Implementing the Ensemble Kalman Filter (EnKF)

Flavia Ferrus Marimon

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Contents

1 Experimental data

In this research the Ensemble Kalman Filter (EnKF) is implemented over a fluid system describing a wind flow along a round pipe. The Data Assimilation method is computed using the experimental data collected simultaneously for three different measurement points: the initial point (E) and two experimental points positioned on the middle of the round pipe at different x positions (A and C).

2 Simulated data

Using the COMSOL Multiphysics environment, different simulations taking various assumptions are implemented in order to model the system and provide theoretical data necessary to update the Ensemble Kalman Filter data assimilation method and improve the filtered values.

2.1 Longitudinal profile

The longitudinal data sets for t=3 min are used as new observations on the update step for the EnKF as a Data Assimilation method.

The Laminar flow simulation has been implemented for different diameter values, since the experimental one produced a solution with greater magnitude than the experimental values. This could be explained by the pipe's losses and wall friction forces, considered more negligent in the laminar simulated case. The corresponding profiles are represented on figure 1.

Additional data sets are generated using the Turbulent Flow environment, considering the possibility of having high enough Reynolds number causing disturbances on the wind flow that evolve to a chaotic and more turbulent flow, further from the laminar expected flow. However, the convergence of the system gets more complex as the inertial terms need to be in consideration when solving the governing equations. Therefore, to ease the system's convergence, it is needed to study the stationary solution of the system, using the experimental boundary condition (as aforementioned in the Laminar flow simulations). The stationary solution is used as the initial condition for the time dependent case, turning out in a turbulent transient system depending on time.

The Turbulent Transient system is similarly studied for different diameter values, distributed around the experimental value. However, in this case the we focus on the experimental setup, using the corresponding fixed diameter. Even so, note that there are perturbations due to small interference on the mesh, causing a shift of the velocity distribution over the cross-sectional arc-length, depending on the inlet's diameter. Therefore, different axis have been considered over the longitudinal position so a more accurate/realistic distribution can be obtained from the assymetrical simulated data. The corresponding data sets for different x axis are illustrated in figure 1.

Laminar simulated velocity.

The closer to the experimental configuration is the laminar distribution for 0.04m diameter inlet. However, the distribution that adjust more precisely the experimental observations corresponds to the boundary condition fixed to 0.036m (if needed a study over this distribution could provide accurate results, given the possible experimental losses and wall friction forces).

The mean distribution corresponds to the distribution for 0.037m so we could use this punctual data in order to study a more realistic distribution.

2.2 Punctual distributions over time

The simulated punctual data over time used to implement the KF and the EnKF corresponds to the data passed a time interval of 3 minutes in order to have at least the first minute as a transient interval and a 2 minute interval of more steady data corresponding to the experimental time interval used. We may use the punctual data for the closer configurations to the real system. Therefore, the punctual distributions for

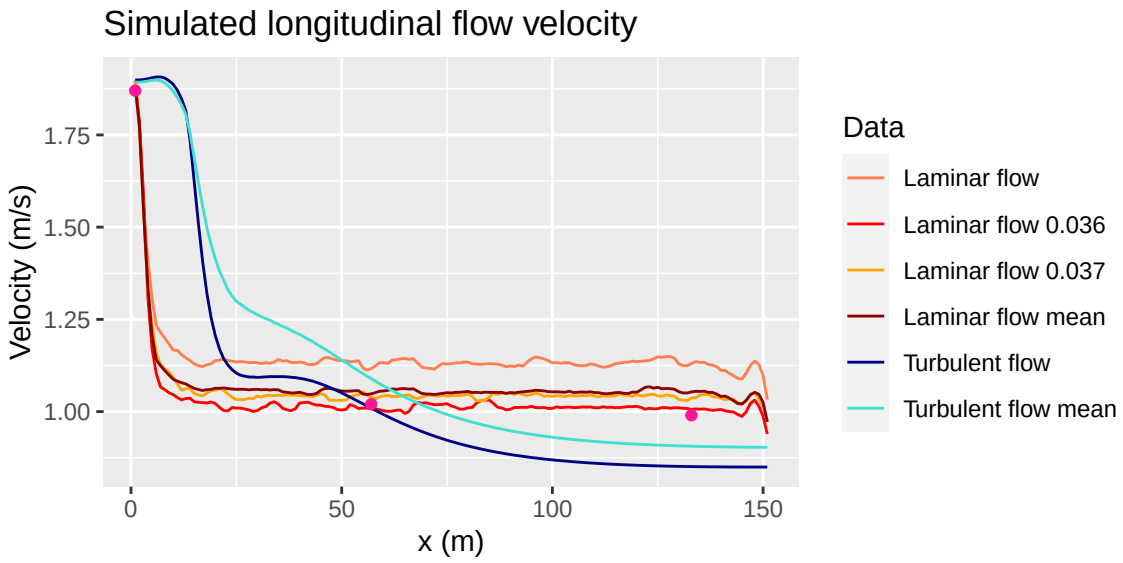

Figure 1: Flow's velocity longitudinal profiles.

the laminar and turbulent flow mean velocity are showed in figure 2, along with the experimental punctual observations.

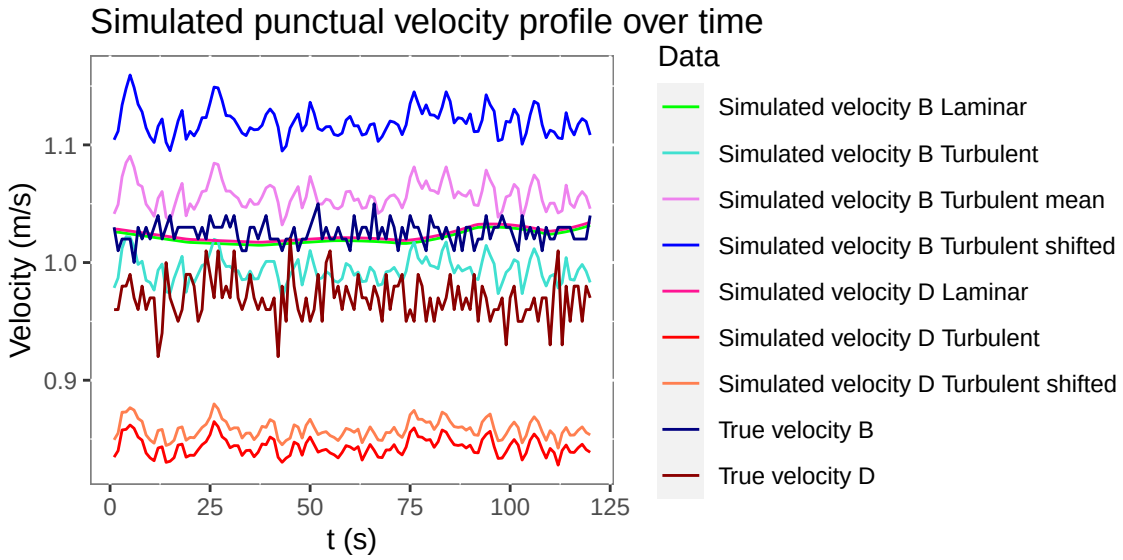

Figure 2: Punctual velocity distributions over time for different simulated models.

Note that the simulated values remain lower than real distribution this time. However, this is caused by the asymmetry of the system's solution. Therefore, the data used for the KF is the obtained computing the mean between the different y axis.

3 Kalman Filter

3.1 Laminar flow

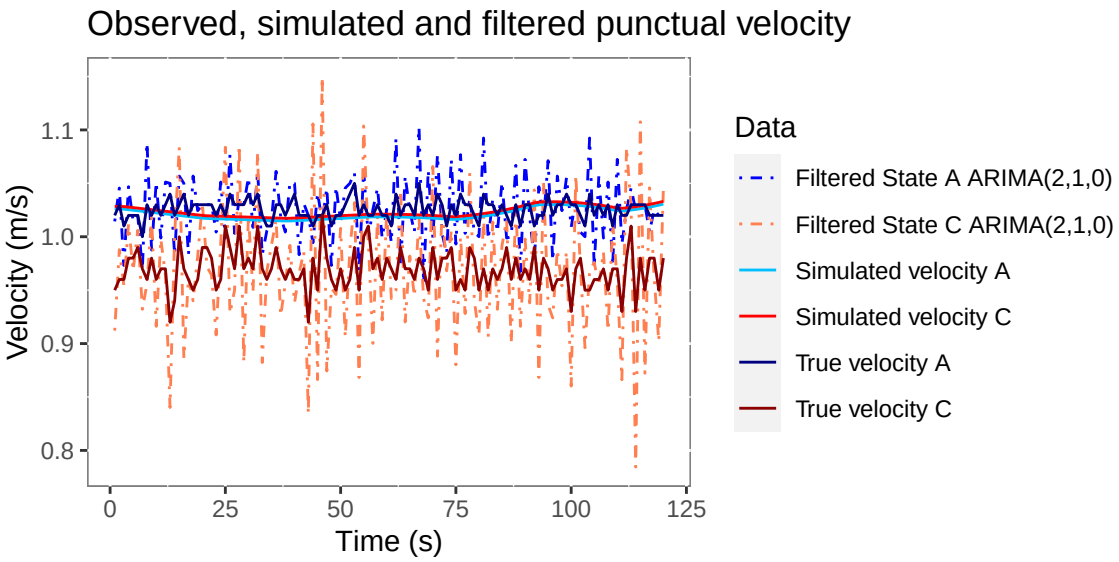

Figure 3: Experimental and simulated flow velocity for the measurement points over time and filtered data using the Kalman Filter with the simulated data set update. Experimental configuration with diameter of 0.04m, and simulated data for the configuration of laminar flow with 0.04m diameter.

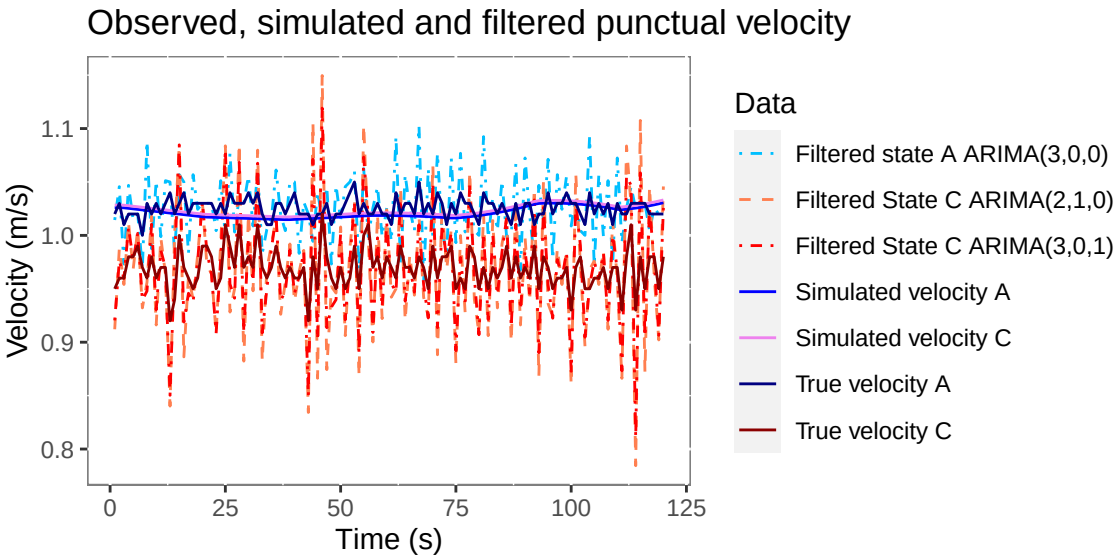

Figure 4: Experimental and simulated flow velocity for the measurement points over time and filtered data using the Kalman Filter with the simulated data set update. Experimental configuration with diameter of 0.04m, and simulated data for the configuration of laminar flow with 0.04m diameter.

3.2 Turbulent flow

We may use the punctual distribution over time given by the mean for each point. Note that on point C (the further point from the wind flow generator) the simulated and experimental distributions are not gathered around the same mean. This can be taken into account when adjusting the corresponding state-space representation for each distribution.

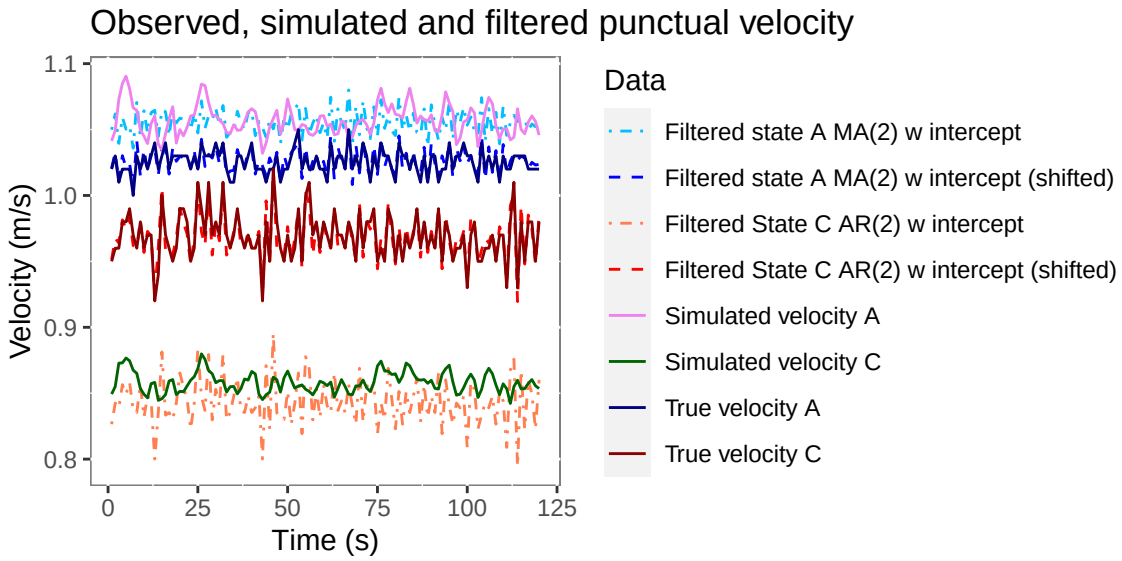

Figure 5: Experimental and simulated flow velocity for the measurement points over time and filtered data using the Kalman Filter with the simulated data set update. Experimental configuration with diameter of 0.04m, and simulated data for the configuration of turbulent flow with 0.04m diameter.

Laminar distribution does not adjust as accurately the experimental observations as the turbulent simulated data. This can indicate that the real system is characterized by high Reynolds numbers, with inertial forces overcoming the viscous forces, due to the lower viscosity of the air at atmospheric conditions.

4 Ensemble Kalman Filter

The EnKF takes into consideration the longitudinal velocity profile and the time dependent discrete observations in order to implement a forecast and an update step using the corresponding state vector (simulated state) and the observation state (measured observations). The EnKF uses an ensemble of both states smoothing the distribution and adjusting to the simulated state-space model.

Note that the longitudinal velocity profile is characterized by a decreasing significant step, corresponding to the first nodes situated closer to the flow generator, which is shifted right at the beginning, distorting the velocity distribution. Therefore, the mean data throughout the steadier nodes (longitudinal positions between [50, 140] cm) is considered in order to implement the EnKF.

4.1 Laminar Flow

WN distribution

AR(2) distribution

5 Turbulent flow

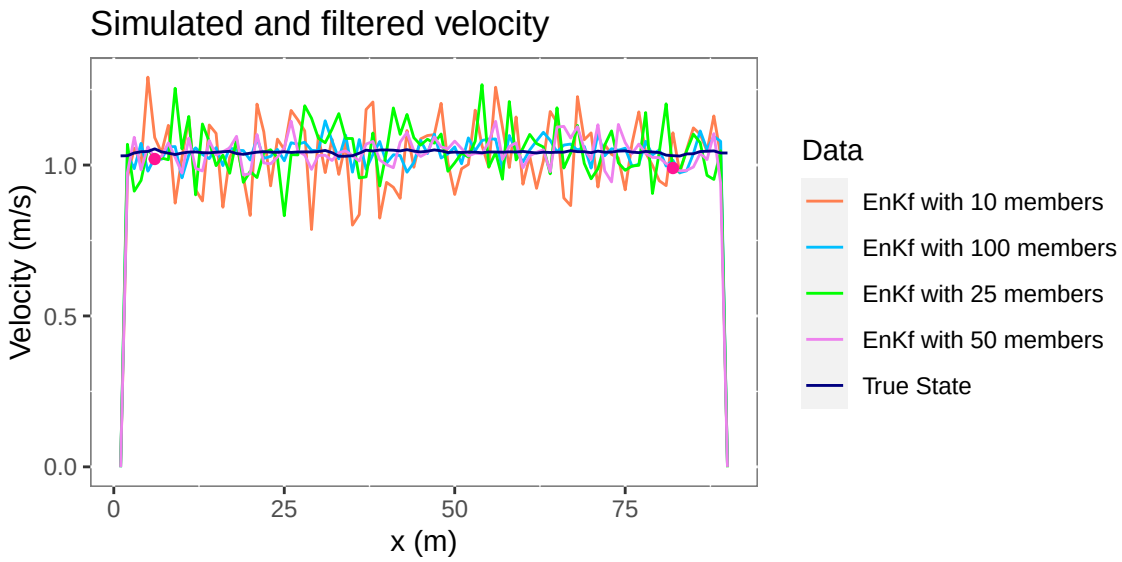

Figure 6: Laminar Flow velocity over longitudinal position adjusting a WN model to the data for different ensemble sizes. Configuration with diameter $0.04m$.

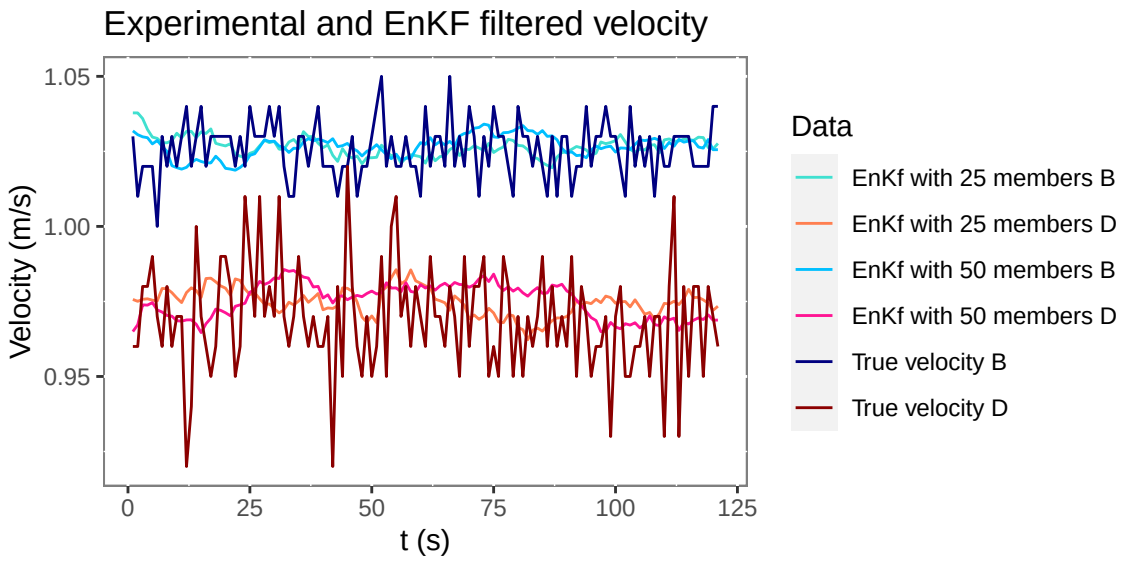

Figure 7: EnKF filtered punctual velocity over time for the configuration of the laminar flow, adjusting an WN model over the simulated data distribution.

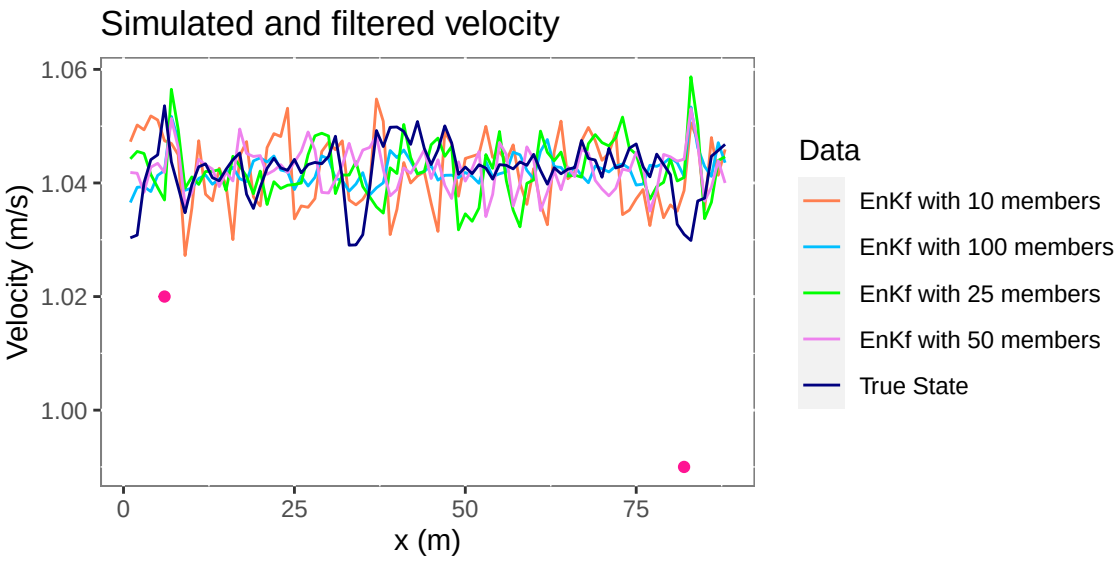

Figure 8: Laminar Flow velocity over longitudinal position adjusting an AR(2) with non zero mean model to the data for different ensemble sizes.

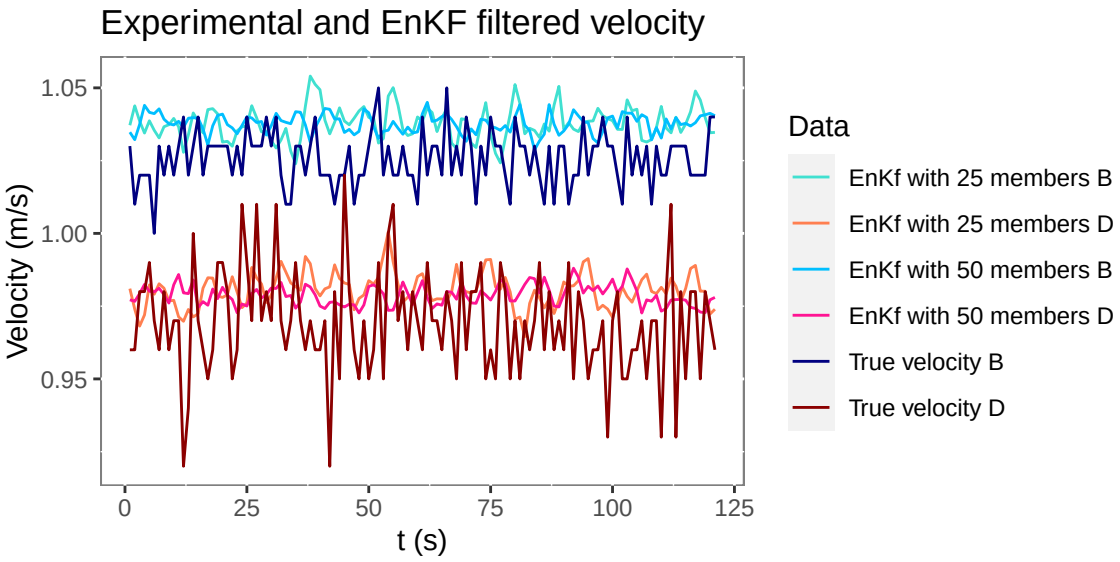

Figure 9: EnKF filtered punctual velocity over time for the configuration of the laminar flow, adjusting an AR(2) model over the simulated data distribution. Configuration with diameter 0.035m.

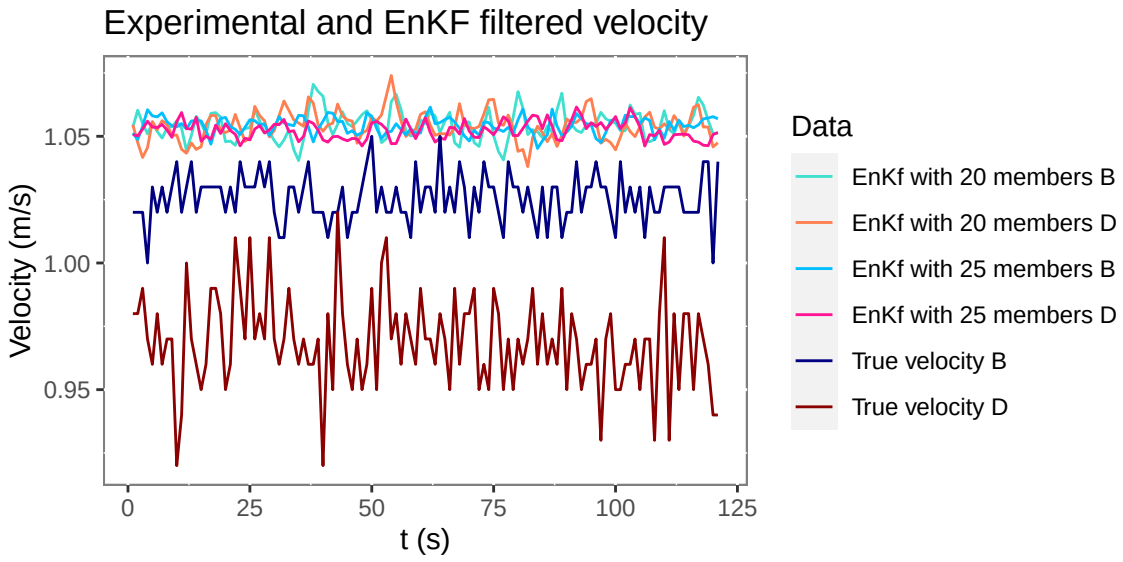

Figure 10: EnKF filtered punctual velocity over time for the configuration of the laminar flow, adjusting an AR(2) model over the simulated data distribution. Configuration with diameter 0.035m.

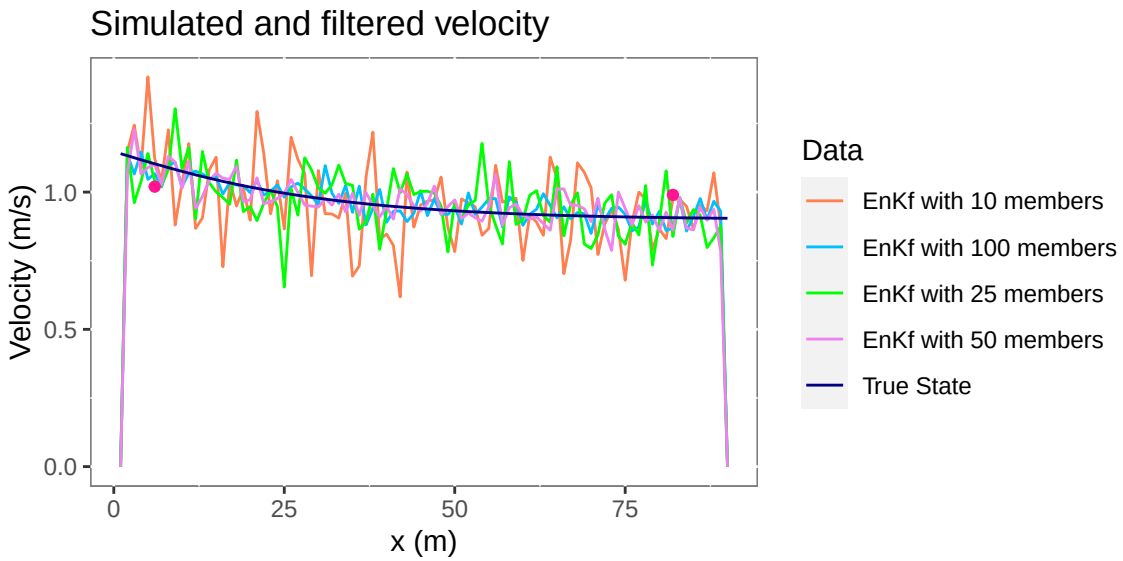

Figure 11: Laminar Flow velocity over longitudinal position adjusting a WN model to the data for different ensemble sizes. Configuration with diameter $0.04m$.

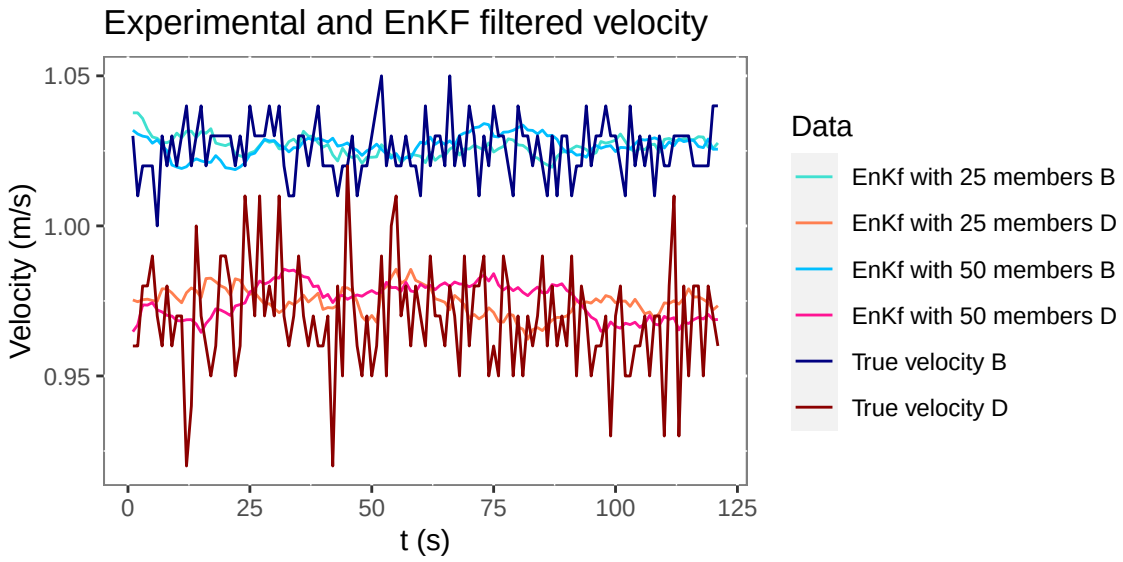

Figure 12: EnKF filtered punctual velocity over time for the configuration of the turbulent flow, adjusting an WN model over the simulated data distribution. Configuration with diameter 0.04m.

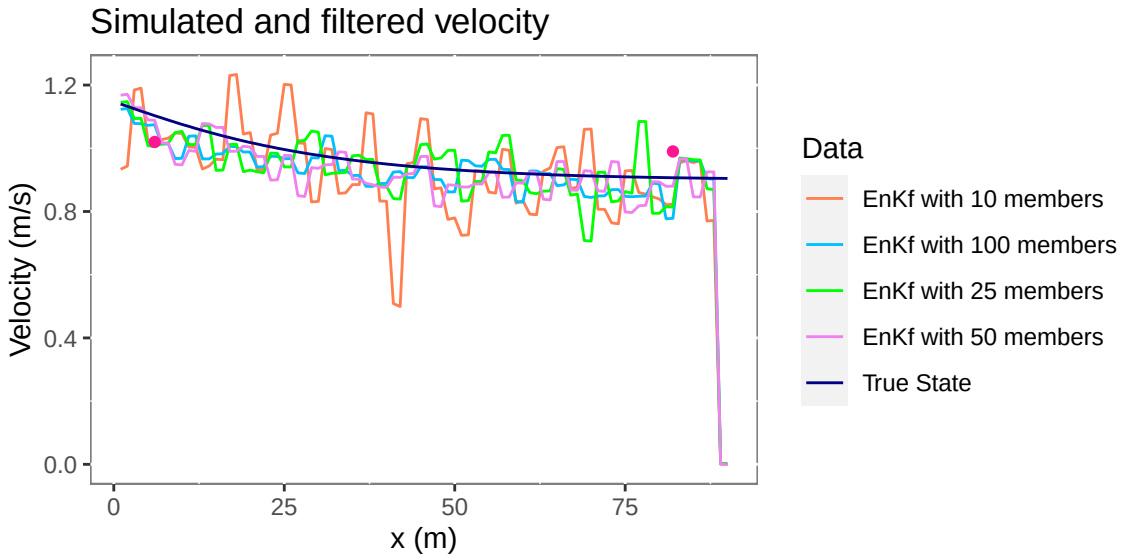

Figure 13: Laminar Flow velocity over longitudinal position adjusting a WN model to the data for different ensemble sizes. Configuration with diameter $0.04m$.

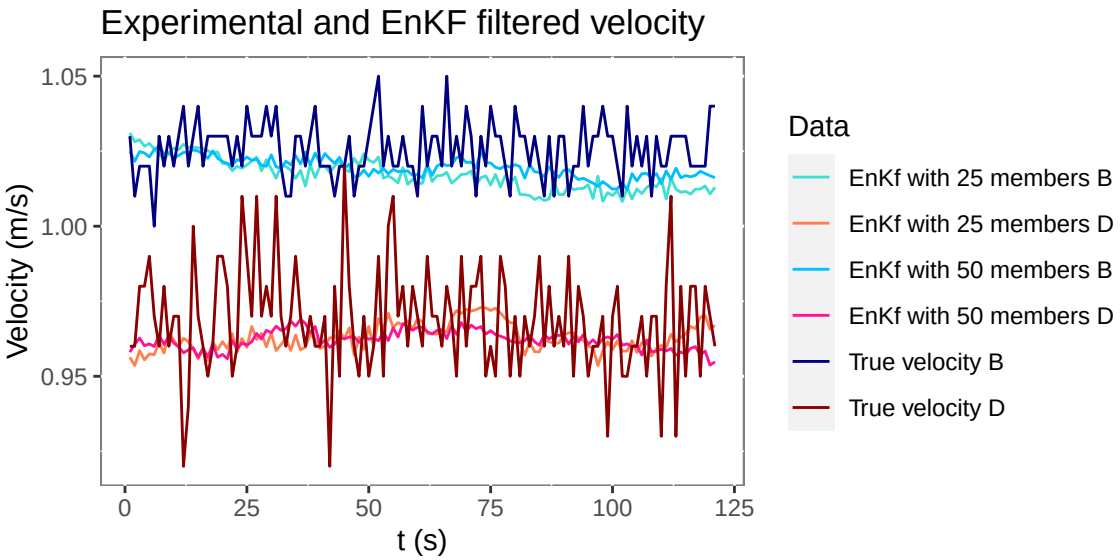

Figure 14: EnKF filtered punctual velocity over time for the configuration of the turbulent flow, adjusting an WN model over the simulated data distribution. Configuration with diameter 0.04m.