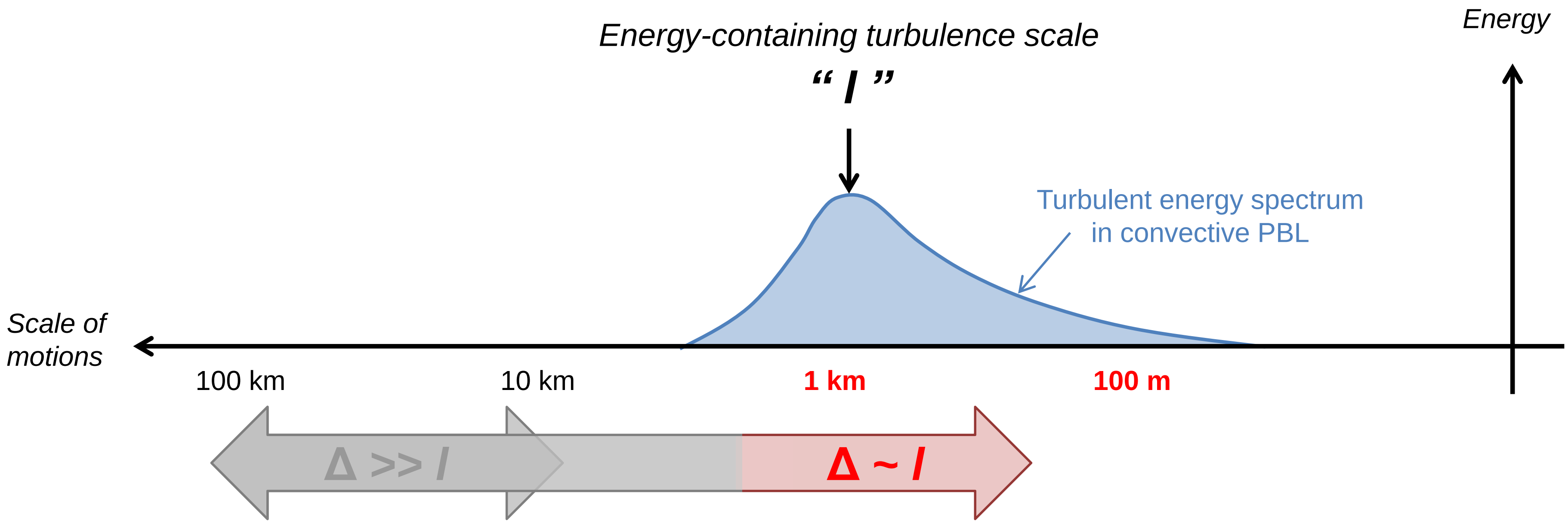
Evaluation of PBL Parameterizations in WRF at Subkilometer Grid Spacings: Response of Resolved Dry Convection to Parameterized Turbulence

Hyeyum (Hailey) Shin and Jimy Dudhia

National Center for Atmospheric Research

With acknowledgement to Peggy LeMone (NCAR)

Model Grid Spacing: *O*(0.1-1km)



For coarse grid spacing

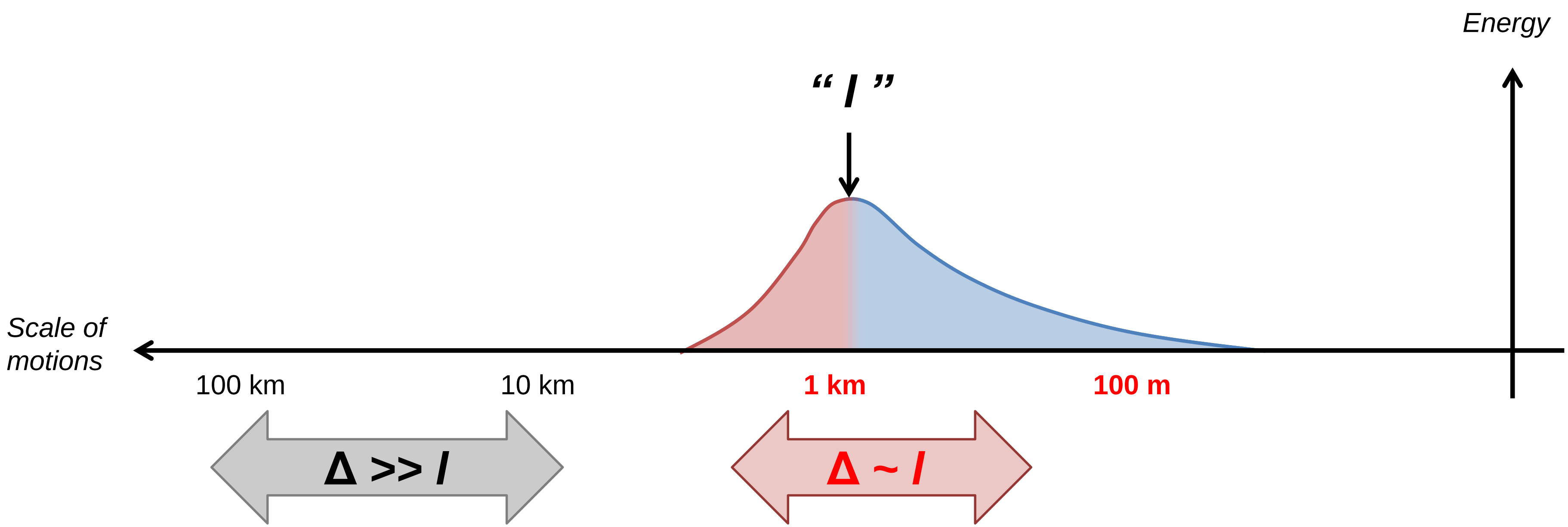
✓ PBL schemes have been **developed for Δ >> *l*.**

For finer grid spacing

✓ **No traditional PBL schemes designed for Δ ~ *l*.**

"Terra Incognita" or "Gray Zone"

From “Parameterized” to “Resolved” Turbulence Statistics



At coarse grid spacing

- ✓ **None** of turbulence is **resolved**.
- ✓ **Evaluation** for:

$$\frac{\partial \overline{c}}{\partial t} = \cdots - \frac{\partial \overline{w'c'}}{\partial z}$$

Mean and parameterized total flux

At finer grid spacing

- ✓ Turbulence is **partially resolved**.
- ✓ Turbulence statistics:

“parameterized” + **“resolved”**

In this study

The performance of PBL parameterizations in WRF model is re-evaluated at sub-kilometer grid spacings, for resolved turbulence statistics.

Methods

1. **Evaluation using reference data: <u>spatially filtered LES output</u>**

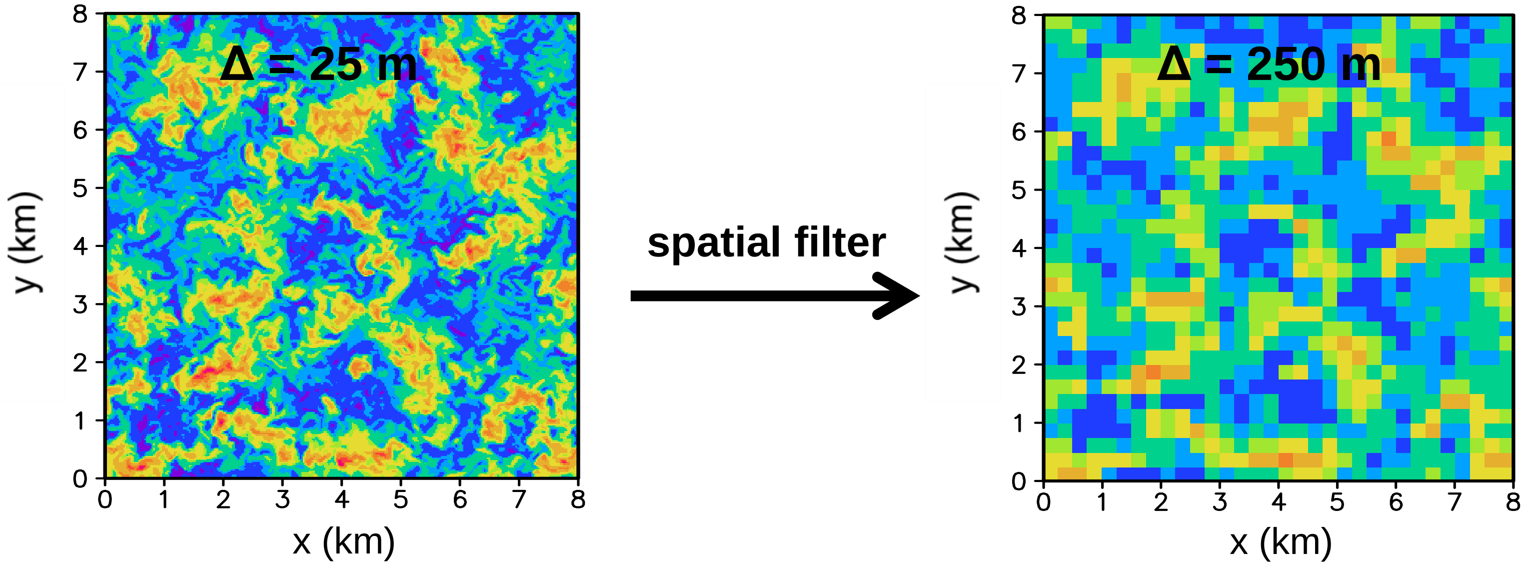
   The most popular way to obtain "reference" for evaluating parameterizations at kilometric and sub-kilometer scales (Honnert et al. 2011; followed by Dorrestijn et al. 2013; Shin and Hong 2013)

2. **PBL schemes selected: <u>characterized by different nonlocal terms</u>**

   Importance of nonlocal terms in sub-kilometer and kilometric grid spacing (Honnert et al. 2011; Shin and Hong 2013, 2015)

Spatially filtered LES output for sub-kilometer grid spacing

(Cheng et al. 2010; Honnert et al. 2011; Dorrestijn et al. 2013; Shin and Hong 2013)



“benchmark” LES fields: w

reference “resolved” fields: $\tilde{w}^{\Delta}$

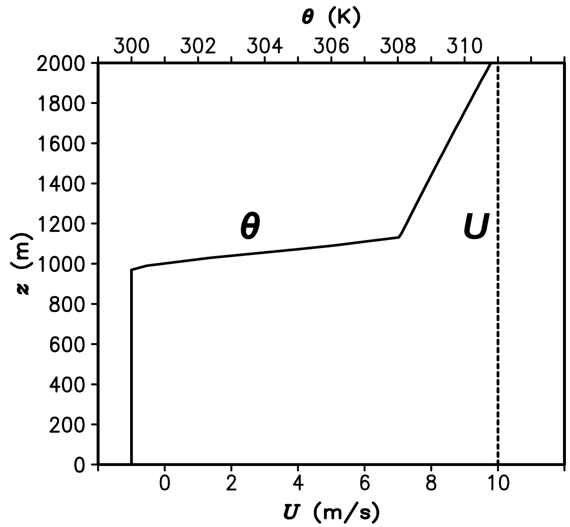
reference “subgrid-scale” perturbations:

$$w' = w - \tilde{w}^{\Delta}$$

Experimental Setup

An idealized convective boundary layer (CBL)

Initial profiles



- ✓ no moisture
- ✓ a constant surface heat flux: 0.2 K m s^{-1}
- ✓ $U_{initial}$ = 10 m s^{-1}
- ✓ u_*/w_* = 0.27 ($-z_i/L$ = 18.58); not in a roll regime

Model setup

	Subgrid-Scale vertical transport	Subgrid-Scale horizontal transport	Grid spacing (m)	No. of grids	Domain size (km^2)
LES	3D TKE	3D TKE	25	320^2	8^2
Reference	Filtered from the LES		250, 500, 1000	32^2, 16^2, 8^2	8^2
Simulations	**PBL schemes**	3D TKE	**250, 500, 1000**	32^2	8^2, 16^2, 32^2

An Overview of PBL Parameterizations in WRF

Representation of unresolved vertical transport

$$\overline{w'c'} = -K_c \frac{\partial \bar{c}}{\partial z} + C_{NL}$$

1st-order vs. 1.5-order (TKE)

nonlocal vs. local

An important part that determines ***a scheme's performance at sub-kilometer grid spacing***

	K_c	C_{NL}
YSU	1st-order	$C_{NL} = K_c\gamma_c + \overline{w'c'}_h \left(\frac{z}{h}\right)^3$
ACM2	$K_{u,v} = k w_s z \left(1-\frac{z}{h}\right)^2$	$C_{NL} = \mathrm{M2u}\,\bar{c}_1^{\Delta} - \mathrm{M2d}_k \bar{c}_k^{\Delta} + \mathrm{M2d}_{k+1}\bar{c}_{k+1}^{\Delta}\frac{\Delta z_{k+1}}{\Delta z_k}$
EDMF	1.5-order	$C_{NL} = \mathrm{M}_u\left(c_u - \bar{c}^{\Delta}\right) \quad \mathrm{M}_u = a_u w_u$
TEMF	$K_c = l\sqrt{e}S_c$	$C_{NL} = \mathrm{M}_u\left(c_u - \bar{c}^{\Delta}\right) \quad \mathrm{M}_u = a_u w_u$
MYNN		0

Examples of previous studies

Coarse grid spacing (Δ >> *l*)

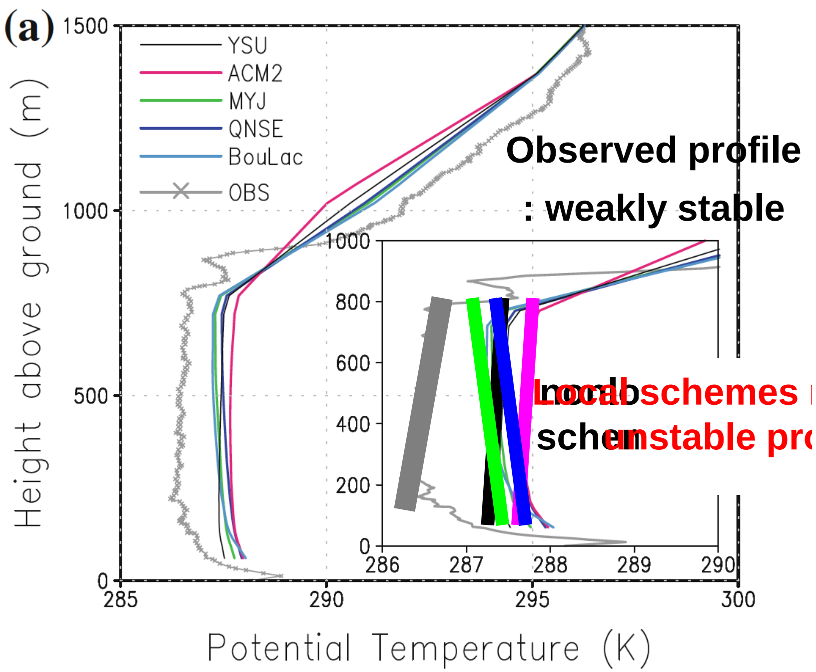


Figure is taken from Shin and Hong (2011)

Fine grid spacing (Δ ~ *l*)

at 1-km grid spacing
with 25-pts averaging

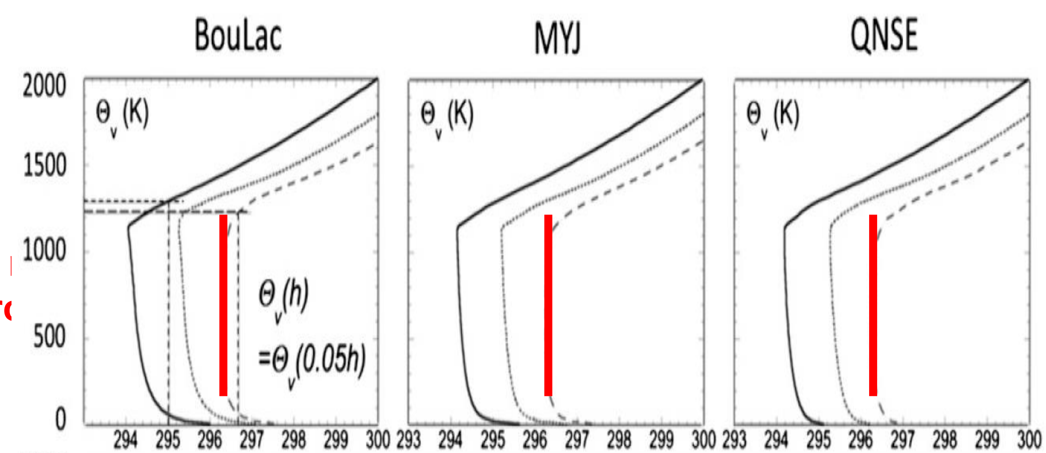
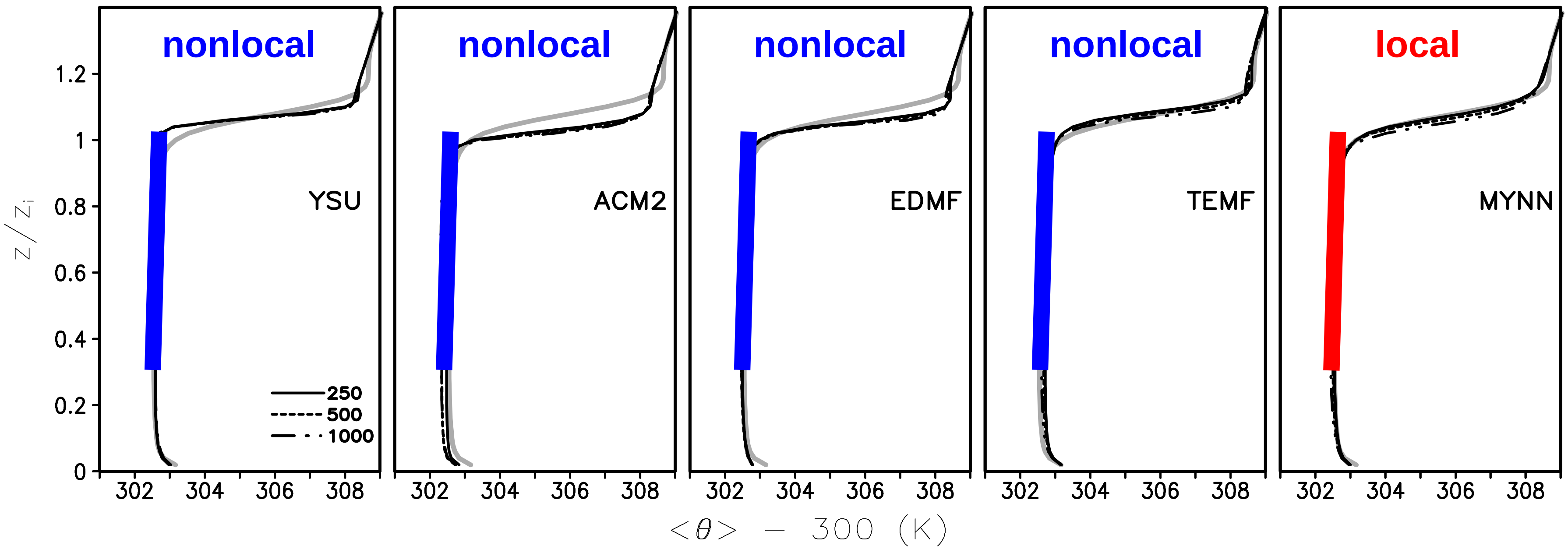


Figure is taken from LeMone et al. (2013)

Temperature Profile

At sub-kilometer and 1-km grid spacing



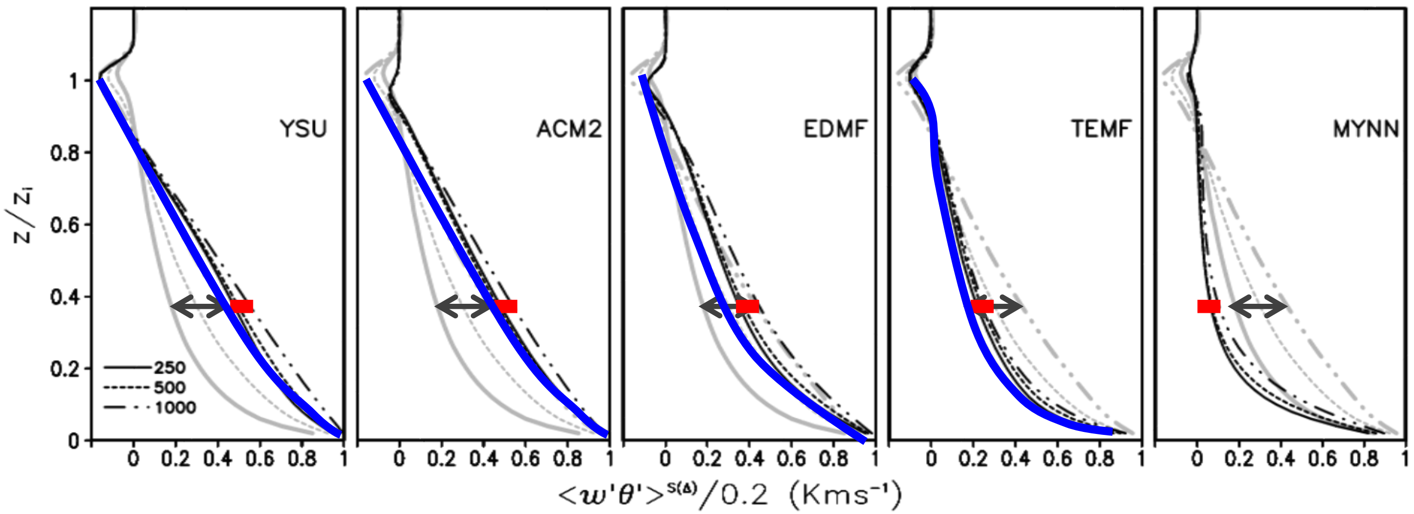
1. The local PBL scheme reproduces a weakly stable/neutral profile.
2. There is almost no resolution dependency.

Vertical Heat Transport Profile

“Parameterized” vertical heat transport

GRAY: reference

BLACK: experiments

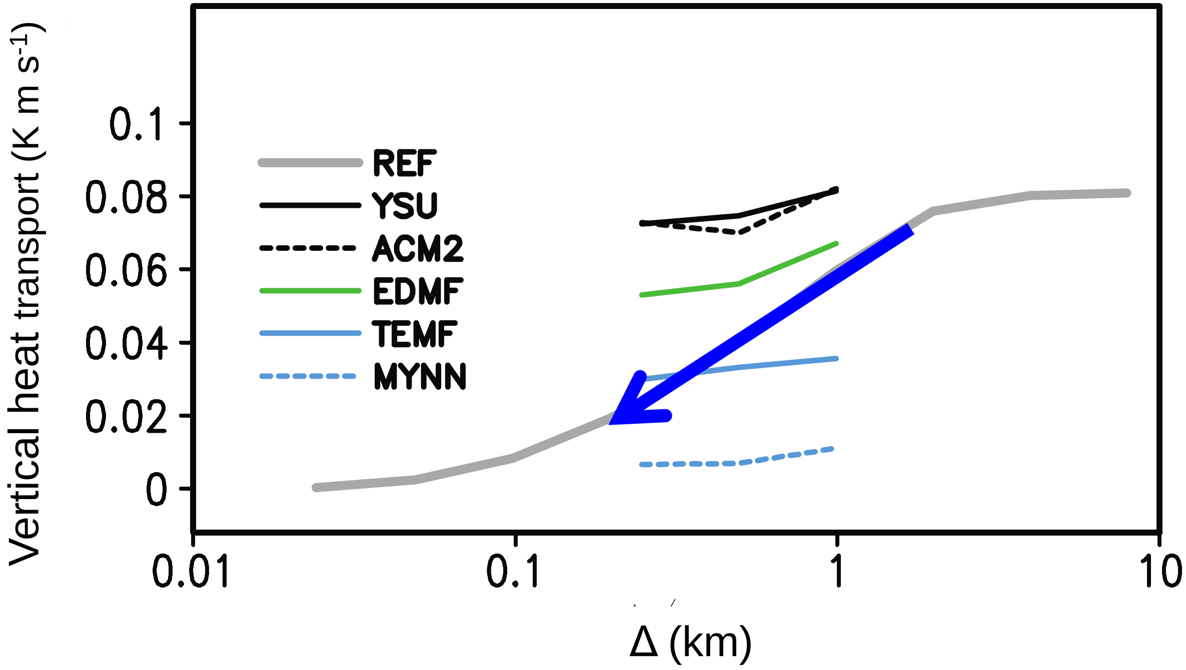


YSU and ACM2: 1000 m **EDMF: ~500 m** **TEMF: 250 m** **MYNN: <250 m**

1. **None of them are scale-aware: little resolution dependency.**
2. **Each parameterization has its own best-performing grid size.**

Parameterizations' Resolution Dependency

"Parameterized" vertical transport <w'θ'>
In mixed layer



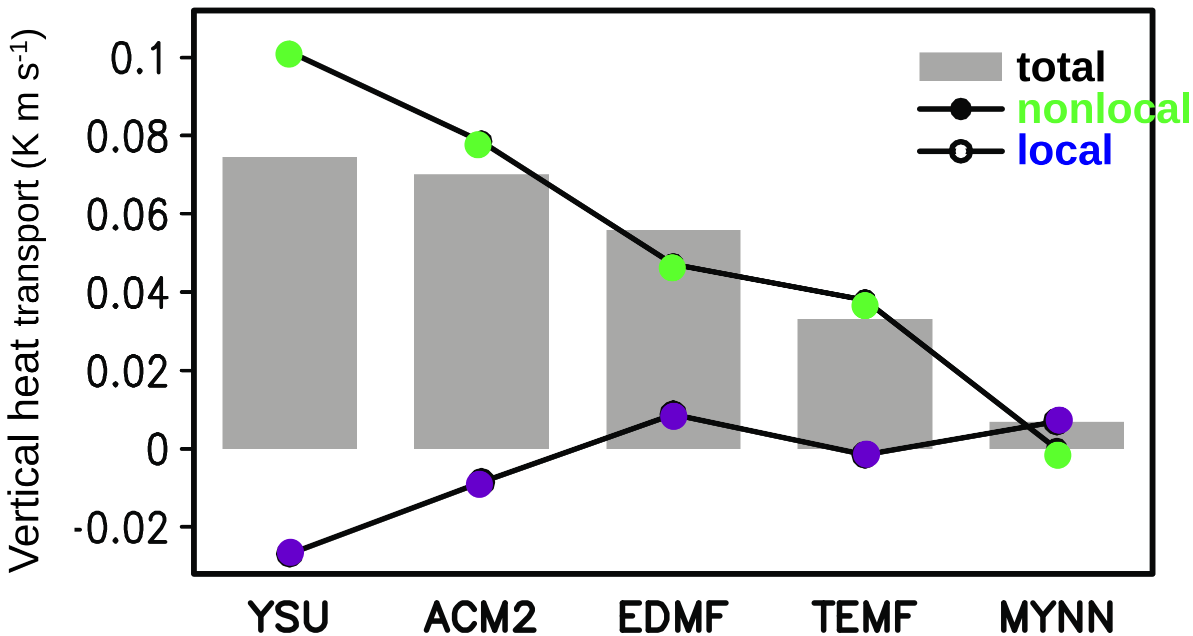
Parameterizations' Resolution Dependency

"Parameterized" vertical transport <w'θ'>

=

Parameterized "nonlocal" transport **+** **Parameterized "local" transport**

C_{NL} **>** $-K_\theta \frac{\partial \theta}{\partial z}$



Grid size for the best performance: 1000 m, 500 m, 250 m, < 250 m

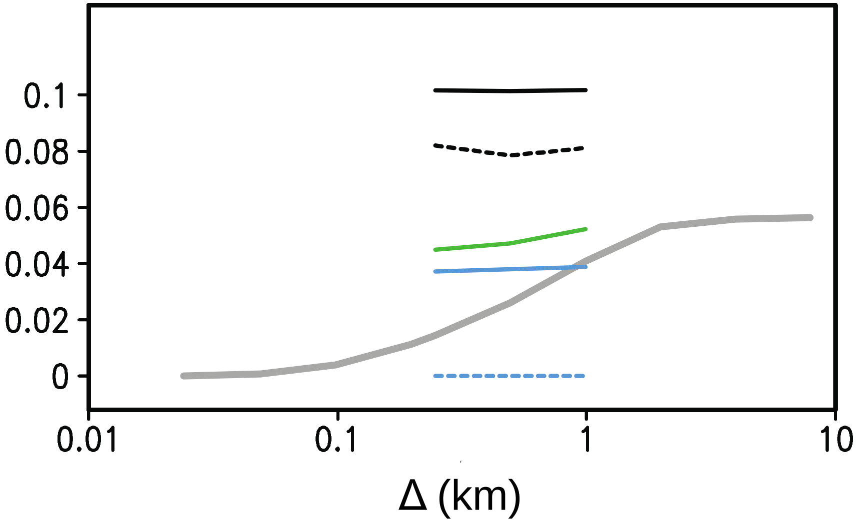
Parameterizations' Resolution Dependency

"Parameterized" vertical transport <w'θ'>

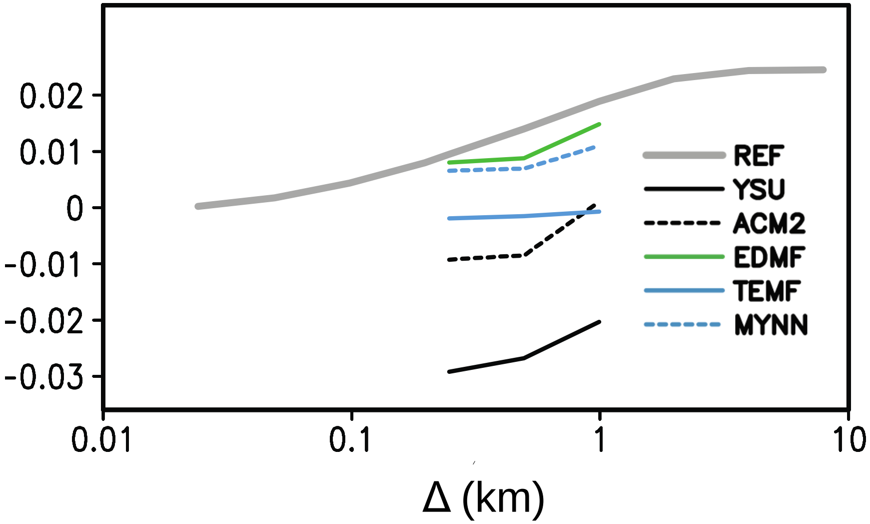
=

Parameterized "nonlocal" transport + Parameterized "local" transport

C_{NL} $-K_\theta \frac{\partial\theta}{\partial z}$

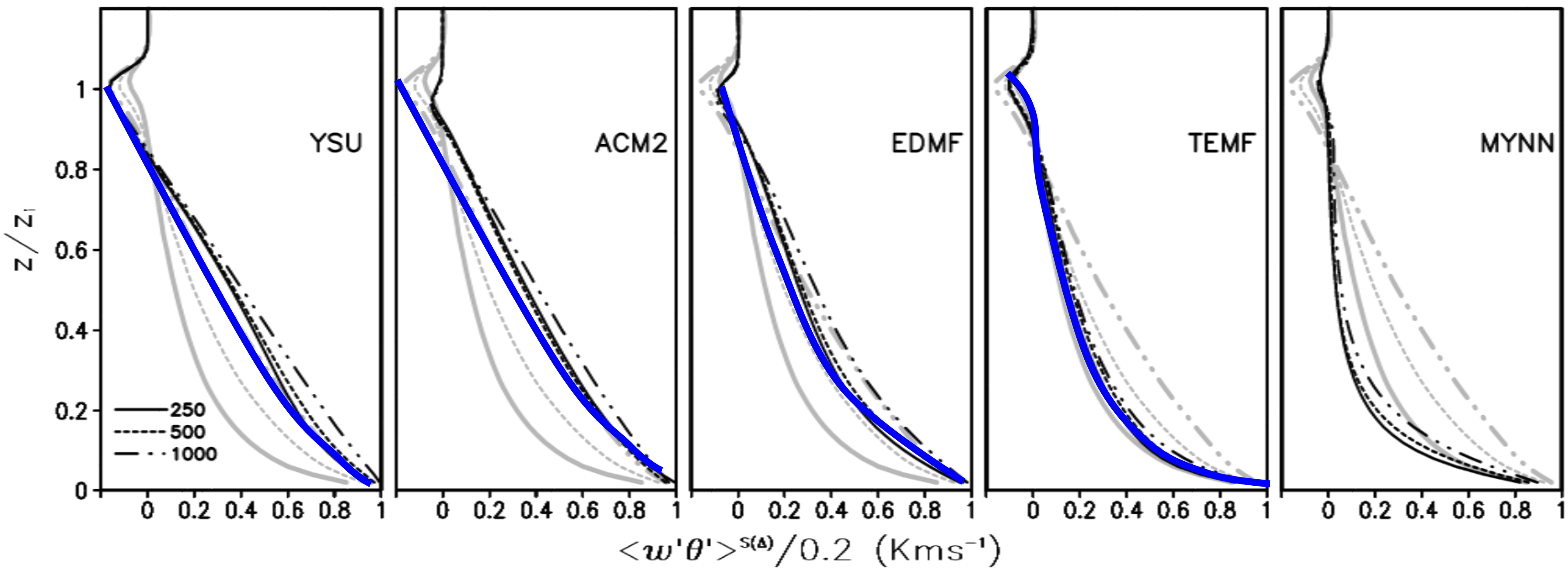


: shows little resolution dependency.



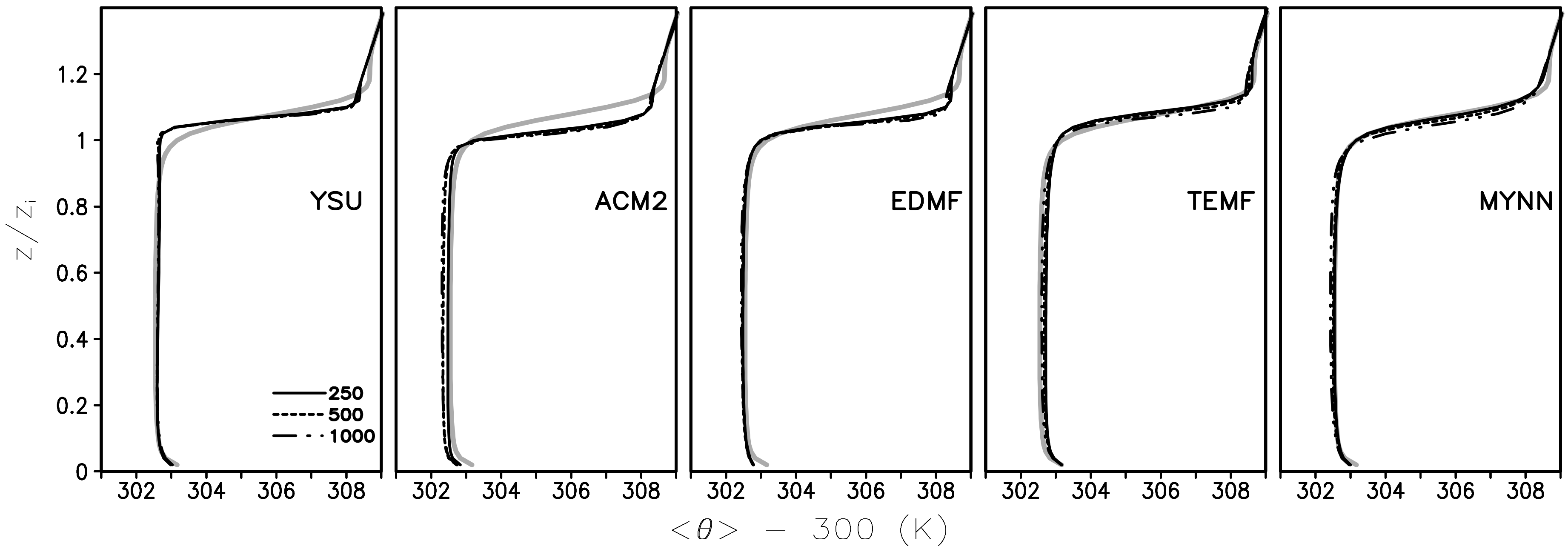
: decreases as Δ decreases.

Vertical Heat Transport Profile



YSU and ACM2: 1000 m **EDMF: ~500 m** **TEMF: 250 m** **MYNN: <250 m**

Temperature Profile

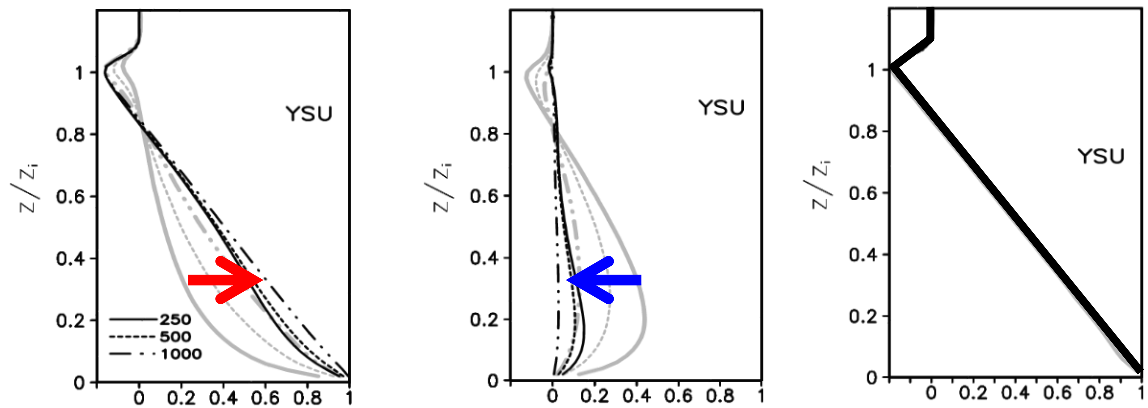


Interactions between Parameterized and Resolved Components

YSU

SGS heat transport is overestimated.

➔Resolved θ' and w' are underestimated.

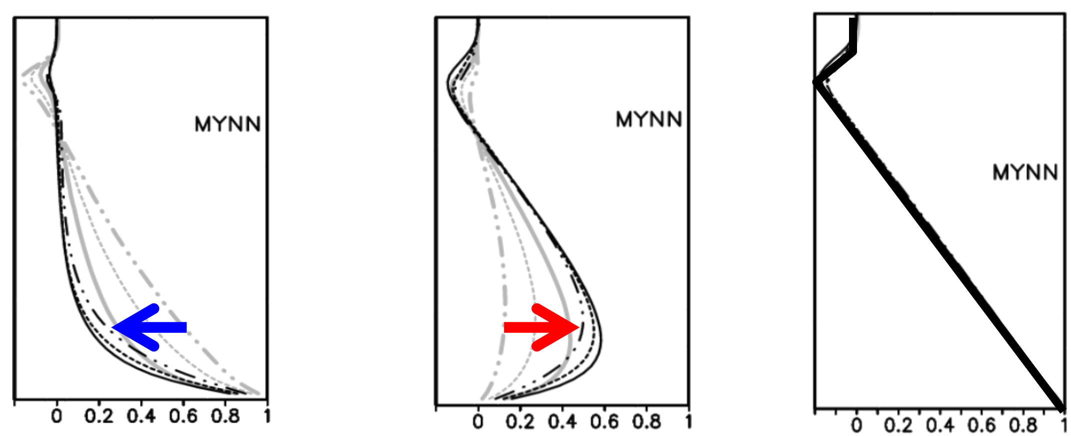


SGS + Resolved = Total

MYNN

SGS heat transport is underestimated.

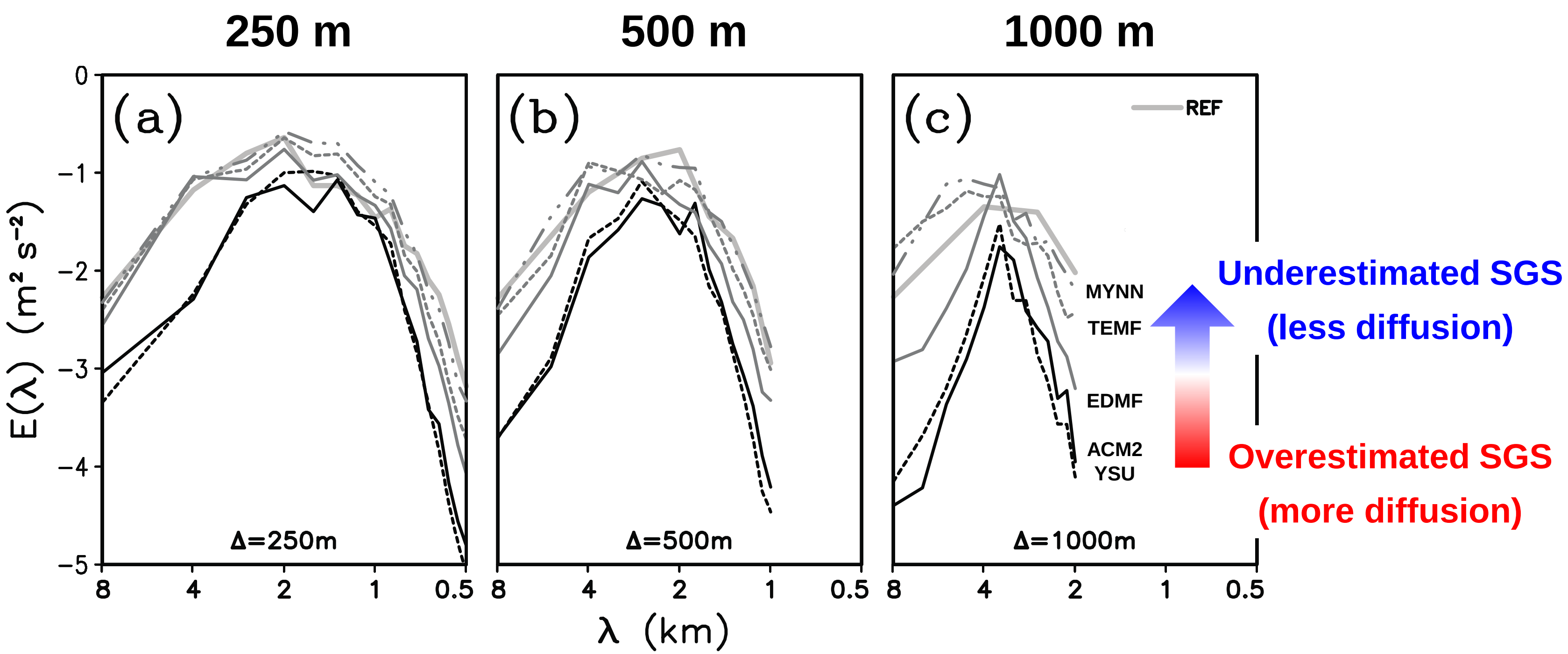
➔Resolved θ' and w' are overestimated.



All the tested PBL parameterizations reproduce well total (resolved + parameterized) vertical transport, therefore mean temperature profiles.

➔ **High-resolution modeling for improving resolved fields**

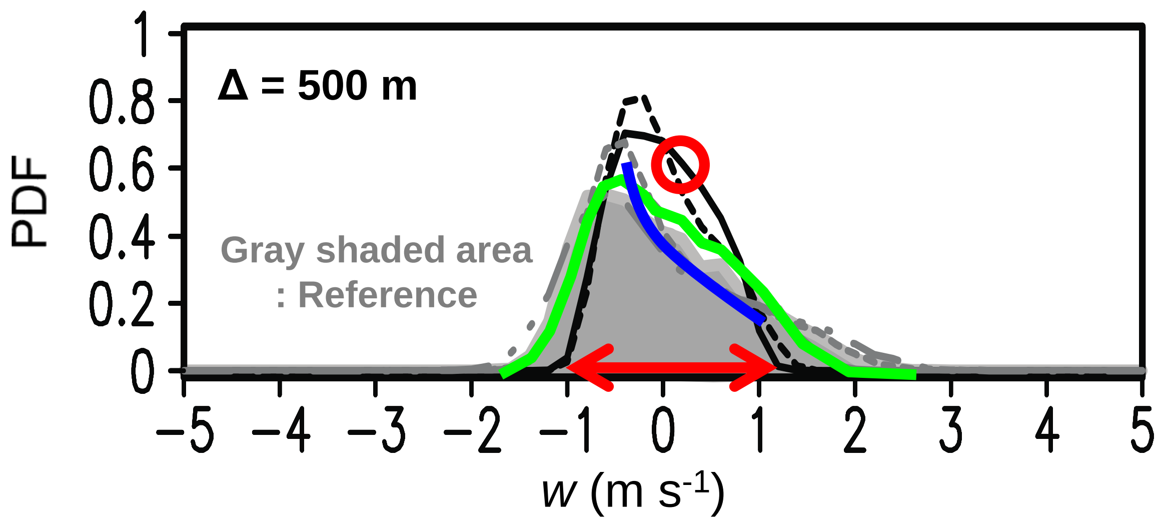
w Spectrum



250 m
500 m
1000 m
(a)
(b)
(c)
REF
MYNN
TEMF
EDMF
ACM2
YSU
Δ=250m
Δ=500m
Δ=1000m
E(λ) (m² s⁻²)
λ (km)
0
−1
−2
−3
−4
−5
8
4
2
1
0.5
Underestimated SGS
(less diffusion)
Overestimated SGS
(more diffusion)

PDF of *w*

Statistical representation of the distribution of *w*



YSU and ACM2

: near-zero *w*

EDMF

: ~ Reference

TEMF and MYNN

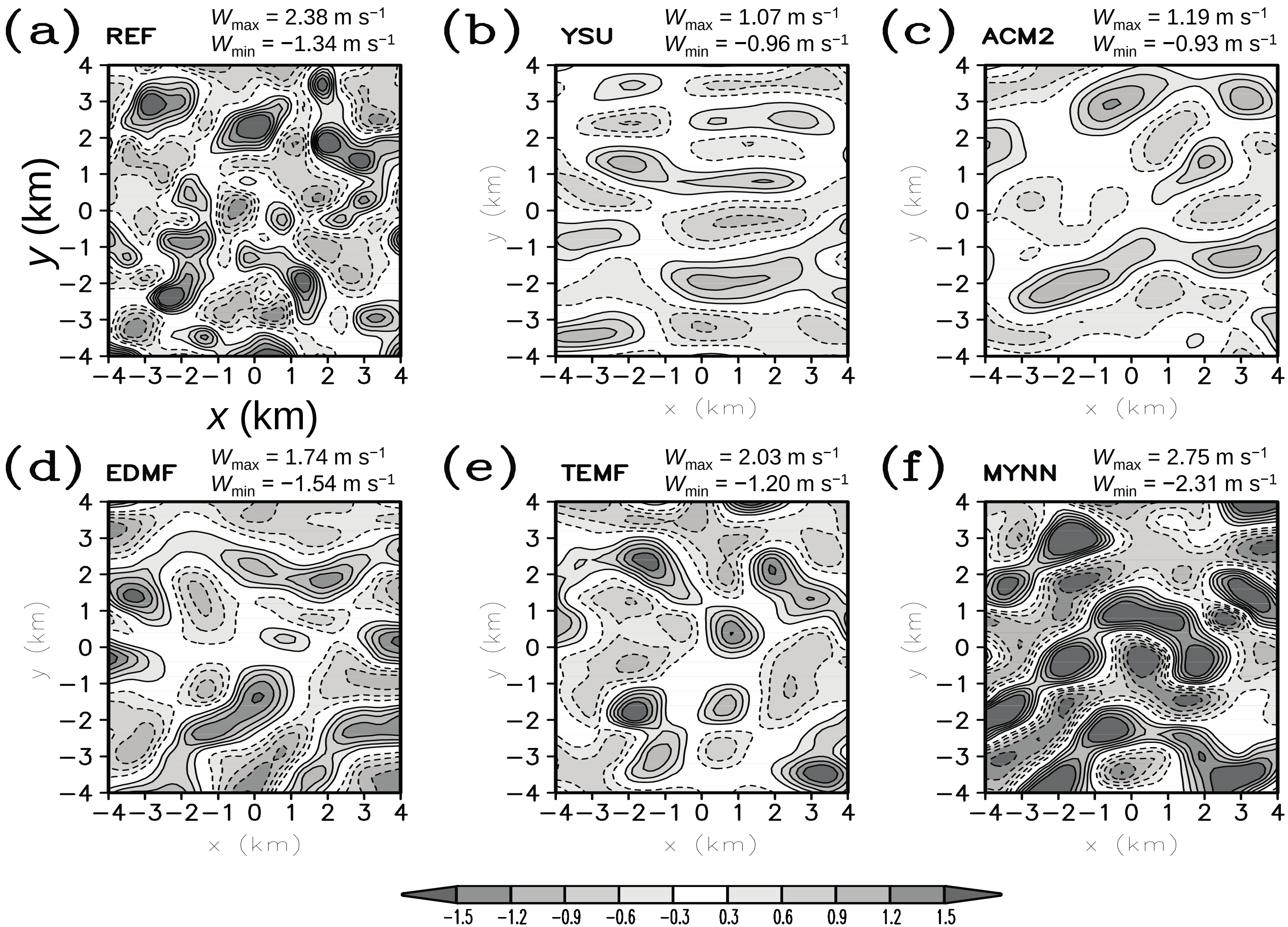
: more downdrafts, less updrafts

Overestimated SGS

Underestimated SGS

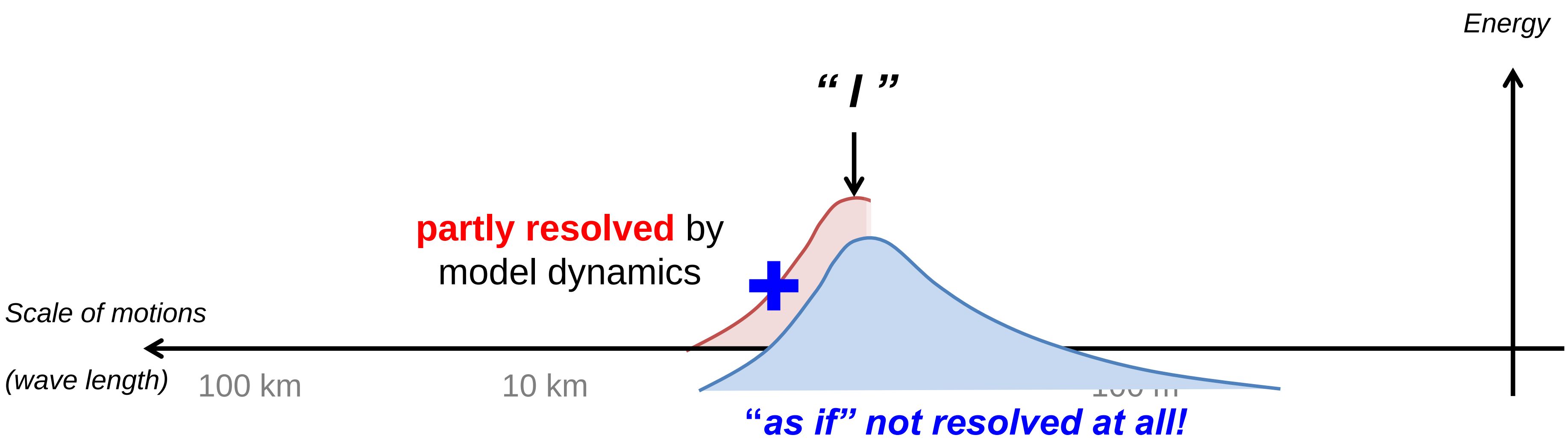
Reference: positively skewed (a few strong thermal updrafts surrounded by a large number of weak inter-thermal downdrafts)

Distribution of w at $0.5z_i$



Gray Zone

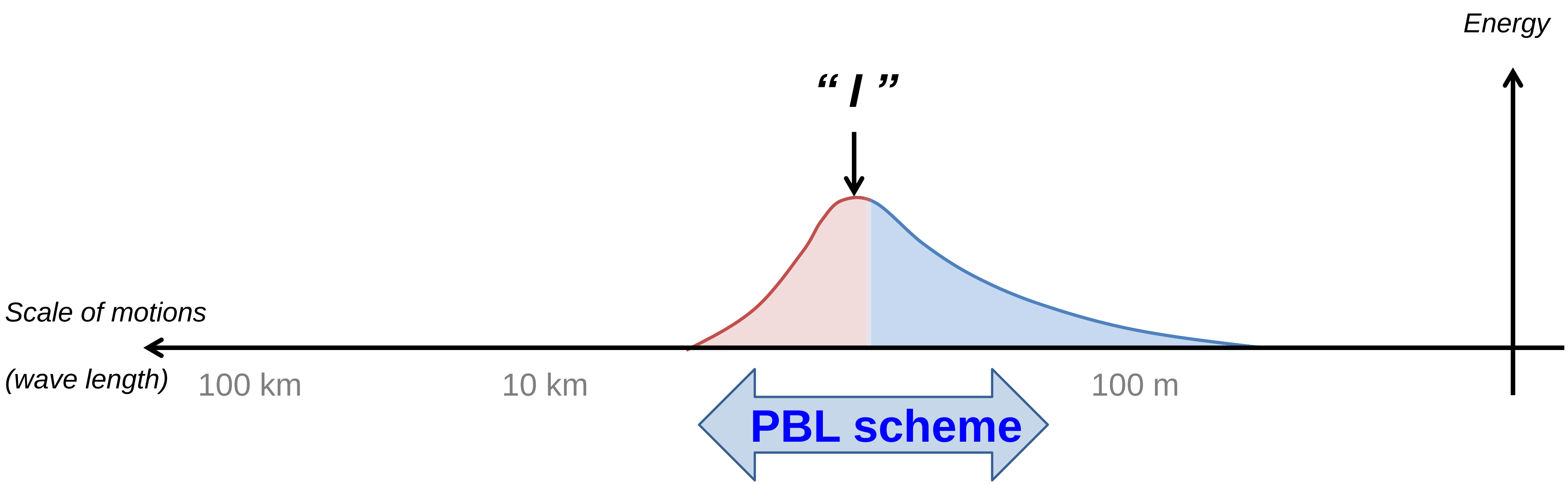
At higher morel resolution, Δ ~ *O*(0.1-1 km): Δ ~ *l*



Gray-zone problem = “Double counting” problem?

Gray Zone

At higher morel resolution, Δ ~ *O*(0.1-1 km): Δ ~ *l*



"Partitioning"

Recent development by modifying traditional schemes

Shin and Hong (2015), replacing YSU PBL (Hong et al. 2006) in WRF
Boutle et al. (2014), replacing Lock PBL (Lock et al. 2000) in UM