LES is More with Rica-struction *

With information and graphics from various sources: Chow, Street, Carati, Wyngaard, etc.

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*a working title
Outline

• LES Filtering Basics
• Reconstruction of Subfilter Stress
• Motivation for Rica-struction
• Rica-struction of Subgrid Stress
Simulations Out There

- Direct Numerical Simulation (DNS)
- Reynolds-averaged Navier-Stokes (RANS)
- Large Eddy Simulation (LES)
Simulations Out There

Direct Numerical Simulation (DNS)

Reynolds-averaged Navier-Stokes (RANS)

Large Eddy Simulation (LES)
Simulations Out There

- Direct Numerical Simulation (DNS)
- Reynolds-averaged Navier-Stokes (RANS)
- Large Eddy Simulation (LES)
LES is More ...

- ... computationally efficient than DNS
- ... descriptive than RANS
- It can depict turbulent structures, RANS has time averaged results
Spatial Filters

- Remove high frequency signals that cannot be resolved by the grid and time step
- Spatially averages the data
- The grid itself acts like a cutoff filter

Moiré Patterns

http://en.wikipedia.org/wiki/Moiré_pattern
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Filter Effects

“With the Waves” by Natasha Wescoat
Filter Effects

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Time for Equations!

- **Momentum**

\[
\frac{\partial u_i}{\partial t} + \frac{\partial u_i u_j}{\partial x_j} = -\frac{1}{\rho_0} \frac{\partial p}{\partial x_i} + \nu \frac{\partial^2 u_i}{\partial x_j \partial x_j} - \frac{\rho}{\rho_0} g \delta_{ij} + \epsilon_{imn} f_n u_m
\]

- **LES Equations: Filtered (-) & Gridded (∼)**

\[
\frac{\partial \tilde{u}_i}{\partial t} + \frac{\partial \tilde{u}_i \tilde{u}_j}{\partial x_j} = -\frac{1}{\rho_0} \frac{\partial \tilde{p}}{\partial x_i} + \nu \frac{\partial^2 \tilde{u}_i}{\partial x_j \partial x_j} - \frac{\tilde{p}}{\rho_0} g \delta_{ij} + \epsilon_{imn} f_n \tilde{u}_m - \frac{\partial \tilde{S}_{ij}}{\partial x_j}
\]

- \( F_{ij} = A_{ij} + B_{ij} = \overline{u_i u_j} - \tilde{u}_i \tilde{u}_j \)

- \( \overline{A_{ij}} = \frac{\overline{u_i u_j} - \tilde{u}_i \tilde{u}_j}{\overline{u_i u_j}} \) modeled with Rica-struction!

- \( B_{ij} = \overline{\tilde{u}_i \tilde{u}_j} - \tilde{u}_i \tilde{u}_j \) reconstructed!
What we can get with LES

Resolved Subfilter
“What Reconstruction gets”

Numerical Error
“What we don’t get”

Resolved
“What we get right away”

Subgrid
“What we don’t get right”

Carati et al. 2001, Chow and Street 2005
This problem has at least two parts

- Get all the information possible:
  - Reconstruct the resolvable subfilter scale (RSFS) stress
  - Model the subgrid scale (SGS) stress
  - Combine the RSFS and SGS stresses and plug into N-S equation to get resolved velocities at the next time step
Physical Mechanisms in Reconstruction

Reconstruction is influenced by the same physical processes as the resolved velocities:

- Buoyancy
- Coriolis
- Diffusion
- Pressure
- Advection
Reconstructing the RSFS
as done by Tina Katapodes Chow

- Estimate an unfiltered velocity with the smoothing filter and resolved velocities
- Plug it into the RSFS stress in the momentum equation
- Use the RSFS stress in the Navier-Stokes equation

Truncation error and properties of filtering create the lost subfilter scale stress

What we’ll have!
Gaussian & Grid Filtered, Reconstruction Levels 0, 1, 5, 10, 100, and 1000

pictures courtesy of Tina Chow
Gaussian & Grid Filtered, Reconstruction Levels 0, 1, 5, 10, 100, and 1000

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Smagorinsky, a not-so good SGS model

\[ \bar{A}_{ik} = 2 \nu_T \tilde{S}_{ik} \]

- It’s simple and easy
- It follows that theory about whorls and swirls going onward to viscosity
- It’s not completely lying, it’s just withholding a lot of the truth
The Lies....

- Strain rate and stress tensors are **NOT** aligned in practice
- The Smagorinsky model does **NOT** account for backscatter from smaller scales to larger scales
- Shear stress is overestimated
Rica-struction
(aka multistress aka stressing me out)

SGS stress can be modeled as a sum of:

- transport/diffusion terms
- production terms
- pressure strain terms
- buoyancy generation terms
ARPS: The Advanced Regional Prediction System

- Development began in 1989 and continues today
- Started at the Center for Analysis and Prediction of Storms at the University of Oklahoma
- 3D, nonhydrostatic, compressible, terrain-following
- Runs on workstations and supercomputers
Oh, the Places I’ll Go!

- Redefine Rica-struction
- Combine Rica-struction with Tina Chow’s Reconstruction
- Create analgous SGS models for the water vapor and potential temperature calculations
- Compare with HATS fieldwork data
Recap

• **Subfilter** information can be reconstructed with resolved velocities

• **Subgrid** information is lost and must be modeled
Thank You!

NSF GRFP, NCAR ASP, NSF ATM-0073395
Bob Street, Frank Ludwig, Tina Chow, Peter Sullivan, Megan Bela, Johnson Gong, Megan Daniels, Andrew Lamperski, everyone at the EFML, the Atmosphere/Energy Group, and the TOY Summer School!
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