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From small-scale turbulence to large-scale convection: a unified scale-adaptive EDMF parameterization

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Shedding light on the greyzone

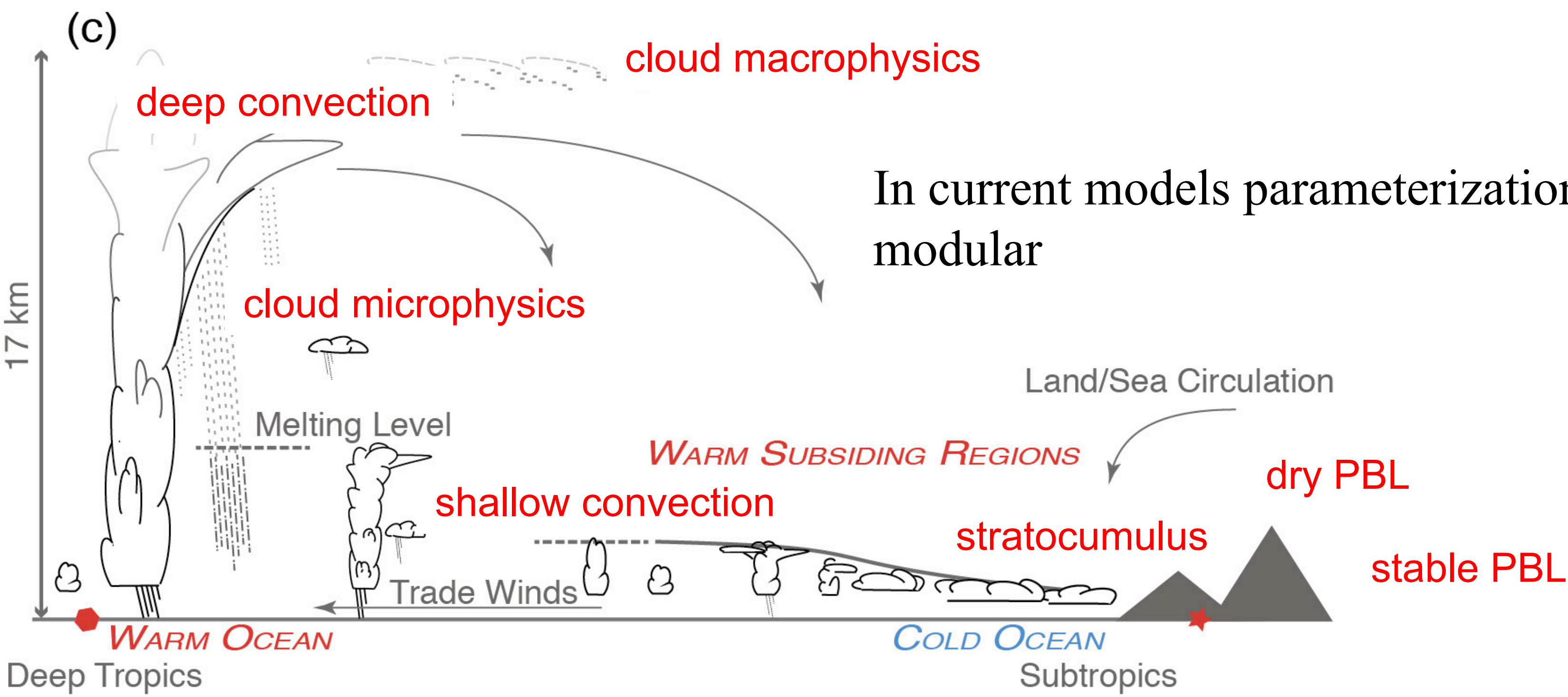
ECMWF, Nov 14, 2017

From small-scale turbulence to large-scale convection: a unified scale-adaptive EDMF parameterization

1. **Unified approach to parameterization**
   - Eddy-Diffusivity/Mass-Flux model

2. **Scale adaptive eddy-diffusivity approach**

Turbulence, convection and cloud parameterizations



In current models parameterizations are modular

Artificial modularity leads to many problems: interfaces, transition

Goal: unified parameterization for boundary layer, convection and macro/micro-physics

Turbulence and convective parameterizations

Reynolds-averaged conservation equations:

$$\frac{\partial \overline{\varphi}}{\partial t} + \frac{\partial}{\partial x}\left(\overline{u}\,\overline{\varphi}\right) + \frac{\partial}{\partial y}\left(\overline{v}\,\overline{\varphi}\right) + \frac{\partial}{\partial z}\left(\overline{w}\,\overline{\varphi}\right) = -\frac{\partial}{\partial z}\left(\overline{w'\varphi'}\right) + \overline{S},$$

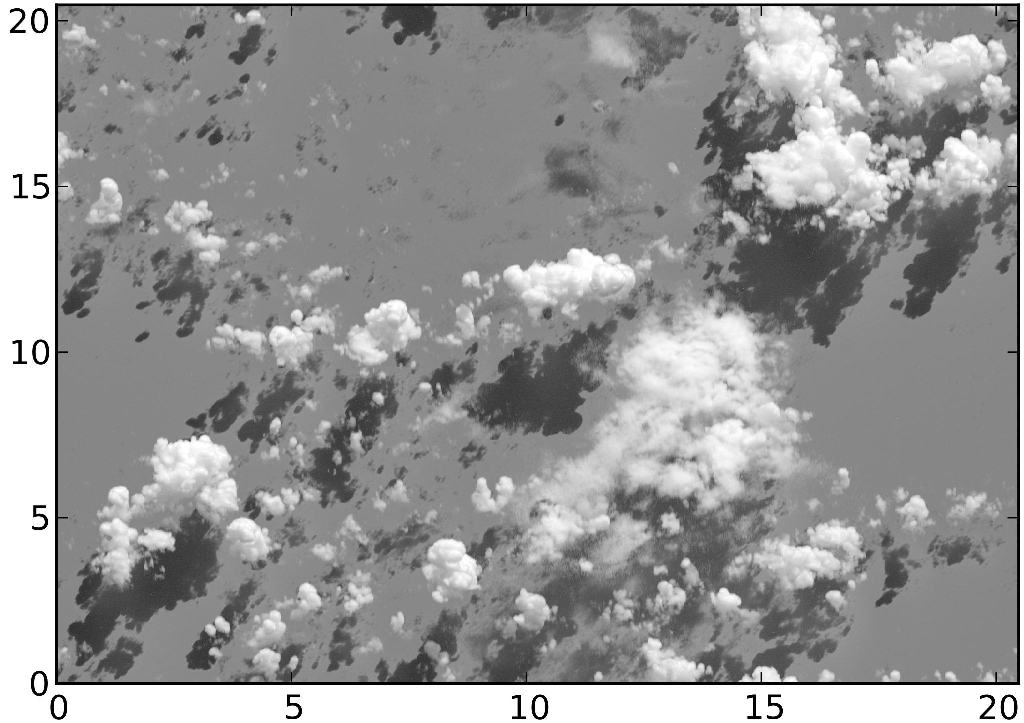
Boundary Layer	Shallow Convection	Deep Convection
$\overline{w'\phi'} \cong -K\frac{\partial\overline{\phi}}{\partial z}$ Eddy-Diffusivity (ED)	$\overline{w'\phi'} \cong M(\phi_u - \overline{\phi})$ Mass-Flux (MF)	
$\frac{\partial}{\partial t}\left(\overline{w'\varphi'}\right) = -\frac{\partial}{\partial z}\left(\overline{w'w'\varphi'}\right) + \ldots$ Higher-Order Closure, e.g. CLUBB		

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

Eddy-Diffusivity/Mass-Flux (EDMF)

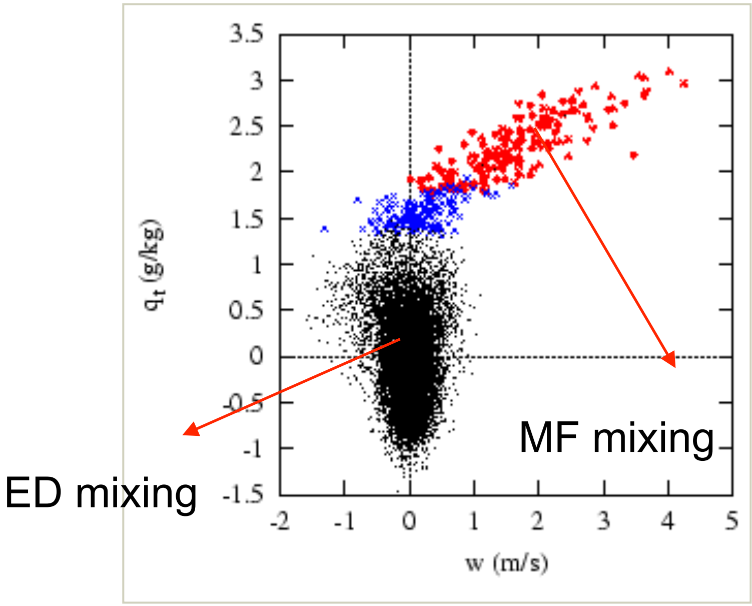
LES model-informed parameterization development

- LES models solve filtered version of conservation (e.g. Navier-Stokes) equations
- High-resolutions (~ 1 - 100m) in all 3 dimensions
- LES models resolve most of the essential turbulence/convection
- Closures still needed for scales < 10m (but simpler than GCMs)



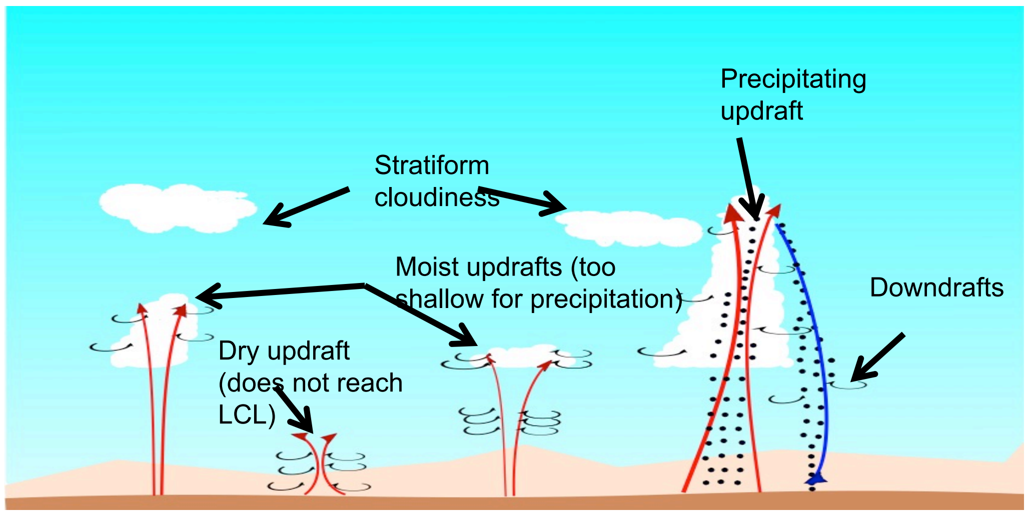
Courtesy of G. Matheou

Bimodal joint pdf(w,q_t) for convective case



Our EDMF approach

- Multiple convective plumes – Mass-Flux (MF) model, sum of uniform PDFs
  - Surface driven updrafts
  - Precipitation driven downdrafts
- Non convective environment - Eddy-Diffusivity (ED) model, joint normal PDFs



$$\overline{\varphi} = a_e \varphi_e + \sum_i a_i \varphi_i$$

i	Convective elements
e	Environment
a_e, a_i	Fractional areas

$$\overline{\varphi'\psi'} = a_e \overline{\varphi'\psi'}|_e + a_e(\varphi_e - \overline{\varphi})(\psi_e - \overline{\psi}) + \sum_i a_i \overline{\varphi'\psi'}_i + \sum_i a_i(\varphi_i - \overline{\varphi})(\psi_i - \overline{\psi})$$

ED — Compensating sub. — Sub-plume var. — Multiple MF

Shallow and deep version of EDMF

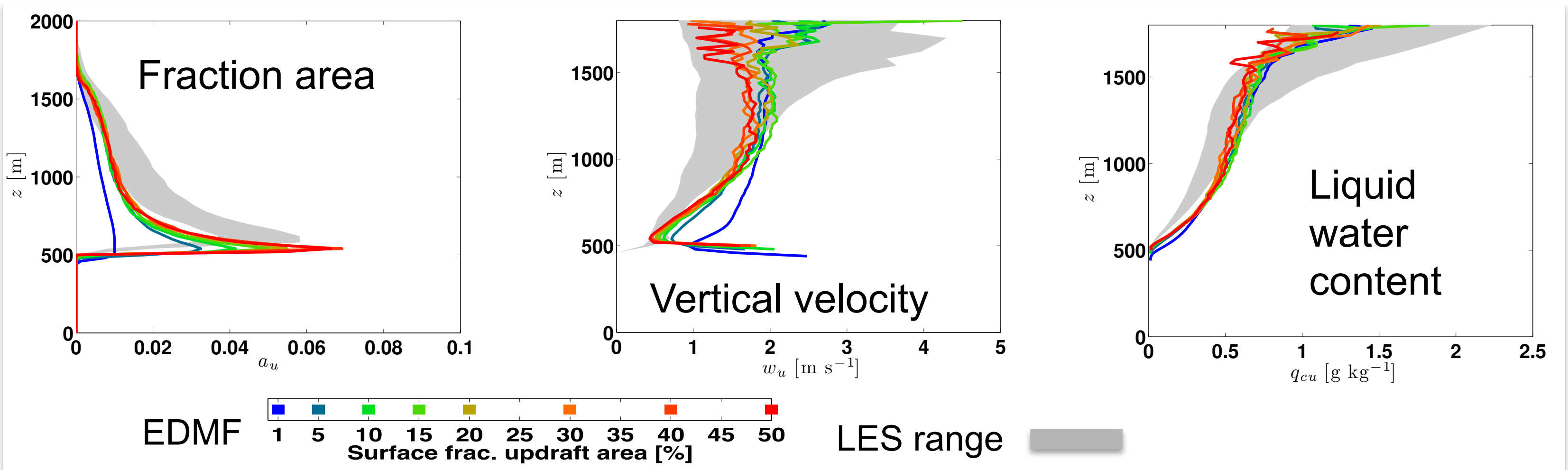
- Non-convective environment:
  - TKE-based eddy-diffusivity approach
- Mass-flux
  - Multiple surface-forced plumes, starting from surface PDF
  - Stochastic entrainment rate
  - Simple Kessler-type microphysics coupled to updraft dynamics
  - Downdrafts driven by evaporation of rain
  - Precipitation-driven cold pools
  - Cold pools impact on updraft entrainment rates and surface PDF

Main advantages:

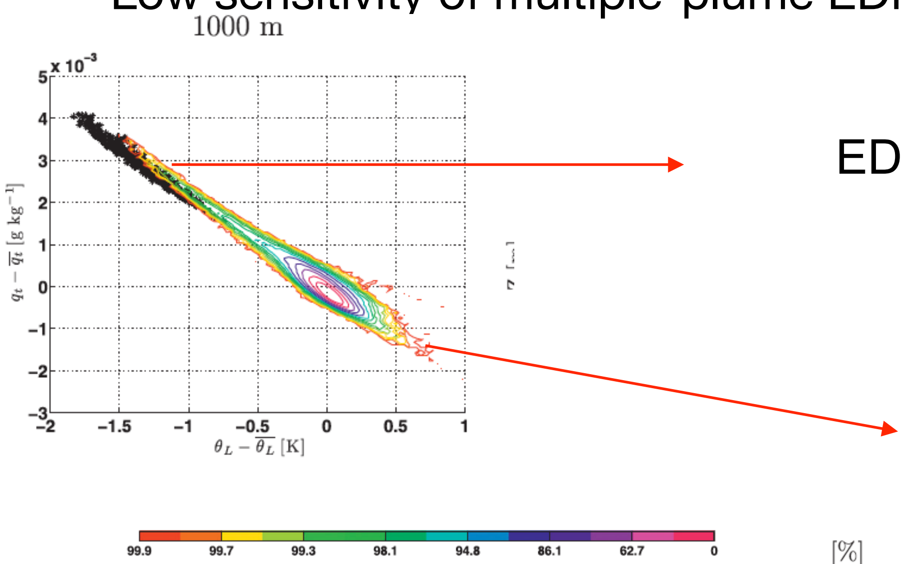
- **Different types of convection within one grid-box**
- **No need for trigger functions and explicit convective closures**
- **Smooth transition between convective regimes (dry, shallow, deep)**

Shallow convection case - BOMEX

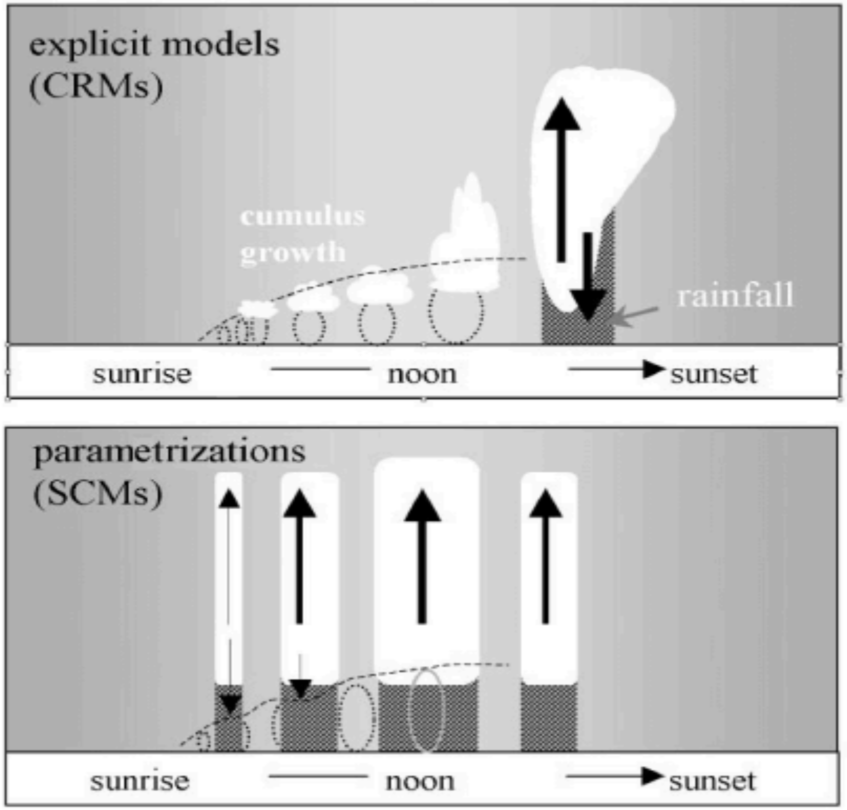
BOMEX: Comparison of EDMF moist updraft properties against LES results



Low sensitivity of multiple-plume EDMF to surface updraft area



Diurnal cycle of continental convection



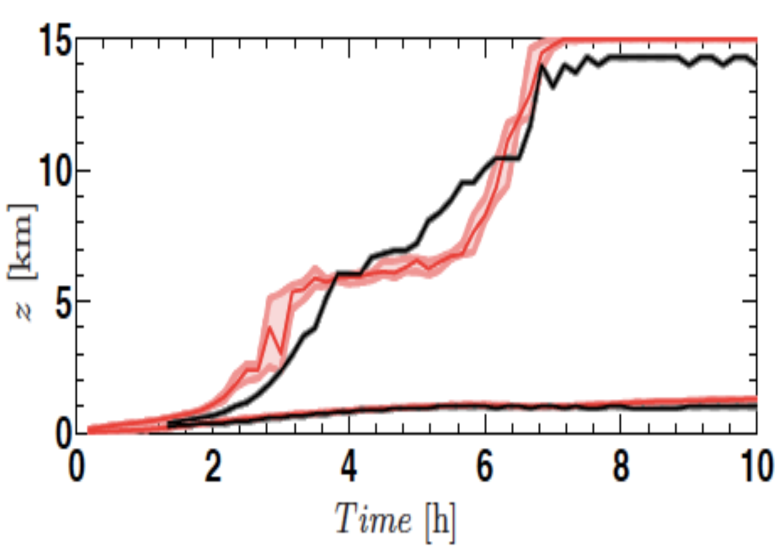
Guichard et al, QJRMS, 2004

Climate and weather models often struggle to represent transition between convective regimes

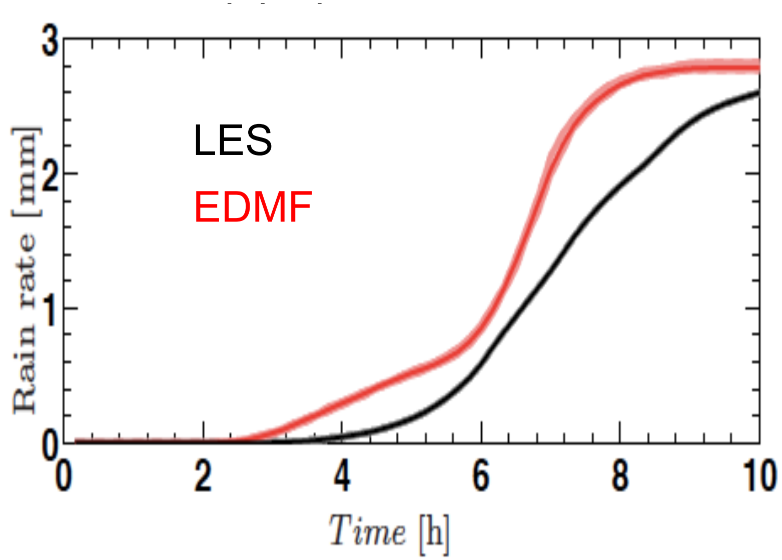
Unified EDMF, diurnal cycle of convection over land

- New fully unified (PBL + shallow + deep convection) EDMF
- EDMF with cloud microphysics
- LBA diurnal cycle of precipitating convection

Cloud base and



Cumulative surface



Realistic transition with EDMF from shallow to deep convection

Scale adaptive ED closure for the dry convective boundary layer: from LES to climate scales

$$\overline{\varphi' u_i'} = -K \frac{\partial \overline{\varphi}}{\partial x_i}$$ where $$K = l\sqrt{tke}$$

$$l^{-2} = l_{3d}^{-2} + l_{1d}^{-2}$$

Merging the 3D (LES-scale) and 1D (GCM-scale) limits

$$l_{3d} = (\Delta x \Delta y \Delta z)^{1/3}$$

LES scale length (Δx~10 m)

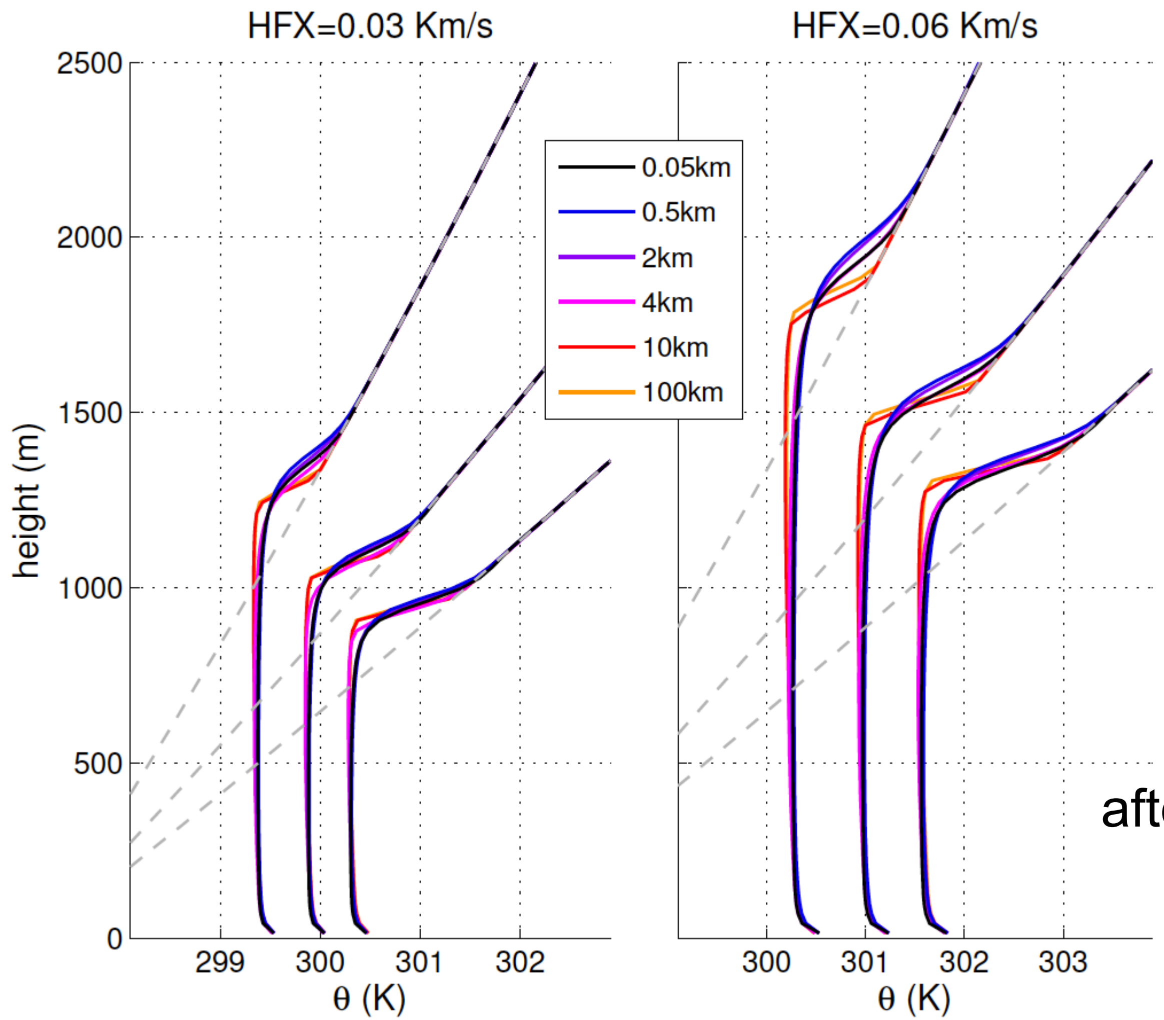
$$l_{1d} = f(kz, \tau\sqrt{tke})$$

GCM scale (Δx~100 km):

Dry convective boundary layer

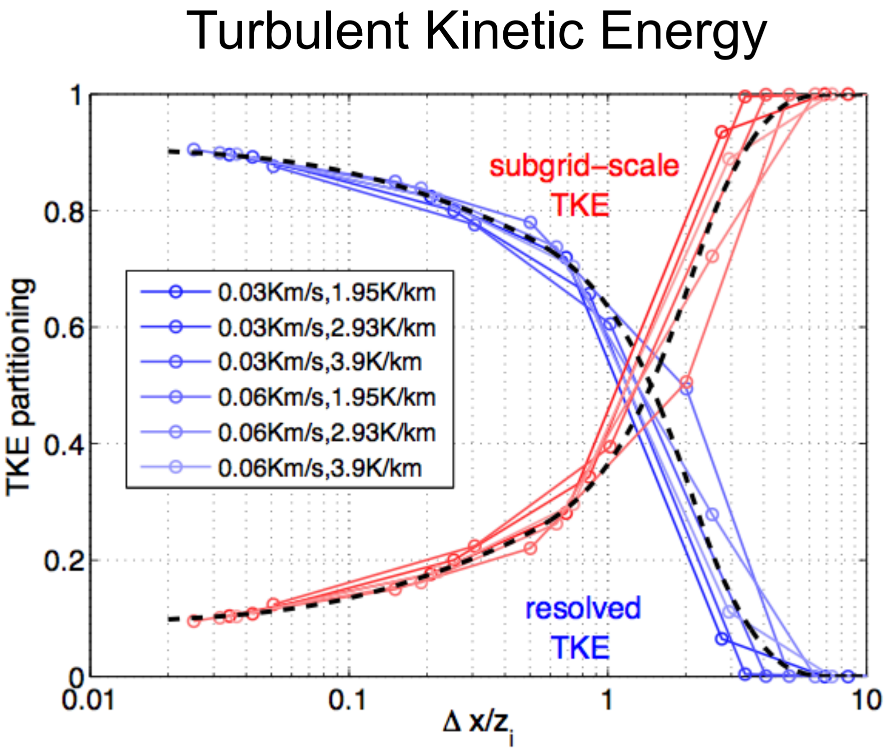
WRF model from LES (Δx=50 m) to NWP/Climate (Δx=100 km)

6 cases:
- 3 different stratifications
- 2 different surface heat flux values

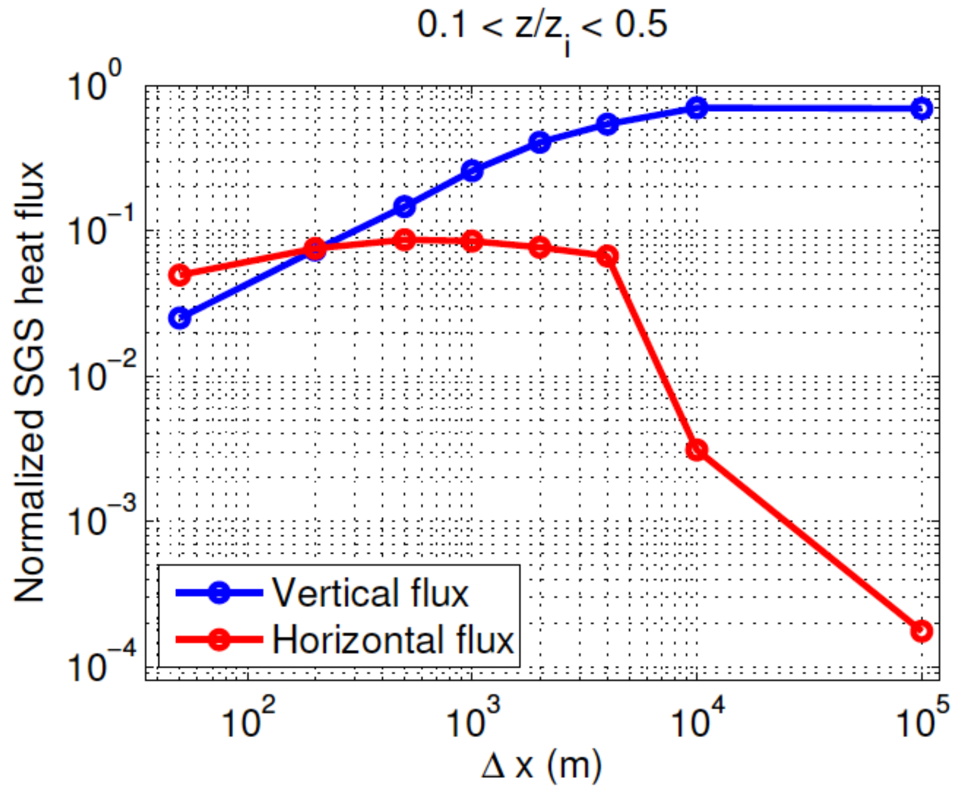


after 10h

Gradual transition from resolved to parameterized turbulence



Partitioning between resolved and SGS TKE



SGS vertical vs horizontal turbulent fluxes:
Horizontal fluxes decrease significantly from 1 to 100 km

SUMMARY

- Unified EDMF parameterization can represent boundary layer turbulence, shallow and deep convection (EDMF versions implemented into ECMWF, NAVGEM, NCEP)
- Multiple Plumes: New EDMF version using multiple plumes represents well shallow and deep convection
- Simple scale-adaptive approach leads to gradual transition from LES (50 m) to climate model resolutions (100 km)
- Key Challenges: Scale-adaptive plume models; Plume-plume interaction; Prognostic plumes; Coupling to microphysics; Stable boundary layer.