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Stochastic Convection Parameterizations: the Eddy-Diffusivity/Mass-Flux (EDMF) Approach

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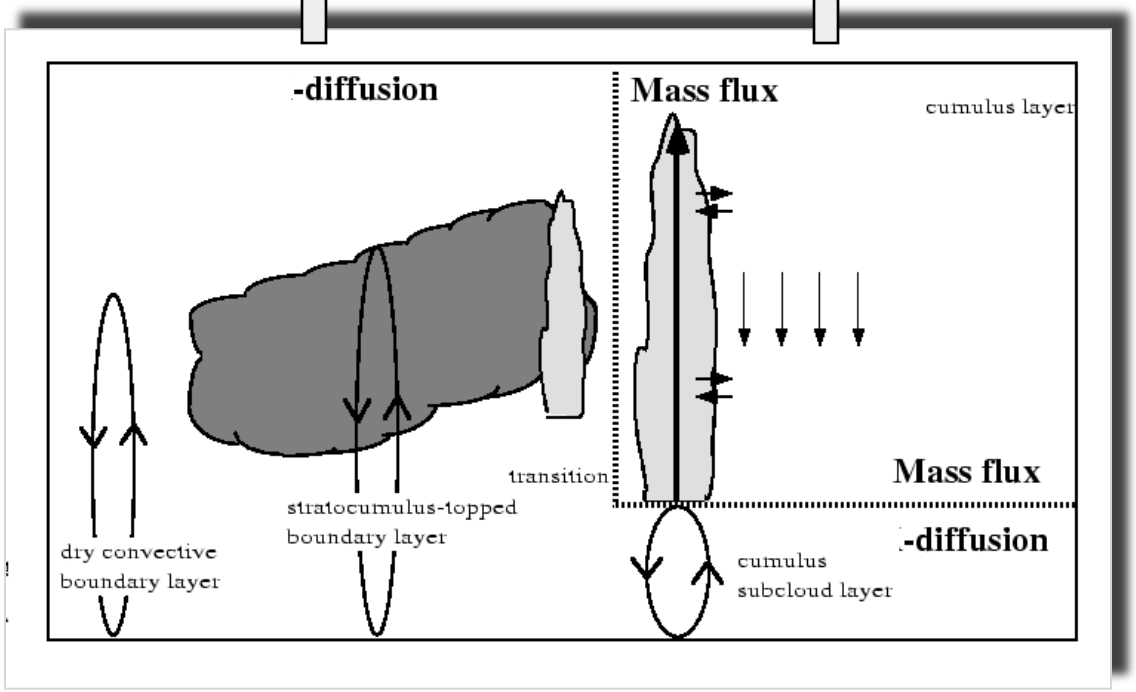
Parameterization Modularity

Standard parameterizations for subgrid flux are modular:

$$\overline{w'\phi'} \cong -K\frac{\partial\bar{\phi}}{\partial z} \qquad \overline{w'\phi'} \cong M(\phi_u - \bar{\phi})$$



Artificial modularity leads to problems:

- "Double counting" of processes
- Interface problems
- Problems with transitions between different regimes

Key Problem: artificial modularity in vertical mixing parameterizations

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An Integrated Approach: Eddy-Diffusivity/Mass-Flux (EDMF)

Dividing a grid square in two regions (updraft and environment) and using Reynolds decomposition and averaging leads to

$$\overline{w'\varphi'} = a_u \overline{w'\varphi'}_u + (1-a_u)\overline{w'\varphi'}_e + a_u(1-a_u)(w_u - w_e)(\varphi_u - \varphi_e)$$

where a_u is the updraft area. Assuming $a_u << 1$ and $w_e \sim 0$ leads to

$$\overline{w'\varphi'} = \overline{w'\varphi'}_e + a_u w_u (\varphi_u - \bar{\varphi})$$

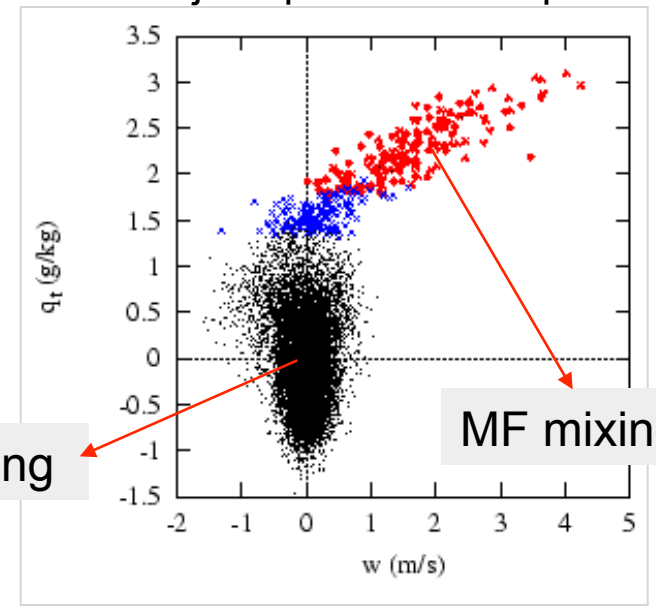
ED closure: assuming ED for 1st term and neglecting 2nd term

MF closure: neglecting 1st term and assuming $M=a_u w_u$

EDMF: $$\overline{w'\varphi'} = -k\frac{\partial \bar{\varphi}}{\partial z} + M(\varphi_u - \bar{\varphi})$$

Siebesma & Teixeira, 2000

Bimodal joint pdf of w and qt



EDMF represents different turbulence and convection scales

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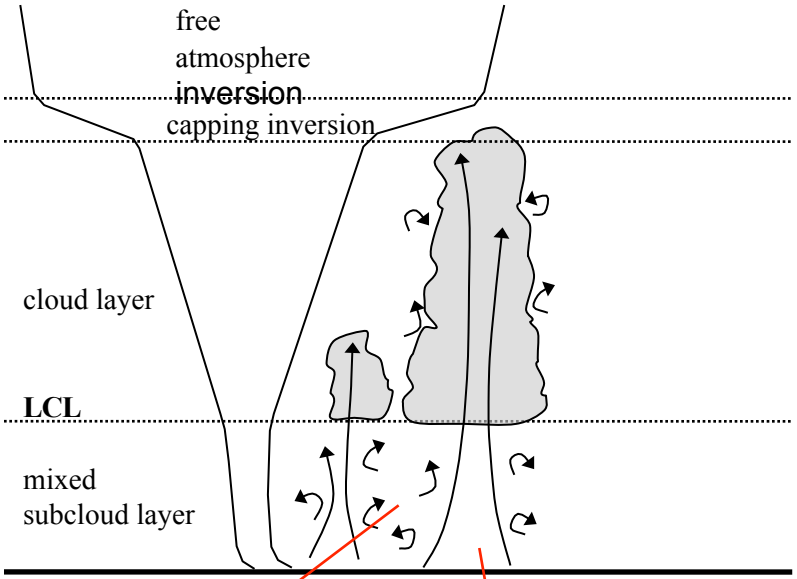
Mass-Flux for Cumulus Plumes/Updrafts



Small-scale
ED mixing

Large-scale
MF mixing

$$\frac{\partial \phi_u}{\partial z} = -\varepsilon(\phi_u - \bar{\phi}) \text{ for } \phi \in \{\theta_l, q_t\}$$

$$M = \sigma_u w_u$$

$$\frac{1}{2}\frac{\partial w_u^2}{\partial z} = -b\varepsilon w_u^2 + a\frac{g}{\theta_0}\left(\theta_{v,u} - \overline{\theta_v}\right)$$

σ_u is updraft/plume area fraction

Lateral entrainment rate: $\varepsilon = \frac{1}{w_u \tau} = \frac{1}{h_c}$

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EDMF: Some Equations

ED component is TKE-based with EDMF buoyancy flux:

$$\frac{\partial e}{\partial t} = -\frac{\partial}{\partial z}\overline{w'e} - w\frac{\partial e}{\partial z} - \overline{w'u'}\frac{\partial u}{\partial z} - \overline{w'v'}\frac{\partial v}{\partial z} + \frac{g}{\theta_v}\overline{w'\theta_v'} - \varepsilon_e,$$

Parameterization of cloud-base PDF of updraft properties

Variance diagnostic equation (dissipation balance production):

$$2\overline{w_u'\varphi_u'}\frac{\partial \varphi_u}{\partial z} = (C/\tau)\overline{\varphi_u'\varphi_u'}$$

Which leads to

$$\overline{\varphi_u'\varphi_u'} = \frac{3}{2}\frac{\tau_u^2}{C} w_u^2 \epsilon^2 (\varphi_u - \varphi)^2,$$

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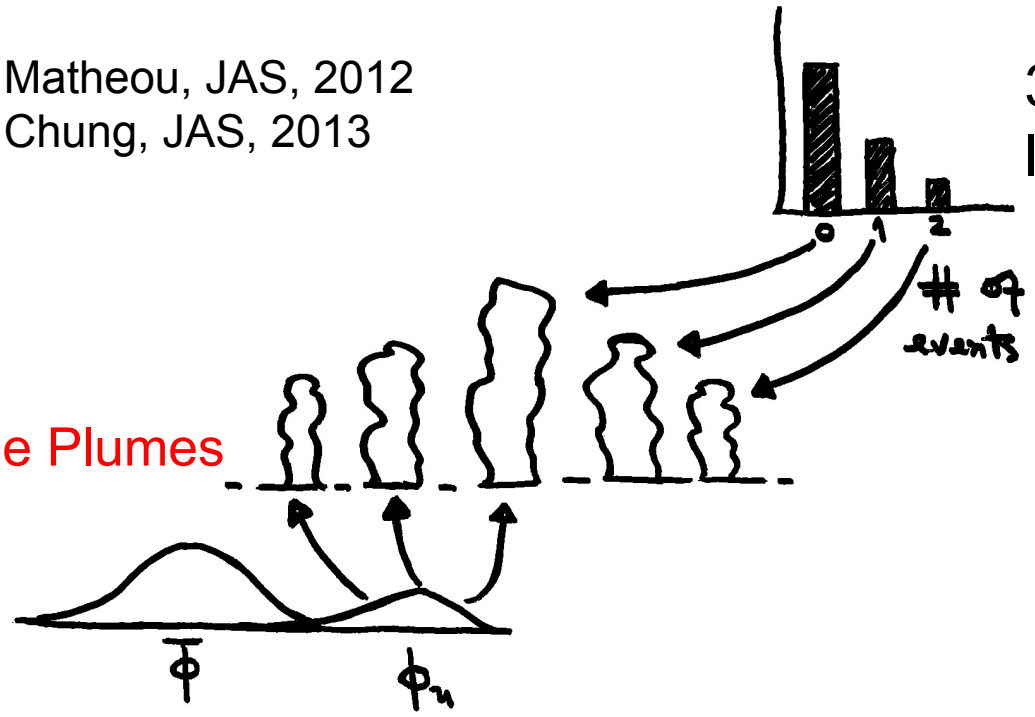
EDMF and moist convection: updraft PDF and stochastic entrainment

Suselj, Teixeira & Matheou, JAS, 2012
Suselj, Teixeira & Chung, JAS, 2013



3) Stochastic lateral entrainment

partly following Romps & Kuang, JAS, 2010

1) Parameterization of PDF of updraft properties at cloud base
2) Monte Carlo sampling of updraft PDF to produce multiple plumes

Provides estimates of updraft area and avoids need for cloud base closure

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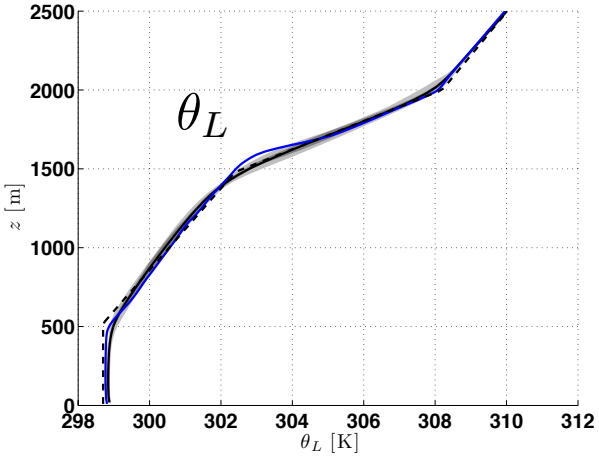
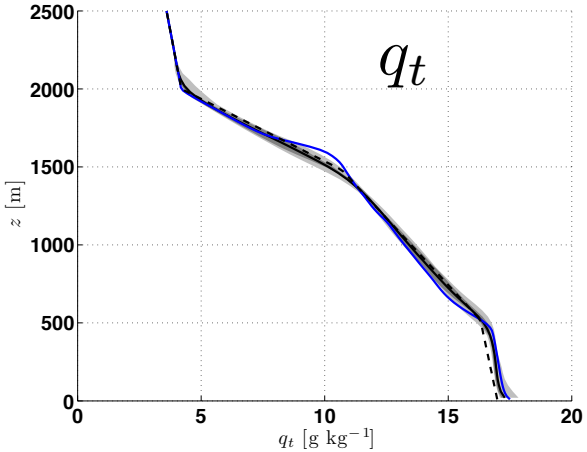
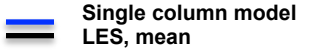
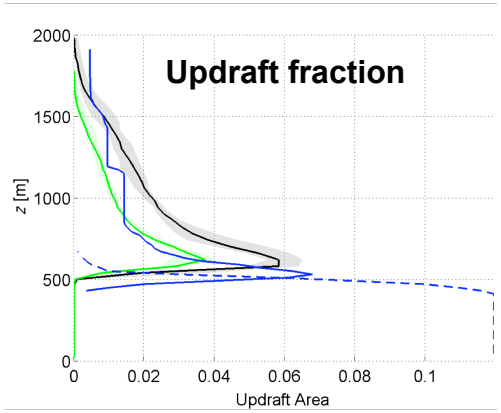
EDMF simulation of cumulus BOMEX case: comparison with LES

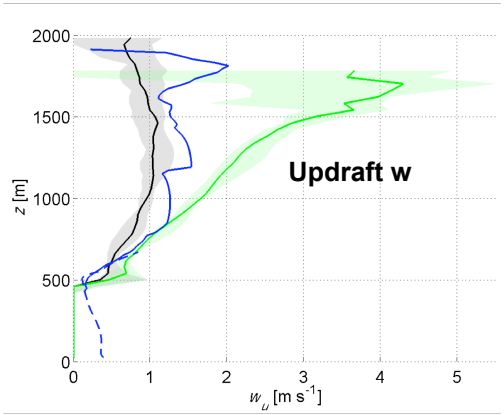
Mean profiles between 3rd and 4th simulation hour

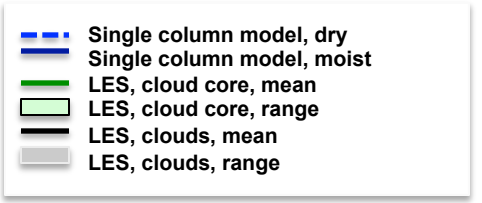












Suselj et al, JAS, 2012, 2013

New aspect: Using PDF of updraft properties and stochastic entrainment

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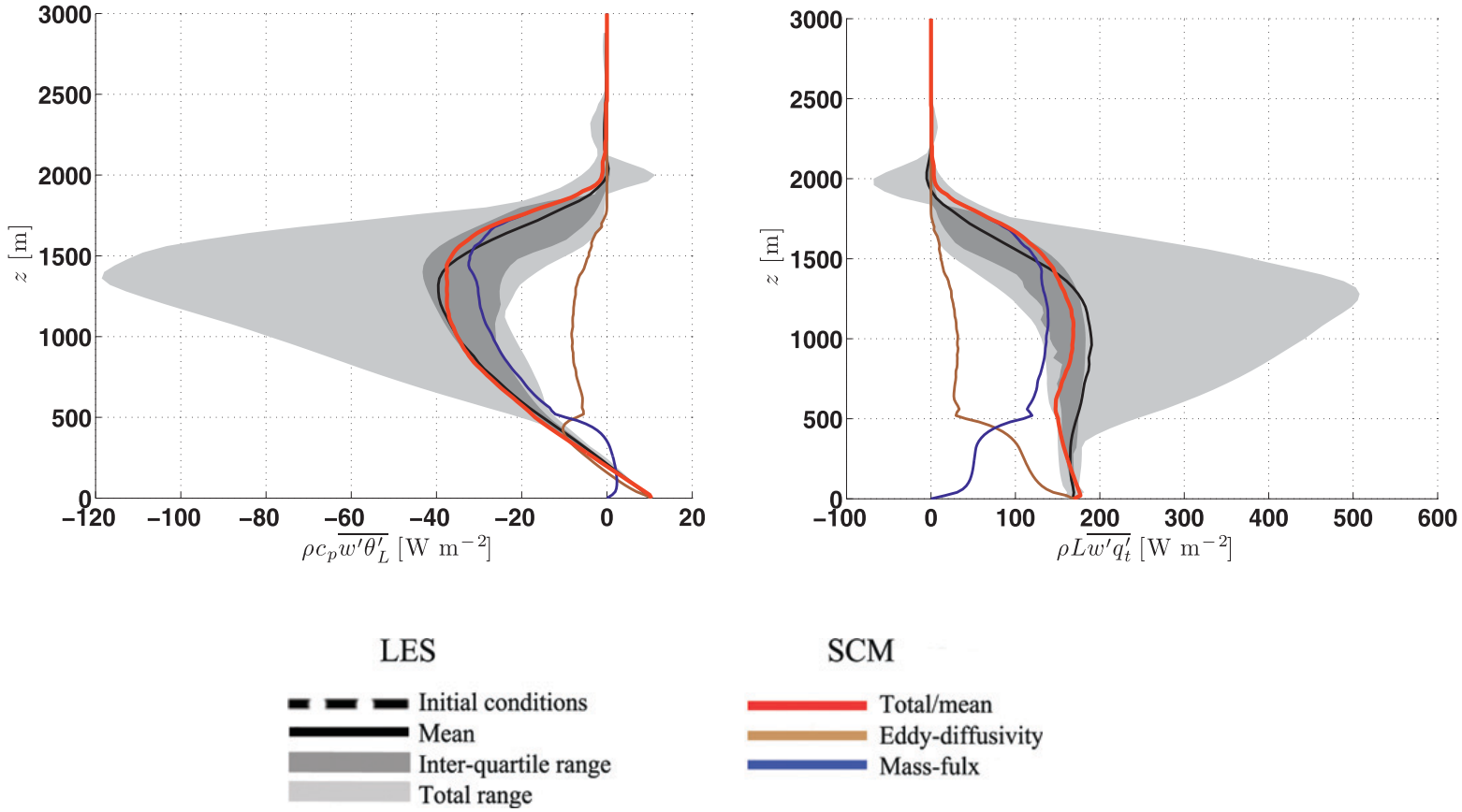
EDMF and BOMEX: ED versus MF

Vertical sub-grid fluxes



Sub-grid fluxes are well represented – Some ED in cloud layer

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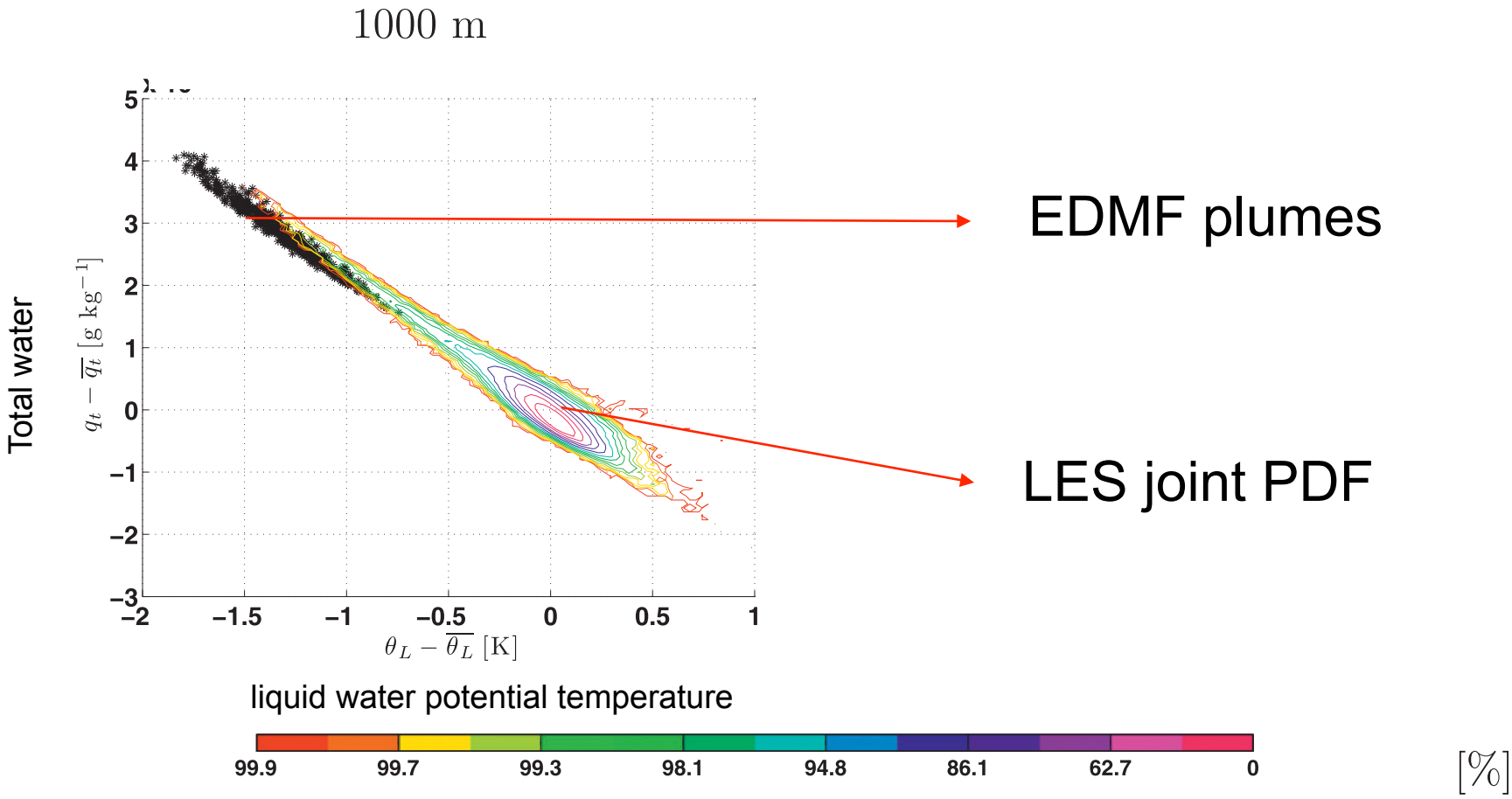
BOMEX: LES PDF vs EDMF plumes



EDMF multiple plumes represent skewed part of PDF

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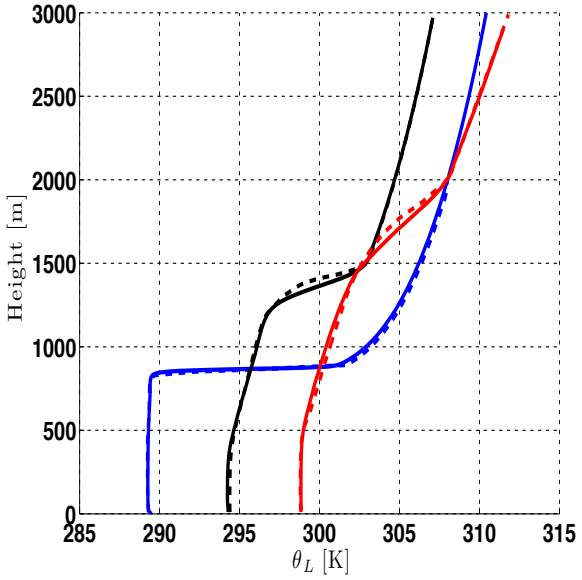
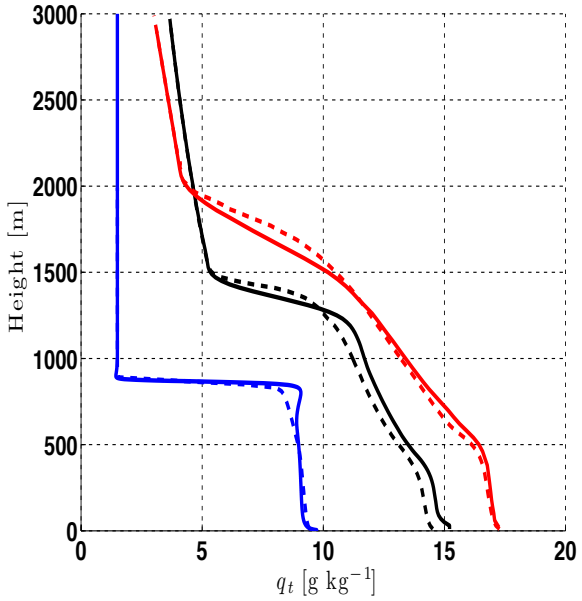
Stochastic EDMF: Transition from stratocumulus to cumulus

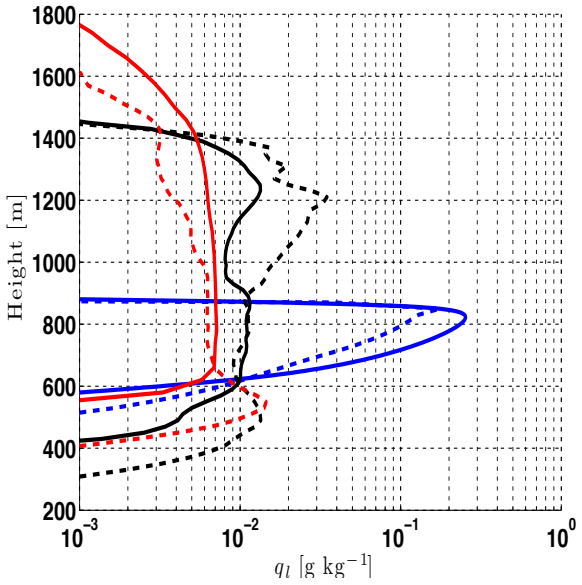
Liquid water potential temperature



Total water



Liquid water



LES
SCM

Stratocumulus
Transition
Cumulus

EDMF is able to represent vertical dynamics of the transition

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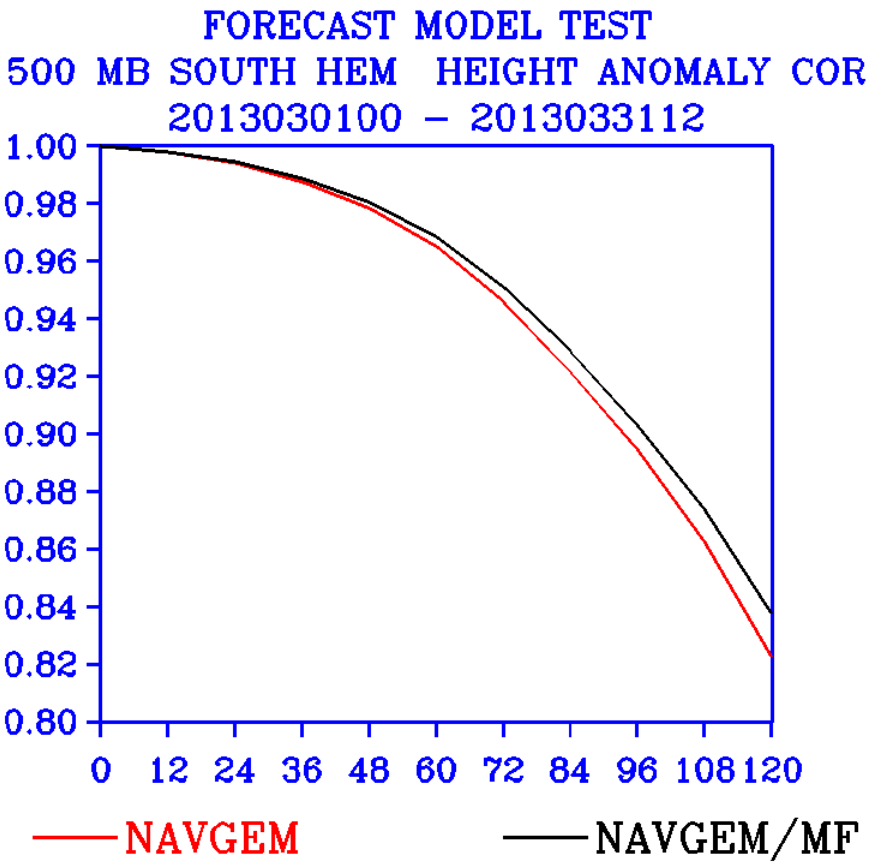
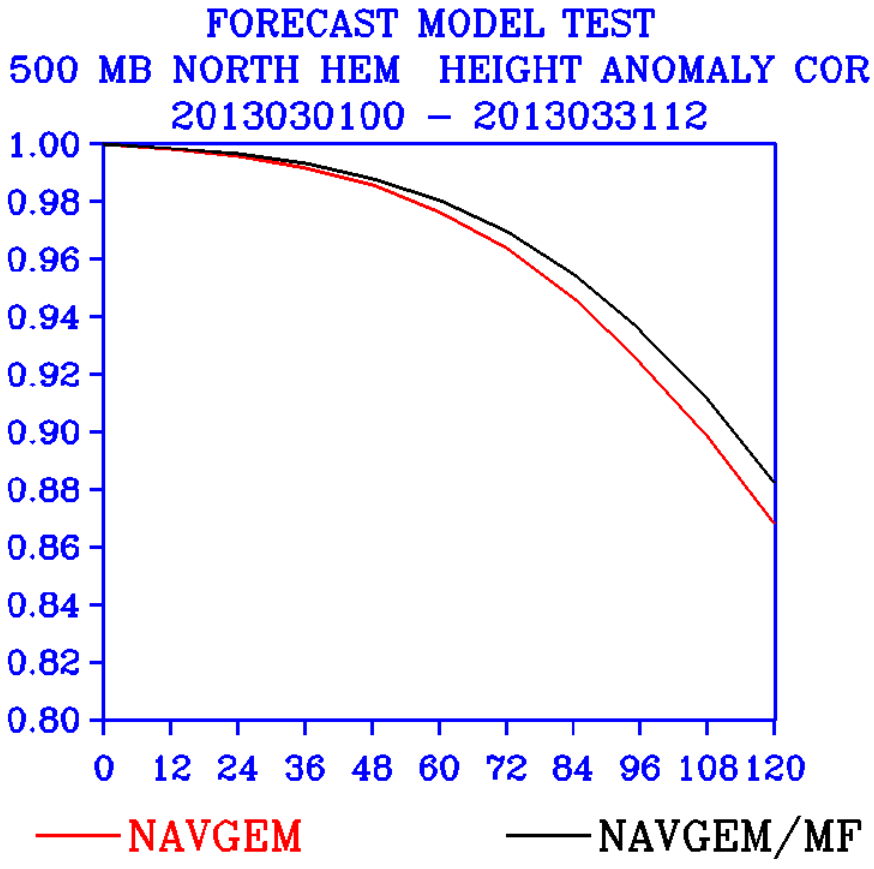
Stochastic EDMF implementation into US Navy global model NAVGEM

Southern and Northern Hemisphere 500 hPa Anomaly Correlations for NAVGEM and NAVGEM with EDMF - Full data assimilation (T359L50)





Stochastic EDMF significantly improves Navy NAVGEM model

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Summary

- EDMF combines ED and MF to represent in an integrated manner turbulence and convection in atmospheric models
- New stochastic EDMF version parameterizes cloud base PDF to generate multiple plumes to represent shallow convection
- Simple (mostly dry) versions of EDMF have been implemented operationally at ECMWF and tested at NCEP and GMAO
- Latest stochastic EDMF was implemented operationally into US Navy global NWP deterministic model in Nov.2013