Analysis of Lagrangian stretching in turbulent channel flow using a task-parallel particle tracking method in the Johns Hopkins Turbulence Databases

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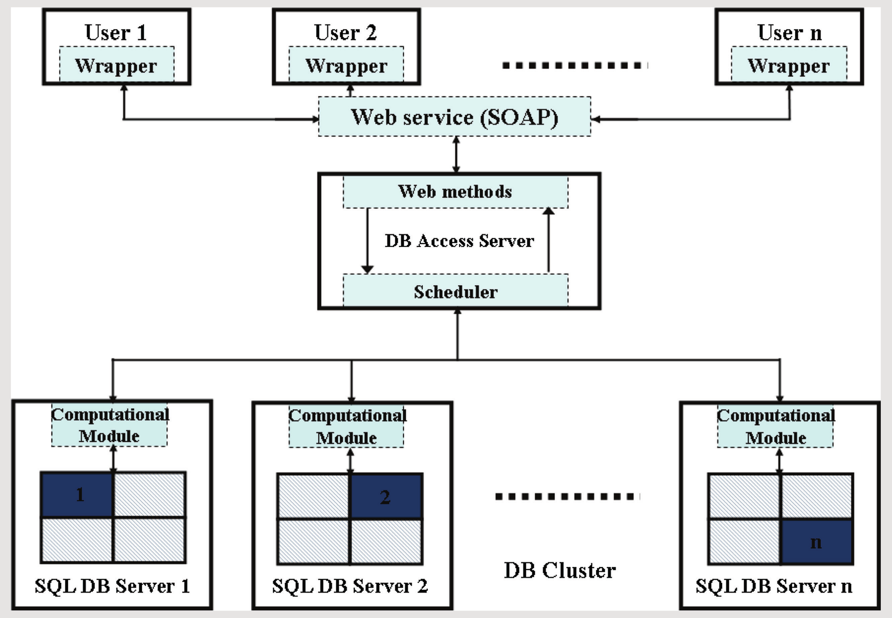
Johns Hopkins Turbulence Databases (JHTDB)

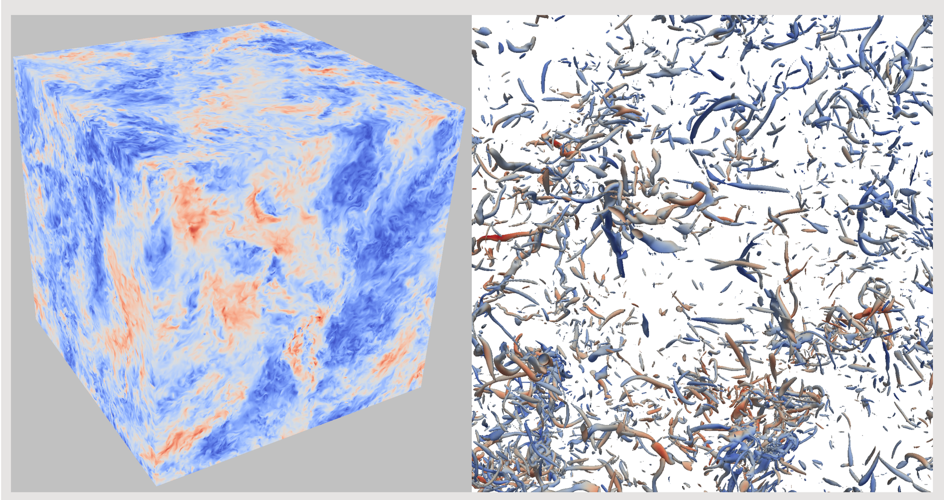
- http://turbulence.pha.jhu.edu/
- access via web services
- Fortran, C, Matlab, HDF5 cutout
- built-in functions
  - e.g. getVelocity, getPressureHessian
  - interpolation & finite-differencing
- Currently hosts four datasets:
  - Isotropic: $1024^3 \times 5024$
  - Magnetohydrodynamics: 1024^4
  - Channel: $2048 \times 512 \times 1536 \times 4000$
  - Mixing: $1024^3 \times 1012$



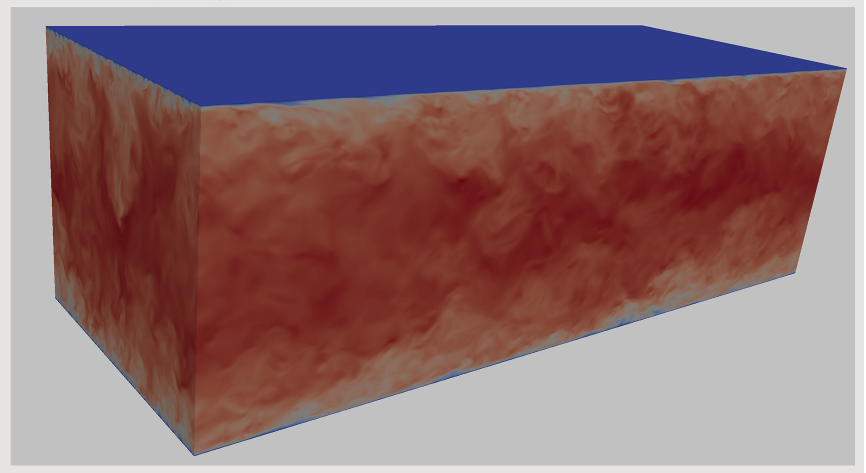
Homogeneous Isotropic Turbulence vs. Turbulent Channel Flow

incompressible Navier-Stokes: $$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \nu \frac{\partial^2 u_i}{\partial x_j \partial x_j} + f_i, \qquad \frac{\partial u_j}{\partial x_j} = 0$$

- isotropic forcing in a periodic box
- for studying small-scale turbulent motions

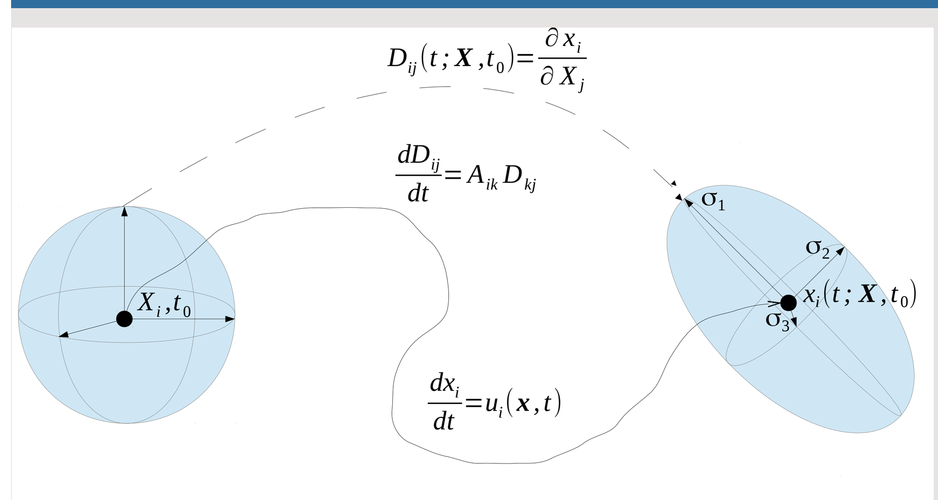


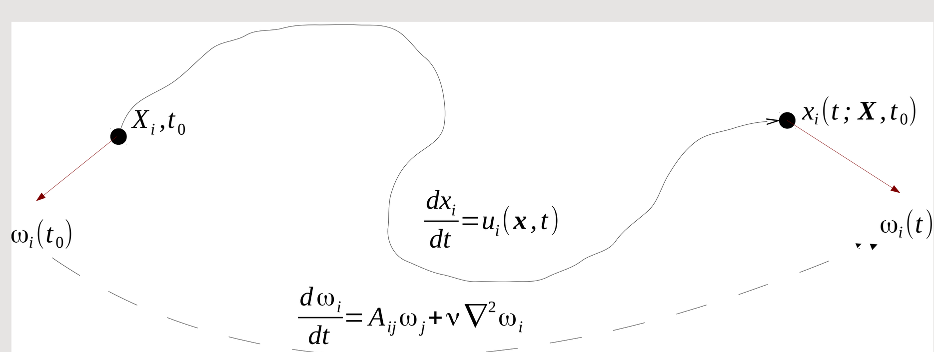
- flow between infinite flat plates ($\mathbf{u} = 0$ B.C.)
- for studying turbulence near boundaries



- Local isotropy hypothesis: zoom-in to any flow, statistically like isotropic turbulence

Stretching of Fluid Elements and Vorticity

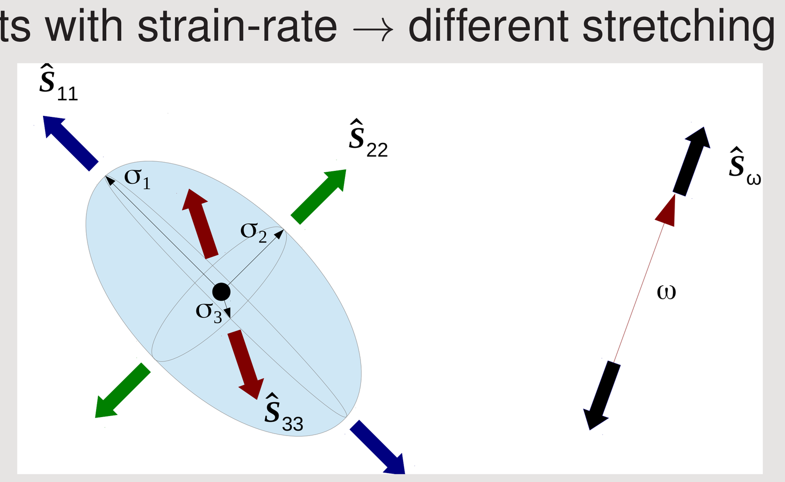




- fluid elements and vorticity both stretched and rotated by same mechanism
- BUT, different alignments with strain-rate $\rightarrow$ different stretching rates

$$\frac{d\sigma_i}{dt} = \widehat{S}_{(ii)}\sigma_i$$

where $\widehat{S}_{(ii)}$ is strain-rate along i^{th} semi-axis



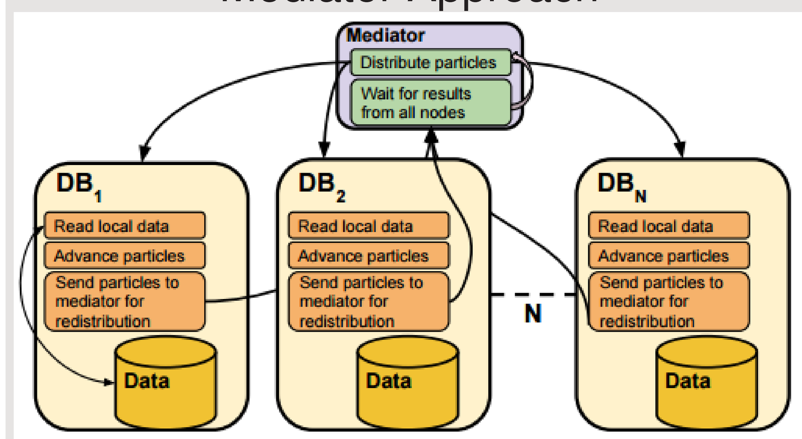
$$\frac{d\omega}{dt} = \widehat{S}_\omega \omega$$

where $\widehat{S}_\omega$ is strain-rate along vorticity axis

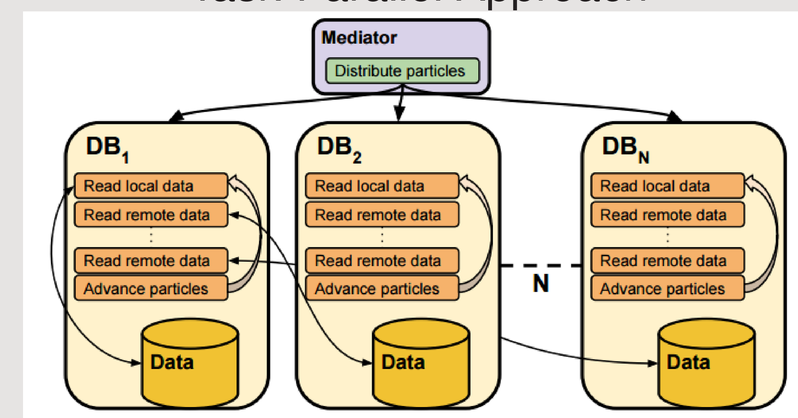
Fluid Particle Tracking

- Fluid particles follow the local flow velcity: $\dot{\mathbf{x}} = \mathbf{u}(\mathbf{x}(t), t)$
- 2nd-order method prevents particles from crossing physical boundaries

Mediator Approach



Task-Parallel Approach

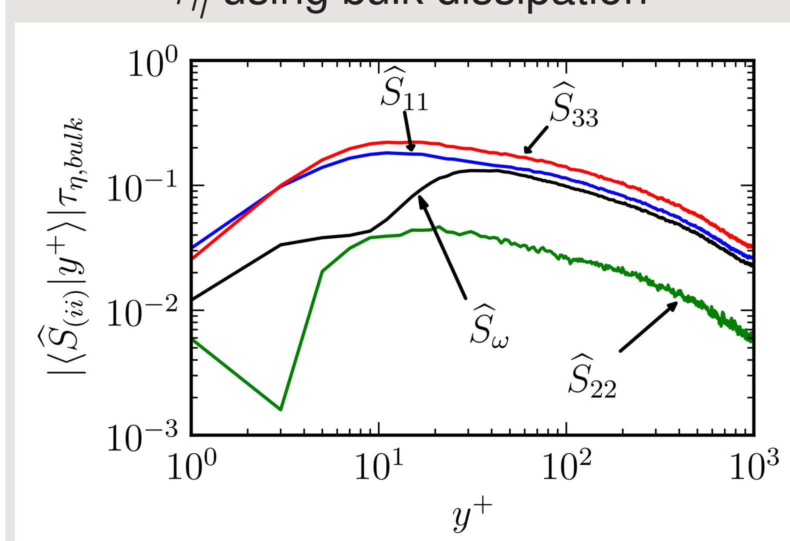


- Kanov & Burns (SC '15) showed that task-parallel approach is faster
- here: implement for channel

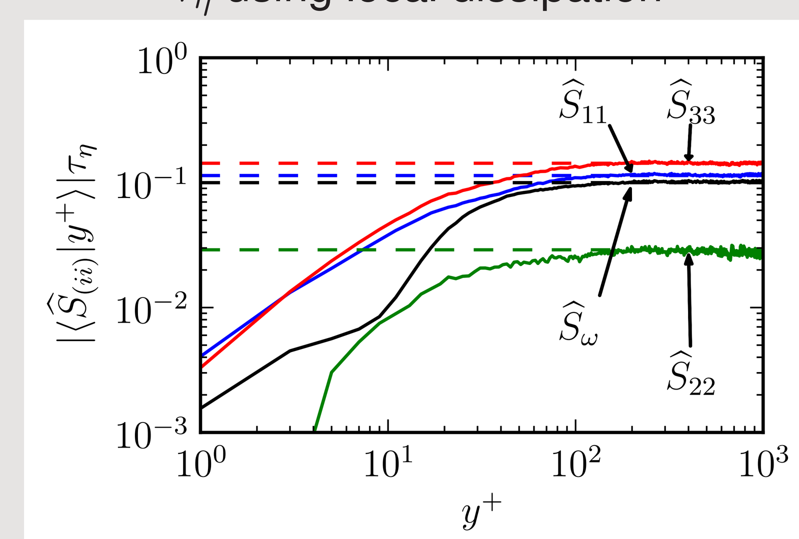
Stretching Rates: Mean

Strength of strain-rate $S_{ij} \sim \tau_\eta^{-1}$ varies with distance from boundary.

τ_η using bulk dissipation



τ_η using local dissipation

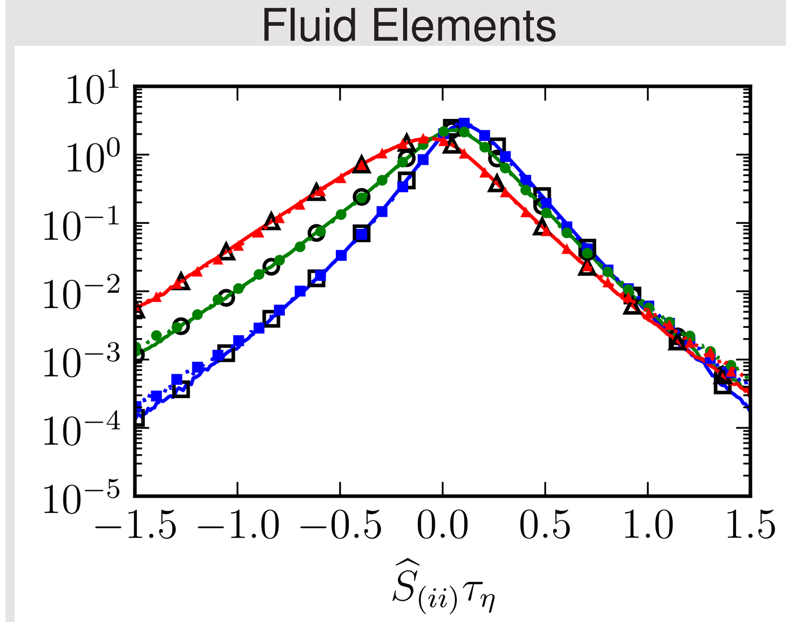


- Peak stretching close to boundary: $10 < y^+ < 50$
- Local isotropy in core: $y^+ > 100$
- Near boundary: less efficient
- Investigate alignment between strain-rate and fluid element/vorticity.

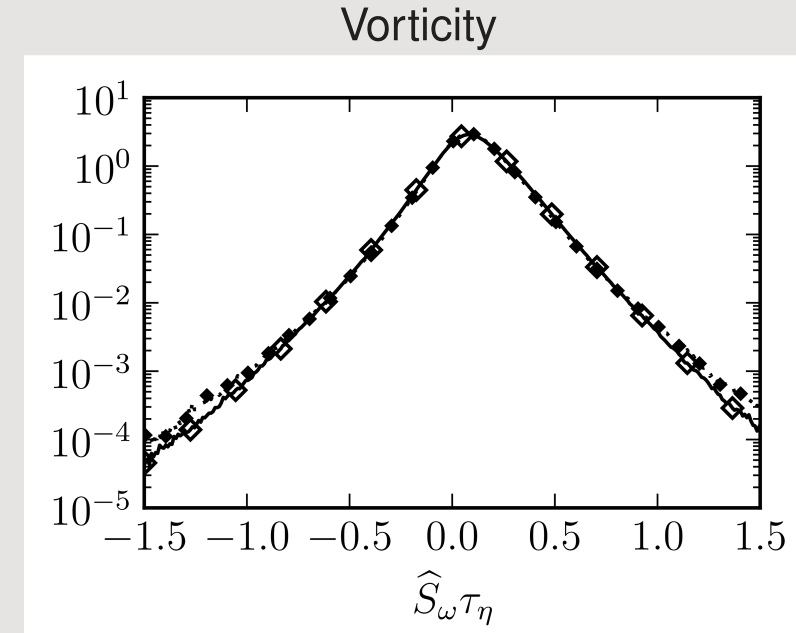
Stretching Rates: Full Probability Distribution

All locations $y^+ > 100$, normalized by local dissipation.

Fluid Elements

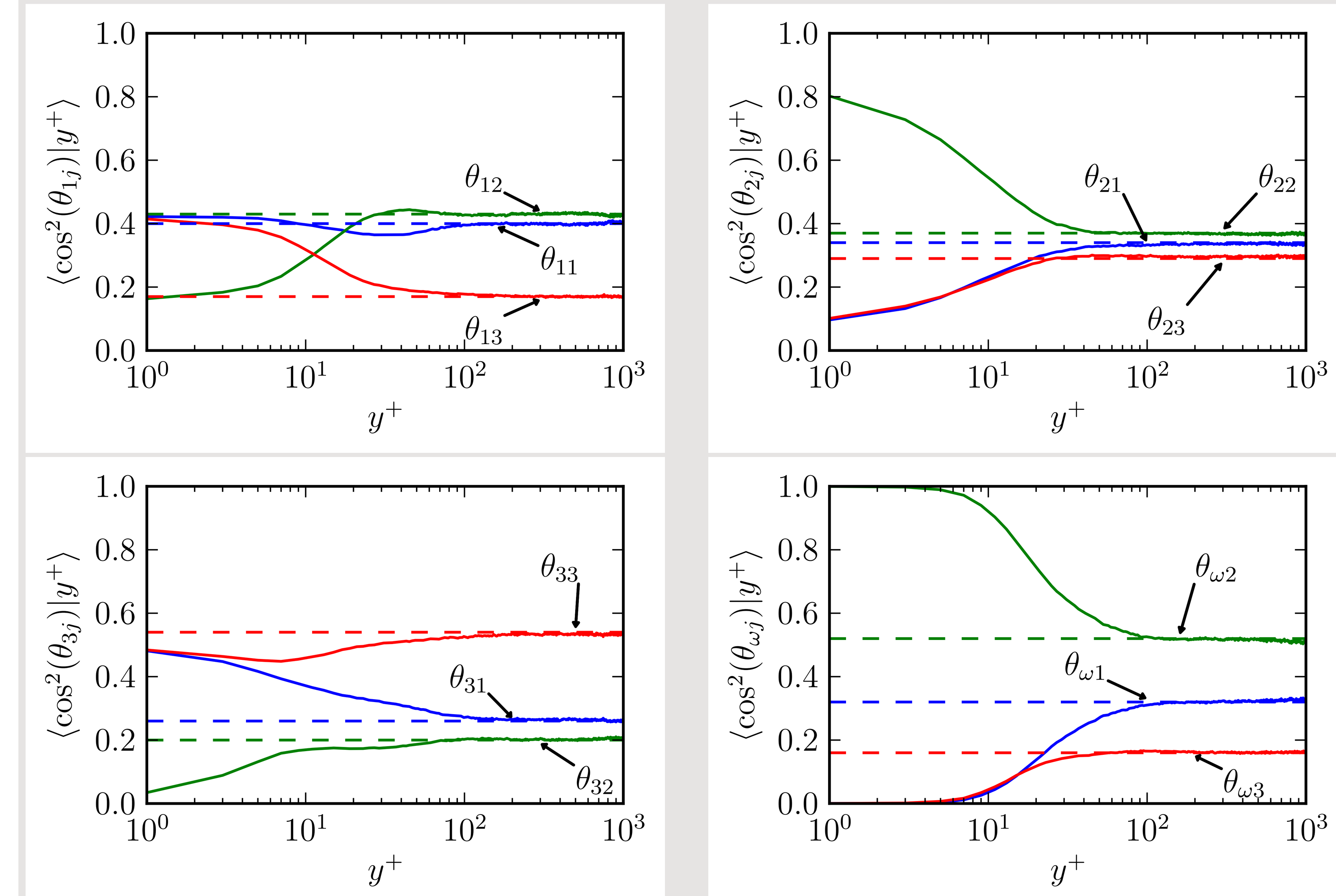


Vorticity

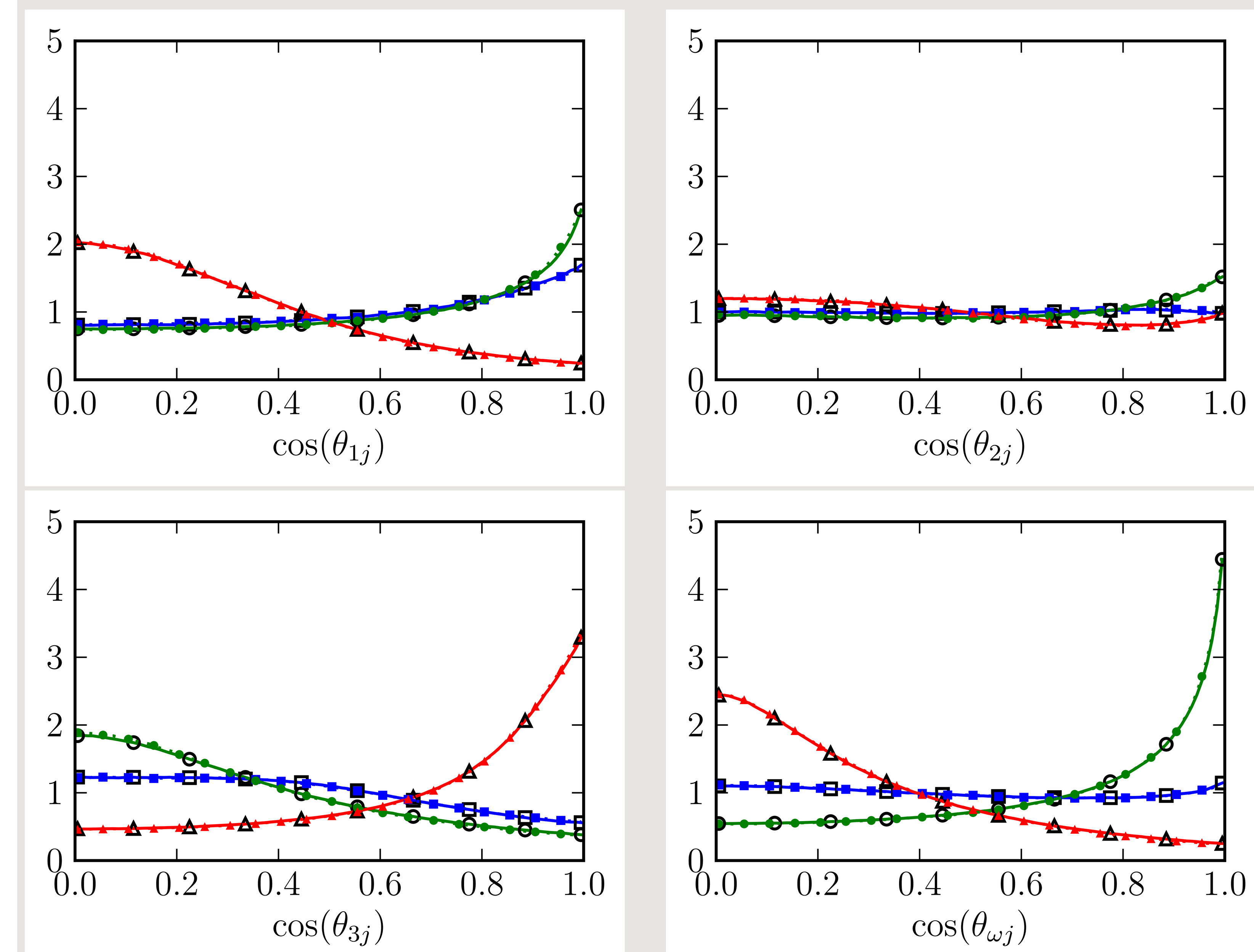


- More detailed support for local isotropy hypothesis in the core of the channel.

Alignment with Strain-Rate: Mean



Alignment with Strain-Rate: Full Probability Distribution



Conclusions

- Local isotropy in core ($y^+ > 100$), less favorable alignments near the wall.
- Overall, channel has 50% lower mean stretching rates per unit dissipation.