Terra Incognita となる解像度のための Mellor-Yamada モデルの拡張

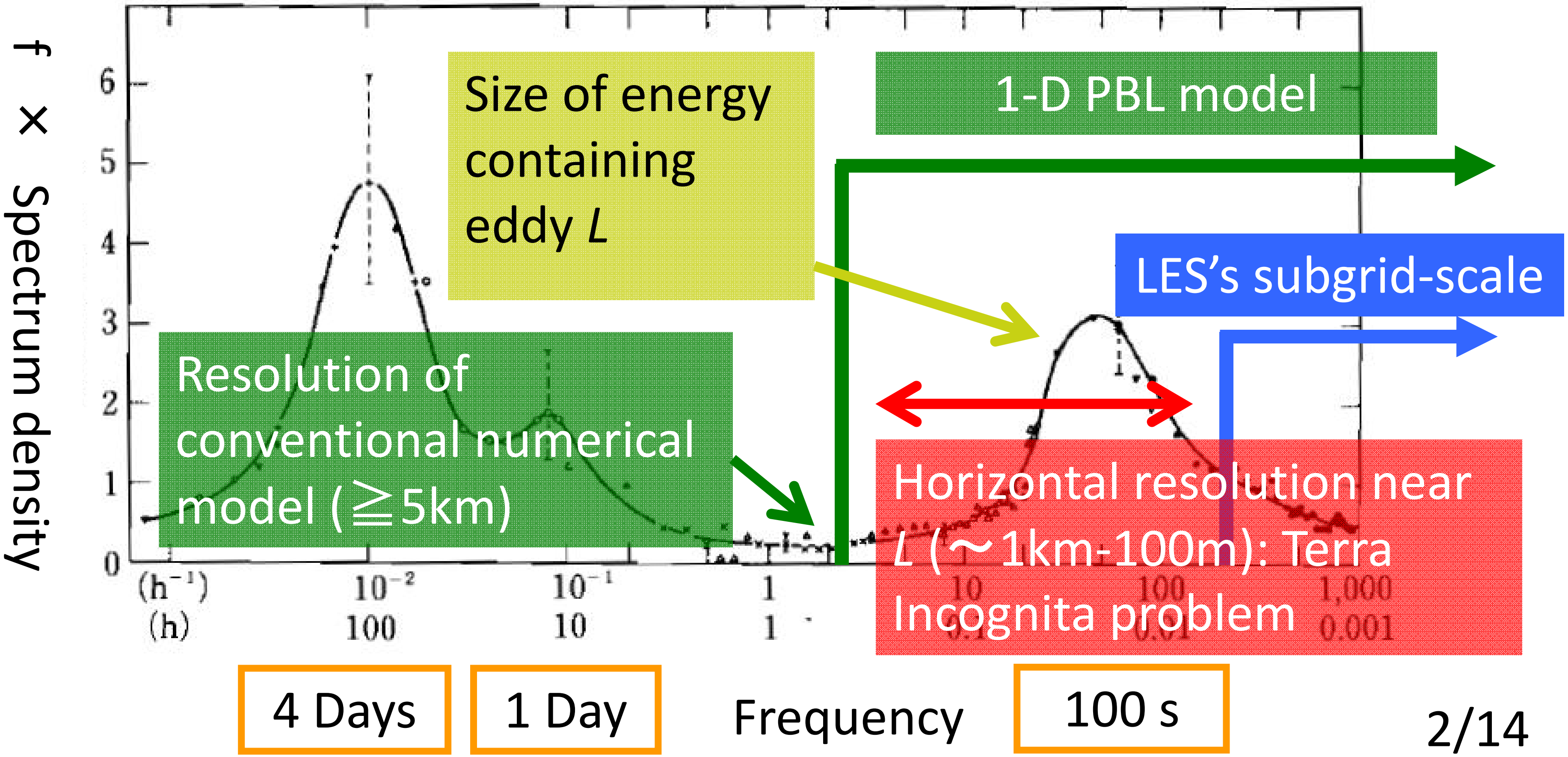
An extension of Mellor-Yamada model to apply for the resolution of Terra Incognita

伊藤純至（東大AORI/気象研)
新野宏 (東大AORI)
中西幹郎 (防衛大)
Chin-Hoh Moeng (NCAR)

1. "Terra Incognita" (Grey Zone) problem in PBL turbulence modeling

※ Terra Incognita: 未知の領域
PBL: Planetaty Boundary Layer　大気境界層

Spectrum of wind near surface



Objectives

Develop **a new PBL model** for resolution of Terra Incognita(TI)

- Design based on LES reference

  e.g. Honnert et al. (2012); Shin and Hong (2013); Kitamura@MRI (Submitted)

- Test run of a new model with horizontal resolution of TI

e.g. Ramachandran et al. (2011); Boutle et al. (2014)

↑

An extension of UK model's non-local PBL scheme

→ **Pragmatic extension** of Mellor-Yamada's PBL scheme used in JMANHM etc.

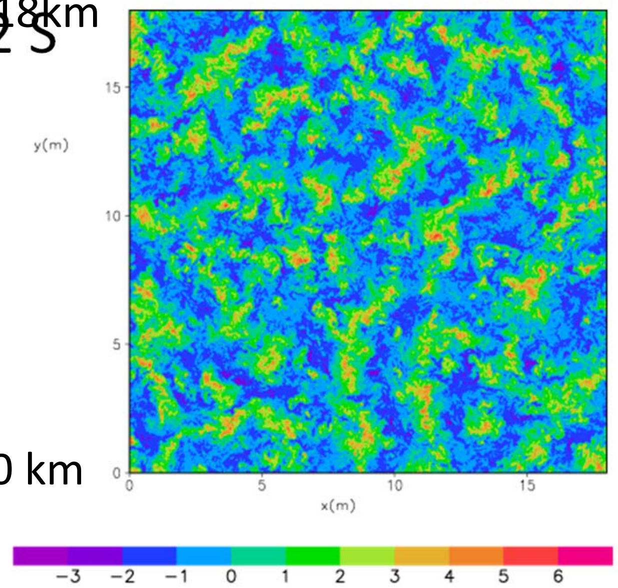
2. LES Reference

- Basic equation : Boussinesq approximation, Dry, Smagorinsky-Lilly's SGS
- Domain: 18km × 18km × 4.5km
- Resolution: 25m
- Lateral Bound.: Doubly periodic
- Bottom Bound.: Bulk method (Momentum) / Heat flux Q=0.2K × m/s
- Geostropic winds: V=5 m/s
- Δt: 0.2 S

CBL (Convective Boundary Layer) grows

Sensitivity on Q and V (not shown)

Vertical velocity in middle of CBL



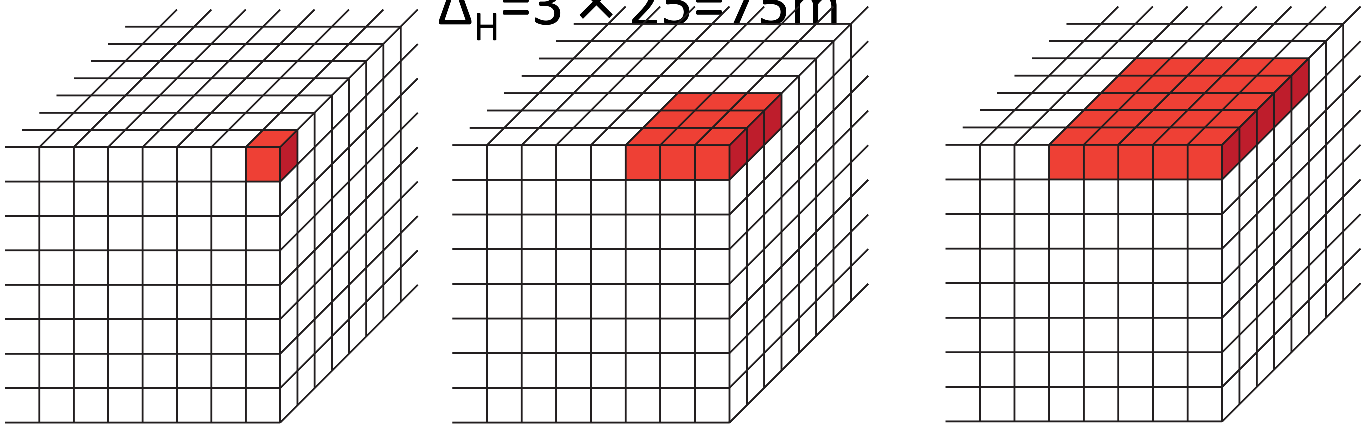
Horizontal filter

Top-hat filter: $\overline{f(x_i)} = \iint f(x_i)G(x_i - x_i')dx_i'$ $\quad G(x_i - x_i') = \begin{cases} 1/\delta_h & (|x_i - x_i'| \le \delta_h) \\ 0 & (|x_i - x_i'| > \delta_h) \end{cases}$

Grid values

Horizontal filter of size $\Delta_H = 3 \times 25 = 75$m

$\Delta_H = 5 \times 25 = 125$m



Larger Δ_H →

Obtain ↓ Only w

↓

		Associated with	
Average	$\overline{w}$	-------- Grid scale motions	should be modeled for resolution Δ_H
Variation	$\overline{w^2}$	-------- Sub-filter TKE	
Triplet	$\overline{w^3}$	-------- Turbulent transport	

Scaling and TKE budget

Free convection scaling (Deardroff 1970) is operated on results with "*"

- Length: height of convective boundary layer *h*
- Velocity : Convective velocity w_*
- Heat flux : Surface flux Q

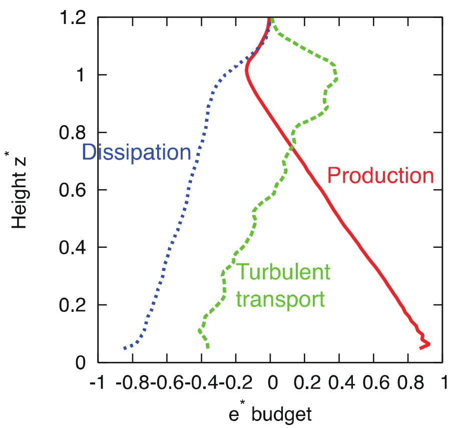
Range $0.5 < \Delta_H^* (\equiv \Delta_H/h) < 2$ correspond to TI scale

---

MY model solves prognostic equation of TKE（乱流運動エネルギー):

Advection **Production** **Turbulent transport** **Dissipation**

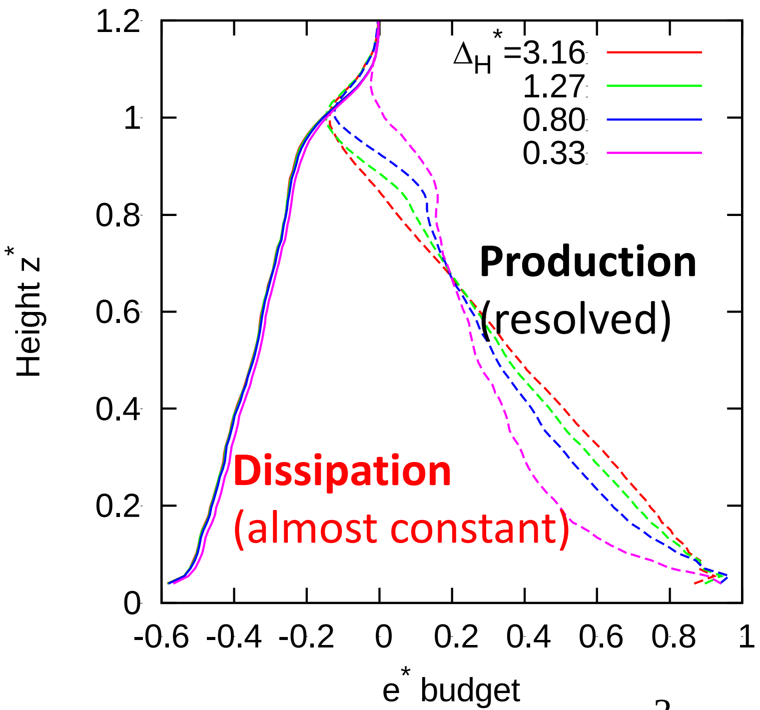
$$\frac{\partial e}{\partial t} + \boxed{u_i \frac{\partial e}{\partial x_i}} = \boxed{-\tau_{ij} S_{ij} + \frac{g}{\theta_0} f_3} - \boxed{\frac{\partial}{\partial x_i}\left(\overline{u_j e} - \overline{u_j}\,\overline{e}\right) - \frac{1}{\rho_0}\left(\overline{u_j p} - \overline{u_j}\,\overline{p}\right)} - \boxed{\varepsilon}$$

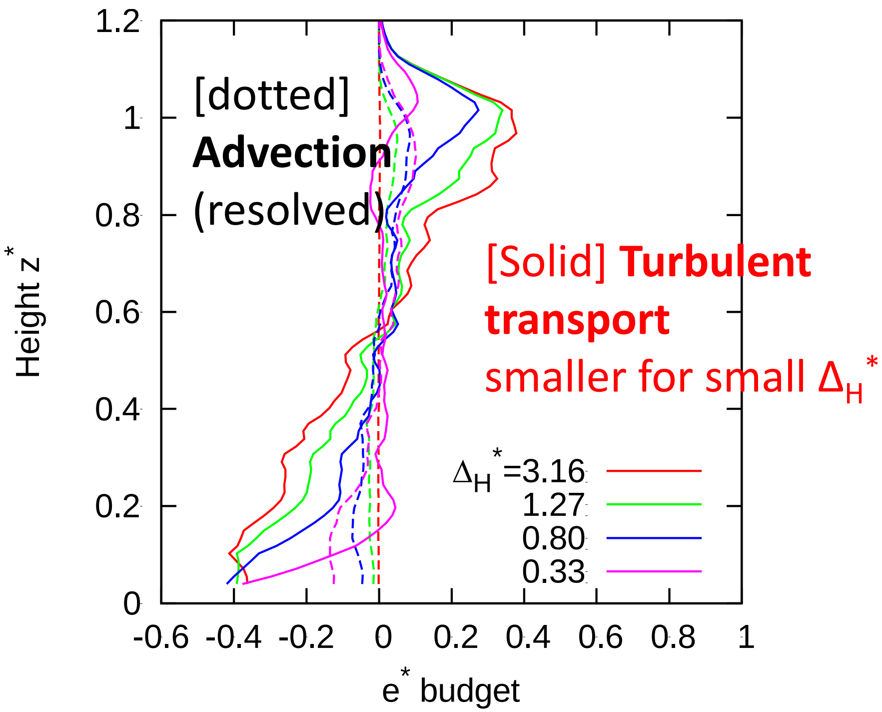


Vertical profiles of over whole x-y cross section ← $\Delta_H^* \rightarrow \infty$: Meso-scale limit

3. Design of model: Estimated terms in TKE budget for various Δ_H^*

Vertical Profiles of terms in TKE budget (horizontal average)



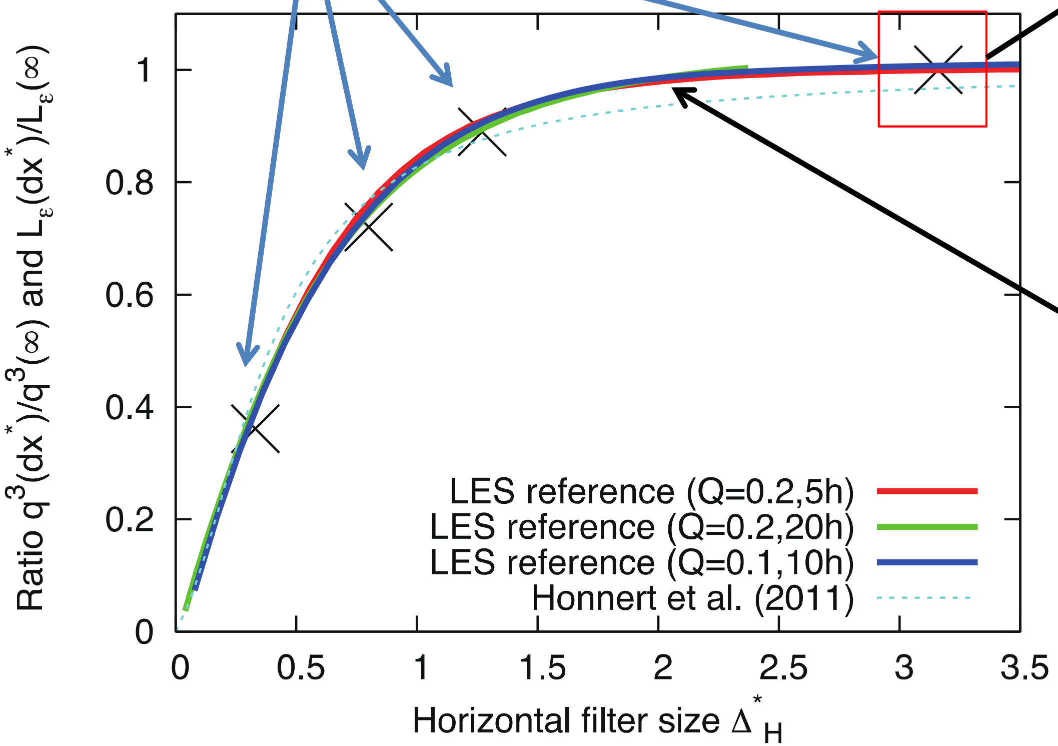


① Dissipation: $\varepsilon = -\dfrac{q^3}{L_\varepsilon}$ → q: Turbulent velocity ∝ TKE

② Turbulent transport (T.T.): $T.T. = -qL_h \dfrac{\partial e}{\partial x_i}$ Assumed down-gradient form

① Horizontally averaged Dissipation length <L_ε>

Estimated <L_ε> for various $\Delta_H{}^*$



L_ε of Meso-scale limit (e.g. Nakanishi and Niino,2009)

"Partition function" of TKE

$$F = \left(\frac{\Delta_H^{*2} + (7/100)\Delta_H^{*2/3}}{\Delta_H^{*2} + (3/21)\Delta_H^{*\,2/3} + 3/42} \right)^{\frac{2}{3}}$$

(Honnert et al. 2012) can prescribe <L_ε> for TI scale as $L_\varepsilon \times F(\Delta_H{}^*)$

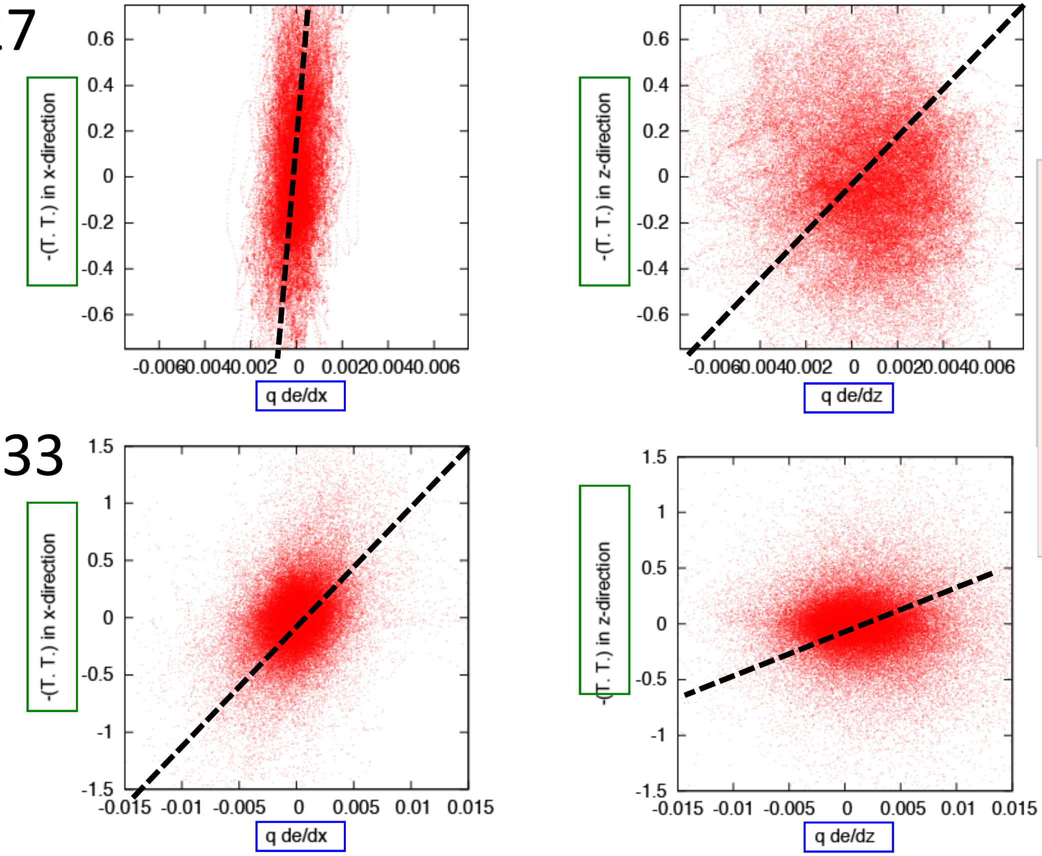
② Diffusion length

Turbulent transport=$-L_d\ q\partial TKE/\partial x_i$

Horizontal diffusion　　Vertical diffusion

$\Delta_H^*=1.27$

$\Delta_H^*=0.33$



Slope correspond to L_d

! Neglect *counter-gradient diffusion* plotted in 2nd and 4th quadrants

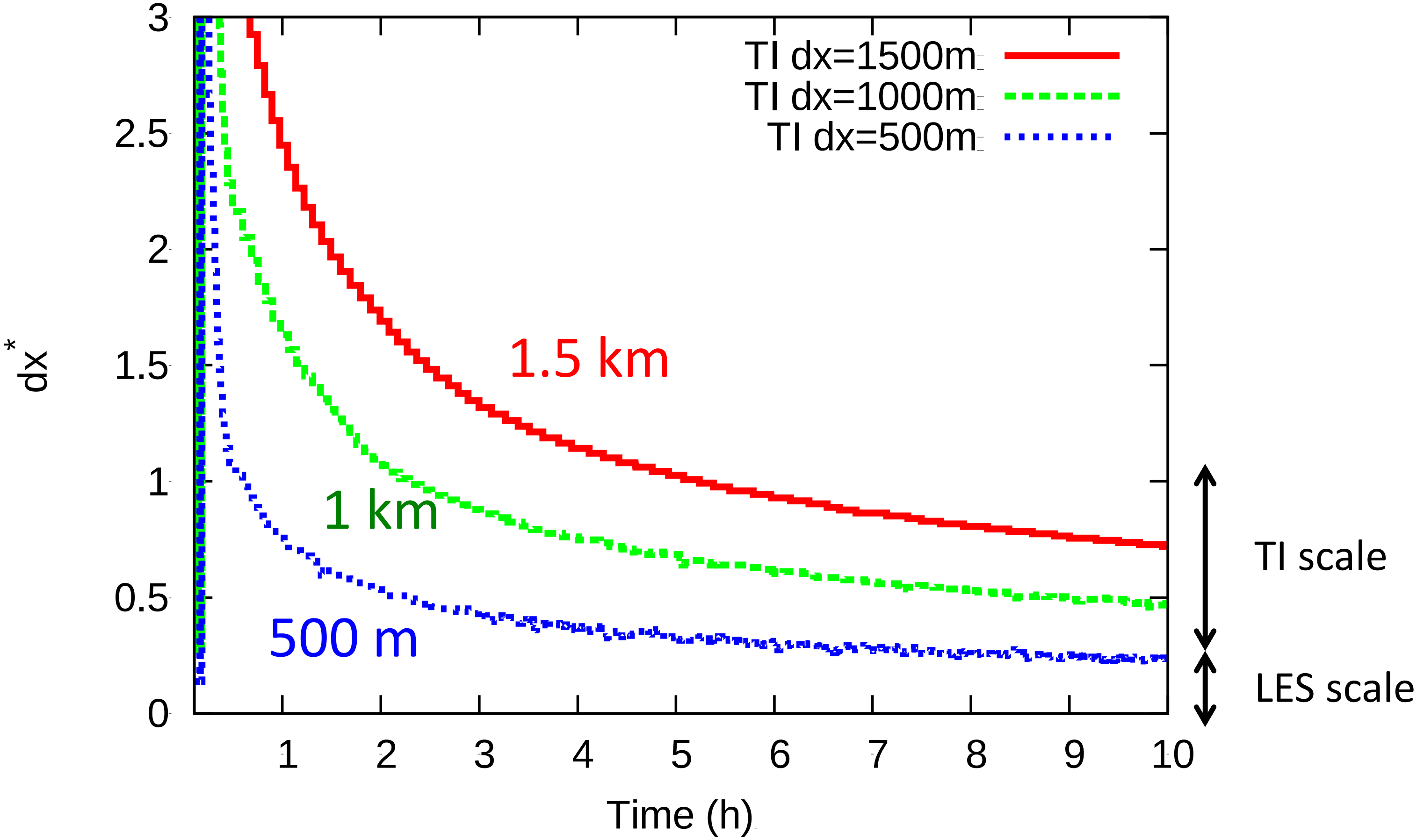
To reduce $L_d(\Delta_H^*)$ as $L_d(\infty)\times F(\Delta_H^*)$ seem reasonable

To rationalize the neglect of counter-gradient diffusion → A posteriori test

4. A posteriori test

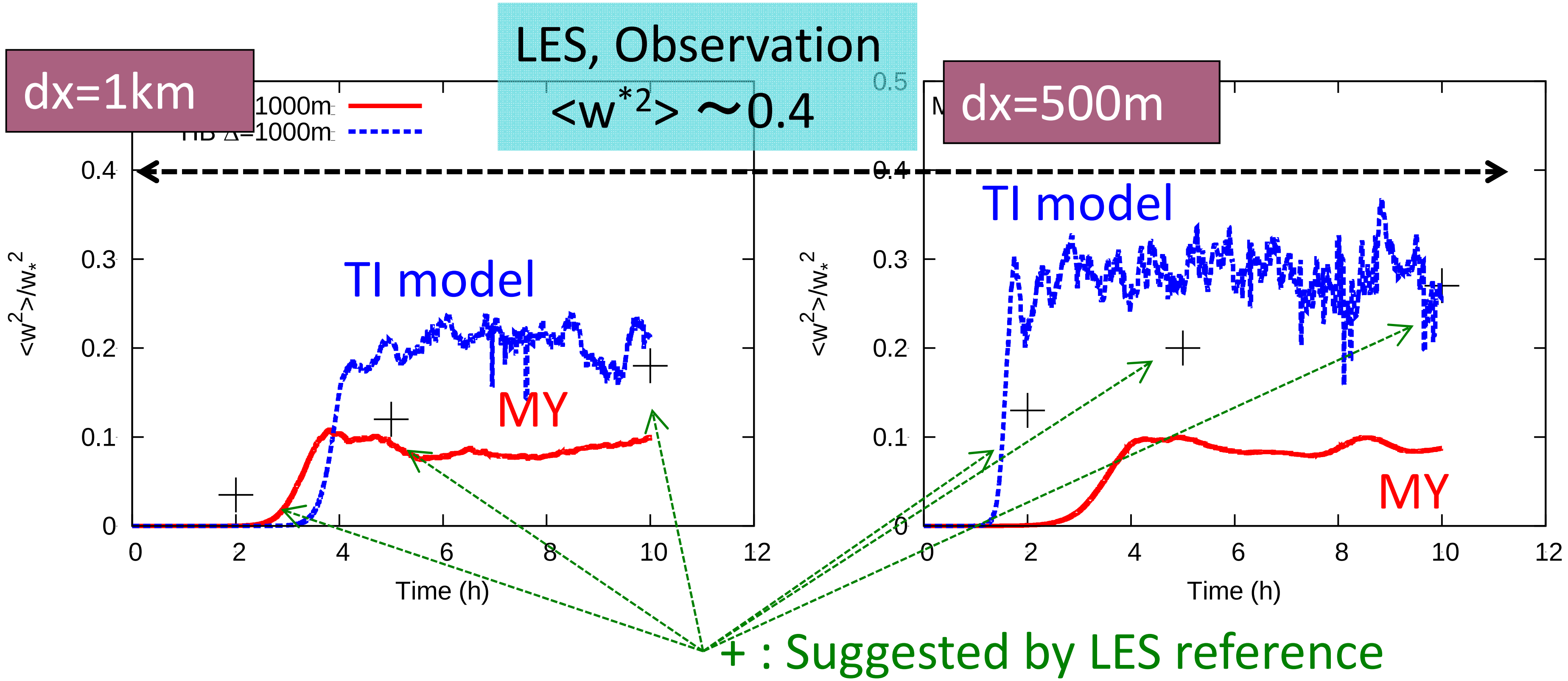
- Replace Smagorinsky's model in LES to
  "TI model" | MY model (Nakanishi and Niino 2009)
- Grid number: 12 × 12 × 150
- Horizontal resolution dx=1.5km | 1km | 500m
  Typical "TI scale" ↑
- Vertical resolution: dz=25m
- Environments are the same for LES reference to compare

Non-dimensional horizontal resolution dx* (≡ dx/h)



Strength of resolved convection w^{*2}

$\langle w^{*2} \rangle$@z=0.5h



"TI Model" reproduce resolved convection in accord with **LES reference**

Conclusion 1/2

- Design of “TI model” based on LES

  → **Almost completed** (To be sumitted to BLM?)

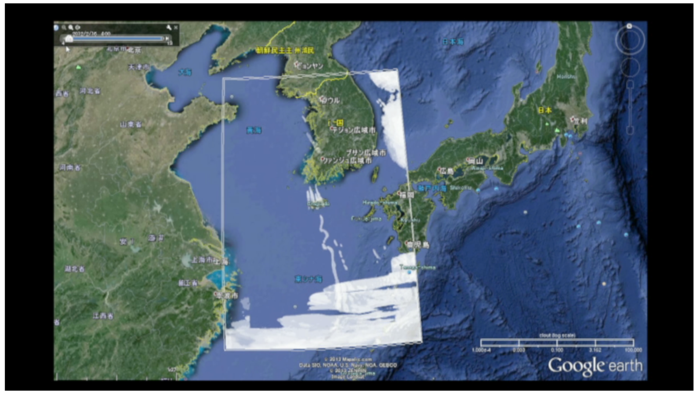
- Implement in a numerical weather prediction (e.g. JMANHM, WRF) would be very easy

  ↑ only reduce length scale in MY model

- We will *not* peruse further refinement (3rd order closure? stochastic forcing?)

Conclusion 2/2

- Current JMANHM with MY model may behave qualitatively similar manner to “TI model” (伊藤ら,2013年春気象学会), but it is unjustified
- Seeking verification by JMANHM with “TI model” ← Karman vortex shading was not good…

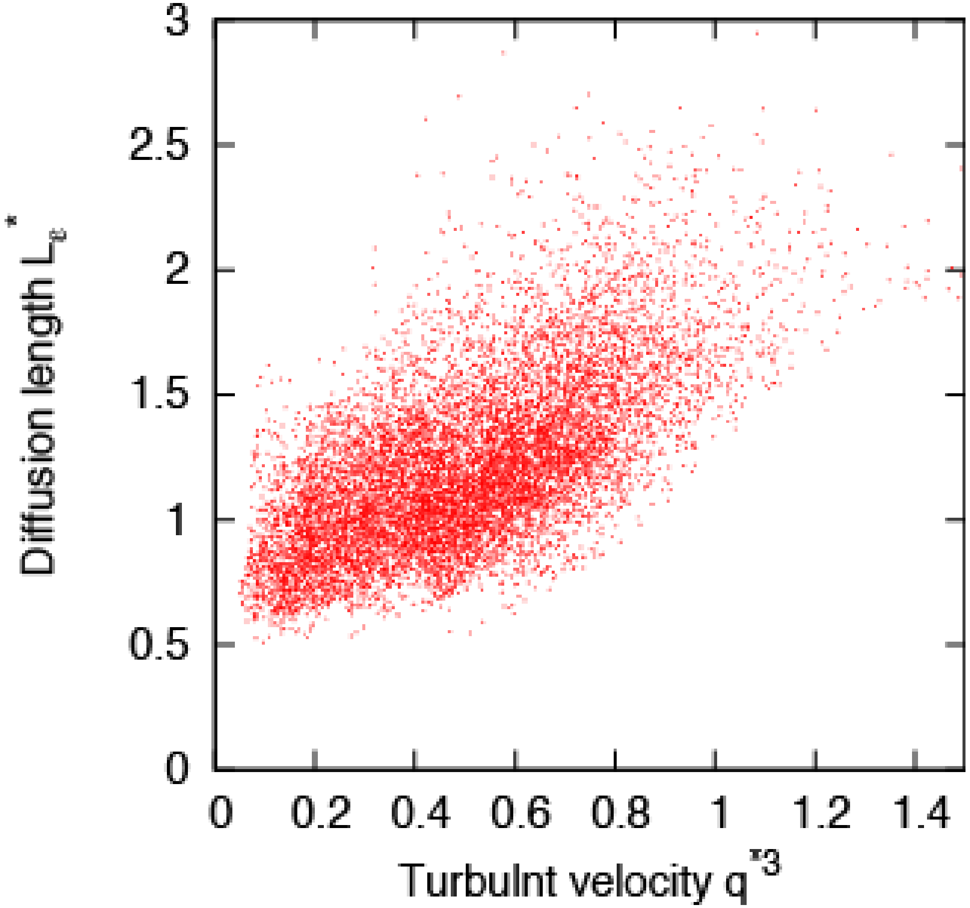


Simulated cloud

by JMANHM with a LFM configuration (dx=2km)

Local L_ε

L_ε *without* horizontal average @ Δ_H^*=0.8, z^*=0.5



鉛直速度w@5h,z=0.5h