The MUST model evaluation exercise: Statistical analysis of modelling results

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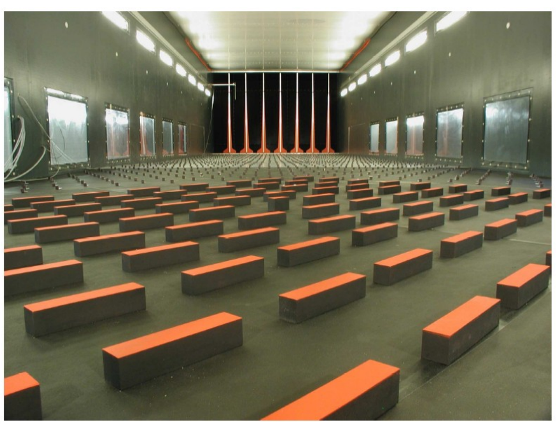
Outline

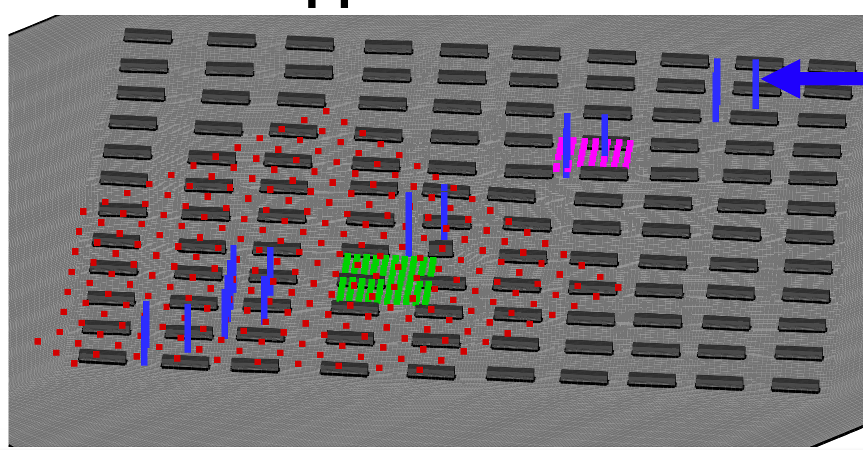
- Introduction
- Definition of hit rate
- Resulting metrics for the flow field at towers
- Definition of BOOT metrics for concentrations
- Resulting metrics for concentrations
- Definition of mean metrics for concentrations
- Resulting mean metrics for concentrations
- Conclusions

Introduction

- **COST 732 protocol for model evaluation – validation part**
  - qualitative data analysis
  - quantitative data analysis with metrics
- **Metrics for validation**
  - hit rate and BOOT metrics
  - point by point comparison (paired in space; statistically steady results)
  - available for **app. 30 CFD model runs** (in principle)

    => Statistics of metrics from individual model results (N-version testing)
- **MUST wind tunnel case with –45° approach flow**





Definition of hit rate for flow field

- **Hit rate**

$$q = \frac{1}{N}\sum_{n=1}^{N} i_n \qquad i_n = \begin{cases} 1 & \text{if } \left|\left(O_n - P_n\right)/O_n\right| \le \Delta_r \text{ or } \left|O_n - P_n\right| \le \Delta_a \\ 0 & \text{otherwise} \end{cases}$$

with N: number of measurement positions

O_n: observation at position n

P_n: prediction at position n

Δ_r = 0.25 (allowed **relative** difference)

Δ_a (allowed **absolute** difference)

equal to measurement uncertainty

	U/U_{ref}	W/U_{ref}	k/U_{ref}^2
Δ_a	**0.008**	**0.007**	**0.005**

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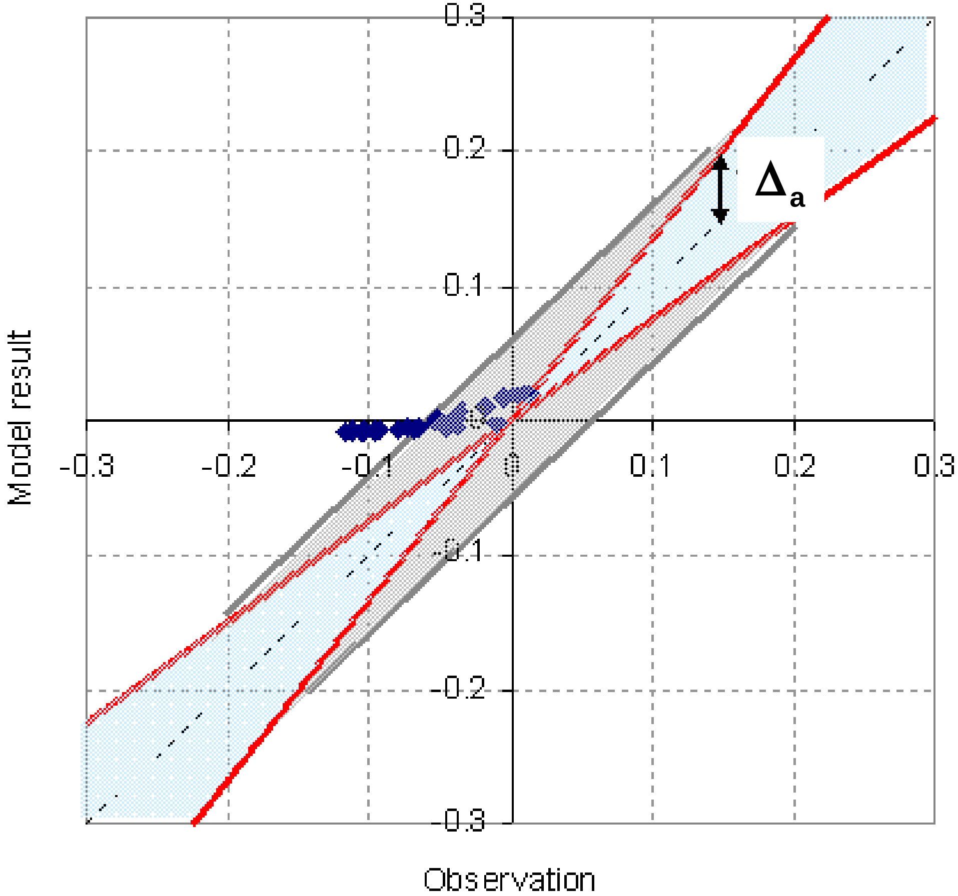

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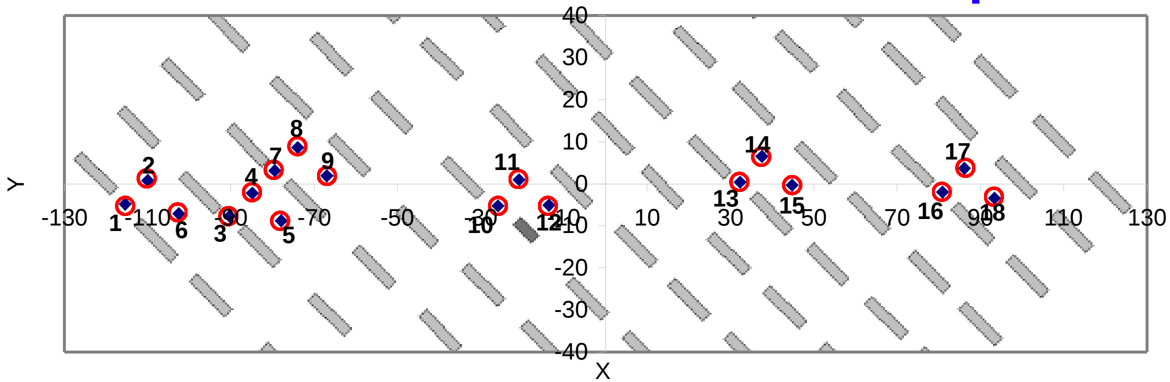
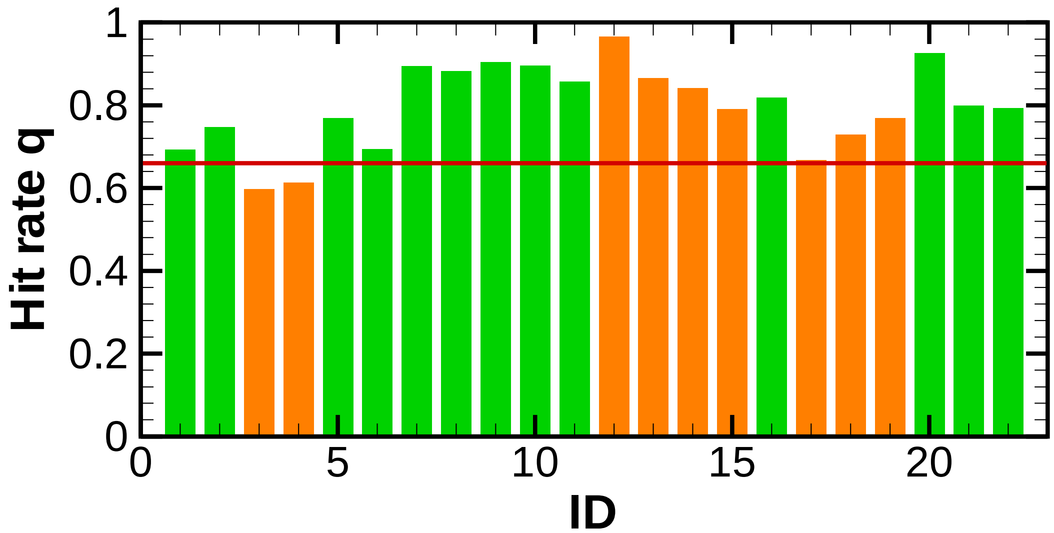
=> evaluated at 497 tower measurement positions



Results for –45° approach flow case

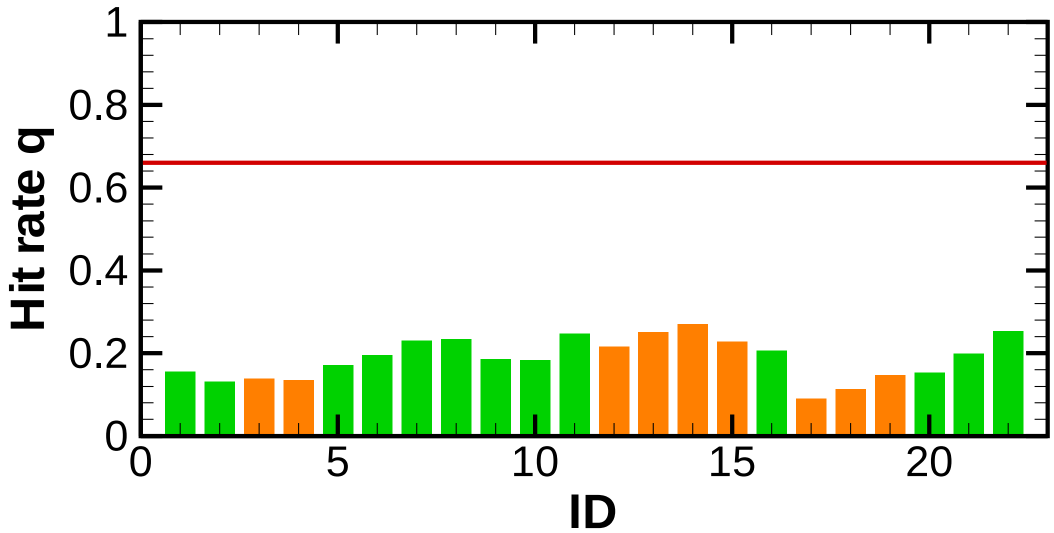
- **Hit rate for mean velocities (at 497 tower measurement positions)**

U/U$_{ref}$



q ≥ 0.66 (VDI)

W/U$_{ref}$

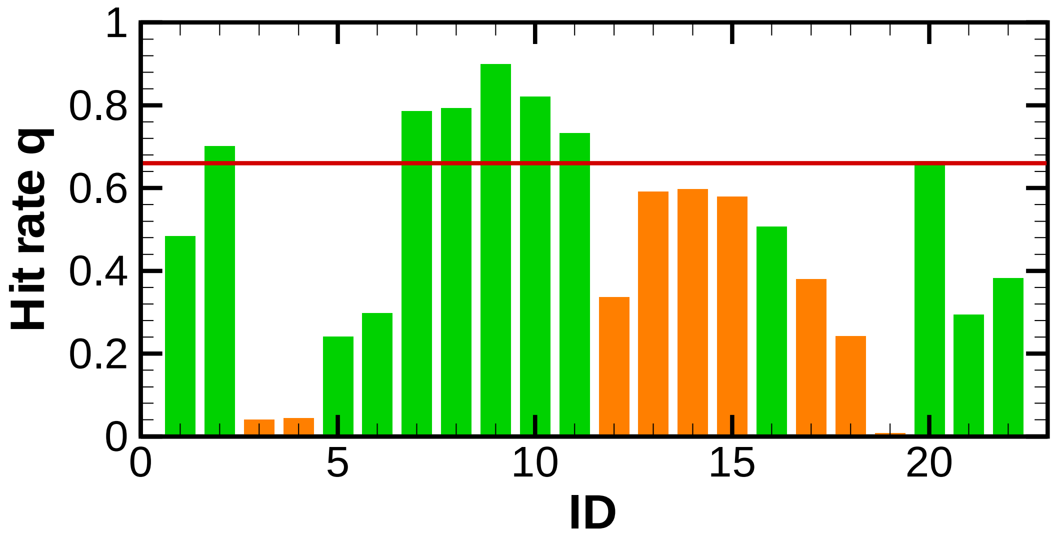


q ≥ 0.66 (VDI)

Results for –45° approach flow case

- **Hit rate for turbulent kinetic energy (at towers)**

k/U_{ref}^2



$q \geq 0.66$ (VDI)

difference in definition

$$\left(k/U_{ref}^2\right)_o = 0.5 \cdot \left[\left(U_{rms}/U_{ref}\right)_o^2 + 2 \cdot \left(W_{rms}/U_{ref}\right)_o^2\right]$$

$$\left(k/U_{ref}^2\right)_p = 0.5 \cdot \left[\left(U_{rms}/U_{ref}\right)_p^2 + \left(V_{rms}/U_{ref}\right)_p^2 + \left(W_{rms}/U_{ref}\right)_p^2\right]$$

has only a very small influence on the hit rate

Definition of BOOT metrics for dispersion

- **Normalised concentration** $C^* = C \cdot U_{ref} \cdot H^2 / Q_{source}$
- **BOOT metrics** $FAC2 = \text{fraction of data with } 0.5 \le C_p^* / C_o^* \le 2$

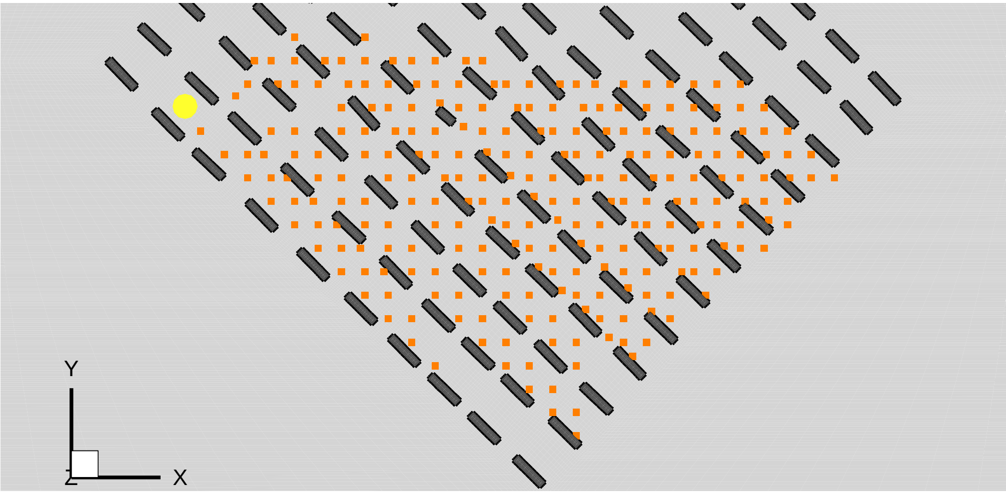
$$FB = 2\left(\langle C_o^* \rangle - \langle C_p^* \rangle\right) / \left(\langle C_o^* \rangle + \langle C_p^* \rangle\right) \qquad NMSE = \left\langle \left(C_o^* - C_p^*\right)^2 \right\rangle / \left(\langle C_o^* \rangle \cdot \langle C_p^* \rangle\right)$$

$$MG = exp\left(\langle ln\, C_o^* \rangle - \langle ln\, C_p^* \rangle\right) \qquad VG = \exp\left[\left\langle \left(\ln C_o^* - \ln C_p^*\right)^2 \right\rangle\right]$$

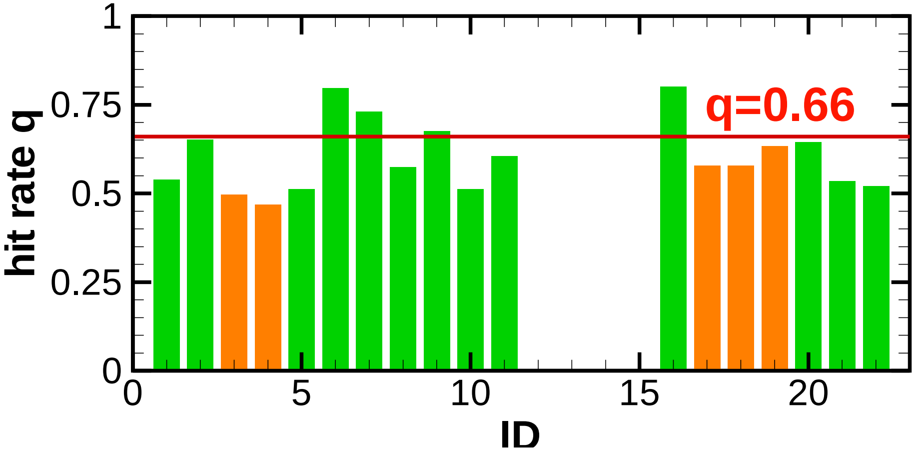
for MG and VG threshold Δ_a = 0.003 (measurement uncertainty)

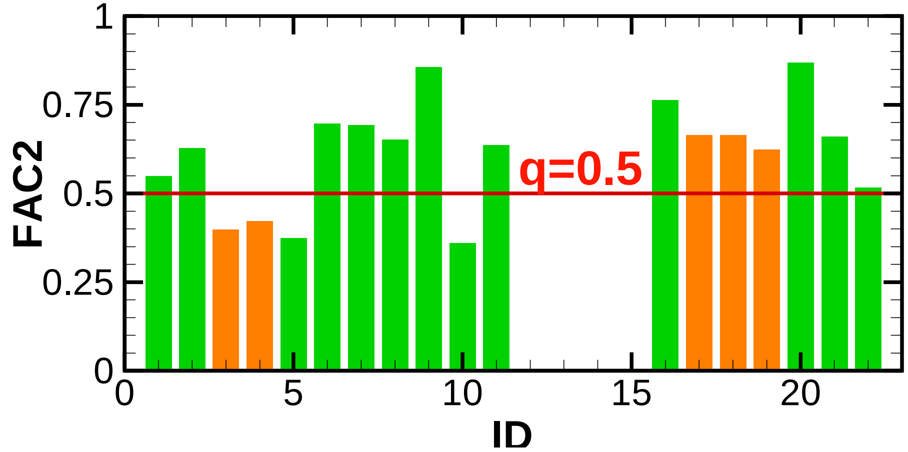
- **Measurement positions (256)**

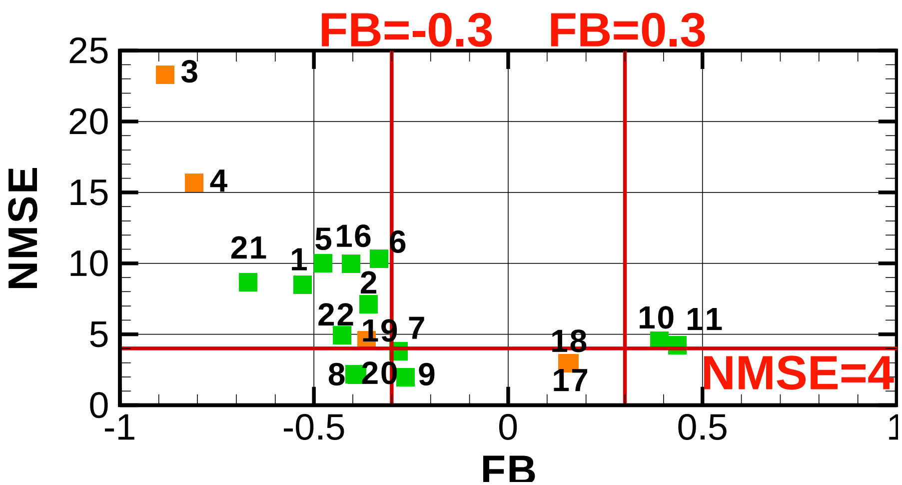
z = H/2

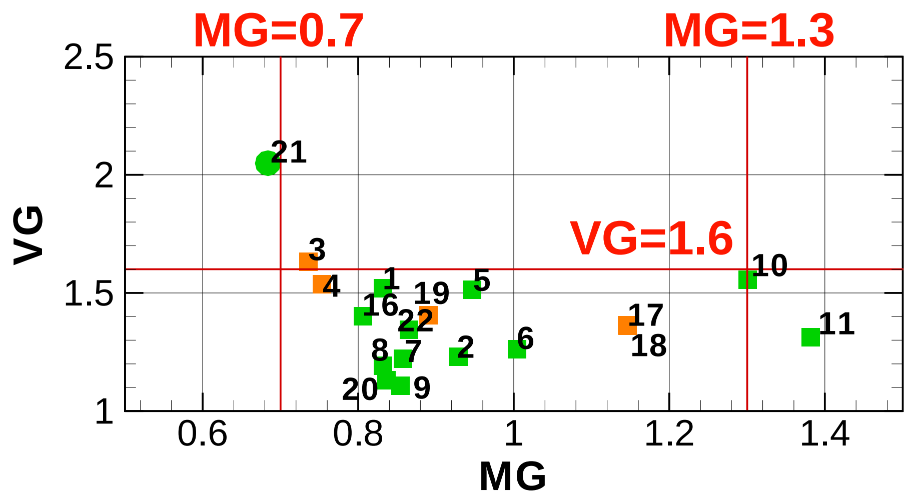


Results for –45° approach flow case









Definition of mean metrics (N-version testing)

- **Metrics from mean results at measurement positions (M=13)**

$$\overline{C_p^*} = 1/M \sum_{j=1}^{M} C_{p,j}^* \qquad \tilde{C}_p^* = median\left[C_{p,j}^*\right]_{j=1,M}$$

=> e.g. $\bar{q} \equiv q\left(\overline{C_p^*}\right), \quad \tilde{q} \equiv q\left(\tilde{C}_p^*\right)$

- **Mean metrics from individual metrics of the models (M=13)**

metrics of model run j: X_j

mean metrics $\hat{Y} = 1/M \sum_{j=1}^{M} X_j \qquad \hat{Z} = median\left[X_j\right]_{j=1,M}$

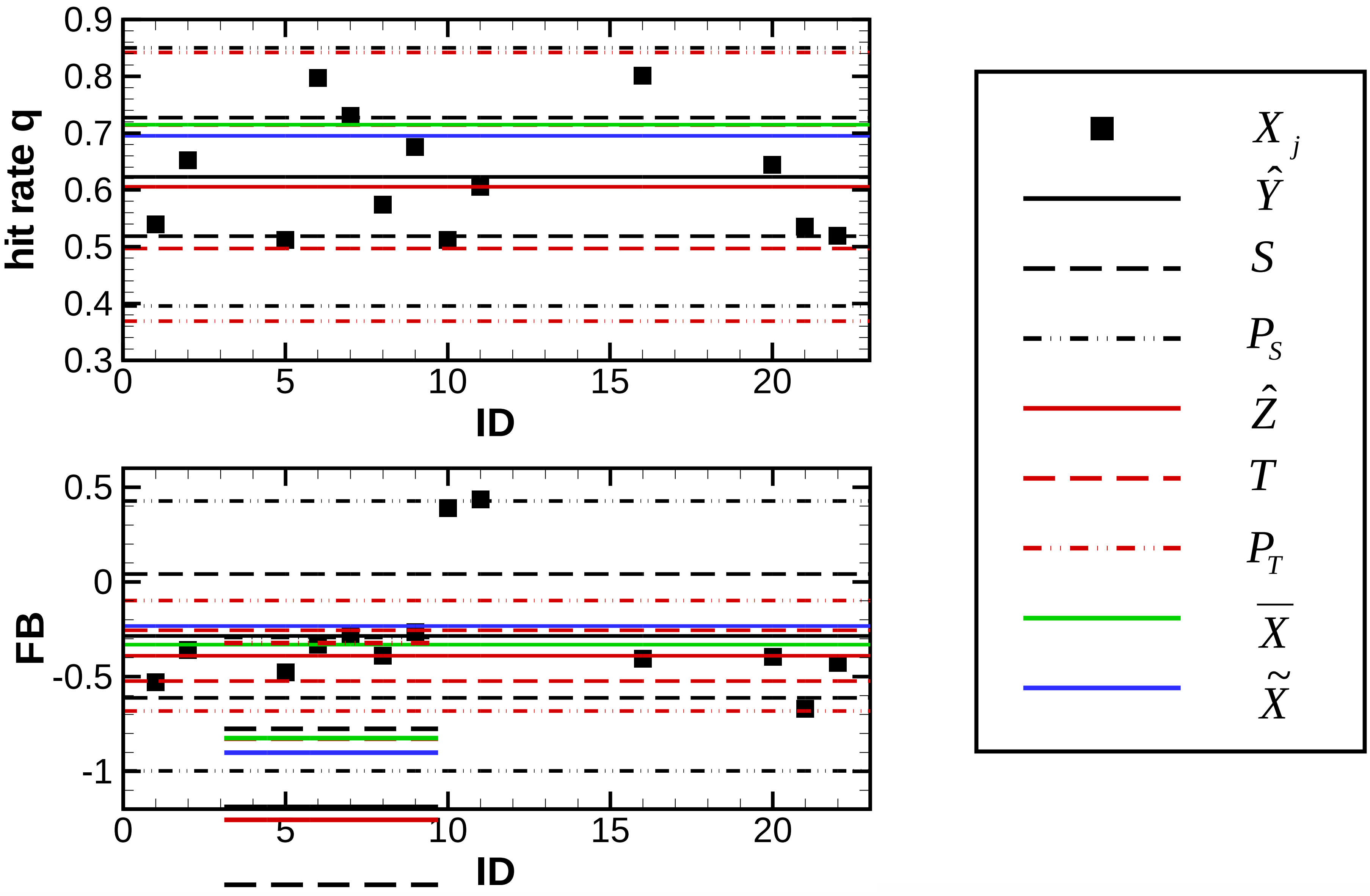
standard deviations

$$S = \left[1/(M-1)\sum_{j=1}^{M}\left(X_j - \hat{Y}\right)^2\right]^{1/2} \quad T = 1/0.6745\sqrt{M/(M-1)}\,median\left(\left|X_j - \hat{Z}\right|\right)$$

confidence intervals (95%, based on student t distribution)

$$P_S = 2.179S \qquad P_T = 2.179T$$

Results for –45° approach flow case



Conclusions

Validation metrics for the MUST –45° case

- concise indication of model performance
- hit rate for flow low for velocity components with small magnitude
- state of the art achievable for all concentration metrics
- further analysis of the statistics of metrics (N-version testing) necessary

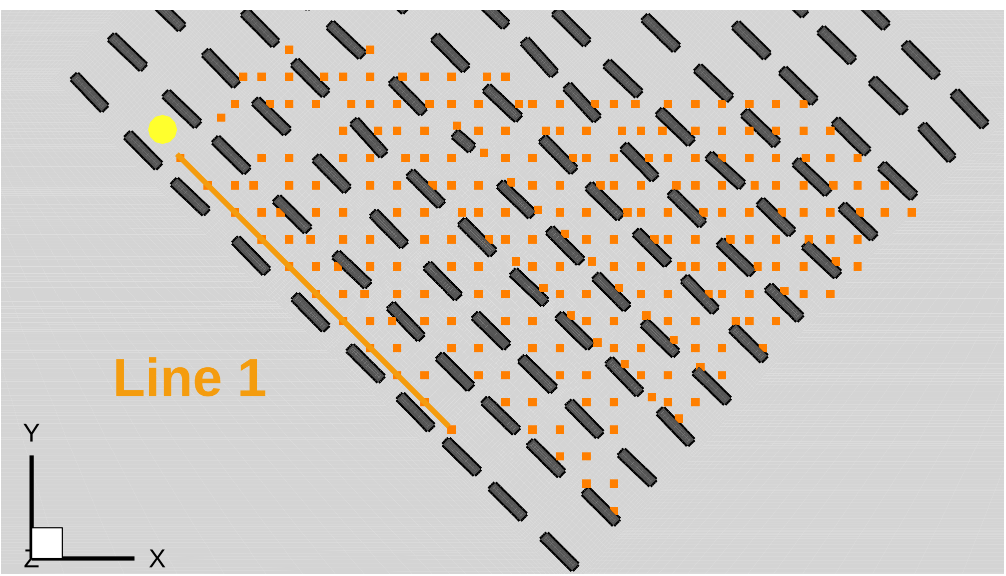
Results of mean metrics

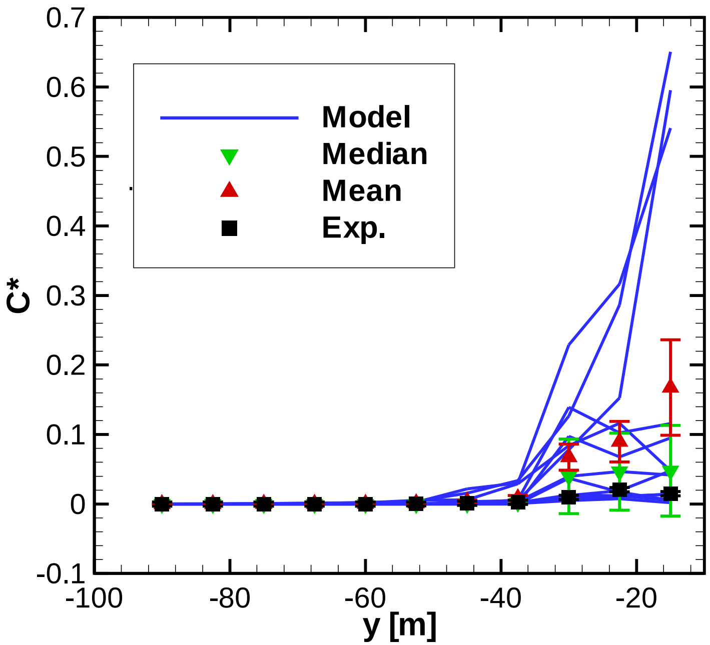
- **Metrics from mean results at measurement positions (M=13)**

averages $\overline{C_p^*} = 1/M \sum_{j=1}^{M} C_{p,j}^*$ $\qquad \tilde{C}_p^* = median\left[C_{p,j}^*\right]_{j=1,M}$

standard deviations

$$\overline{\sigma_p} = \left[\frac{1}{M-1}\sum_{j=1}^{M}\left(C_{p,j}^* - \overline{C_p^*}\right)^2\right]^{1/2} \qquad \tilde{\sigma}_p = 1/0.6745\sqrt{M/(M-1)}\,median\left(\left|C_{p,j}^* - \tilde{C}_p^*\right|\right)$$





Results of mean metrics