Can the Kolmogorov eddies become smaller that the viscous sublayer length?

Practical turbulence estimates

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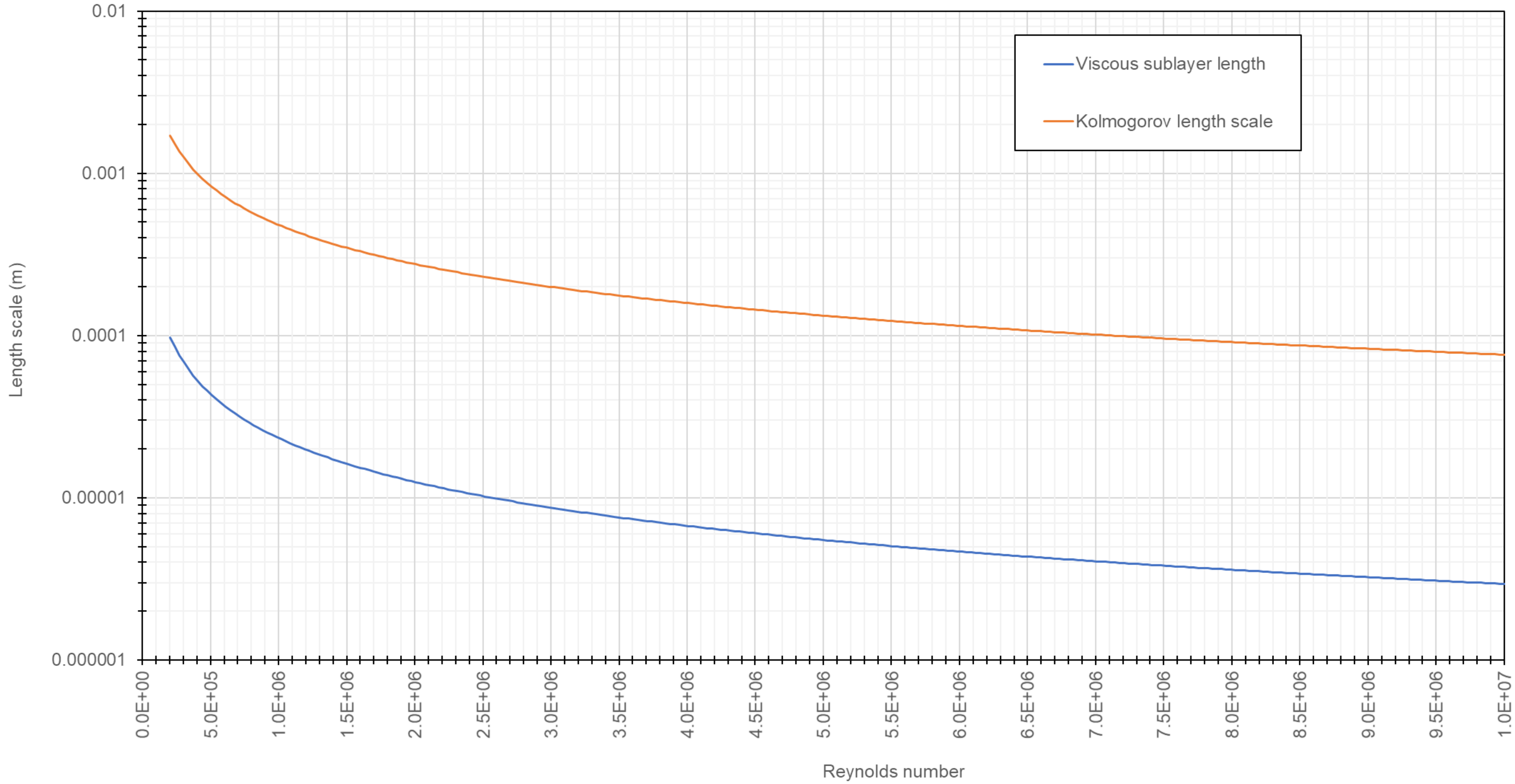

- In few words, no.
- In this case, the viscous sublayer is always at least one order of magnitude thinner than the Kolmogorov eddies.
- The viscous sublayer cannot accommodate Kolmogorov eddies.

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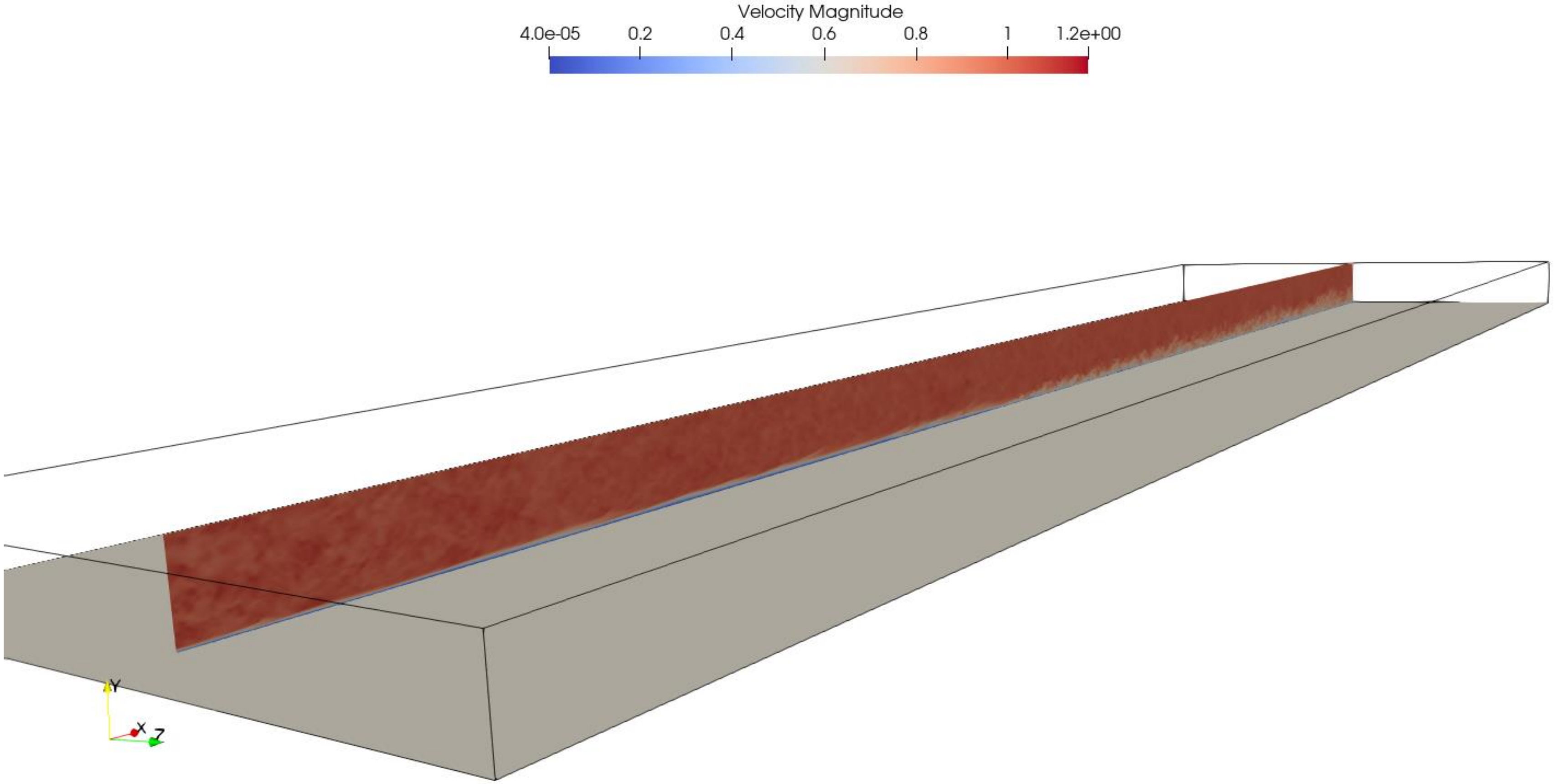

- As dissipation takes place at the viscous sublayer, it cannot accommodate Kolmogorov eddies.
- The viscous sublayer will always adapt so it is thinner than the Kolmogorov eddies.

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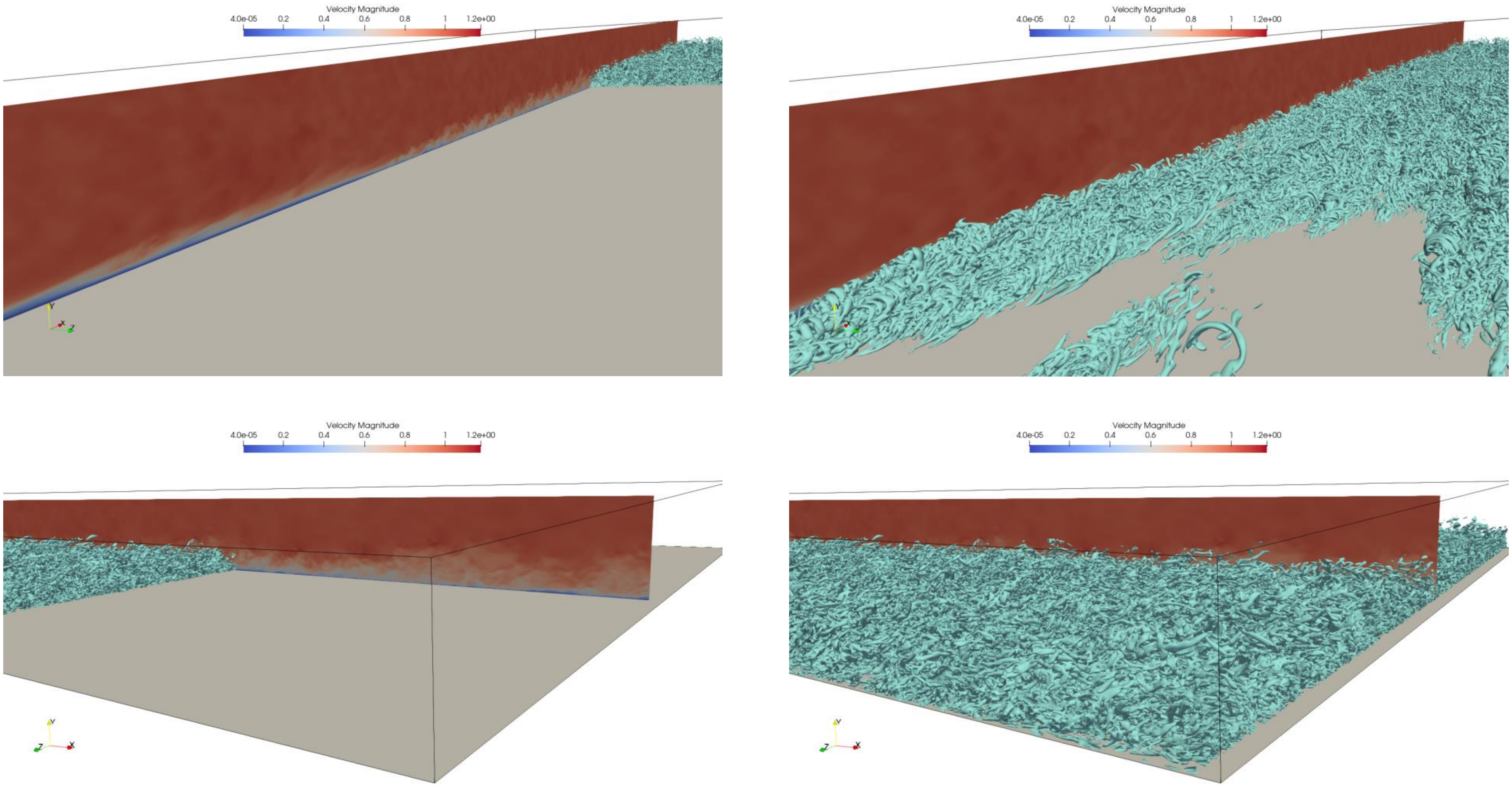

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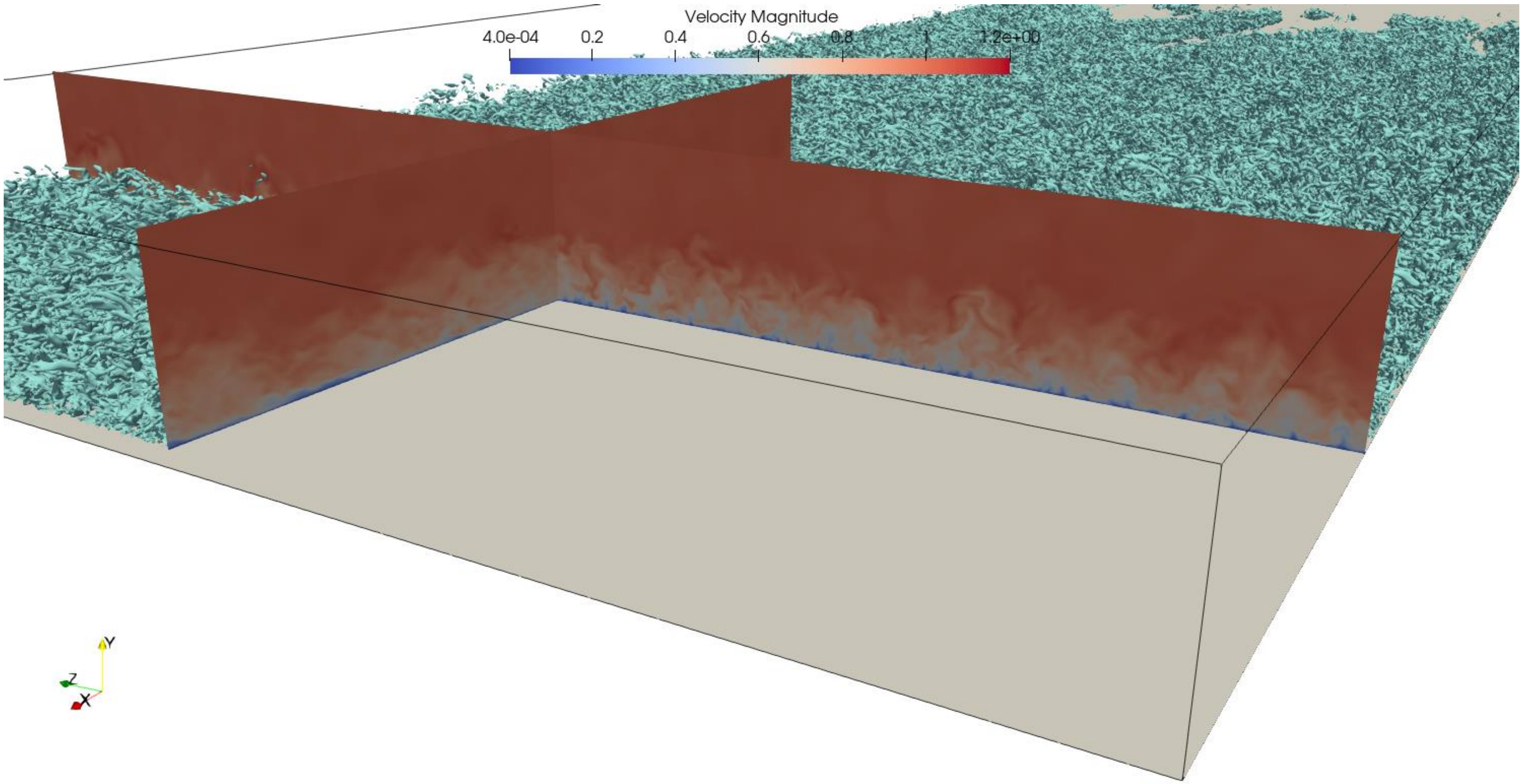

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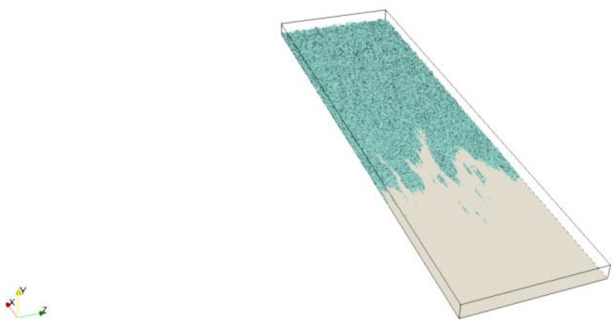

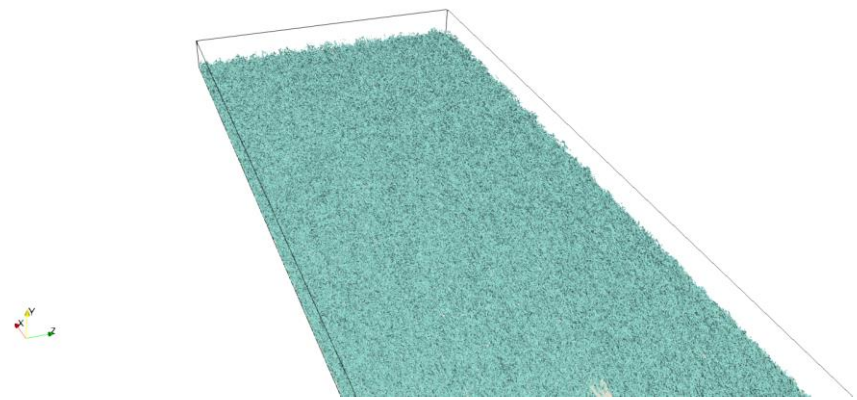

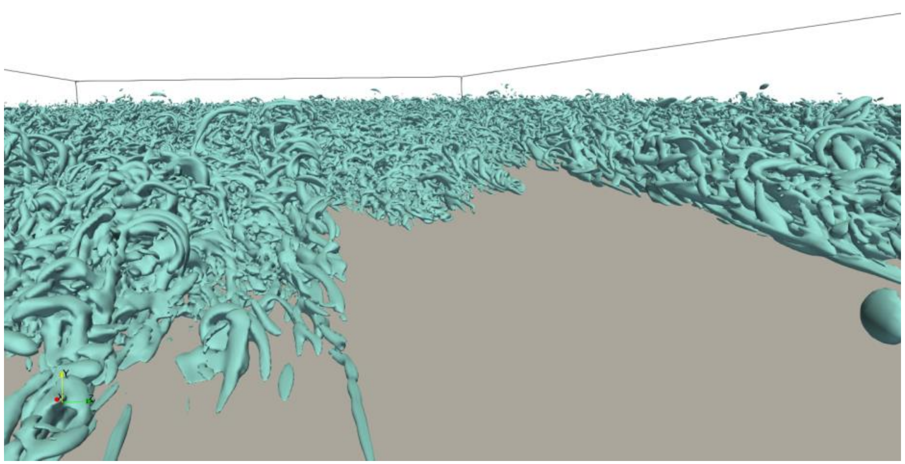

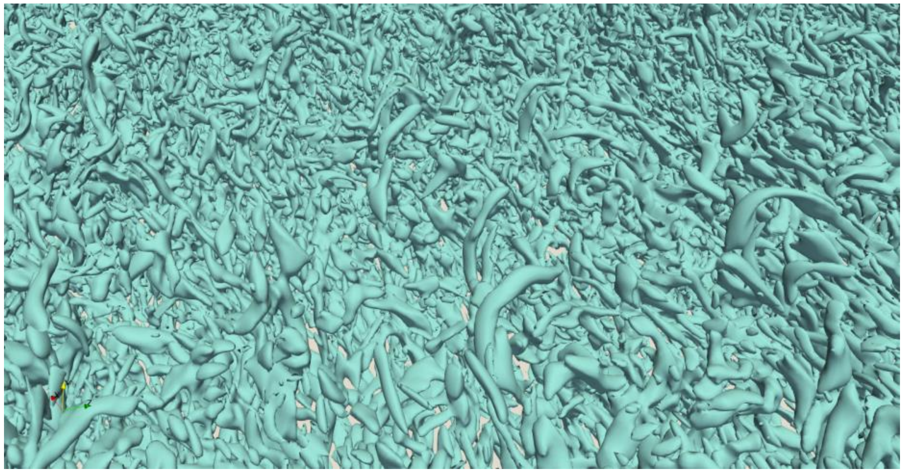

- To give you an idea how time consuming the postprocessing of large-scale simulations is:
  - We are looking at one timestep of a DNS simulation. The input file is about 17 GB, and it required about 110 GB of RAM memory, a GPU of 16 GB, 16 cores, and about 5 minutes to open and manipulate the data (mesh size approximately 1.5 billion grid points).

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- Turbulence is a continuum phenomenon.
- The Kolmogorov scales are well above the molecular scales.
- A parameter used to determine when the continuum hypothesis is not valid anymore is the Knudsen number.
- The Knudsen number is the ratio of the mean free path* to a characteristic dimension (e.g., body length, turbulent scales, and so on).

$$Kn = \frac{\lambda}{L}$$

Mean free path

- Although there is no definitive criterion, the continuum flow model starts to break down when the Knudsen number is roughly of the order of 0.1.
- At this Knudsen number value, the flow is rarefied and cannot be treated as a continuum.
- In the case of Kn > 0.1, different equations need to be used.
- In these lectures, we will deal only with the continuum equations.

* The mean free path is the average distance travelled by a moving particle (such as an atom, a molecule, a photon) between successive impacts (collisions), which modifies its direction or energy or other particle properties.

Practical turbulence estimates

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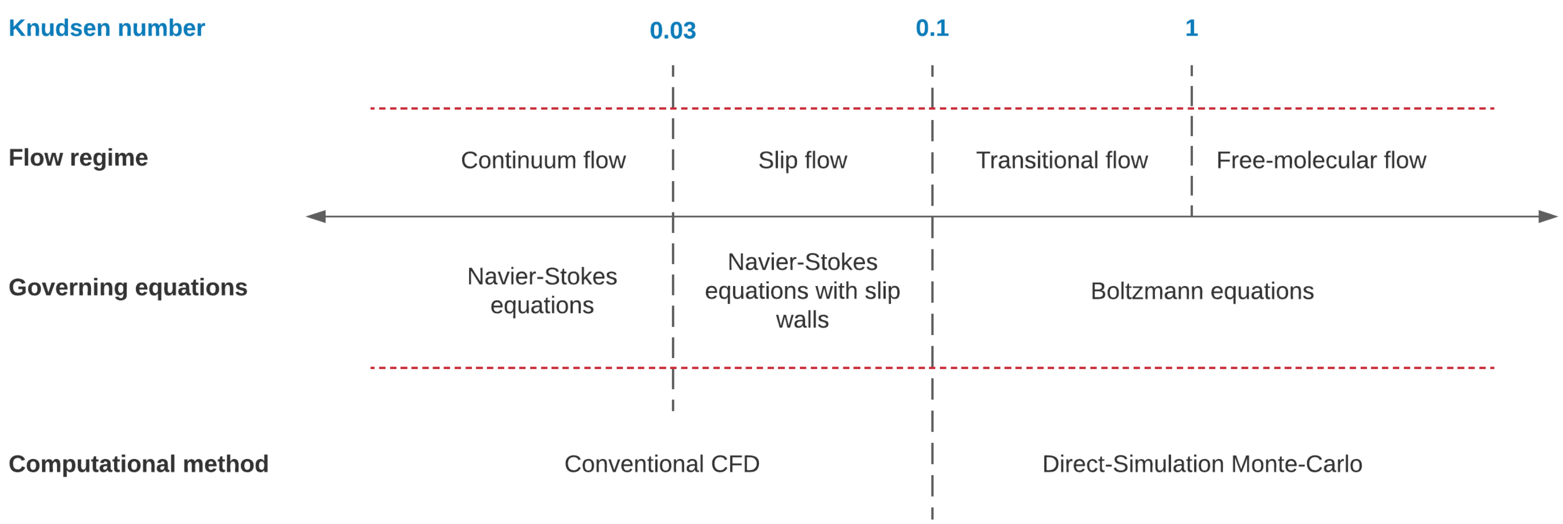
- Although there is no definitive criterion, the continuum flow model starts to break down when the Knudsen number is roughly of the order of 0.1.
- For Knudsen numbers up to approximately 0.03 the continuum hypothesis is valid.
- For Knudsen numbers between 0.03 and 0.1, the Navier-Stokes equations are valid in the freestream, but we need to use slip conditions at the walls.
- For Knudsen numbers larger than 0.1 the Navier-Stokes equations cannot be used anymore.



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- Taking air under atmospheric conditions as an example, the mean free path is 6.5 x 10^{-8} m (65 nanometers)
- The mean time between successive collision of a molecule is 10^{-10} s.
- In comparison, the smallest geometric length scale in a flow is seldom less than 0.1 mm (or 10^{-4} m).
- Which for flow velocities up to 100 m-s^{-1}, yields to a flow timescale larger than 10^{-6} s.
- Thus, even for this example of a flow with small length and time scales, these flow scales exceed the molecular scales by three or more orders of magnitude.
- This separation can be seen in the plot below, where for very large Reynolds number, the Kolmogorov scales are well above the molecular scales.