Flood inundation data assimilation and big data

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Motivation

Flooding, in particular, urban flooding is a high risk event with large human and financial costs associated. Thus early and accurate prediction of a potential flood is of utmost importance.

Lots of effort goes into designing hydraulic models which give predictions of flood events in future from known current state of the system along with input data from hydrologic models.

Models are not perfect, they have errors from:

- imperfect input (e.g. inflow, topography, initial conditions);
- numerical schemes, resolution, parametrisation;
- model errors and biases.

Motivation

Flooding, in particular, urban flooding is a high risk event with large human and financial costs associated. Thus early and accurate prediction of a potential flood is of utmost importance along with associated forecast error.

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Why do DA?

Data assimilation (DA) is an emerging mathematical technique for improving predictions from large and complex forecasting models, by combining uncertain model predictions with a diverse set of observational data.

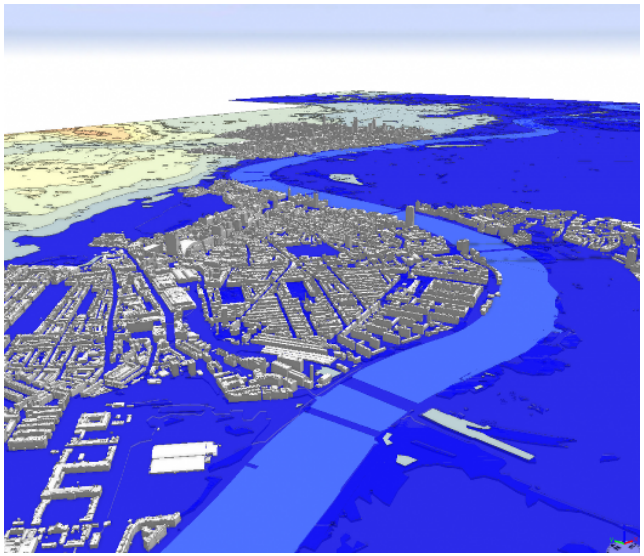


Figure: Numerical Model

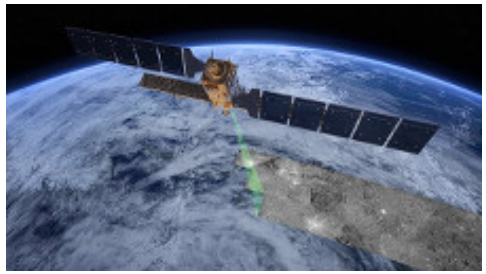


Figure: Observations

Why do DA?

Given a dynamical model $\mathbf{x}_b = \mathcal{M}(\mathbf{x}_a) + \epsilon_m$, where $\mathbf{x}_b$ is a state vector and given observations $\mathbf{y} = \mathcal{H}(\mathbf{x_t}) + \epsilon_\mathbf{o}$ with associated covariance matrices $\mathbf{Q}, \mathbf{R}$ of model and observation errors, respectively, we combine the two pieces of information in DA as follows:

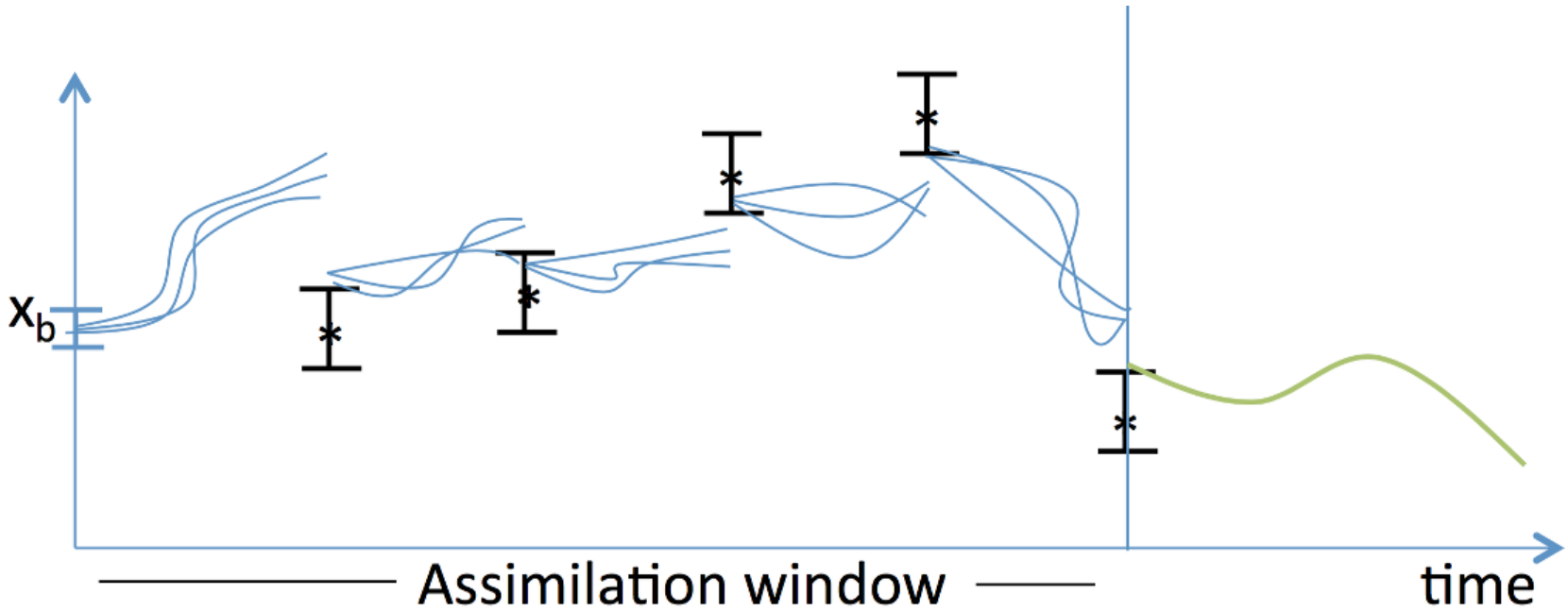


Figure: Schematic of sequential data assimilation methods

The Aim

The aim of this project is to improve urban inundation prediction through development of DA methods specific for urban flooding applications using traditional and innovative large observation data sets.

Importantly the advancement of the science and methods will be achieved through **collaborations** between various research fields, organisations, and the community.

To develop new DA systems suited for urban flood prediction we need:

1. Good dynamical model for urban flooding forecasting;
2. Useful observations of the system;
3. Appropriate DA system that combines points (1) and (2) resulting in improved flood prediction in urban areas.

Urban flood modelling

An appropriate urban inundation model is one which:

- models water flow (using shallow water equations)
- captures shocks
- has high resolution
- models sewers (flood draining and enhancing)
- is computationally feasible

HiPIMS model meets the criterion, is open source and also offers good collaboration opportunities with the development team.

`https://research.ncl.ac.uk/hydrosystems/projects/hipims/`

Difficulties with urban flooding prediction

Urban flood modelling is a difficult task due to:

- high spatial resolutions needed to resolve flow around buildings;
- many sources and sinks in the system, e.g. sewers, underground, building basements;
- short time scale.

All urban inundation models must have:

- necessary hydrologic data to drive the hydraulic model;
- appropriate physics to represent water processes;
- corresponding parameters, e.g. channel friction.
- initial conditions

Difficulties with urban flooding DA

This presents many challenges also for DA methods due to

- high nonlinearity in the model and observations;
- difficult terrain;
- many uncertain parameters;
- model & observation errors;
- uncertainties in driving data;
- bounded variables and parameters;
- use of novel observation types;
- short timescale of the events.

Urban flood modelling

To investigate DA methods, first we are going to develop and test new DA methods applicable to urban modelling on well known simple inundation models such as LISFLOOD.

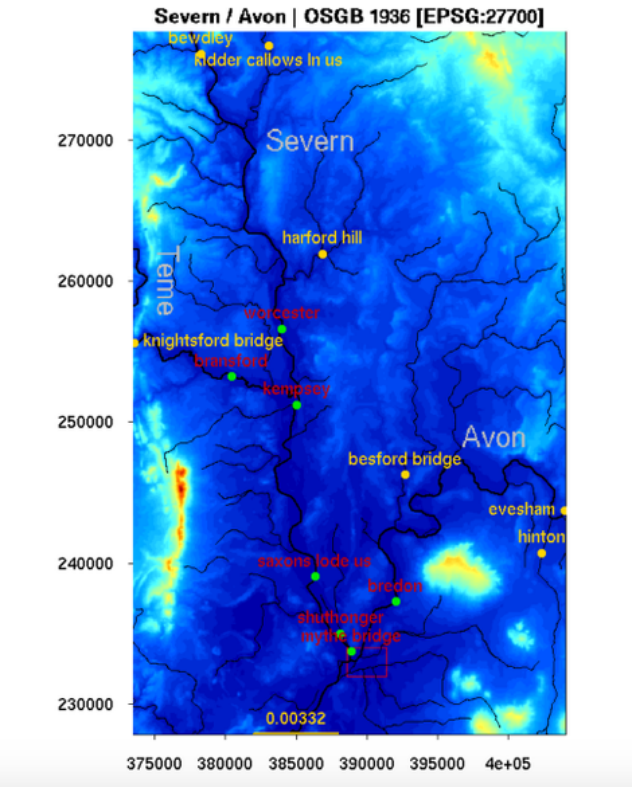


Image from Garcia-Pintado et al. 2013

- well known model and dynamics
- lots of data available both direct and satellite images
- simpler dynamics
- many parallel issues with more complex model, e.g. inflow error estimation, observation error correlation localisation.

Urban flood modelling

PLAN:

Develop DA methods and theory for urban inundation models using a simpler LISFLOOD model. In particular:

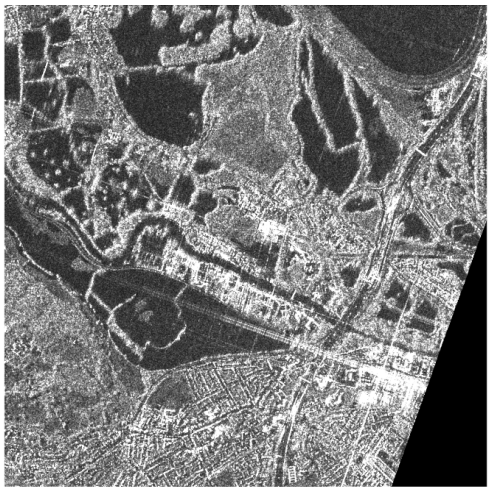
- the best DA methods for online inflow error estimation in inundation models;
- investigate Gaussian anamorphosis to flood inundation model.

Transfer and use above developed DA methods with urban flood models such as HiPIMS.

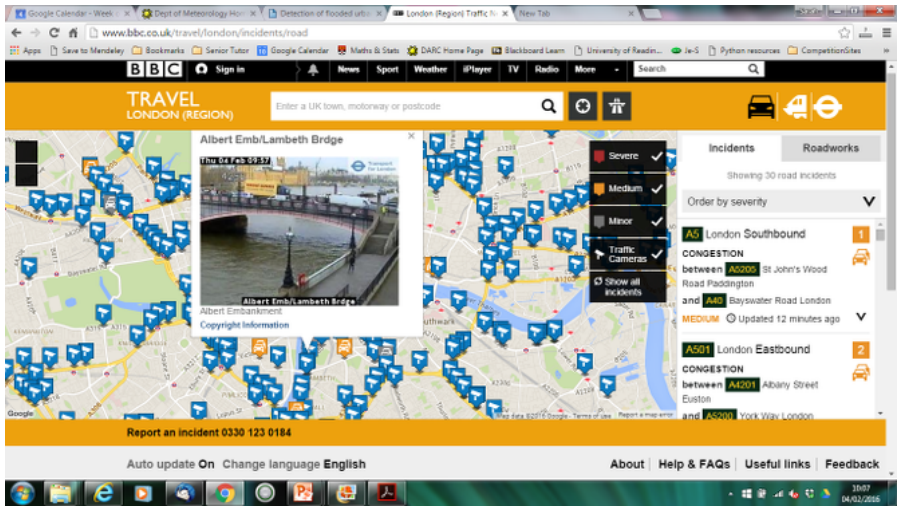
Observations

Good news - lots of data available:

- satellite (SAR) images;
- river water level measurements, gauges;
- traffic & river cameras;
- smartphone images of flooding;
- CCTV cameras (on buildings, streets)
- social media posts



CSK image of Thames flood west of London on 12/02/2014.



Observations

PLAN:

Use flood risk maps from EA in areas of interest (e.g. London, Thames Valley, Loddon Valley, Newcastle, Leeds, Exeter) to compile a database of webcams (traffic & river) which are in high flooding risk areas.

Familiarise ourselves with data and write scripts for recording data.

Work with David Mason on final phase of SAR algorithm verification and use SAR images later in developed DA system.

Collaborate with other data users in flooding community where possible.

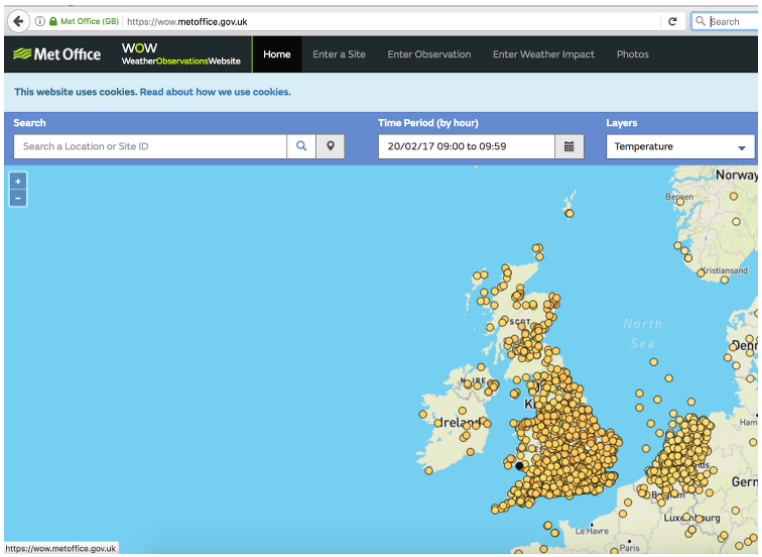
Use of new observations

Detailed local information of flood extent is also available through crowd sourcing, e.g.:

- Met Office WoW system;
- FloodCrowd (Loughborough University)
- Twitter

Crowd sourcing data

In this project we will use our website to raise public awareness & interest in urban flooding events. We will encourage public to share their smart data with the research community by adding their photos etc on Met Office WoW site.



PLAN:

- Contribute to WoW database (MO developing new API);
- Encourage public to use WoW through local networks, website, Twitter etc.;
- Join efforts with other projects in collecting/sharing data, e.g. NERC FFIR, SINATRA, TENDERLY

Summary of current PLAN

- Investigate and develop DA methods for urban flooding prediction using large data
  - starting with simpler LISFLOOD model to investigate online inflow estimation (possibly Gaussian anamorphosis).
  - transfer developed methods to urban flood inundation model, e.g. HiPIMS.
- Create webcam database with cameras which are in high flood risk zones in areas of interest.
- Familiarise ourselves with data and write scripts for recording data.
- Encourage public to contribute to WoW database when new API is ready.
- Collaborate with other data collectors/users in flooding community.
- Use SAR images in developed DA methods.

References on urban flood modelling & large data

Urban flood modelling:

- Bradbrook K. (2006) JFLOW: a multiscale two-dimensional dynamic flood model. Water and Environment Journal, 20, pp.79-86.
- Liang Q, Smith L.S. (2014) A High-Performance Integrated Hydrodynamic Modelling System for Urban Flood Inundation, Journal of Hydroinformatics, 17(4):518-533.
- Liu L. Liu Y, Wang X., Yu D., Liu K., Huang H., Hu G. (2015) Developing an effective 2-D urban flood inundation model for city emergency management based on cellular automata. Natural Hazards and Earth System Sciences,15, pp.381-391.

Large data:

- Mason, D.C., Schumann, G. J.-P., Neal, J.C., Garcia-Pintado, J. and Bates, P.D. (2012) Automatic near real-time selection of flood water levels from high resolution Synthetic Aperture Radar images for assimilation into hydraulic models: a case study. Remote Sensing of Environment, 124. pp. 705-716.
- Filonenko A., Wahyono, Hernandez D.C., Seo D., Jo K.H. (2015) Real-Time Flood Detection for Video Surveillance, IECON 2015, Yokohama, Japan, Nov 9, 2015.
- Lo S-W., Wu J-H., Lin F-P., Hsu C-H. (2015) Visual Sensing for Urban Flood Monitoring. Sensors, 15(8), pp. 20006-20029.
- Saxena A., Chung S.H., Ng A.Y. (2008) 3-D Depth Reconstruction from a Single Still Image. International Journal of Computer Vision, 76, pp. 53-69.

References on urban flood DA

- Cooper E.S., Dance S.L., Garcia-Pintado J., Nichols N.K., Smith P.J. (In preparation) Observation impact, domain length and parameter estimation in data assimilation for flood forecasting.
- Garcia-Pintado, J., Neal , J., Mason, D., Dance, S. and Bates, P. (2013) Scheduling satellite-based SAR acquisition for sequential assimilation of water level observations into flood modelling. Journal of Hydrology, 495. pp. 252-266.
- Garcia-Pintado, J., Mason, D., Dance, S. L., Cloke, H., Neal, J. C., Freer, J. and Bates, P. D. (2015) Satellite-supported flood forecasting in river networks: a real case study. Journal of Hydrology, 523. pp. 706-724.
- Liang Q, Smith L.S. (2014) A High-Performance Integrated Hydrodynamic Modelling System for Urban Flood Inundation, Journal of Hydroinformatics, 17(4):518-533.
- Seo D.-J., Cajina L., Corby R., Howieson T. (2009) Automatic State Updating for Operational Streamflow Forecasting via Variational Data Assimilation, 367, Journal of Hydrology, 255-275.
- Stringer, S. M., Nichols, N.K. (1993) The estimation of flow demands in a linear gas network from sparse pressure telemetry. In: Symposium on Post-graduate Research in Control and Instrumentation, SERC/Institute of Measurement and Control, Nottingham.
- Young P.C., Sumislawska M. (2012) A control systems approach to input estimation with hydrological applications. 16th IFAC Symposium on System Identification.