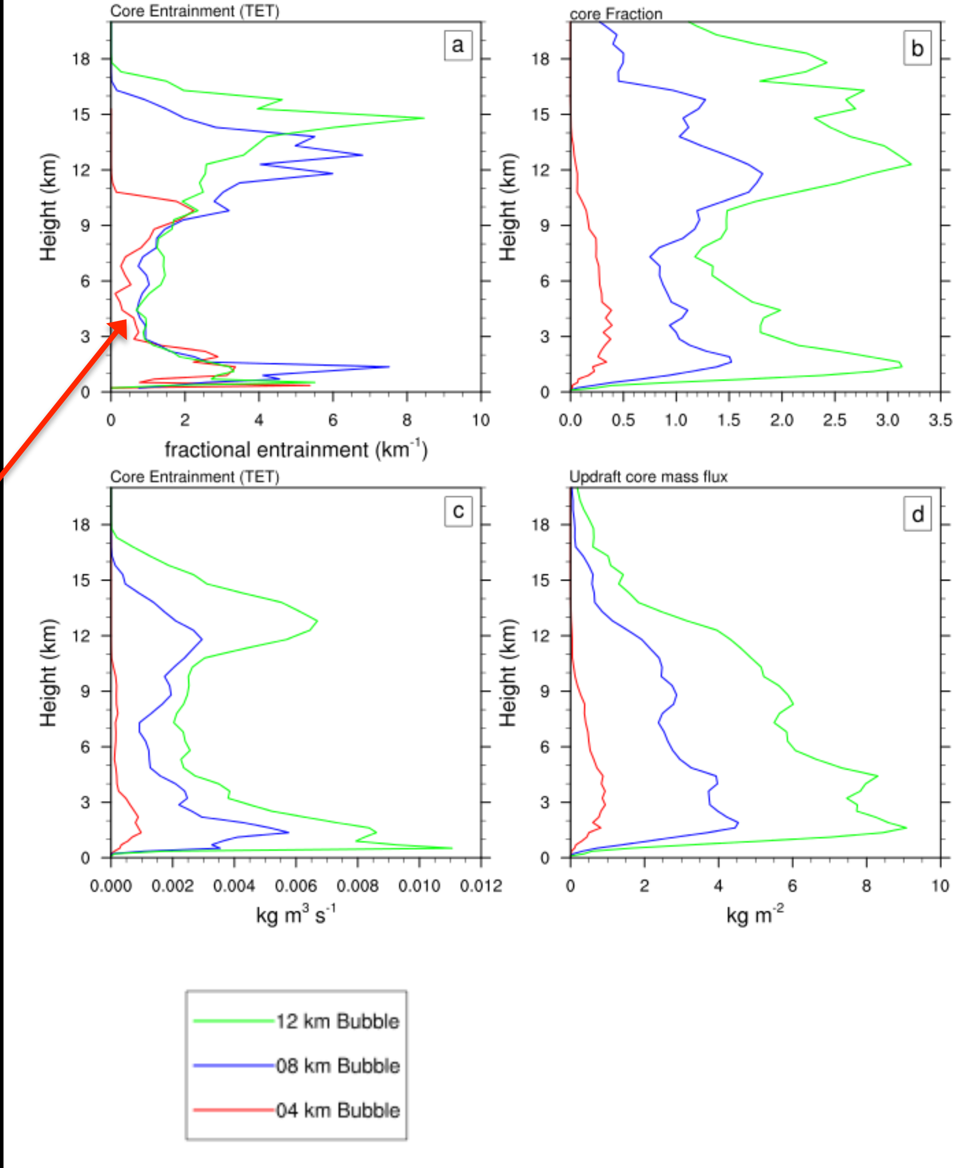
Control Simulations

$$\varepsilon = \frac{E}{M}$$

Larger bubble radius:

- Higher cloud top
- Larger cloud fraction
- Stronger updrafts
- Larger entrainment?

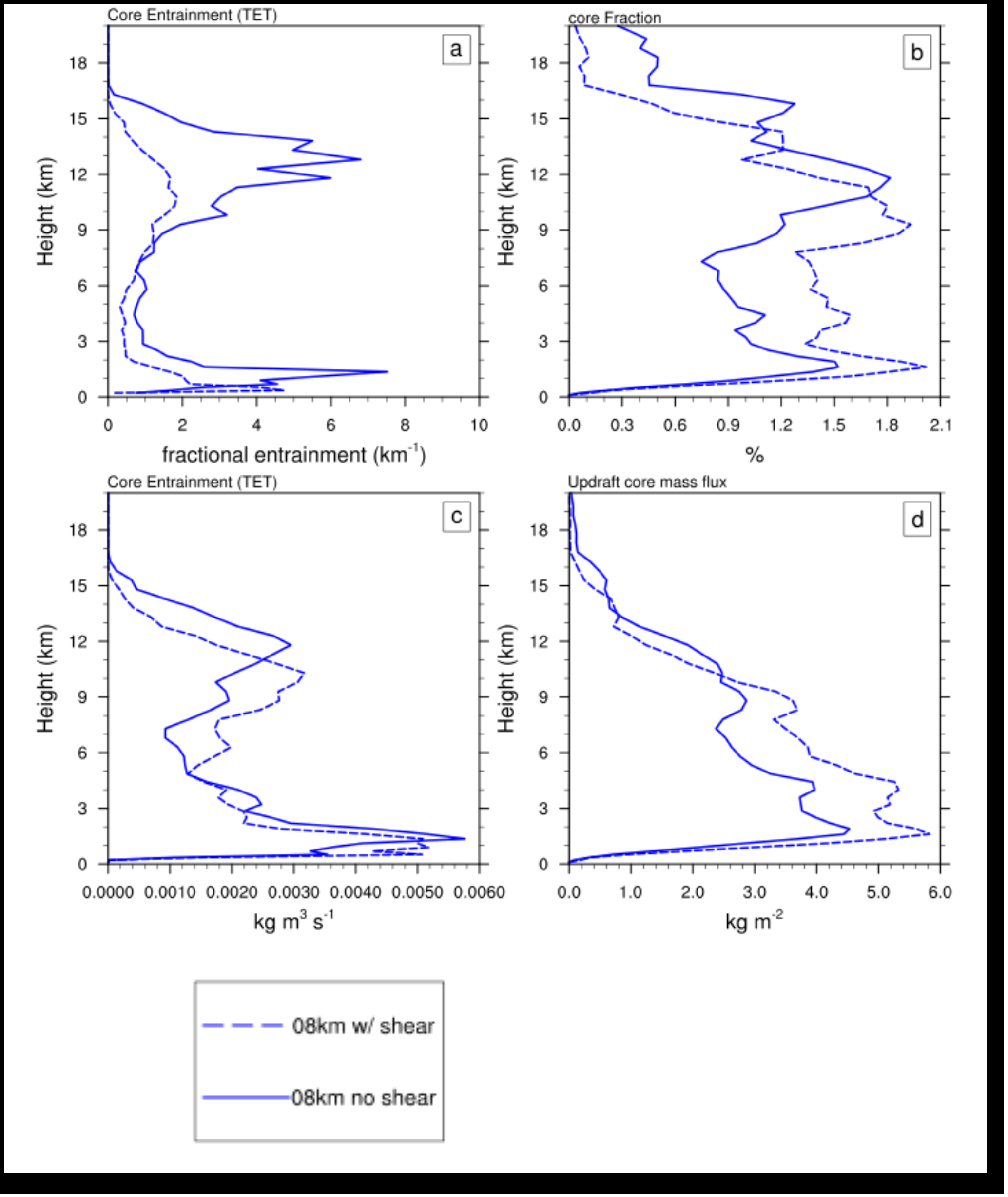
Traditional plume model predicts weaker entrainment with larger radius



Shear Effects

Adding shear:

- Lower cloud top
- Slightly stronger updrafts
- Weaker entrainment



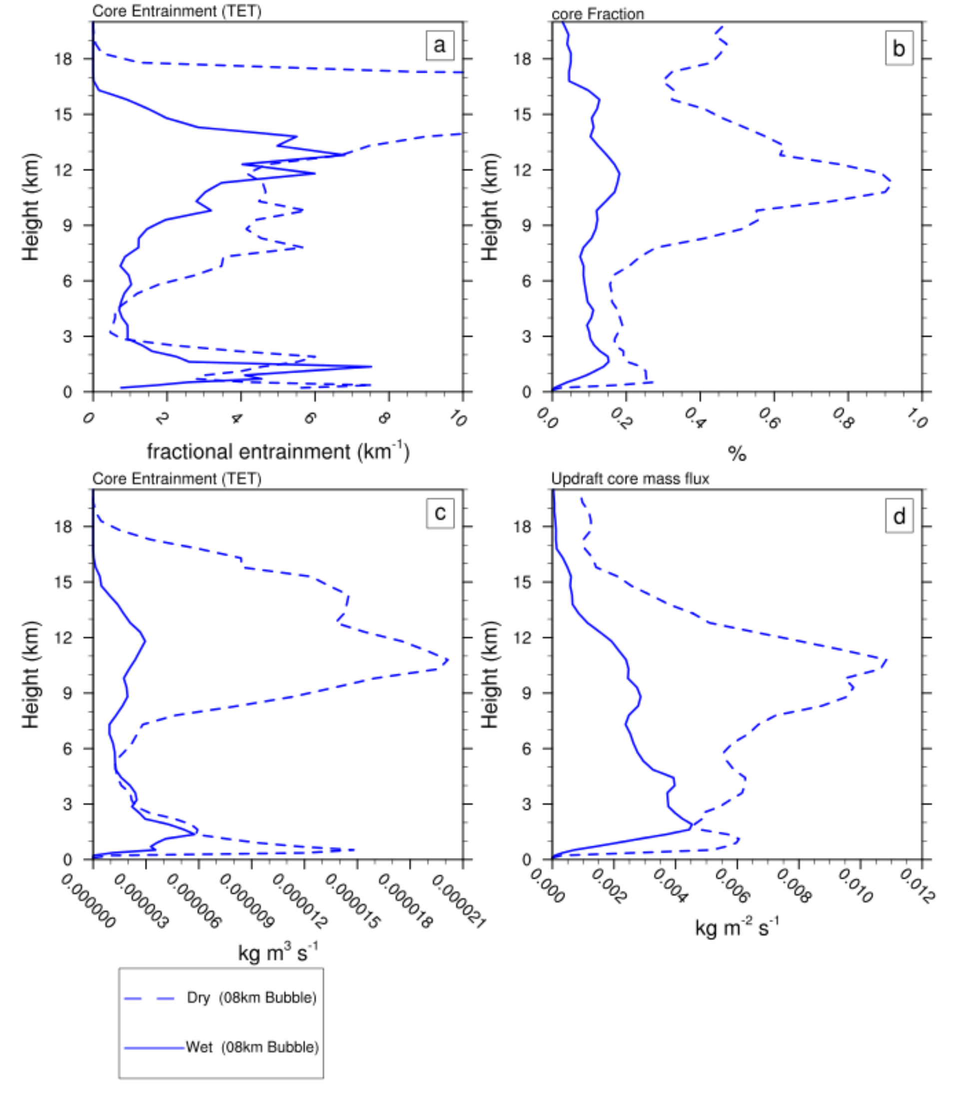
Humidity Effects

Higher Humidity:

- Higher cloud top
- Larger cloud fraction
- Stronger updrafts
- Stronger entrainment?

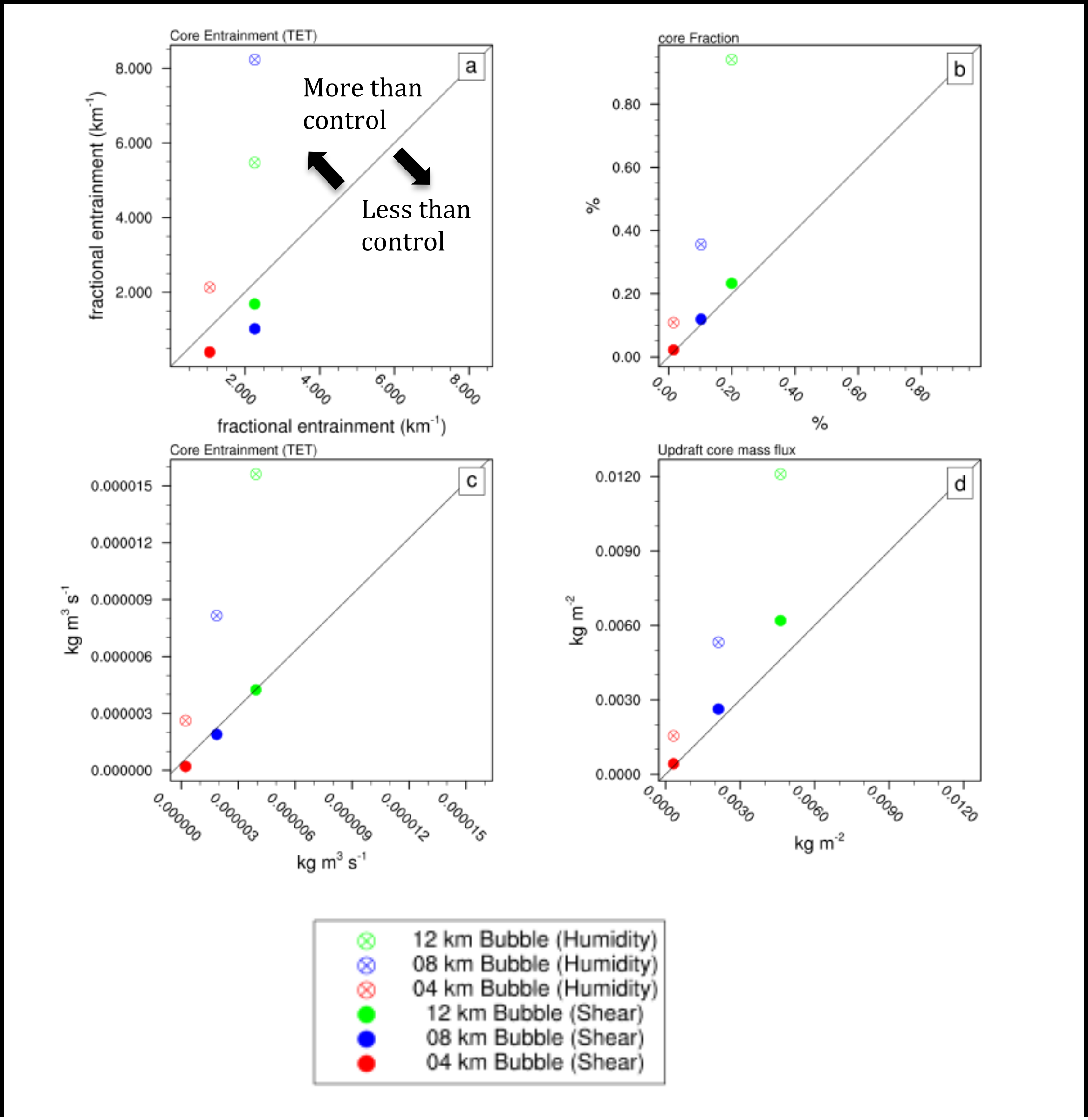
Bechtold et al. (2008) predicted the opposite

$$\varepsilon = \underbrace{c_0}_{\text{turb}} F_{\varepsilon,0} + \underbrace{c_1 \frac{\overline{q}_s - \overline{q}}{\overline{q}}}_{\text{org,deep,buoy>0}} F_{\varepsilon,1}; \quad F_{\varepsilon,i} = \left(\frac{\overline{q}_s}{\overline{q}_{s,\mathrm{b}}}\right)^{\beta_i}$$



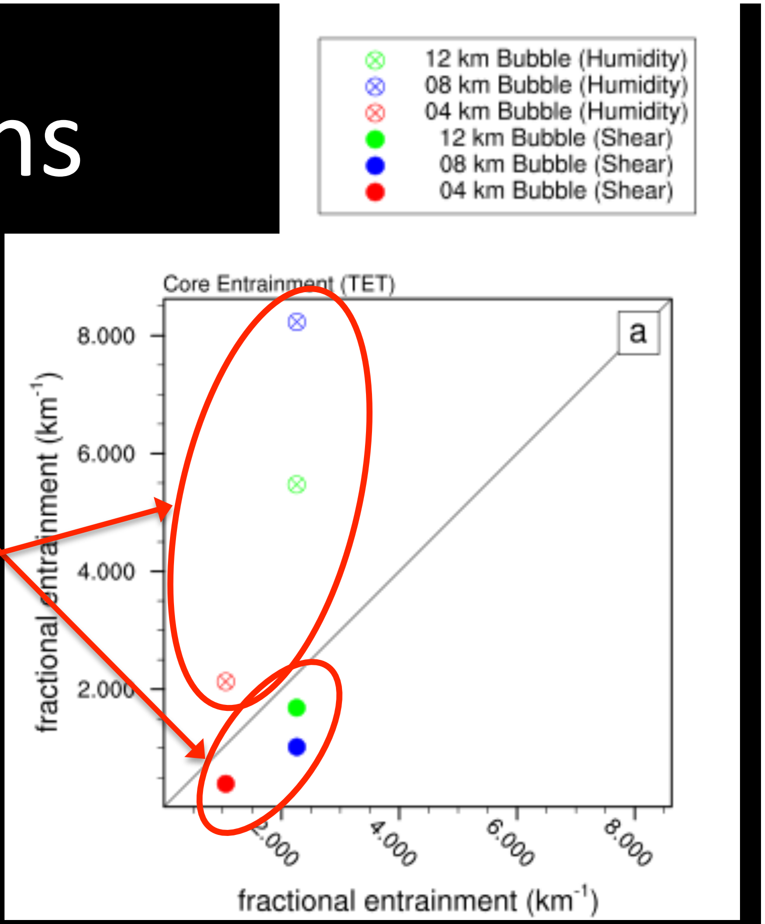
Column Average

$$\varepsilon = \frac{E}{M}$$


More than control

Less than control

Conclusions

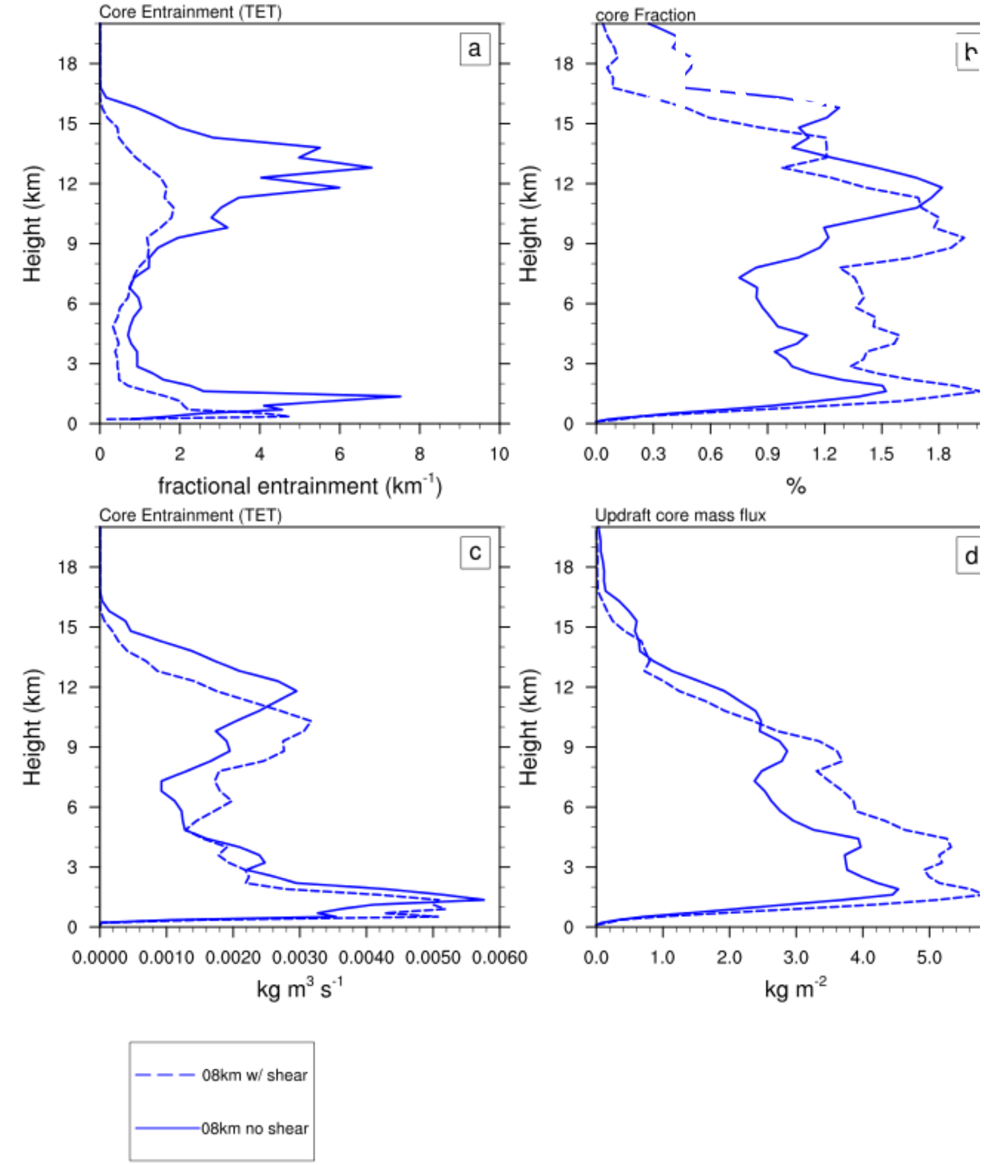


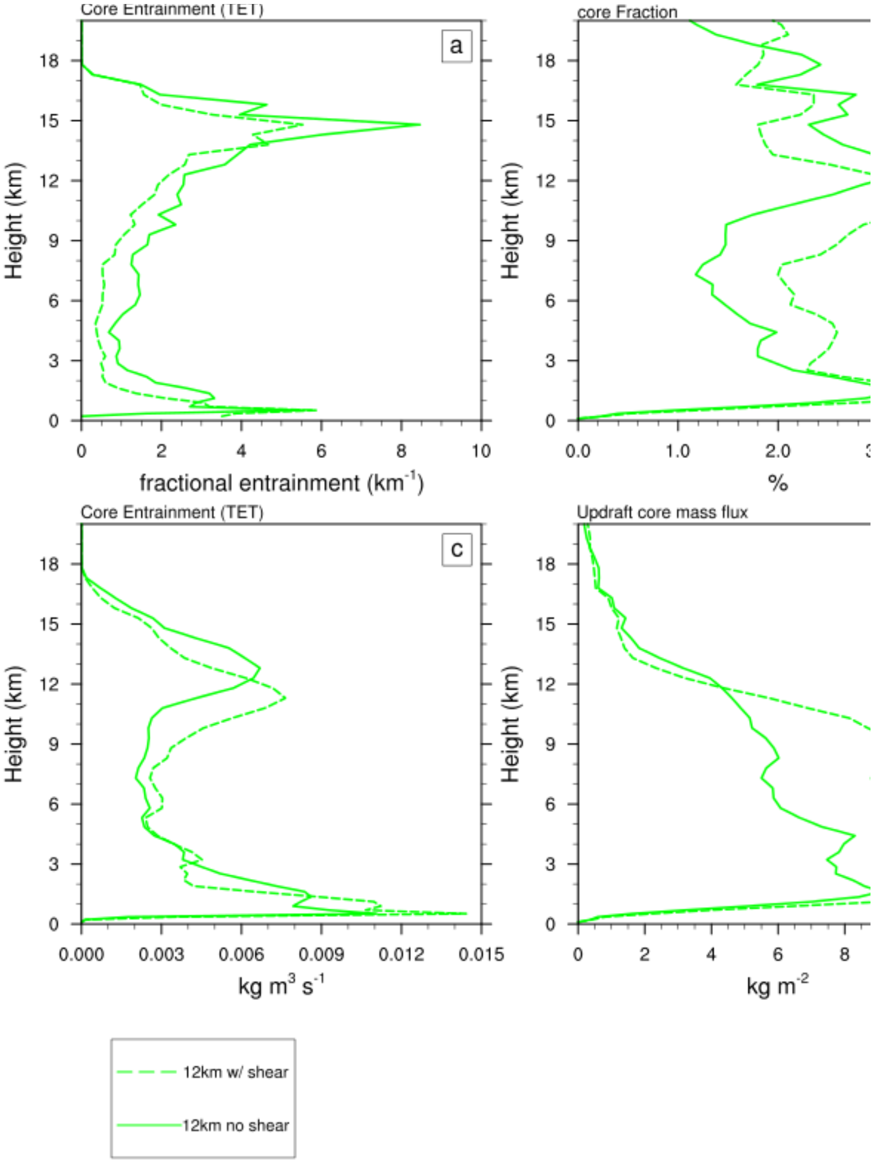
- Shear effects
  - Bulk of the cloud has weaker ε
  - Clouds are slightly larger and lower
- Humidity effects
  - ε is stronger
  - Clouds are higher and larger
  - Larger mass flux

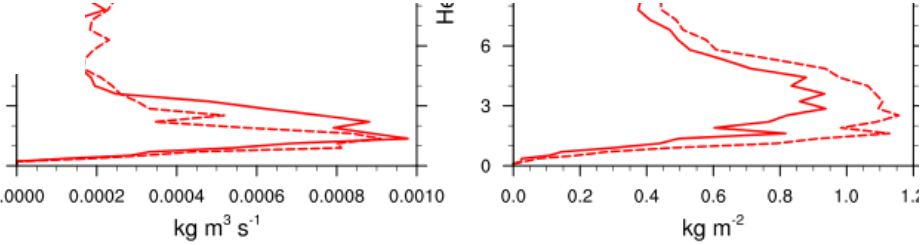
- Caveats
  - Highly idealized experiment
  - Profile of shear was not realistic
  - Large-scale forcing not considered
  - No cloud interaction
- Further Work
  - Do entrainment and dilution mean the same thing?
  - Is the impact of mesoscale organization similar to shear?

Questions?

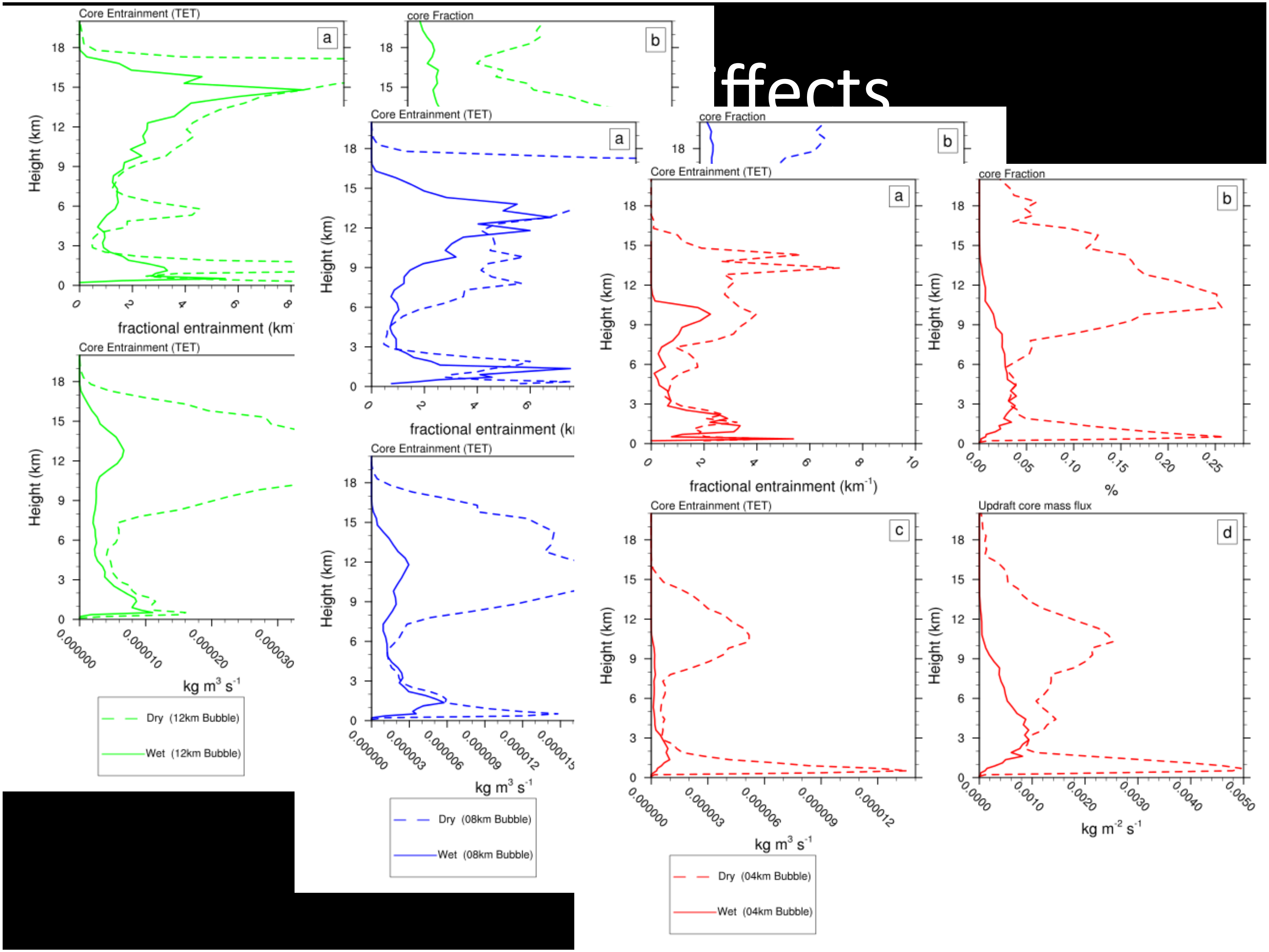
- Intro
  - What is entrainment?
  - Direct entrainment
- Simulation
  - Setup
  - Animations
- Entrainment comparison
  - Impact of bubble width
  - Shear vs non-shear
  - Impact of more humid environment
  - Scatter plots
    - E vs sheared E
    - E vs Humid E


Core Entrainment (TET)
a
Height (km)
fractional entrainment (km^{-1})
core Fraction
b
%
Core Entrainment (TET)
c
kg m^3 s^{-1}
Updraft core mass flux
d
kg m^{-2}
08km w/ shear
08km no shear


Core Entrainment (TET)
a
Height (km)
fractional entrainment (km^{-1})
core Fraction
%
Core Entrainment (TET)
c
kg m^3 s^{-1}
Updraft core mass flux
kg m^{-2}
12km w/ shear
12km no shear


kg m^3 s^{-1}
kg m^{-2}

ffects


Core Entrainment (TET)
a
Height (km)
fractional entrainment (km
core Fraction
b
Core Entrainment (TET)
kg m3 s-1
Dry (12km Bubble)
Wet (12km Bubble)
Core Entrainment (TET)
a
Height (km)
fractional entrainment (k
core Fraction
b
Core Entrainment (TET)
kg m3 s-1
Dry (08km Bubble)
Wet (08km Bubble)
Core Entrainment (TET)
a
Height (km)
fractional entrainment (km-1)
core Fraction
b
%
Core Entrainment (TET)
c
kg m3 s-1
Updraft core mass flux
d
kg m-2 s-1
Dry (04km Bubble)
Wet (04km Bubble)
0
3
6
9
12
15
18
0.00
0.05
0.10
0.15
0.20
0.25
0.000000
0.000003
0.000006
0.000009
0.000012
0.000015
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0.000020
0.000030
0.0000
0.0010
0.0020
0.0030
0.0040
0.0050
2
4
6
8
10