The JHU Turbulence Databases (*JHTDB*)

TURBULENT CHANNEL FLOW AT $\mathrm{Re}_\tau = 5200$ DATA SET

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The turbulent channel flow at $\mathrm{Re}_\tau = 5200$ database [1] is produced from a direct numerical simulation (DNS) of wall bounded flow with periodic boundary conditions in the longitudinal and transverse directions, and no-slip conditions at the top and bottom walls. In the simulation, the Navier-Stokes equations are solved using a wall–normal velocity–vorticity formulation [2]. Solutions to the governing equations are provided using a Fourier-Galerkin pseudo-spectral method for the longitudinal and transverse directions and seventh-order Basis-splines (B-splines) collocation method in the wall normal direction. Dealiasing is performed using the 3/2-rule [3]$^{(1)}$. Temporal integration is performed using a low-storage, third-order Runge-Kutta method. The flow is driven by a uniform pressure gradient, which varies in time to ensure that the mass flux through the channel remains constant. The fields are not outputted until the flow achieves statistical stationarity.

The simulation is performed using the petascale DNS channel flow code (PoongBack) developed at the University of Texas at Austin by Prof. Robert Moser's research group [4]. The pressure is obtained from the Poisson equation,

$$\nabla^2 p = -\nabla \cdot [\nabla \cdot (\boldsymbol{u} \otimes \boldsymbol{u})] \tag{1}$$

where p is the pressure divided by density, and $\boldsymbol{u}$ the velocity. The Neumann boundary condition, expressed as

$$\frac{\partial p}{\partial y} = \nu \frac{\partial^2 v}{\partial y^2} \tag{2}$$

where ν is the molecular kinematic viscosity and v the wall-normal velocity component, is used at the top and bottom walls. This calculation is performed independently from the velocity field solution only when outputting fields.

After the simulation has reached a statistical stationary state, 11 frames of data with 3 velocity components and pressure are stored in the database. The frames are apart from each other for around 0.7 flow-through time.

Information regarding the simulation setup and resulting statistical quantities are listed below. Note that the averaging operation for mean and other statistical quantities is applied in time and over x–z planes.

Simulation parameters

- Domain Length: $L_x \times L_y \times L_z = 8\pi h \times 2h \times 3\pi h$ where h is the half–channel height ($h = 1$ in dimensionless units)
- Grid: $N_x \times N_y \times N_z = 10240 \times 1536 \times 7680$ (wavemodes); $15360 \times 1536 \times 11520$ (collocation points); data is stored at the wavemode resolution, i.e. $N_x \times N_y \times N_z = 10240 \times 1536 \times 7680$ at grid point nodes in physical space.
- Viscosity: $\nu = 8 \times 10^{-6}$ (non-dimensional)

Flow statistics [1, 5]

- Bulk velocity: $U_b = 1$
- Centerline velocity: $U_c \sim 1.10$
- Friction velocity: $u_\tau = 4.14872 \times 10^{-2}$
- Viscous length scale: $\delta_\nu = \nu/u_\tau = 1.9283 \times 10^{-4}$
- Reynolds number based on bulk velocity and half channel height: $\mathrm{Re}_b = \frac{U_b h}{\nu} = 1.25 \times 10^5$
- Centerline Reynolds number: $\mathrm{Re}_c = U_c h/\nu \sim 1.375 \times 10^5$
- Friction velocity Reynolds number: $\mathrm{Re}_\tau = u_\tau h/\nu = 5185.897$

Grid spacing in viscous units

- x direction: $\Delta x^+ = 12.7$
- y direction at first B-spline knot point from the wall: $\Delta y_1^+ = 0.498$
- y direction at centerline B-spline knot point: $\Delta y_c^+ = 10.3$
- z direction: $\Delta z^+ = 6.4$

In the following figures several quantities from the simulation are shown. Figure 1 shows an instantaneous snapshot of the flow. Figure 2 shows the mean velocity along with the standard U^+ profiles in the viscous sublayer and log-layer. The Reynolds stresses, mean pressure, pressure variance, and velocity–pressure covariances are shown in Figures 3–5. In the remaining plots, the power spectral densities of velocity and pressure are shown for various y^+ locations. Streamwise spectra are shown in Figure 6, whereas spanwise spectra are shown in Figure 7.

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(1) *Note:* The divergence-free condition in the simulation is enforced based on the spectral representation of the derivatives. The JHTDB analysis tools for gradients are based on finite differencing of various orders. Therefore, when evaluating the divergence using these spatially more localized derivative operators, a non-negligible error in the divergence is obtained, as expected.

References

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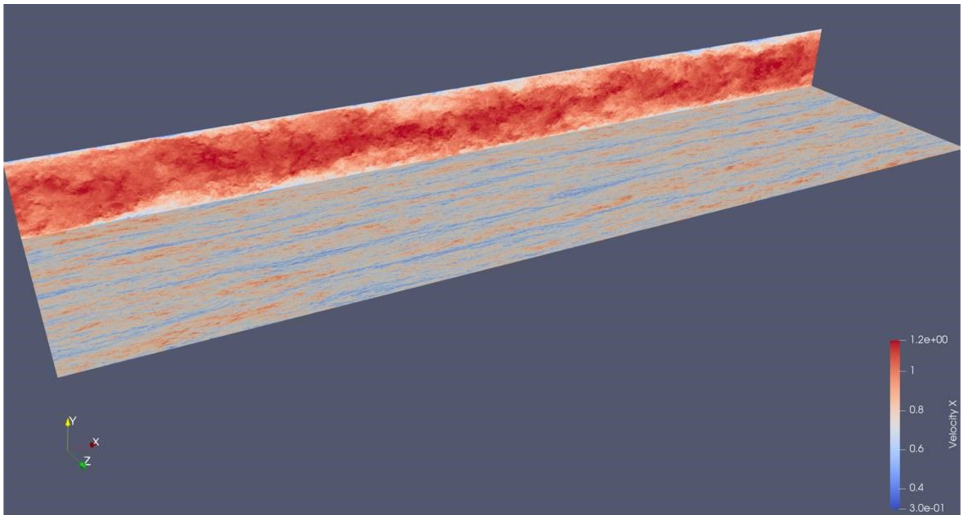

Figure 1: Two planar slices of an instantaneous snapshot of the flow, showing streamwise velocity contours. The flow is from left to right.

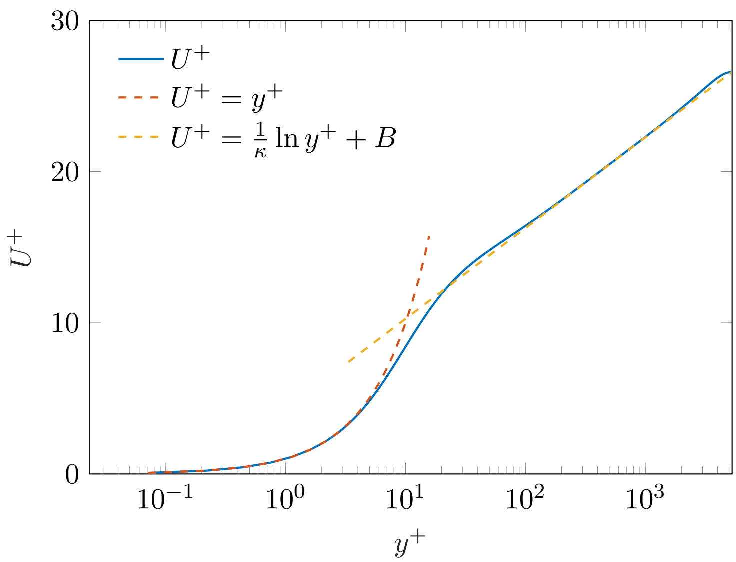

Figure 2: Mean velocity profile in viscous units. Standard values of $\kappa = 0.384$ and $B = 4.27$ are used in the log-law (dashed line) for reference.

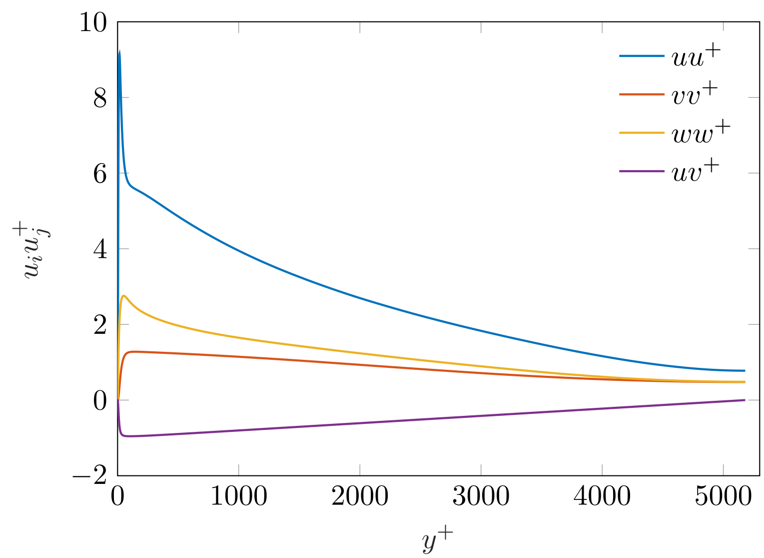

Figure 3: Velocity covariances in viscous units

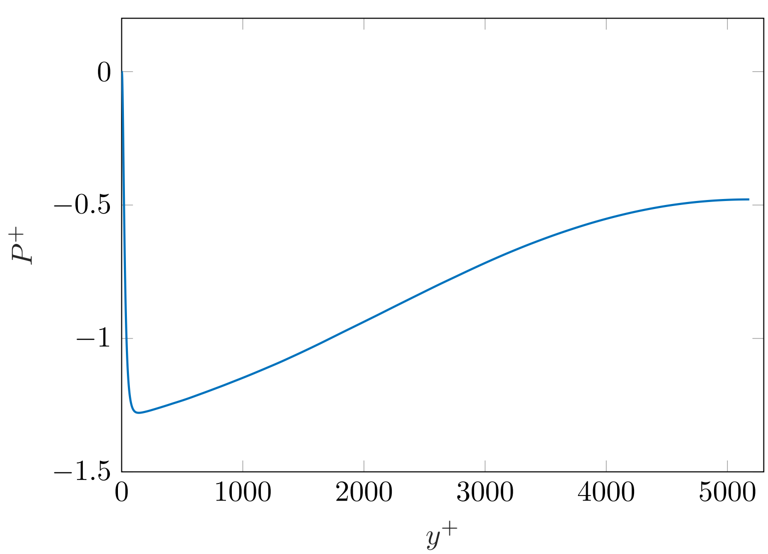

Figure 4: Mean pressure $P^+ = -vv^+$ profile in viscous units

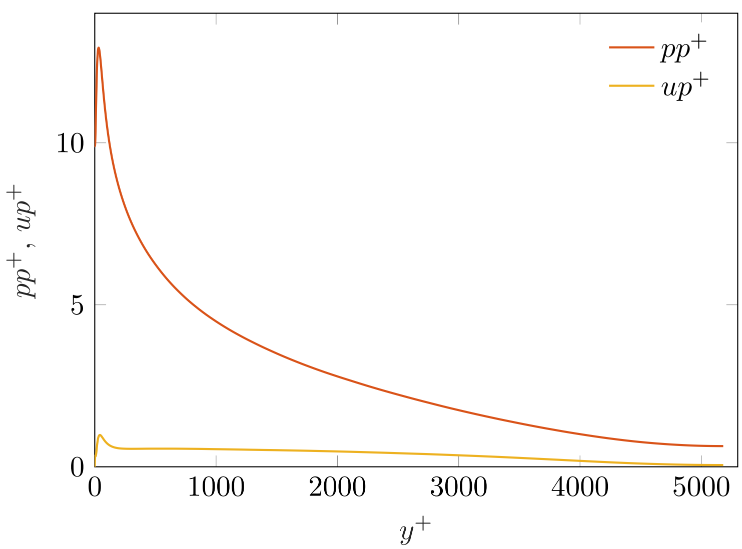

Figure 5: Pressure variance and pressure-velocity covariance in viscous units

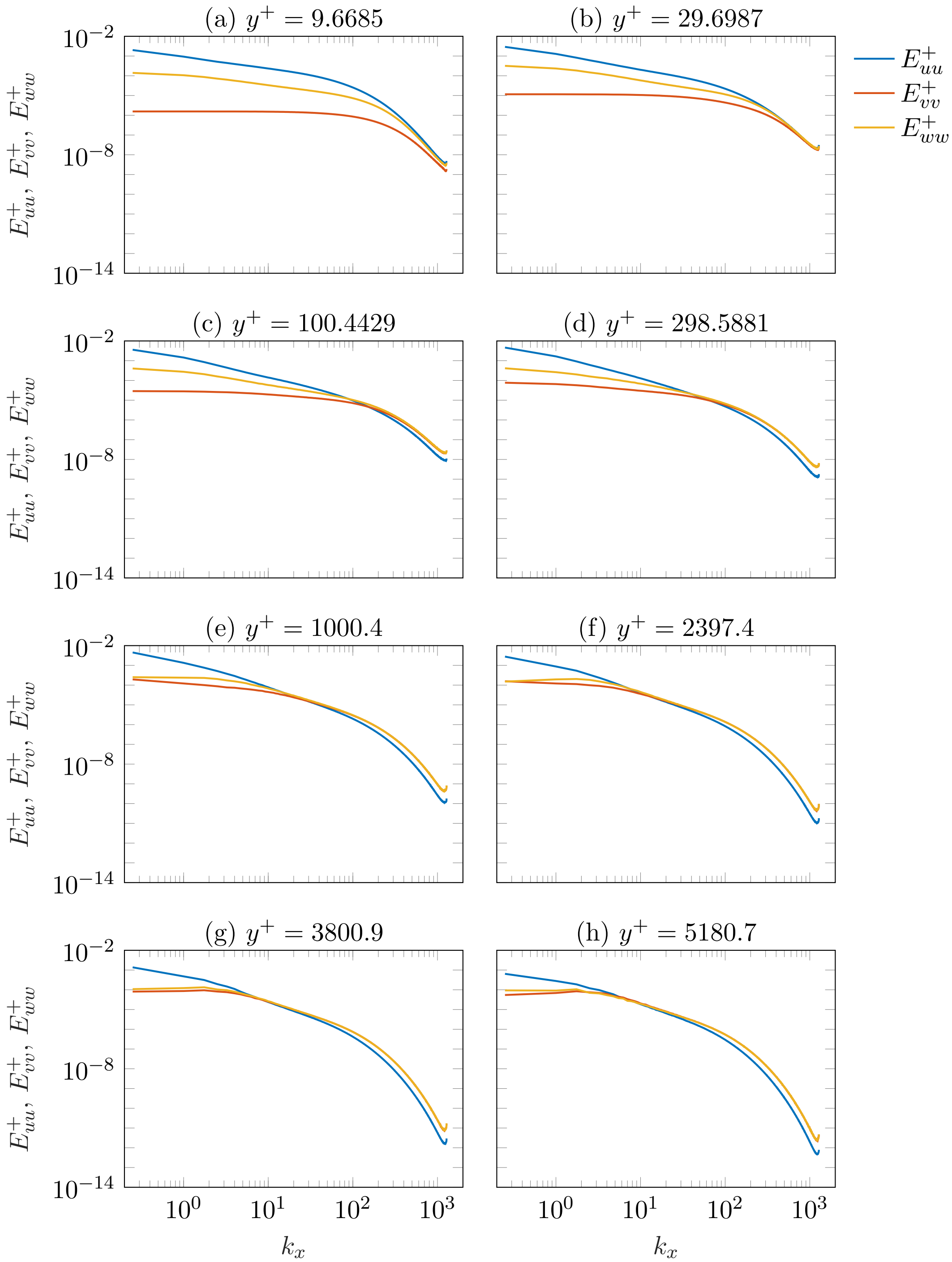

Figure 6: Streamwise power spectral densities at various y^+ locations as function of k_x

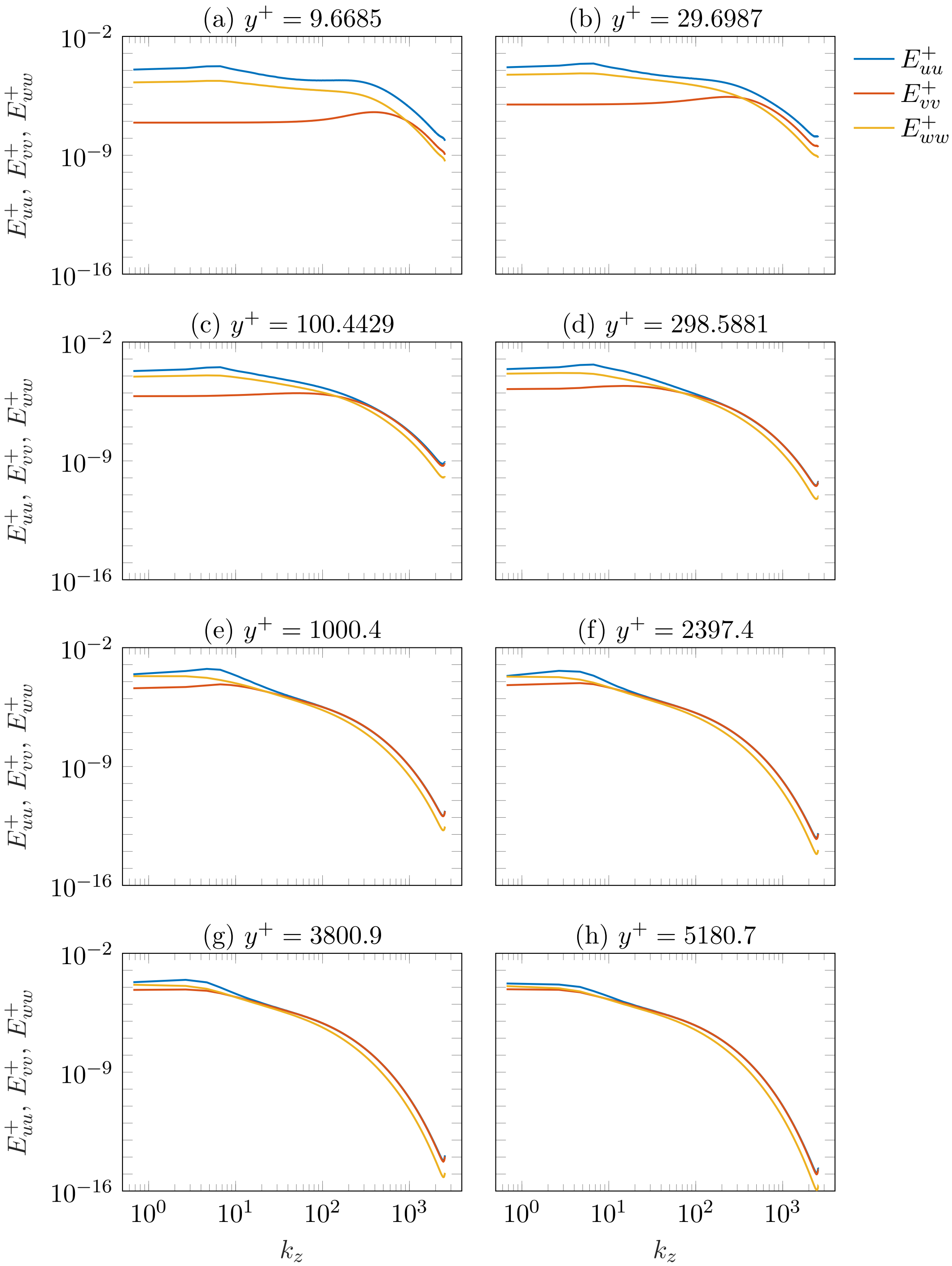

Figure 7: Spanwise power spectral densities at various y^+ locations as function of k_z