HOST vs. MOST for stably stratified surface layer

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Tnx to Željko Večenaj, Sergej S. Zilitinkevich & Larry Mahrt

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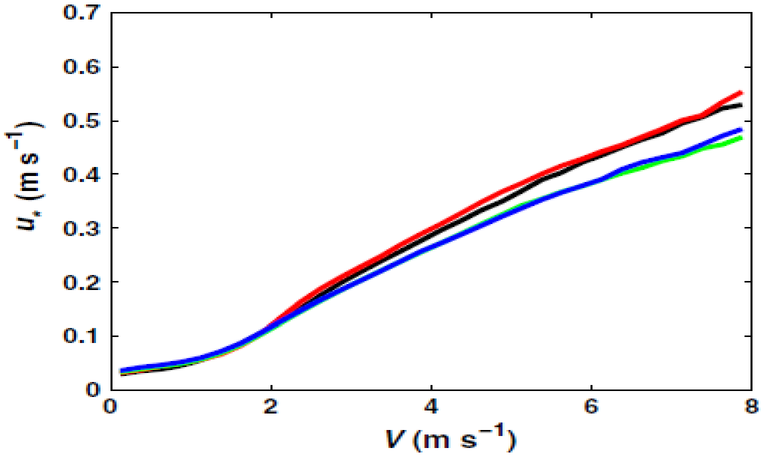
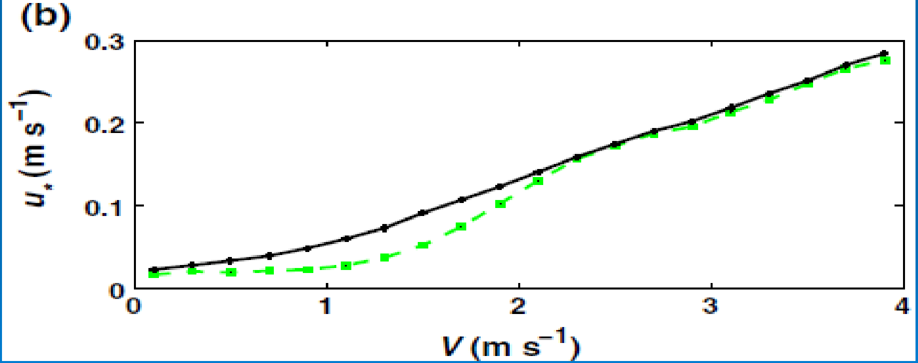
Fig. 4 The dependence of u_* on V based on averages over the upland stations (*black*, A1, A4 and A14), up-valley gully stations (*red*, A2, A3 and A5), the mid slope stations (*blue*, A10, A12, A13, A18 and A19) and the valley-floor stations (*green*, A7, A8, A11 and A16). Station locations are identified in Fig. 1



L. Mahrt, J. Sun & D. Stauffer, BLM 2015

← Shallow Cold Pool Exp. [SCP], NE Colorado, USA, semiarid grassland, 1.6 km ASL, 10-11.2012

↓ Focus here: regime 1 ↔ 2, red No. on black lines



↑ Weak stratification ⇔ black

strong stratif. ⇔ green = hockey-stick behavior

JANUARY 2012 SUN ET

J. Sun, L. Mahrt, R. Banta & Y. Pichugina, JAS

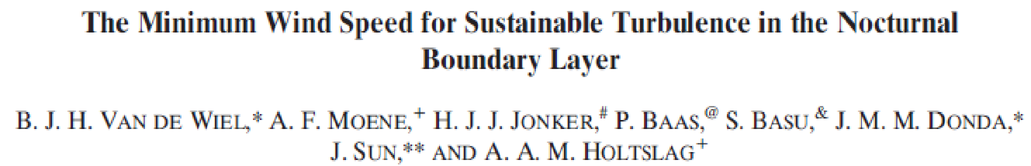
FIG. 2. Schematic of the three turbulence regimes (red numbers) and the three categories of turbulence intermittency (green letters) commonly observed during CASES-99 at each observation height. Turbulence in regime 1 is mainly generated by local instability. Turbulence in regime 2 is mainly generated by the bulk shear. Turbulence in regime 3 is mainly generated by top-down turbulent events.

What are MOST & HOST?

- ***MOST** - well established view: **M**onin & **O**bukhov **S**imilarity **T**heory for geophysical surface layer flows*
- *Assume H. H., vertical turbulent fluxes of key fields, small-to-moderate departures from the logarithmic law by corrections, v.s. **z/Lo**=height/[Obukhov length]*
- *Strong departures from the log-law, e.g., weak mean wind, or extreme stratification, can't be seen as 'corrections' in MOST*
- ***HOST**, **Ho**ckey-**S**tick **T**ransition, goes beyond MOST local fixes & accepts unsteady, nonlocal, submeso effects on sfc. fluxes*

OUTLINE

- ***Intro***: *motives, missing physics, modeling*
- ***Linear approach***: *simple HOST vs. extend. MOST*
- ***Nonlinear view***: $u_*^2 = C_d U^2 + u_{*0}^2$
- ***Data & examples***: *SCP, FLOSSII, CASES-99…*
- ***Tentative end***: *qualitative agreement between MOST & HOST*



The Minimum Wind Speed for Sustainable Turbulence in the Nocturnal Boundary Layer

B. J. H. VAN DE WIEL,* A. F. MOENE,+ H. J. J. JONKER,# P. BAAS,@ S. BASU,& J. M. M. DONDA,*
J. SUN,** AND A. A. M. HOLTSLAG+

↓ V. d. Wiel et al. JAS 2012,
Cabauw data, u_*^2 *vs. V*

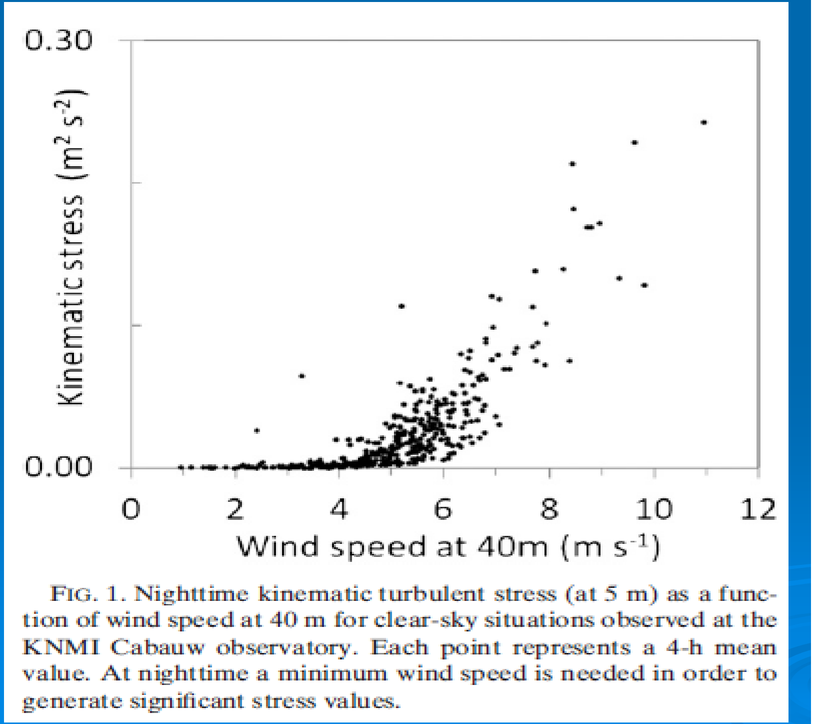


FIG. 1. Nighttime kinematic turbulent stress (at 5 m) as a function of wind speed at 40 m for clear-sky situations observed at the KNMI Cabauw observatory. Each point represents a 4-h mean value. At nighttime a minimum wind speed is needed in order to generate significant stress values.

↓ Jielun Sun, u_* *vs.* ***V****, made adapted from* JAS 2012, note the tick black line ⇔ simple MOST result

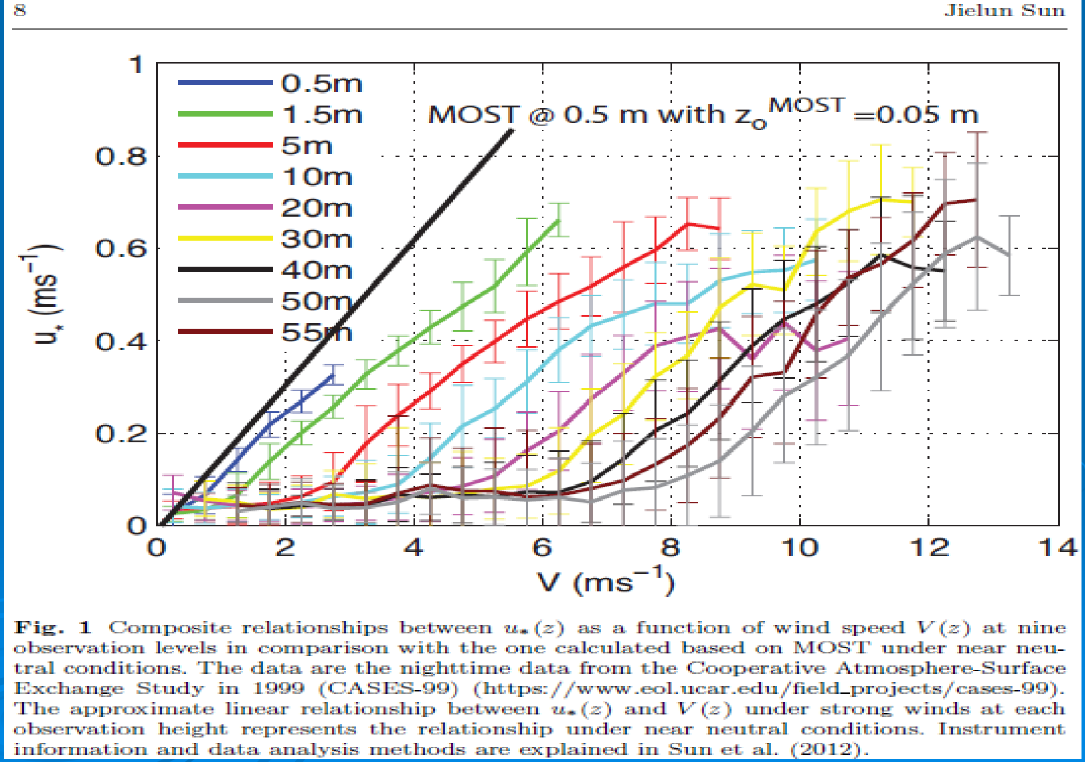


Fig. 1 Composite relationships between $u_*(z)$ as a function of wind speed $V(z)$ at nine observation levels in comparison with the one calculated based on MOST under near neutral conditions. The data are the nighttime data from the Cooperative Atmosphere-Surface Exchange Study in 1999 (CASES-99) (https://www.eol.ucar.edu/field_projects/cases-99). The approximate linear relationship between $u_*(z)$ and $V(z)$ under strong winds at each observation height represents the relationship under near neutral conditions. Instrument information and data analysis methods are explained in Sun et al. (2012).

Linear approach: ***simple HOST vs. extended MOST***

- *J. Sun et al. BLM 2016: weak-to-moderate departures from neutrality, trying* ***$u_*(z) = \alpha(z)U(z) + \beta(z)$****, as a simple HOST*

- *S. Zilitinkevich & P. Calanca, QJRMS 2000:*

$$\frac{\partial U(z)}{\partial z} = \frac{u_*(z)}{k}\left(\frac{1}{z} + \frac{a}{Lo} + \frac{bN}{u_*(z)}\right)$$
$$= \frac{u_*(z)}{k}\left(\frac{1}{z} + \frac{a}{Lo}\right) + \frac{b}{k}N\,,$$

←

$$U(z) = \frac{u_*}{k}\left[ln(z/z_0) + \frac{az}{Lo}\right] + \frac{b}{k}Nz$$
$$u_* = \frac{k}{ln(z/z_0) + az/Lo}U - \frac{bNz}{ln(z/z_0) + az/Lo}.$$

- *Not promising – compare to the ↑ plausible terms in* ***$u_* = \alpha U + \beta$***

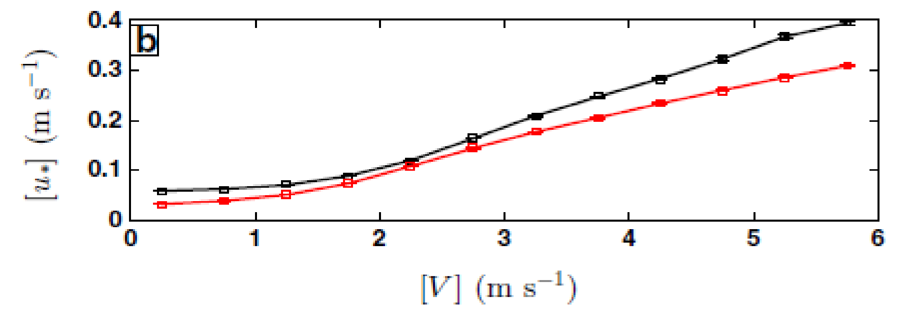
- *Other fix-ups tried, but the plots of $\alpha(z)$, $\beta(z)$ &* ***$u_*(U)$****, Sun et al. do not fit in!*

Missing physics, modeling issues

- *Basic **MOST**: stationarity, horizontal homogeneity, monotonous increase of U(z), Taylor hypothesis, unimportant directional mean wind shear, continuous turbulence, or an extreme: no turbulence,* $Pr_{turb} \approx 1$*,…*

- *But **turbulence** can be patchy, intermittent, generated non-locally, i.e., in **disequilibrium**; it may interact with short buoyancy waves – mixing more momentum than temperature & scalars, e.g.* $Pr_{turb} > 1$*,* $Ri_{grad} >> 1$*,…*

NONLINEAR VIEW - FLUX FORM, u_*^2



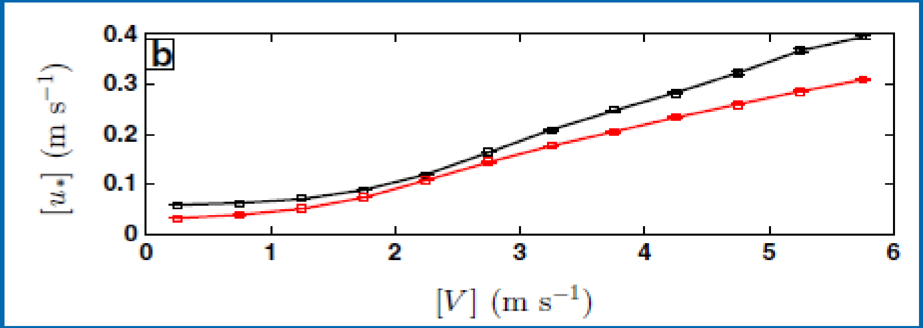
*⇔ Mahrt, BLM 2017: **u_*** remains significant even for dying **U(z) !***

*SCP - red, FLOSSII - black; thus, his **concept of generalized turbulence velocity scale** [Mahrt, QJRMS 2008] – **surrogate for unresolved meso-motions***

Here: $u_*^2 = C_d U^2 + u_{*0}^2$… allows: $u_*^2 = C_{d1} U^2 + u_{*0}^2$, $U > V_s$

$u_*^2 = C_{d2} U^2 + u_{*0}^2$, $U < V_s$; usually $C_{d2} \leq C_{d1}$

NONLINEAR VIEW - FLUX FORM, u_*^2



⇔ *Mahrt, BLM 2017:* ***u_**** *may remain significant even for vanishingly* ***small U(z)*** *SCP - red, FLOSSII - black; thus, his* ***concept of generalized turbulence velocity scale*** *[Mahrt, QJRMS 2008] –* ***surrogate for unresolved meso-motions***

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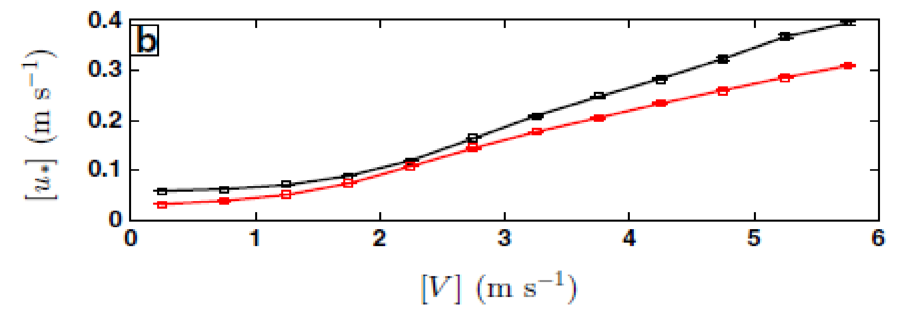
$u_*^2 = C_{d2} U^2 + u_{*0}^2$, $U < V_s$; *usually* $C_{d2} \leq C_{d1}$

1. $U > V_s \rightarrow u_* \approx C_{d1}^{1/2} U + u_{*0}^{\ 2} / (2\, C_{d1}^{1/2} U)$ - … ⇔ *roughly* $\boldsymbol{u_* \sim U}$

NONLINEAR VIEW - FLUX FORM, u_*^2



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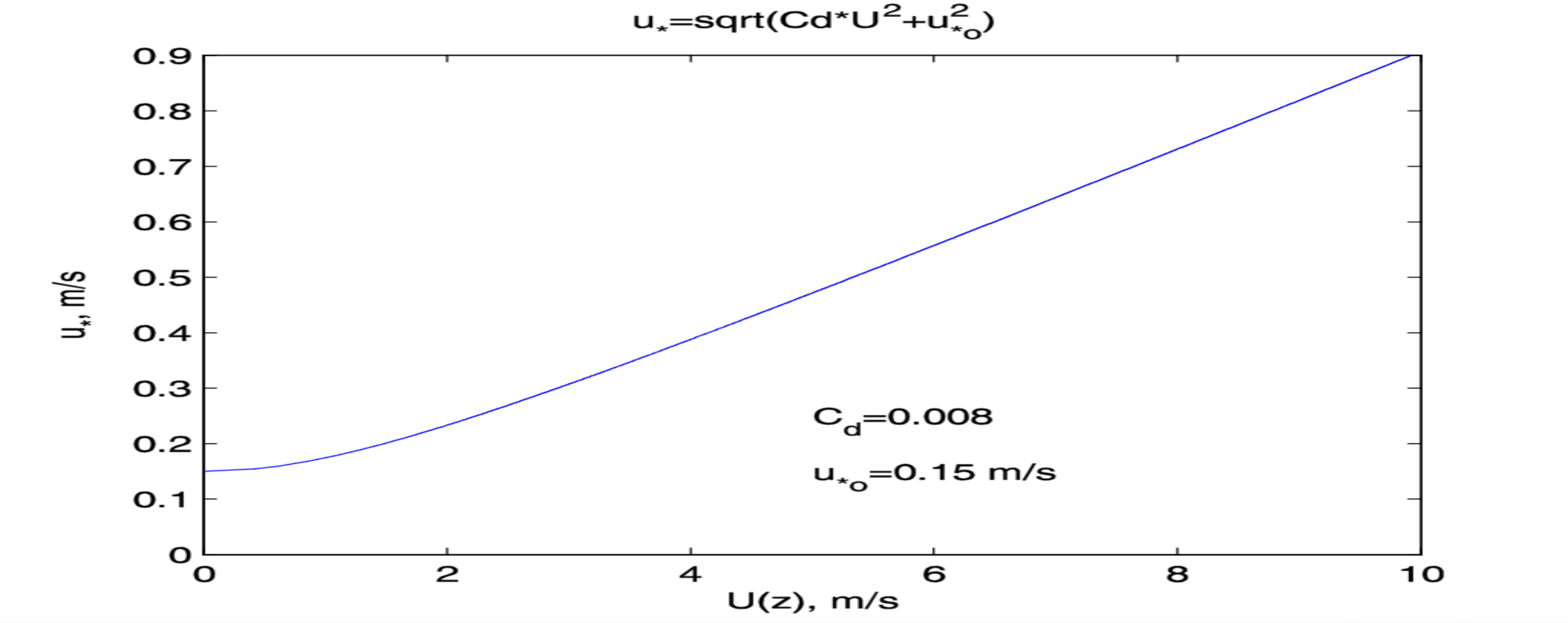
2. $U < V_s \rightarrow u_* \approx u_{*0} + C_{d2}U^2/\ (2\ u_{*0})$ - … ⇔ *roughly* $\boldsymbol{u_* \sim u_{*0}}$

SIMPLE ANALYTIC SKI-LIKE BEHAVIOR



Like HOST: ski-like dependency $u_*(U)$ based on $u_*^2 = C_d U^2 + u_{*0}^2$. Similar to Mahrt et al. (2015; their Figs. 4, 5a & 8b), Sun et al. (2016; their Figs. 4a & 13a), etc. Calculated V_s here 1.7 m/s

Relating (V_s, u_{*0}, u_{*c}) in 2 regimes

- ***Matching***: $U(z) = V_s(z)$

1. $u_*^2 = C_{d1}U^2 + u_{*0}^2$, $U > V_s$

2. $u_*^2 = C_{d2}U^2 + u_{*0}^2$, $U < V_s$

$\longrightarrow$ $u_{*c}^2 = C_{dd}V^2 + u_{*0}^2$, for $U = V_s$

At $U = V_s$ both terms ↑ on the R.H.S. contribute equally

$$\Leftrightarrow \quad u_{*c} = (2C_{dd})^{1/2}V_s = 2^{1/2}u_{*0}$$

Examples

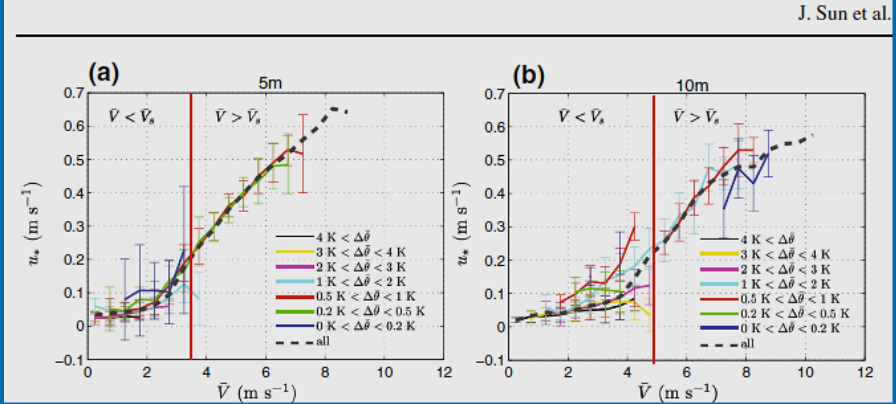
- Assume $C_{dd} = 1.6\cdot10^{-3}$, $V_s = 2\ \mathrm{ms}^{-1}$; → $u_{*0} = (C_{dd})^{1/2}V_s =$ 8 cms^{-1} , $u_{*c} \approx 11.3\ \mathrm{cms}^{-1}$

  Accidental coincidence: $\min(u_*) = 7\ \mathrm{cms}^{-1}$ in MIUU mesoscale model !

- J. Sun et al. BLM 2016: V_s, u_{*c} ⟵

  $C_{dd} \approx 1.6\cdot10^{-3}$, $1.4\cdot10^{-3}$ @ 5, 10 m

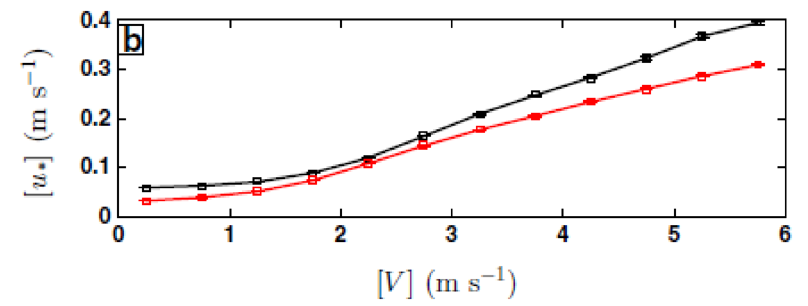
  $u_{*0} \approx 14, 18\ \mathrm{cms}^{-1}$ @ 5, 10 m



L. Mahrt BLM 2017: V_s, u_{*c}, 5 m ⟵

≈ (1.25 ± 0.1) ms^{-1}, (7 ± 0.15) cms^{-1}

⬄ $u_{*0} \approx 6.8\ \mathrm{cms}^{-1}$, SCP - red, FLOSSII - black



Discussion

- *The issue: sufficiently weak large-scale flow → generation of turbulence by unresolved (sub)mesoscale motions important, $u_* \neq C_d^{1/2}U$*

- *Concept of generalized turbulence velocity scale used, similar for e.g. sheared convection, ABL depth, generalized mixing length scale, …*

- *Weakness/strength of the approach: multitude of processes are lumped together into $\boldsymbol{u_{*0}}$ or $\boldsymbol{u_{*c}}$*

Conclusions

- *HOST ↔ MOST for stably stratified sfc. layer tackled*
- *Needed for better, more complete data interpretation*
- *All operational NWP & climate models still have the need to parameterize some mesoscale processes including turbulence*
- *We obtained ski-like behavior, a key ingredient of HOST, via simple quadratic relation for fluxes, that also yields:*

$$u_{*c} = (2C_{dd})^{1/2}V_s^2 = 2^{1/2}u_{*0}$$

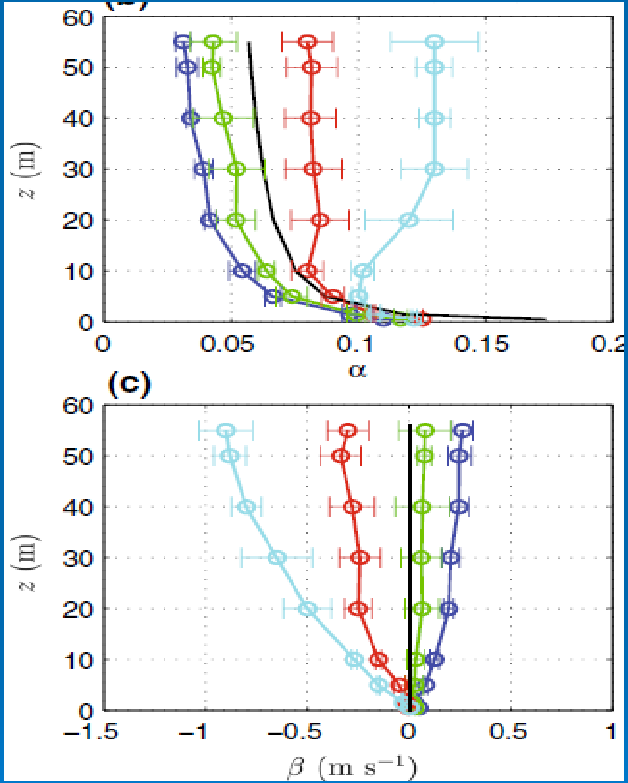
- *…Still far from a firm & complete theory … More data analysis, model implementation & testing…*

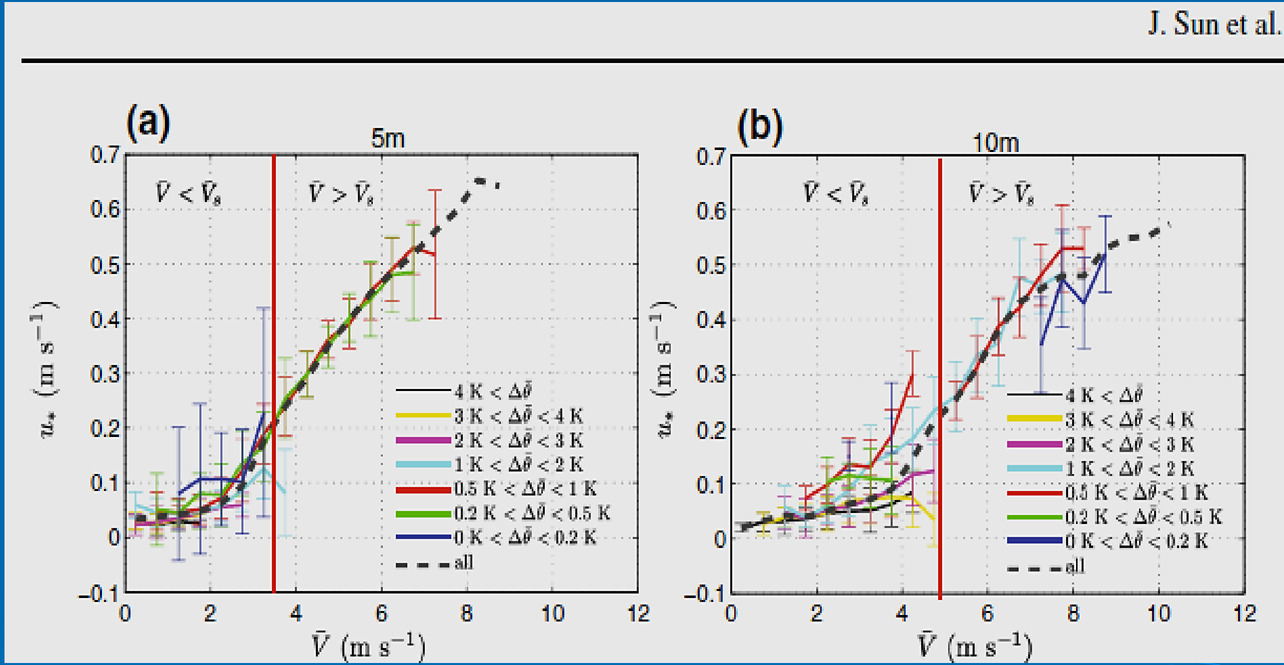
Is the HOST yet another hostile bla-bla… against my dear miaou-MOST?

http://www.pmf.unizg.hr/geof

bgrisog@gfz.hr

J. Sun at al. BLM 2016





Ski-like, or HOckey-Stick Transition, i.e., HOST behavior of friction velocity vs. mean wind speed, i.e., $u_*(U) = u_*(V)$ dependency observed, CASES-99

Light blue ⇔ Stable Sfc. Layer [SSL], red ⇔ neutral, note $\beta \le 0$ allowing $u_* < 0$?

-These obs. $\alpha(z)$, $\beta(z) \ne \alpha$, β from Zilitinkevich & Calanca, QJ 2000

Jielun Sun, Don Lenschow, Peggy LeMone, Larry Mahrt, BLM 2016

The focus here: ↓ ↔ ↓

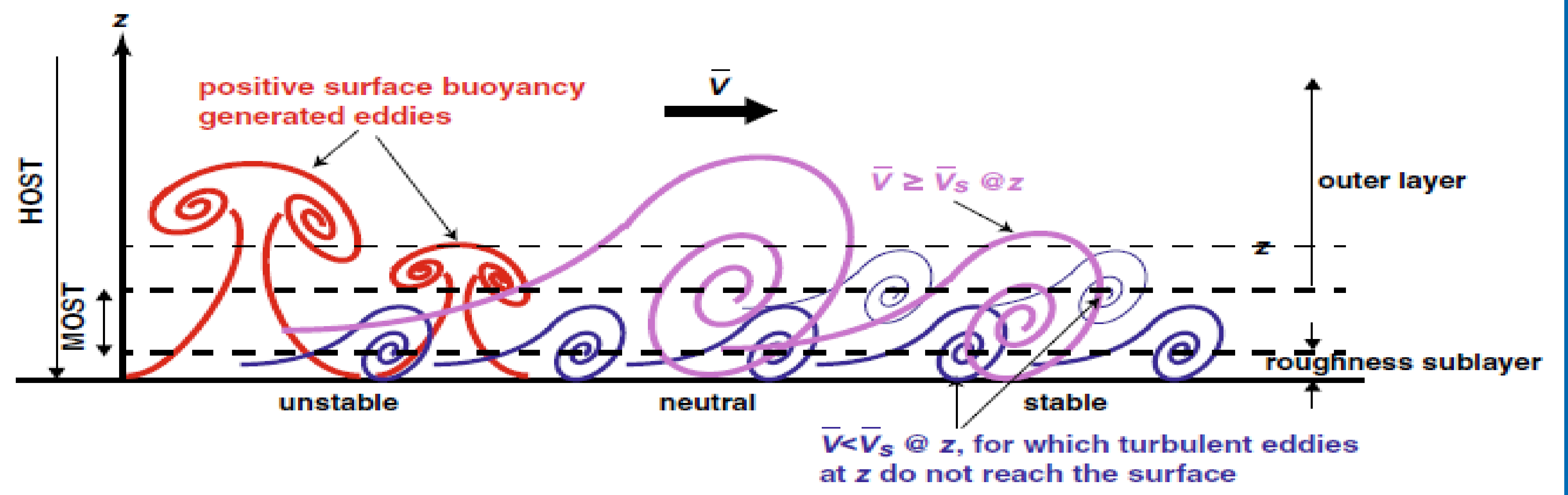
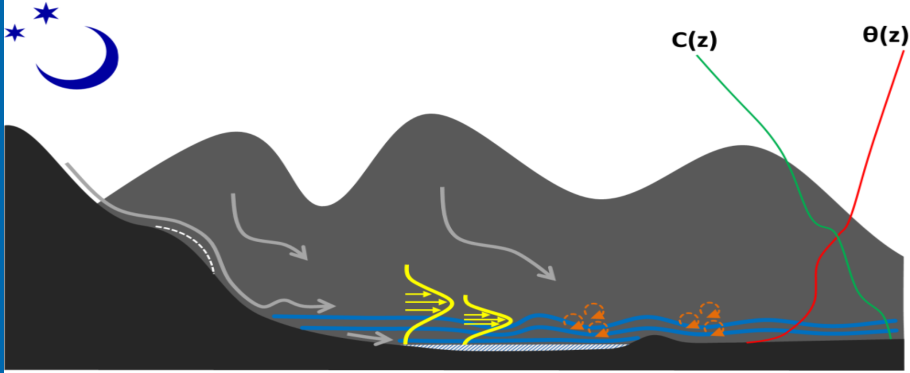
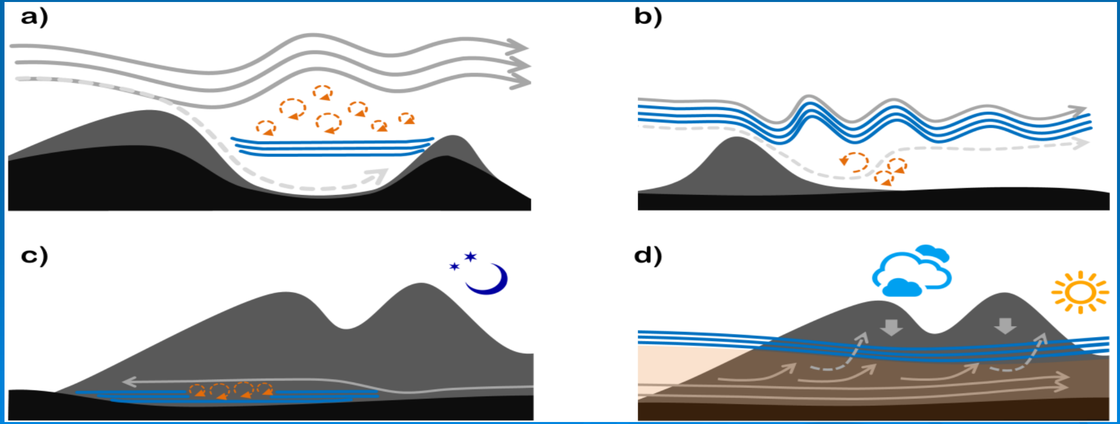


Fig. 1 Schematic illustration showing the thin layer where MOST is valid (between the two *thick dashed lines*), and the characteristic sizes of turbulent eddies described in the HOST hypothesis. Turbulent eddies in *purple* and *blue* are generated by shear $\delta\bar{V}(z)/\delta z$ for $\delta z = z$ and $\delta z < z$, respectively. The *thick* and *thin blue* eddies represent the situations when turbulent eddies are attached to the surface but the shallow turbulence layer is below height z, and when turbulent eddies are generated by elevated shear above the surface; in both situations, turbulent eddies at z do not reach the surface. Turbulent eddies in *red* represent those generated by positive buoyancy from heated surface

Sketches of small mesoscale flows



Drainage flows, very low-level jets, cold-air pools, short buoyancy waves, elevated turbulence, enhanced intermittent mixing, boundary-layer separation, flow reattachment…



Stable layers, blue, controlling or affecting multi-scale interactions

Serafin, Adler, Cuxart, de Wekker, Gohm, Grisogono, Kalthoff, Kirshbaum, Rotach, Schmidli, Stiperski, Večenaj, Zardi: Exchange Processes in the Atmospheric Boundary Layer Over Mountainous Terrain. *Atmosphere 2018.*

*J. Sun, L. Mahrt,
R. Banta &
Y. Pichugina,
JAS 2012:*

*HOST again but
now at various
heights*

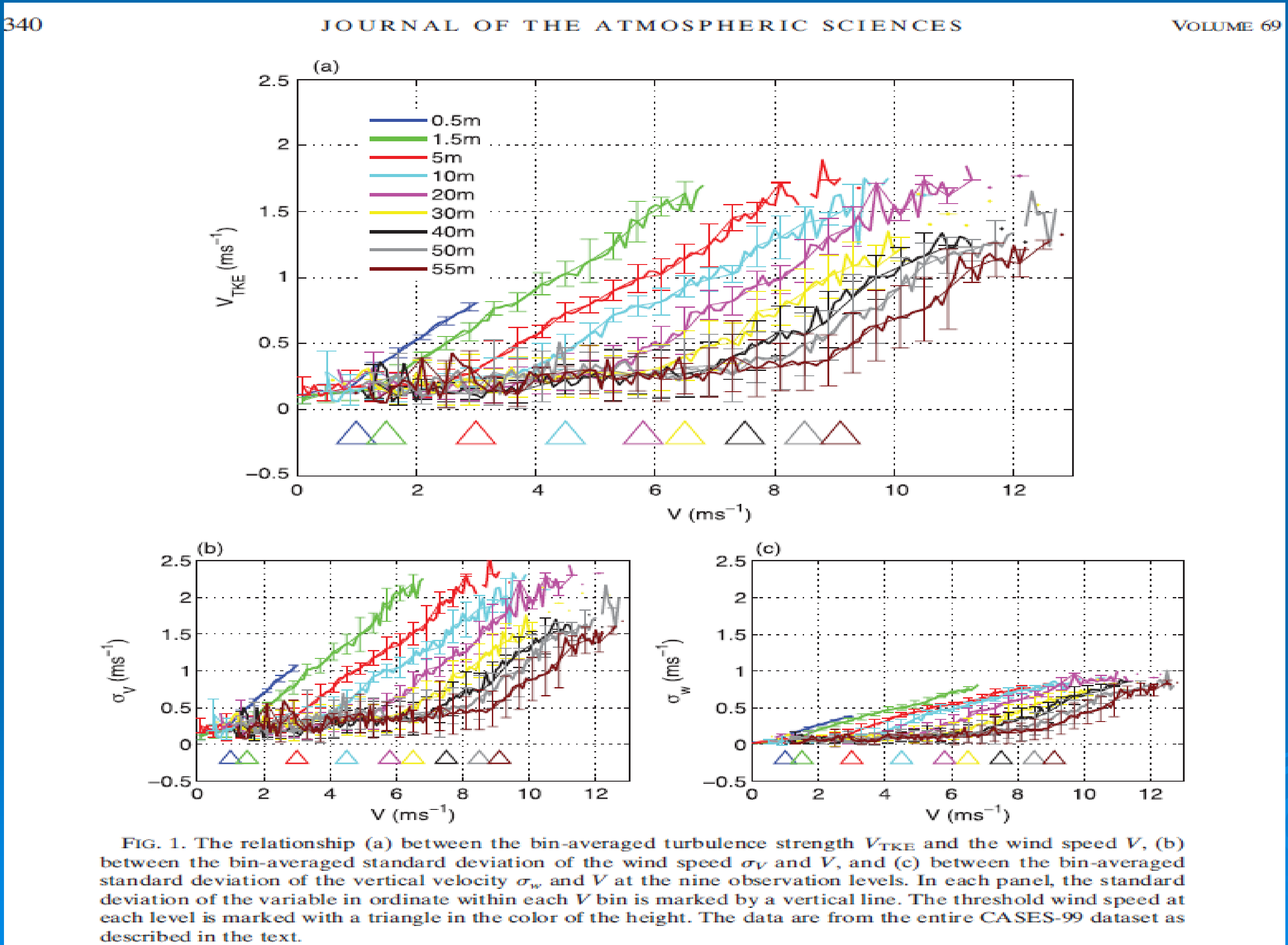


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FIG. 1. The relationship (a) between the bin-averaged turbulence strength V_{TKE} and the wind speed V, (b) between the bin-averaged standard deviation of the wind speed σ_V and V, and (c) between the bin-averaged standard deviation of the vertical velocity σ_w and V at the nine observation levels. In each panel, the standard deviation of the variable in ordinate within each V bin is marked by a vertical line. The threshold wind speed at each level is marked with a triangle in the color of the height. The data are from the entire CASES-99 dataset as described in the text.