Improving WRF’s Large-Eddy Simulation Capability With New Subfilter Stress Models

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Streamwise $u$-spectra from LES of neutral, geostrophically-forced boundary layer flow over flat terrain

Parameters: $U_g=10\text{m/s}$, Coriolis=$45^\circ$, $z_0=0.1$, Surface stresses specified from $u(i,1,j)$ and $v(i,1,j)$ using the log law, Doubly periodic lateral boundary conditions, Domain: $(\Delta Hx\Delta Z) = (4096\times1024) \text{ m}$

$\Delta h=16\text{m}$ and $32\text{m}$ are LES, $\Delta h=64\text{m}$ is marginal, $\Delta h=128\text{m}$ is not LES
LES resolves the important scales of turbulence, models effects of subfilter scales.
Three new turbulence subfilter models were added to WRF

- **Nonlinear Backscatter and Anisotropy SGS model (Kosovic, 1997)**
  - Nonlinear at the tensor level
  - Explicitly accounts for backscatter and anisotropy
  - Has only 1 free parameter (backscatter coefficient)

- **Dynamic eddy viscosity SGS model (Wong and Lilly, 1994)**
  - SGS $K$ are function of resolved stresses on a coarsened mesh
  - $K$ require filtering, clipping, separate near-wall stress model
  - These “parameters” require tuning for different flow configurations

- **Resolvable Subfilter-Scale Stresses model (Chow et al, 2005)**
  - ”Reconstructs” stresses from scales attenuated by numerical errors
  - Additional SFS stress term that augments SGS stresses
Wind speed scaled by $u^*$ vs. $z/h$
Streamwise $u$-velocity spectra at three heights

- DWL and NBA increase energy near surface, increase/decrease energy at high/low $f$
- Solutions converge with increasing resolution, distance above surface
Adding RSFS stresses changes the partitioning of the stresses; less resolved, more subfilter.
Simulated flow over a gently-sloping terrain feature at high resolution indicates separation and recirculation in hill lee

1024m³ domain, forced with $U_G = 10$ m/s, $V_G = 0$, $z_0 = 0.1$ m

“Truth” snapshot from high-resolution simulation, $\Delta h$, $\Delta z = 8.4$ m, TKE SGS model
Histograms of u-velocity taken at ~30m above surface ~250m behind hill
from high-resolution ‘truth’ simulation
Coarsening resolution results in erroneous velocity distributions in hill lee

\[ \Delta h, \Delta z = 8.4 \text{ m} \]

\[ \Delta h, \Delta z = 32.8 \text{ m} \]
Coupling RSFS stresses with TKE SGS model (and SMAG, not shown) at coarse resolution slightly improves velocity distributions in hill lee.

\[ \Delta h, \Delta z = 8.4 \text{m} \quad \Delta h, \Delta z = 32.8 \text{m} \]
Coupling RSFS stresses with NBA SGS model (and DWL, not shown) at coarse resolution significantly improves velocity distributions in hill lee.
Conclusions

The new SFS models implemented into WRF improve its LES capability
- Improved wind speed profiles
- Improved spectra, especially near surface
- Improved flow structures behind terrain features

Future work:
- Further evaluation of new models
- Extension to non-neutral flows
- Extension to more complex terrain
- Extension to Mesoscale-LES coupling
Update on progress with the Immersed Boundary Method (IBM) to represent complex terrain in WRF

Computational mesh with explicit terrain

IBM assigns values to "ghost nodes" (G) to represent the effects of solid surfaces on the flow above

Computational mesh with immersed terrain
Update on progress with the Immersed Boundary Method (IBM) to represent complex terrain in WRF
Update on progress with the Immersed Boundary Method (IBM) to represent complex terrain in WRF

Terrain cross section of Owens Valley region
Update on progress with the Immersed Boundary Method (IBM) to represent complex terrain in WRF

Terrain cross section of Owens Valley region

Simulated flow over Owens Valley region using IBM
Questions?

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