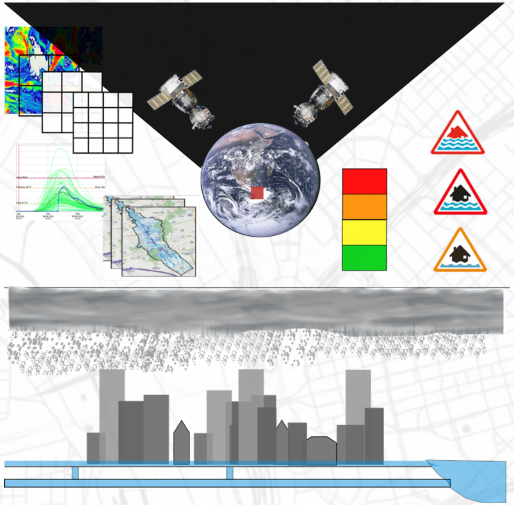
High-Resolution Ensemble Precipitation for Pluvial Flood Forecasting in the Urban Data Scarce city of Alexandria, Egypt



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IHE Delft Institute for Water Education
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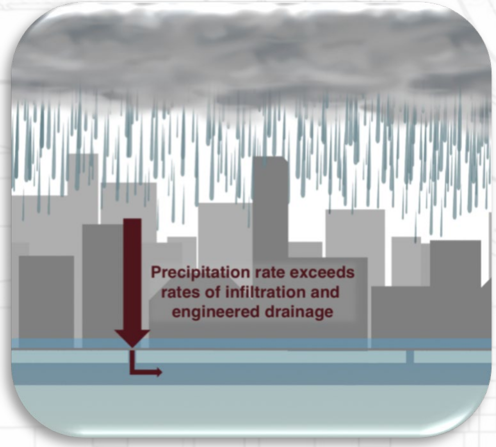
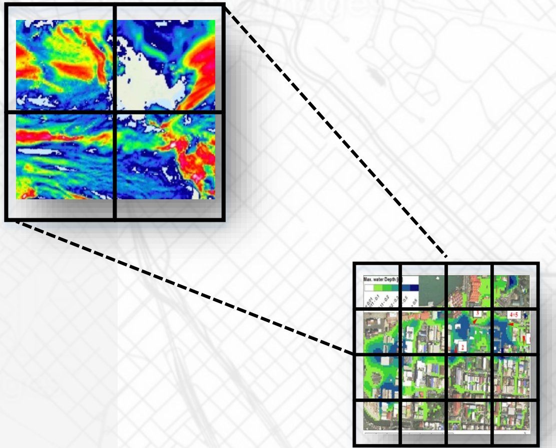
Problem Statement

Urban Pluvial (surface water) Flooding



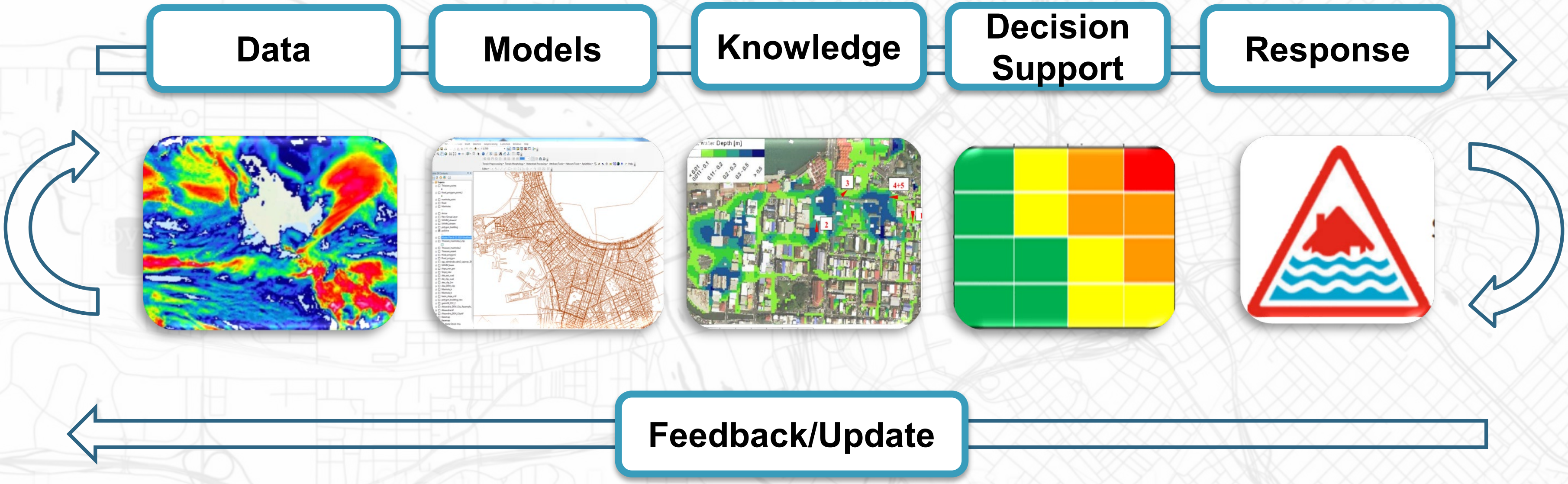
- Increased urban drivers
- Population growth
- Increased frequency & intensity of rainfall events
- Aging infrastructure

- Sensitive to rainfall intensity/spatial variability
- Short time of concentration
- Harder to predict and shorter lead-times
- Difficult to model processes
- High spatial and temporal data requirements



Anticipatory Flood Management

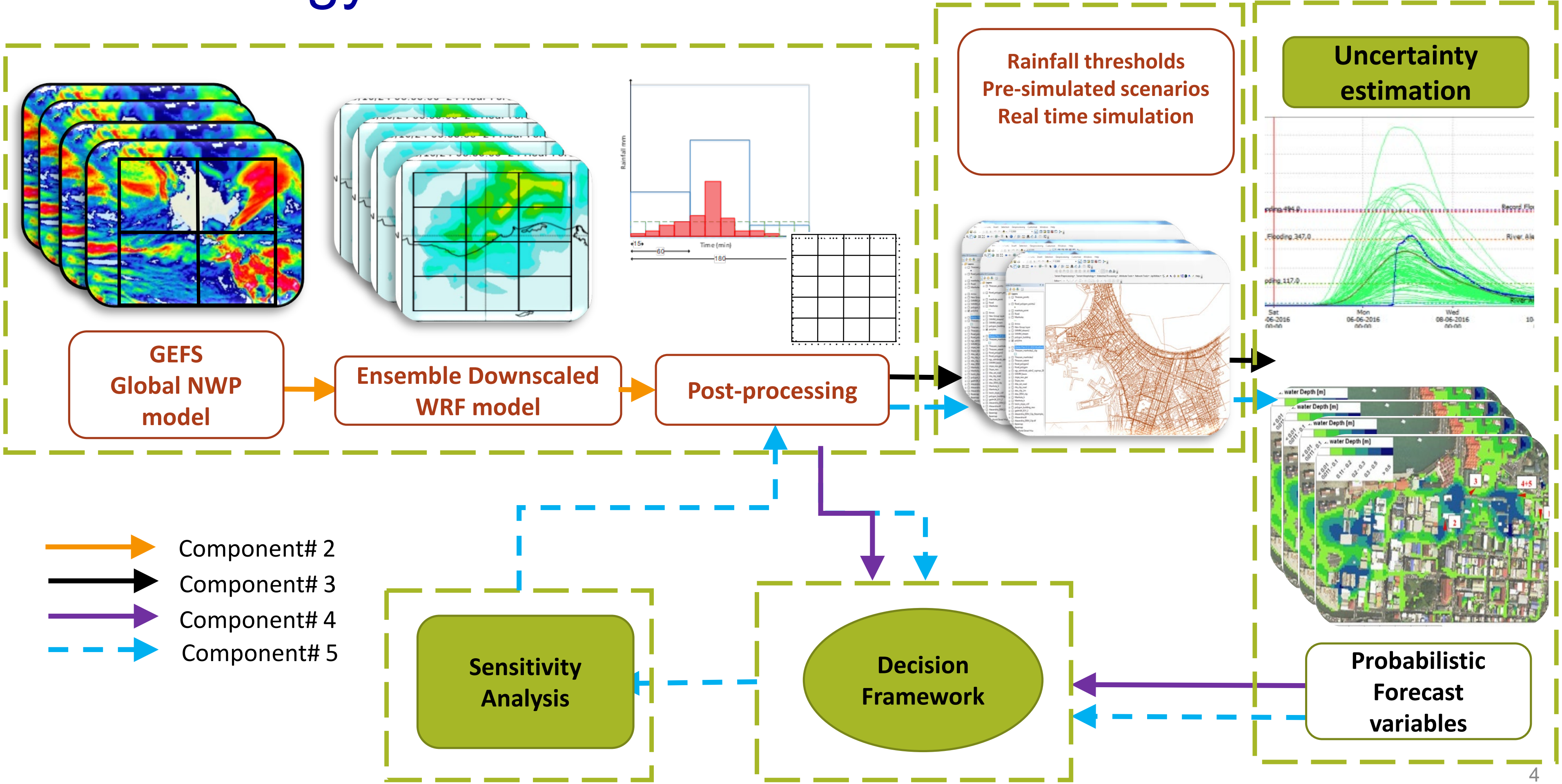
Hybrid and low-regret flood mitigation measures adaptable to uncertain external drivers



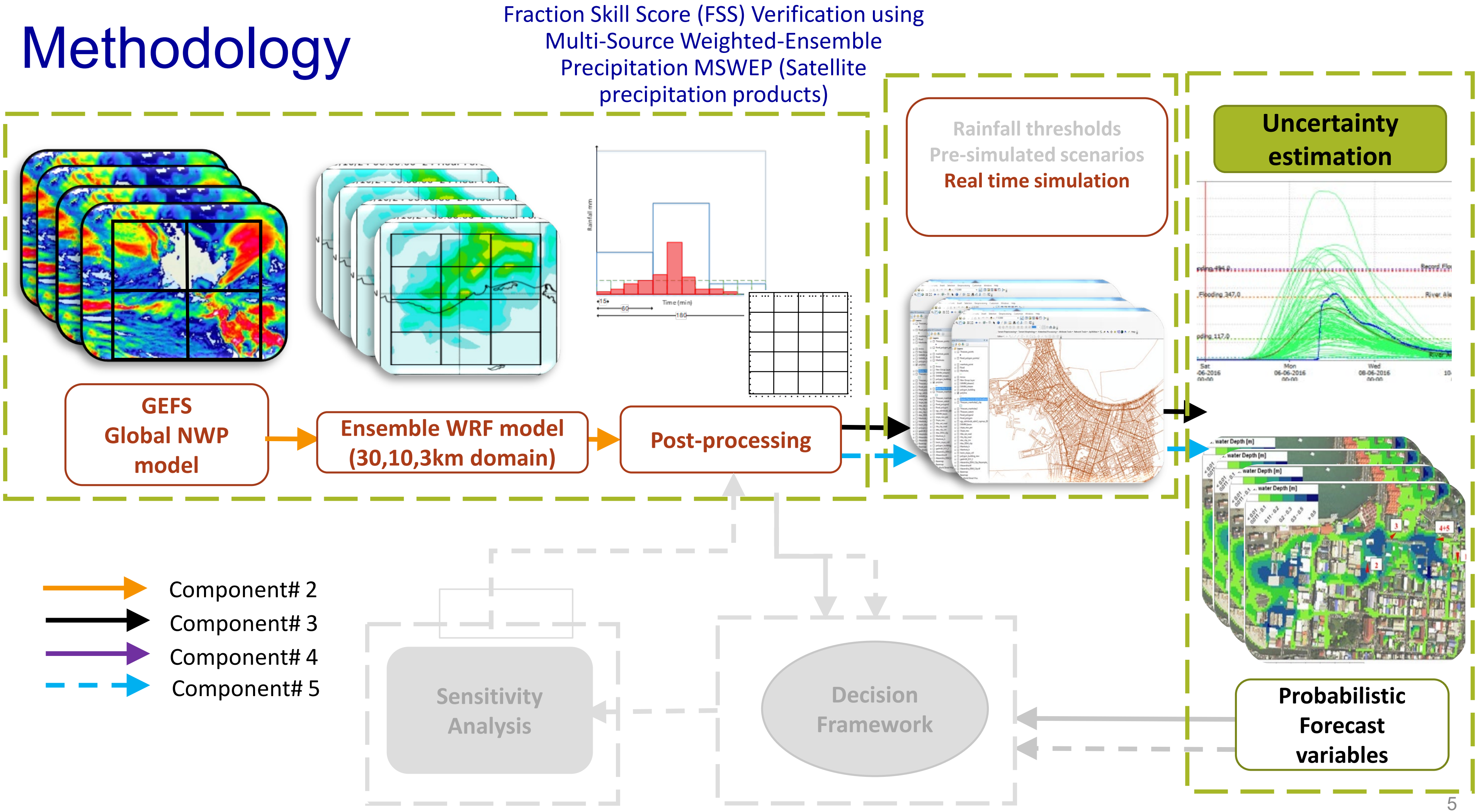
The is a cascading effect down the forecast chain

Understanding the limit of your input data and how it contributes to overall uncertainty in decision making for local scale actions

Methodology

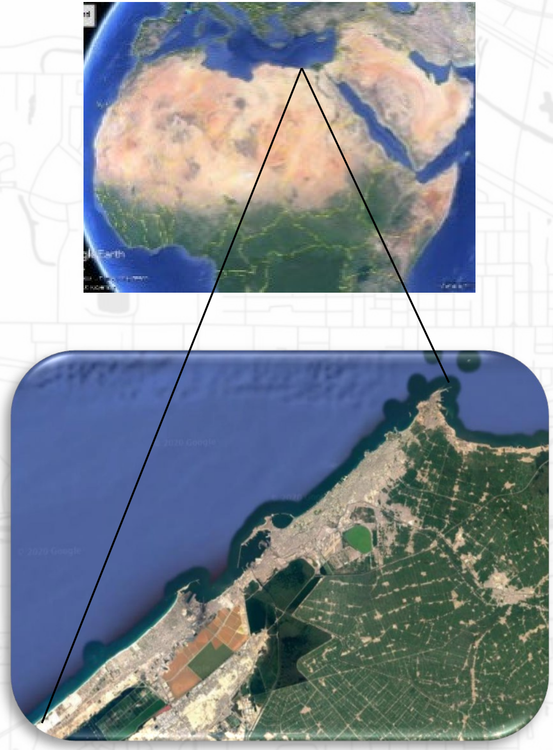


Methodology



Alexandria City, Egypt (data-scarce)

The Mediterranean coastal city experiences flooding due to annual winter storms.



In 2015 Experienced "worst flooding" due to extreme rainfall, deficiencies in the urban drainage infrastructure and high vulnerability to flooding.

At present:

- No formalised flood forecasting system
- Few rainfall gauges in the city
- Limited historical rainfall & flood records
- Daily rainfall resolution
- No radar available
- Lack of flow data to calibrate models
- Coarse terrain model
- Limited Impact data

High Resolution Precipitation for Pluvial Flood Forecasting in the urban data scarce city of Alexandria, Egypt

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...und

...cities around the world, ...are needed to reduce ...ion support before an

...(NWP)s ...temporal

...models resolve weather ...les and sub-daily temporal resolutions ...in more accurate forecast but instead ...putational requirements

...data-scarce regions additional challenges persist with ...cation of forecast due to a lack of high resolution observed ...all and spatial data

Research Questions

- Does modelling at smaller grid resolutions improve forecast skill?
- Can WRF forecast be used for urban flood forecasting?

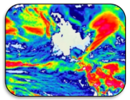
The main objective of this analysis is to understand at what scales is a WRF forecast useful for urban scale model

Case Study

The coastal city of Alexandria in Egypt and its neighbouring region have an arid climate but experience flooding due to migratory cyclones and fronts approaching from the west over the Mediterranean Sea. Floods cause disruption of traffic throughout the city and damage to properties. The drainage system comprises a combined sewer network which discharge at treatment plants via lift stations.

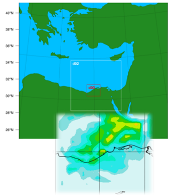
Model set up & Data

- The Weather Research Forecasting (WRF) convection-permitting model was set up using three domains. GFS 0.25 grid (~27km) was used as forcing boundary conditions. The MIKE urban drainage model is set up using the existing sewer drainage network for the El Gomork district (5km2).



Forcing boundary conditions

Global Forecasting System (GFS) 0.25° grid (~27km), 3hourly
Lead times: 24 & 48 hrs
Event: Oct 25th 2015

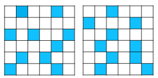


WPS & WRF pre-configuration (WPS 4.1)

D1 -10km (320 x 270 grid points)
D2 - 3.3 km (300 x 300 grid points)
D3 -1.1 km (250 x 250 grid points)

Parameterisations

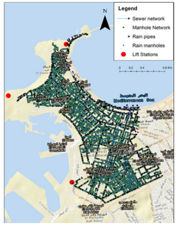
Single-moment 6-class WSM6 scheme
Rapid Radiative Transfer Model (RRTM)
Dudhia scheme
Yonsei University scheme
Land Surface Model scheme
Cumulus physics
No cumulus scheme (R1)
Grell-Freitas cumulus (R2)
Spin up -12 hours



$$FSS = 1 - \frac{\left[(P_{fcst} - P_{obs})^2\right]}{(P_{fcst}^2) - (P_{obs}^2)}$$

Performance evaluation

Multi-Source Weighted-Ensemble Precipitation (MSWEP) (0.1° reanalysis)
Fraction Skill Score (FSS) neighbourhood spatial verification
RMSE
Bias



Urban Flood Modelling

1D hydrodynamic MIKE urban + model
WRF rainfall input D1 & D3 for the 24hr leadtime only
Model was calibrated using flood observations for satellite derived MSWEP rainfall.
Results were validated using 1D and 1D/2D results for node flooding using MSWEP rainfall

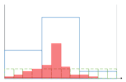


Figure 1. Methodology and data used for the WRF, rainfall forecast validation and Mike urban plus

Performance Evaluation & Results

- Results were evaluated for 48 hour accumulations for Domain 1 (10km grid) and Domain 3 (1.11km grid) at the 48 and 24 hour LT over a 10,000km^2 area.
- Thresholds were selected based on previous analysis of critical rainfall thresholds. Forecast performed better with the shorter lead time
- The 10km (D1) grid resolution has a higher skill.
- The scale aware cumulus scheme also performed better with a lower RMSE
- The no scheme resulted in an overestimation of the forecast and lower skill detecting accumulations over 50mm (extreme rainfall)

Table 1. Fraction Skill Score for different thresholds and Root Mean Square Error. for 48 hour accumulation

No cumulus scheme (Run1)

		Fraction Skill Score					RMSE
Rainfall Thresholds mm		≥ 1	≥12	≥20	≥32	≥50	mm
Leadtime	D1_48hrs	1.00	0.75	0.71	0.64	0.25	17.37
	D3_48hrs	0.97	0.97	0.98	0.60	0.20	22.91
	D1_24hrs	1.00	0.99	1.00	0.98	0.67	10.82
	D3_24hrs	1.00	0.99	0.99	0.95	0.69	13.75

Scale aware cumulus scheme (Run2)

		Fraction Skill Score					RMSE
Rainfall Thresholds mm		≥ 1	≥12	≥20	≥32	≥50	mm
Leadtime	D1_48hrs	0.99	0.46	0.14	0.06	0.00	22.36
	D3_48hrs	0.89	0.64	0.54	0.17	0.47	22.60
	D1_24hrs	0.99	0.98	1.00	1.00	0.99	7.51
	D3_24hrs	1.00	0.99	1.00	1.00	0.99	8.01

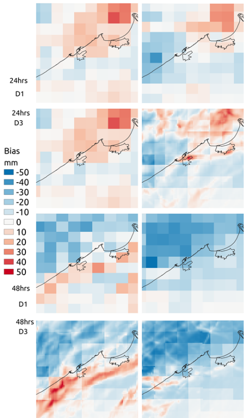


Figure 2. Forecast Bias. R1 has a tendency to over forecast as well the smaller spatial resolution D3.

Res...

- MIKE Urban model was run usin... D3 for R2 at the 24hr LT to eval... against previous satellite-deriv... more rainfall variability and m... the flooding detected with th...

Figure 3 Rainfa... a single grid w...

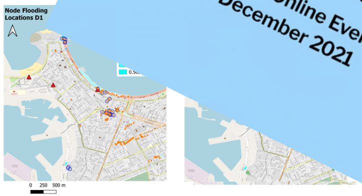


Figure 4 Comparison of max node flooding for D1, D3 and satellite-derived rainfall. 1D/2D flood locations used to valid flood forecast locations. More locations were detected for D3 (171 flooded nodes) compared to D1(33 flooded nodes). Calibration run (133 flooded nodes)

Conclusions & Future research

- The main objective of this analysis is to understand at what scales a WRF forecast is useful for urban scale modelling.
- The analysis found both scales show good skill but there was no significant improvement in FSS between the 10km and 1.1km grid over a ~1000km2 area
- The choice of cumulus scheme had a greater effect with the Grell-Freitas scheme performing better than no cumulus scheme and reduced skill at longer lead times
- The 10km grid did have a lower RMSE score but the spatially distributed rainfall of D3 had better agreement with observed rainfall and 1D/2D model results.
- This illustrates the importance of still having high resolution rainfall inputs for urban modelling. Results are expected to vary with the size the study area
- Forecast are verified against a 0.1 observed which is a limitation of the study but serves has substitute in data scarce regions.

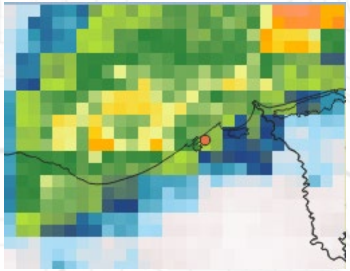
Future Research

- Future research will focus on carrying out hindcast analyses for other events.
- Using ensemble rainfall forecast for urban modelling to assess the uncertainty in the forecast
- Use of value of information approaches to evaluate the value of forecast for decision making in urban data scare regions.

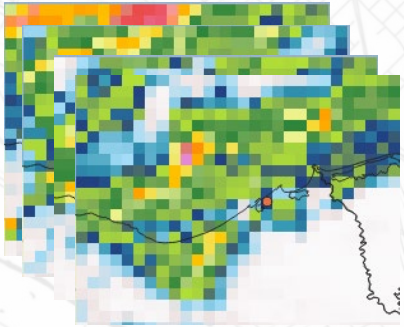
WRF Ensemble Results (Oct 2015)

(mm)	0–11.99	12–19.99	20–31.99	>32
Hazard class 2011	No to minimal flooding	Minor flooding	Significant flooding	Severe flooding

Young et al.,2021

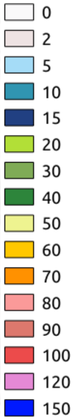


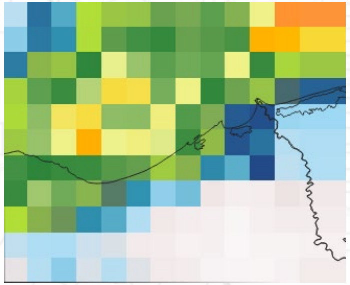
MSWEP ~0.1 – 48hr accu



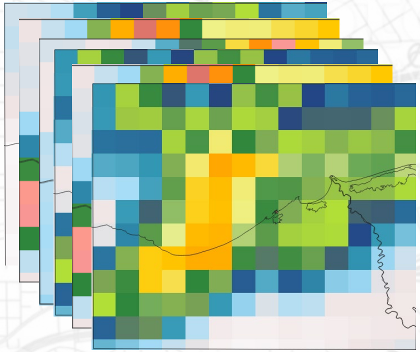
21 ensembles WRF ~ 0.1

Rainfall mm

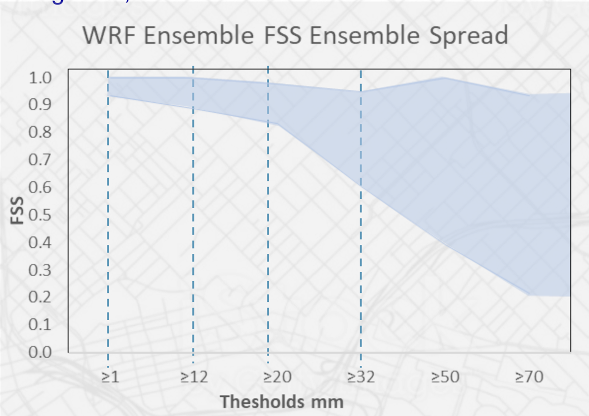


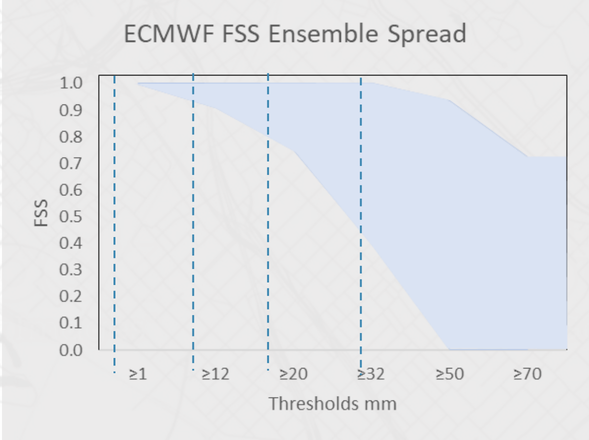


MSWEP ~0.2 – 48hr accu



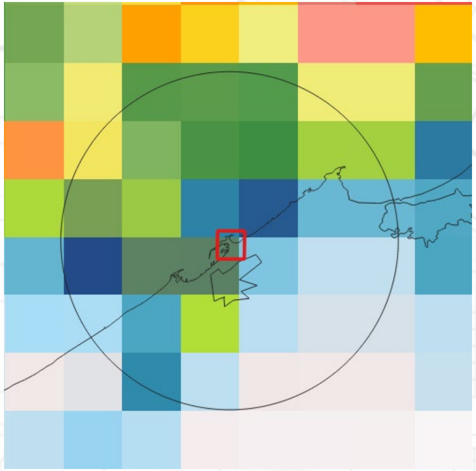
50 ensembles ECMWF ~ 0.2





MSWEP V2 global 3-hourly 0.1° precipitation - https://doi.org/10.1175/BAMS-D-17-0138.1
GEFS archive: https://www.ncei.noaa.gov/products/weather-climate-models/global-ensemble-forecast
ECMWF -Ensemble Atmospheric model accessed via MARS

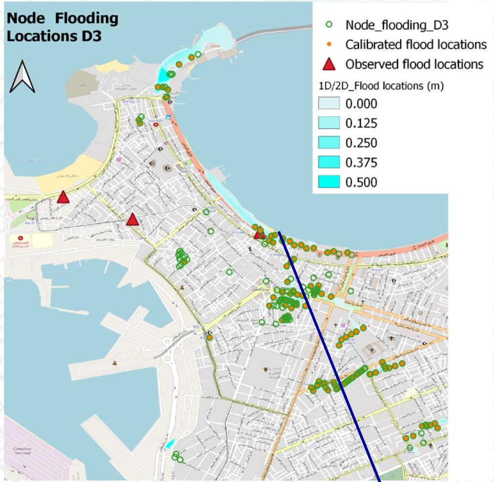
Urban Model Results

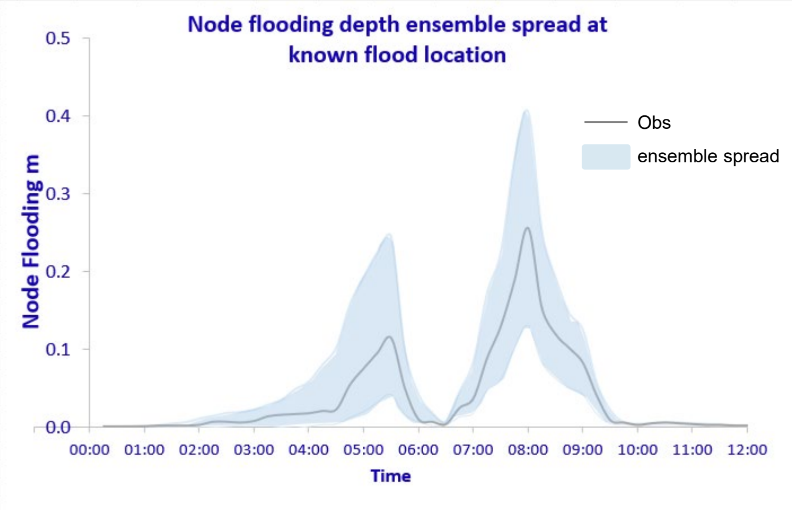


Neighborhood post-processing approach
95 percentile within a 30km radius (Golding et al., 2016, Böing et., al 2020)

1D MIKE urban model ~5km2

57% of ensembles produced flooding at nodes in excess of observed rainfall.





Conclusions

- Challenges of pluvial flood forecasting (FF) in data scarce regions: **resolutions**, **modeling** and **verification**
- There are **limits** of the **input data** and it contributes to overall **uncertainty**
- Ensembles show some degree of **spatial** skill compared with MSWEP but it varies with **thresholds**
- **Wide spread** and **high uncertainty** in the node flooding but is it still **useful** for **decision making?**

Future work

- Analyse additional rainfall events over a winter season
- Revisit forecast scales needed for urban modelling
- Use probability distributions in a decision model