Danish experiences with short term forecasting in urban drainage applications

RainGain workshop on
fine-scale rainfall nowcasting
31 March 2014, Antwerp

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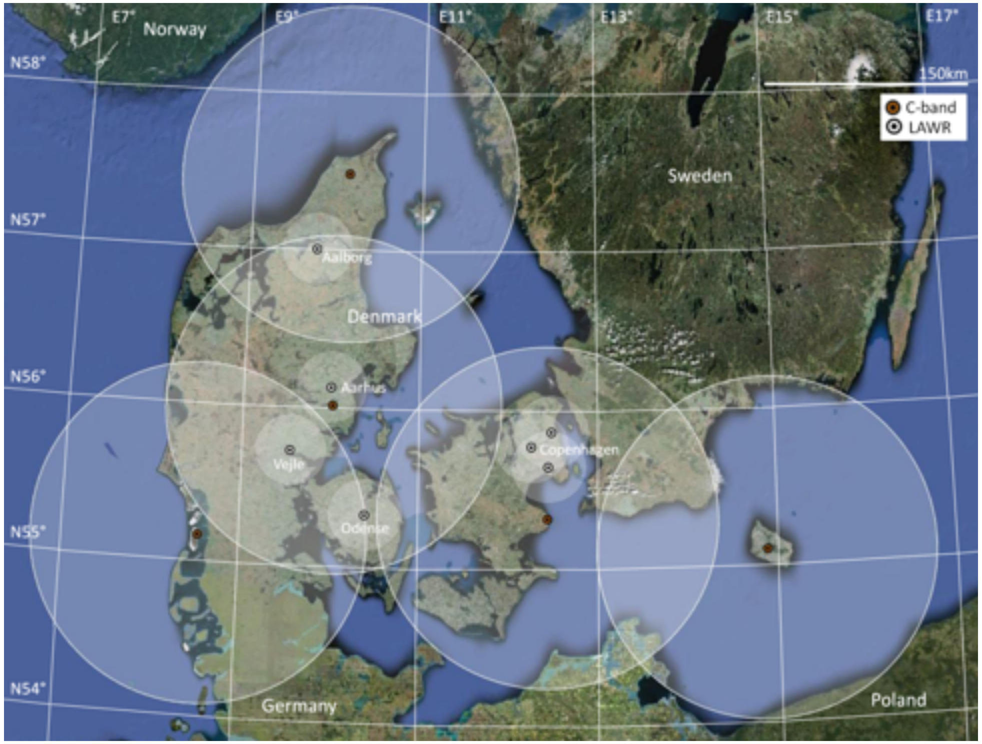
Aalborg University
Denmark

Weather radars in Denmark

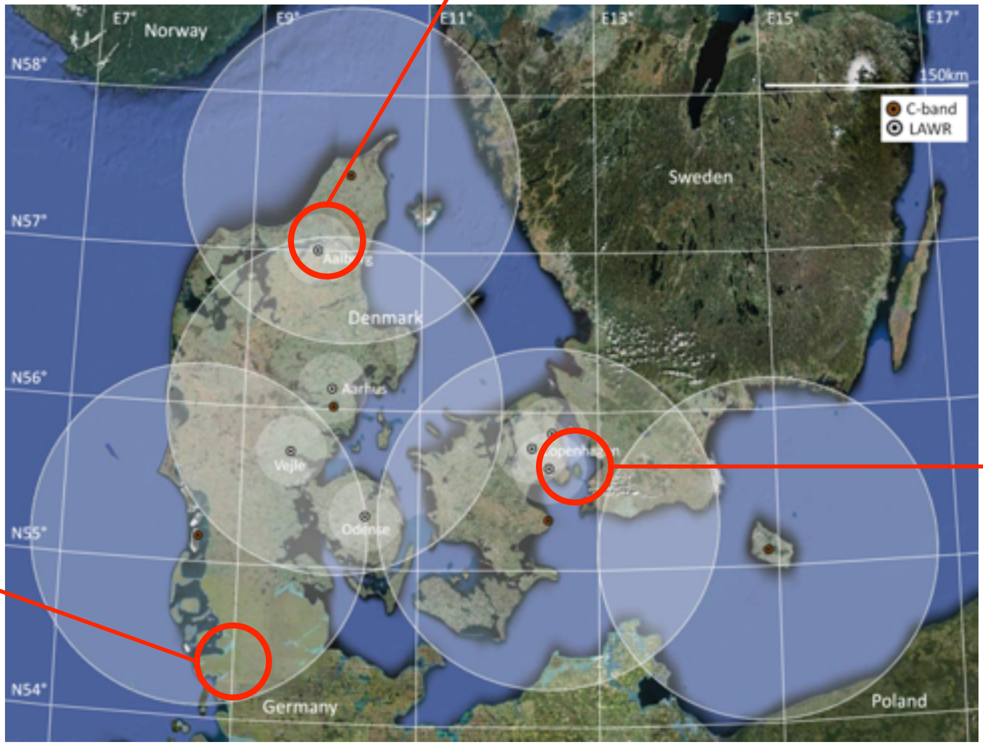


Cases: Real time applications in 2014

Aalborg
- Real time modelling of in-flow to WWTP.
- Nowcast Sindal Radar.
- Purpose: RTC of ATS

KRÜGER VEOLIA WATER Solutions & Technologies

BREAKING NEW GROUND AALBORG UNIVERSITY



Copenhagen
- Real time modelling of in-flow to Lynetten WWTP.
- Nowcast Stevns Radar.
- Purpose: RTC of ATS

Tønder
- Real time modelling of in-flow to Tønder WWTP.
- Nowcast Rømø Radar.
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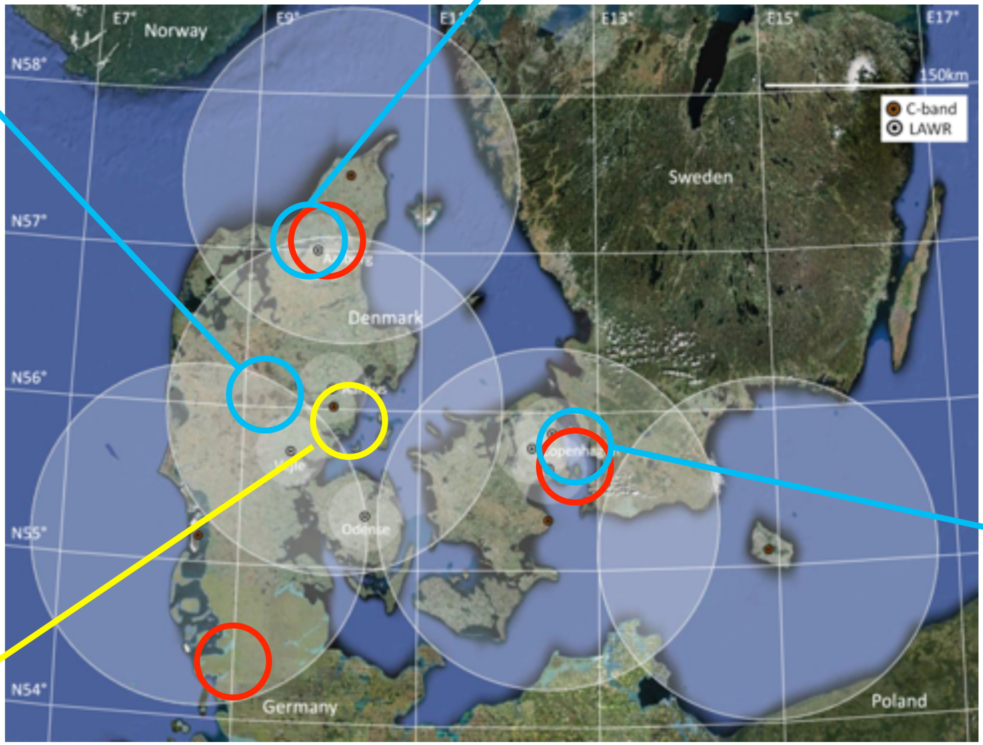
Cases: Non real time applications

Frejlev (test catchment)
- Modelling of distributed urban runoff.
- Radar Nowcast and NWP.

Silkeborg
- Ground water modelling
- Road construction
- Ensample Radar Nowcast, NWP, and assimilation



Copenhagen (Lynetten WWTP and other catchments)
- Radar Nowcast and NWP
- Grey box modelling of urban runoff.

Virring (Radar test site)
- X-band (LAWR)
- C-band (DMI)
- Disdrometers
- Rain gauges

Comparison Of Short Term Rainfall Forecasts For Model Based Flow Prediction In Urban Drainage Systems

Objectives

- To investigate potentials for model based flow (and water level) forecasting in key points of drainage systems comparing different rainfall inputs:
  - Rain gauge observations
  - Weather radar observations
  - Weather radar nowcasts
  - Numerical Weather Prediction models (NWP)
- How does these inputs perform in forecasting inflow to a Waste Water Treatment Plant?

The Lynetten WWTP catchment

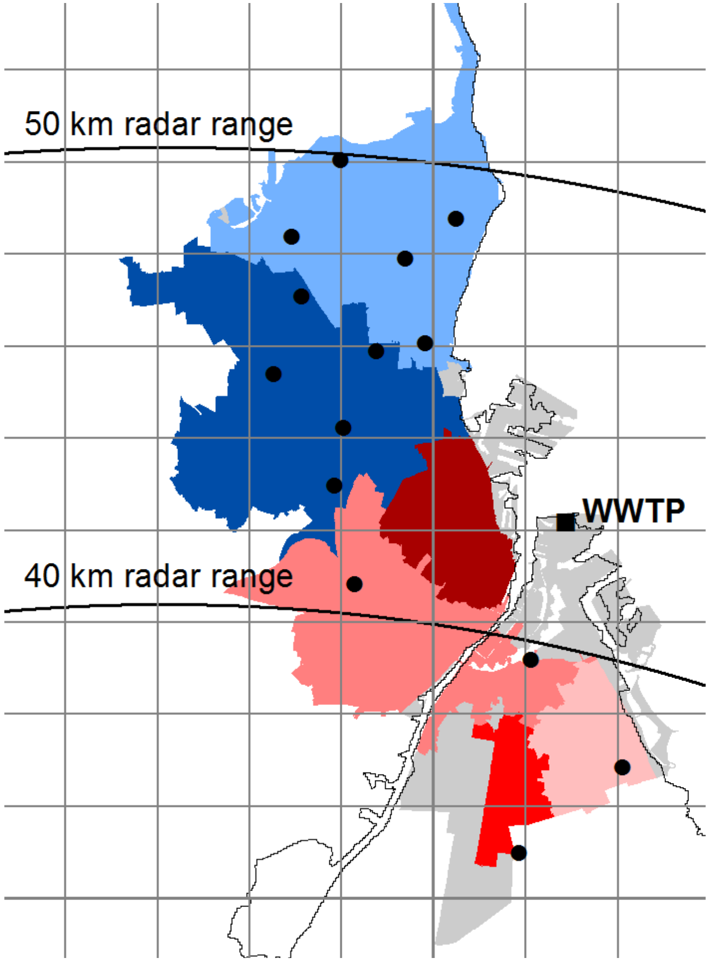
- Area: 77 km^2
- 30 % impervious area
- 87 % combined and 13 % separate sewer systems
- 500.000 inhabitants

- Key point: Inlet flow to the WWTP

- Wet weather operation (ATS operation) is implemented when the inlet flow exceeds 4.7 m^3/s

- The maximal inlet flow to the WWTP is 12 m^3/s

- **It is expected that forecast of the inflow to the WWTP will improve treatment during rain.**

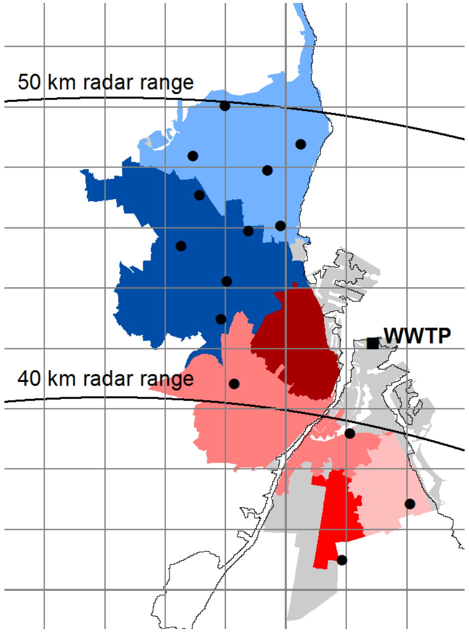


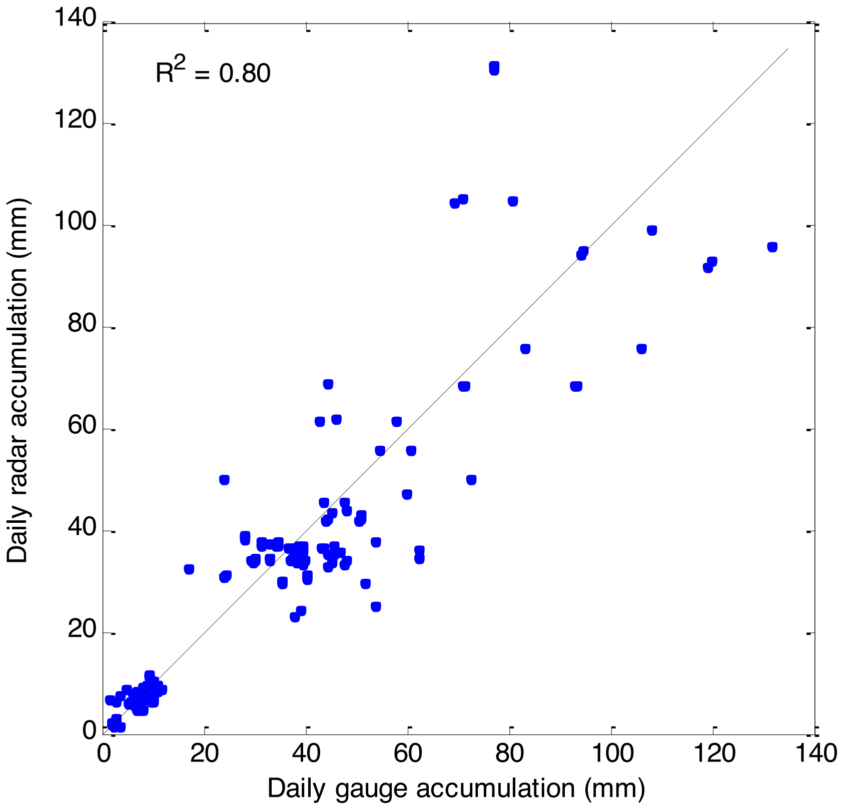
Radar data

- One single C-band radar located at Stevns approx. 50 km south of Copenhagen
- Range 0-240 km
- Quantitative range 0-75 km
- Spatial resolution 2 x 2 km^2 (CAPPI)
- Temporal resolution: 10 min
- QPE from Marshall and Palmer Z-R relationship with standard parameters (A=200 and B=1.6)

Radar data

- Radar data is mean field bias adjusted on daily rain gauge accumulations
- 14 rain gauges are located within the catchment





Radar nowcast (AAUforecast)

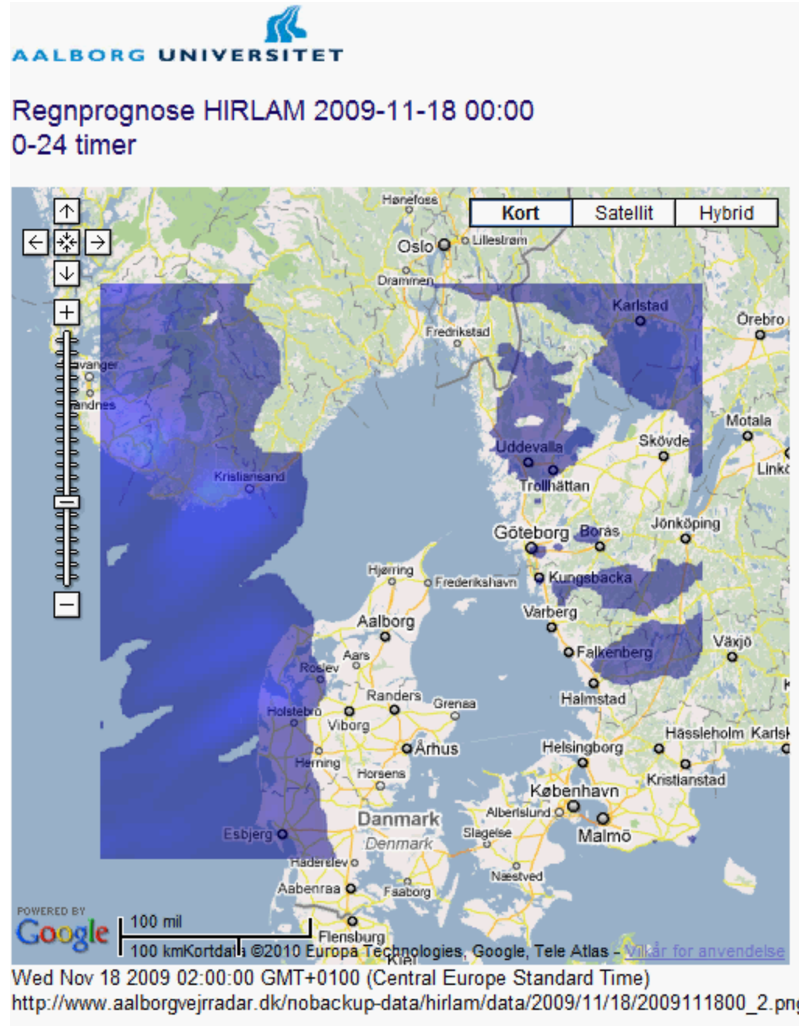
- Extrapolation of observed radar rainfall based on correlation between radar images
- Method: CO-TREC
- Lead time: 0 – 2 hours
- No growth/decay
- A new nowcast is produced every 10 min

Observation

Nowcast model

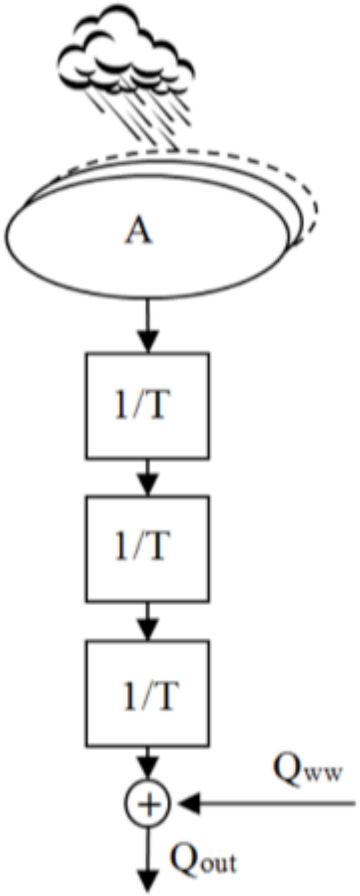
Numerical weather prediction (NWP) model: DMI-HIRLAM-S05

- Spatial resolution: 0.05° (approx 5 km) over 40 vertical levels
- Temporal resolution: 1 hour
- Lead time: 1 - 24 h (in this study)
- The NWP model is run every 6 hours at 00, 06, 12, 18 UTC



Runoff model

- WaterAspects (Krüger, Veolia Water)
- Simple linear reservoir model
- Parameters
  - Contributing Area (*A*)
  - Time constant (*T*)
  - Dry weather flow (Q_{ww})
- In the current setup the Lynetten catchment is divided into six sub-catchments
- The model must be calibrated against observations in the drainage system



Runoff model – auto-calibration

- The runoff model is auto-calibrated against flow observations at the WWTP using the past 48 hours of data
- Method: Quasi-Newton optimization
- The concept is to obtain the best possible model fit of the observed flow at the current time step before initiation of the flow forecast.
- This ensures the best possible initial conditions for the runoff model before simulating future flow based on the forecasted rainfall input.

Events

Event 1: 1 - 4 July 2011

Event 2: 13 - 16 August 2011

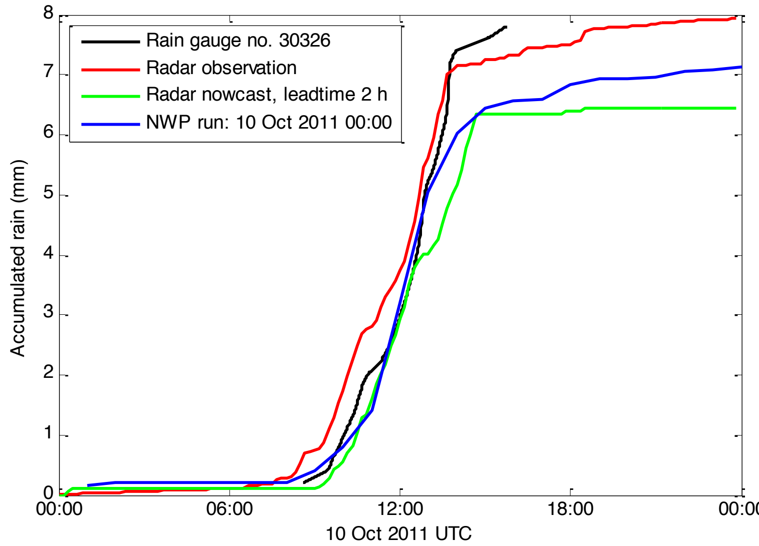
Event 3: 5 - 8 October 2011

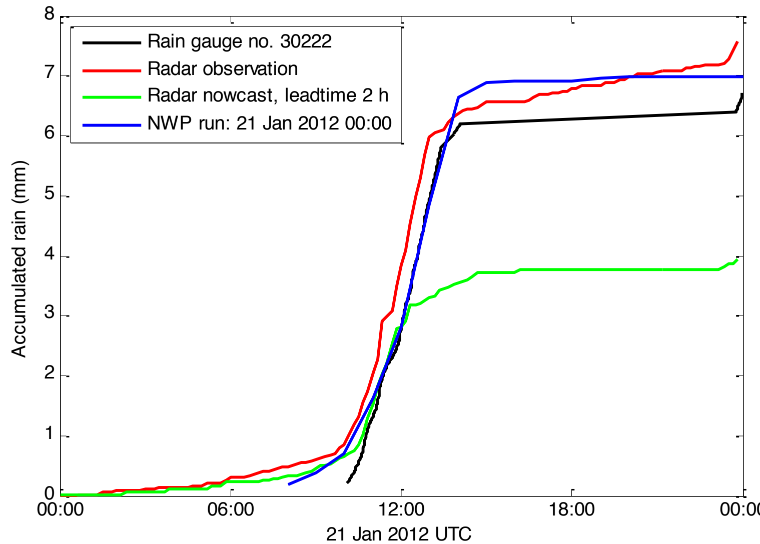
Event 4: 10 -12 October 2011

Event 5: 17 – 19 January 2012

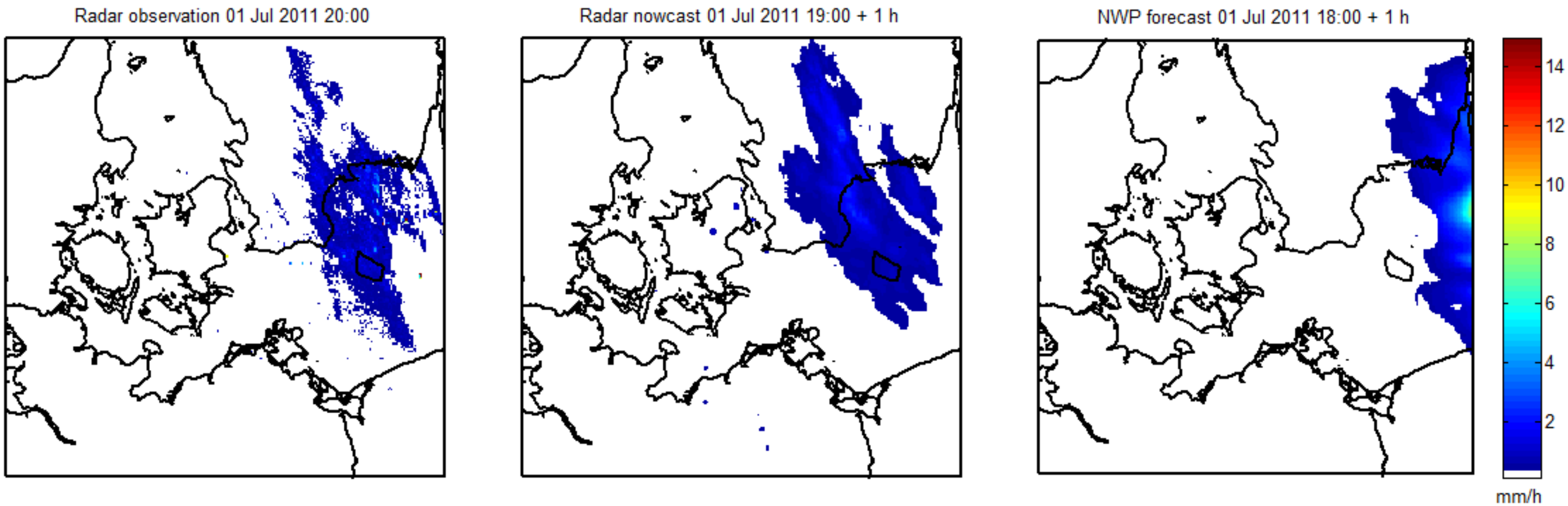
Event 6: 21 – 24 January 2012

These events are simulated as historical events, but the system is currently running in real time with the radar nowcast.



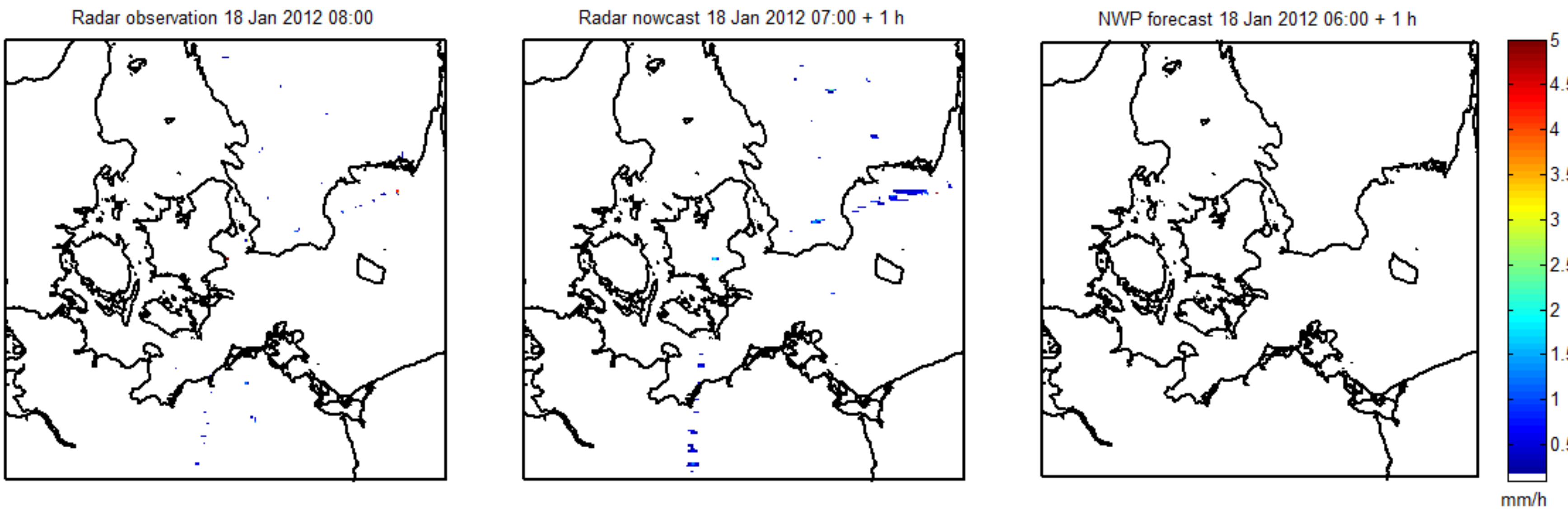


Event 1: 2 July 2011



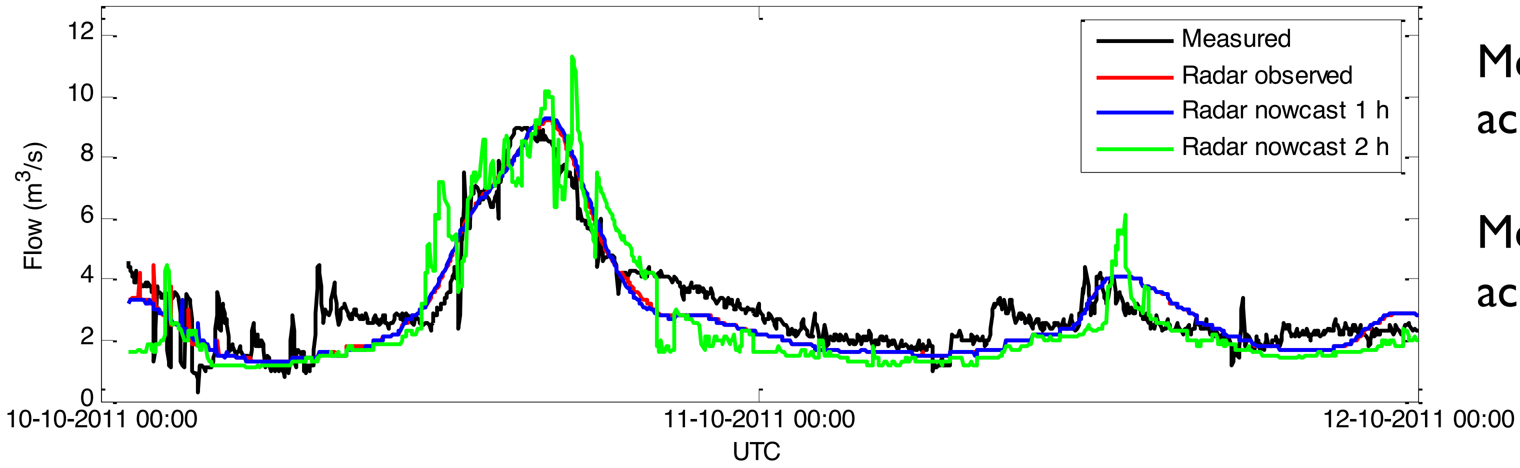
	Rain gauges	Radar obs.	Radar nowcast		NWP model forecast				
Leadtime	0h	0 h	1 h	2 h	1 h	2 h	6 h	12 h	24 h
Mean accum. (mm)	68.2	63.0	40.6	21.4	41.0	69.7	99.9	7.8	21.7

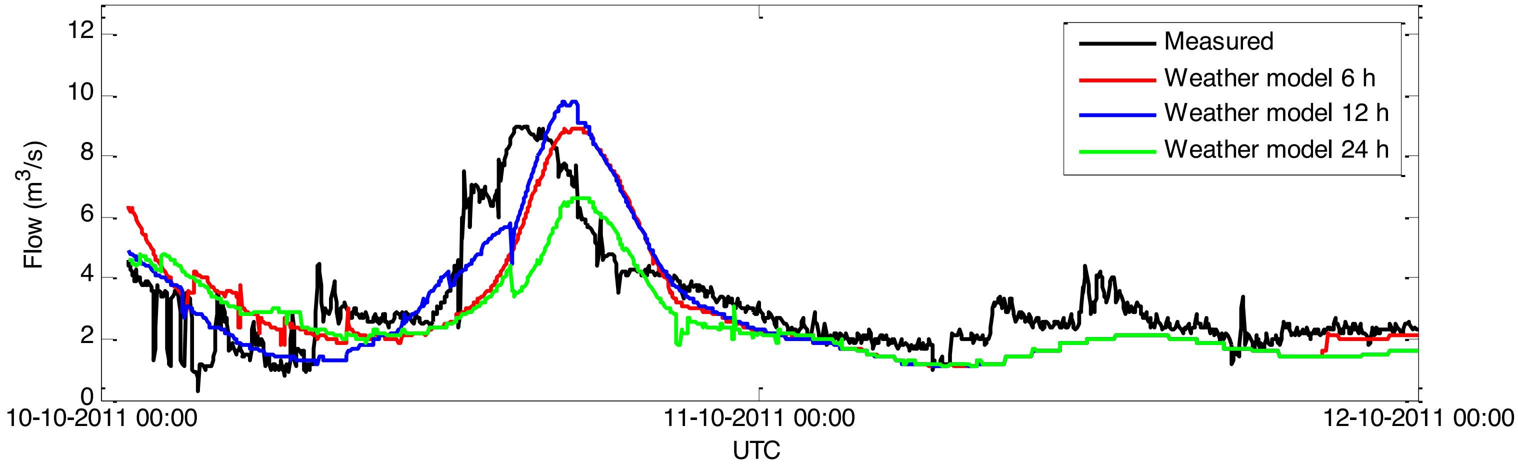
Event 6: 18 January 2012



	Rain gauges	Radar obs.	Radar nowcast		NWP model forecast				
Leadtime	0h	0 h	1 h	2 h	1 h	2 h	6 h	12 h	24 h
Mean accum. (mm)	8.6	7.3	7.0	3.5	8.4	9.0	9.0	8.8	8.6

Flow forecast results - Event 4: 10 - 12 October 2011

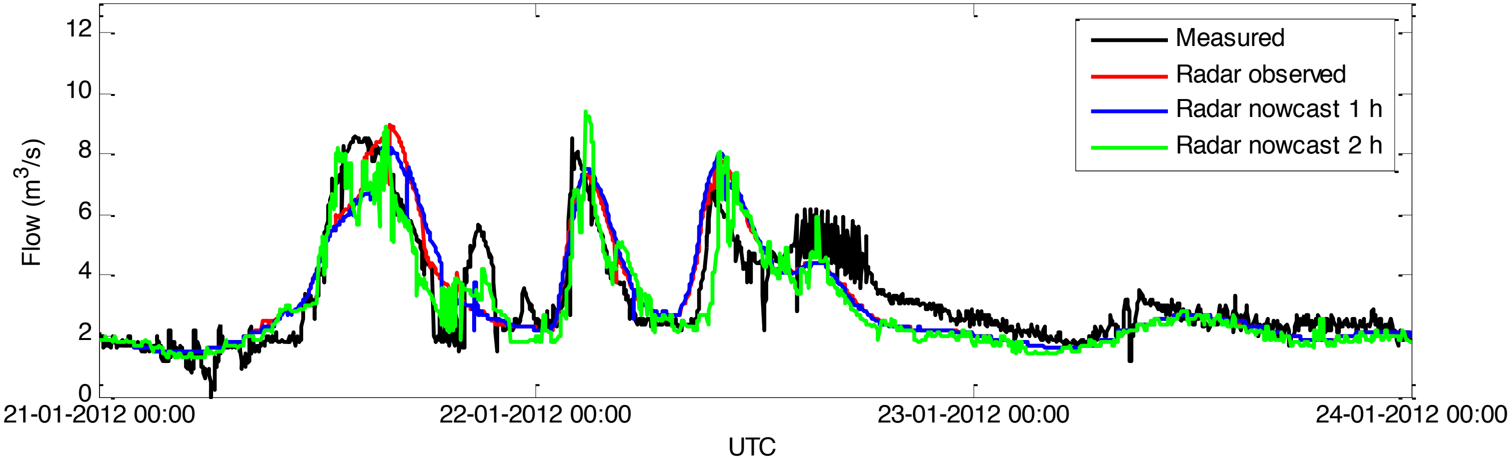




Mean rain gauge accum.: 8.5 mm

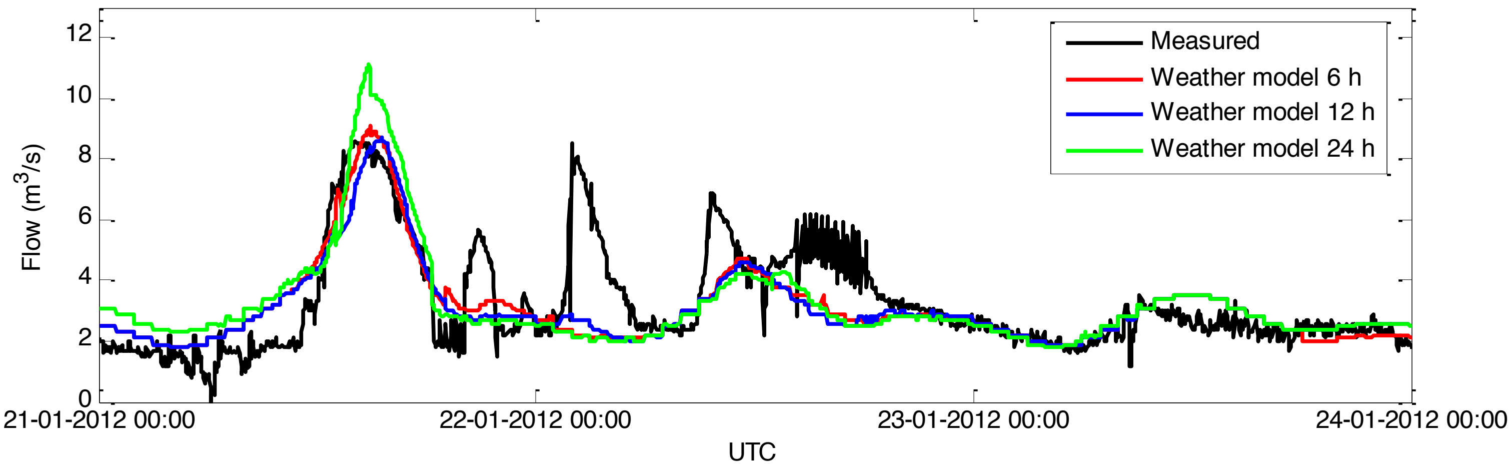
Mean obs. radar accum.: 9.1 mm

Flow forecast results - Event 6: 21 – 24 January 2012

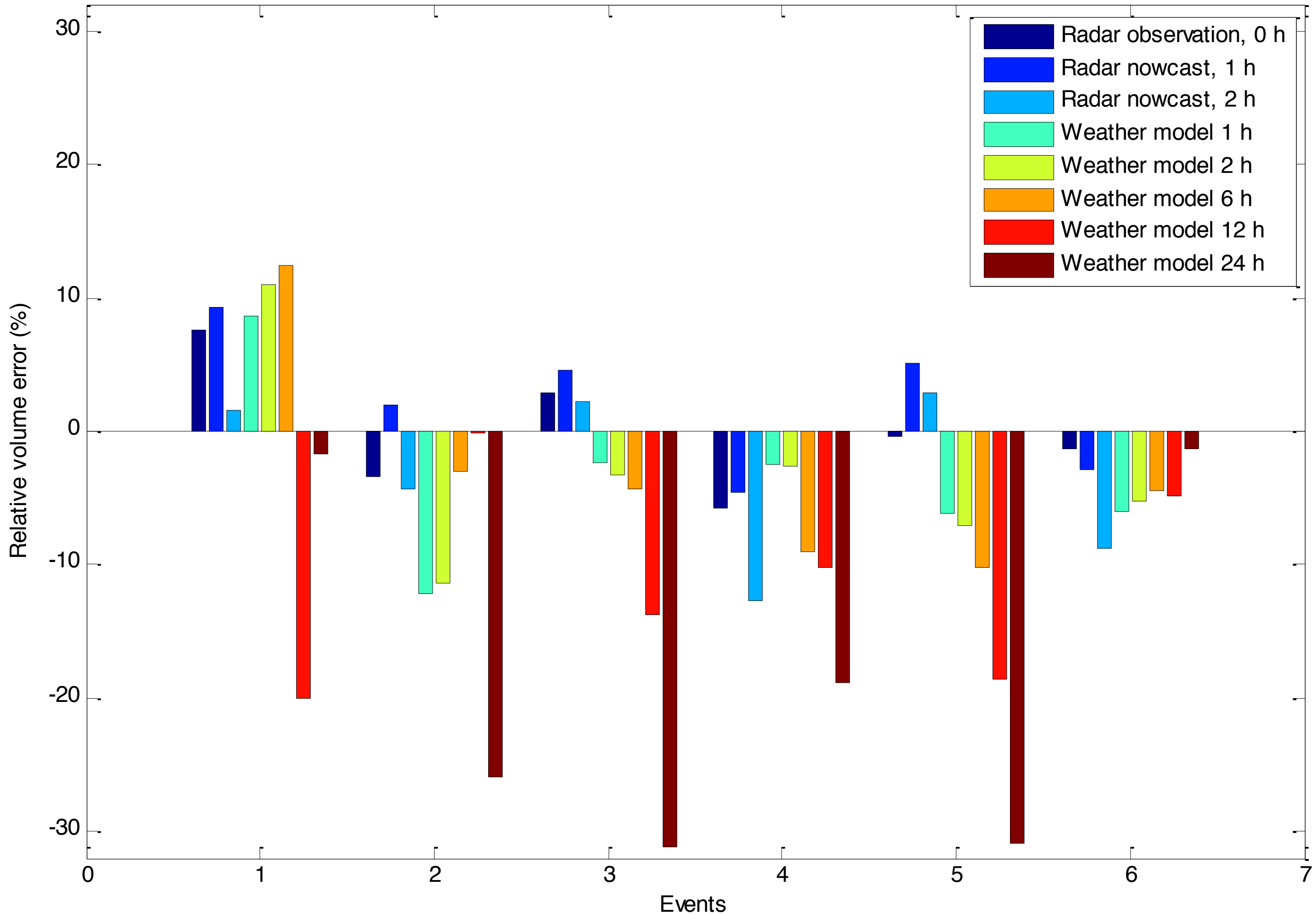


Mean rain gauge accum.: 8.6 mm

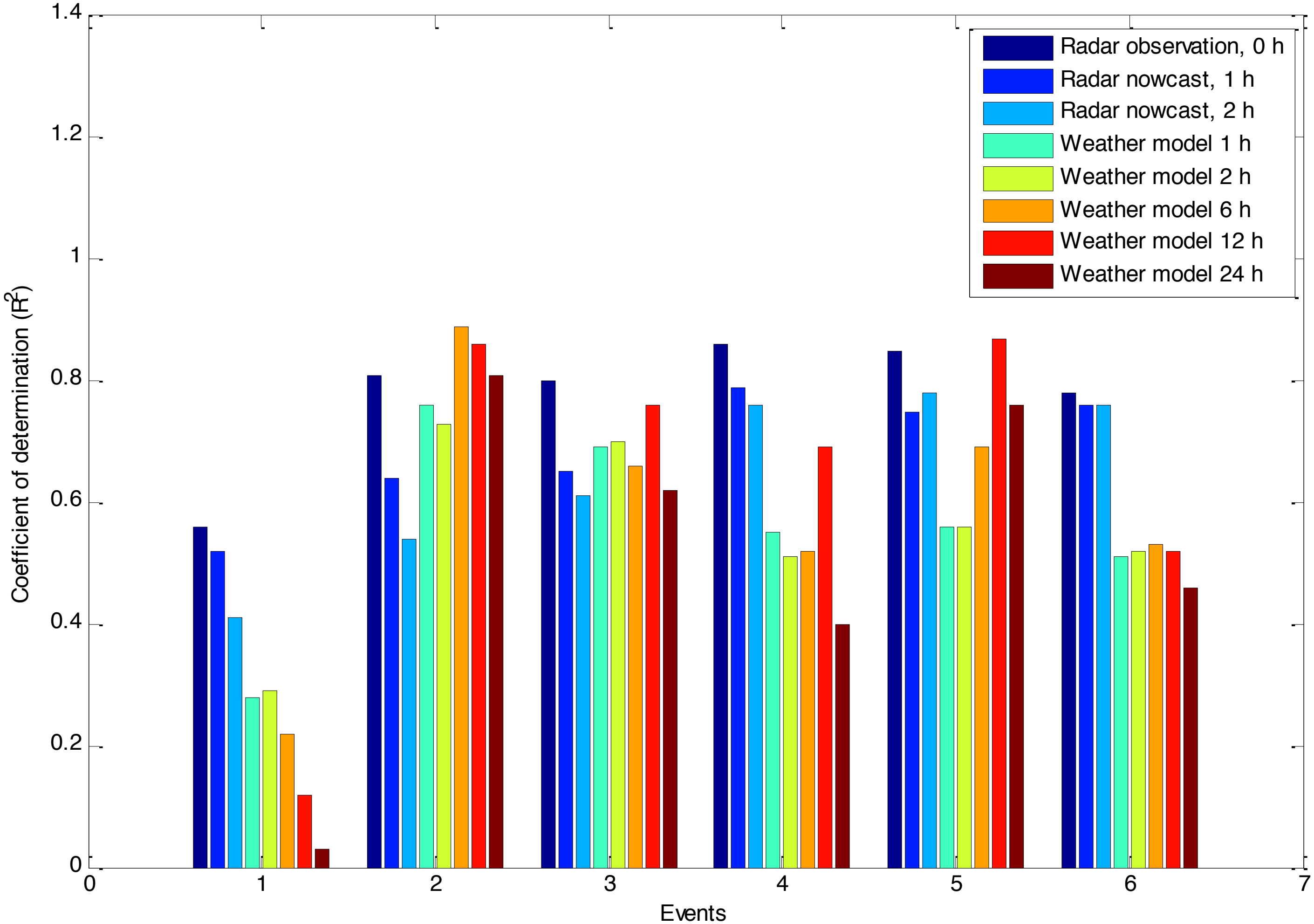
Mean obs. radar accum.: 7.3 mm



Relative volume errors – observed vs. forecasted flow



Coefficient of determination (R^2) - observed vs. forecasted flow time series



Conclusions I

- It is possible to forecast the inlet flows with both radar nowcast and weather model forecasts with remarkable good results.
- Radar nowcast shows best performance during stratiform conditions, but even though it underpredicts rainfall rates during convective conditions, the timing seems to be reasonable.
- The numerical weather forecast shows better performance predicting rainfall with lead times from 6 to 12 hours than with shorter lead times, due to implementation of the initial conditions and succeeding spin-off in the HIRLAM model.

Recommendation:

- Apply radar nowcast for short leadtimes (0-2 hours) and the NWP data for leadtimes > 2 hours.
- combine the two products by a blending or assimilation technique

Conclusions II

- Volume errors are generally low due to implementation of the auto-calibration routine.

- In almost every situation it is possible to produce reliable results as long as the timing on the rainfall forecast is accurate.

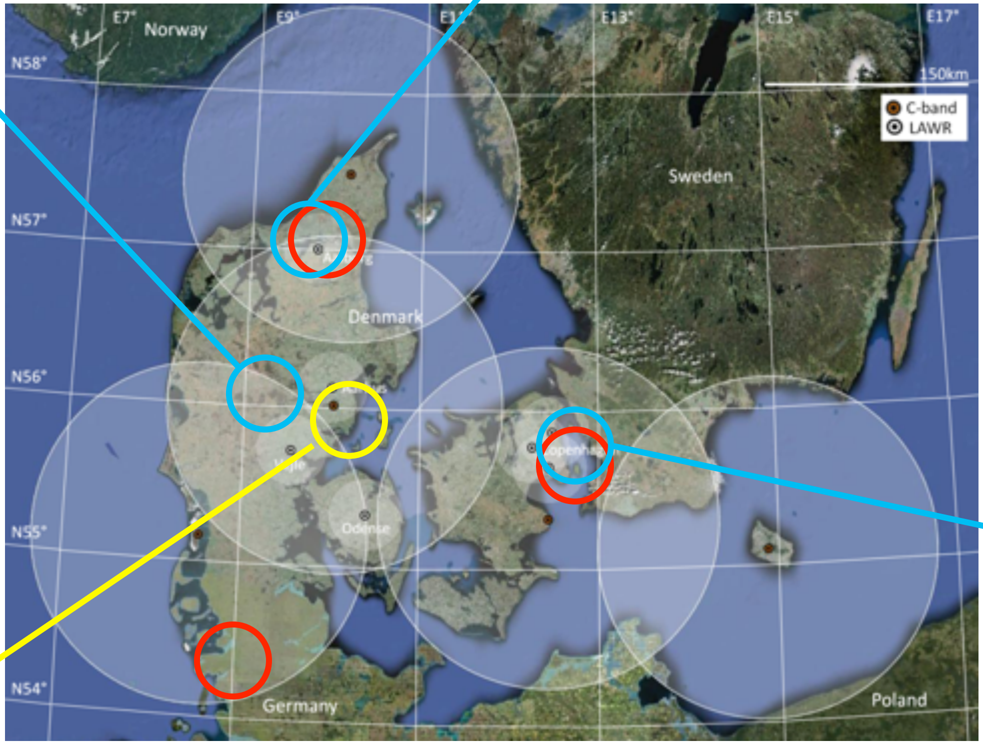
- In 5 out of 6 events the system is able to produce a reliable forecast with lead time most likely long enough to improve the treatment at the WWTP.

- 2 July 2011 which caused massive flooding and combined sewer overflows in Copenhagen, is too large to benefit from extended lead time of the system. In such extreme events flooding and combined sewer overflow is unavoidable, however the system could be applied to issue warnings rather than to optimize the waste water treatment.

Cases - Non real time applications

Frejlev (test catchment)
- Modelling of distributed urban runoff.
- Radar Nowcast and NWP.

Silkeborg
- Ground water modelling
- Road construction
- Radar Nowcast, NWP, and assimilation



Virring (Radar test site)
- X-band (LAWR),
- C-band (DMI)
- Disdrometers
- Rain gauges

Copenhagen (test catchments)
- Grey box modelling of urban runoff.
- Nowcast Stevns Radar

Short-term forecasting of urban storm water runoff with extrapolated radar rainfall data

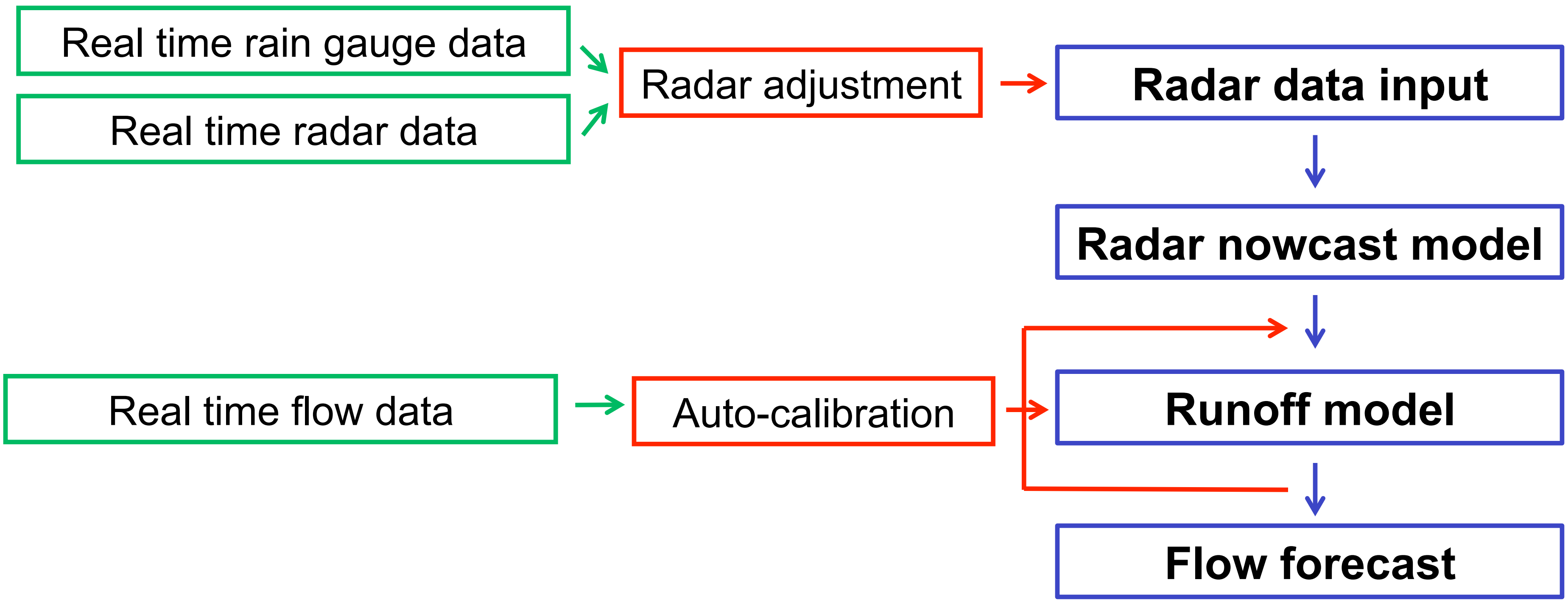
Objectives:

- Investigate potentials for radar based short term flow forecasting in distributed drainage systems

  - Forecasting of combined sewer overflow
  - Flood forecasting
  - Forecasting of inflow to WWTPs pumping stations, etc.
  - Real time control of drainage systems

- To develop a real time model setup

System


Real time rain gauge data
Real time radar data
Radar adjustment
Radar data input
Radar nowcast model
Real time flow data
Auto-calibration
Runoff model
Flow forecast

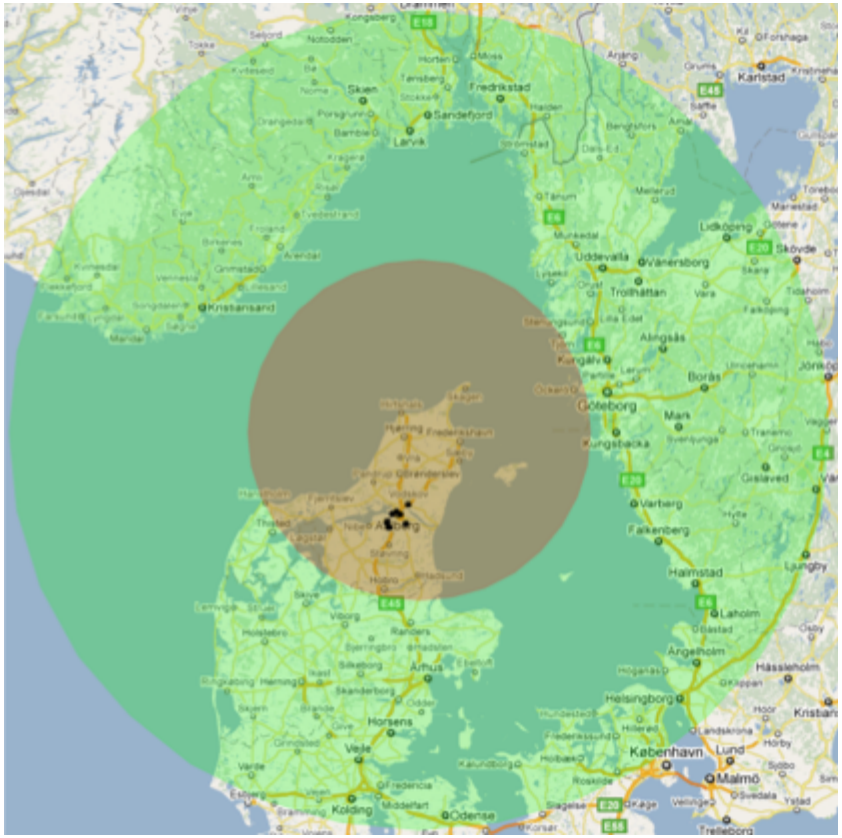
Radar data

Data from a single C-band weather radar located in Sindal, Denmark:

Radar operated by the Danish Meteorological Institute (DMI)

Radar specifications:

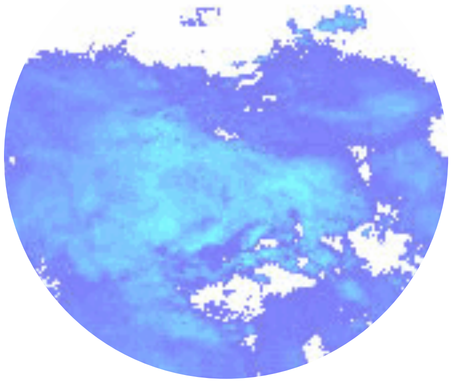
- Range: 240 km
- Quantitative range: 75-100 km
- Spatial resolution: 2 x 2 km^2 (CAPPI)
- Temporal resolution: 10 min



Radar rainfall extrapolation

Radar nowcast model based on CO-TREC

- Correlation based estimation of movement vectors
- Extrapolation of vector field
- Leadtime of 0 to 2 hours
- Simulation every 10 min.



Observation

Nowcast model

The urban catchment Frejlev

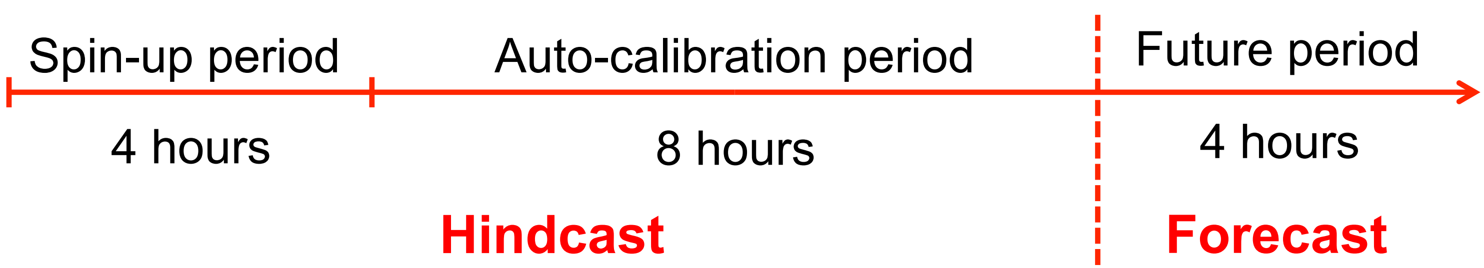
- Partly combined and partly separated sewer system

- 0.8 km^2 urban area,
- 40 % impervious
- 2000 inhabitants

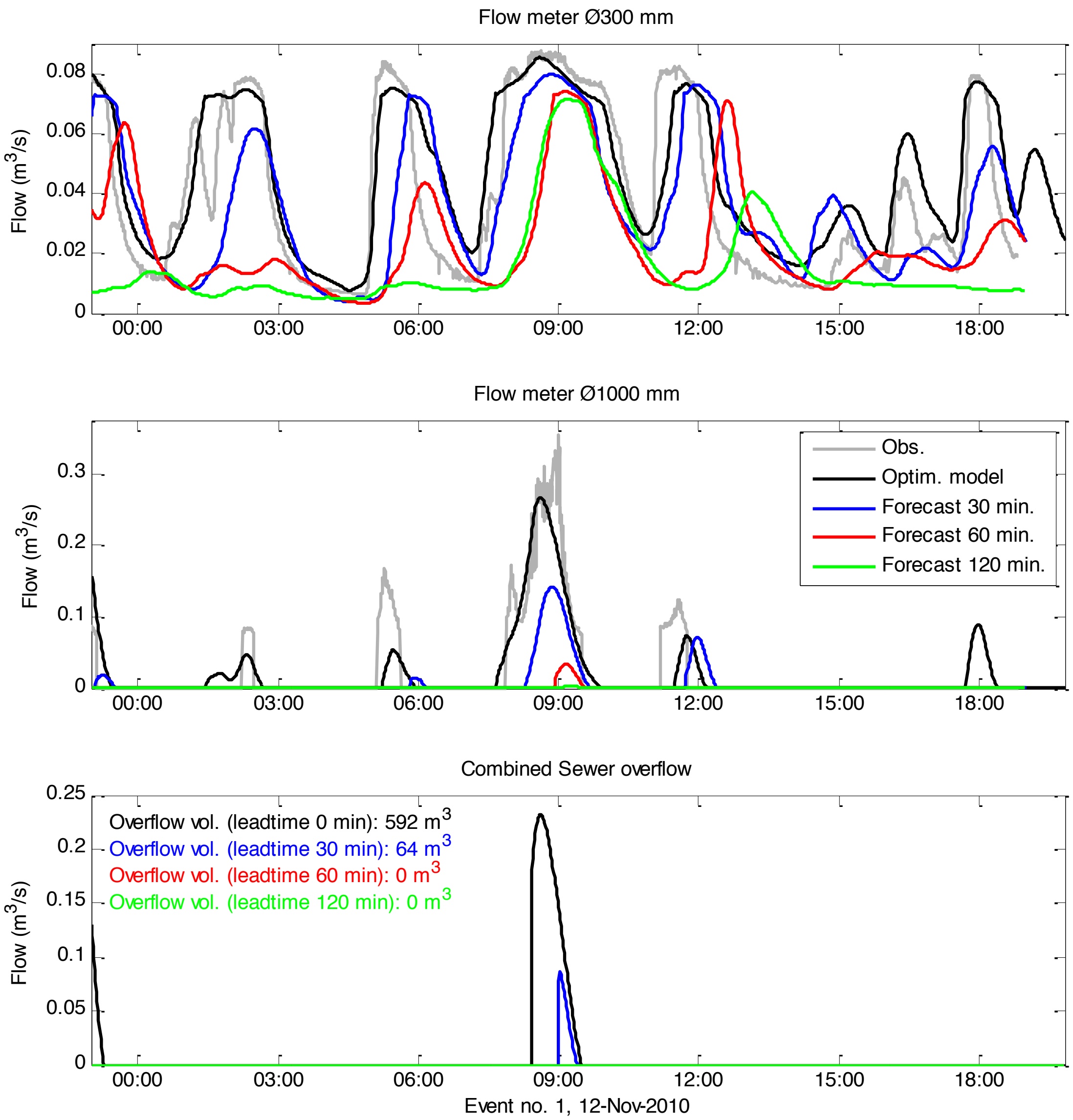
- Equipped with two electro-magnetic flow meters (data in real time)

Real time runoff model

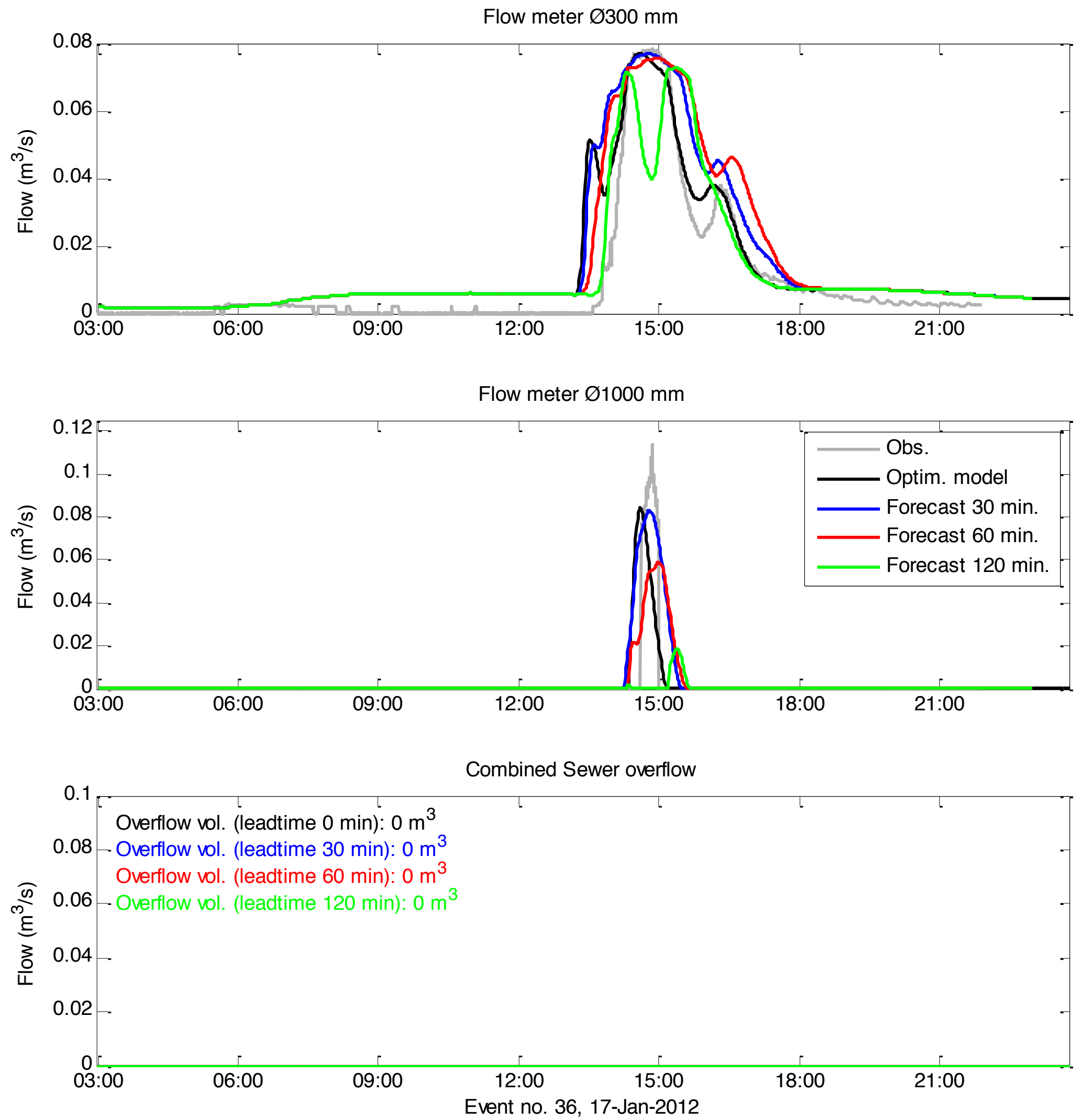
- Fully distributed and well calibrated MOUSE/MIKE URBAN model
- Simulating in real time every 10 min.
- Due to model computation times the auto-calibration procedure is initiated every 30 min (every third model run)



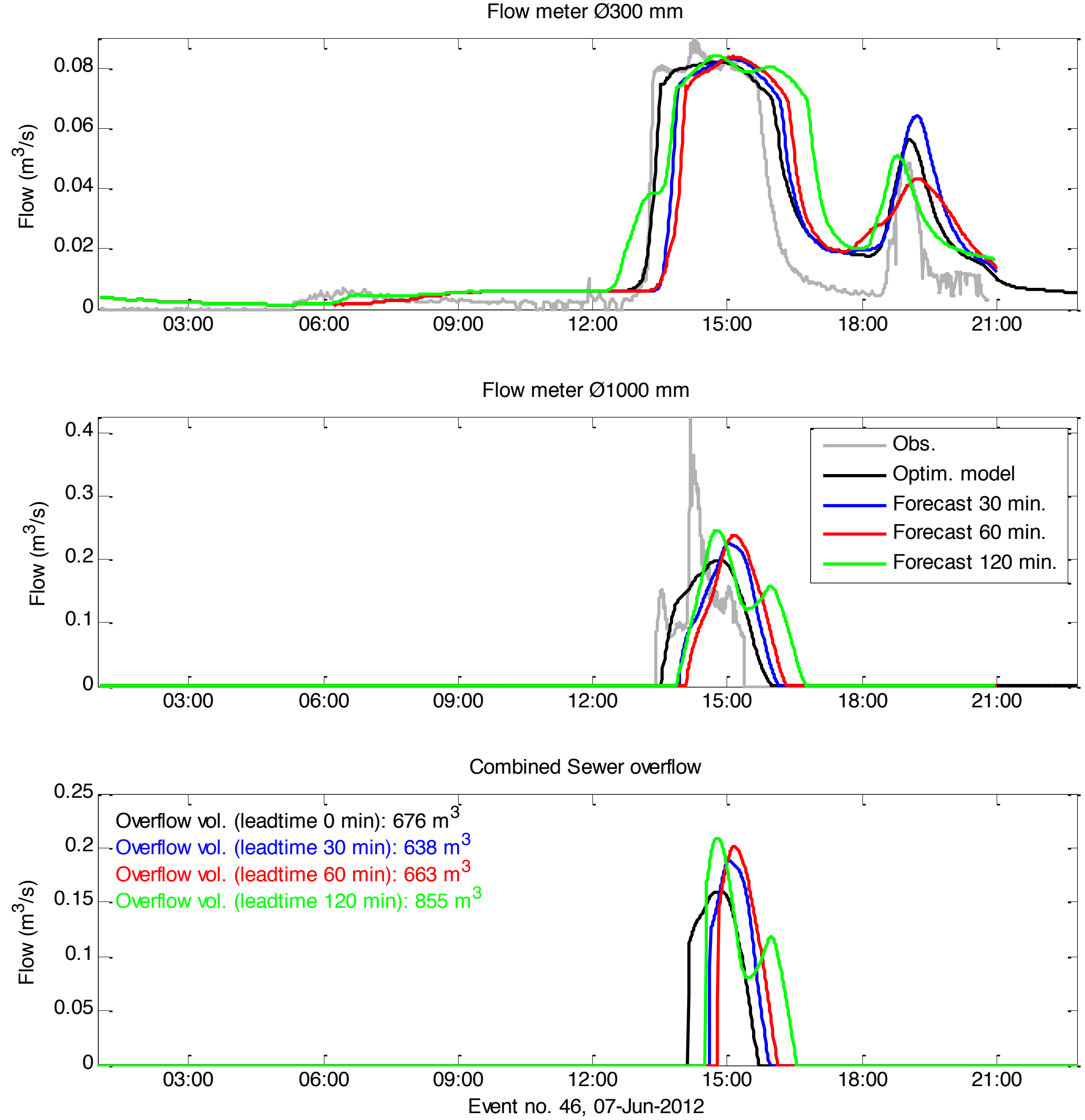
Example I


Flow meter Ø300 mm
Flow (m3/s)
0.08
0.06
0.04
0.02
0
00:00
03:00
06:00
09:00
12:00
15:00
18:00
Flow meter Ø1000 mm
Flow (m3/s)
0.3
0.2
0.1
0
Obs.
Optim. model
Forecast 30 min.
Forecast 60 min.
Forecast 120 min.
Combined Sewer overflow
Flow (m3/s)
0.25
0.2
0.15
0.1
0.05
0
Overflow vol. (leadtime 0 min): 592 m3
Overflow vol. (leadtime 30 min): 64 m3
Overflow vol. (leadtime 60 min): 0 m3
Overflow vol. (leadtime 120 min): 0 m3
Event no. 1, 12-Nov-2010

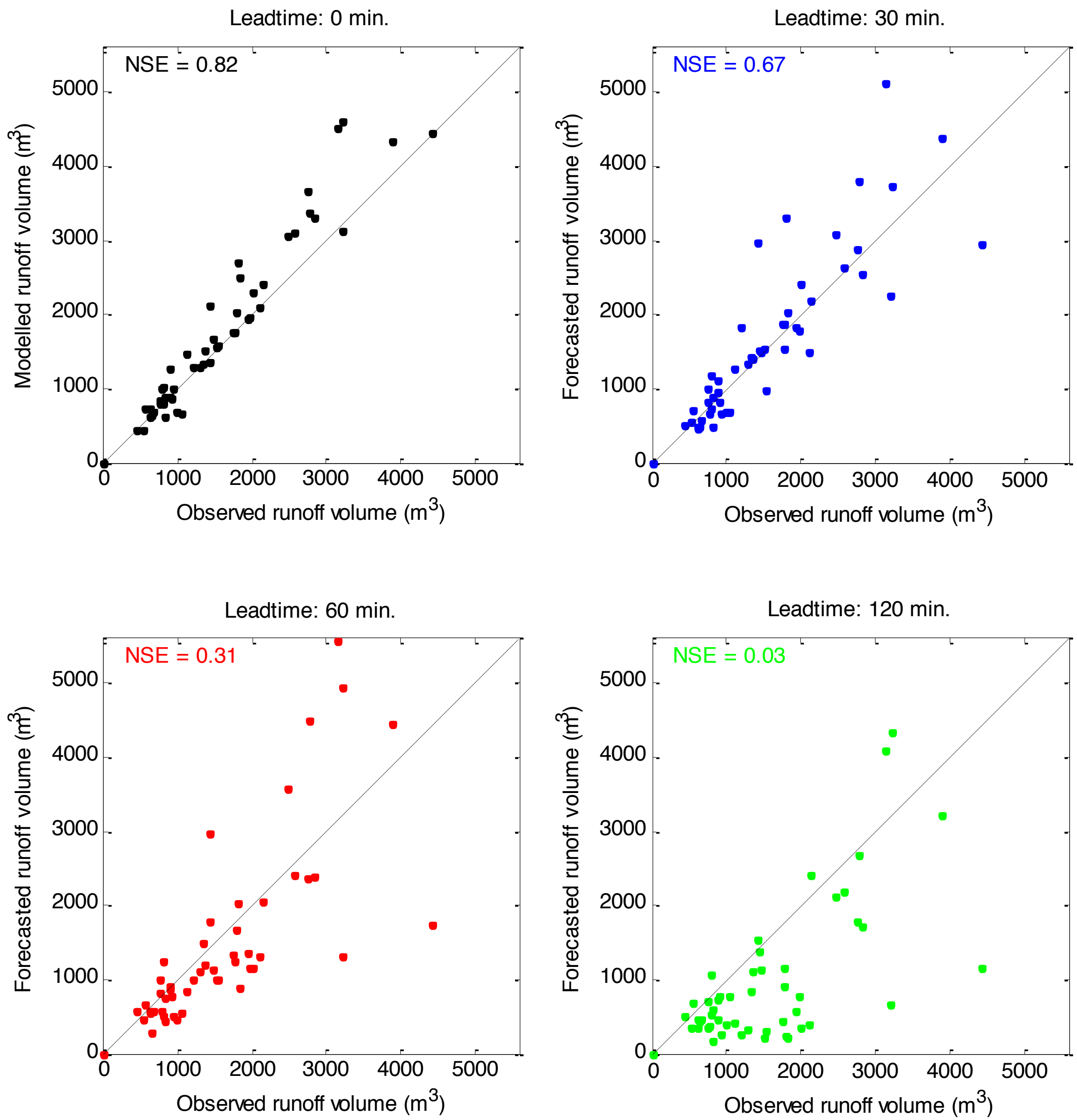
Example 2


Flow meter Ø300 mm
0.08
0.06
0.04
0.02
0
Flow (m3/s)
03:00
06:00
09:00
12:00
15:00
18:00
21:00
Flow meter Ø1000 mm
0.12
0.1
0.08
0.06
0.04
0.02
0
Flow (m3/s)
Obs.
Optim. model
Forecast 30 min.
Forecast 60 min.
Forecast 120 min.
Combined Sewer overflow
Overflow vol. (leadtime 0 min): 0 m3
Overflow vol. (leadtime 30 min): 0 m3
Overflow vol. (leadtime 60 min): 0 m3
Overflow vol. (leadtime 120 min): 0 m3
0.1
0.08
0.06
0.04
0.02
0
Flow (m3/s)
Event no. 36, 17-Jan-2012

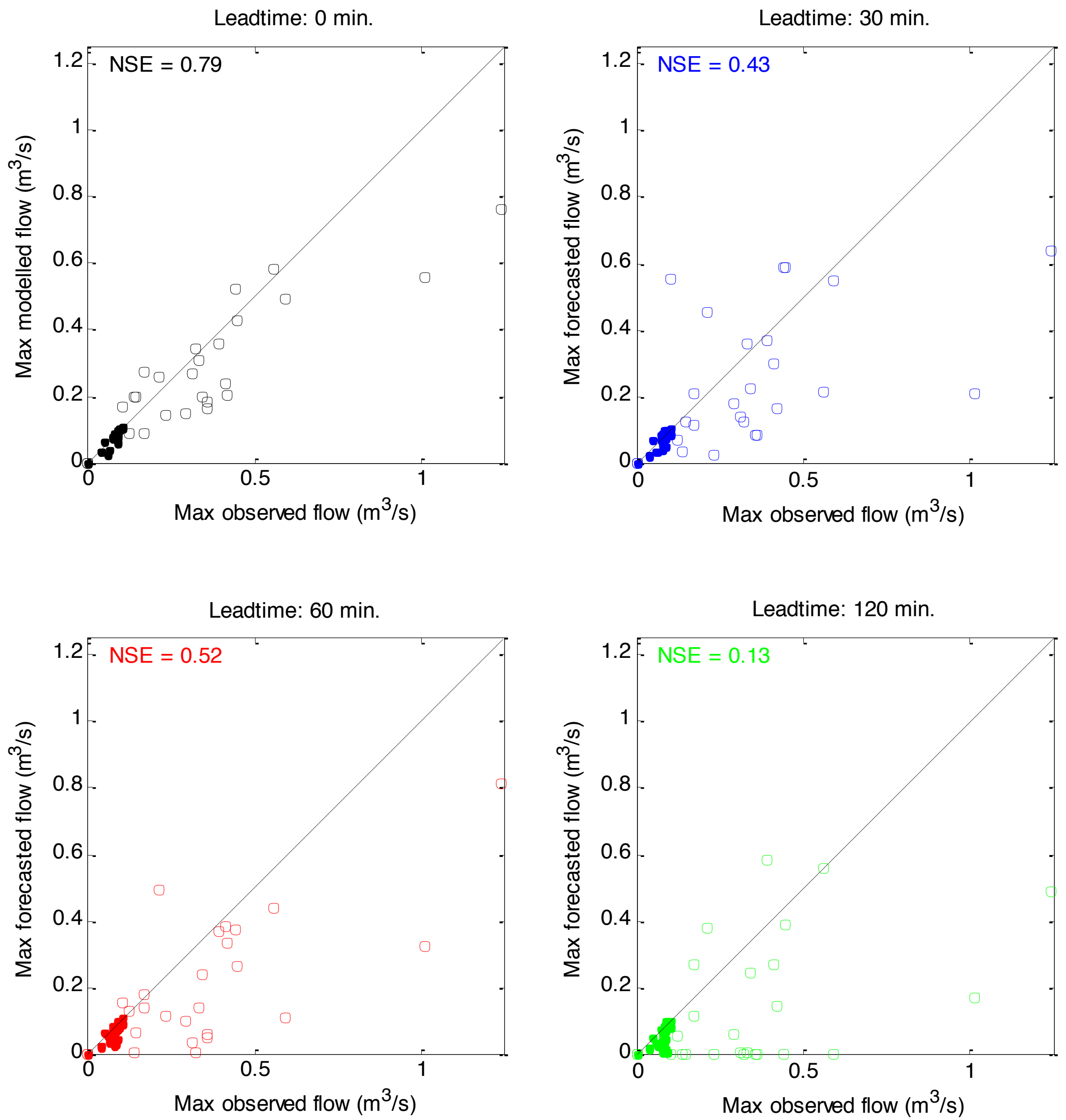
Example 3


Flow meter Ø300 mm
Flow (m3/s)
0.08
0.06
0.04
0.02
0
03:00
06:00
09:00
12:00
15:00
18:00
21:00
Flow meter Ø1000 mm
0.4
0.3
0.2
0.1
Obs.
Optim. model
Forecast 30 min.
Forecast 60 min.
Forecast 120 min.
Combined Sewer overflow
0.25
0.2
0.15
0.1
0.05
Overflow vol. (leadtime 0 min): 676 m3
Overflow vol. (leadtime 30 min): 638 m3
Overflow vol. (leadtime 60 min): 663 m3
Overflow vol. (leadtime 120 min): 855 m3
Event no. 46, 07-Jun-2012

Runoff volumes



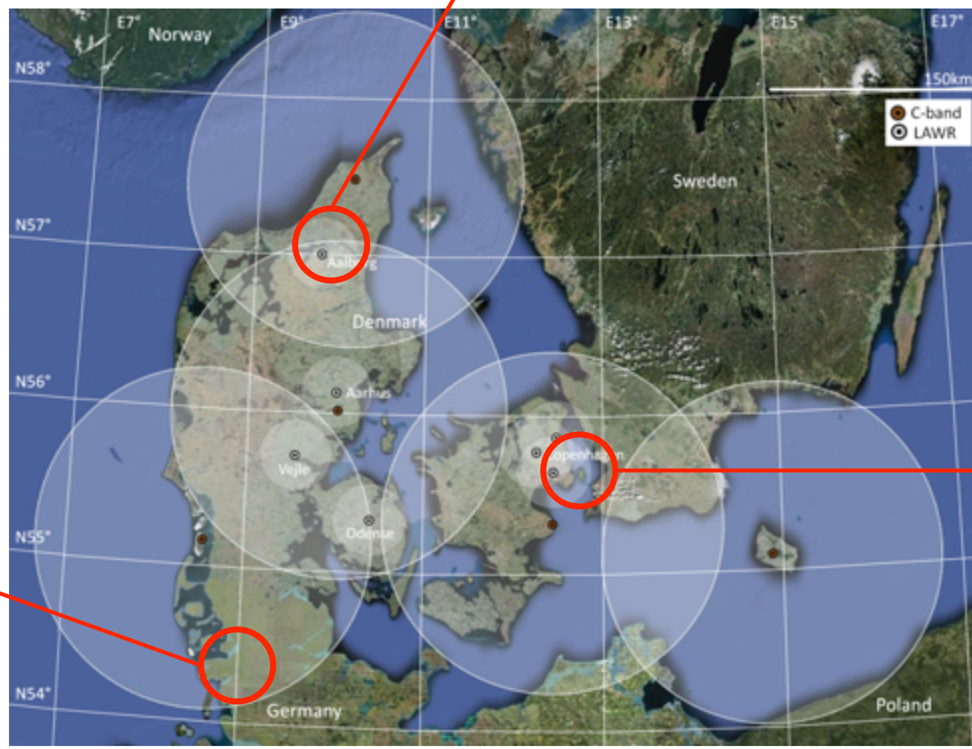
Peak flows


Leadtime: 0 min.
NSE = 0.79
Max modelled flow (m3/s)
Max observed flow (m3/s)
Leadtime: 30 min.
NSE = 0.43
Max forecasted flow (m3/s)
Max observed flow (m3/s)
Leadtime: 60 min.
NSE = 0.52
Max forecasted flow (m3/s)
Max observed flow (m3/s)
Leadtime: 120 min.
NSE = 0.13
Max forecasted flow (m3/s)
Max observed flow (m3/s)

Conclusions

- For the current systems it is possible to do reliable forecasts with a lead time of 0 - 2 hours.
- The Quasi Newton optimization algorithm has proven usable for this application (relatively few iterations, approx. 20 -100)
- A more reliable forecast is obtained with auto-calibration on real time flow data compared to forecasting without.
- The systems definitely shows potentials for distributed forecasting of CSO volumes, exceedance water levels and flows, and real time control

Cases Real time applications



Aalborg

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Tønder

- Real time modelling of in-flow to Tønder WWTP.
- Nowcast Rømø Radar.
- Purpose: RTC of ATS

Copenhagen

- Real time modelling of in-flow to Lynetten WWTP.
- Nowcast Stevns Radar.
- Purpose: RTC of ATS

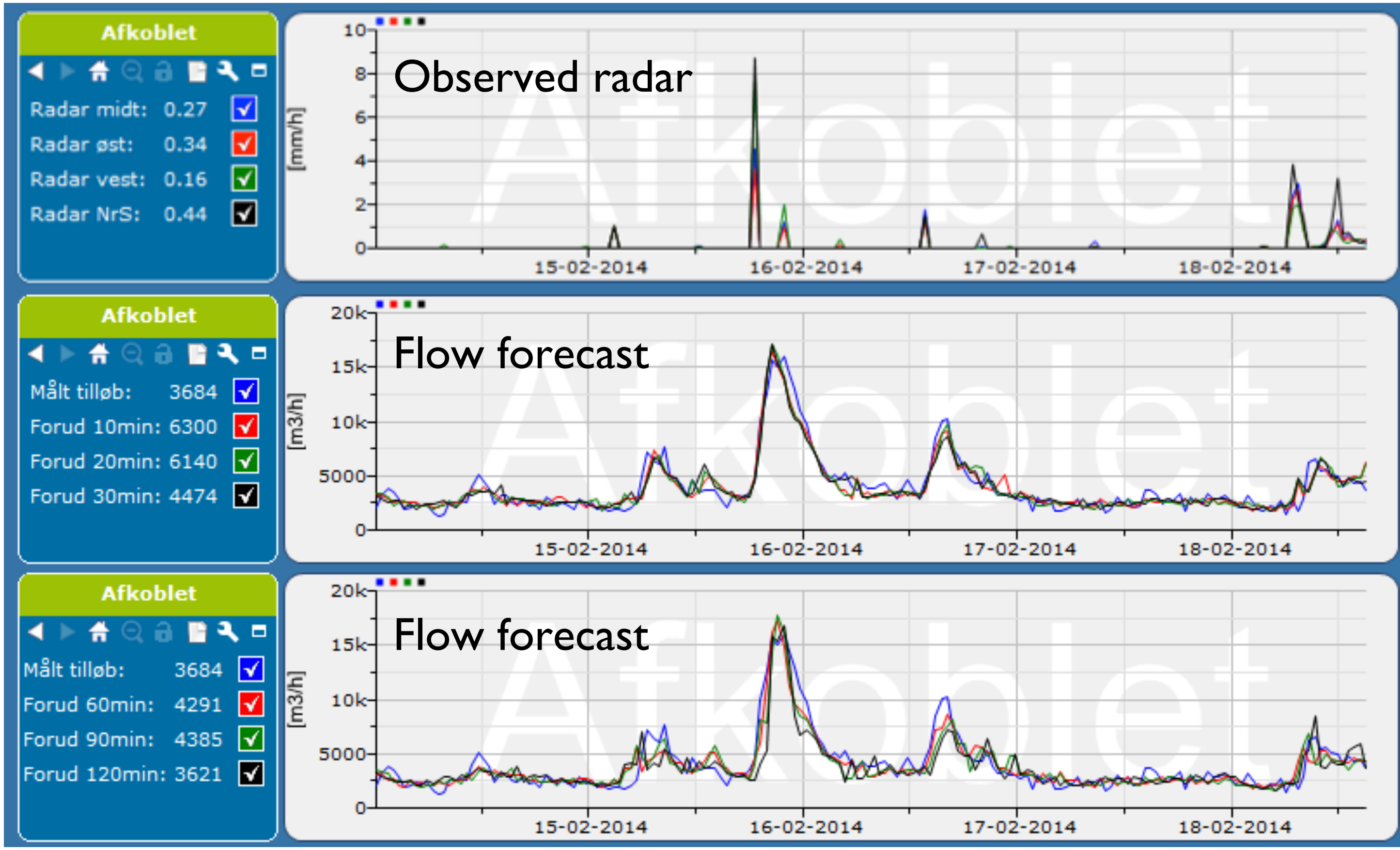
Aalborg WWTP, West

Catchment: 40 km^2

- Real time ATS operation with radar nowcasted inputs

Example

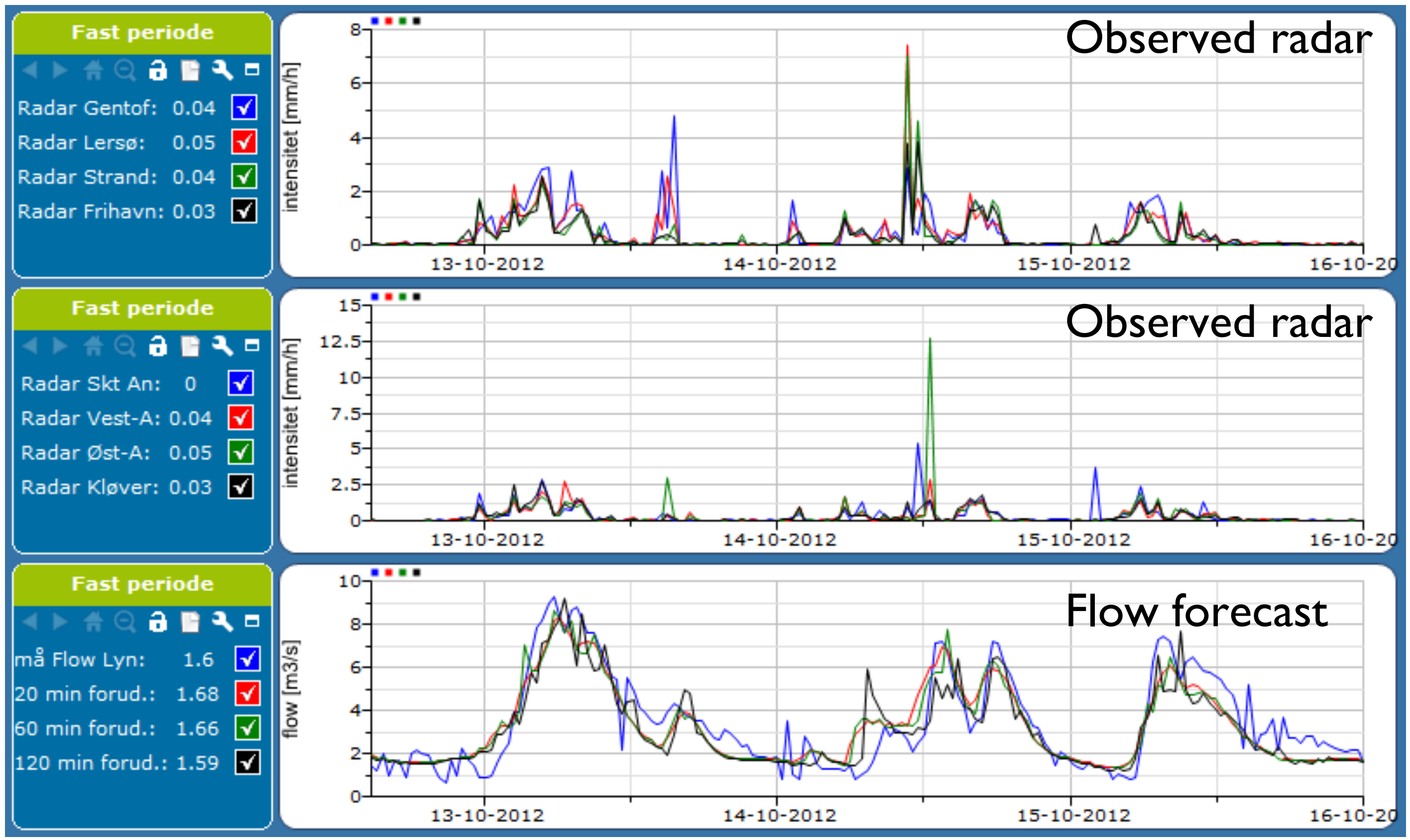
- 4 days with approx 25 mm rain



Lynetten WWTP

Catchment: 77 km^2

- Real time ATS operation with radar nowcasted inputs
- Preliminary results: > 20 % reduction of bypassed water during wet weather



Current and future works

- Ensample radar nowcast
- National mosaic
- Implementation of advection interpolation in real time in order to increase temporal resolution of radar data
- Assimilation of radar observations and nowcast into numerical weather models

Papers on nowcasting

Thorndahl, S., Rasmussen, M. R. (2013). **Short-Term Forecasting of Urban Storm Water Runoff in Real-Time using Extrapolated Radar Rainfall Data.** Journal of Hydroinformatics 15 (3): 897–912.

Thorndahl, S., Poulsen, T. S., Bøvith, T., Borup, M., Ahm, M., Nielsen, J. E., Grum, M., Rasmussen, M. R., Gill, R., Mikkelsen, P. S. (2013) **Comparison of short term rainfall forecasts for model based flow prediction in urban drainage systems**. Water Science and Technology Vol 68 No 2 pp 472–478.

Nielsen, J.E., Thorndahl, S., Rasmussen, M.R., (2014) **A numerical method to generate high temporal resolution precipitation time series by combining weather radar measurements with a nowcast model,** Atmospheric research 138, 1-12

Thorndahl, S., Bøvith, T., Rasmussen, M.R., Gill, R.S. (2012), **On Combining NWP and Radar QPF Models for Forecasting of Urban Runoff,** IAHS Publication series 351. ISBN 978-1-907161-26-1