Evaluation of PBL Parameterizations in WRF at Sub-Kilometer Grid-Spacing

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With acknowledgement to

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PBL parameterization

Role in atmospheric models

To quantify effects of **unresolved turbulence** **to grid-box mean**

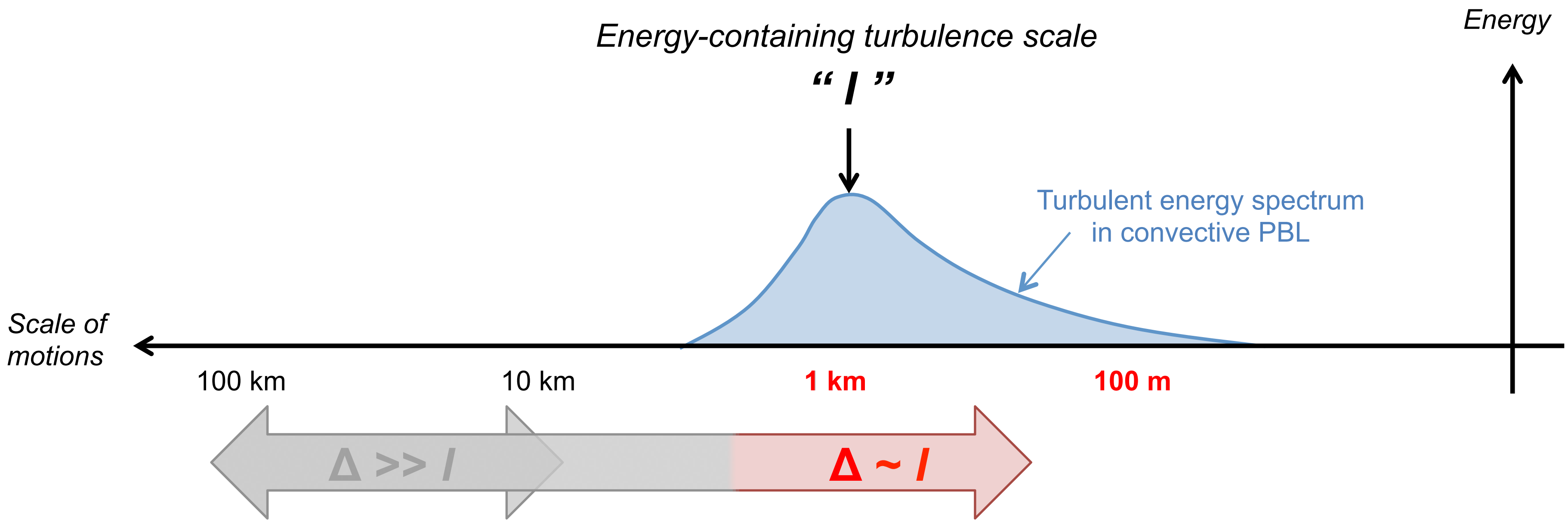
$$\frac{\partial \overline{c}}{\partial t} = \cdots - \frac{\partial \overline{w'c'}}{\partial z}$$

via representation of **unresolved vertical transport**

Evaluation studies

	Typical coarse grid spacing (most of previous studies)	**Fine grid spacing (in this study)**
Model Grid Size	*O*(1-100 km)	***O*(0.1-1km)**
Evaluated Variables	$\overline{w'c'}, \overline{c}$	**"Resolved"** turbulence statistics

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



For coarse grid spacing

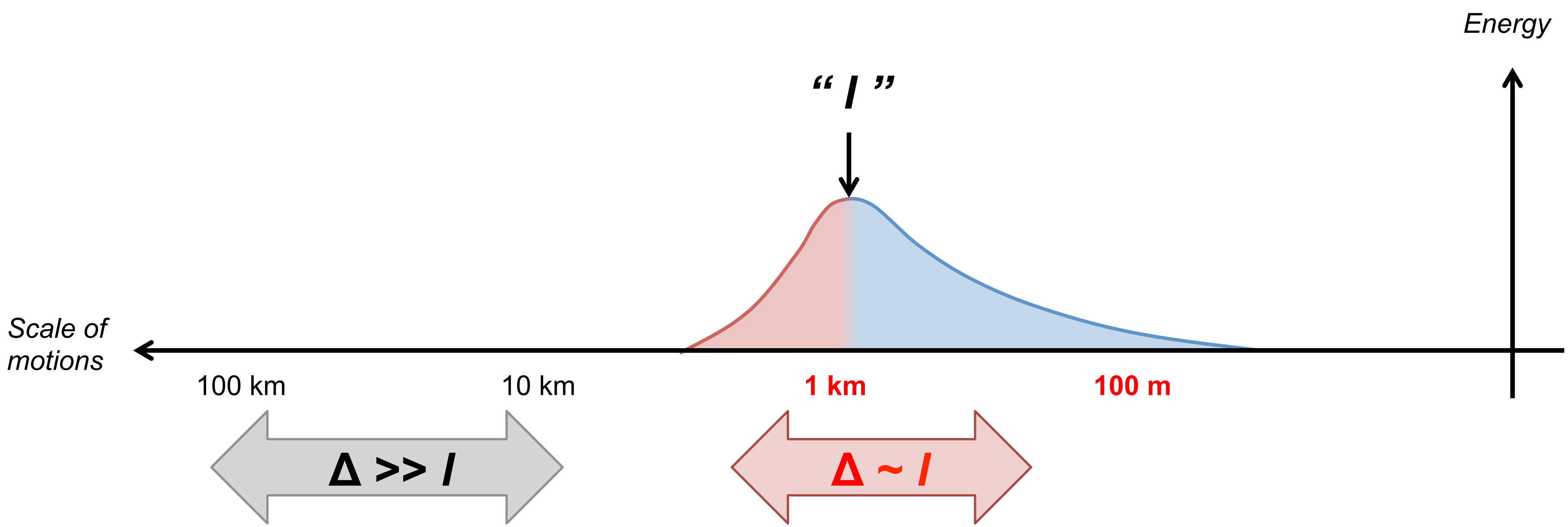
- ✓ PBL schemes have been **designed for Δ >> *l*.**

For recent find grid spacing

- ✓ There are **no traditional PBL schemes designed for Δ ~ *l*.**

➔ **It is not clear how various types of PBL schemes behave on the find grid mesh.**

Evaluated variables: “Resolved” turbulence statistics



At coarse grid spacing

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

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

Mean and parameterized total flux

At recent fine grid spacing

- ✓ Turbulence is **partly resolvable**.
- ✓ High-resolution modeling is **aimed at improving resolved fields**.

➔ **Resolved turbulence statistics are important parameters to be evaluated.**

In this study

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

Methods

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

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

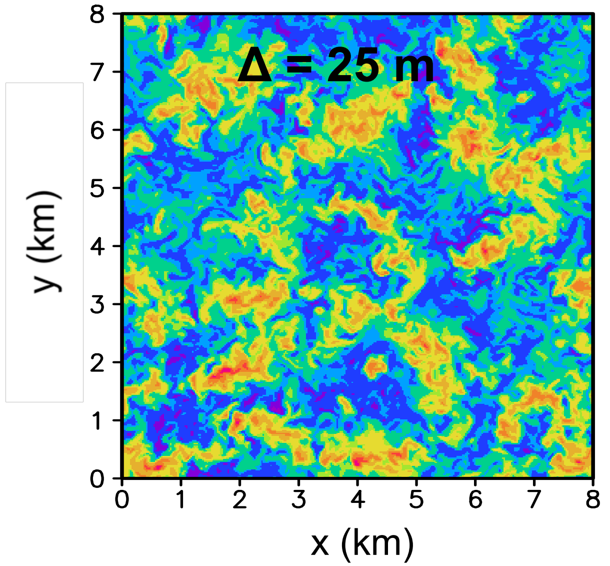
2. **Selected PBL schemes: <u>characterized by different nonlocal terms</u>**

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

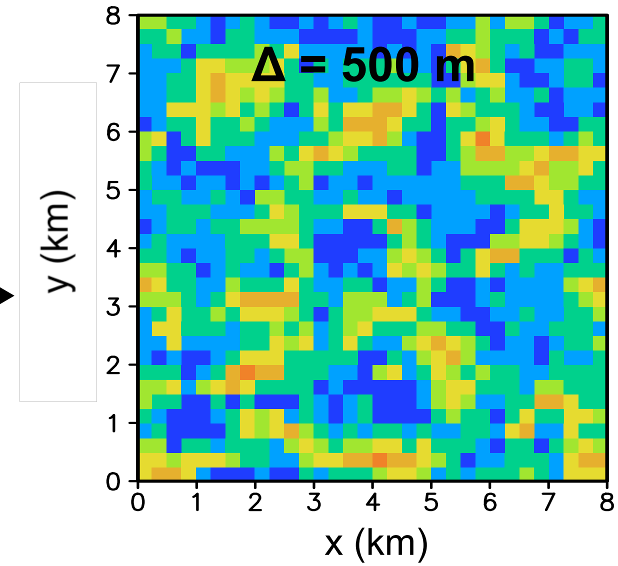
Reference data

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)



spatial filter →



"benchmark" LES fields: w

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

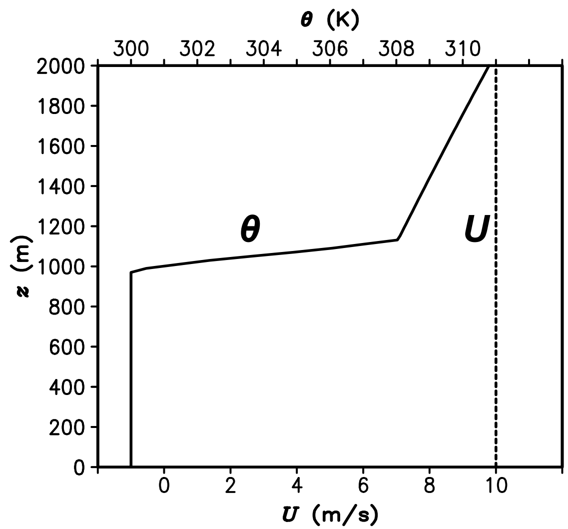
reference "subgrid-scale" perturbations:

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

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
Experiments	**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

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

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

(1) Temperature profile

Examples of previous studies

Coarse grid spacing (Δ >> *l*)

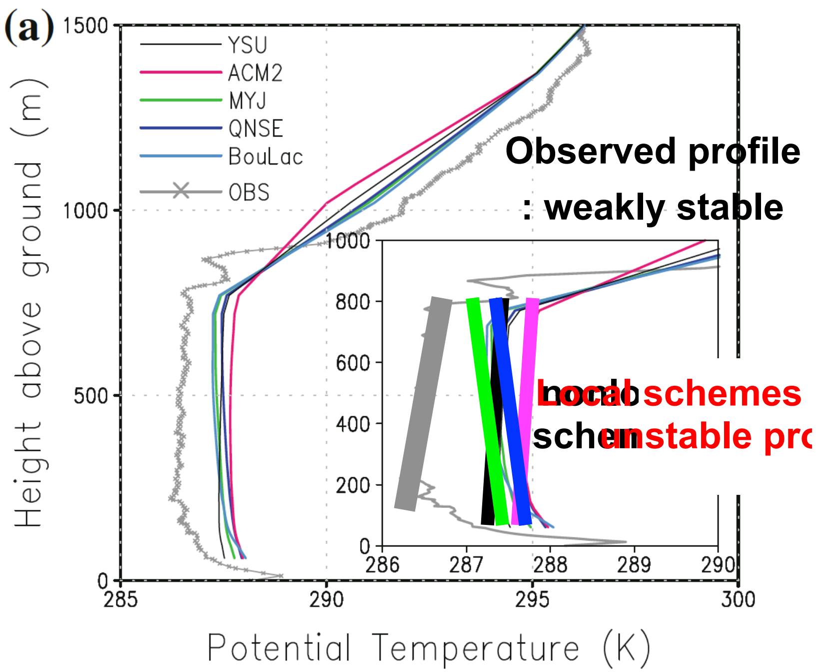


Figure is taken from Shin and Hong (2011)

Fine grid spacing (Δ ~ *l*)

at 1-km grid spacing
with 25-pts averaging

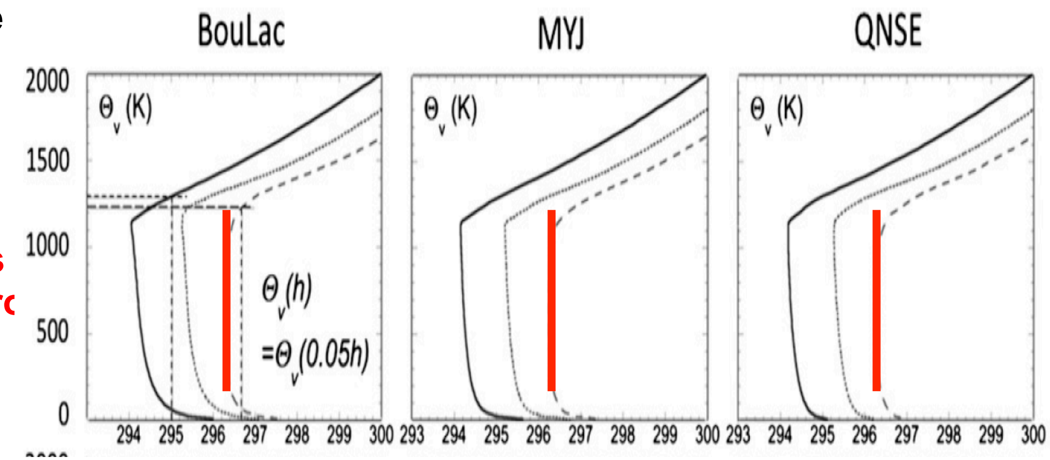
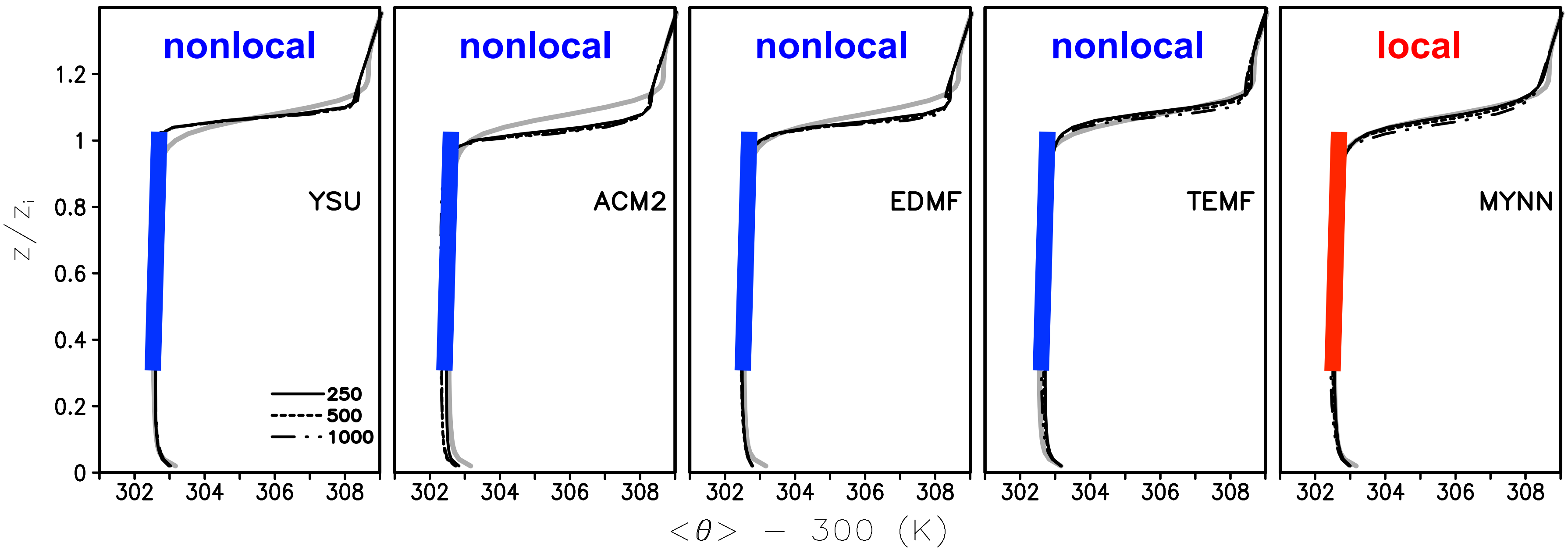


Figure is taken from LeMone et al. (2013)

(1) Temperature profile

At sub-kilometer and 1-km grid spacing



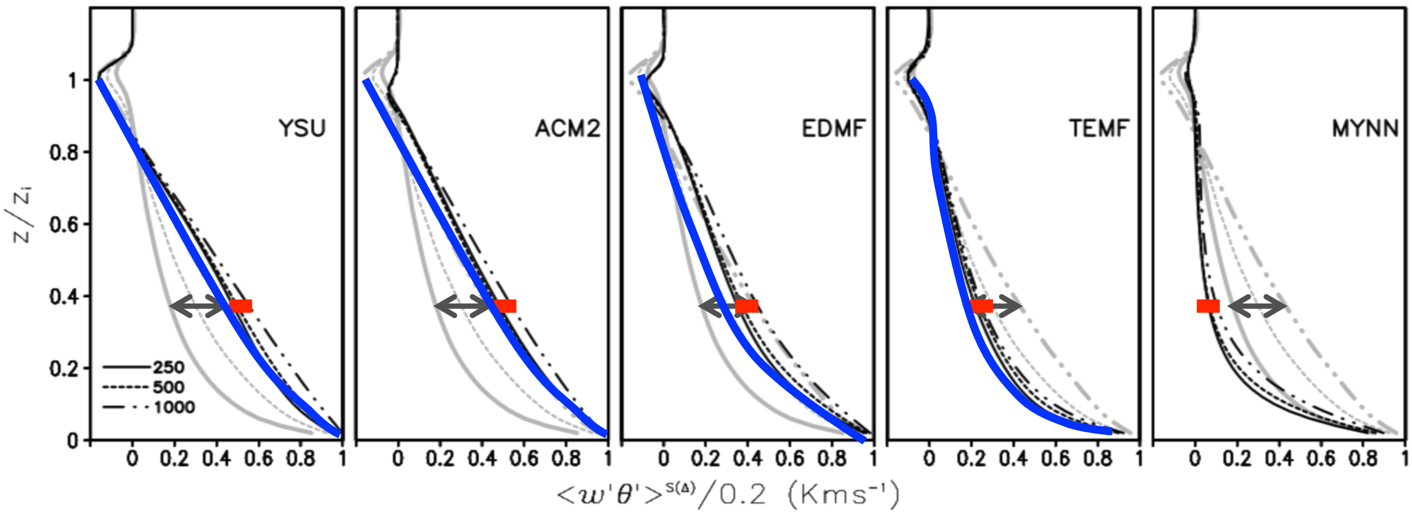
1. The local PBL scheme reproduces a weakly stable/neutral profile.
2. There is almost no resolution dependency.

(2) Vertical heat transport profile

"Parameterized" vertical heat transport

GRAY: reference

BLACK: experiments

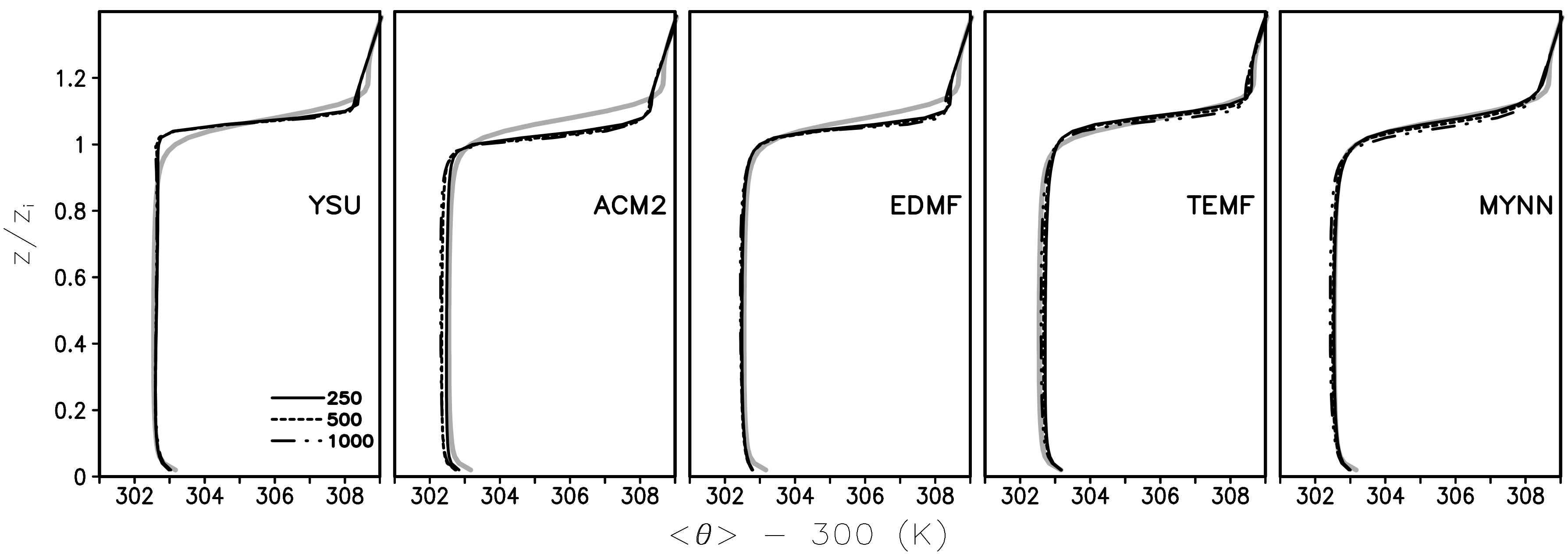


YSU and ACM2: 1000 m **EDMF: ~500 m** **TEMF: 250 m** **MYNN: <250 m**

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

(2) Vertical heat transport profile

Temperature profile



(2) Vertical heat transport profile

Compensation between parameterized and resolved parts

YSU

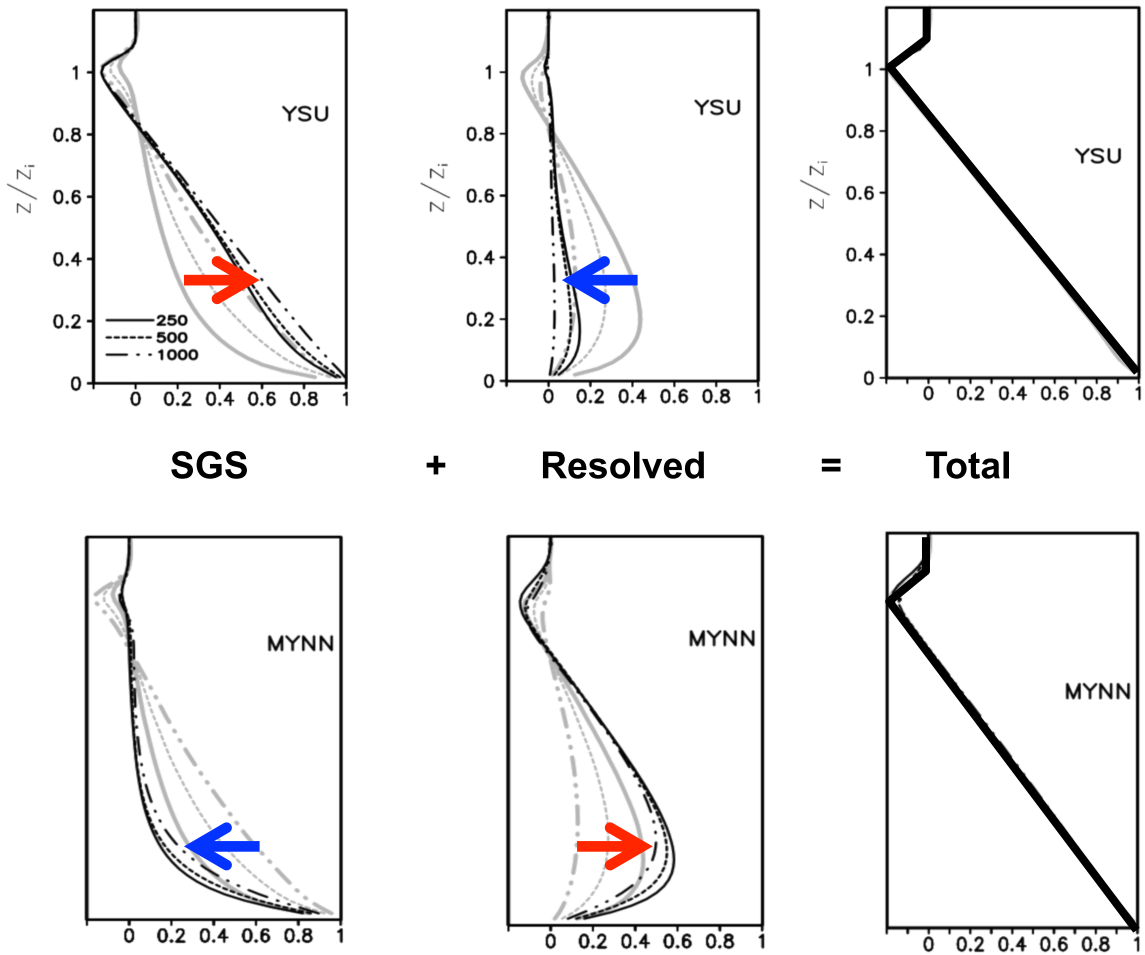
SGS heat transport is overestimated.

➔Resolved θ' and w' are underestimated.

MYNN

SGS heat transport is underestimated.

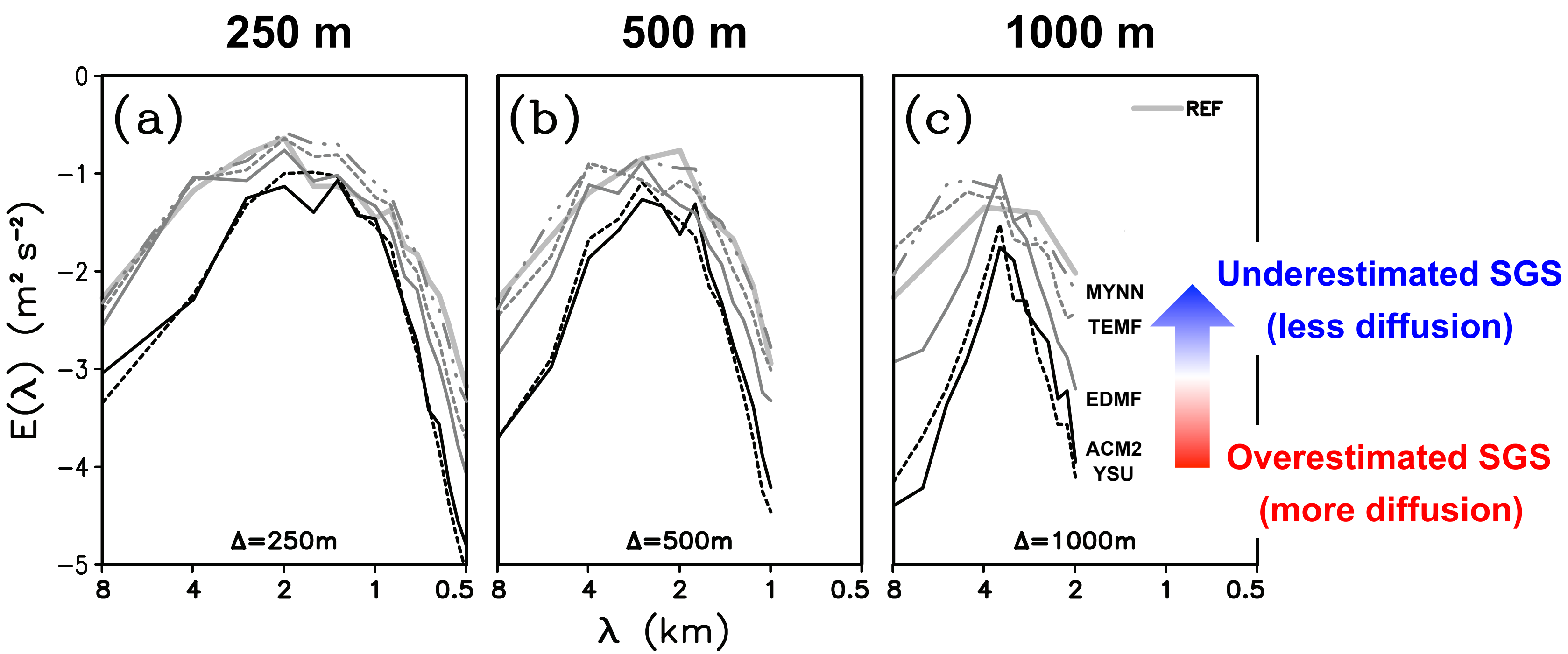
➔Resolved θ' and w' are overestimated.



All the tested PBL parameterizations succeed in simulating total (resolved + parameterized) vertical transport, therefore mean temperature profiles.

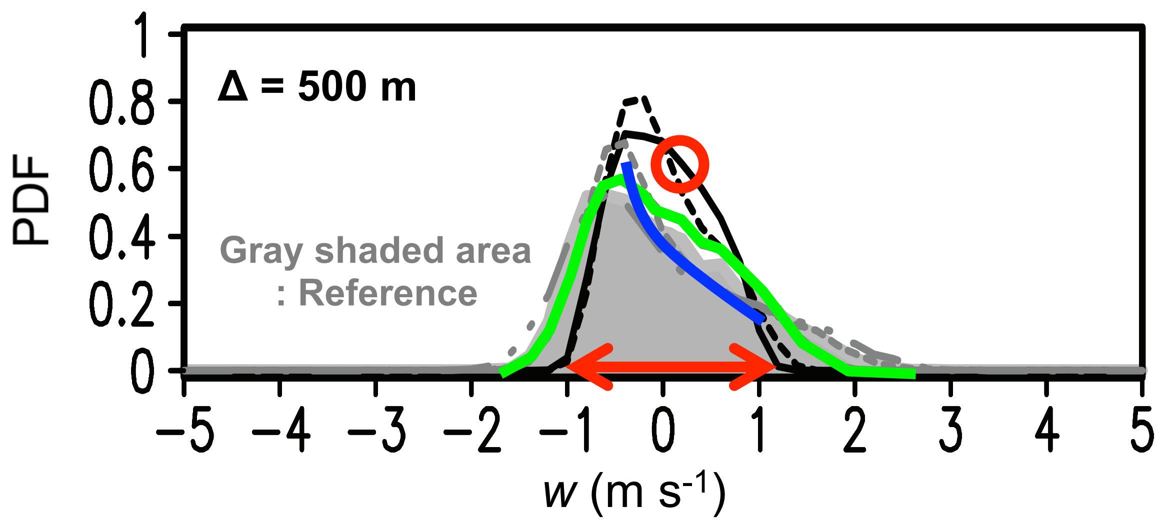
➔ **High-resolution modeling is aimed at improving resolved fields.**

(3) Resolved *w* spectrum



(4) PDF of resolved *w*

Statistical representation of the distribution of *w*



YSU and ACM2

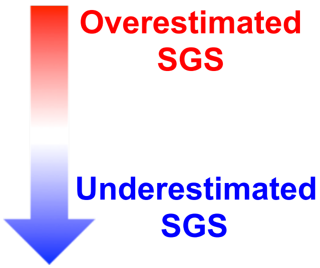
: near-zero *w*

EDMF

: ~ Reference

TEMF and MYNN

: more downdrafts, less updrafts



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

Summary

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

Overestimated SGS

Underestimated SGS

	Δ = 250 m	500 m	1000 m	
YSU ACM2	O	O	O	mean & total transport
			O	parameterized transport
				energy spectrum (scale)
				histogram (structure)
EDMF	O	O	O	mean & total transport
		O		parameterized transport
	Δ	Δ		energy spectrum (scale)
	O	O	O	histogram (structure)
TEMF MYNN	O	O	O	mean & total transport
	O			parameterized transport
	Δ	Δ		energy spectrum (scale)
	O			histogram (structure)

New PBL option in WRFV3.7: Shin and Hong (2015)

✓ **Coded based on YSU PBL,**

with modified convective PBL mixing for "Δ < 2*PBL_Height".

✓ **Prescribed nonlocal heat transport profile**

YSU: $K_h \gamma_h$ (correction term) ➔ New: LES-based nonlocal transport profile

✓ **Explicit grid-size dependency function is included.**

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

✓ **A bug in the new option (q_v tendency) has been fixed. Please, contact me.**

	Δ = 250 m	**500 m**	**1000 m**	
New	O	O	O	mean & total transport
	O	O	O	parameterized transport
	Δ	Δ		energy spectrum (scale)
	O	O		histogram (structure)

Thank you! Questions and comments?

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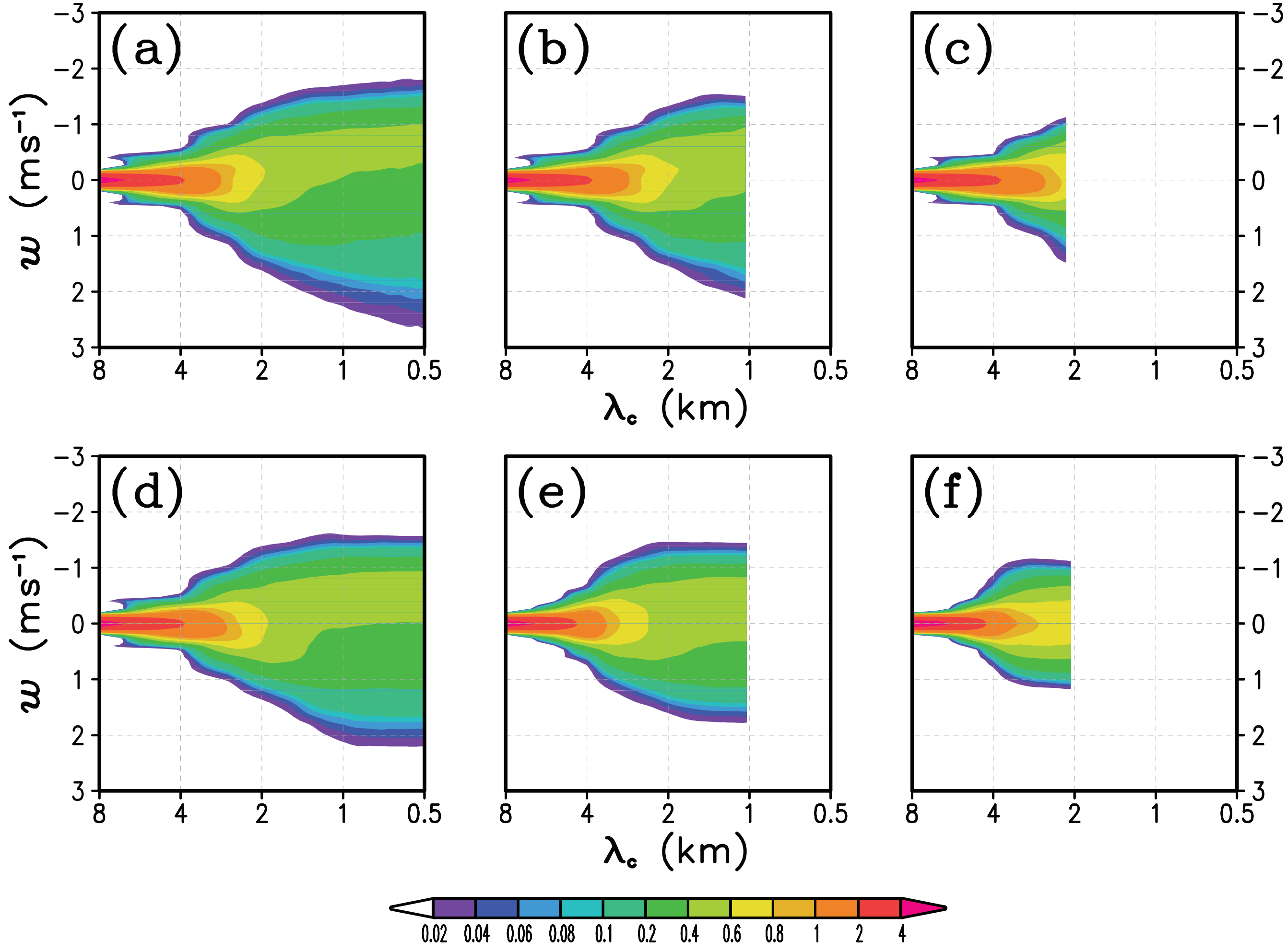
(5) Scale dependency of *w* histogram



(6) Horizontal w at $0.5z_i$