9.14 EFFECTS OF STABILITY AND FILTER SIZE ON MODEL COEFFICIENTS AND INTERMITTENCY OF SUBFILTER FLUXES IN THE ATMOSPHERIC BOUNDARY LAYER

Jan Kleissl, Charles Meneveau, and Marc B. Parlange
Center for Environmental and Applied Fluid Mechanics
Johns Hopkins University, Baltimore, Maryland

1. INTRODUCTION

Field experiments, which are specifically designed to study subfilter-scale (SFS) modeling are crucial for our understanding and improvement of SFS models for Large Eddy Simulation (LES) of the atmospheric boundary layer (ABL). A number of field campaigns have been carried out by JHU to study SFS physics (Iowa 1998, Davis 1999; see Porté-Agel et al., 2001); other investigators presented results in Tong et al., 1999. More recently, the Horizontal Array Turbulence Study (HATS) was conducted with NCAR in Kettleman City (CA) in September 2000. The instrumentation setup consists of 14 three-dimensional sonic anemometers arranged in two parallel, crosswind horizontal arrays in the atmospheric surface layer downwind of a long homogeneous fetch of stubble. From four weeks of continuous sampling with different array heights and widths, data encompassing a wide range of atmospheric stability conditions, and turbulence regimes are obtained. For details on the data sets and filtering operations, see companion talk by Horst et al., 2002 (paper 9.6). Crucial in our ability to address LES modeling issues is the direct measurement of the SFS stress tensor from the data according to its definition

$$\tau_{ij} = \widetilde{u_i u_j} - \tilde{u}_i \tilde{u}_j . \qquad (1)$$

A tilde denotes filtering at scale Δ.

2. EFFECT OF STABILITY AND FILTER SIZE ON MODEL COEFFICIENTS

The most commonly used SFS model is the Smagorinsky model (Smagorinsky 1963), which expresses the SFS-stress as

$$\tau_{ij}^{smag} = -2\nu_T \tilde{S}_{ij}, \nu_T = \left(c_s \Delta\right)^2 \left|\tilde{S}\right| . \qquad (2)$$

c_s is the Smagorinsky coefficient, which is typically prescribed empirically and must be reduced by a damping function close to the wall (Mason, 1994). This model as well as more advanced versions, which determine the coefficient dynamically during the simulation (Porté-Agel et al. 2000a, Germano et al. 1992), can be studied from experimental observations (Porté-Agel et al., 2000b). Specifically, from the field data, c_s^2 can be determined by matching the measured mean SFS dissipation with the model expression.

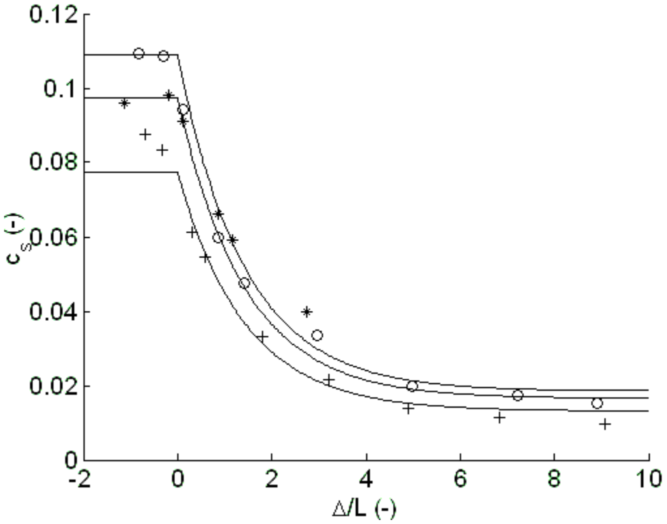

Figure 1: Smagorinsky coefficient c_s versus stability parameter Δ/L. +: Δ/z~4, o: Δ/z~2, *: Δ/z~0.5, solid lines: empirical fit. Measured and modeled SFS energy dissipation are conditionally averaged in intervals with similar stability. Then equation 1 is applied on the conditionally averaged SFS dissipations to yield $c_s = c_s(\Delta/L, \Delta/z)$. Solid lines: empirical fit

$$c_s^2 = \frac{-\left\langle \tau_{ij}\tilde{S}_{ij} \right\rangle}{\left\langle 2\Delta^2 \left|\tilde{S}\right| \tilde{S}_{ij}\tilde{S}_{ij} \right\rangle} . \qquad (3)$$

Figure 1 shows results for c_s from averaging SFS energy dissipations obtained from 115 different data segments, each of 27 minutes. Data segments are divided into subsets depending on their Monin-Obukhov length L. The dependence of the coefficient on Δ/L and filter size normalized

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* *Corresponding author address:* Jan Kleissl, JHU – DoGEE - 313 Ames Hall, 3400 N. Charles St., Baltimore, MD 21218-2686, e-mail: kleissl@jhu.edu

with height Δ/z becomes apparent. From its neutral value, c_s decreases strongly under stable atmospheric conditions. Moreover, a smaller Δ/z leads to an increase in the model coefficient, consistent with the use of damping functions for c_s close to the wall. The solid lines are based on an empirical fit of $c_s = c_s(\Delta/L, \Delta/z)$. The proposed expression can be used in LES, since Δ/L and Δ/z are known quantities during simulations.

3. EFFECT OF STABILITY AND FILTER SIZE ON INTERMITTENY OF MODEL COEFFICIENTS AND SFS FLUXES

In measuring c_s from equation 3 we have used time averaging procedures, conceptually assuming statistically stationary conditions. However, it is well known that in the ABL flow physics are highly non-stationary and intermittent. Hence, the question arises "how variable is c_s"? To address this issue, we examine the dependence of c_s upon the length of time, T, over which the averages of equation 3 are evaluated. By varying T from 3.2 seconds to 27 minutes we find that the spread in the pdf of c_s for fixed Δ/z and neutral atmospheric stability increases for small T, but reassuringly the median of c_s does not depend on T. Surprisingly, for stable conditions the spread in the pdf does not increase for decreasing T. The median of c_s is constant for stable conditions and much smaller than for neutral conditions, in agreement with figure 1.

We also observe that backscatter events (with negative c_s^2 over segment length T) occur more frequently for small T and more frequently in neutral atmospheric stability than under stable conditions.

The same procedure can be applied to determine coefficients of SFS models for the SFS heat flux

$$q_i^{smag} = -\frac{\nu_T}{\Pr_T}\partial_i\tilde{\theta}, \qquad (4)$$

where θ is the temperature. We find that the turbulent Prandtl number $\Pr_T$ is nearly constant with stability, but an inverse dependence on Δ/z is observed. This implies that the entire model coefficient for the scalar SFS model, $c_s^2 \Pr_T^{-1}$, depends strongly on stability and increases with decreasing Δ/z.

The degree of intermittency (measured by the kurtosis) of the SFS energy dissipation χ impacts the choice of a timescale to be used to compute averages for SFS model coefficients. Thus we examine dependence of intermittency on the parameters introduced above, Δ/L and Δ/z. As expected, intermittency increases with decreasing Δ/z.

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