

# The MUST model evaluation exercise: Patterns in model performance

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# MODEL VALIDATION

- Processing of the experimental data
- What variables to compare?
- How should the variables be compared?
- How should the model be run and the results interpreted? (modelling inputs, set-up, post-treatment of outputs ...)
- **Exploratory data analysis (Olesen et al.)**
- Metrics for a Model Validation (Franke et al.)
- Quality acceptance criteria
- Baseline approach to model validation

# Main message

- Exploratory data analysis is indispensable when you wish to assure quality!
- Look at data, explore them graphically!

# Exploratory analysis in the case of the MUST exercise:

- An extensive set of available model results and tools.
- The tools are mainly Excel-based (developed by Ruwim Berkowicz)
- Results from a large number of model have been put into the same framework
- This gives us a unique opportunity to inspect data graphically, compare results, and identify and explore patterns.
- A big bonus: Anomalies are detected. Anomalies are often a symptom of errors.

# What do we gain from the exploratory analysis within the MUST exercise?

- Detect anomalies
- Identify problems common to several models
- Get an indication of the state of the art
- Potential for digging deeper into cause and effect for model behaviour

# MUST - MODELS INVOLVED

Models can be thought for general OR SPECIFIC applications, it is important to check their fitness for purpose when we use them for solving a problem or for a new application...

- Computational Fluid Dynamics (CFD) models
- MISKAM
  - FLUENT
  - ADREA
  - STAR-CD
  - FINFLO
  - CFX
  - MITRAS
  - TSU/M2UE
  - VADIS
  - CODE\_SATUR
  - NE

## 15 GROUPS INVOLVED

- **0° case:** about 40 model flow results
- **-45° case:** about 30 model flow results
- **-45° case:** about 20 model dispersion results

## 7 GROUPS INVOLVED

- **-45° case:** about 10 model dispersion results

- LASAT
- ADMS-URBAN
- RAMS
- OML
- ESCAPE
- CALPUFF

Non-CFD models

# MUST – Rules of the game as presented here

- Focus on CFD models
- The validation data were measured in the wind tunnel in Hamburg
- 3 cases:
  - (0 degree flow)
  - 45 degree flow
  - 45 degree dispersion

# Rules of the game for this presentation...

- The same model can be represented several times, but run by different groups (e.g., Fluent was run by many groups).
- Tests with different resolutions etc. are not included here – only the modeller's preferred result.
- Each group is only represented once with each model (exceptions for Fluent/RSM and Fluent/k-e)
- Model names are not always disclosed



# Note: What do I mean when I speak of a 'model version' during the next slides?

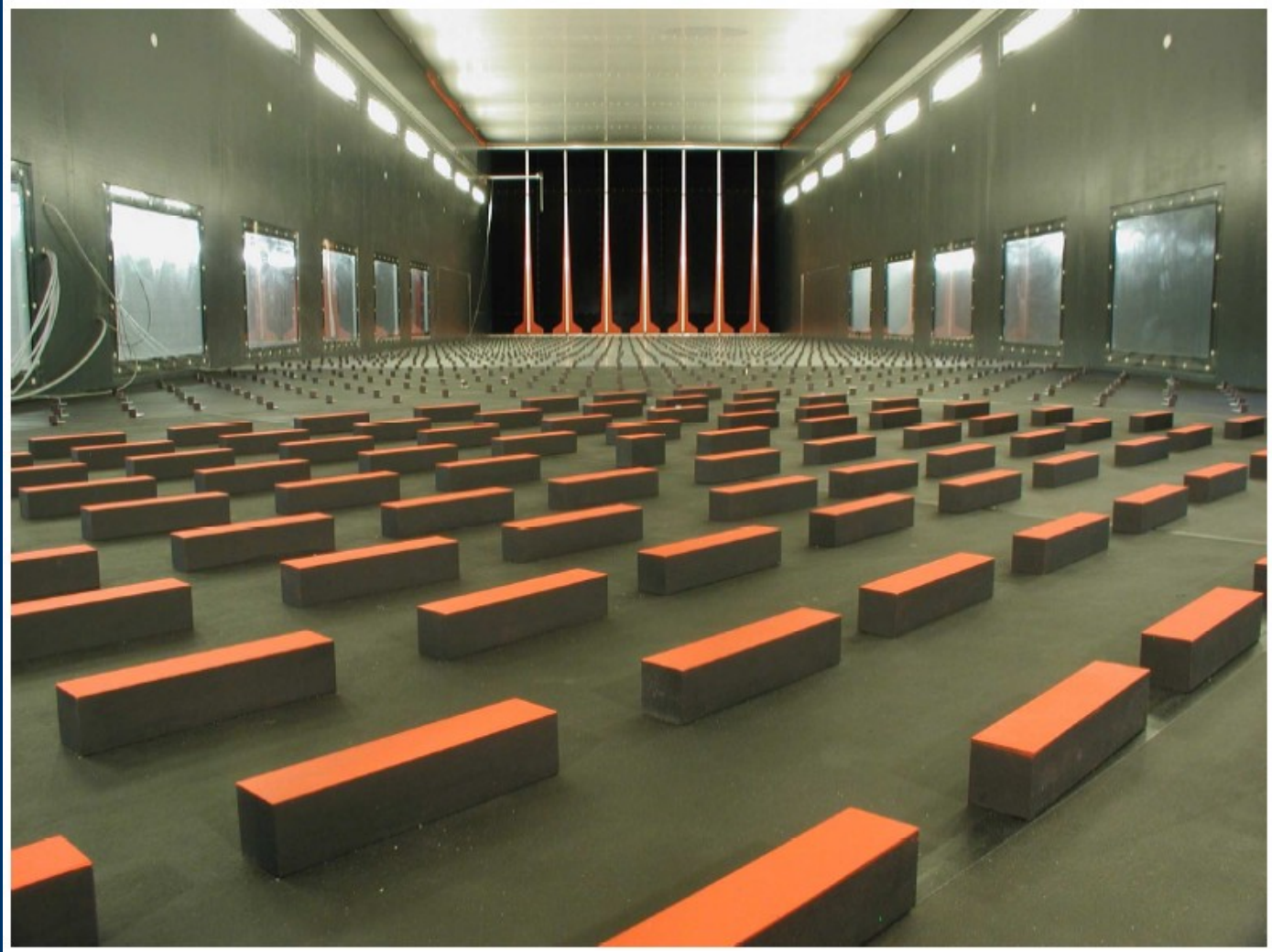
- It is a model, combined with the way that it is set up. E.g. Fluent, set up with a certain mesh and certain options, run by a specific group.

'Model version' := a model including its setup

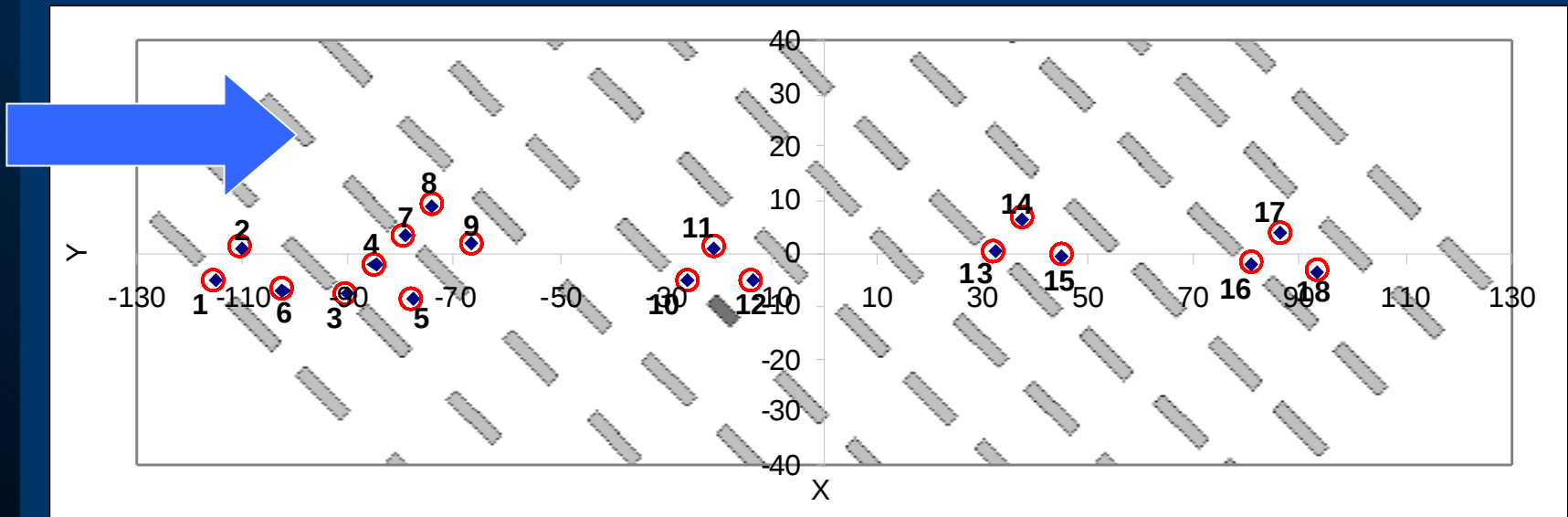
# Detailed example

- Are the models capable of predicting the  $u$  component of the wind?
- We consider the -45 degree flow case with measurements at 18 'towers'

# Minus 45 degree flow



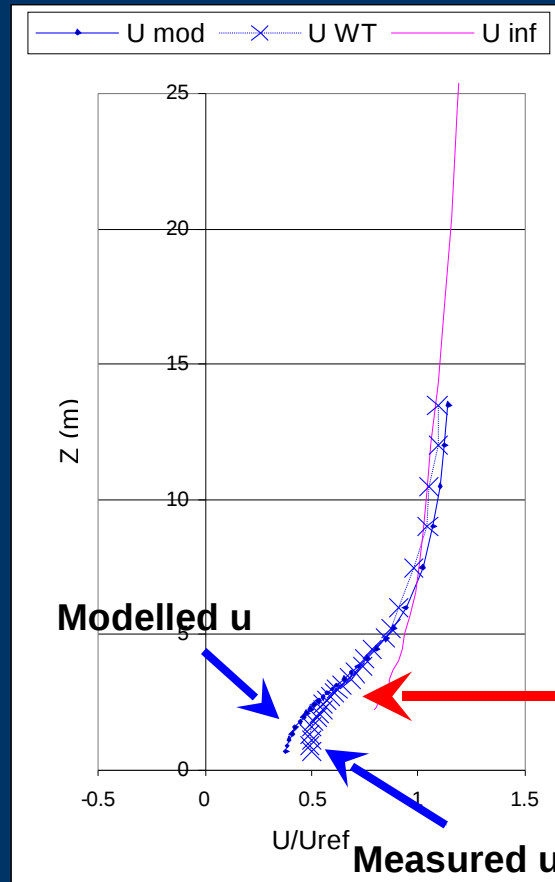
# Minus 45 degree flow case – view from above



260 m

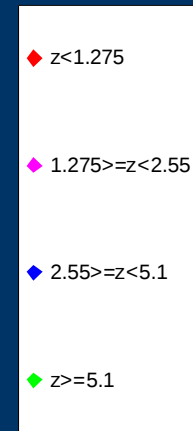
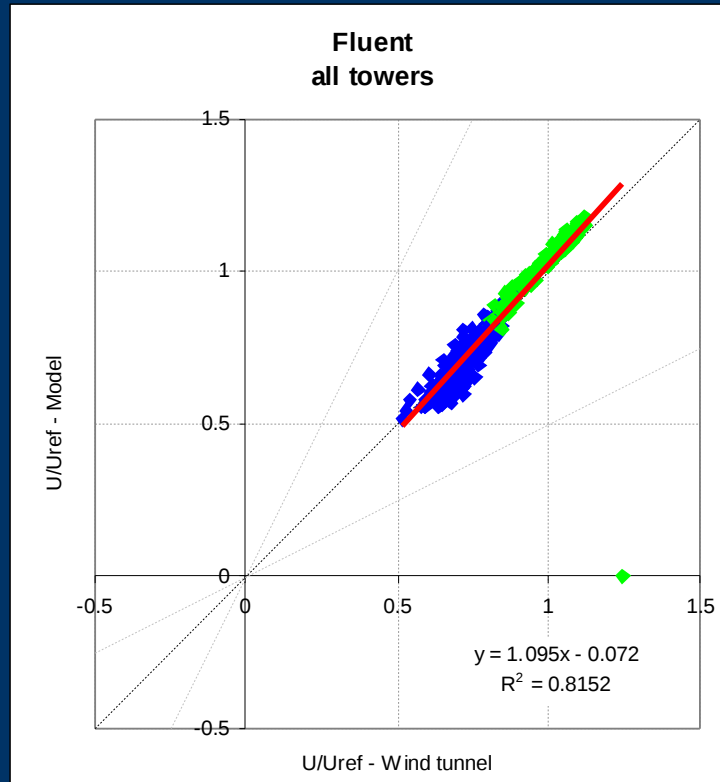
# -45 degree flow

## Example of profile of $u$ along a 'tower'

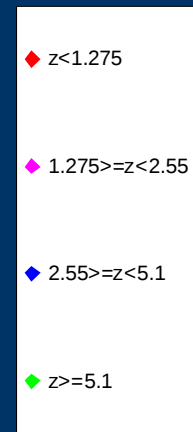
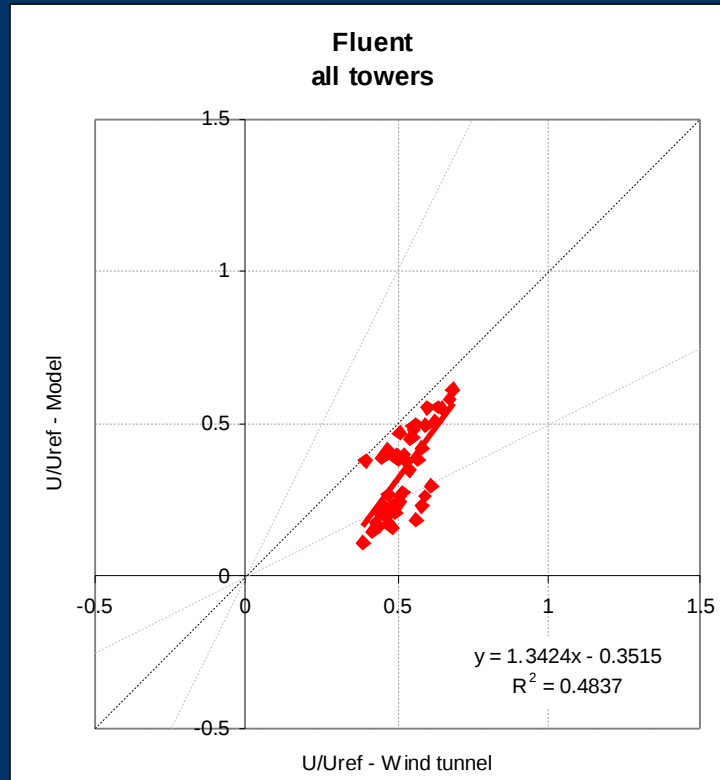


Roof top at 2.54 m

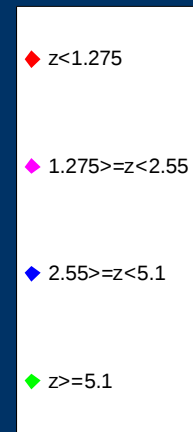
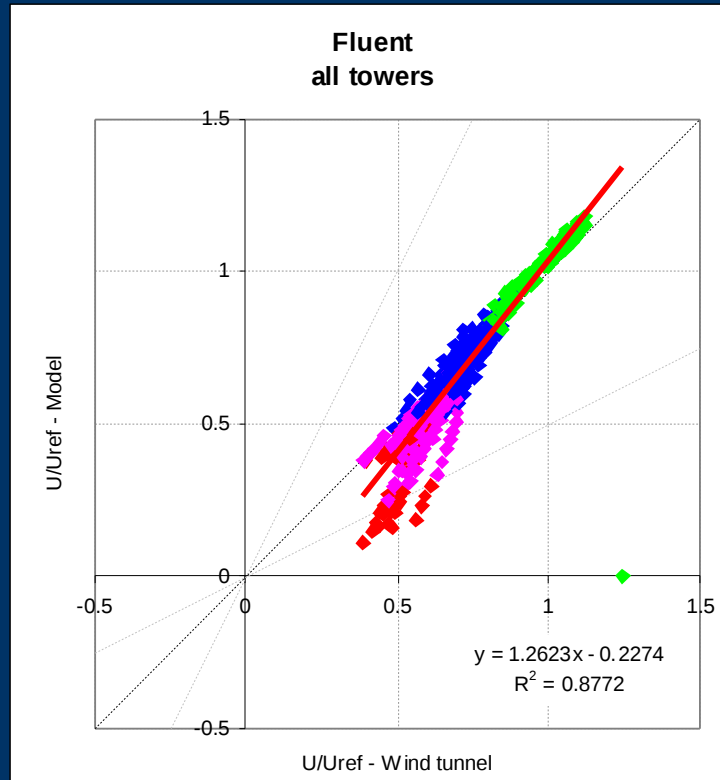
# -45 degree flow, all towers u component above building roof



# -45 degree flow, all towers u component below 1.25 m

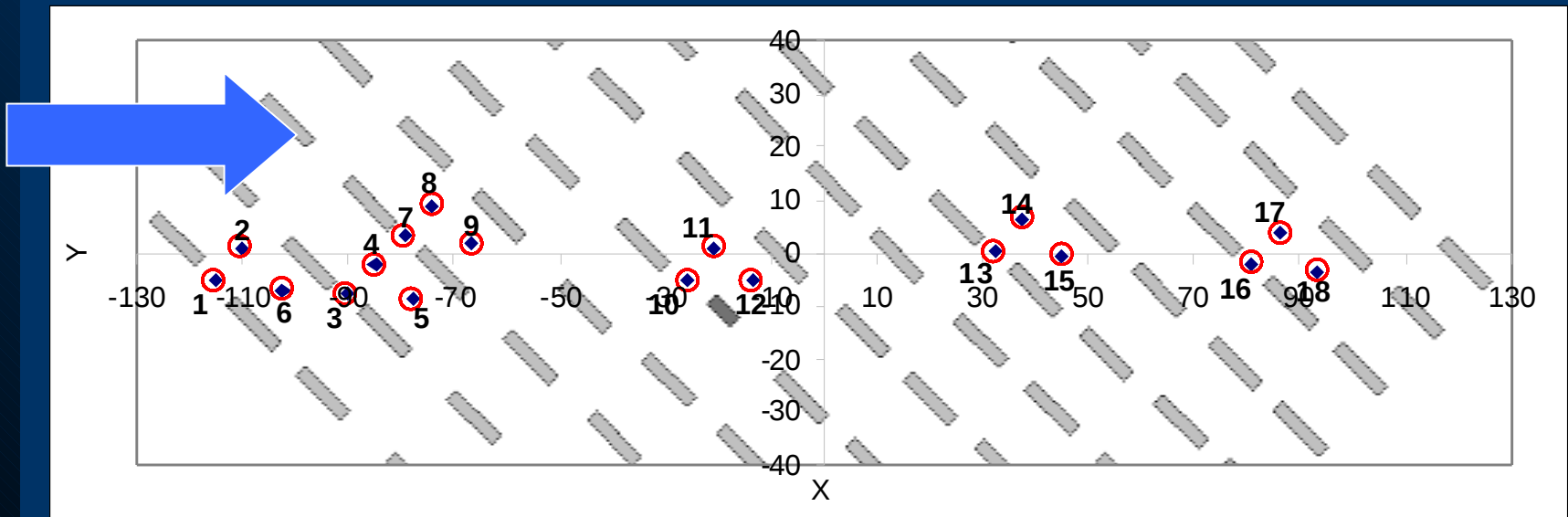


# -45 degree flow, u component all heights



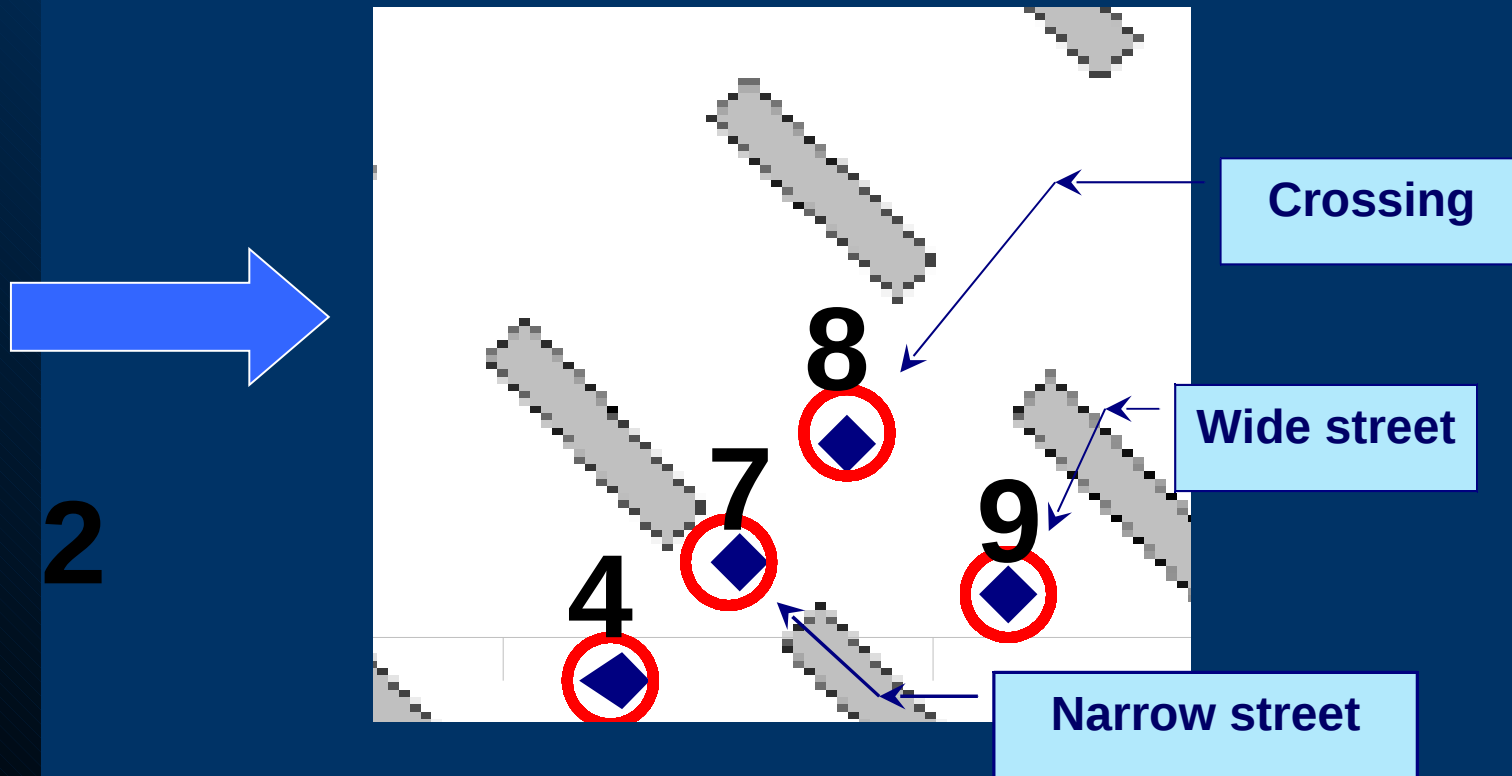


# Minus 45 degree flow case – view from above

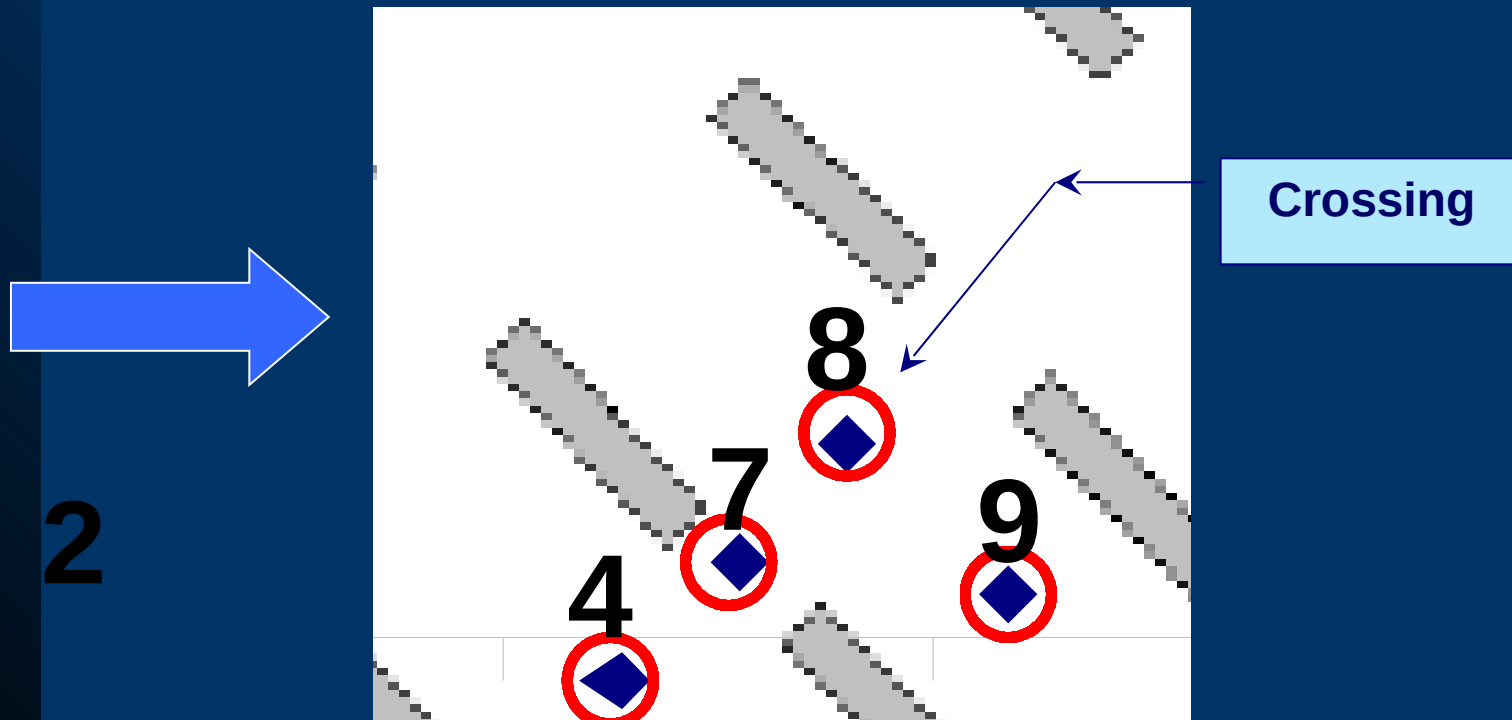


260 m

# - 45 degree flow



# - 45 degree flow



2

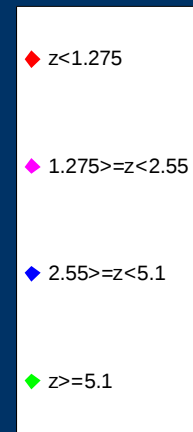
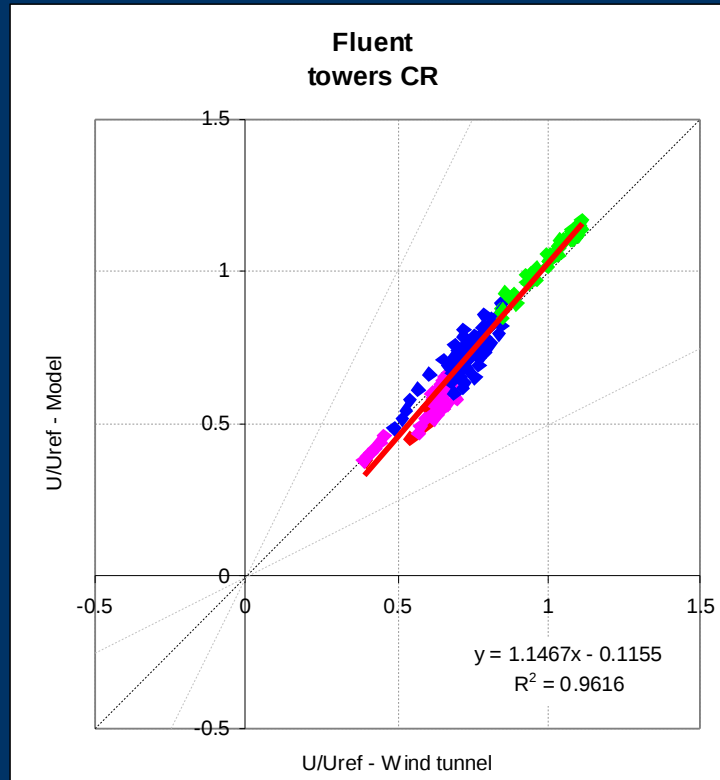
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3

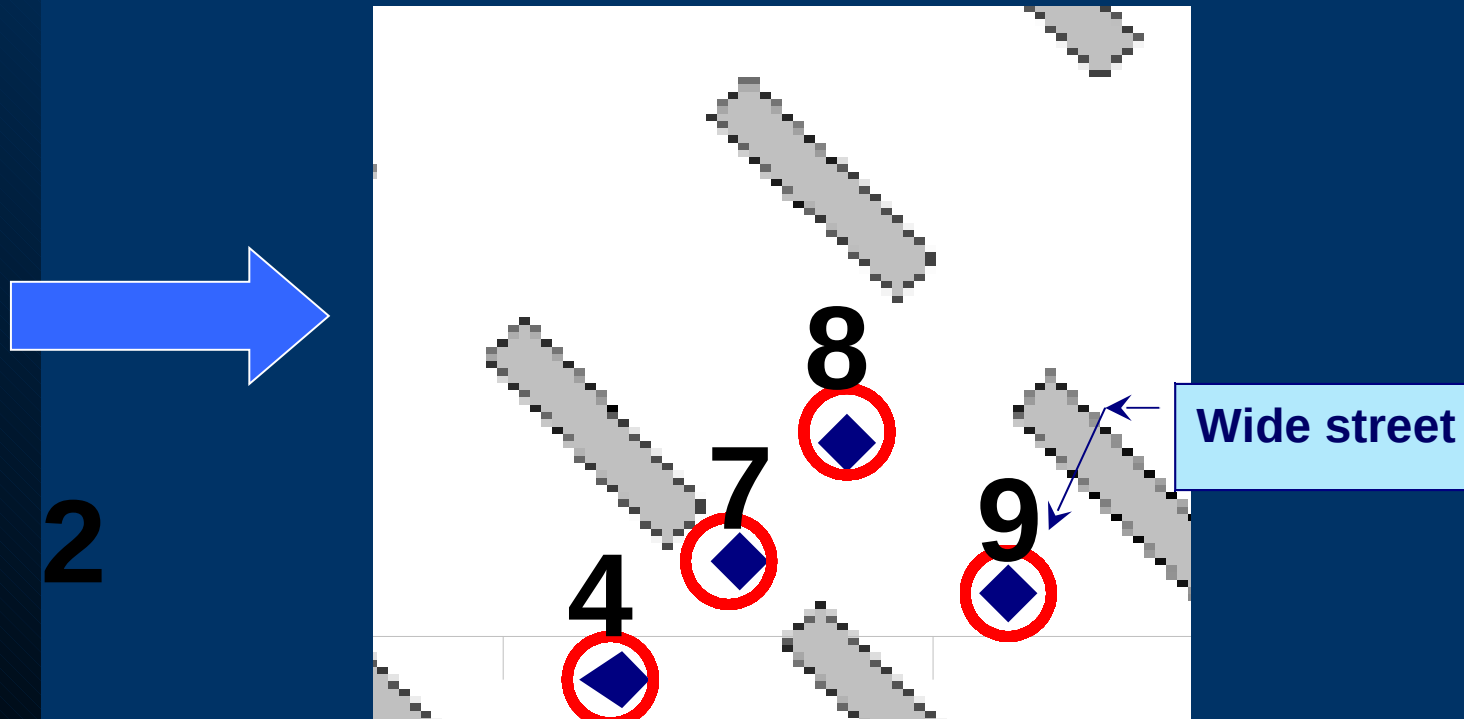
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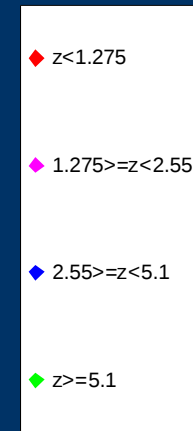
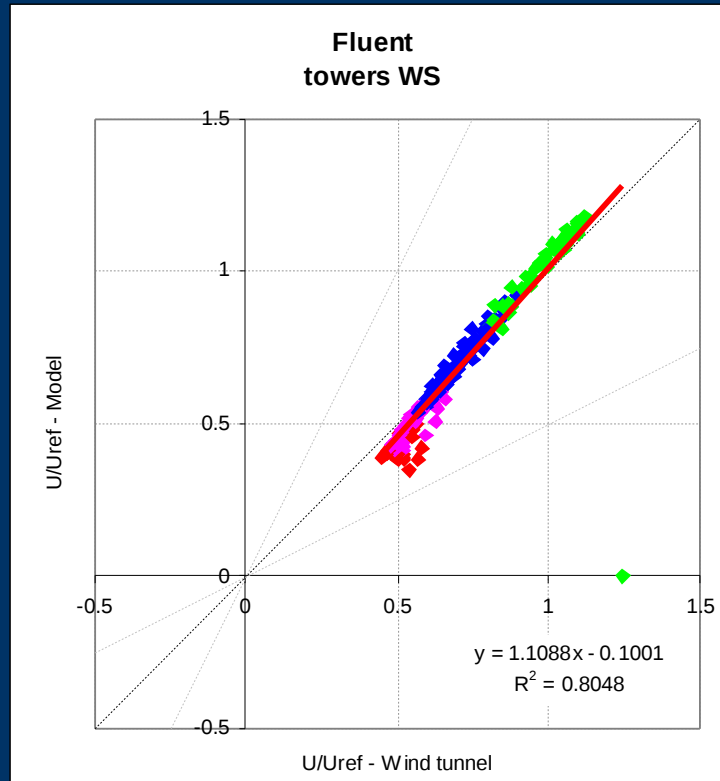
# -45 degree flow, u component all heights - Crossings



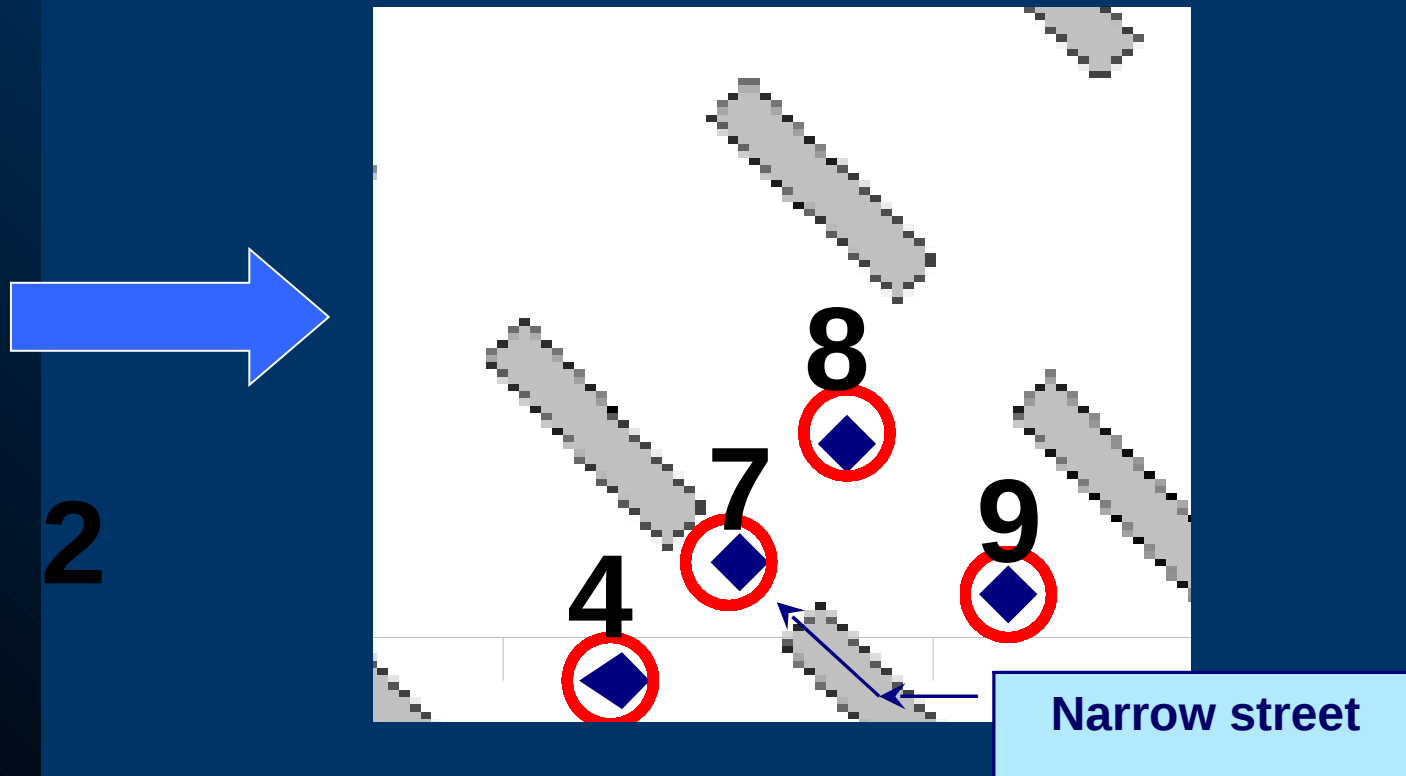
# - 45 degree flow



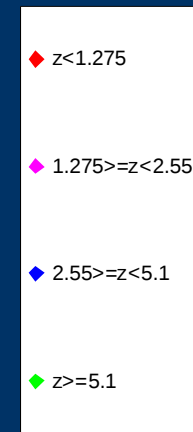
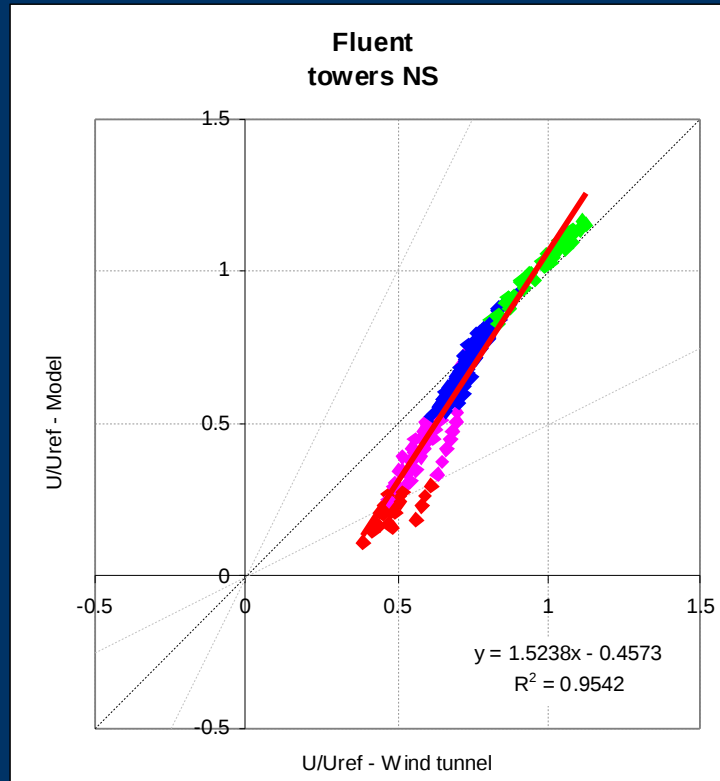
# -45 degree flow, u component, all heights - Wide Streets



# - 45 degree flow

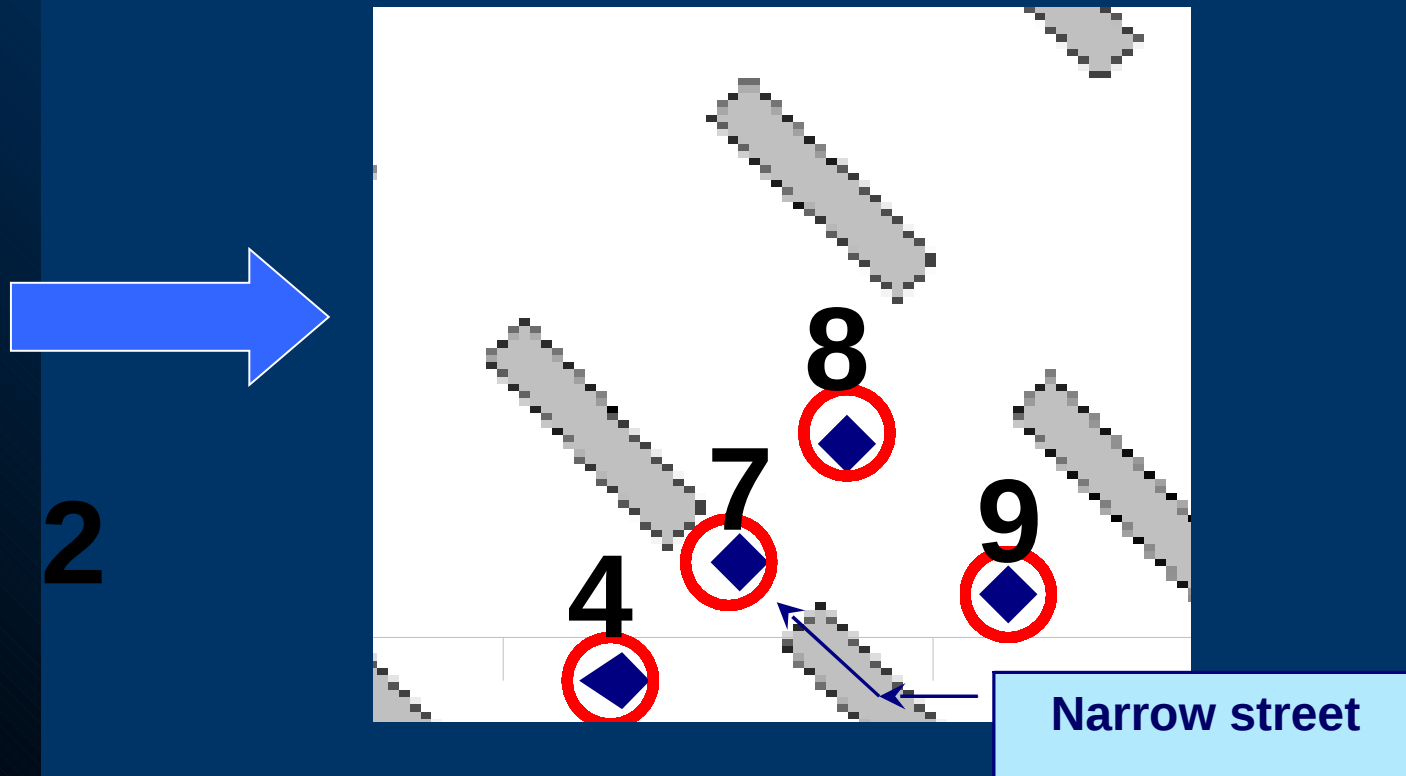


# -45 degree flow, u component, all heights - Narrow Streets





# - 45 degree flow

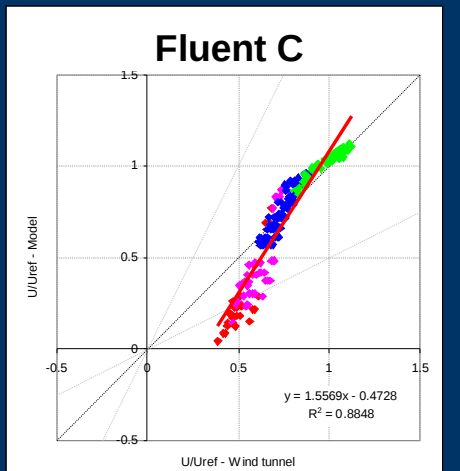
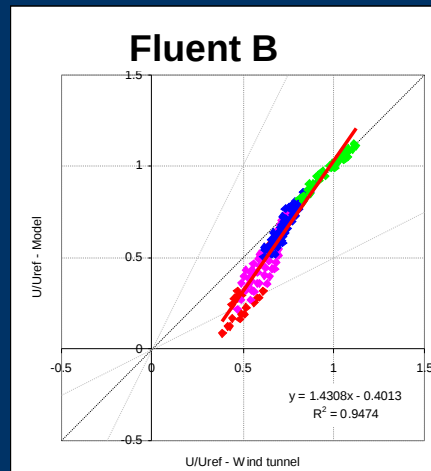
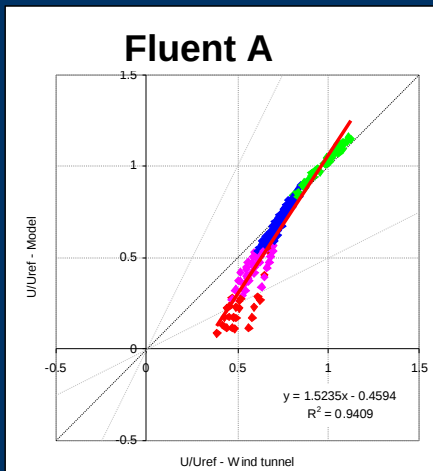
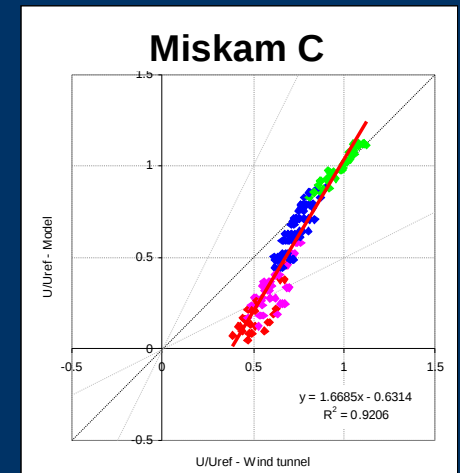
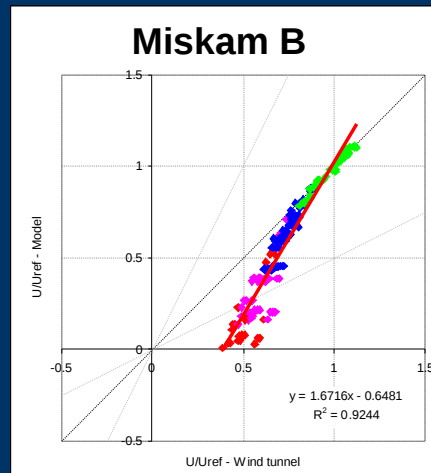
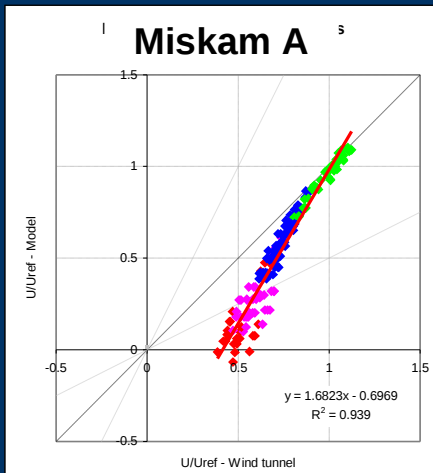


# Conclusion so far...

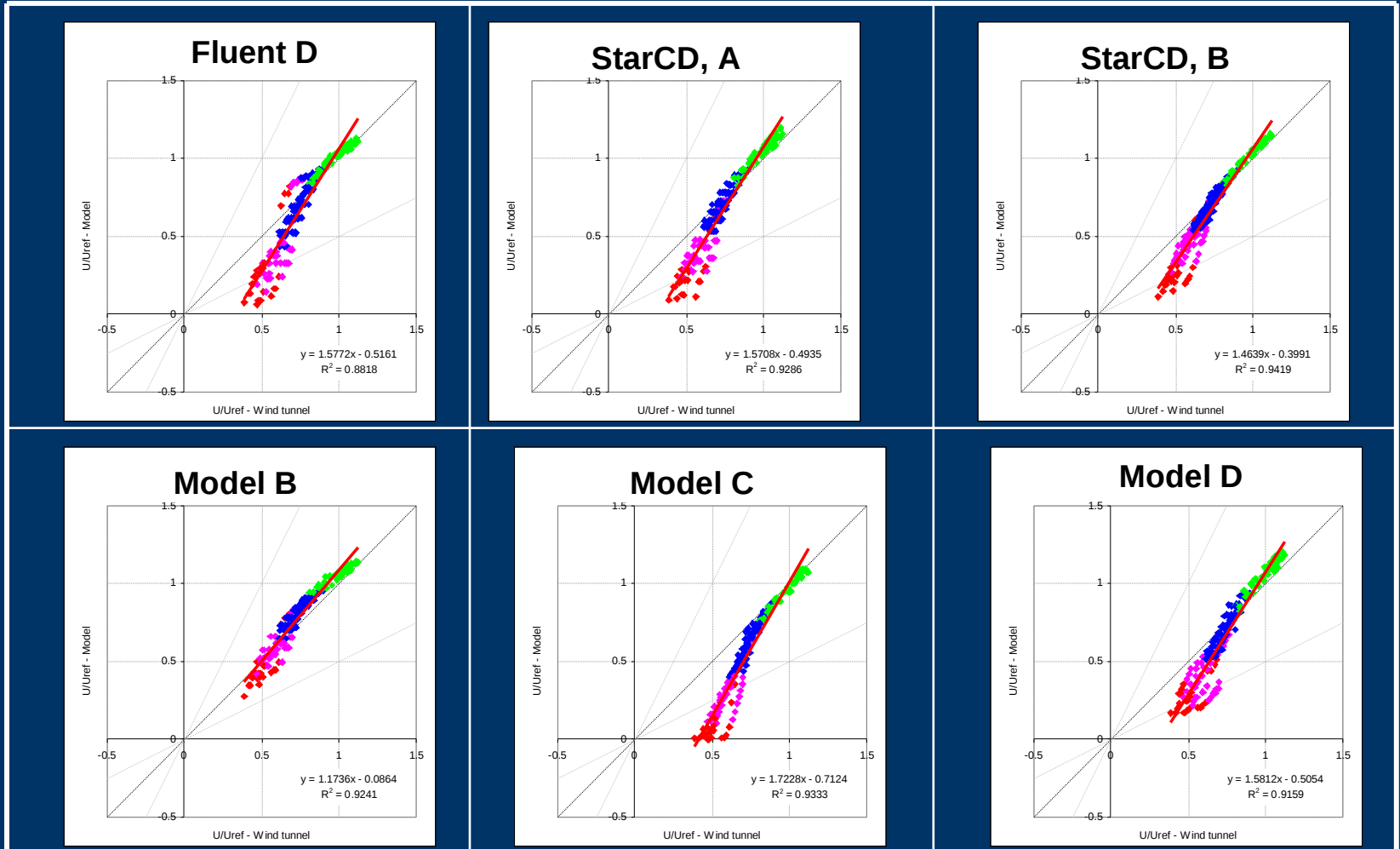
Referring to prediction of u component for the model setup in question (model Fluent):

- Crossings: good prediction
- Wide streets: good prediction
- Narrow streets: Clear underprediction for points below roof

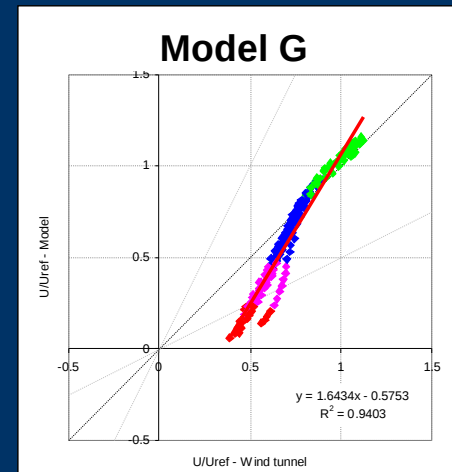
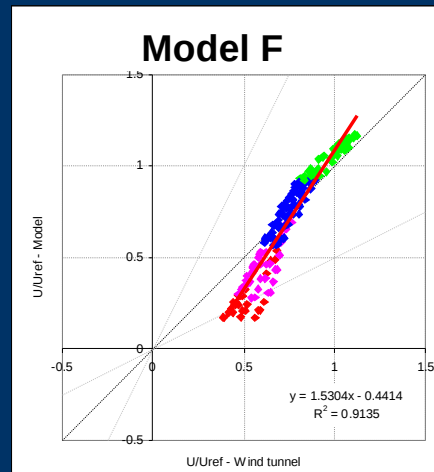
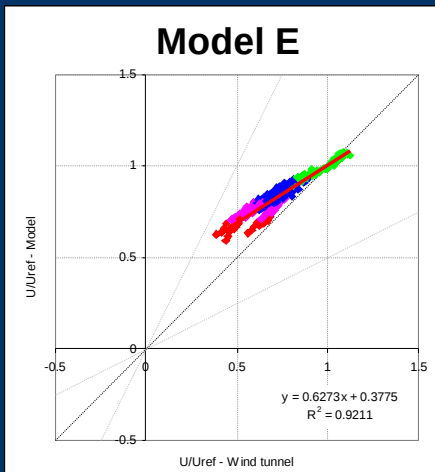
# u component, several models – Narrow streets (panel 1)



# u component, several models – Narrow streets (panel 2)



# u component, several models – Narrow streets (panel 3)



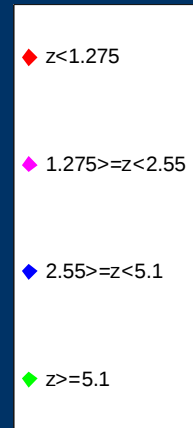
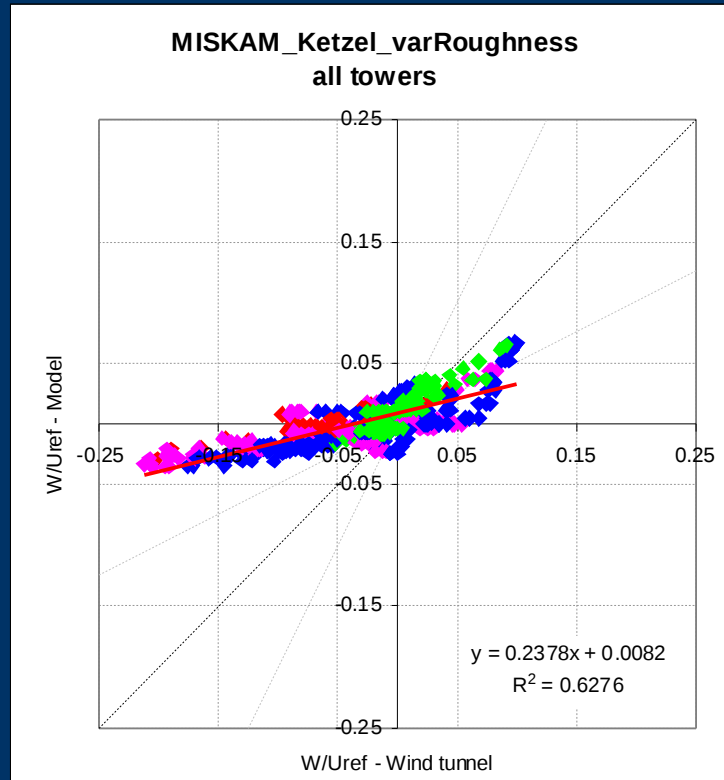
# Common feature for models at -45 degree

- **Narrow streets is too tough a challenge: u is underpredicted at low heights in 'Narrow streets'**

# Are the models capable of predicting the $w$ component?

- **Note: This is a difficult task. Vertical flow can go up and down, and the sign can vary even within a grid cell.**

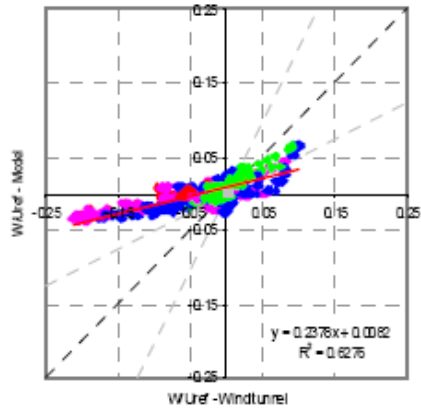
# -45 degree flow, w component, all towers



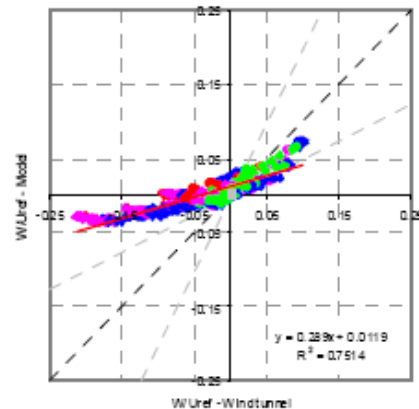


# -45 degree flow, w component, all towers

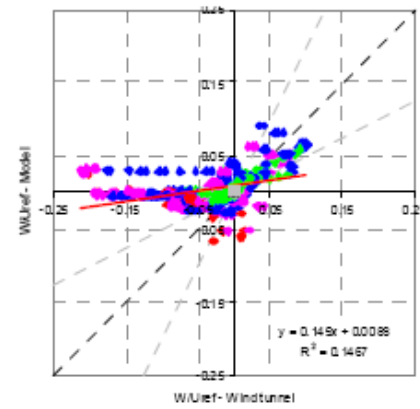
### Miskam A



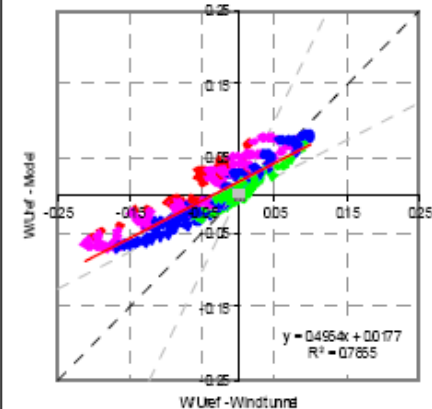
### Miskam B



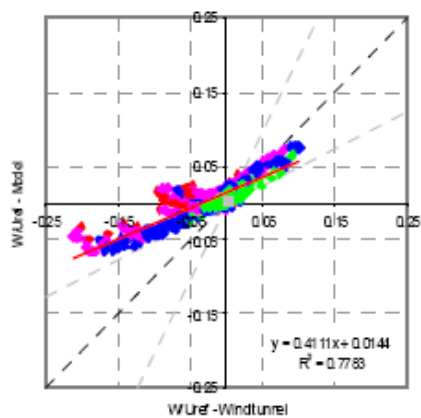
### Miskam C



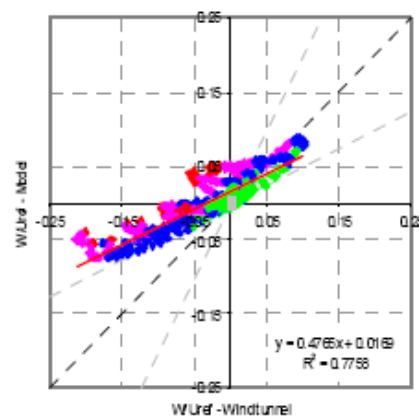
### Fluent A



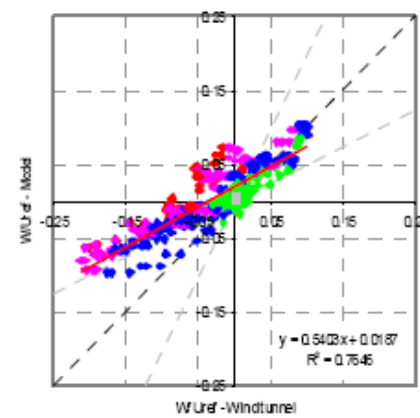
### Fluent B



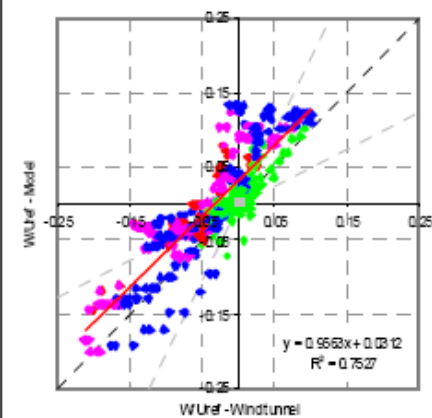
### Fluent C



### Fluent D

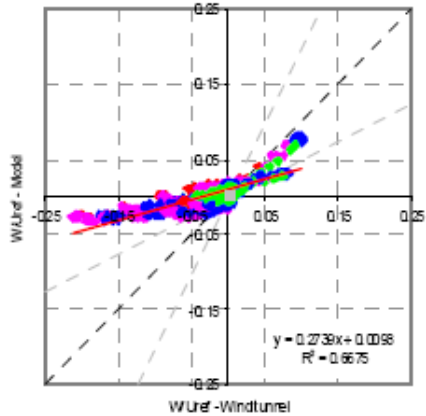


### Fluent E

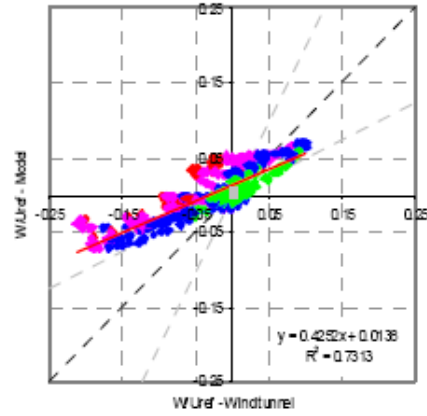


# -45 degree flow, w component, all towers

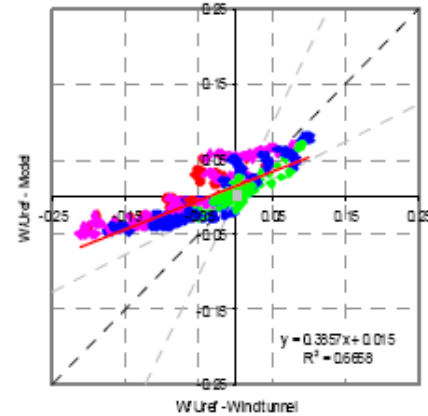
Star CD A



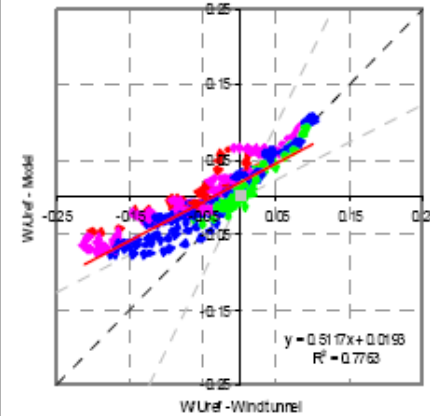
Star CD B



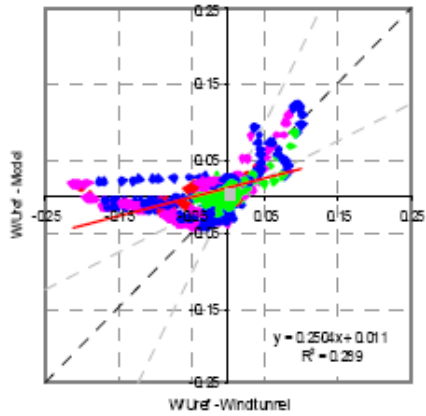
Model A



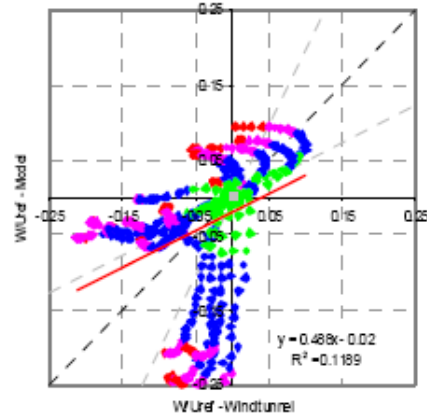
Model B



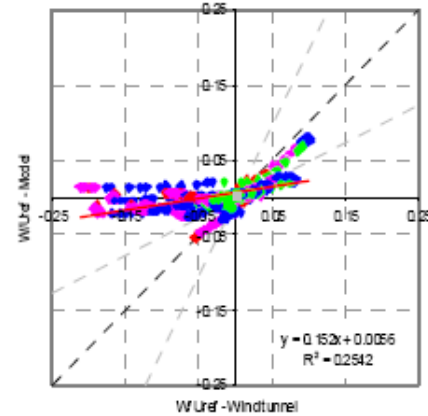
Model C



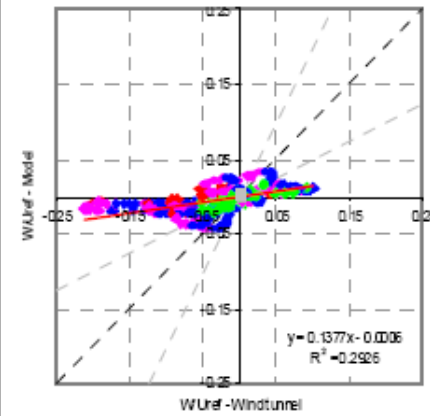
Model D



Model E



Model F



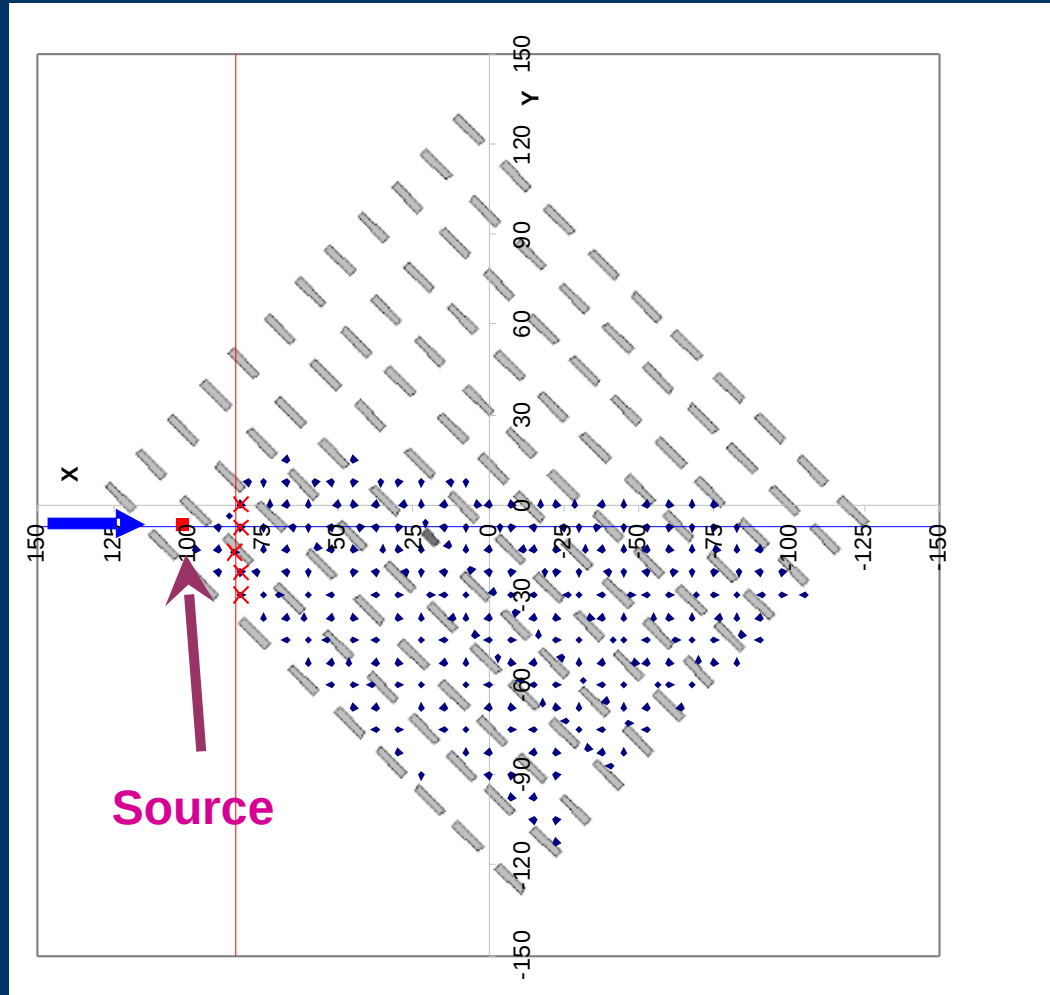
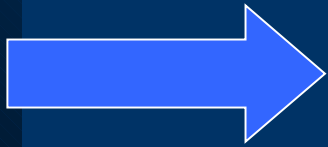
# Common feature for models at -45 degree

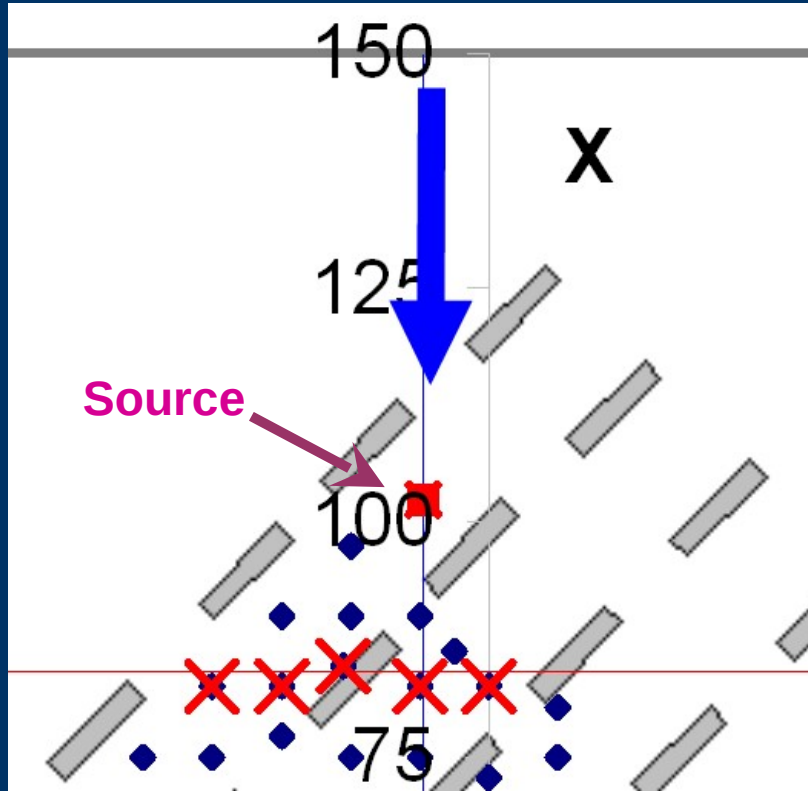
- Models have difficulty in reproducing  $w$ , in particular negative values of  $w$

# The power of exploratory analysis used on a group of models

- Similarities and differences stand clearly out, potential problems are revealed.
- An unusual pattern is often the symptom of some underlying problem (misplaced buildings, shifted coordinate systems)

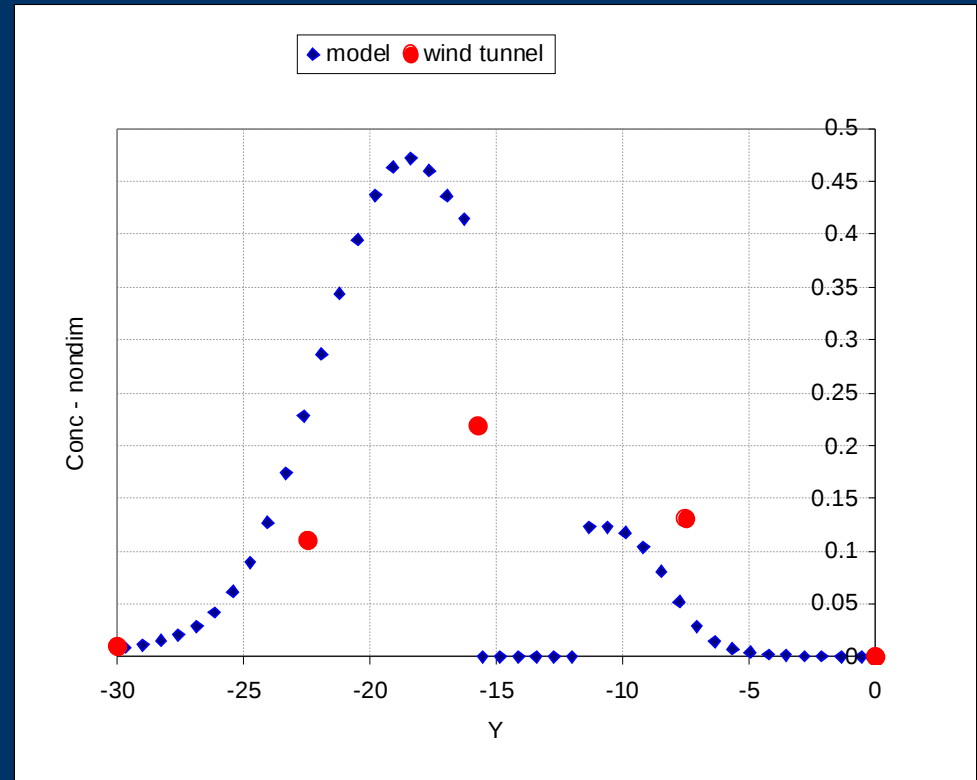
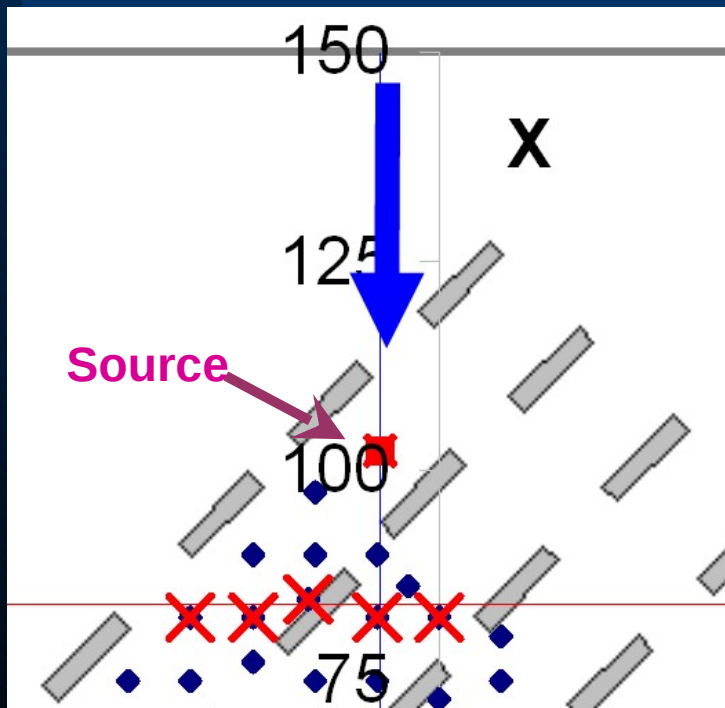
# Next example: Minus 45 degree dispersion case



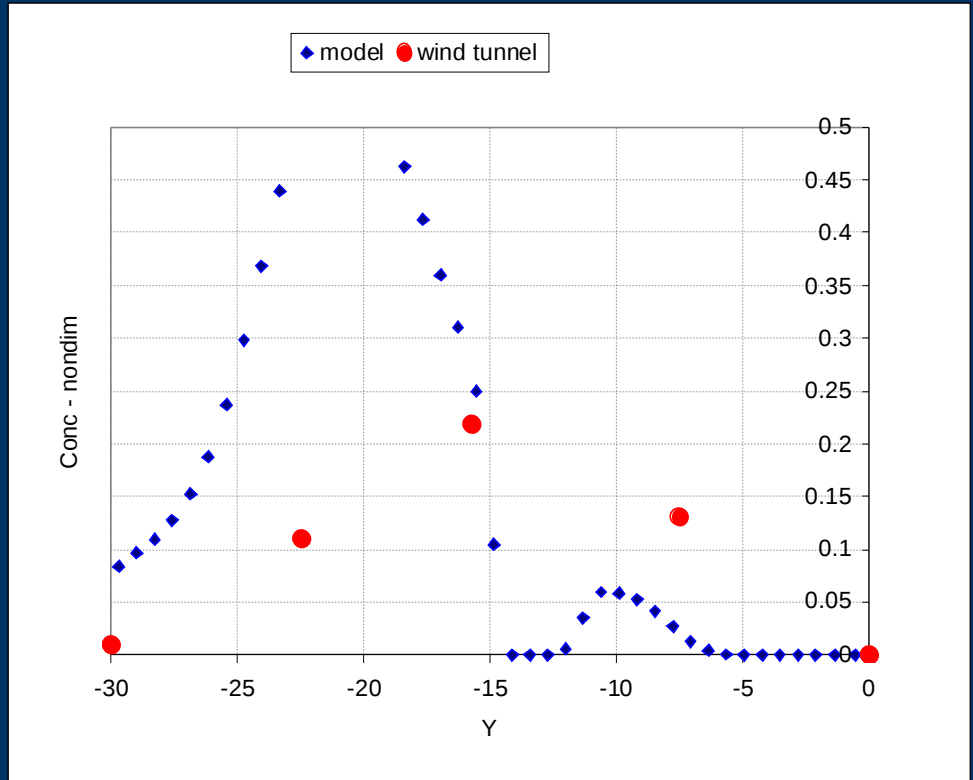
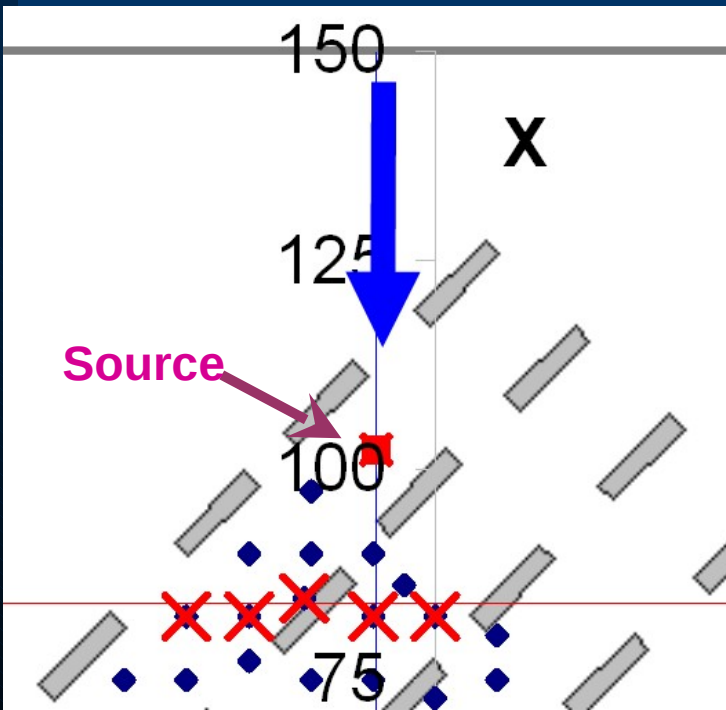


18 m

# Next example: Minus 45 degree dispersion case, Miskam A, 18 m

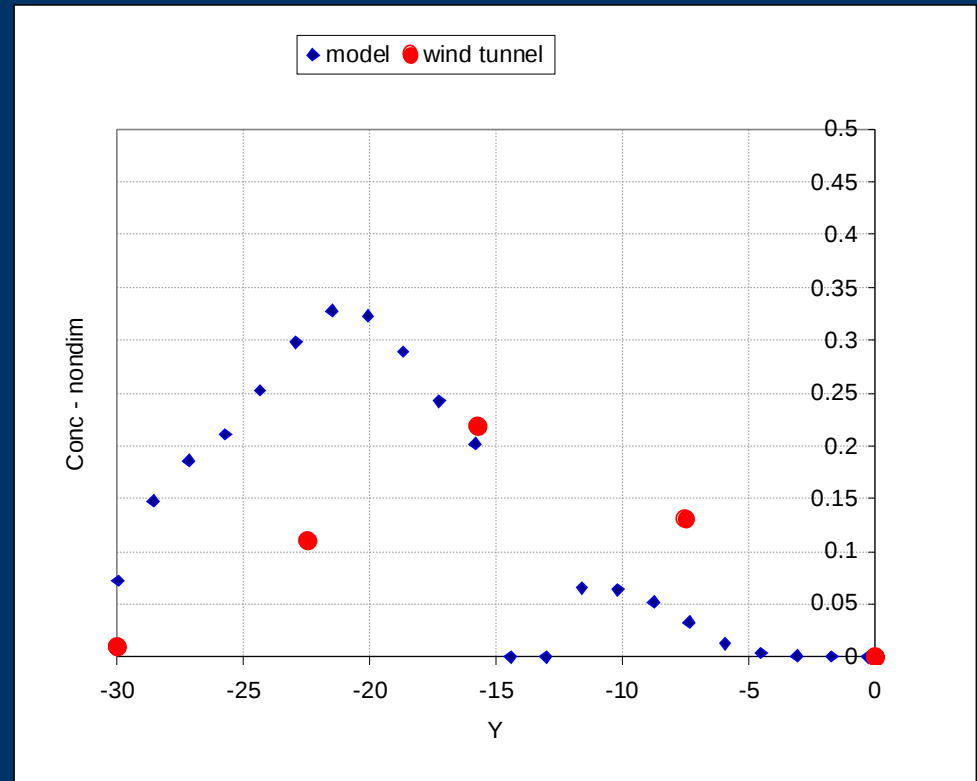
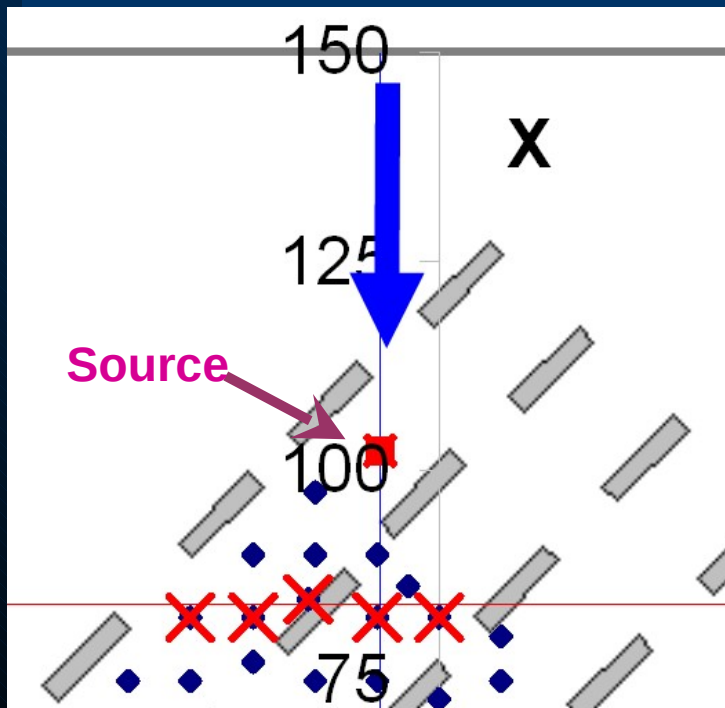


# Next example: Minus 45 degree dispersion case, Miskam B, 18 m

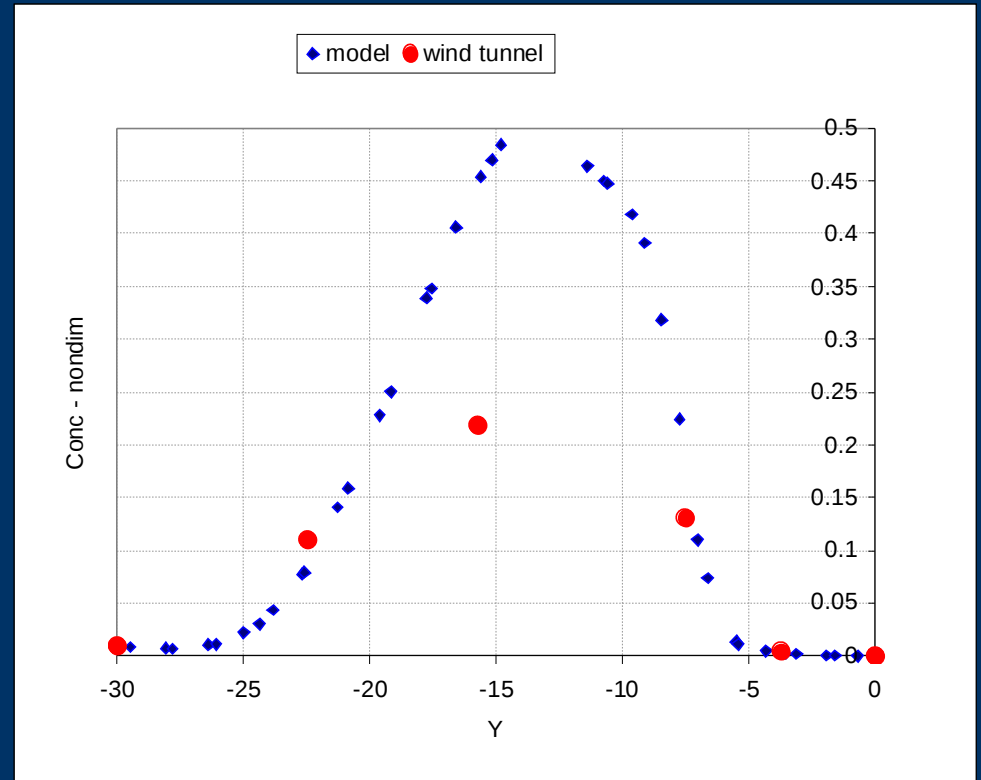
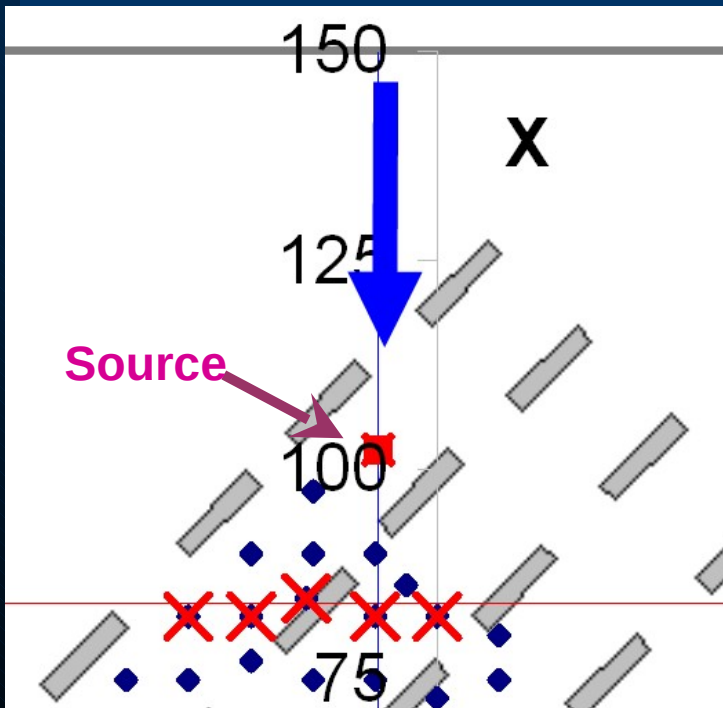




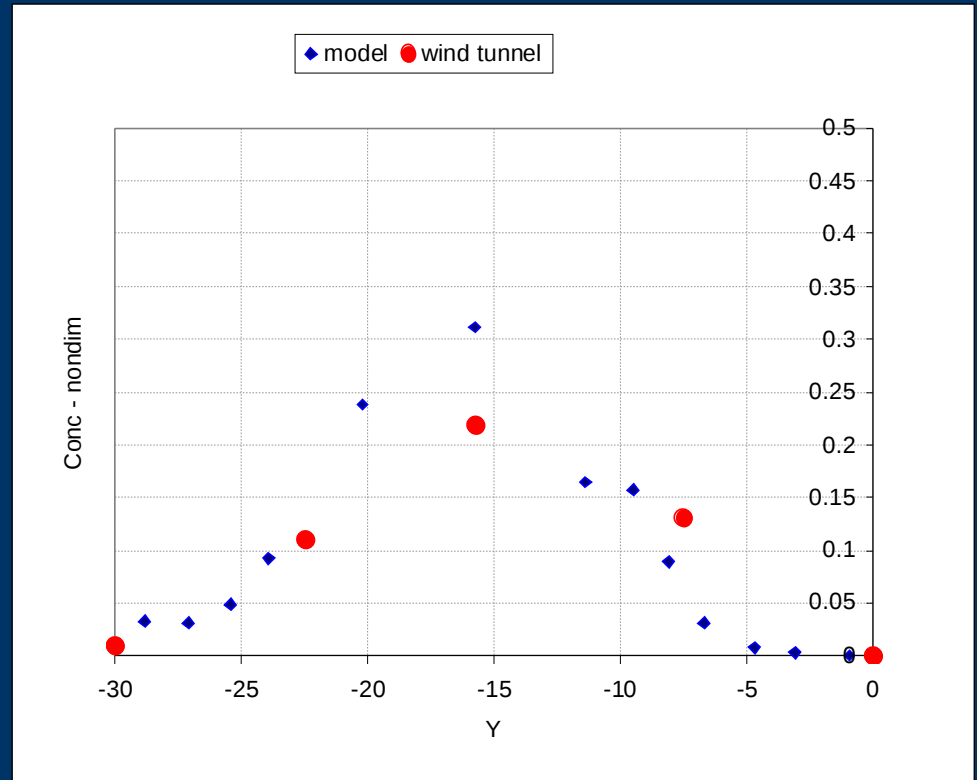
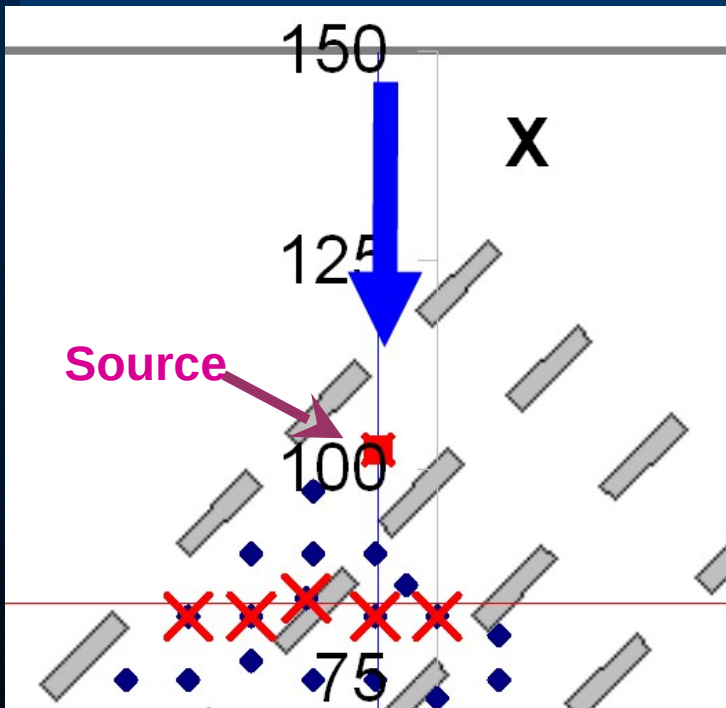
# Next example: Minus 45 degree dispersion case, Miskam C, 18 m



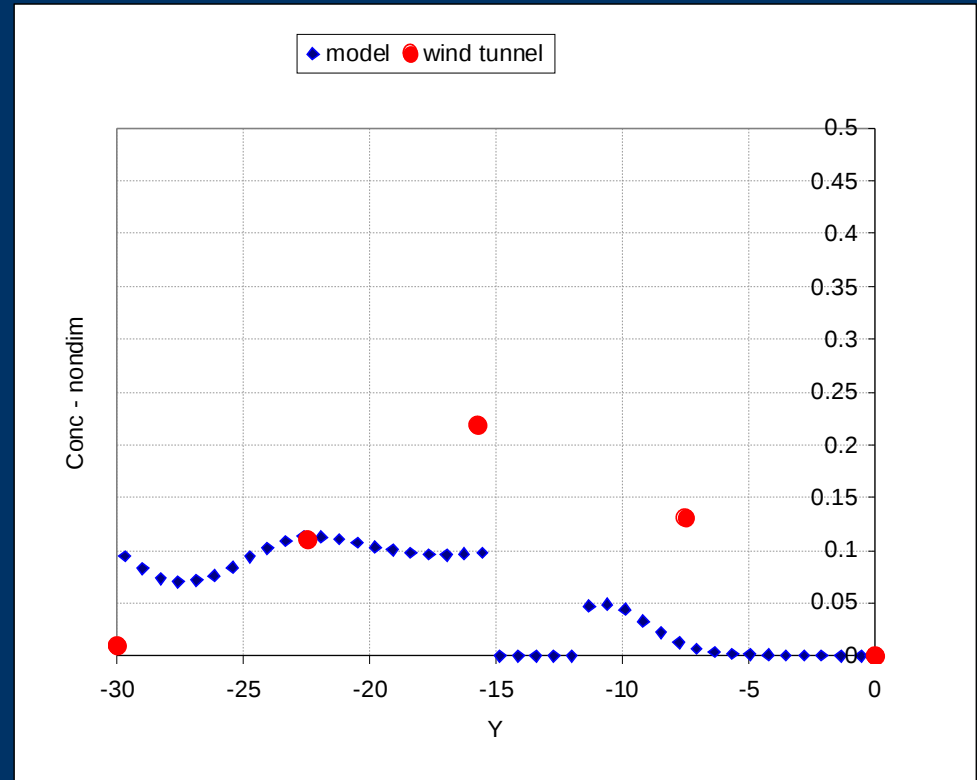
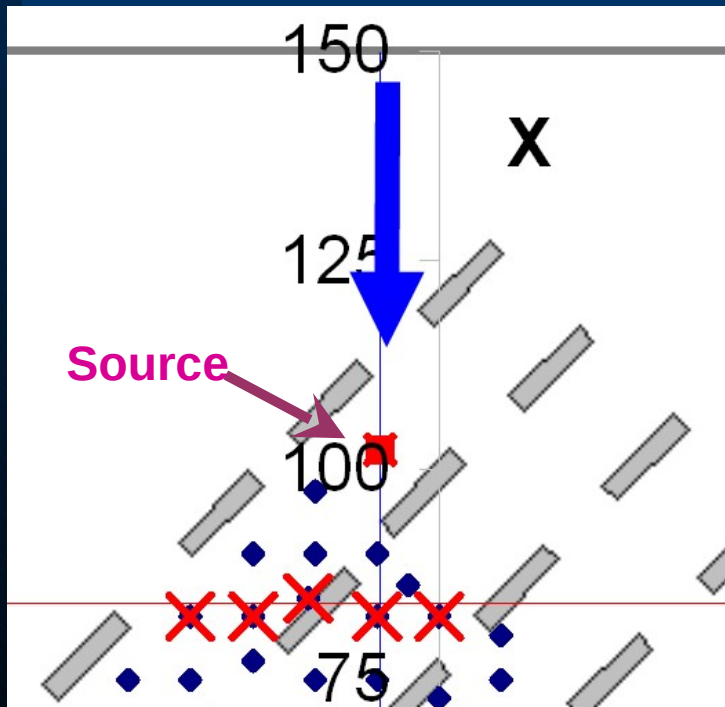
# Next example: Minus 45 degree dispersion case, Fluent A, 18 m



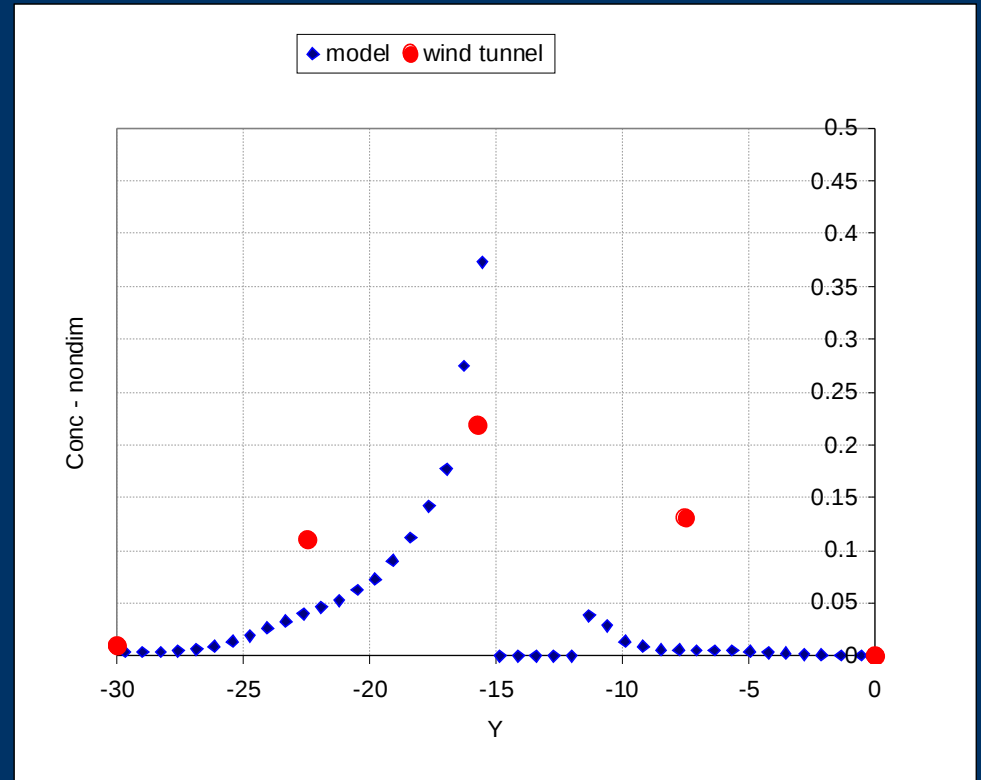
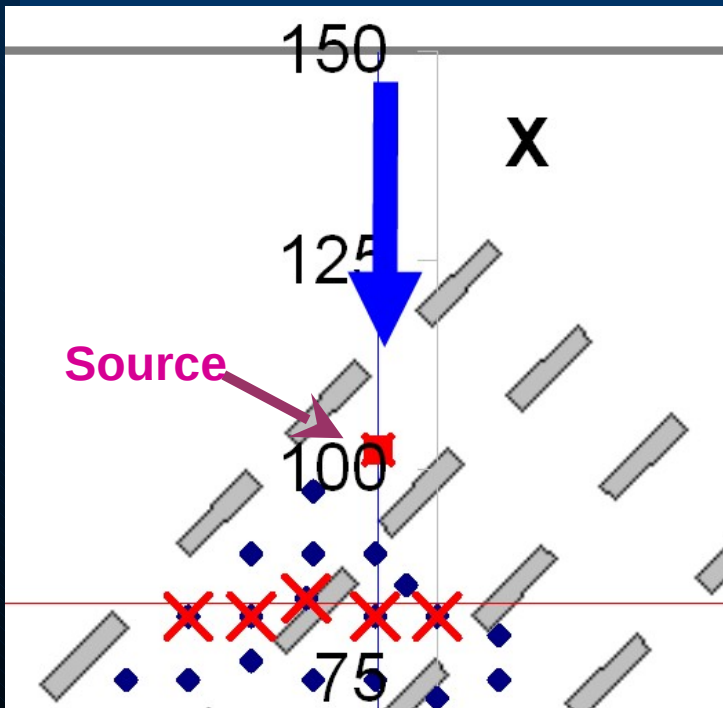
# Next example: Minus 45 degree dispersion case, Fluent B, 18 m



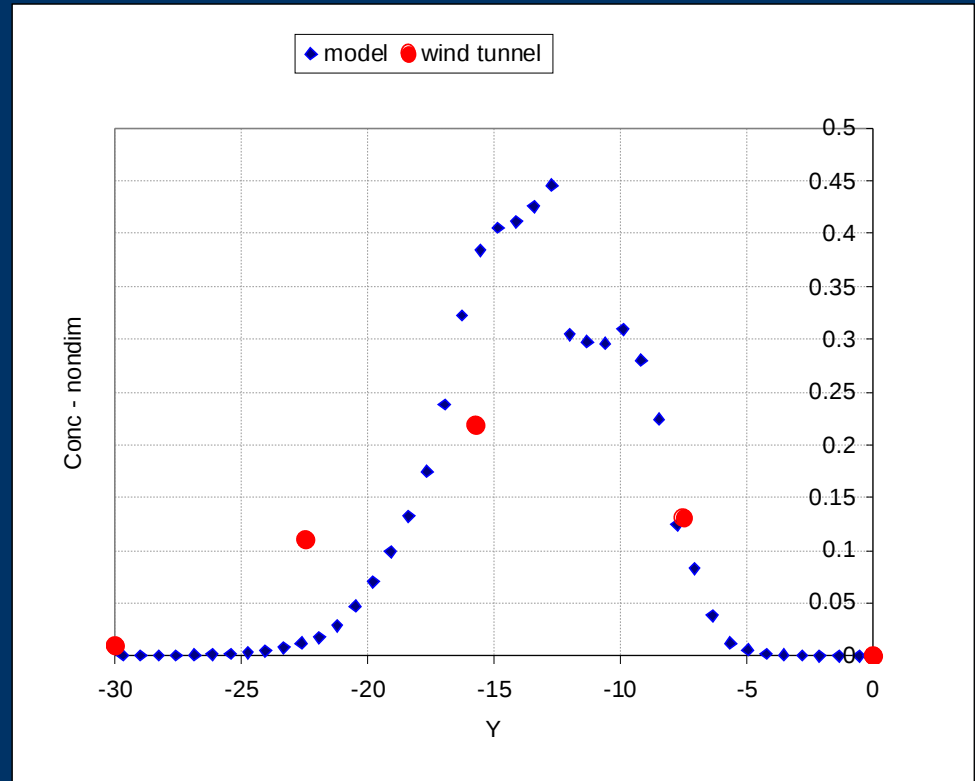
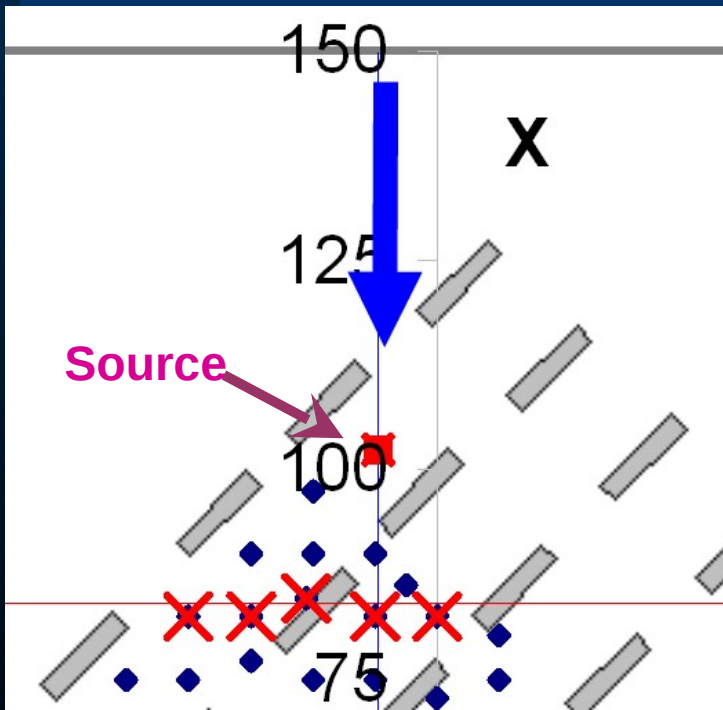
# Next example: Minus 45 degree dispersion case, Fluent C, 18 m



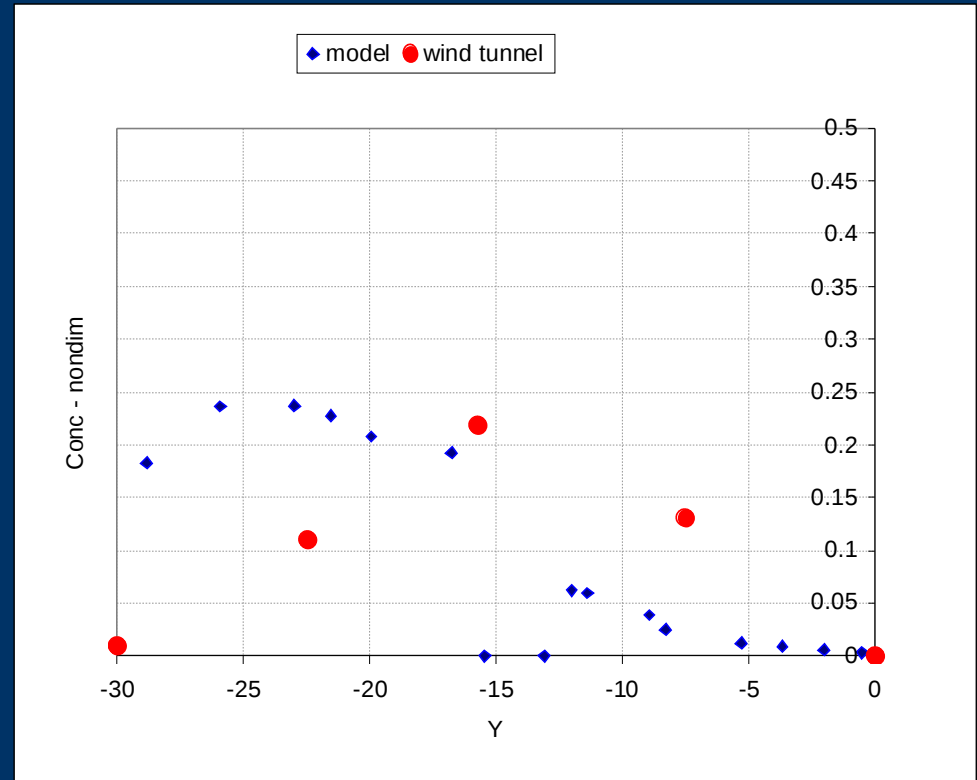
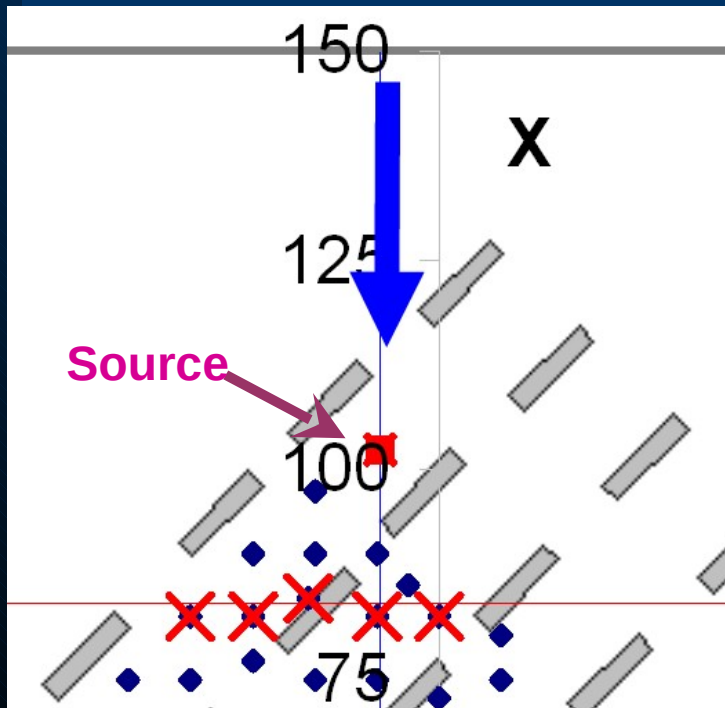
# Next example: Minus 45 degree dispersion case, Fluent D, 18 m



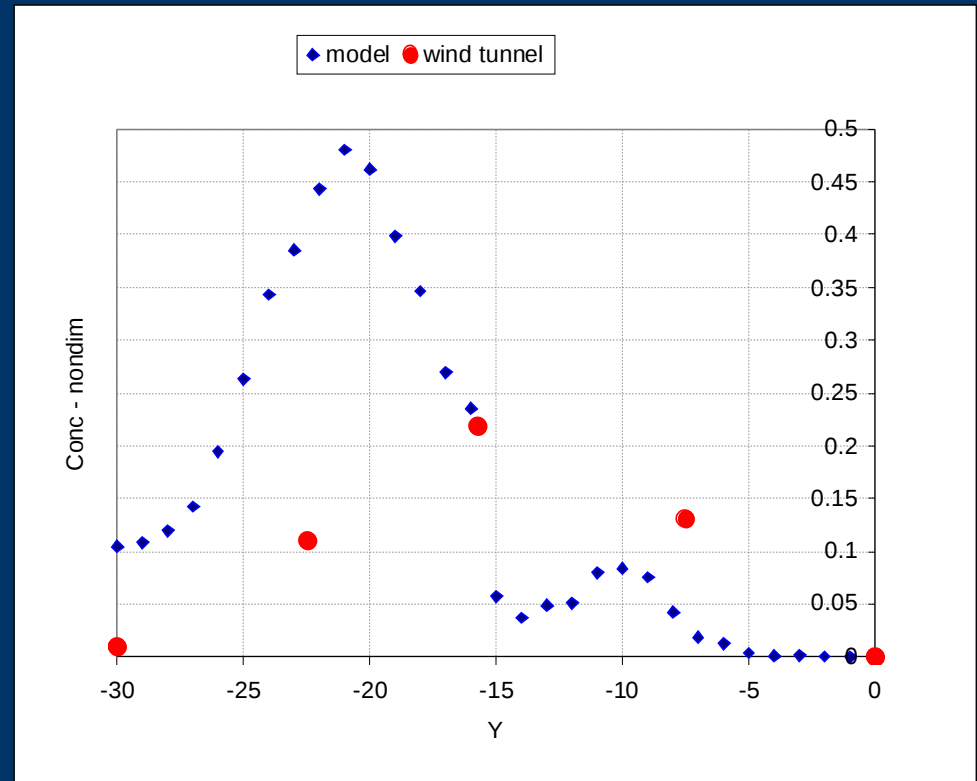
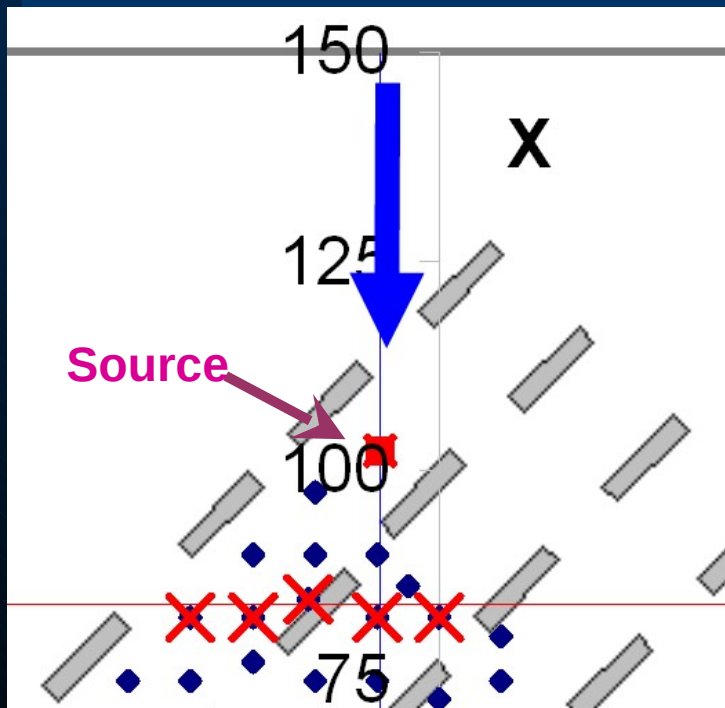
# Next example: Minus 45 degree dispersion case, Model A, 18 m



# Next example: Minus 45 degree dispersion case, Model B 18 m

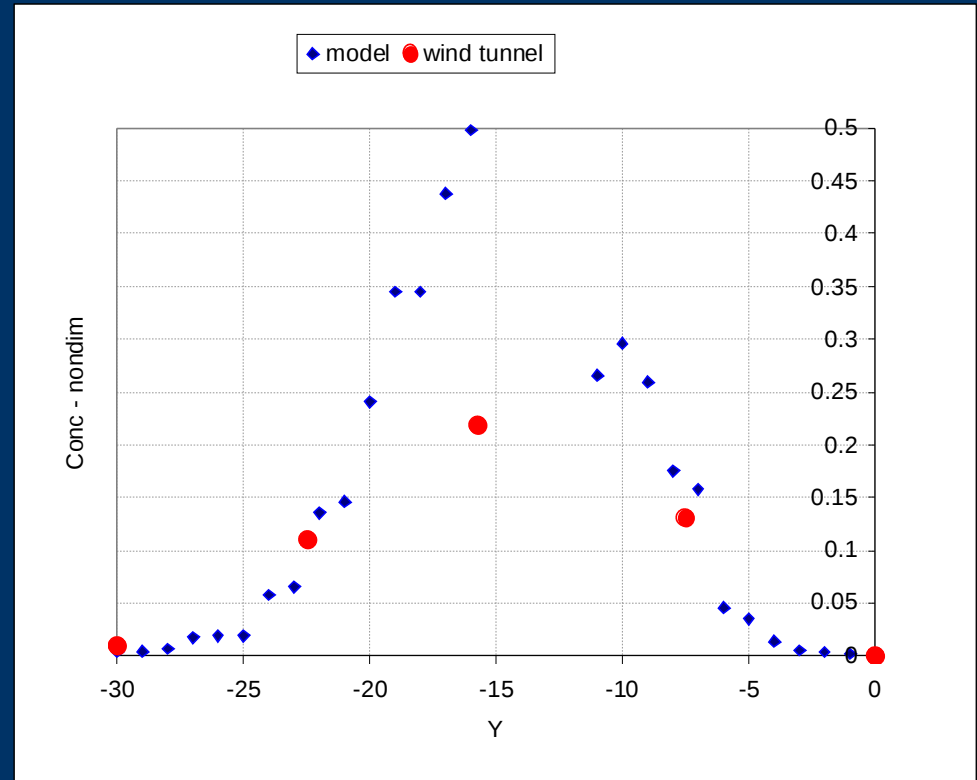
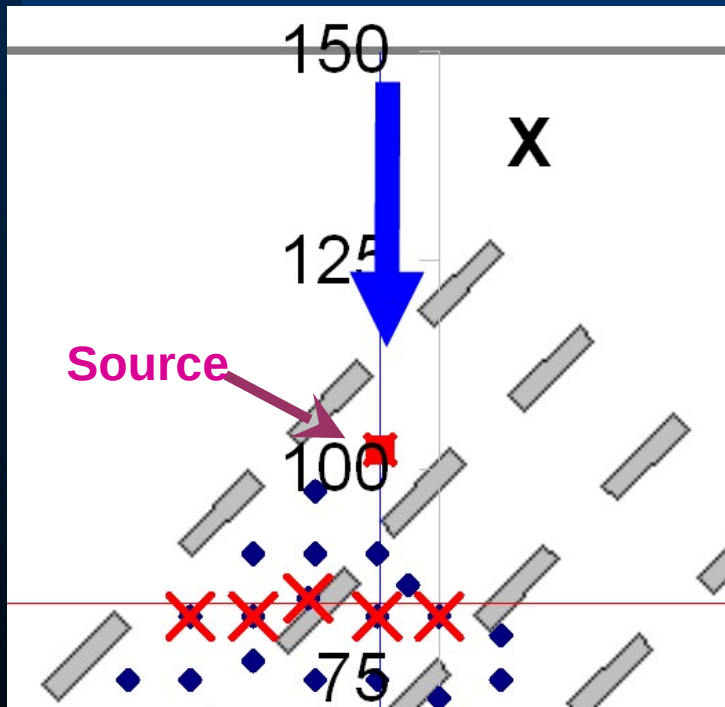


# Next example: Minus 45 degree dispersion case, Model C, 18 m

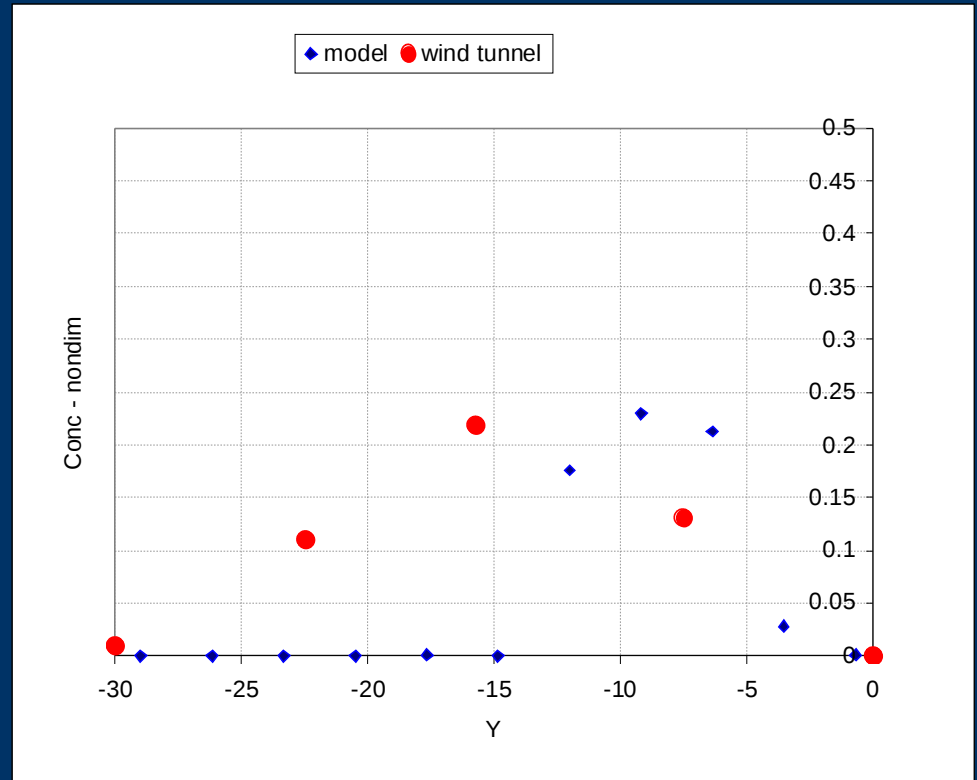
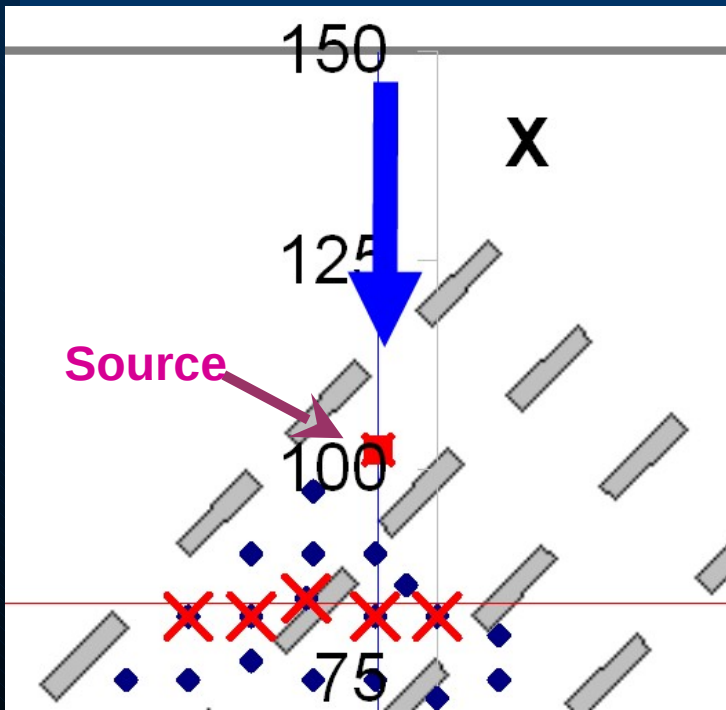




# Next example: Minus 45 degree dispersion case, Model D, 18 m

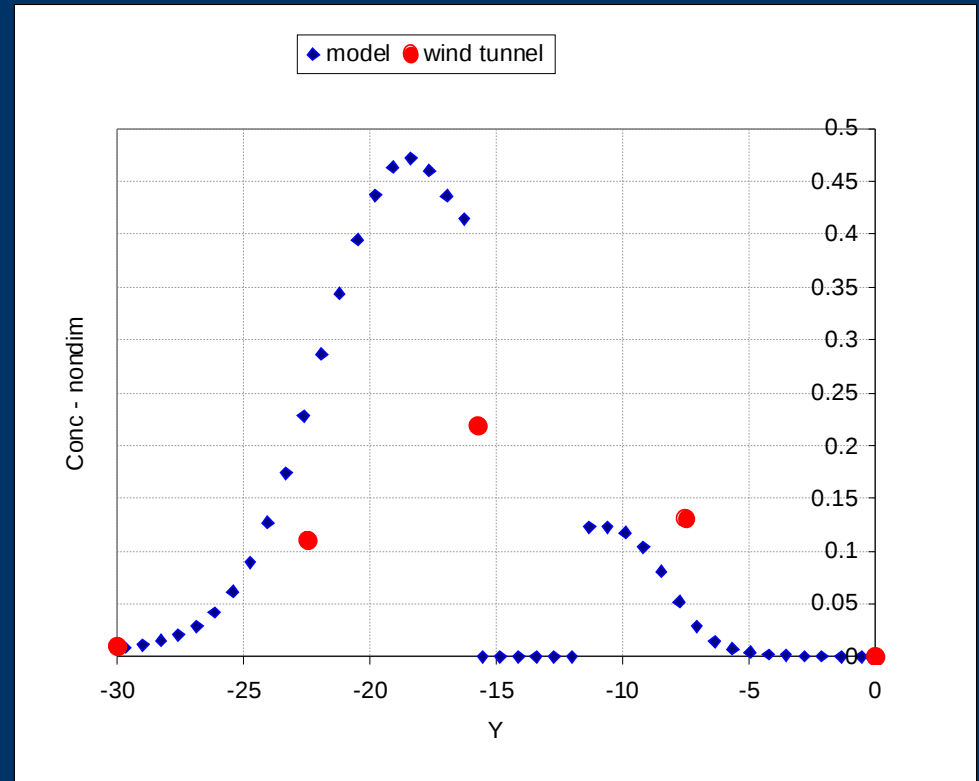
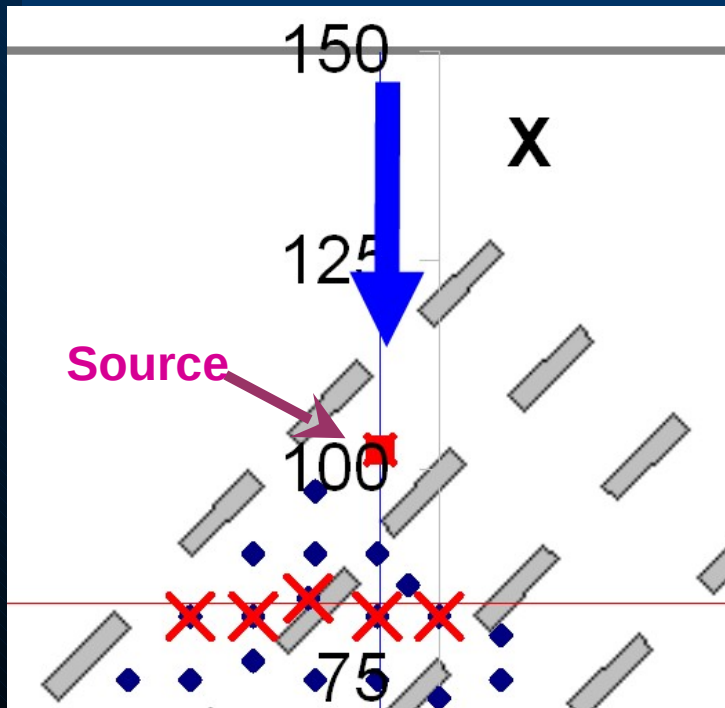


# Next example: Minus 45 degree dispersion case, Model E, 18 m



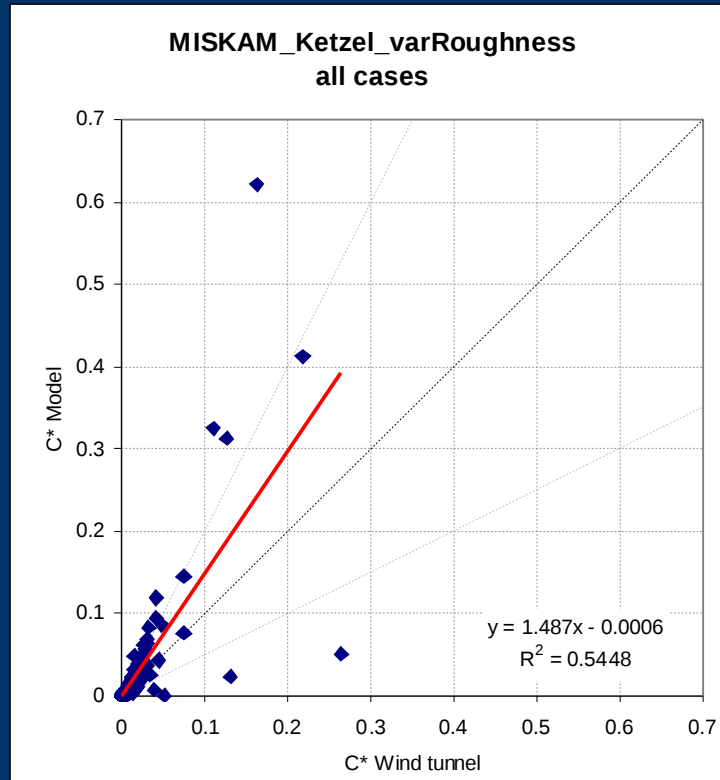


# Minus 45 degree dispersion case, Miskam Ketznel 18 m



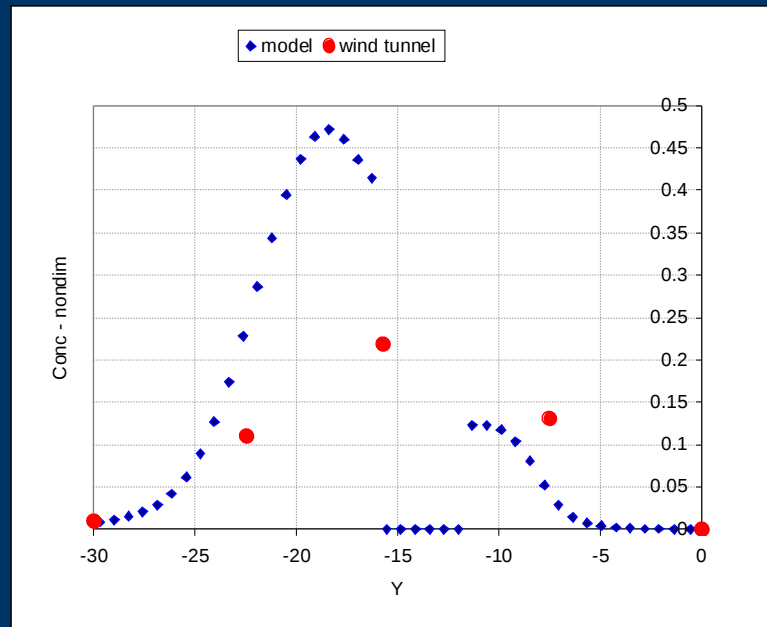
One option: Look at pairs of observations/model results

Hit rate: 0.74



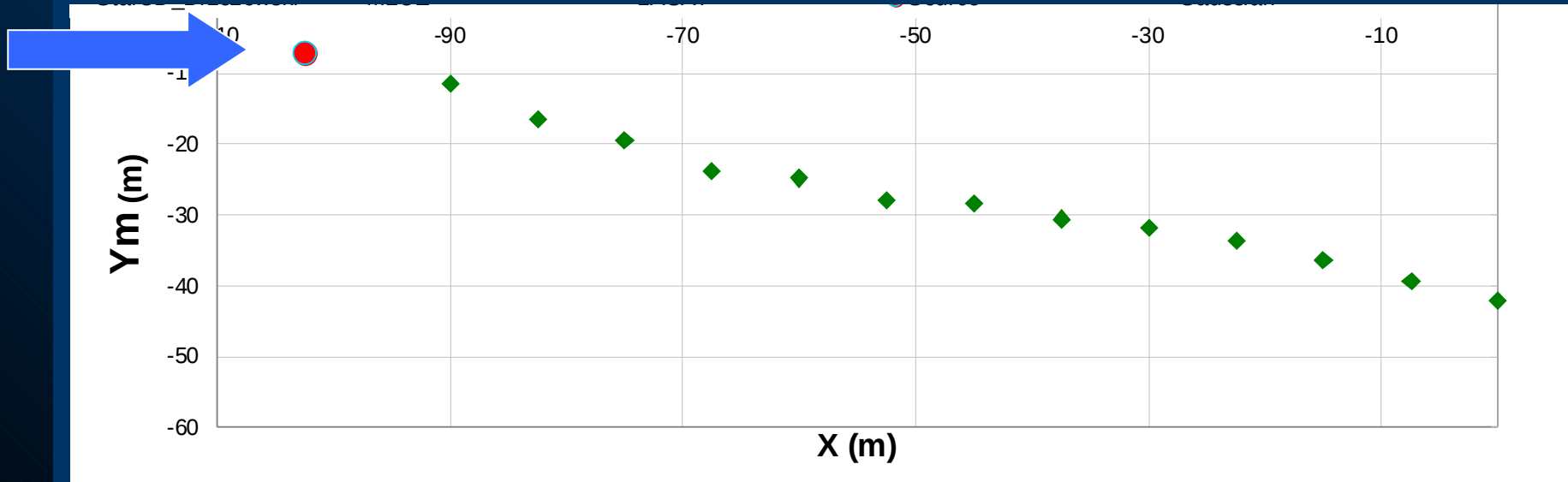
# Gaussian fitting

- The plume is so coherent that Gaussian fitting to measurements and model results makes sense.



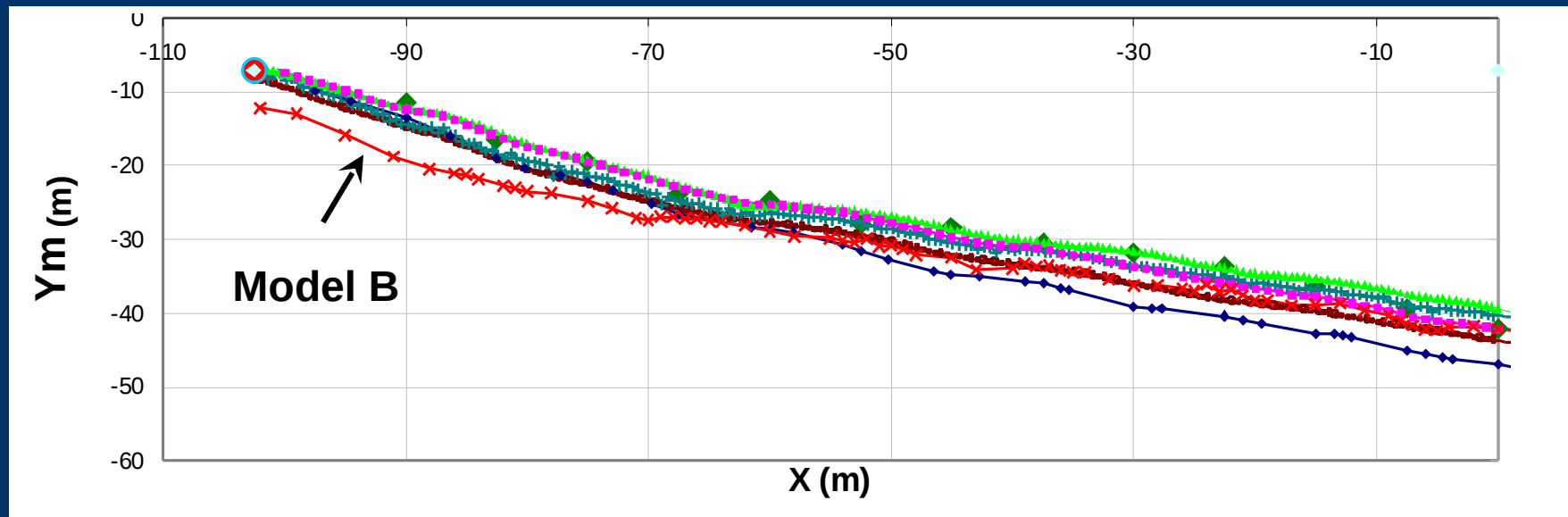
# Result of Gaussian fitting

## An x-y map



# Result of Gaussian fitting

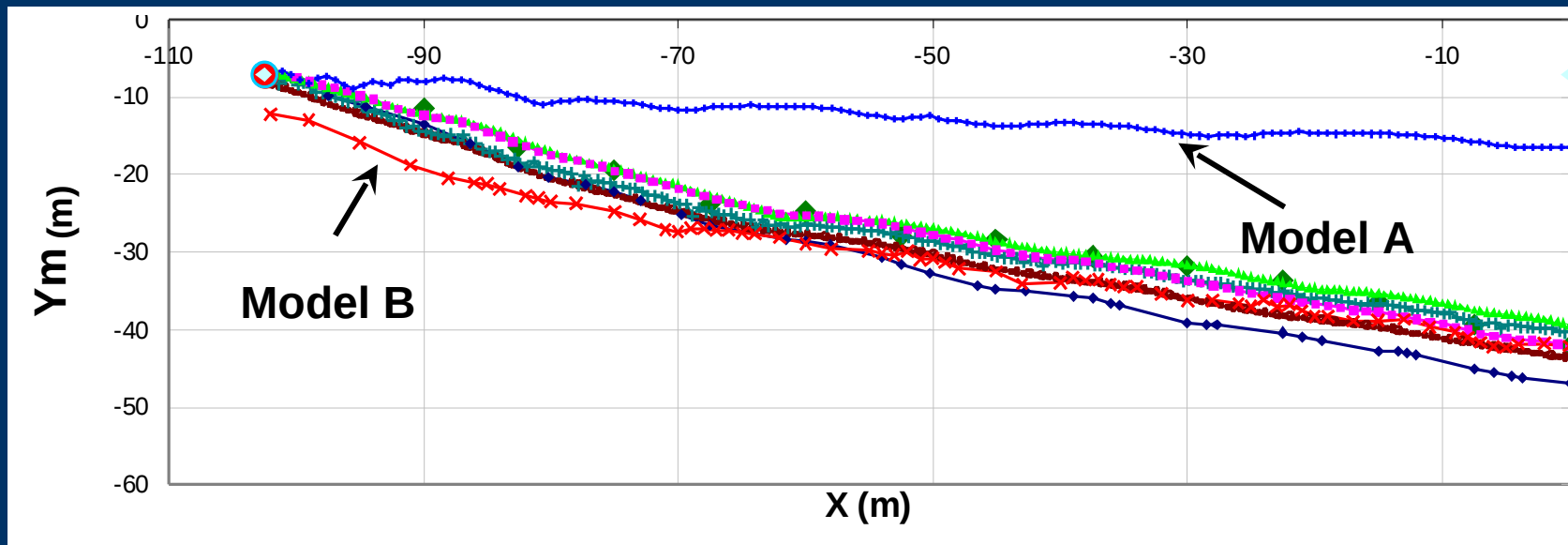
## An x-y map





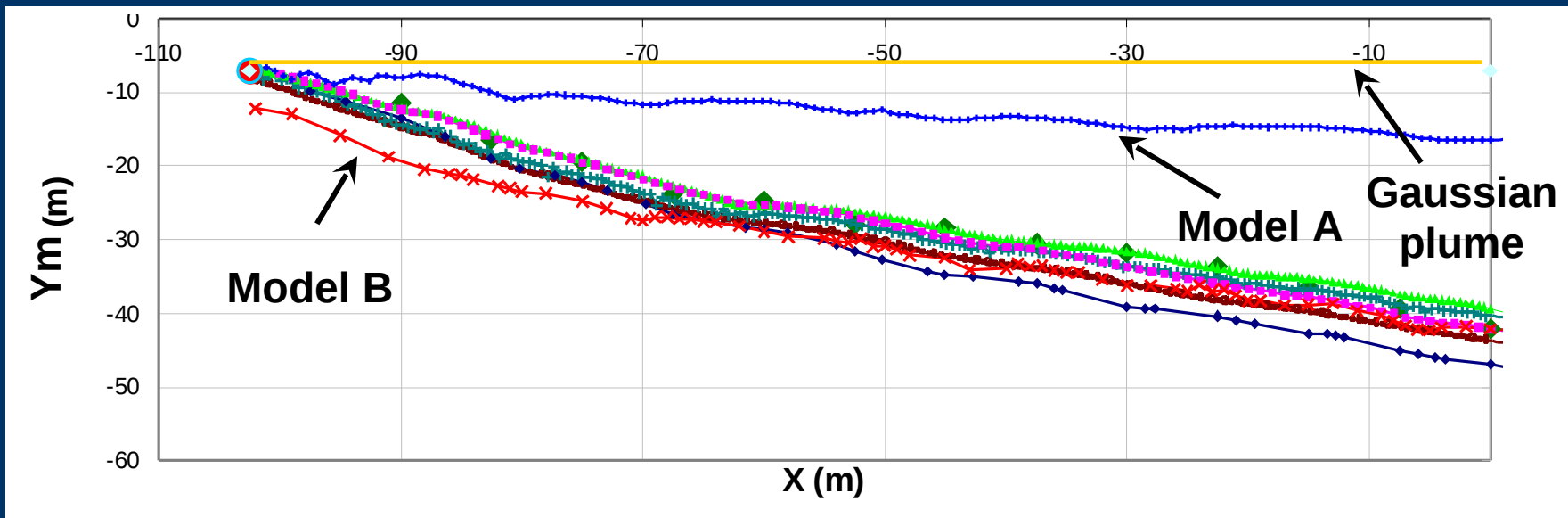
# Result of Gaussian fitting

## An x-y map



# Result of Gaussian fitting

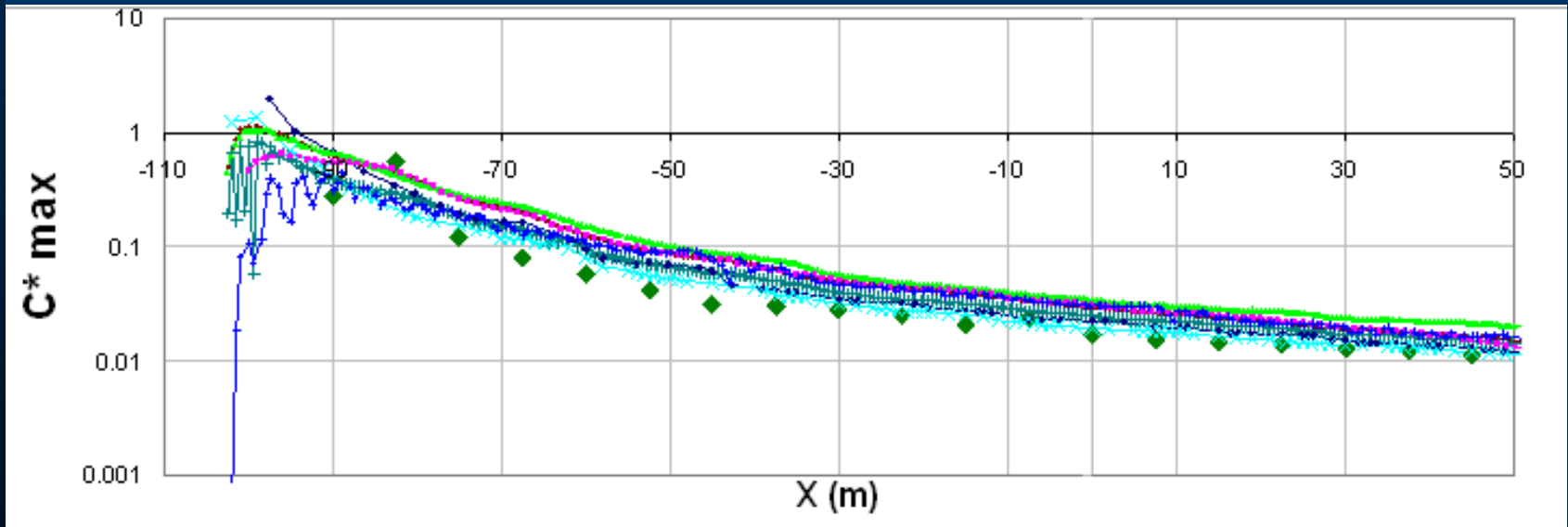
## An x-y map



**Model B has the highest Rit Rate of all models!**

- **Metrics alone do not assure quality!**

# Maximum concentration values, derived from Gaussian fitting



# Some conclusions about dispersion

- Models predict the plume trajectory well – with minor exceptions
- It is a common feature that models tend to overpredict the centerline concentration of the plume

# Some conclusions about flow

- **-45 degree flow case**
  - **u is predicted well in many locations, but 'Narrow streets' is too tough a challenge: u is underpredicted at low heights in 'Narrow streets'**
  - **Models have difficulty in reproducing w, in particular negative values of w**
  - **Models have difficulty in reproducing turbulent kinetic energy (TKE)**

# Availability of the tools and results

- A limited version of the Excel tools is available through the COST 732 web page.
- A full version will become available at that address
- Send a me mail if you wish to be notified when the full version goes public

# Main message

- **Exploratory data analysis is indispensable when you wish to assure quality!**