Real time modeling of water infrastructure using hydraulic models and data assimilation

Smart Sustainable Cities seminar
DTU Lyngby
6th of February 2017

By
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DTU Environment

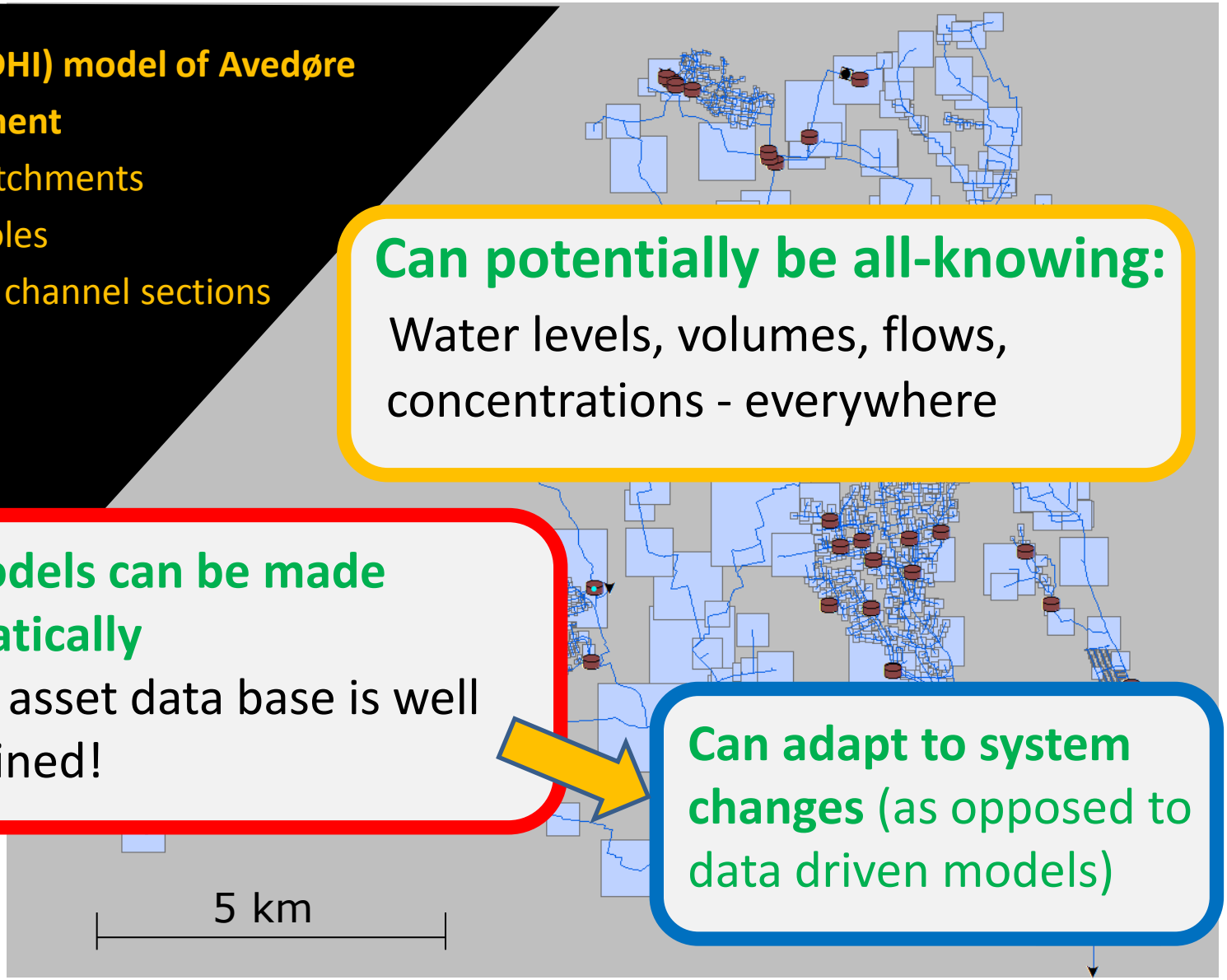
Contents

- Detailed urban hydrological models (HIFI models)
  - Why online HIFI models
- The Ensemble Kalman Filter (EnKF)
- Surrogates of HIFI models

Detailed urban hydrological models (HIFI models)

Mike Urban (DHI) model of Avedøre WWTP catchment

- 1707 sub-catchments
- 6601 Manholes
- 7749 Pipe & channel sections
- 40 Pumps
- 40 Basins
- Etc.



Can potentially be all-knowing:

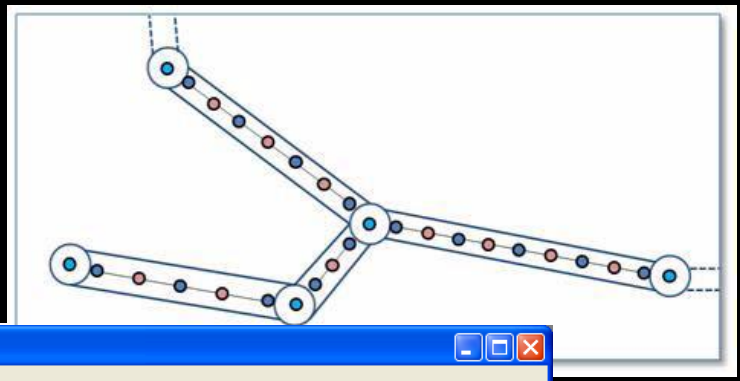
Water levels, volumes, flows, concentrations - everywhere

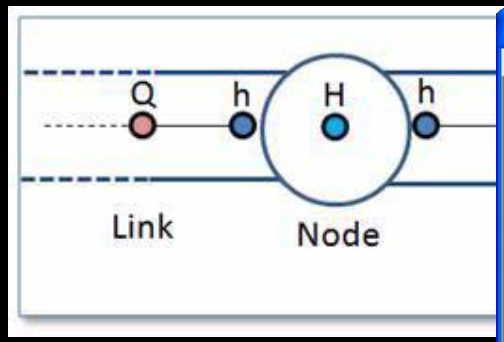
The models can be made automatically

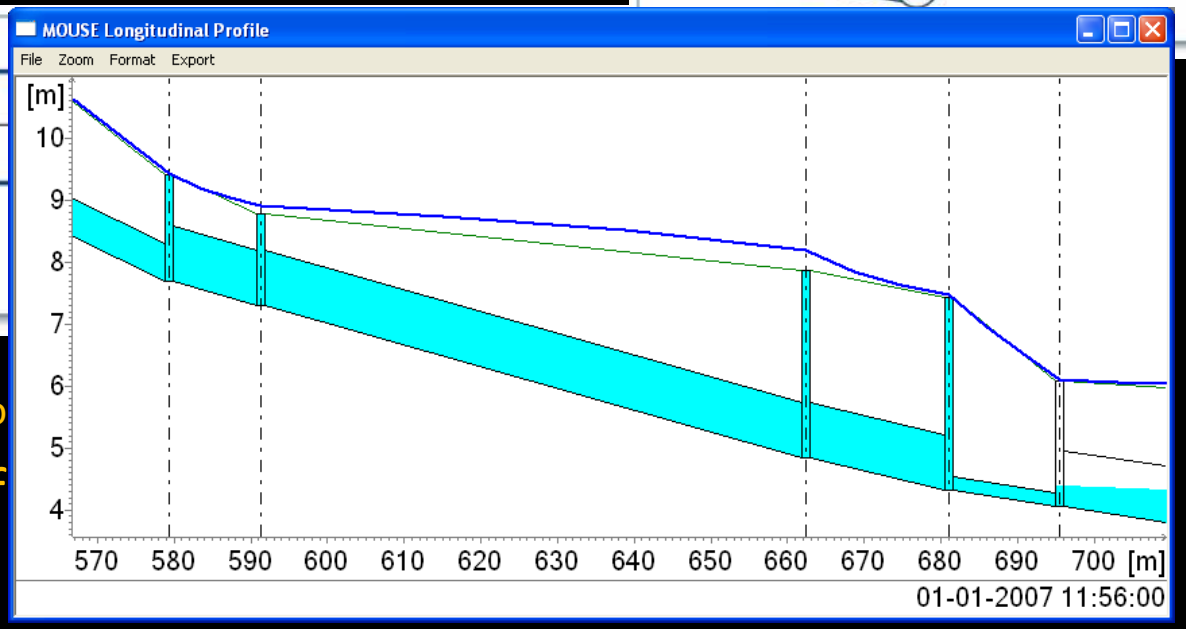
- If the asset data base is well maintained!

Can adapt to system changes (as opposed to data driven models)

Hydraulic computations







- Full 1D St. Venant equatio

Conservation of

Conservation of momentum:

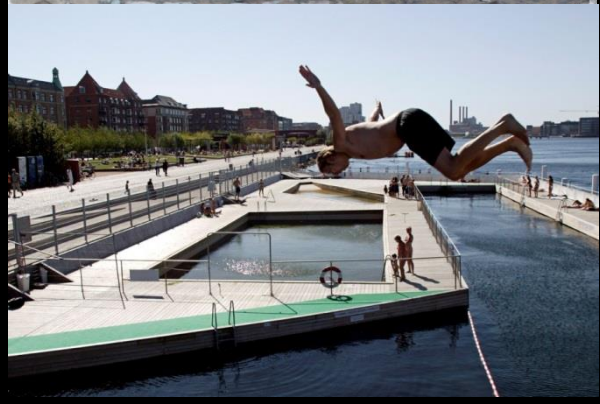
$$\frac{\partial Q}{\partial t} + \frac{\partial\left(\alpha \frac{Q^2}{A}\right)}{\partial x} + gA\frac{\partial y}{\partial x} + g\,AI_f = gAI_0$$

Potential of online HIFI model

- Warning system
- Real time control
- Online supervision of gauges
- Error detection

Not used because:

- **Computational** cost
- Very **uncertain rain** input
- Lack of **update** algorithm's



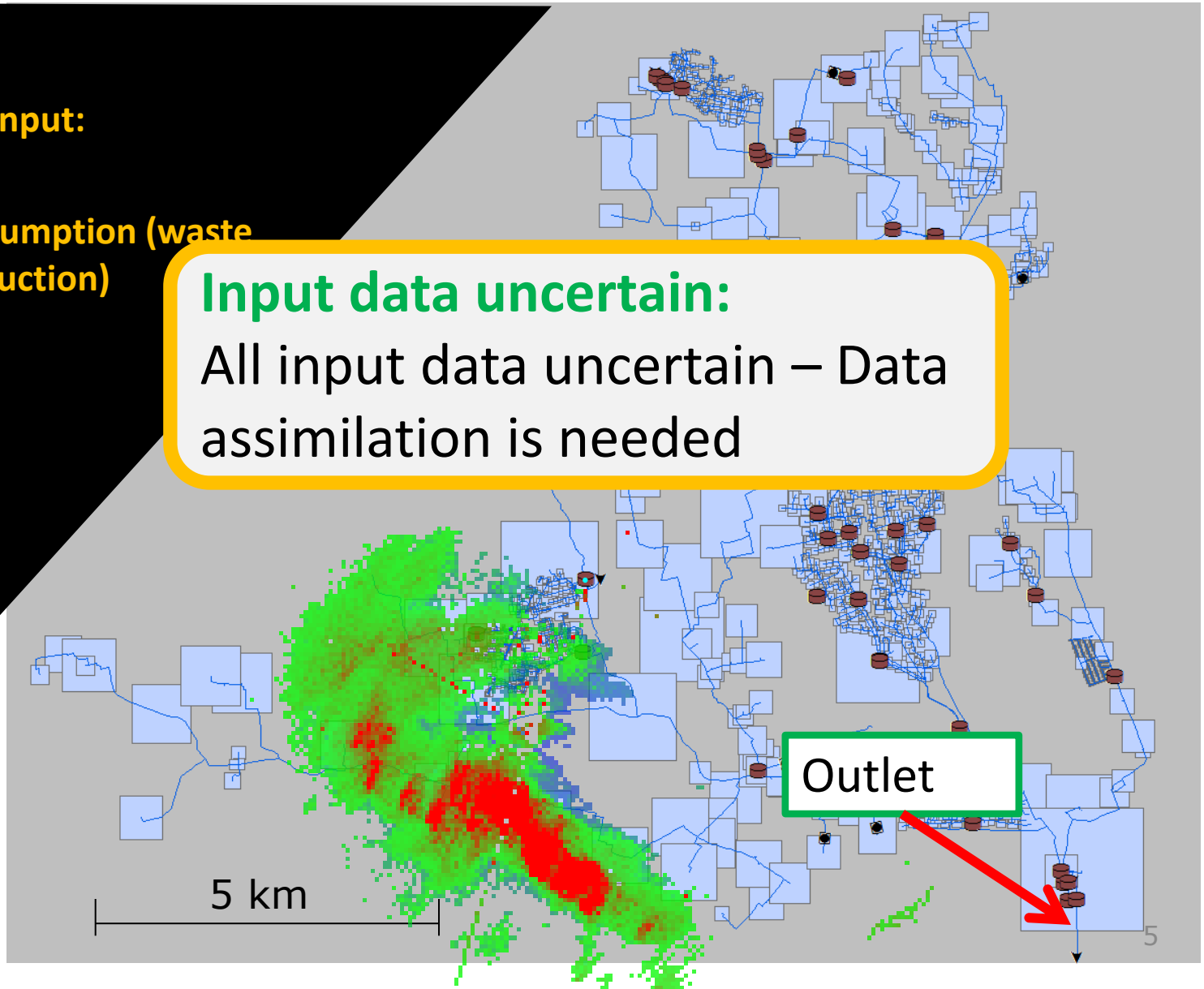
Detailed urban hydrological models (HIFI models)

Main model input:

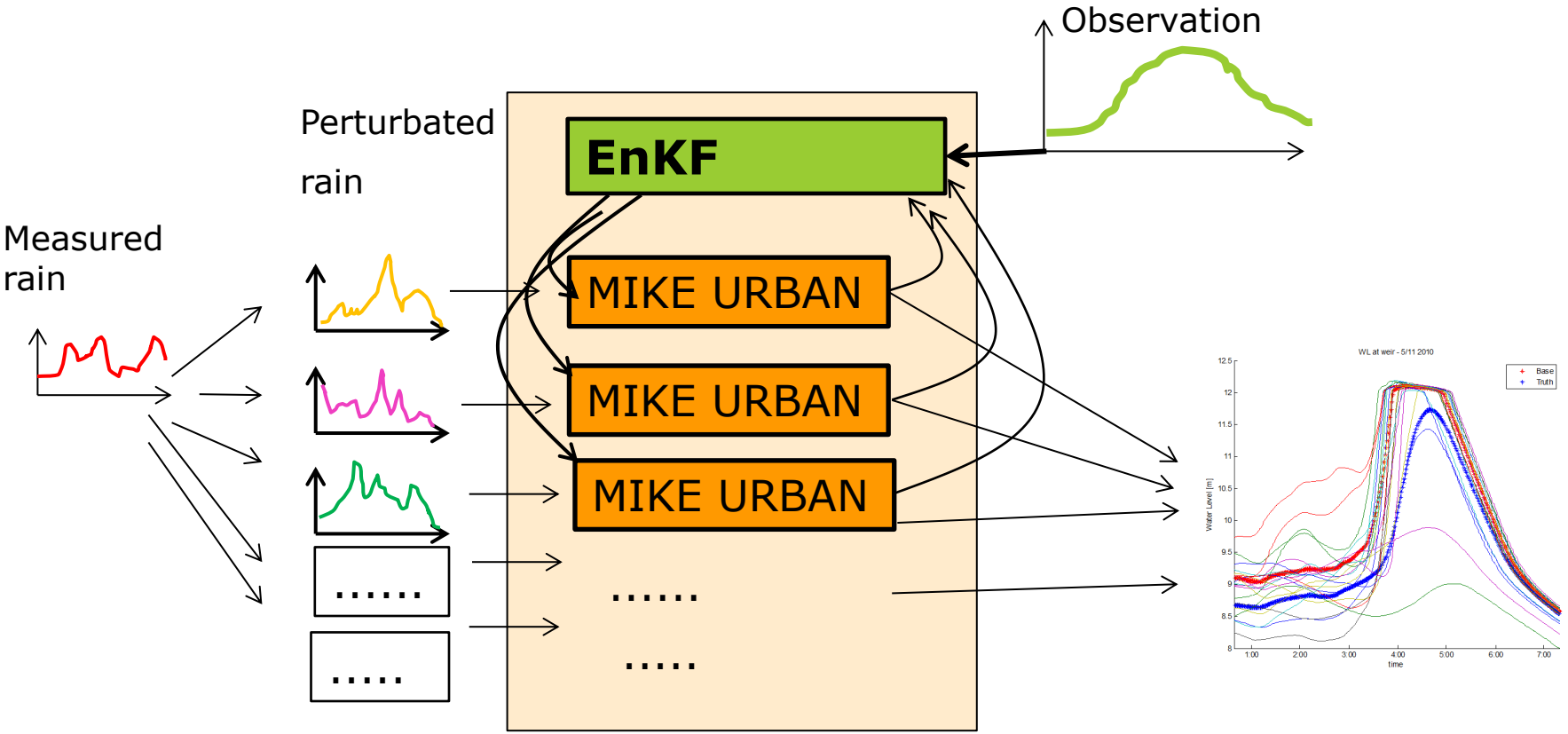
- **Rain data**
- **Water consumption (waste water production)**

Input data uncertain:

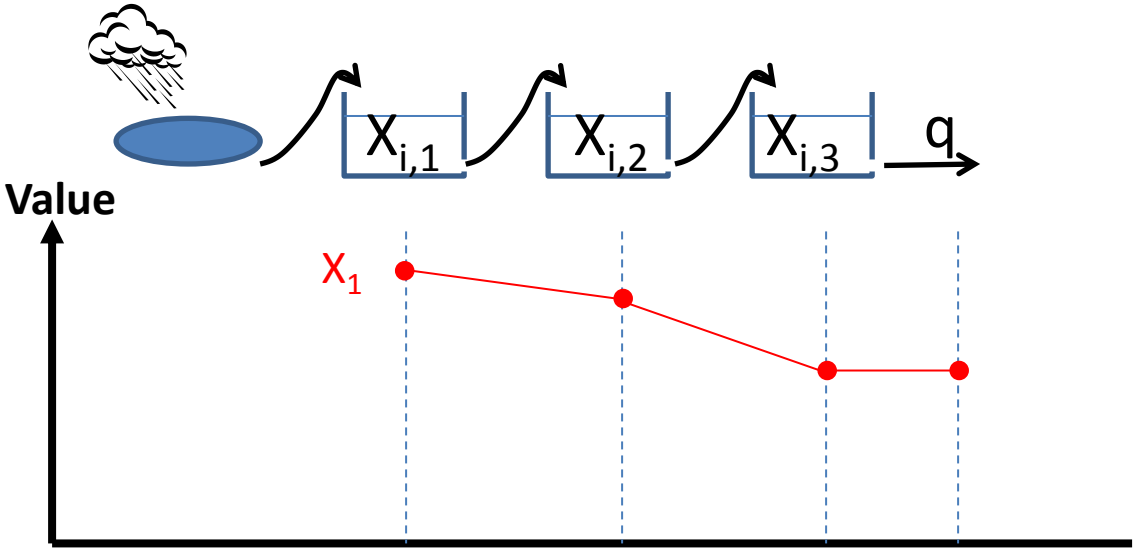
All input data uncertain – Data assimilation is needed



Ensemble based updating



Ensemble **K**alman **F**ilter



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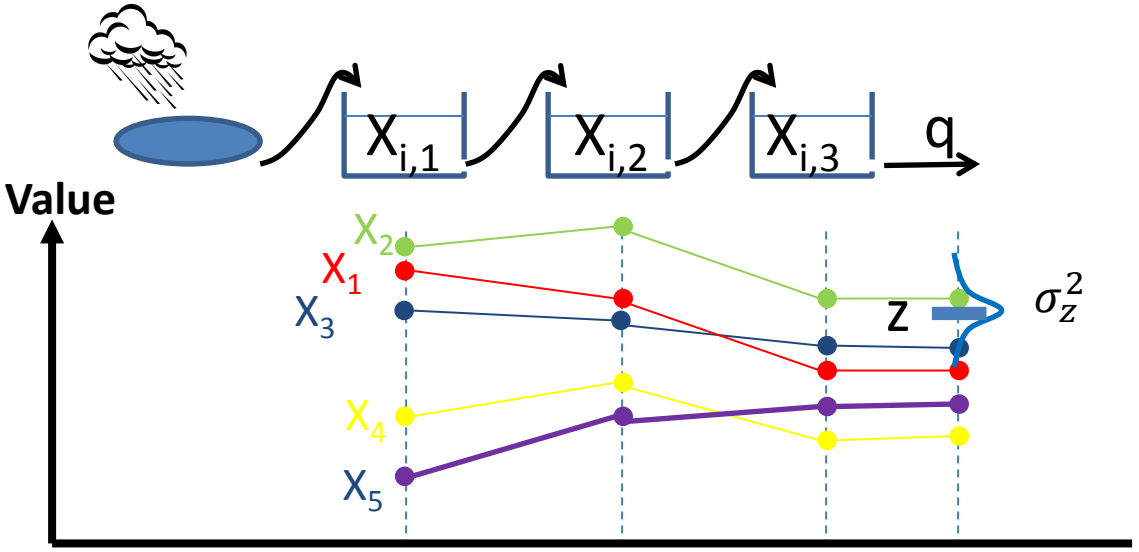

Ensemble of models used to represent state uncertainty (model error)

Estimate of the error covariance can be calculated directly from ensemble:

$$\sigma_{1,3} = \frac{1}{N-1}\sum_{i}^{N}(X_{i,1} - \overline{X_{,1}})(X_{i,3} - \overline{X_{,3}})$$

$$X_{1,3} = \widehat{X_{1,3}} + \frac{\sigma_{X_{1,3},q}}{\sigma_q^2 + \sigma_z^2}(z - q)$$

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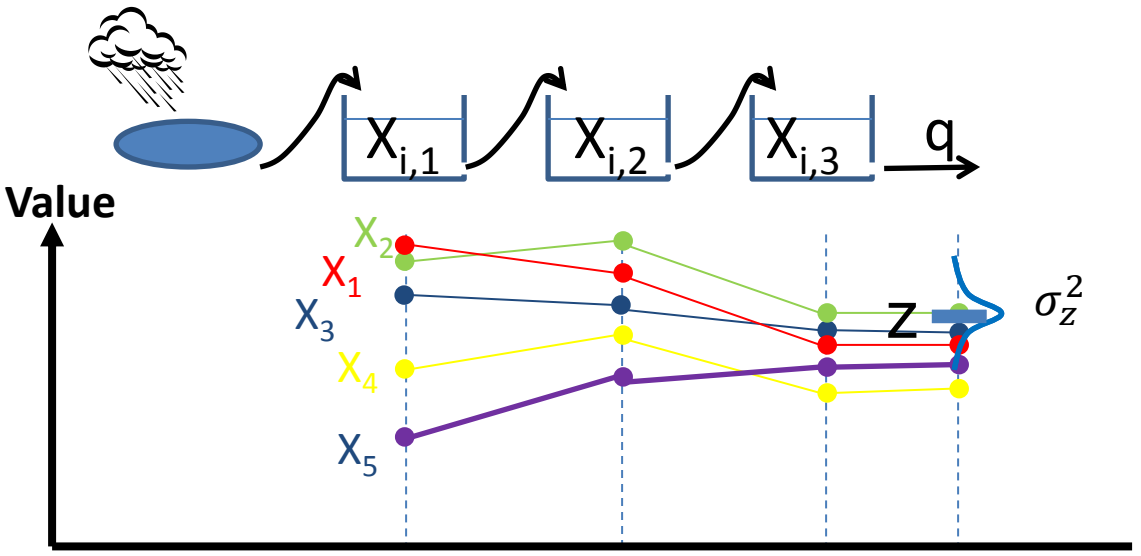

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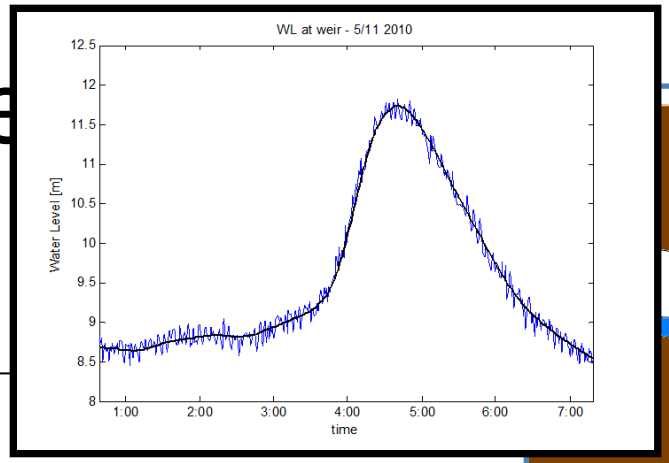
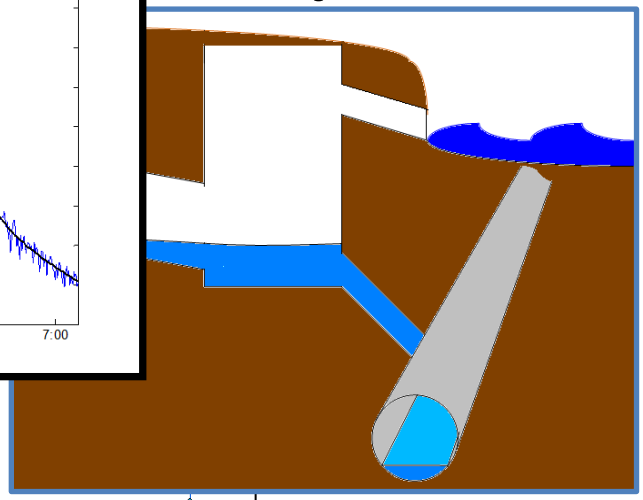
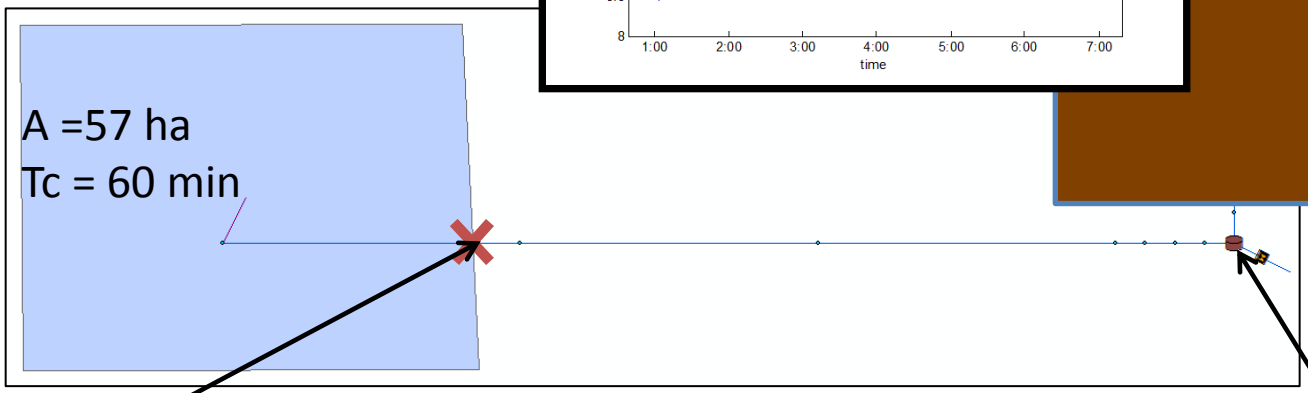
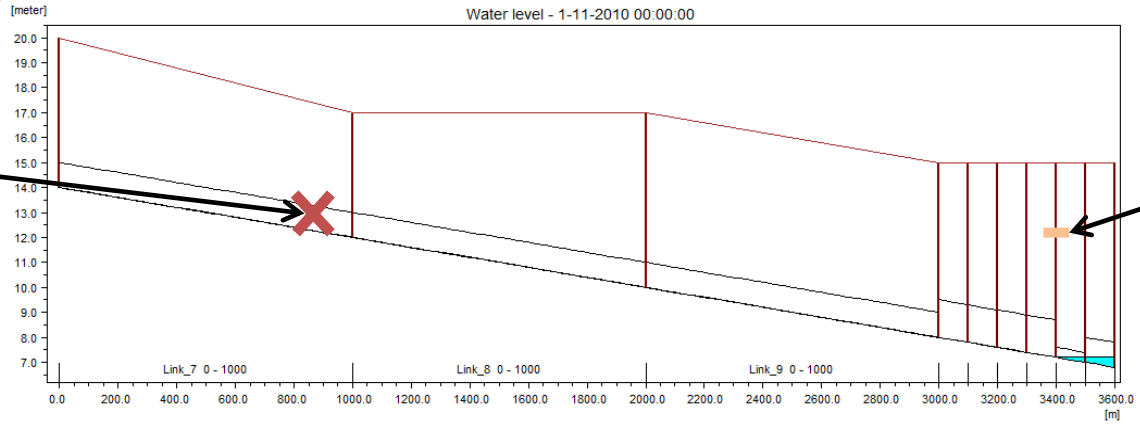








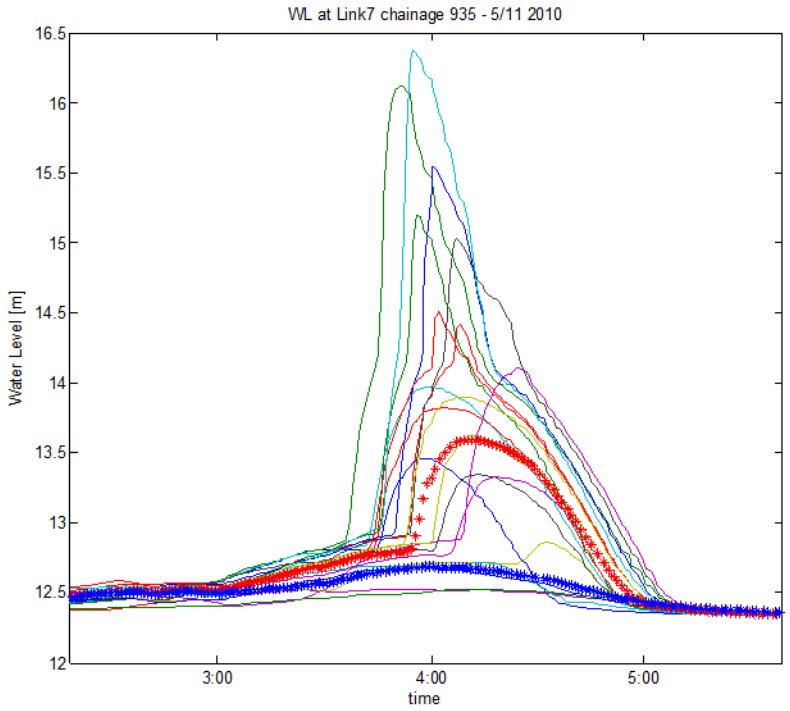
Point at Link 7

Weir

Situation without update

Ensemble of 20 – No update

Link 7



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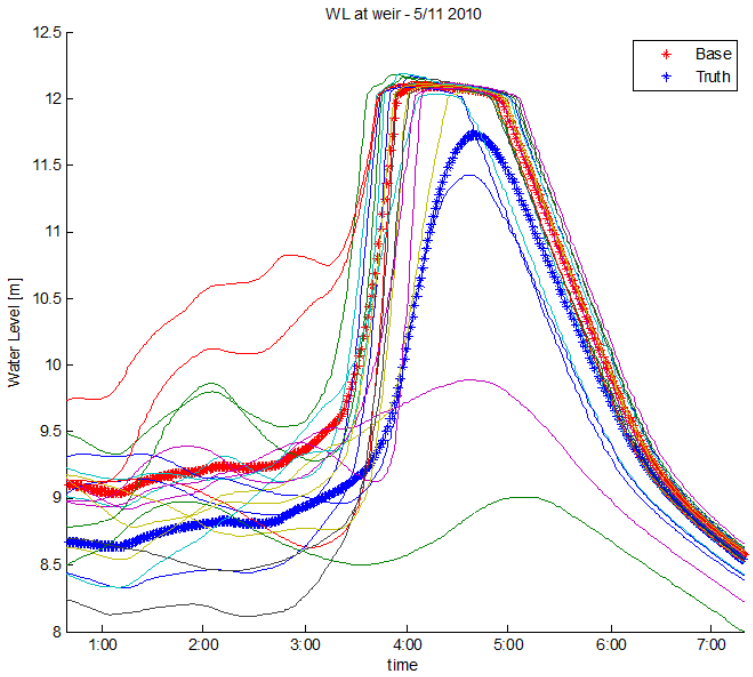
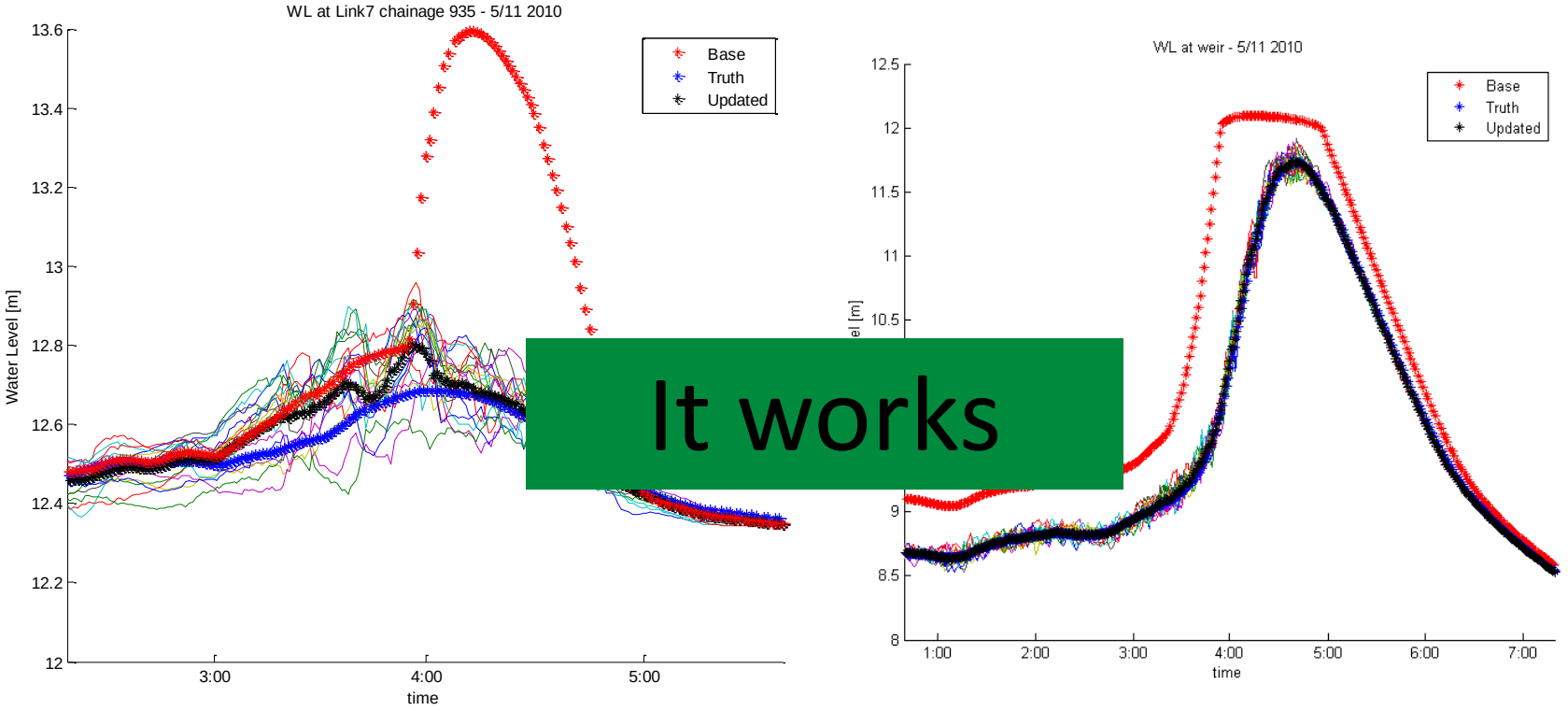


When updating using EnKF

Link 7

Weir



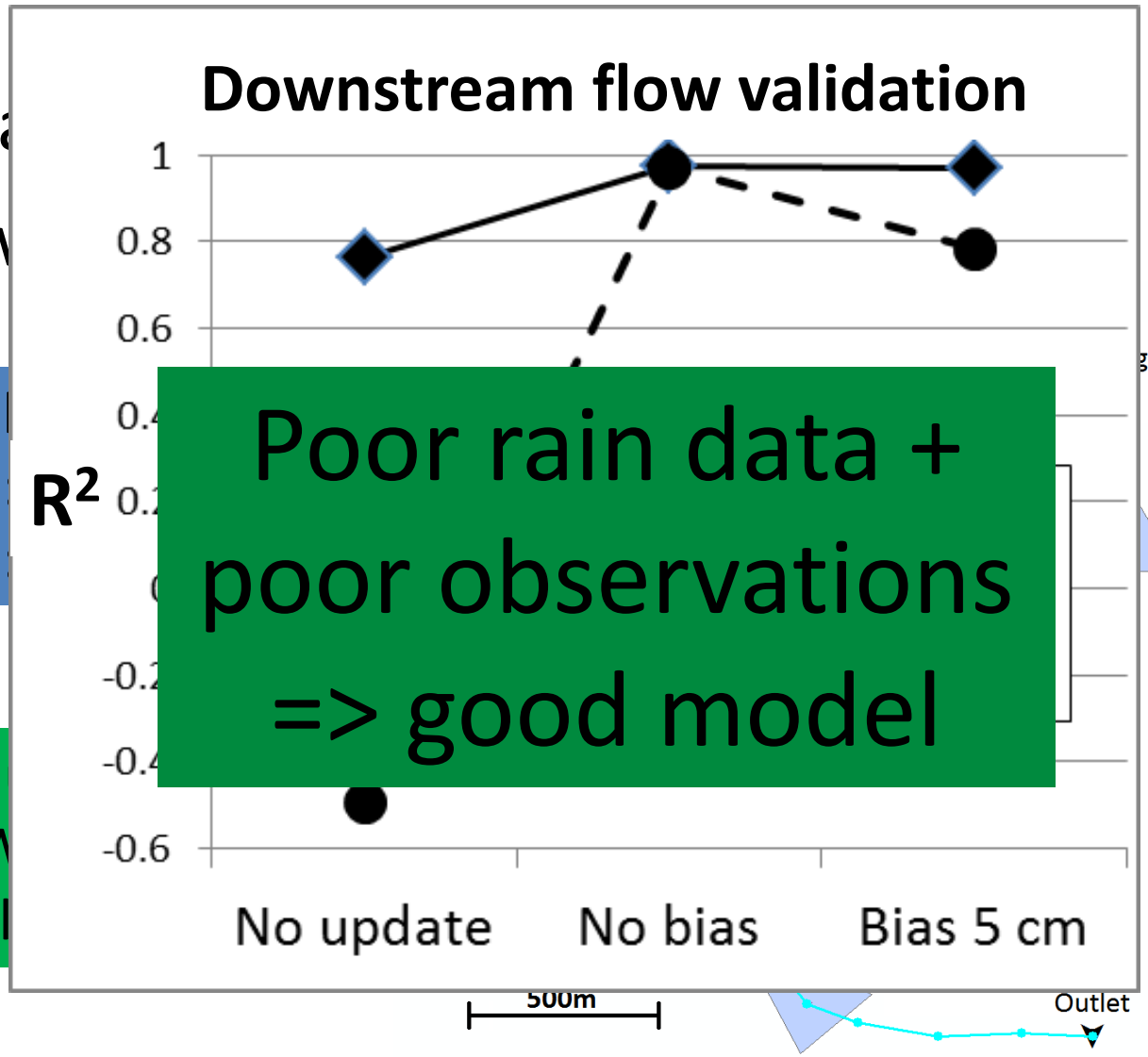
It works

Synthetic test on distributed system

- Upda
- Dow

Two rainfal
Scenario 1:
Scenario 2:

Two wl ga
No bias: W
Bias: + Col



Benefits in using EnKF for HIFI models

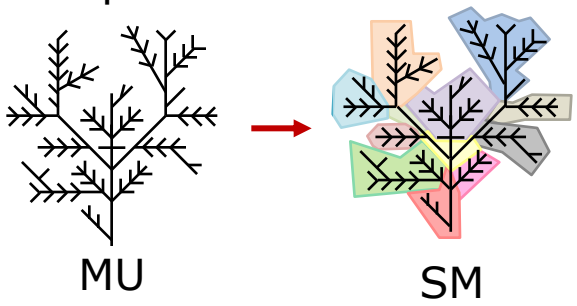
- Robust
- Flexible
- Good uncertainty estimates
- Can utilize ensemble input
- Can utilize most kinds of observations

Drawbacks:

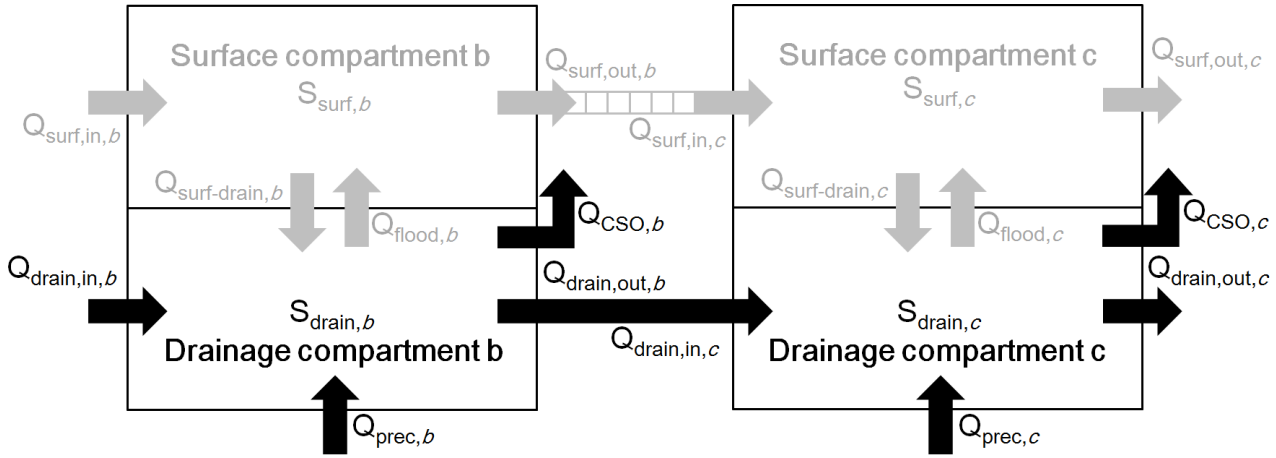
- computational cost

Making Surrogates of HIFI models

- Division of system into compartments:



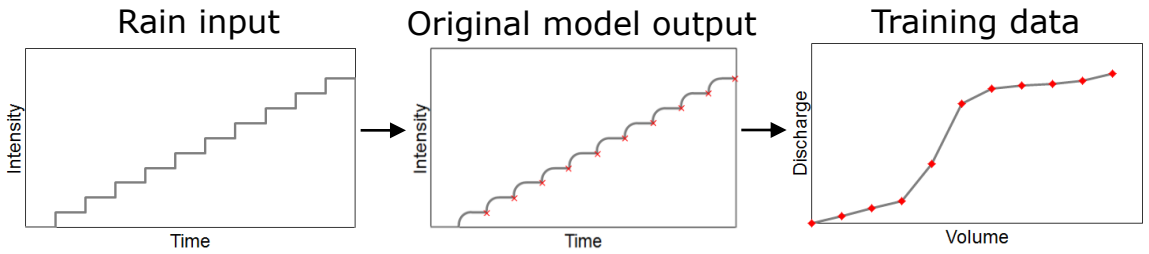
- Model volume of water with mass balance:

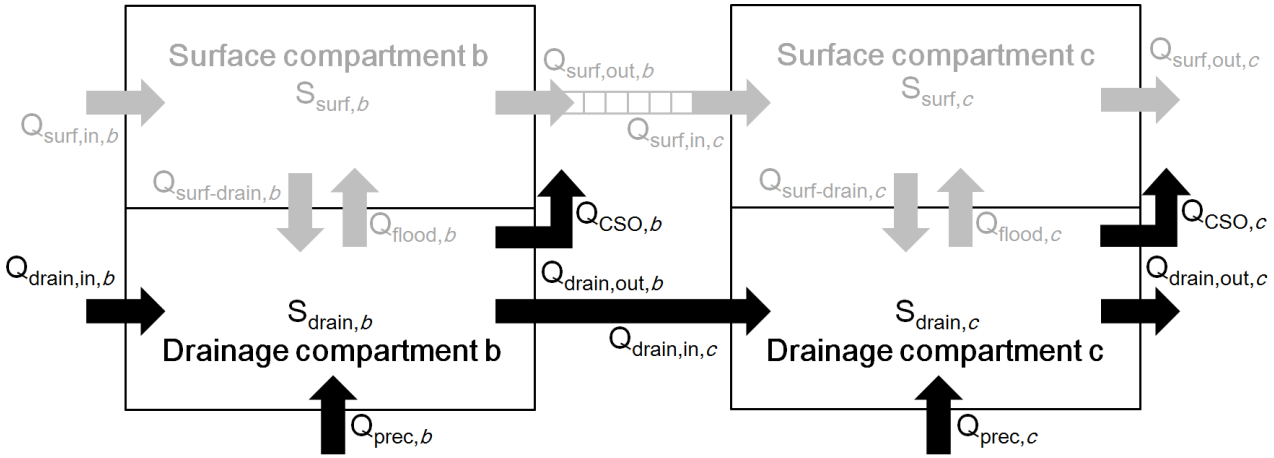


Slides by Cecilie Thrysøe

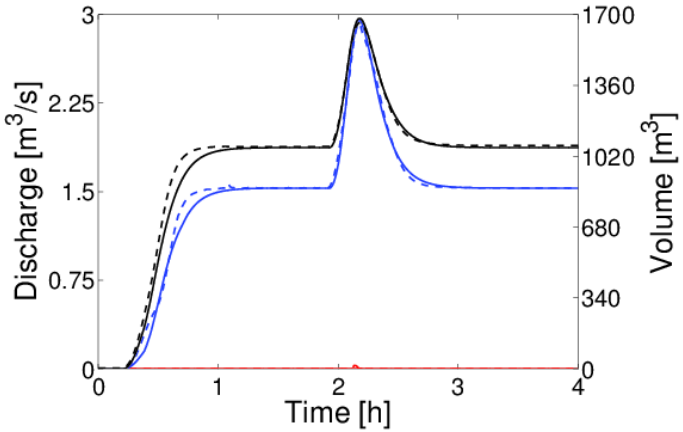
Training data for SM

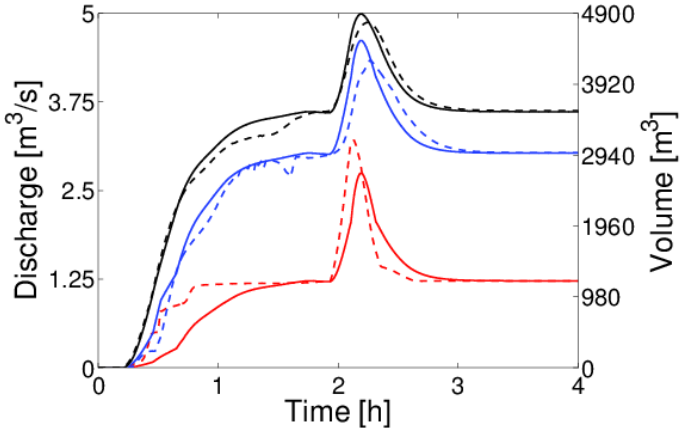
- Vol-Q relationships are extracted from steady state values

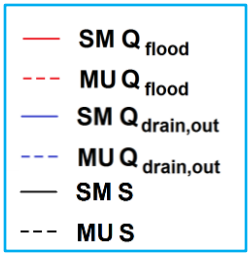


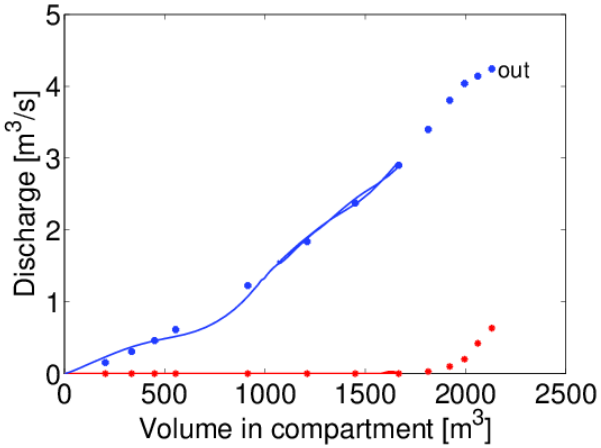


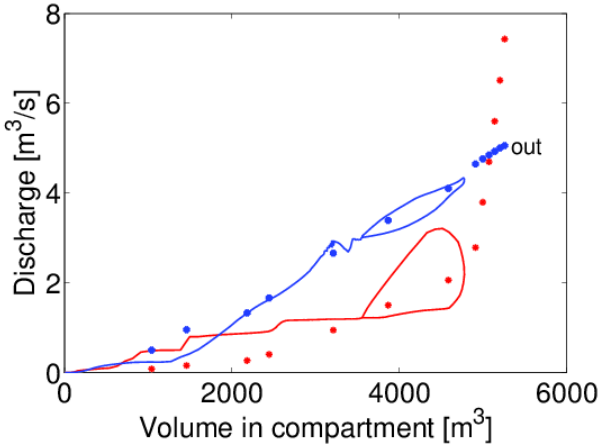
- # Drainage system results

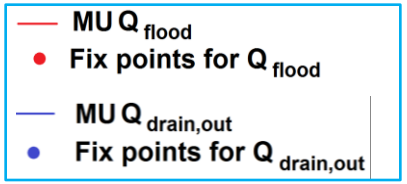






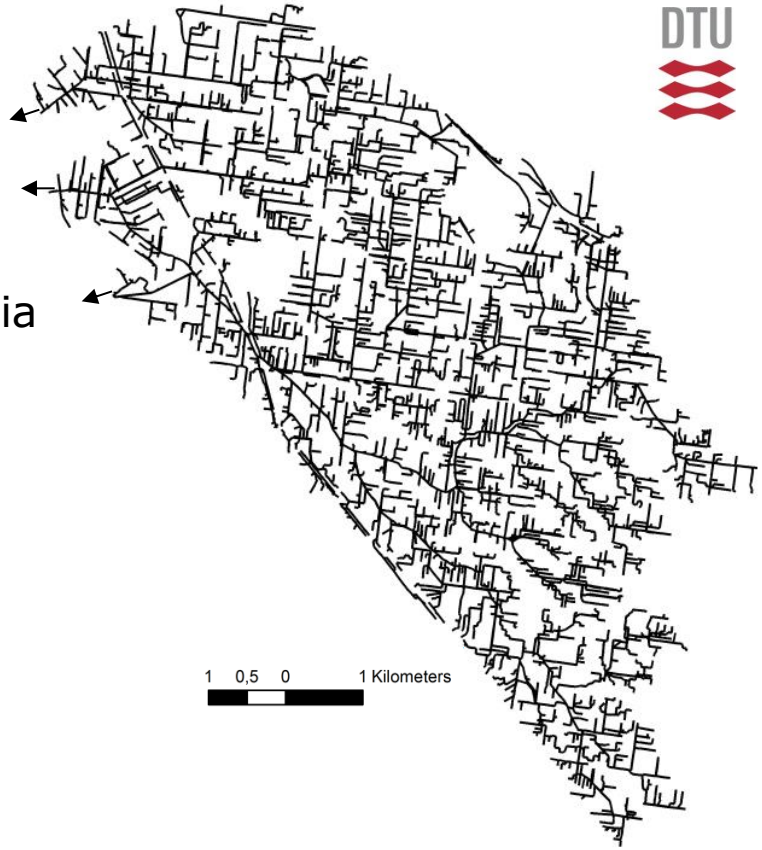






Preliminary results

- Elster Creek catchment, Melbourne, Australia



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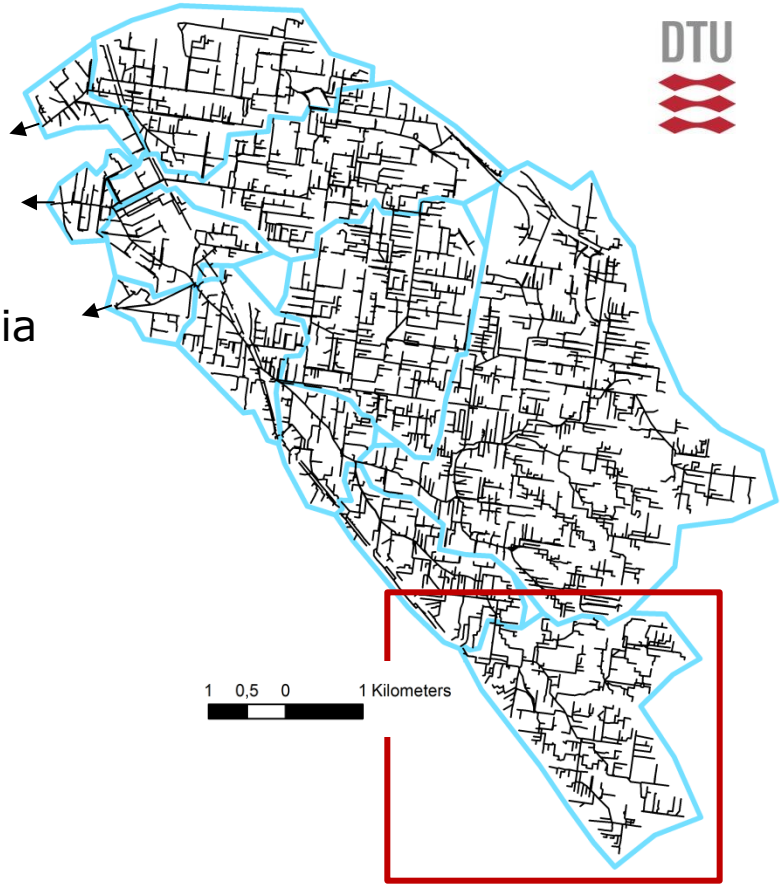

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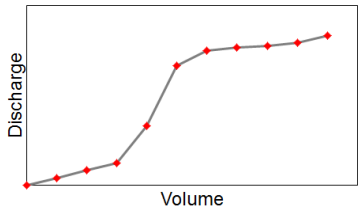
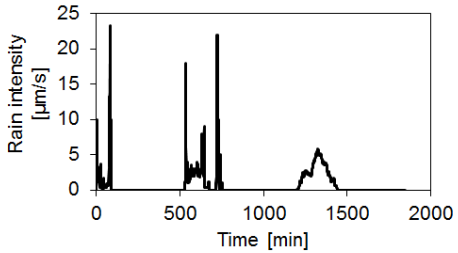
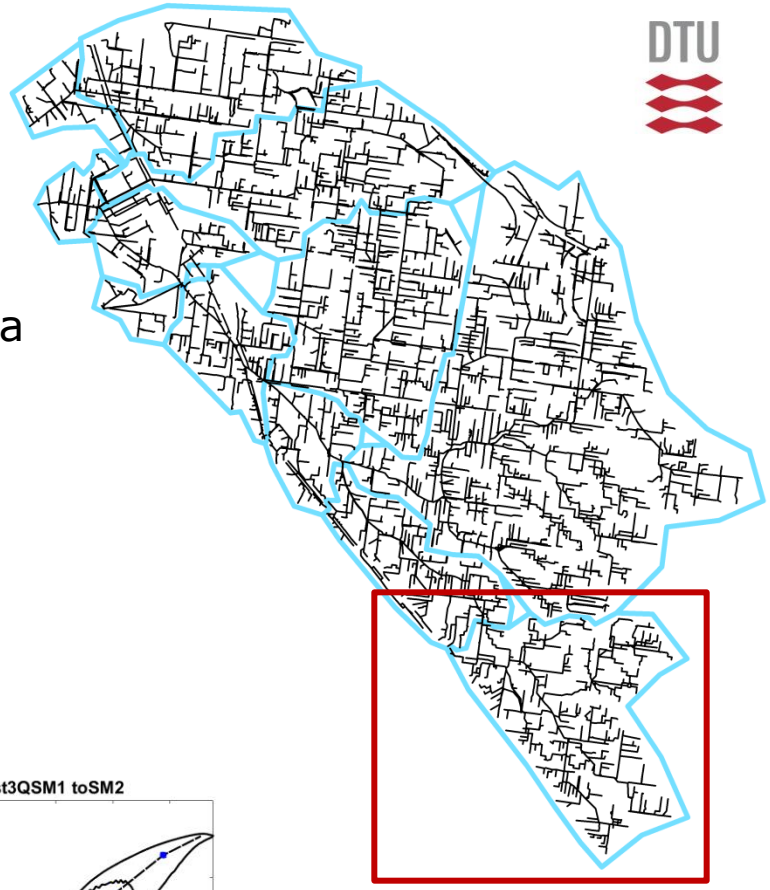
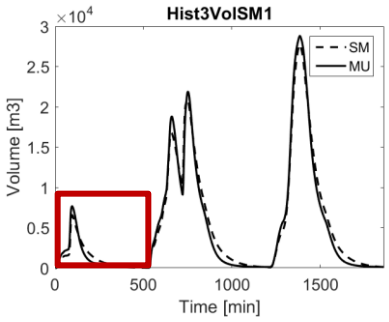
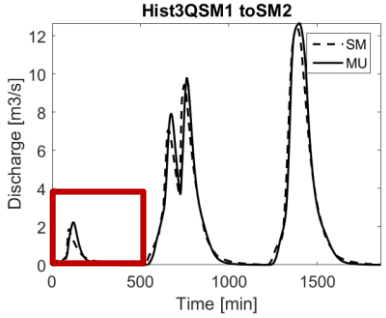


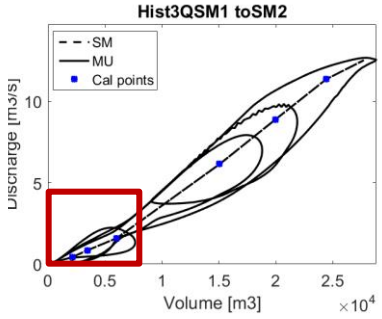




- SM output







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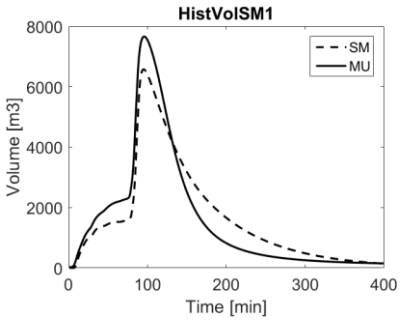

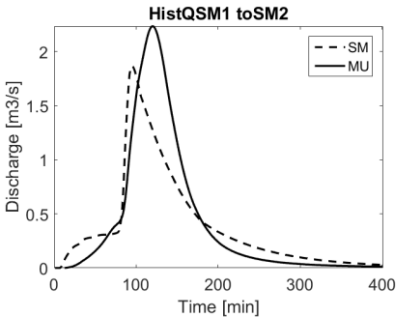

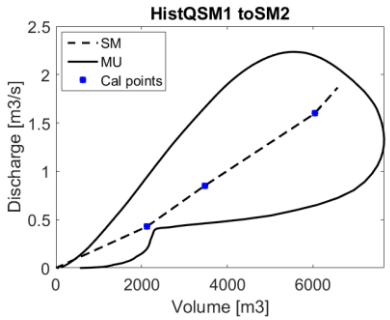

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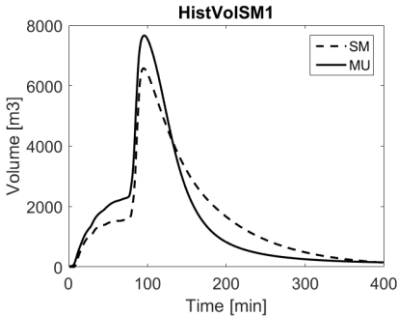
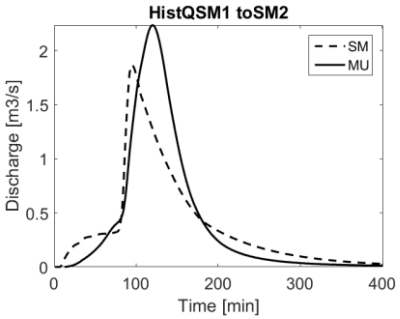
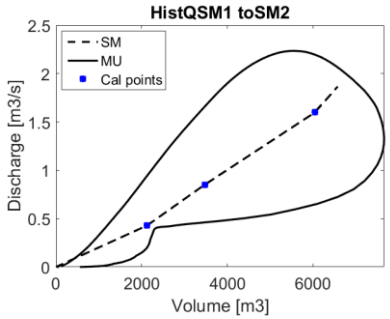
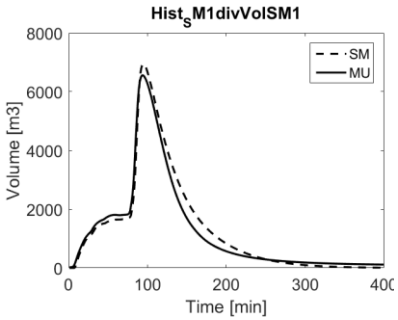
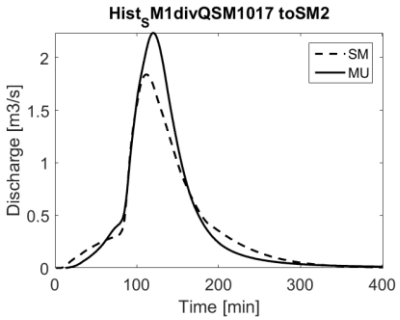


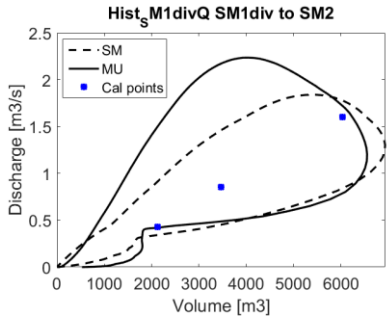




- Splitting compartment







Conclusions

- EnKF can be used to make online models with HIFI models
- Surrogate models can be made for HIFI models to achieve large reduction in computational costs.

Questions?