# 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)

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# LES is More ...

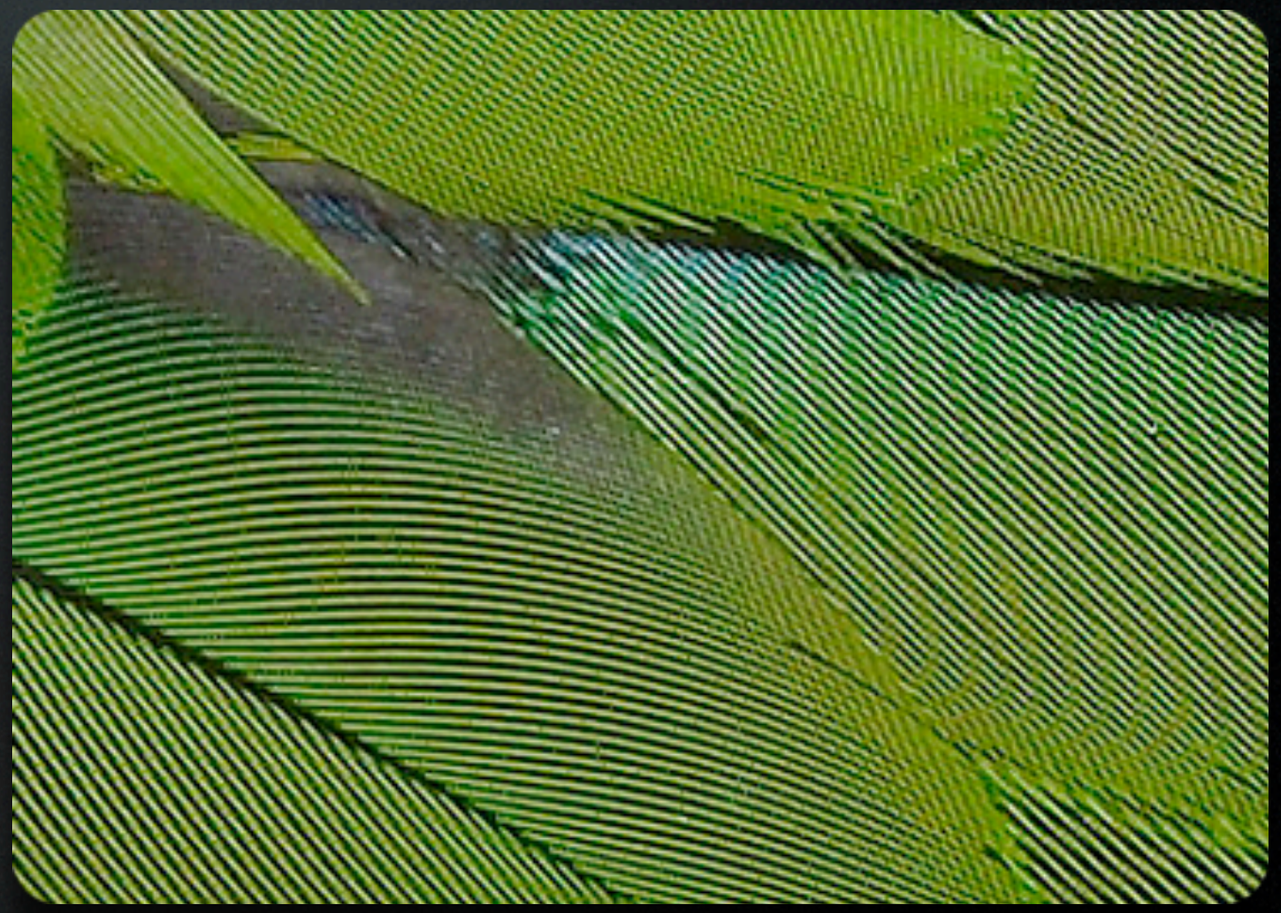
- ... computationally efficient than DNS
- ... descriptive than RANS
- It can depict turbulent structures, RANS has time averaged results

# Spatial Filters

- Remove high frequency signals that cannot be resolved by the grid and time step

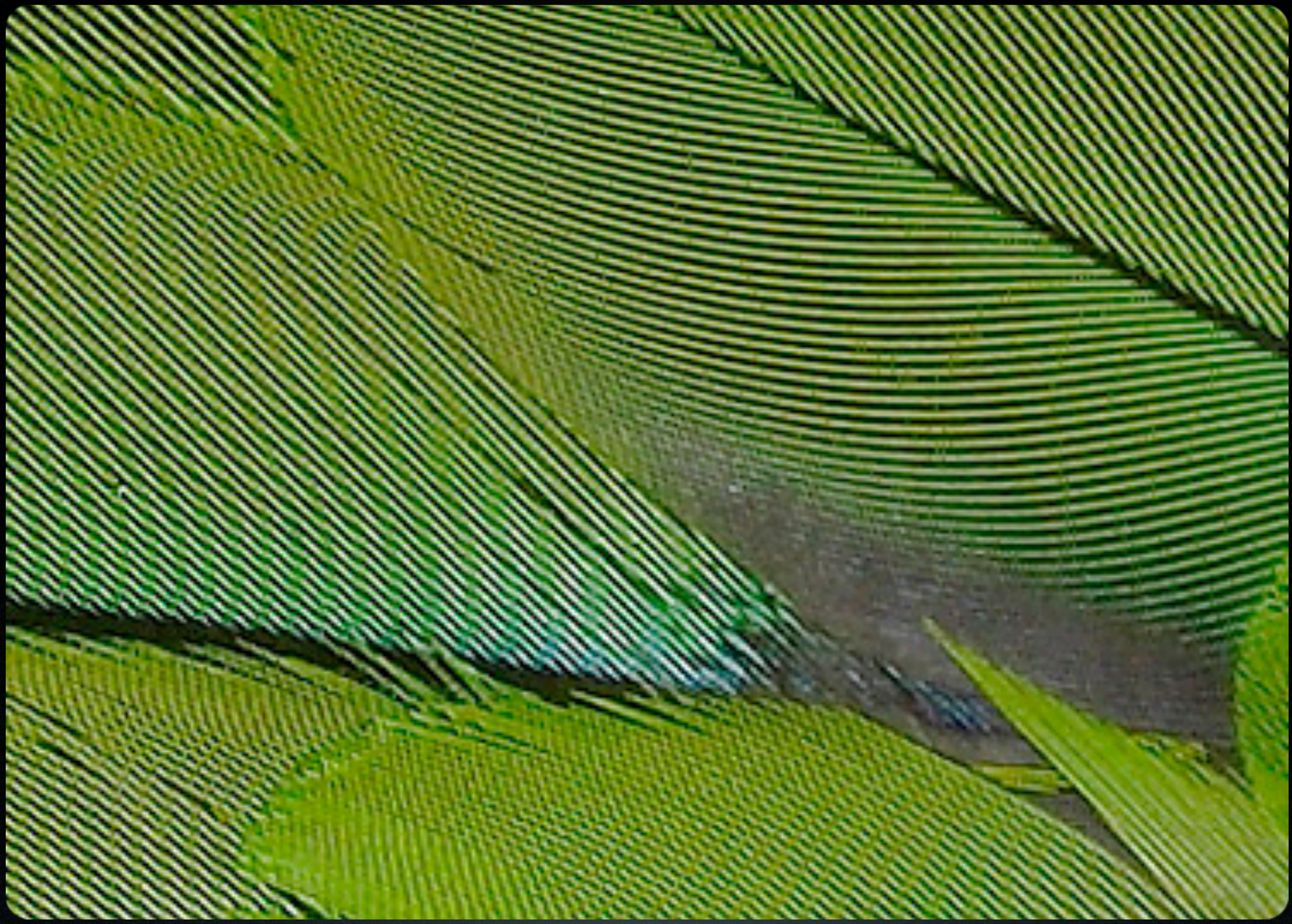
- Spatially averages the data

- The grid itself acts like a cutoff filter



Moiré Patterns

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



# Filter Effects

"With the Waves" by Natasha Wescoat

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# Time for Equations!

- Momentum

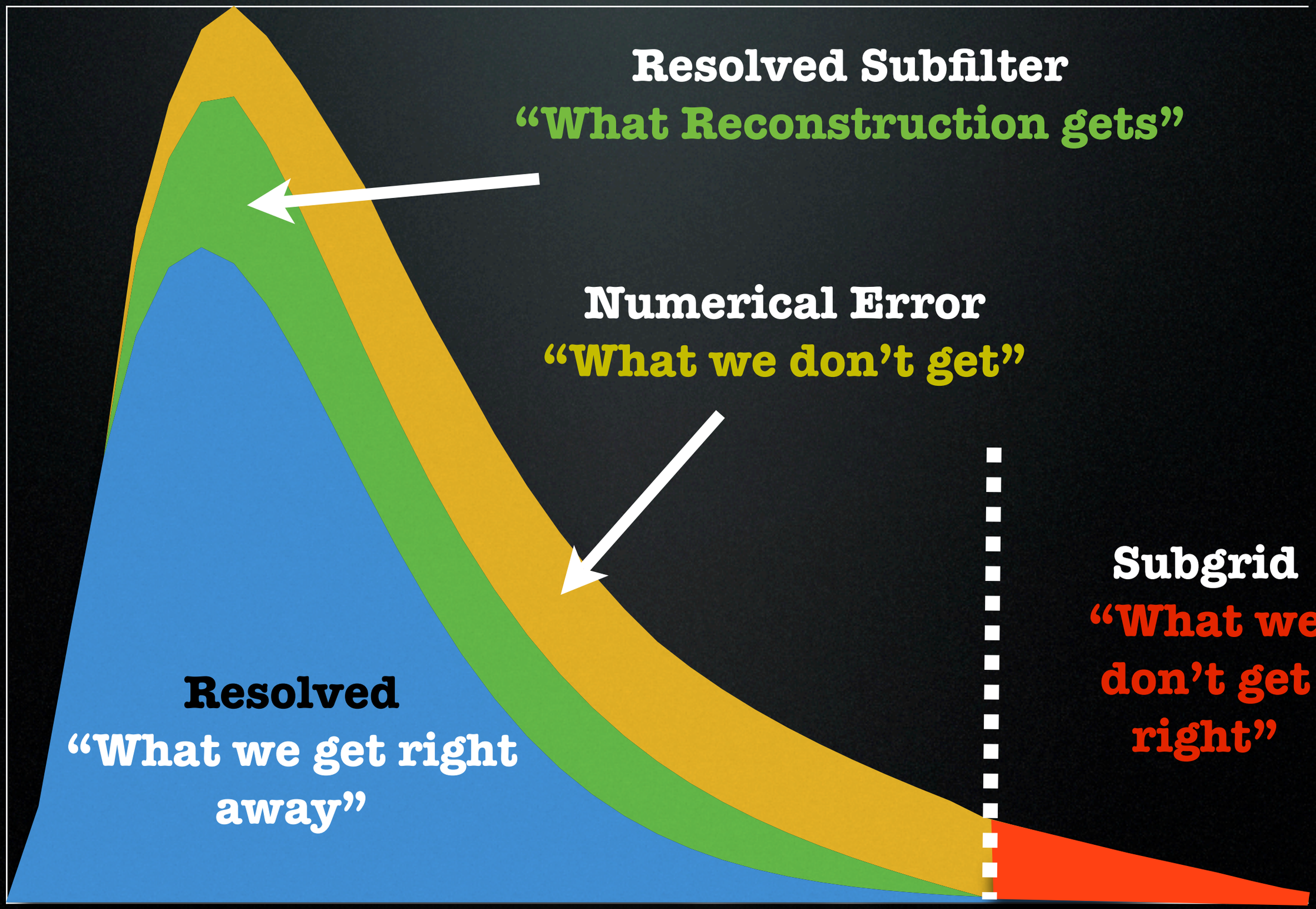
$$\frac{\partial u_i}{\partial t} + \frac{\partial u_i u_j}{\partial x_j} = -\frac{1}{\rho_0}\frac{\partial p}{\partial x_i} + \nu\frac{\partial^2 u_i}{\partial x_j \partial x_j} - \frac{\rho}{\rho_0} g\delta_{i3} + \epsilon_{imn} f_n u_m$$

- LES Equations: Filtered (-) & Gridded (⌢)

$$\frac{\partial \tilde{\bar{u}}_i}{\partial t} + \frac{\partial \widehat{\tilde{\bar{u}}_i \tilde{\bar{u}}_j}}{\partial x_j} = -\frac{1}{\rho_0}\frac{\partial \tilde{\bar{p}}}{\partial x_i} + \nu\frac{\partial^2 \tilde{\bar{u}}_i}{\partial x_j \partial x_j} - \frac{\tilde{\bar{\rho}}}{\rho_0} g\delta_{i3} + \epsilon_{imn} f_n \tilde{\bar{u}}_m - \frac{\partial \tilde{\Im}_{ij}}{\partial x_j}$$

- $\mathcal{F}_{ij} = \overline{A_{ij}} + B_{ij} = \overline{u_i u_j} - \tilde{\bar{u}}_i \tilde{\bar{u}}_j$
- $\overline{A_{ij}} = \overline{u_i u_j} - \overline{\tilde{u}_i \tilde{u}_j}$ modeled with Rica-struction!
- $B_{ij} = \overline{\tilde{u}_i \tilde{u}_j} - \tilde{\bar{u}}_i \tilde{\bar{u}}_j$ reconstructed!

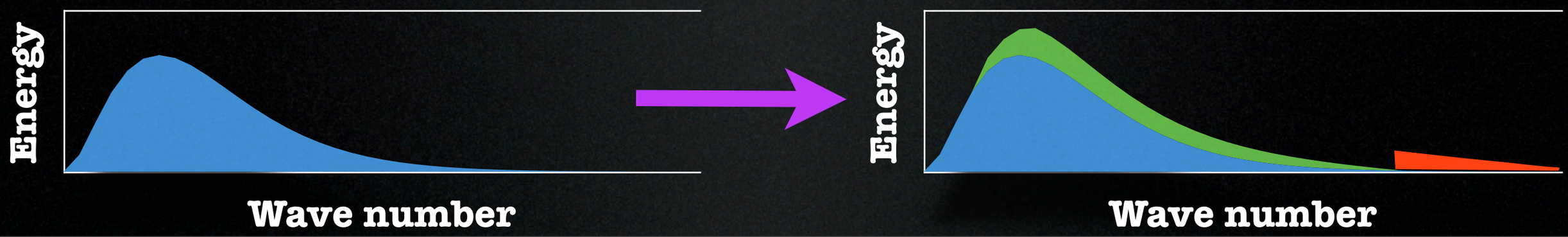
# What we can get with LES




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 velocites at the next time step



# Physical Mechanisms in Reconstruction

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

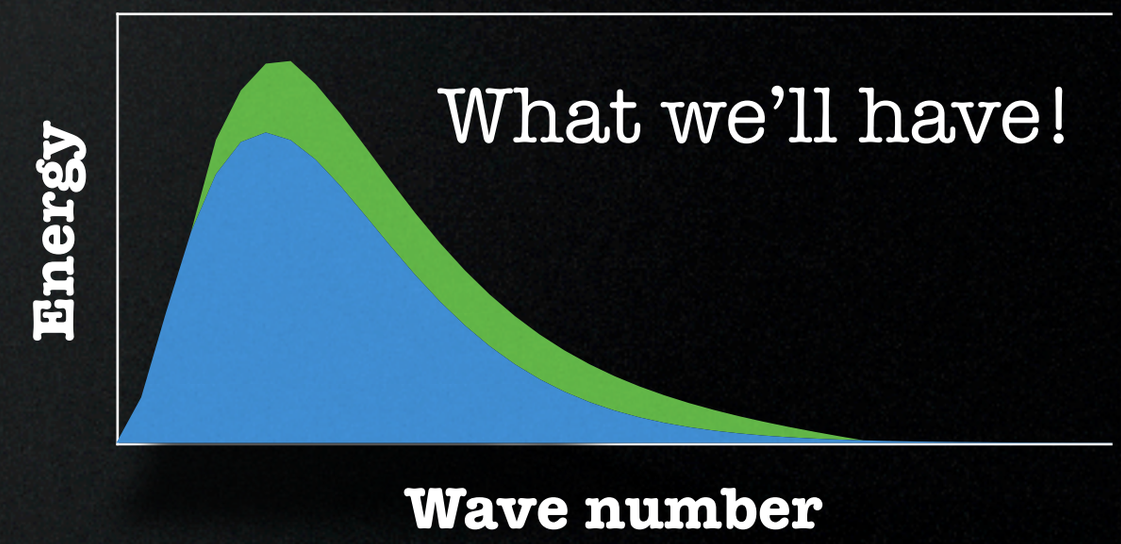
- Buoyancy
- Coriolis
- Diffusion
- Pressure
- Advection

# 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



Gaussian & Grid Filtered, Reconstruction Levels 0, 1, 5, 10, 100, and 1000

Original

pictures courtesy of Tina Chow

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# Smagorinsky, a not-so good SGS model

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

- 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 velocites
- 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!

Khawp jai

Dannaba

Wokol a wala

Grazia

Sabkaa

Koloombo

Ahsante

Birepo

Dot nuet

Fayyaa ta'aa

Paylla

Hvala

Chyeju gaba sai

Dankon

Salamat

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