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From limited observations to the state of turbulence: Fundamental difficulties of flow reconstruction[1]

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Numerical simulations of turbulence can resolve all the flow scales and provide non-intrusive access to quantities of interest, although they often invoke idealizations that can compromise realism. In contrast, experimental measurements probe the true flow with lesser assumptions, but they continually contend with spatio-temporal sensor resolution. Assimilating observations directly in simulations can combine the benefits of both approaches and mitigate their respective deficiencies. The problem is expressed in variational form, where we seek the flow field that satisfies the Navier-Stokes equations and optimally reproduces available data. In this framework, observations are no longer a mere record of the instantaneous, local quantity, but rather an encoding of the antecedent flow events that we aim to decode using the governing equations. Chaos plays a central role in obfuscating the interpretation of the data: observations that are infinitesimally close may be due to entirely different earlier conditions. We will examine a number of state estimation problems that expose important aspects of wall turbulence and the fundamental difficulties of reconstructing the full state from limited observations.

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