Mitteilung

Fachgruppe: Turbulenz und Transition

COMPARING ASSIMILATION TECHNIQUES FOR PRESSURE AND TEMPERATURE FIELDS IN TURBULENT RAYLEIGH-BÉNARD CONVECTION

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Velocity fields of flows can be measured precisely on temporal and spatial scales, e.g., by particle tracking velocimetry (PTV) [1,6]. Many interesting flows in scientific or industrial contexts, e.g., the ventilation of closed passenger cabins [5], are temperature-driven and it is a challenging task to also measure the temperature field with the same resolution as the velocity fields. Käufer et al. showed in [3] that it is indeed possible to measure the temperature field on the same scales as the velocity field by using thermo-liquid crystals as tracer particles for PTV. This method is intriguing but difficult to realize in general setups since a specific fluid medium is required to make the thermo-liquid crystals buoyancy neutral. Therefore, new methods – as described in [1,2,4] among others – attempt to infer unknown properties, such as the temperature or pressure fields of the flow, from the known velocity field using governing equations. We compare two of these methods – a physics informed neural network (PINN) approach [4] and the fractional step approach used by proPTV [1] – using ground truth data generated by a direct numerical simulation (DNS) of turbulent Rayleigh-Bénard convection in a cubic cell with system parameters, i.e., Prandtl and Rayleigh numbers:

$$Ra = 1 \cdot 10^6 \quad , \quad Pr = 0.7 \tag{1}$$

The governing flow equations are given by the incompressible Navier-Stokes equation in the Boussinesq approximation and the energy equation for the temperature:

$$\partial_t \vec{u} + (\vec{u} \cdot \nabla)\vec{u} = -\nabla p + \sqrt{\frac{Pr}{Ra}} \Delta \vec{u} + \mathrm{T} \cdot \vec{e_z} \tag{2}$$

$$\partial_t T + (\vec{u} \cdot \nabla) T = \frac{1}{\sqrt{Ra \cdot Pr}} \Delta T \tag{3}$$

$$\nabla \cdot \vec{u} = 0 \tag{4}$$

Here $\vec{e_z}$ is the unit vector in vertical direction along which gravity acts. The PINN tries to learn temperature and pressure fields to minimize the residuum of all three equations (2)-(4) for a given velocity field. proPTV uses a method based on the fractional step, typically applied in DNS to determine a pressure which is used to correct the velocity to be incompressible in each iteration. This method can only calculate an isothermal pressure field and a guess of the temperature is provided by rearranging equation (2) to solve for T. A direct comparison of the assimilated temperature and pressure is shown in figure 1. At the STAB conference we are going to present the comparison of the two methods in more detail as well as an extension of proPTV by combining both methods to assimilate a better temperature field.

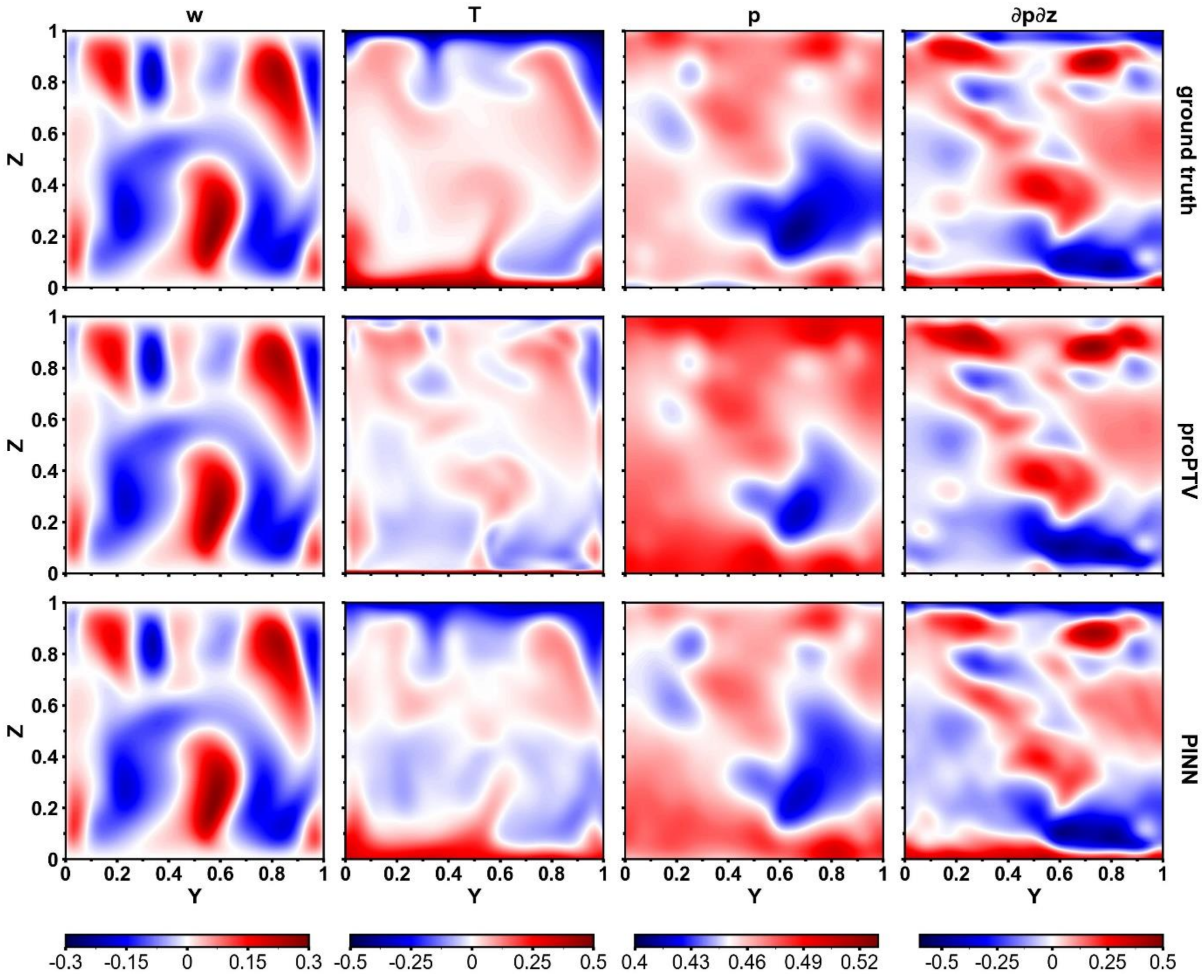

Figure 1. Comparison of the assimilated temperature T and pressure p obtained using proPTV and PINN. The ground truth fields are shown in the top panels. The vertical velocity component w and the pressure gradient in the vertical direction $\partial p/\partial z$ are also shown.

References

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