Air Quality Research Group

Concentration fluctuations of a passive scalar in a regular street network

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Introduction

This study aims to characterize concentration fluctuations in an urban area by analyzing moments and probability density functions within a regular street network, using data from direct numerical simulations. We investigate whether position within the plume significantly impact the results.

Methodology

Direct numerical simulations (DNS) were performed within the DIPLOS (Dispersion of Localized Releases in a Street Network) project (Auerswald et al., 2024). The domain consists of a regular array of rectangular buildings elongated in y-direction. The simulations were run with a time step of $\Delta t = 0.00025\,T$ and data were collected every 20 time steps ($0.005\,T$), with $T = 1.23$ the non-dimensional time scale. Passive scalars were released from a ground continuous source at an intersection.

We consider four probability distributions that are most applied in the dispersion literature for point sources (Cassiani et al., 2020): 2-parameter gamma, lognormal and Weibull, and 4-parameter beta. Using the same methodology as Efthimiou et al. (2016), we calculate the inverses of the cumulative density function (ICDF) from 75th to 99th percentiles of concentration, which correspond to the upper tail of the data. We use the metrics defined by Chang and Hanna (2004) for evaluating the performance of air quality models.

Results

- The shape of the histogram varies by location: approximately exponential near the source and between the edge of the plume and outside of it; asymmetrical at the edge of the plume; and approximately bell-shaped at the center of the plume.

- Exponential-like histogram areas: wide concentration range, high incidence of zero concentrations and peaks. Bell-shaped histogram areas: narrower concentration range, fewer extreme values, no zero concentrations.

Table 1 – General performance of the distributions for 75th – 99th percentiles of the ICDF of concentrations. The results represent the mean values considering all points within the street network.

PD	FAC2	FB	NMSE	RE	R
2p-Gamma	0.9952	0.006959	0.03563	0.04537	0.9925
4p-Beta	0.9956	0.01255	0.05017	0.005957	0.9931
2p-Lognormal	0.9987	-0.01804	0.04457	0.01443	0.9916
2p-Weibull	0.9999	0.004904	0.01513	0.00848	0.9920

- The performance of all models for the 75th-99th ICDF of concentrations was satisfactory. Considering only the 99th percentile, which represents extreme concentrations, the models' performance decreased but remained acceptable, except for the lognormal distribution.

- For the first four moments, gamma and beta distributions generally demonstrated the best performance. The Weibull distribution also performed well for mean and variance. However, for skewness and kurtosis, the models diverged considerably from the DNS data for many locations, with the lognormal distribution in particular showing very large discrepancies.

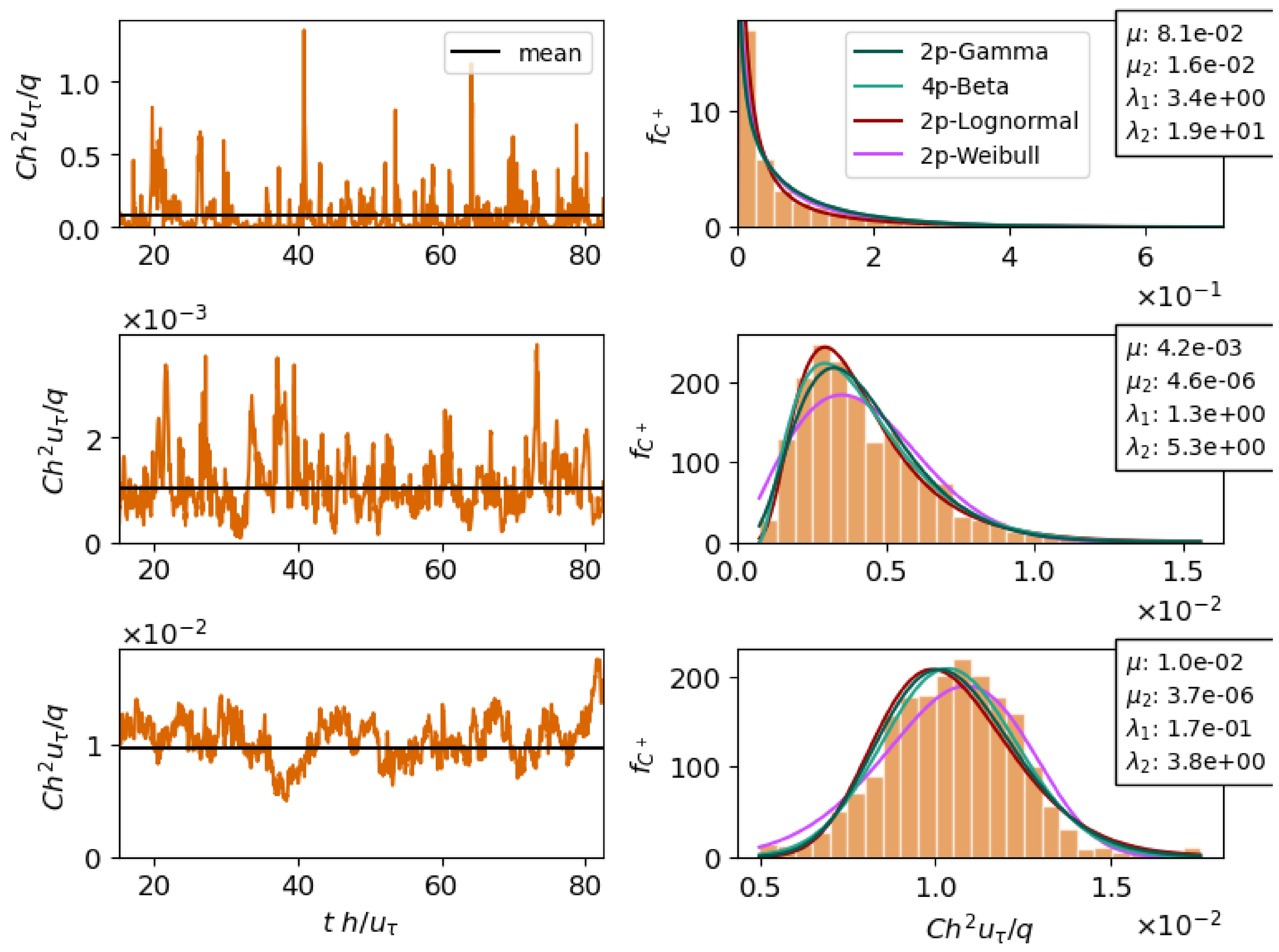

Fig. 1 – Stationary time series of concentration and the corresponding histograms and PDFs for specific points at z = 0.5h. μ, μ_2, λ_1 and λ_2 represent mean, variance, skewness and kurtosis, respectively.

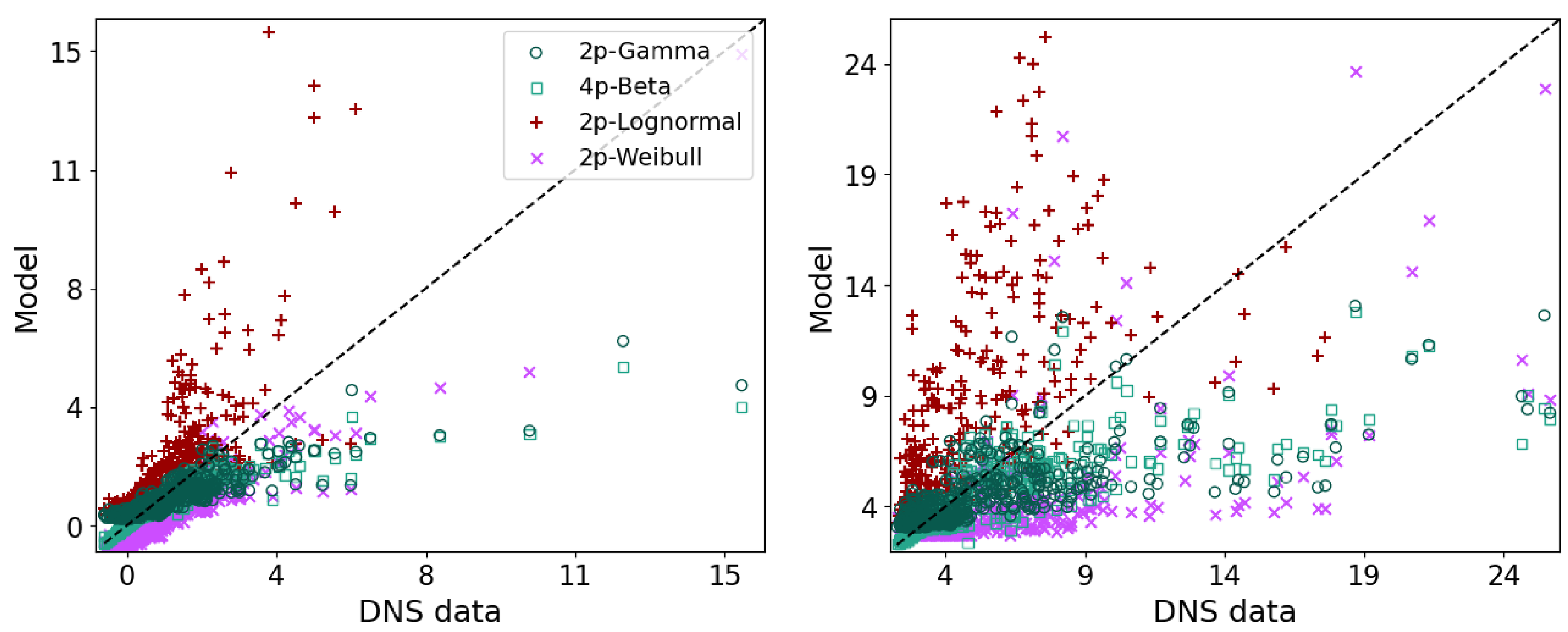

Fig. 2 – Comparison of skewness and kurtosis calculated from the DNS data with those estimated from theoretical distributions.

References

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