Subgrid-Scale Model Tests Using Petascale Computers

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Petascale computing facilities provide unprecedented computing power and great opportunities to improve simulations

Increased resolution brings mesoscale simulations into *Terra Incognita* (Wyngaard 2004)

Surface layer in LES of the atmospheric boundary layer

Neither traditional Reynolds stress nor SGS models appropriate

Model development an essential task for improving simulation

Model testing an important aspect of model development

Traditional SGS model tests:

A priori: Compare the modeled and true SGS stress, e.g., their correlation. Difficult to relate test results to LES statistics (model performance in LES)

A posteriori: Compare profiles of statistics from LES and measurements. Difficult to identify model deficiencies from LES results.

Two types of tests disconnected. Difficult to compare.

The main goal for LES is to correctly predict resolvable-scale velocity and scalar statistics

Traditional tests provide no link between model and LES statistics

A new SGS model test approach based on the conditions for LES to correctly predict these statistics

One-point velocity JPDF equation (Chen et al. 2003)

$$\frac{\partial f}{\partial t}+v_j\frac{\partial f}{\partial x_j}=\frac{\partial^2}{\partial v_i\partial x_j}\left[\left\langle \tau_{ij}\left|\underline{u}^r=\underline{v}\right\rangle f\right]+\frac{\partial^2}{\partial v_i\partial v_j}\left[\left\langle -\frac{1}{2}P_{ij}\left|\underline{u}^r=\underline{v}\right\rangle f\right]\right.$$

$$+\frac{\partial^2}{\partial v_i\partial x_i}\left[\left\langle p^r\left|\underline{u}^r=\underline{v}\right\rangle f\right]+\frac{\partial^2}{\partial v_i\partial v_j}\left[\left\langle p^r\frac{\partial u_j^r}{\partial x_i}\left|\underline{u}^r=\underline{v}\right\rangle f\right]\right.$$

$$+\frac{g}{\Theta}\frac{\partial}{\partial v_3}\left[\left\langle \theta^r\left|\underline{u}^r=\underline{v}\right\rangle f\right]\right.$$

$$\tau_{ij}=(u_iu_j)^r-u_i^ru_j^r,\quad P_{ij}=-\left\{\tau_{ik}\frac{\partial u_j^r}{\partial x_k}+\tau_{jk}\frac{\partial u_i^r}{\partial x_k}\right\}$$

Necessary conditions for LES to reproduce the JPDF: The SGS model correctly predicts $\langle \tau_{ij} | \underline{u}^r = \underline{v} \rangle$ and $\langle P_{ij} | \underline{u}^r = \underline{v} \rangle$ (Chen et al. 2003, Chen & Tong 2006). Production also important

New (statistical) model tests:
A priori: compute $\langle \tau_{ij} | \underline{u}^r = \underline{v} \rangle$ and $\langle P_{ij} | \underline{u}^r = \underline{v} \rangle$ using measurements (e.g., the resolvable-scale strain rate) as model input (Chen et al. 2003, Chen & Tong 2006)

A posteriori: compute $\langle \tau_{ij} | \underline{u}^r = \underline{v} \rangle$ and $\langle P_{ij} | \underline{u}^r = \underline{v} \rangle$ using LES fields as model input

Two types of tests analyze the same statistics and can be compared.

$\left\langle \tau_{ij} \middle| \underline{u}^r = \underline{v} \right\rangle$ and $\left\langle P_{ij} \middle| \underline{u}^r = \underline{v} \right\rangle$ are conditional means conditional on the three resolvable-scale velocity components at the same location

Three-dimensional sample space (higher if scalars are included), requiring large data sizes for statistical convergence

Peta-scale computers can provide much larger data sets

- Larger computational domain
- Longer runs

Allow tests previously not feasible

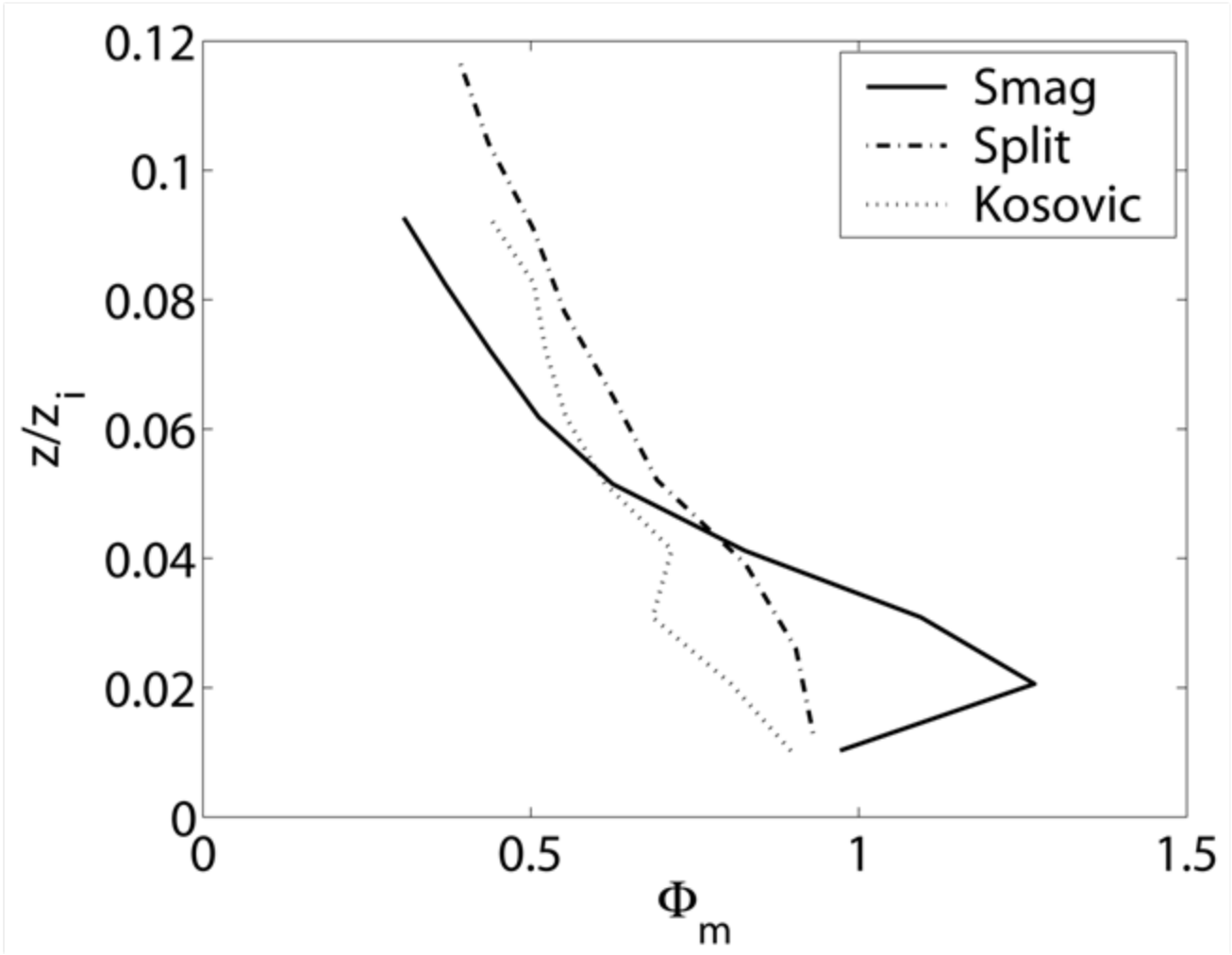
Field measurements (HATS 2000)

- Measurement data taken during the Horizontal Array Turbulence Study field program in 2000.
- The HATS field measurement design based on the transverse array technique (Tong et al. 1998,).
- Moderately convective ABL

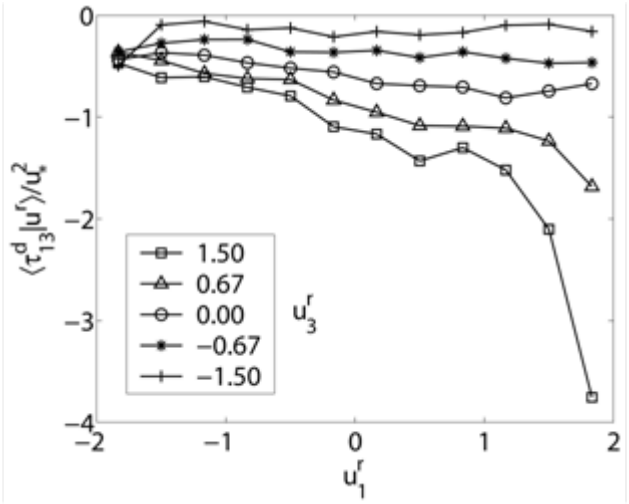
LES data

Case	L_xxL_yxL_z *(m)*	N_xxN_yxN_z	Q_* *(Km/s)*	U_g *(m/s)*	u_* *(m/s)*	$-z_i/L$
Sullivan 1994 (split)	10000x10000x2000	250x250x128	0.1	20.0	0.66	5.63
Otte 2001 (Smag)	2500x2500x999	144x144x160	0.2	15.0	0.66	6.04
Otte 2001 (Kosovic)	2500x2500x1000	140x140x160	0.2	15.0	0.65	5.57

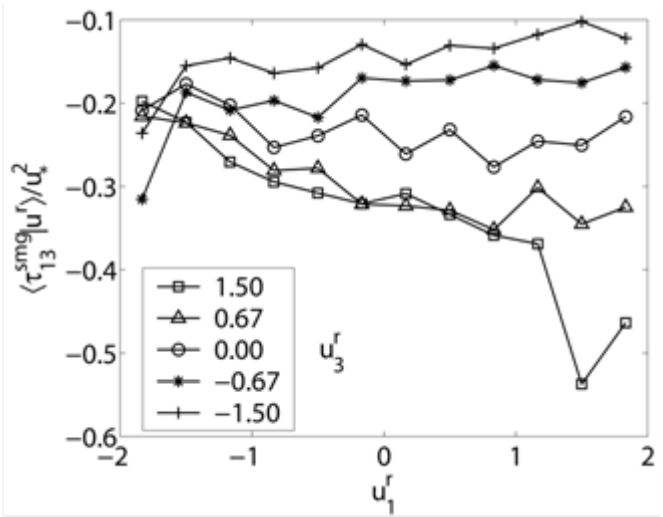
LES non-dimensional vertical shear $\frac{\partial \langle u_1 \rangle}{\partial x_3}$



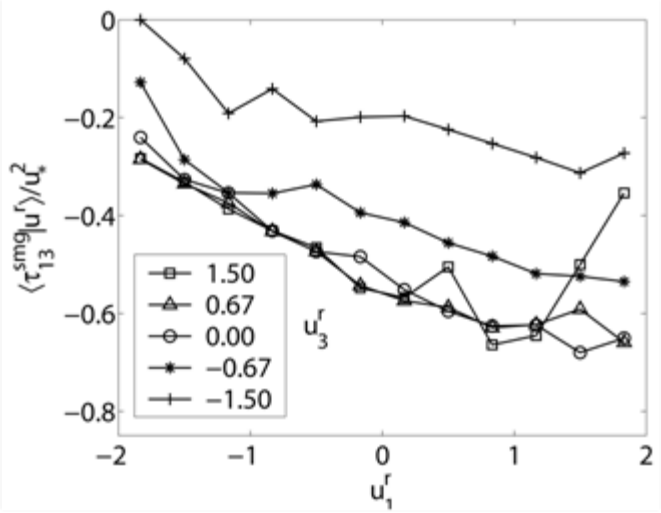
Conditional SGS shear stress



Measurement

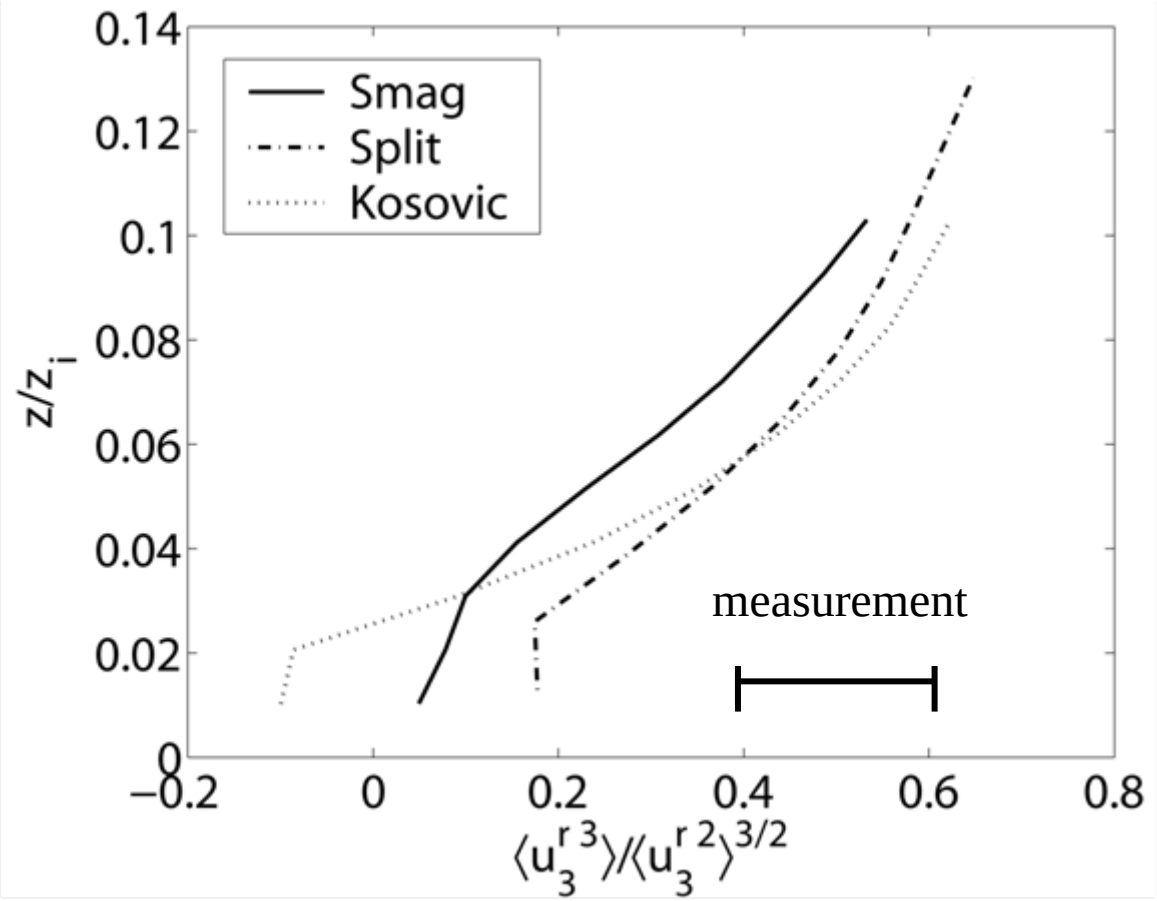


a priori test

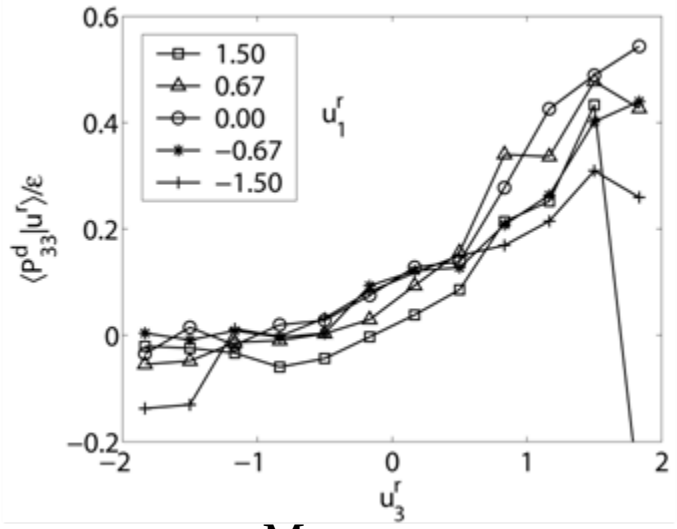


LES (Smagorinsky)

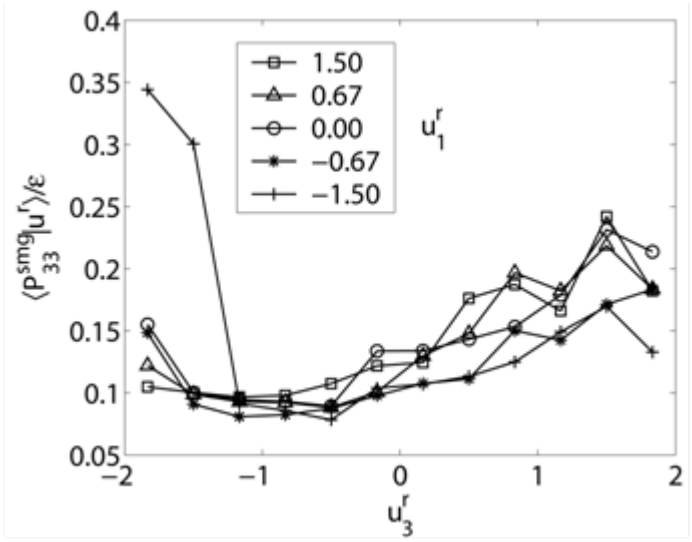
LES vertical velocity skewness



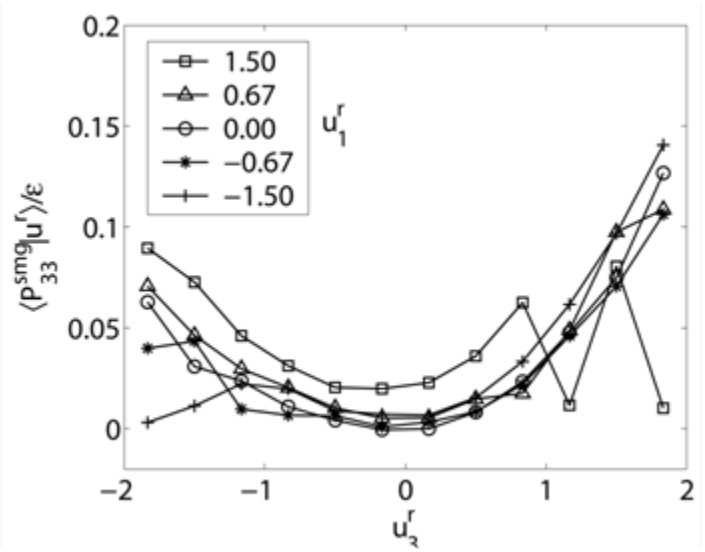
Conditional SGS stress production rate



Measurement



a priori test



LES (Smagorinsky)

The statistical a posteriori tests are based on the variables important for the dynamics of the SGS turbulence. Can provide new physical understanding for mode development

Peta-scale computers can provide data sets containing much larger amounts of independent samples, allowing more meaningful tests previously not feasible