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Investing in Opportunities

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EDITED BY **AUDE MULARD**, ENPC

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BLOCK 1

ULTRA-FAST & HIGH RESOLUTION RAINFALL MEASUREMENT FOR AIRPORT RUNWAY EXCURSION WITH SOLID-STATE ELECTRONIC SCANNING RADAR

FREDERIC BARBARESCO, ADVANCED RADAR CONCEPTS BUSINESS UNIT, THALES AIR SYSTEMS, FRANCE, FREDERIC.BARBARESCO@THALESGROUP.COM

On Airport, a runway excursion occurs when an aircraft departs the runway in use during the take-off or landing run. Main factor influencing runway excursion accidents is Runway contaminant (water, snow, ...) on pavement which is detrimental to the friction characteristics of the pavement surface. In the framework of European FP8 "Future Sky - Safety" project, THALES Air Systems proposes to develop a ground segment of Runway Excursion Prevention System based on Airport X-band Radar and Water Runoff model. The cumulative predicted Rain on Runway based on Ultra-Fast High Resolution Radar is used with a prior mapping of runway slope and texture. This 30 minutes forecast of runway contaminant based on Solid-state Electronic scanning X-band radar could be used by the pilot to secure the landing phase with a precise estimation of braking capacity (ROPS: Runway Overrun Prevention System) in order to reduce risks of runway excursion, and to select in coordination with ATC the exit taxiway to reduce the Runway Occupancy Time.

This new generation radar for airport uses "pulse compression" to increase range resolution, and electronic scanning to improve update rate.

ALTERNATIVE BUSINESS MODEL HYPOTHESES FOR WIDESPREAD DEPLOYMENT OF X BAND RADARS

ERIC KNAPP, UNIVERSITY OF MASSACHUSETTS, KNAPP@ECS.UMASS.EDU
DAVID MCLAUGHLIN, UNIVERSITY OF MASSACHUSETTS, MCLAUGHLIN@ECS.UMASS.EDU
ROBERT PALUMBO, RAYTHEON COMPANY, ROBERT_A_PALUMBO@RAYTHEON.COM
RICHARD MORO, RAYTHEON COMPANY, RICHARD_MORO@RAYTHEON.COM

In large government owned national networks, weather radars are typically separated by hundreds of kilometers. At these distances, the curvature of the earth and blockage by terrain leads to a coverage gap in the lower atmosphere. The inability to observe this region leads to inaccuracies in weather forecasting, inefficient operations in a number of industries and inaccurate warnings to severe weather. In recent years, dual-polarized X-band radars have been developed to provide augmented weather surveillance capability with higher spatial and temporal resolution radar data in specific areas that lack adequate coverage such as in Raingain and CASA. Small-scale phased array systems are an emerging technology that could allow large scale networks of X-band radars due to their low-maintenance operation and small infrastructure impact. They can be easily deployed in urban areas, or other locations where the field of view is limited. However, the cost deploying networks of phased array systems is still too cost-prohibitive for most individual end users.

This paper presents a new business model to enable the widespread use of networks of phased array systems for many different end users and application areas. The model focuses on a privately owned phased array network operating as a data service where each end user is a customer. The flexible scanning capability of phased arrays means different radar missions for each customer can be supported simultaneously. Scanning and waveform strategies could be tailored to meet each customer's needs. In this model, a phased array network would be owned and operated by a single entity, and data or services would be provided to customers. Customers would receive the actionable information they need without incurring the high upfront infrastructure costs. We seek Raingain conference participant reactions to the value proposition, customer segments, key resources, activities, and other elements of our hypothesized business model.

BLOCK 2

DEVELOPMENT OF HIGH RESOLUTION SPATIO-TEMPORAL RADAR DATA USING A NETWORK OF OPERATIONAL POLARIMETRIC X-BAND RADARS

DONG-IN LEE, DEPARTMENT OF ENVIRONMENTAL ATMOSPHERIC SCIENCES, PUKYONG NATIONAL UNIVERSITY, BUSAN, KOREA, LEEDI@PKNU.AC.KR
YU-RA KIM, DEPARTMENT OF ENVIRONMENTAL ATMOSPHERIC SCIENCES, PUKYONG NATIONAL UNIVERSITY, BUSAN, KOREA, YRKIM@PKNU.AC.KR
MASAYUKI MAKI, DEPARTMENT OF RESEARCH AND EDUCATION CENTER FOR NATURAL HAZARDS, KAGOSHIMA UNIVERSITY, JAPAN, MAKI@RDC.KAGOSHIMA-U.AC.JP
JONG-HOON JEONG, FORECAST RESEARCH DIVISION, NATIONAL INSTITUTE OF METEOROLOGICAL RESEARCH, SEOUL, KOREA, JEONGJH737@KOREA.KR

Localized convective precipitation rapidly develops in a very short time and causes extreme heavy rainfall. The X-band polarimetric radar is useful to analyze the convective precipitation because it can provide polarimetric radar parameters to understand microphysical process in the precipitation. The radar observation has some limitations in detecting initial stage of rapid developing convective cell, since the radar volume scan strategy in conventional radar has been operated five minute interval.

In this study, to investigate three dimensional structure of early developing stage of convective cell, we developed the algorithm which reproduces higher resolution spatio-temporal volumetric data using the operational network of two X-band polarimetric radars. The algorithm, which is based on the linear interpolation method and the TREC method, reproduced higher resolution radar data at an interval of 1 min. and 0.2°. In addition, the mosaic of radars could be benefit for getting the more information of precipitation cells from radar observation. The algorithm was applied to radar data of convective precipitations observed in Kanto area, Japan in 2012. The new volumetric data could be recognized rapid developed echoes more detail and detected the first appearance of convective echo at upper layer. The developed spatio-temporal high resolution radar data will be useful for early detection of convective precipitation at upper layer and nowcasting or very short-term forecasting.

A REGIONAL X-BAND RADAR NETWORK

ANDREA ANTONINI, CONSORZIO LAMMA, ANTONINI@LAMMA.RETE.TOSCANA.IT
SAMANTHA MELANI, CONSORZIO LAMMA/CNR-IBIMET, MELANI@LAMMA.RETE.TOSCANA.IT
ALESSANDRO MAZZA, CONSORZIO LAMMA/CNR-IBIMET, MAZZA@LAMMA.RETE.TOSCANA.IT
ALBERTO ORTOLANI, CONSORZIO LAMMA/CNR-IBIMET, ORTOLANI@LAMMA.RETE.TOSCANA.IT
SIMONE CRISTOFORI, CONSORZIO LAMMA, CRISTOFORI@LAMMA.RETE.TOSCANA.IT
BERNARDO GOZZINI, CONSORZIO LAMMA/CNR-IBIMET, GOZZINI@LAMMA.RETE.TOSCANA.IT

In recent years precipitation monitoring by radar has undergone a remarkable expansion and development. The modern X-band radar systems offer the possibility to use advanced technologies with reduced costs compared to more common C- and S-band systems. Furthermore they have proved to be very useful monitoring instruments to assess the dynamics of precipitating systems, and their use in operational weather nowcasting systems and procedures is widespread.

Certainly, conventional weather radars still offer better performances and higher measurements accuracies as compared to X-band systems. Conversely, these latter allow to obtain much higher resolutions with, of course, reduced spatial domains and offer the considerable advantage of using very reliable technologies, compact size with virtually no impact on the landscape and extreme simplicity of installation.

In recent years, LaMMA Consortium (the Tuscany region weather monitoring center) has been implementing an X-band weather radar network, that spatially overlaps and completes the Italian weather radar network over the high Tyrrhenian area. Two radar systems have been installed: one in the Elba island and the other in the Livorno harbor. Within some months a third X-band radar will be available. Data provided by this observational network are one of the input data sources for the weather nowcasting and forecasting chain in the institutional activity of LaMMA.

In this work the preliminary results of the implemented monitoring system are presented. As the used systems are not coherent, a special effort has been made in the attempt to remove the clutter signal due to not weather echoes in the radar scans. Different algorithms have been implemented for sea and land clutter, respectively.

Finally, as the spatial coverage of this network involves areas covered by other national and extra-national weather radar systems an algorithm for data comparison and fusion has been implemented and preliminary tested for some case studies.

THE GERMAN RADAR PRECIPITATION CLIMATOLOGY AND ITS APPLICATION POSSIBILITIES

ANNA SCHMITT, DEUTSCHER WETTERDIENST, ANNA.SCHMITT@DWD.DE
THOMAS JUNGHÄNEL, DEUTSCHER WETTERDIENST
TANJA WINTERRATH, DEUTSCHER WETTERDIENST
ELMAR WEIGL, DEUTSCHER WETTERDIENST
MARIO HAFER, DEUTSCHER WETTERDIENST

Heavy rain events with its sudden character are ubiquitous phenomena in Germany. Especially in urbanized areas they can cause great damages wherefore careful planned proactive measurements in urban planning, civil protection and additionally individual self-provision measures are necessary to minimise them.

To arrange adaption measures in an effective way detailed climatological information from high resolution measurement systems is needed whereby central questions can be answered like

How are heavy rain events distributed over Germany? Are there any hotspots that can be identified?

And in a final step, is there a visible development towards a greater frequency of extreme precipitation incidents in the last 15 years in the context of climate change?

The project "Radar climatology" under the leadership of the Deutscher Wetterdienst (DWD) in cooperation with further four public authorities has therefore the aim to develop a German radar precipitation climatology.

It is based on the DWD RADOLAN (radar online adjustment) data, available since 2001.

RADOLAN combines reflectivity data of the 17 German radar stations with precipitation data of numerous German rain gauge stations resulting in a high spatio-temporal resolution (1 x1km, 1h) quantitative precipitation analysis.

By homogenising the data set, applying further correction methods and adding new rain gauge information several reanalysed data sets are established during the project.

To guarantee a real benefit for applicants importance is put on a user-specific processing as well as a user-friendly format of the results. Yet in an early project phase users are identified and workshops are conducted to find out the requirements for a smooth application of results in the field of urban planning, civil protection, agriculture and hydrology.

In the talk, first project results will be presented.

Investing in Opportunities
This project has received European Regional Development Funding through INTERREG IV B.
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BLOCK 3

THE IMPACT OF HIGH RESOLUTION INITIALIZATION OF NWP MODELS ON THEIR ABILITY TO MAKE SHORT TERM QUANTITATIVE PRECIPITATION ESTIMATES

SIJIN ZHANG, METSERVICE OF SINGAPORE
GEOFF AUSTIN, AUCKLAND UNIVERSITY
LUKE SUTHERLAND-STACEY, WEATHERRADAR.CO.NZ

(Very) short range quantitative precipitation forecasting (QPF) plays an important role in both meteorological and hydrological risk management in New Zealand. Since New Zealand is an island country that is surrounded by the Tasman Sea and South Pacific Ocean, most high impact weather systems, especially heavy rainfall systems, usually initialize and develop in the regions where there are only satellite observations of cloudiness and rainfall. Experiments are described which combine satellite observations with radar in regions close to the coast to improve the prediction of rainfall in both in the nowcasting domain (0-3 hrs) and by initializing WRF at high resolution in the subsequent several hours. Comparisons with different models with and without high resolution initialization are presented. It is concluded that for short range QPF a simple model that is properly initialized performs consistently better than a more sophisticated model initialized at low resolution.

WEATHER RADAR DATA ASSIMILATION FOR HIGH-RESOLUTION QUANTITATIVE PRECIPITATION FORECASTING AT MÉTÉO-FRANCE: STATUS AND PLANS

OLIVIER CAUMONT, CNRM-GAME, TOULOUSE, FRANCE, OLIVIER.CAUMONT@METEO.FR
CLOTILDE AUGROS, CNRM-GAME, TOULOUSE, FRANCE AND METEO-FRANCE, TOULOUSE, FRANCE
LUCAS BESSON, LATMOS/IPSL, GUYANCOURT, FRANCE
PASCAL BROVELLI, METEO-FRANCE, TOULOUSE, FRANCE
VERONIQUE DUCROCQ, CNRM-GAME, TOULOUSE, FRANCE
NICOLAS GAUSSIAT, METEO-FRANCE, TOULOUSE, FRANCE
JOËL HOFFMAN, METEO-FRANCE, TOULOUSE, FRANCE
JEAN-FRANÇOIS MAHFOUF, CNRM-GAME, TOULOUSE, FRANCE
THIBAUT MONTMERLE, CNRM-GAME, TOULOUSE, FRANCE
JACQUES PARENT DU CHATELET, CNRM-GAME, TOULOUSE, FRANCE
PIERRE TABARY, METEO-FRANCE, TOULOUSE, FRANCE
ÉRIC WATTRELOT, CNRM-GAME, TOULOUSE, FRANCE

Initially dedicated to the real-time detection of precipitation, weather radars are currently used for a wide variety of applications including quantitative precipitation estimation and data assimilation into numerical weather prediction (NWP) systems. As state-of-the-art limited-area NWP systems are now able to run at horizontal resolutions of the order of one kilometre with detailed physics, radar data have become a data source of choice to improve their initial states and subsequent short-term forecasts, including in terms of quantitative precipitation.

Since December 2008, Météo-France uses the Arome NWP system operationally to elaborate short-term weather forecasts. The operational version of Arome has been upgraded in April 2015 to run at a horizontal resolution of 1.3 km over a domain centred on France and covering a large part of Western Europe. Observations are assimilated with a three-dimensional variational (3DVar) assimilation system every hour. Among a great deal of other observations, both reflectivity and Doppler velocity data from the Aramis network are assimilated operationally. Aramis is the weather radar network operated by Météo-France that covers mainland France and Corsica. It is currently composed of 27 radars in the S, C and X bands.

After reviewing the current status of radar data assimilation in Arome, the presentation will cover the on-going endeavours to i/ bridge the gap between NWP and nowcasting, ii/ assimilate data from other European countries, and iii/ assimilate novel radar data such as dual-polarization observations and refractivity.

STOCHASTIC GRIDDED MULTI-SITE SIMULATION OF HOURLY RAINFALL

TOBIAS MOSTHAF, UNIVERSITÄT STUTTGART, TOBIAS.MOSTHAF@IWS.UNI-STUTTGART.DE
SEBASTIAN HÖRNING, UNIVERSITÄT STUTTGART, SEBASTIAN.HOERNING@IWS.UNI-STUTTGART.DE
THOMAS MÜLLER, UNIVERSITÄT STUTTGART, THOMAS.MUELLER@IWS.UNI-STUTTGART.DE
ANDRÁS BÁRDOSSY, UNIVERSITÄT STUTTGART, ANDRAS.BARDOSSY@IWS.UNI-STUTTGART.DE

Rainfall time series are essential for a great variety of hydrological applications. Unfortunately rainfall time series with an adequate quality and a sufficient duration are only available for a few locations. As a response to this shortcoming, synthetically generated rainfall time series can be used.

For the generation of rainfall time series at ungauged locations a spatial interpolation of observed time series could be used. Interpolated time series would represent the mean of the rainfall values sufficiently well, but would lead to an incorrect representation of e.g. the variance or the autocorrelation. Therefore, the simulation of rainfall time series is more convenient than an interpolation procedure.

A stochastic model which is based on interpolated rainfall characteristics is used for the simulation of point wise time series. The used rainfall characteristics can be divided into two groups. One serves the reproduction of the rainfall structure (containing e.g. autocorrelation and scaling parameters) while the other contains distributions of hourly rainfall intensities.

Based on the point wise simulation gridded multi-site time series can be generated with a recently developed Random Mixing approach of spatial random fields. These multi-site time series could be used for hydraulic and polluting load simulations to dimension drainage systems or to quantify polluting loads in sewage water.

The gridded multi-site simulation of hourly rainfall values will be presented for a 18 km x 16 km study region around the city Freiburg in Southwest Germany with a spatial resolution of 1 km.

GENERATION OF 2D RAIN MAPS WITH REALISTIC PROPERTIES: METHODOLOGY AND RESULTS

NAWAL AKROUR, UNIVERSITE DE VERSAILLES SAINT QUENTIN EN YVELINES (UVSQ)/ LABORATOIRE ATMOSPHERES, MILIEUX, OBSERVATIONS SPATIALES (LATMOS), NAWAL.AKROUR@LATMOS.IPSL.FR
CECILE MALLET, UNIVERSITE DE VERSAILLES SAINT QUENTIN EN YVELINES (UVSQ)/ LABORATOIRE ATMOSPHERES, MILIEUX, OBSERVATIONS SPATIALES (LATMOS), CECILE.MALLET@LATMOS.IPSL.FR
LAURENT BARTHES, UNIVERSITE DE VERSAILLES SAINT QUENTIN EN YVELINES (UVSQ)/ LABORATOIRE ATMOSPHERES, MILIEUX, OBSERVATIONS SPATIALES (LATMOS), LAURENT.BARTHES@LATMOS.IPSL.FR
AYMERIC CHAZOTTES, UNIVERSITE DE VERSAILLES SAINT QUENTIN EN YVELINES (UVSQ)/ LABORATOIRE ATMOSPHERES, MILIEUX, OBSERVATIONS SPATIALES (LATMOS), AYMERIC.CHAZOTTES@LATMOS.IPSL.FR

The Precipitations are due to complex meteorological phenomenon's and unlike other geophysical constituents such as water vapor concentration they present a relaxation behavior leading to an alternation of dry and wet periods. Thus, precipitations can be described as intermittent process. The spatial and temporal variability of this phenomenon is significant and covers large scales. This high variability can cause extreme events which are difficult to observe properly because of their suddenness and their localized character. For all these reasons, the precipitations are therefore difficult to model.

This study aims to adapt a one-dimensional time series model previously developed by the authors [Akrour et al., 2013, 2015] to a two-dimensional rainfall generator. The original time series model can be divided into 3 major steps: rain support generation, intra event rain rates generation using multifractal and finally calibration process. We use the same kind of methodology in the present study. Based on dataset obtained from meteorological radar of Météo France with a spatial resolution of 1 km x 1 km we present the used approach: Firstly, the extraction of rain support (rain/no rain area) allowing the retrieval of the rain support structure function (variogram) and fractal properties. This leads us to use either the rain support modelisation proposed by [Schleiss et al., 2014] or directly real rain support extracted from radar rain maps. Then, the generation (over rain areas) of rain rates is made thanks to a 2D multifractal Fractionnally Integrated Flux (FIF) model [Schertzer et al. 1987]. This second stage is followed by a calibration/forcing step (forcing average rain rate per events) added in order to provide rain rate coherent with observed rain-rate distribution. The forcing process is based on a relation identified from the average rain rate of observed events and their surfaces. Our model has 12 parameters, 4 are universals and 8 depend on the climatic area.

The presentation will first explain the different steps presented above, then some results illustrating the simulator's capabilities will be provided. They show that the simulated two-dimensional fields have coherent statistical properties in term of cumulative rain rate distribution but also in term of power spectrum and structure function with the observed ones at different spatial scales (1, 4, 16 km2) involving that scale features are well represented by the model.

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SPACE-TIME WEATHER AND MACROWEATHER PRECIPITATION MODELS

S. LOVEJOY, PHYSICS DEPARTMENT, MCGILL UNIVERSITY, MONTREAL, CANADA
M. I. P., DE LIMA, INSTITUTE OF MARINE RESEARCH (IMAR) AND MARINE AND ENVIRONMENTAL SCIENCES CENTRE (MARE), PORTUGAL; AND DEPARTMENT OF CIVIL ENGINEERING,
UNIVERSITY OF COIMBRA, COIMBRA, PORTUGAL

In addition to the familiar weather and climate regimes, over the range of time scales from about 10 days to 30–100 years, there is an intermediate “macroweather” regime characterized by negative temporal fluctuation exponents; implying that fluctuations tend to cancel each other out, that averages tend to converge.

We first review some of the more familiar space-time scaling properties of precipitation in the weather regime comparing various precipitation products (gauges, satellite radar and reanalyses) and the corresponding cascade (Fractionally Integrated Flux, FIF) models. We then show theoretically and numerically how these weather regime models can be extended into the macroweather regime so that macroweather precipitation can be modelled by the stochastic weather-climate model (the Climate Extended Fractionally Integrated Flux, model, CEFIF) first proposed for macroweather temperatures.

However the CEFIF model is theoretically and numerically difficult to manage. We therefore propose a simplified stochastic model in which the temporal behavior is modeled as a fractional Gaussian noise but the spatial behaviour as a multifractal (climate) cascade: a spatial extension of the recently introduced Scaling LInear Macroweather model, SLIM. Both the CEFIF and this spatial SLIM model have a property often implicitly assumed by climatologists: that climate statistics can be “homogenized” by normalizing them with the standard deviation of the anomalies. Physically, it means that the spatial macroweather variability corresponds to different climate zones that multiplicatively modulate the local, temporal statistics. This simplified macroweather model provides a framework for macroweather forecasting that exploits the system’s long range memory and spatial correlations. We test factorization and the model with the help of three centennial, global scale precipitation products that we analyze jointly in space-time.

BLOCK 4

RADARS AND WEATHER NOWCASTS ADDING VALUE TO WASTEWATER MANAGEMENT

MORTEN GRUM, KRUGER, DENMARK, MG@KRUGER.DK

While radar and weather modelling science is still in raging development, products and solutions have already been developed and are today adding value to urban drainage management. Flow forecasts using radar data as input are ensuring optimized wet weather management at wastewater treatment plants and reducing combined sewer overflow through risk based network wide real time control. Combinations of radar data and numerical weather modelling are providing real time flood forecasts for improved contingency management during extreme precipitation. Ensemble precipitation forecasts are playing an essential role in saving energy costs by coupling wastewater management to the smart-grid. The technologies behind these products include advanced nowcasting techniques, stochastic modelling, data assimilation, real time risk assessment and automated optimization procedures. Practical experience with these technologies will be presented through selected real world cases.

ACCURATE MEASUREMENT OF PRECIPITATION BY X-BAND RADAR: HYDROLOGICAL APPLICATIONS IN THE MARITIME ALPS

E. MOREAU, NOVIMET, EMOREAU@NOVIMET.COM
E. LE BOUAR, NOVIMET, ELEBOUAR@NOVIMET.COM
P. ESNAULT, CG06 - DIRECTION ENVIRONNEMENT ET GESTION DES RISQUES, PESNAULT@CG06.FR

For several years the X-band weather radar installed at the Mont Vial has measured precipitation operationally in the Maritime Alps for risk management topics, forecasts and flood alerts and urban water management.

The purpose of this presentation is first to focus on the radar measurement constraints in complex mountainous area and the technical choices adopted to ensure accurate measurement of precipitation.

Several types of X-band weather radar configurations (with or without radome, various sensitivities, single or dual polarisation) were simulated from Hydrix® radar observations and results in terms of accumulation precipitation were compared to ground stations.

Second, we will focus on the variety of applications related to precipitation measurement, focusing on a few emblematic storms occurred recently in the department.

SPATIO-TEMPORAL RAINFALL INPUT RESOLUTION REQUIREMENTS FOR URBAN DRAINAGE MODELLING: A MULTI-CATCHMENT INVESTIGATION

SUSANA OCHOA-RODRIGUEZ[A,1*], LI-PEN WANG[B,2], AUGUSTE GIRES[C,3], RUI DANIEL PINA[A,4], RICARDO REINOSO-RONDINEL[D,5], GUENDALINA BRUNI[E,6], ABDELLAH ICHIBA[C,7], SANTIAGO GAITAN[E,8], ELENA CRISTIANO[E,9], JOHAN VAN ASSEL[E,10], STEFAN KROLL[E,11], DAMIAN MURLÀ-TUYLS[B,12], BRUNO TISSERAND[G,13], DANIEL SCHERTZER[C,14], IOULIA TCHIGUIRINSKAIA[C,15], CHRISTIAN ONOF[A,16], PATRICK WILLEMS[B,17] MARIE-CLAIRE TEN VELDHUIS[E,18]

[a]Urban Water Research Group, Department of Civil and Environmental Engineering, Imperial College London, Skempton Building, London SW7 2AZ, UK
[b]Hydraulics Laboratory, KU Leuven, 3001, Heverlee (Leuven), Belgium
[c]Laboratoire Eau Environnement et Systèmes Urbains (LEESU), École des PontsParisTech, 6-8 avenue Blaise Pascal, Cité Descartes, Champs sur Marne, 77455 Marne-la-Vallée cedex 02, France
[d]Department of Geosciences and Remote Sensing, Faculty of Civil Engineering and Geosciences, Delft University of Technology, PO Box 5048, 2600 GA Delft, the Netherlands
[e]Department of Water Management, Faculty of Civil Engineering and Geosciences, Delft University of Technology, PO Box 5048, 2600 GA Delft, the Netherlands
[f]Aquafin NV, Dijkstraat 8, 2630 Aartselaar, Belgium
[g]Veolia Environment Research and Innovation, Chemin de la Digue, BP 76, 78603 Maisons Laffitte Cedex, France

[1*]**Corresponding author:** s.ochoa-rodriguez@imperial.ac.uk / +44 (0)20 7594 6018;
[2]Lipen.Wang@bwk.kuleuven.be; [3]auguste.gires@leesu.enpc.fr; [4]r.pina13@imperial.ac.uk;
[5]r.r.reinosorondinel@tudelft.nl; [6]G.Bruni@tudelft.nl; [7]abdellah.ichiba@leesu.enpc.fr; [8]S.Gaitan@tudelft.nl;
[9]E.Cristiano@tudelft.nl; [10]johan.vanassel@aquafin.be; [11]stefan.kroll@aquafin.be;
[12]Damian.MurlaTuyls@bwk.kuleuven.be; [13]bruno.tisserand@veoliaeau.fr; [14]Daniel.Schertzer@enpc.fr;
[15]ioulia.tchiguirinskaia@enpc.fr; [16]c.onof@imperial.ac.uk; [17]Patrick.Willems@bwk.kuleuven.be;
[18]j.a.e.tenveldhuis@tudelft.nl

Urban hydrological applications require high resolution precipitation and catchment information in order to well represent the spatial variability, fast runoff processes and short response times of urban catchments. Although fast progress has been made over the last few decades, including increasing use of weather radars, the resolution of the currently available rainfall estimates (typically 1 x 1 km2 in space and 5 min in time) may still be too coarse to meet the spatial-temporal scales characteristics of urban catchments. In the framework of the EU Interreg RainGain project, a collaborative study was conducted which investigated the impact of rainfall estimates for a range of spatial and temporal resolution combinations on the outputs of operational semi distributed models of seven urban catchments in North-West Europe. Nine storm events measured by a dual polarimetric X-band weather radar, located in the Cabauw, the Netherlands, were selected for analysis. Based on the original radar estimates, at 100 m and 1 min resolutions, 15 different combinations of coarser spatial and temporal resolutions, up to 3000 m and 10 min, were generated. These estimates were applied to models of the urban catchments, all of which have similar size (between 3 and 8 km2), but different morphological, hydrological and hydraulic characteristics. Results were analysed in the light of storm and catchment characteristics. Three main features were observed in the results: (1) the impact of rainfall input resolution decreases as catchment drainage area increases; (2) in general, variations in temporal resolution of rainfall inputs affects hydrodynamic model results more strongly than variations in spatial resolution; (3) spatial and temporal resolution of rainfall input estimates strongly interact and cannot be changed independently. Based on these results, initial models to quantify the impact of rainfall input resolution as a function of catchment size and spatial-temporal characteristics of storms are proposed and discussed.

2D HYDRODYNAMICS OF PEARL RIVER ESTUARY USING D-FLOW FLEXIBLE MESH

LI LI, INSTITUTE OF PHYSICAL GEOGRAPHY, UNIVERSITY OF HAMBURG, LI.LI@UNI-HAMBURG.DE

We apply a sophistic hydraulic model called D-Flow Flexible Mesh, to analyse the hydraulic processes between River Estuaries and the Marine System in Pearl River Delta, in order to better understand the tide and flooding inundation on the coastal areas. Pearl River Delta is one of the most complicated river networks and the most developed megalopolises worldwide. The coastal area of the Pearl River delta is more vulnerable to the natural disasters, such as flooding, landslides and weather extremes. This latest model is the first application in such a big domain and such a complicated river network in the worldwide.

We have set up the D-Flow model for the Pearl River Delta, covering the domain between 15.54 - 23.94oN and 108.95 - 117.07 o E. Our domain includes the Pearl River distributaries and approximately 100 km sea area. We simulate the hydraulic interaction process in wet and dry season of the year 1999, 2002 and 2009. We choose different roughness scenarios as the sensitive test of the model in order to calibrate the model performance. Typhoon Utor in 2001 year is examined. The inundation area is validated against satellite image.

This research shows that the discharge distributions depend strongly on temporal hydrodynamic processes influenced by seasons. We could see the model performance differently in the upstream for different roughness as well. Regarding the subtidal discharge in the upstream part of the Pearl River Delta, the discharge from West River is more than North River, which affect the flow direction at cross section to eastwards. Influencing tidal propagation can also have an effect on floods in the Delta. Wet season has much influence on the subtidal discharge in the upstream part of the Pearl River Delta and in case of relative high lateral sources of river discharge on the downstream bays.

FROM RAINFALL FIELDS TO FLOOD HAZARD AND FLOOD RISK: ADVANTAGES OF (SEMI-) CONTINUOUS SIMULATION

CHRISTINE POULARD, IRSTEA, UNITE DE RECHERCHE HYDROLOGIE-HYDRAULIQUE, CHRISTINE.POULARD@IRSTEA.FR
ETIENNE LEBLOIS, IRSTEA, UNITE DE RECHERCHE HYDROLOGIE-HYDRAULIQUE
JEAN BAPTISTE FAURE, IRSTEA, UNITE DE RECHERCHE HYDROLOGIE-HYDRAULIQUE
ALEXIA CHIAVARINO, IRSTEA, UNITE DE RECHERCHE HYDROLOGIE-HYDRAULIQUE

Too often, flood hazard diagnostic and assessment of the effect of flood reduction strategies relied on one "design flood", either historical or probabilistic. The 2007 European Flood Directive should help generalizing better practices, by demanding 3 probabilistic flood hazard maps in each Area of Potentially Significant Flood Risk, and by recommending economic analyses to define flood reduction strategies.

However, considering 3 return periods is only a step towards real regime-wise studies. Moreover the widely used reach-wise approaches do not take correctly into account the effect of the hydraulic infrastructures at catchment scale. Both scientific and operational communities investigate alternative methods retaining the inter- and intra-event variability, and taking into account the effect of hydraulic structures.

Here, we present a chain of tools for continuous simulation. Stochastic distributed rainfall fields are fed into a rainfall-runoff model, which in turn feeds a hydraulic model. Nowadays, computing tools can cope with very long flood time-series, from which flood quantiles can be derived at any point. In its present state, our prototype can highlight the drawbacks of reach-wise approaches, and help advocate the use of this approach, for urban floods or for catchment-scale management.

We shall discuss the perspectives to better take into account extreme events, and to work at larger scales, where several weather types exist on different parts of the catchment.

We shall also discuss the interest of estimating expected damages from the flood hazard time series, using damage curves. From the damage time-series, Average Annual Damages (AAD) can be derived. In theory, AAD are ideal indicators of flood risk and, by difference of scenarios, can help assess the efficiency of flood risk reduction measures but also of a whole strategy. In practise, it is important to know their drawbacks to make the best use of them, among other indicators.

BLOCK 5

REAL TIME RADAR DATA CORRECTION FOR OPERATIONAL SEWER MANAGEMENT IN THE CITY OF HAMBURG

DR. STEFAN KRÄMER, INSTITUTE FOR TECHNICAL AND SCIENTIFIC HYDROLOGY LTD., HANOVER, GERMANY, S.KRAEMER@ITWH.DE
ANDREAS KUCHENBECKER, HAMBURGWATER, HAMBURG, ANDREAS.KUCHENBECKER@HAMBURGWASSER.DE

General objectives for using radar rainfall information in the field for sewer management in the City of Hamburg are:

- Increased insight into hydraulic system behaviour and model calibration
- Assessment and proof of extreme rainfall events
- Real time control of sewer systems to minimize discharges
- Support of sewer system operation and maintenance

However, the highly dynamic rainfall runoff processes in urban catchments and sewer systems require radar rainfall information with a high level of accuracy and reliability. In addition radar rainfall information must be provided in real time to meet the requirements for operational sewer management.

C-band radar measurements are affected by physical effects such as rain induced radar signal attenuation and radar reflectivity has to be converted into the target figure rain intensity. In consequence C-band radar rainfall underestimates the “true” rainfall at a magnitude of 50%. The traditional method: radar data adjustment by means of a network work of rain gauges is not appropriate for urban water management since its quality depends on the density of the gauge network and storm characteristics and it does not work in real time.

The alternative is the correction of the physical effects on radar measurements. The proposed correction methodology (for single polarized radar data) accounts for the following physical influences:

1. Clutter
2. Wet-radome attenuation
3. Rainfall induced attenuation of radar signal
4. R-Z conversion (based on real time disdrometer observations)

Results for rainfall events of different character (convective / stratiform) show that the real time correction method is able to reduce systematic errors (bias) in radar rainfall estimates within bounds of ±20% under- / overestimation when validated with gauge observations.

It will be demonstrated that the remaining uncertainty in the corrected radar data is less than error of the traditional assumption of homogeneous rainfall by gauges (areal extrapolation of gauge observations).

TOWARDS REAL-TIME MODELLING OF DRAINAGE SYSTEMS WITH RADAR RAINFALL INPUTS

SØREN THORNDAHL, AALBORG UNIVERSITY, DEPARTMENT OF CIVIL ENGINEERING, DENMARK, ST@CIVIL.AAU.DK

Real time modelling and forecasting of the state and loading on a drainage system has great potential in climate change adaption solutions. There are environmental and economic potentials 1) in predicting inlet flows to waste water treatment plants in order to optimize treatment processes and 2) in real time control drainage systems of in order to minimize combined sewer overflow or other untreated discharges to receiving waters. Furthermore there are potentials in minimizing costs and impacts of urban flooding e.g. by: 3) issuing warnings, 4) real time contingency and emergency planning, or maybe 5) model-based real time control of urban water infrastructure in order to prevent flooding.

Either type of forecasts requires rainfall inputs and models in high resolution in time and space in order for the predictions to be successful and trustable. This is a key research area at Aalborg University, Denmark.

This presentation will show different Danish cases of real time modelling of drainage systems with radar data observations and nowcasts as inputs. We will highlight some of our experience with different cases and discuss issues of bias adjustment of radar data, radar rainfall extrapolation, distributed vs simple drainage systems, data resolution, observations and calibration, leadtime, ensample nowcasting, etc. We will show examples with great performance and potentials as described above, but also highlight some cases and events which has proven difficult to predict and thus needs improvement on way or the other.

HIGH RESOLUTION RADAR OBSERVATIONS FROM A MOBILE RADAR X-BAND RADAR IN SUPPORT OF URBAN WASTE WATER INFRASTRUCTURE

LUKE SUTHERLAND-STACEY, WEATHERRADAR.CO.NZ
GEOFF AUSTIN, AUCKLAND UNIVERSITY

A monitoring project was undertaken with a mobile X Band unpolarized weather radar in winter/spring of 2013 and 2014 to obtain high resolution radar observations of rainfall over the Auckland Isthmus. The study was commissioned by city authorities to supply data to support sewer and combined sewer modelling of urban wastewater systems with short response times and large fractions of impervious surfaces.

Collected radar data was calibrated against the permanent long-term rain-gauge network around the city and the resulting rainfall maps were validated against temporary rain gauges deployed in the study catchments. The radar rainfall estimates agreed well with the validation rain gauges on a point-to-point basis. Validation statistics indicating no significant long term bias between the radar and gauge measurements and a standard deviation of 1mm for 24 hour accumulations on rainy days. The R2 statistics for the radar-gauge comparison range between 0.70 and 0.96, indicating the radar has a good ability to estimate rainfall intensity variations.

The radar data also yielded extra information about the spatial distribution of rain accumulation between rain gauges on minute to minute time scales. A number of rainfall events during the study exhibited highly heterogeneous rainfall patterns. In these cases the radar was able to characterise the different amounts of rain falling into ungauged regions of the study catchments. This spatial information should prove useful for calibration and validation of the catchment models.

Examples of the resulting data and sewer model (infoworks CS) simulations driven with rain gauge or radar data are presented. Also, cases of chaotic behaviour emerging in the sewer network/ sewage treatment plant as a result of extreme localised rainfall in the city catchments are discussed.

DISTRIBUTED FLOOD FORECASTING FROM COUNTRYWIDE TO URBAN SCALES

ROBERT J. MOORE, CENTRE FOR ECOLOGY & HYDROLOGY, UNITED-KINGDOM, RM@CEH.AC.UK
STEVEN J. COLE, CENTRE FOR ECOLOGY & HYDROLOGY, UNITED-KINGDOM, SCOLE@CEH.AC.UK

Experience in the use of the Grid-to-Grid (G2G) distributed hydrological model for flood forecasting in an operational setting over Britain will be outlined. This will cover developments for countrywide 5-day "outlook" forecasting of fluvial flooding, and for short-term forecasting of rapid-response catchments - typically ungauged and of a small area – which demand a probabilistic approach with frequent forecast updates. Consideration of pluvial flooding moves to city scale, and the production of dynamic hazard maps of surface water flooding and likely impacts with the challenge of providing a nationwide capability. G2G surface runoffs are linked to the severity of surface water flooding impacts - on people, property and transport - with the help of a detailed inundation model run offline. Gridded rainfall sources, both observed and forecast in deterministic and ensemble form, used as G2G input in real-time to assess flood risk will be discussed. Applications will illustrate how G2G outputs inform national Flood Guidance Statements and have supported a pilot trial of surface water flood-risk forecasting for the Glasgow 2014 Commonwealth Games.

BLOCK 6

URBAN RAINFALL ESTIMATION IN ROTTERDAM EMPLOYING COMMERCIAL MICROWAVE LINKS

AART OVEREEM, HYDROLOGY AND QUANTITATIVE WATER MANAGEMENT GROUP, WAGENINGEN UNIVERSITY / ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE, THE NETHERLANDS, AART.OVEREEM@WUR.NL
HIDDE LEIJNSE, ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE, THE NETHERLANDS; HIDDE.LEIJNSE@KNMI.NL
REMKO UIJLENHOET; HYDROLOGY AND QUANTITATIVE WATER MANAGEMENT GROUP, WAGENINGEN UNIVERSITY, REMKO.UIJLENHOET@WUR.NL

Urban areas often lack rainfall information. To increase the number of rainfall observations in cities, microwave links from operational cellular telecommunication networks may be employed. The basic principle of rainfall estimation using microwave links is as follows. Rainfall attenuates the electromagnetic signals transmitted from one telephone tower to another. By measuring the received power at one end of a microwave link as a function of time, the path-integrated attenuation due to rainfall can be calculated, which can be converted to average rainfall intensities over the length of a link. This is particularly interesting for urban areas, where the highest density of links is usually found, and where in-situ rainfall observation is generally difficult. Or for those countries where few surface rainfall observations are available.

Although this new potential source of rainfall information has been shown to be promising, its quality needs to be demonstrated more extensively. Here we use received signal powers from microwave links in the Rotterdam region (roughly 1 million inhabitants), The Netherlands, to estimate rainfall with high spatial and temporal resolution. Rainfall maps will be presented and compared to a gauge-adjusted radar rainfall data set. Moreover, a 1-year rainfall time series from link data and gauge-adjusted C-band radar data will be compared. These good results of an application in Rotterdam, one of the cities contributing to RainGain, show that these links may be used as reference for other rainfall data, for example, those from the RainGain X-band radar in Rotterdam. Alternatively, link and radar data could be merged to obtain better urban rainfall estimates in the future.

URBAN HIGH-RESOLUTION PRECIPITATION PRODUCT FOR RAINFALL-RUNOFF SIMULATIONS: COMBINING C-BAND AND LOCAL X-BAND RADAR DATA

KATHARINA LENGFELD, CENTRE DE RECERCA APLICADA EN HIDROMETEOROLOGIA, SPAIN, KATHARINA.LENGFELD@UNI-HAMBURG.DE
MARC BERENGUER, CENTRE DE RECERCA APLICADA EN HIDROMETEOROLOGIA, SPAIN, MARC.BERENGUER@CRAHI.UPC.EDU
MARCO CLEMENS, METEOROLOGICAL INSTITUTE, UNIVERSITY OF HAMBURG, GERMANY, MARCO.CLEMENS@UNI-HAMBURG.DE
FELIX AMENT, METEOROLOGICAL INSTITUTE, UNIVERSITY OF HAMBURG, GERMANY, FELIX.AMENT@UNI-HAMBURG.DE
DANIEL SEMPERE TORRES, CENTRE DE RECERCA APLICADA EN HIDROMETEOROLOGIA, SPAIN, SEMPERE@CRAHI.UPC.EDU

Modelling precipitation induced floods and their impact on flood-prone regions is one of the biggest challenges for hydrometeorological forecasters. The largest source of error in flood forecasting systems is uncertainty in precipitation estimation. In recent years radar systems operating in the X-band frequency range have been developed to provide precipitation fields for areas of special interest in high temporal (1 min or below) and high spatial resolution (250 m or below) in complementation to nationwide radar networks operating in C- or S-band frequency range. These systems benefit from low costs due to small antennas. However, single X-band radars are highly influenced by attenuation. C- or S-band radars have coarser resolutions (typically 1 km in range and 5 min in time), but are less affected by attenuation.

We will introduce a method to merge the precipitation fields derived from the X-band radar into the precipitation field provided by the C-band radar. The observations of C-band radar will be integrated in the correction of the attenuated measurements of the X-band. The merged precipitation field of both radars will be a valid product to improve rainfall-runoff simulations, because it combines the high-resolution of X-band radars with the more accurate rain-rate observations of C-band radars. In addition to the combined precipitation product, a concept for investigating improvement in rainfall-runoff simulations in different kinds of environments (rural, urban, flat, mountainous) will be presented.

HIGH RESOLUTION RAINFALL PRODUCTS FROM THE UK WEATHER RADAR NETWORK.

KATIE NORMAN, MET OFFICE, UNITED KINGDOM, KATIE.NORMAN@METOFFICE.GOV.UK
TIM DARLINGTON, MET OFFICE, UNITED KINGDOM
CAROLINE SANDFORD, MET OFFICE, UNITED KINGDOM
LI-PEN WANG, IMPERIAL COLLEGE LONDON, UNITED KINGDOM AND KU LEUVEN, BELGIUM
STEVEN BEST, MET OFFICE, UNITED KINGDOM
NAWAL HUSNOO, MET OFFICE, UNITED KINGDOM
SHARON JEWELL, MET OFFICE, UNITED KINGDOM
PAT MACKENZIE, MET OFFICE, UNITED KINGDOM
MALCOLM KITCHEN, MET OFFICE, UNITED KINGDOM

In order to model the hydrological processes on the urban scale, rainfall observations are needed as input. Conventionally these are supplied by point surface observations from rain gauges, or from weather radars operated by national meteorological services or other agencies. However, in some cities, the need for higher resolution products has led to investment in local weather radars with shorter range and smaller antenna (e.g. Paris, Leuven, Rotterdam, Tokyo, Fort Worth).

The UK has one of the highest density national weather radar networks in the world with over 80% of the UK land area within 100km of the nearest radar and with excellent coverage of the major conurbations. This makes the existing national infrastructure an obvious resource for provision of high resolution precipitation estimates for urban hydrology. The Met Office and Imperial College, London have developed a very high (100m) resolution rainfall product for greater London that is available in real-time every 5 minutes. The signal and data processing algorithms that have been developed are described along with the evaluation of the product.

INTRODUCTION OF TOKYO METROPOLITAN AREA CONVECTION STUDY FOR EXTREME WEATHER RESILIENT CITIES (TOMACS)

TSUYOSHI NAKATANI, NATIONAL RESEARCH INSTITUTE FOR EARTH SCIENCE AND DISASTER PREVENTION (NIED), NAKATANI@BOSAI.GO.JP

The metropolitan of Tokyo in Japan, where over several million people live and transportation and communication network are highly developed, are inherently vulnerable to extreme weather as torrential rainfall, thunderstorm, and tornado. An increase of water related disasters due to extreme heavy rain, which might be effect of global warming can cause extensive damages to metropolitan cities.

Tokyo Metropolitan Area Convection Study for Extreme Weather Resilient Cities (TOMACS)」 has been started since 2010 July, in order to develop the elementary technologies which are required for the adaptation to future global warming impacts.

More than 25 organizations and over 100 researchers are participated in the TOMACS project and carried out in collaboration with related government institutions, local governments, private companies and residents.

TOMACS project made up from "Studies on extreme weather with dense meteorological observations", "Development of the extreme weather early detection and prediction system" and "Social experiments on extreme weather resilient cities". The advanced X band multi parameter radar network system played important roles in TOMACS.

One of unique points of TOMACS was a fact that including social experiments. Social experiments have carried out in four different disaster prevention disciplines, i.e. rescue services, risk management, infrastructure, and life and education with aim of encouraging early use of advanced radar information to society. Tokyo fire department, local governments, railway companies, construction company, universities and weather company and other organizations were participated in social experiments.

The overview of TOMACS and issues raised from social experiments will be introduced in the symposium.

POSTERS :

RAINFALL MEASURED FROM THE OPPORTUNISTIC USE OF TV RECEIVERS

NAWAL AKROUR, UNIVERSITE DE VERSAILLES SAINT QUENTIN EN YVELINES (UVSQ)/ LABORATOIRE ATMOSPHERES, MILIEUX, OBSERVATIONS SPATIALES (LATMOS), NAWAL.AKROUR@LATMOS.IPSL.FR

FRANÇOIS MERCIER, UNIVERSITE DE VERSAILLES SAINT QUENTIN EN YVELINES (UVSQ)/ LABORATOIRE ATMOSPHERES, MILIEUX, OBSERVATIONS SPATIALES (LATMOS), FRANCOIS.MERCIER@LATMOS.IPSL.FR

CECILE MALLET, UNIVERSITE DE VERSAILLES SAINT QUENTIN EN YVELINES (UVSQ)/ LABORATOIRE ATMOSPHERES, MILIEUX, OBSERVATIONS SPATIALES (LATMOS), CECILE.MALLET@LATMOS.IPSL.FR

LAURENT BARTHES, UNIVERSITE DE VERSAILLES SAINT QUENTIN EN YVELINES (UVSQ)/ LABORATOIRE ATMOSPHERES, MILIEUX, OBSERVATIONS SPATIALES (LATMOS), LAURENT.BARTHES@LATMOS.IPSL.FR

AYMERIC.CHAZOTTES@LATMOS.IPSL.FR

Measurement of rainfall in urban area is an important issue in several domains such as urban hydrology, flash-flood early warning systems. The two main ways of measuring the rainfall rates are rain gauges networks and weather radars. The radars are limited by the reliefs, quite expensive and thus not available everywhere in the world. The traditional rain gauge networks are scarce or poorly maintained. This calls for alternative source of rainfall information. Various studies have recently shown that commercial microwave links from operational cellular communication networks may be used for rainfall monitoring. Despite their potential in rainfall observation the low availability of data or the inadequate frequencies used in some areas (<8 GHz) does not allow their use in all regions.

Previous studies have proved the possibility to rebuild rainfall in time and space at high resolution (a few hundred meters) in using a set of Satellite to Earth commercial microwave links. These links in Ku Band (10-12 GHz) exist all over the world and allow estimating integrated rain attenuation along 5- 7 km long links with a very high temporal resolution (10 seconds case).

A single Ku receiver deployed during Hymex experiment have produced local rainfall fields at resolution 10s and 0.5*0.5 km2 with features similar to radar maps ones at time resolution inferior to 5 minutes and spatial resolution around 1 km2.

Given the density of TV receivers in urban area operating in Ku-band, our goal is to study the quality of the rainfall fields that could be retrieved using this kind of receiver network.

As in the case of a single Ku receiver, the proposed method uses a variational assimilation method (4DVAR) with a dynamic advection model for rain cells evolution. This method integrates the observations from Ku-receivers in a numerical model and minimizes a cost function evaluating the gap between the initial rain field propagated through time by the model and the available observations.

This feasibility study of an opportunistic measurement system is made from simulations in using the following methodology: 1) A rain map simulator based on a rain support simulator associated with calibrated mutifractal simulations is used to generate numerous rain maps observations with actual statistical and spectral properties. 2) A set of rain attenuation times series corresponding to observations that could be made by a Ku-receivers network for corresponding rain maps are obtained. 3) A set of rain times series corresponding to observations that could be made by a realistic rain gauge network for corresponding rain maps are obtained. 4) A variational 4DVAR assimilation setting using an advection model is used to rebuild the rain fields from the attenuation time's series.

Finally, the rain fields obtained with the Ku-band receiver network and with the one obtained from the rain gauge network are compared with the initial rain maps in terms of variability, temporal and spatial resolution.

SUITABILITY OF NEW RAINFALL MEASUREMENT TECHNIQUES FOR HYDROLOGICAL MODELS: COMPARING RAIN GAUGE, RADAR AND MICROWAVE LINK DATA

CLAUDIA BRAUER, HYDROLOGY AND QUANTITATIVE WATER MANAGEMENT GROUP, WAGENINGEN UNIVERSITY, THE NETHERLANDS.
AART OVEREEM, HYDROLOGY AND QUANTITATIVE WATER MANAGEMENT GROUP, WAGENINGEN UNIVERSITY, THE NETHERLANDS, AND ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE
REMKO UIJLENHOET, HYDROLOGY AND QUANTITATIVE WATER MANAGEMENT GROUP, WAGENINGEN UNIVERSITY, THE NETHERLANDS

Several rainfall measurement techniques are available for hydrological applications, each with its own spatial and temporal resolution. We investigated the effect of differences in rainfall estimates on discharge simulations in a lowland catchment by forcing a novel rainfall-runoff model (WALRUS) with rainfall data from gauges, radars and microwave links.

The hydrological model used for this analysis is the recently developed Wageningen Lowland Runoff Simulator (WALRUS). WALRUS is a rainfall-runoff model accounting for hydrological processes relevant to areas with shallow groundwater (e.g. groundwater-surface water feedback). Here, we used WALRUS for case studies in the rural, but human influenced (mostly through extensive drainage) Hupsel Brook catchment.

We used two automatic rain gauges with hourly resolution, located inside the catchment (the base run) and 30 km northeast. Operational (real-time) and climatological (gauge-adjusted) C-band radar products and country-wide rainfall maps derived from microwave link data from a cellular telecommunication network were also used. Discharges simulated with these different inputs were compared to observations.

Traditionally, the precipitation research community places emphasis on quantifying spatial errors and uncertainty, but for hydrological applications, temporal errors and uncertainty should be quantified as well. Its memory makes the hydrologic system less sensitive to missed or badly timed rainfall events, but also emphasizes the effect of a bias in rainfall estimates. The memory of the hydrologic system is probably less pronounced in urban areas than in rural areas. Systematic underestimation of rainfall by the unadjusted operational radar product leads to very dry model states and an increasing underestimation of discharge. Using the rain gauge 30 km northeast of the catchment yields good results for climatological studies, but not for forecasting individual floods.

Results show that radar data are only suitable for hydrologic applications after adjustment using gauges, a fixed bias adjustment factor or physical correction algorithms. Microwave link data can almost be used without additional adjustments in the Hupsel Brook catchment, which is a promising result for urban catchments, where commercial microwave links can provide near-real-time data with high temporal and spatial resolution. Combining measurements (e.g. radar and microwave links) to make the best use of their respective qualities can improve the performance of rainfall-runoff models, increasing their potential for reducing flood damage through real-time control.

EFFECTS OF DIFFERENT SPATIAL-TEMPORAL HIGH RESOLUTION RAINFALL DATA ON THE URBAN HYDROLOGICAL RESPONSE

ELENA CRISTIANO, WATER MANAGEMENT DEPARTMENT, FACULTY OF CIVIL ENGINEERING AND GEOSCIENCES, DELFT UNIVERSITY OF TECHNOLOGY, E.CRISTIANO@TUDELFT.NL
MARIE-CLAIRE TEN VELDHUIS, WATER MANAGEMENT DEPARTMENT, FACULTY OF CIVIL ENGINEERING AND GEOSCIENCES, DELFT UNIVERSITY OF TECHNOLOGY, J.A.E.TENVELDHUIS@TUDELFT.NL
NICK VAN DE GIESEN, WATER MANAGEMENT DEPARTMENT, FACULTY OF CIVIL ENGINEERING AND GEOSCIENCES, DELFT UNIVERSITY OF TECHNOLOGY, N.C.VANDEGIESEN@TUDELFT.NL

Increase of urbanization and of the density of the population in cities facilitates a faster hydrological response to rainfall events, which, due to the climate changes, are becoming shorter and more intense. A fast response of the catchment to intense rainfall events generates a high risk of flooding, In order to prevent and reduce the risk of pluvial flooding, it is important to investigate the sensitivity of urban hydrological response to variability and extremes in rainfall. To this end, the effect that varying combinations of different spatial and temporal high resolutions have on detailed hydrological models at urban scale is investigated.

This study aims to evaluate the sensitivity of urban hydrological response to rainfall variability in lowland areas, where storage processes typically dominate over gravity-driven flow.

The effects of different spatial-temporal rainfall input resolution on hydrological response are studied in different urban sub-catchments of Rotterdam (NL). These catchments are situated in a polder area, below the level of the sea, where ground level variations are nearly absent. The sewer system is particularly complex: it is looped and does not present a dominant slope; this allows the water to flow in different directions, depending on the setting of pumping stations and other regulating structures.

A detailed, semi-distributed hydrodynamic model is used to analyse hydrological response to different spatial and temporal resolutions of rainfall in relation to characteristics of the catchment, such as drainage area size, slope and special structures (weirs, pumping stations), as well as characteristics of the storms, as length, shape and velocity.

High resolution data of nine storms with different characteristics are provided by the dual polarimetric X-band weather radar, located in the Cabauw Experimental Site for Atmospheric Research (CESAR, NL). The storms are studied with 4 different spatial resolutions (3000m, 1000m, 500m and 100m) combined with 4 different temporal resolutions (10min, 5min, 3min and 1min).

BENEFITTING RAINFALL ESTIMATION WITH A MULTIFRACTAL APPROACH TO WIND VELOCITY

GEORGE FITTON, UNIVERSITY PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU, GEORGE.FITTON@LEESU.ENPC.FR
IOULIA TCHIGUIRINSKAIA, UNIVERSITY PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU
DANIEL SCHERTZER, UNIVERSITY PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU

A critical issue in measuring rainfall with radar is the determination of whether the rainfall is convective or stratiform and thus composed of either large concentrated raindrops or small sparsely distributed raindrops respectively. This critical difference in rainfall depends mainly on the turbulent characteristics (i.e. the Reynolds number) of the wind velocity field in particular the vertical velocity profile. The Reynolds number of the system determines the values of the coefficient and the exponent used in Marshall and Palmer's formula for calculating raindrop size. It is therefore of great importance which flow regime should be chosen in order to obtain accurate results. A recent spectral analysis on wind data, taken at 10Hz at the height of 43 meters, showed linear scaling on a log-log plot (i.e. a unique power scaling) for all three of the velocity components at small-scale. At scales larger than 40 seconds isotropic behaviour is no longer visible and there is a departure of scaling for the vertical velocity component. This anisotropy can be exploited with the application of an anisotropic multifractal model which will give a much more detailed picture of the vertical velocity profile. Multifractality of the velocity field as an alternative to Taylor's frozen turbulence hypothesis gives a more efficient and accurate estimation of the Reynolds number.

MINING OPEN SPATIAL DATASETS TO CHARACTERIZE URBAN FLOODING RISKS

S. GAITAN, DEPARTMENT OF WATER MANAGEMENT, FACULTY OF CIV. ENG. AND GEOSCI. DELFT UNIVERSITY OF TECHNOLOGY. S.GAITAN@TUDELFT.NL
J.A.E. TEN VELDHUIS, DEPARTMENT OF WATER MANAGEMENT, FACULTY OF CIV. ENG. AND GEOSCI. DELFT UNIVERSITY OF TECHNOLOGY. J.A.E.TENVELDHUIS@TUDELFT.NL

Cities worldwide are challenged by increasing urban flood risks. Precise and realistic measures are required to reduce flooding impacts. However, currently implemented sewer and topographic models do not provide realistic predictions of local flooding occurrence during heavy rain events. Assessing other factors such as spatially distributed rainfall, socioeconomic characteristics, and social sensing, may help to explain probability and impacts of urban flooding. Several spatial datasets have been recently made available in the Netherlands, including rainfall-related incident reports made by citizens, spatially distributed rain depths, semidistributed socioeconomic information, and buildings age. Inspecting the potential of this data to explain the occurrence of rainfall related incidents has not been done yet. Multivariate analysis tools for describing communities and environmental patterns have been previously developed and used in the field of study of ecology. In this study, multivariate analyses are used to explore urban flood risk patterns using the above-mentioned datasets. Rainfall intensity, population density, house market prices, income, and age of construction are studied to explain the occurrence and distribution of rainfall-related incidents. Results indicate that such occurrence is higher in areas characterized by older infrastructure and higher population density.

VIRTUAL X-BAND RADAR AS A TOOL TO QUANTIFY UNMEASURED SMALL SCALE RAINFALL VARIABILITY

AUGUSTE GIRES, UNIVERSITE PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU, AUGUSTE.GIRES@LEESU.ENPC.FR
ABDELLAH ICHIBA, CONSEIL GENERAL DU VAL-DE-MARNE, DIRECTION DES SERVICES DE L'ENVIRONNEMENT ET DE L'ASSAINISSEMENT (DSEA)
IOULIA TCHIGUIRINSKAIA, UNIVERSITE PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU
DANIEL SCHERTZER, UNIVERSITE PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU

In European countries, radar rainfall is commonly provided by national weather services, with a resolution of 1 km in space and 5 min in time, as a mosaic based on networks of C band radars. For the specific needs of storm water management in urban and peri-urban areas, where the catchments are smaller leading to shorter response time and the proportion of water immediately active is high due to increased imperviousness, the available resolution does not seem sufficient.

In order to quantify the impact of the rainfall variability occurring at scales smaller than a radar pixel, the following methodology is implemented: (i) An ensemble of realistic downscaled rainfall fields is generated with the help of Universal Multifractal discrete cascades. The downscaling simply consists in stochastically continuing the underlying cascade process whose features are estimated on the available range of scales. (ii) Each realisation of rainfall field is then input into a validated hydrological model and the corresponding hydrograph simulated. (iii) The variability observed in the ensemble of hydrographs is characterized, especially for the peak flow which is critical for storm water managers.

The methodology was implemented on three case studies in the Paris area exhibiting a wide range of features: a 34 km2 flat urbanized area in Seine-Saint-Denis (North-East of Paris, France) with a zoom on a 144 ha portion, a steep 3 km2 urban area in Sucy-en-Brie (Val-de-Marne, South-East of Paris) and a 250 ha urban area with a significant portion of forest located on a steep hillside of the Bièvre River (Yvelines County, South-West of Paris). Two types of models are used: (i) Canoe, a semi-distributed operational model used by local authoroties in charge of urban drainage; and (ii) Multi-Hydro, a fully distributed physically based model (2D/1D) currently under development at Ecole des Ponts ParisTech. It consists of an interacting core between open source software packages, each of them representing a portion of the water cycle in urban environment. It appears that the obtained uncertainty associated with small scale unmeasured rainfall variability is high, with furthermore a distribution of the simulated peak flow exhibiting power-law behaviour. This indicates the need for higher resolution rainfall measurement in urban areas, which will finally be discussed in light of the recent installation of a dual polarization X-band radar on the Ecole des Ponts ParisTech campus.

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SCALING FEATURES OF RAINFALL FIELDS THROUGH 1D AND 2D DISDROMETERS MEASUREMENTS

AUGUSTE GIRES, UNIVERSITE PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU,
AUGUSTE.GIRES@LEESU.ENPC.FR
IOULIA TCHIGUIRINSKAIA, UNIVERSITE PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU
DANIEL SCHERTZER, UNIVERSITE PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU
ALEXIS BERNE, LTE, ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE, SWITZERLAND,
ALEXIS.BERNE@EPFL.CH

Rainfall fields exhibit extreme variability over wide range of scales in both space and time, which makes them complex to characterize, simulate and even measure. In this paper we suggest to investigate these features with the help of disdrometers data which give access to drop by drop measurements. Both 1D and 2D disdrometers are used. Analyses are performed in the Universal Multifractal framework which has been extensively used to analyse and simulate geophysical fields extremely variable over wide ranges of scales. Only three parameters are used to characterize variability across scales: C_1 the mean intermittency, α the multifractality index and H the non-conservative exponent.

First data collected with the help of three optical disdrometers of two different types (Campbell Scientific PWS100 and OTT Parsivel2) installed on the roof the ENPC building is investigated. Temporal series with 30s time steps are used. Not only rain rate but also polarimetric radars quantities such as the horizontal reflectivity (Z_h) and specific differential phase (K_{dp}), and DSD parameters such as the total drop concentration (N_t) and the mass-weighted diameter (D_m) are analysed. It appears that R and K_{dp} exhibit scaling over the whole range of available scales (30s – 2h) whereas for N_t and D_m scaling is not observed below few minutes. The scaling observed for Z_h is worse. Results will be interpreted in light of the commonly used radar power-law relations.

Second the 3+1D (3 spatial dimensions + time) structure of rainfall fields was investigated with the help of data recorded by a 2D video disdrometer installed in Ardèche (France) in the framework of an HyMeX campaign. More precisely the position of all the drops in a 35 m column above the measuring device is reconstructed by assuming a constant velocity equal to the one measured at the ground level. Although relying on a very coarse assumption, the analysed columns yield some insights and are indeed the best drop by drop data available at this scale. We showed that the distribution of drops (and its associated moments) exhibits a scaling behaviour over scales ranging from 35 m to roughly 50 cm. For smaller scales it appears that the distribution of drops is homogeneous. This confirms the results of the HYDROP experiment but on an extended range of scales. We also showed that the content of the 35 m columns, updated every second, exhibited great variability in time.

Finally the consequences of these findings on the remote sensing of rainfall with the help of radar will be discussed. The need to use a theoretical 3+1D representation of the rainfall field to improve high resolution measurement will be emphasized.

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FRACTAL ANALYSIS OF URBAN CATCHMENTS AND THEIR REPRESENTATION IN SEMI-DISTRIBUTED MODELS: IMPERVIOUSNESS AND SEWER SYSTEM

AUGUSTE GIRES, UNIVERSITE PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU, AUGUSTE.GIRES@LEESU.ENPC.FR
IOULIA TCHIGUIRINSKAIA, UNIVERSITE PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU
DANIEL SCHERTZER, UNIVERSITE PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU
SUSANA OCHOA RODRIGUEZ, URBAN WATER RESEARCH GROUP, DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING, IMPERIAL COLLEGE LONDON
PATRICK WILLEMS, KU LEUVEN, DEPT. CIVIL ENGINEERING, HYDRAULICS DIVISION, LEUVEN, BELGIUM
ABDELLAH ICHIBA, UNIVERSITE PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU, AND CONSEIL GENERAL DU VAL-DE-MARNE, DIRECTION DES SERVICES DE L'ENVIRONNEMENT ET DE L'ASSAINISSEMENT (DSEA), JOHAN VAN ASSEL,
GUENDALINA BRUNI, DEPARTMENT OF WATER MANAGEMENT, FACULTY OF CIVIL ENGINEERING AND GEOSCIENCES, DELFT UNIVERSITY OF TECHNOLOGY
DAMIAN MURLA TULYS, KU LEUVEN, DEPT. CIVIL ENGINEERING, HYDRAULICS DIVISION, LEUVEN, BELGIUM
LIPEN WANG, KU LEUVEN, DEPT. CIVIL ENGINEERING, HYDRAULICS DIVISION, LEUVEN, BELGIUM
RUI PINA, URBAN WATER RESEARCH GROUP, DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING, IMPERIAL COLLEGE LONDON
MARIE-CLAIRE TEN VELDHUIS, DEPARTMENT OF WATER MANAGEMENT, FACULTY OF CIVIL ENGINEERING AND GEOSCIENCES, DELFT UNIVERSITY OF TECHNOLOGY

Fractal analysis relies on scale invariance and the concept of fractal dimension enables to characterise and quantify the space filled by a geometrical set exhibiting complex and tortuous patterns. Fractal tools have been widely used in hydrology but seldom in the specific context of urban hydrology. In this paper fractal tools are used to analyse data from 10 urban or peri-urban catchments located in 5 European countries, in the framework of the Interreg IV NEW RainGain project (www.raingain.eu). The aim was to characterise urban catchment properties accounting for the complexity and inhomogeneity typical of urban water systems. Sewer system density and imperviousness (roads or buildings), represented in rasterized maps of 2 m x 2 m pixels, were analysed to quantify their fractal dimension, characteristic of scaling invariance. The results showed that both sewer density and imperviousness exhibit scale invariant features and can

be characterized with the help of fractal dimensions ranging from 1.6 to 2, depending on the catchment. In a given area consistent results were found for the two geometrical features, yielding a robust and innovative way of quantifying the level of urbanization. The representation of imperviousness in operational semi-distributed hydrological models for these catchments was also investigated by computing fractal dimensions of the geometrical sets made up of the sub-catchments with coefficients of imperviousness greater than a range of thresholds. It enabled to quantify how well spatial structures of imperviousness were represented in the urban hydrological models.

DEVELOPMENT AND TEST OF THE DISTRIBUTED MULTI-HYDRO PLATFORM IN A PERI-URBAN AREA OF PARIS

YI HONG, UNIVERSITY PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU,
YI.HONG@LEESU.ENPC.FR
AGATHE GIAGOLA-MURZYN,
CELINE BONHOMME, UNIVERSITY PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU
GHASSAN CHEBBO, UNIVERSITY PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU
DANIEL SCHERTZER, UNIVERSITY PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU

During the last few years of development, a physically based and spatially distributed numerical model Multi-Hydro (MH) has been established at the Ecole des Ponts ParisTech (ENPC). This hydro-dynamical model is open-access and has a modular structure, which is designed to be easily scalable and transportable, in order to simulate the dynamics and complex interactions of the water cycle processes in urban or peri-urban environment. Each hydrological module relies on existing and widely validated open source models, such as TREX model for the surface module, SWMM model for the drainage module and VS2DT model for the soil module. This study aims at assessing and improving the model performance, developing the water quality module within the MH platform, as well as comparing the simulation results with the continuous measurements of rainfall, discharge and turbidity.

Model implementation is based on a detailed description of urban land use features, different land-use classes had to be defined in order to satisfy the requirements of water quality modelling. For this purpose, 15 classes of urban land uses were defined in collaboration with the National Institute of Geography of France (IGN) using Digital Orthophoto Quadrangles (5cm). The delimitation of the urban catchment was then performed by operating a Digital Terrain Model which was generated by applying Lidar data (20cm), and by using GIS information of the drainage system. 18 rainfall events were selected between September and December 2014. Model outputs are compared to flows and TSS concentrations (derived from continuous turbidity measurement) at the catchment outlet.

SCALE DEPENDENCY IN URBAN HYDROLOGY: DATA ANALYSIS AND MULTI-SCALE MODELLING

ABDELLAH ICHIBA, UNIVERSITE PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU, AND CONSEIL GENERAL DU VAL-DE-MARNE, DIRECTION DES SERVICES DE L'ENVIRONNEMENT ET DE L'ASSAINISSEMENT (DSEA), ICHIBA.ABDELLAH@LEESU.ENPC.FR
AUGUSTE GIRES, UNIVERSITE PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU
IOULIA TCHIGUIRINSKAIA, UNIVERSITE PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU
DANIEL SCHERTZER, UNIVERSITE PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU
PHILIPPE BOMPARD, CONSEIL GENERAL DU VAL-DE-MARNE, DIRECTION DES SERVICES DE L'ENVIRONNEMENT ET DE L'ASSAINISSEMENT (DSEA)

The case study used in this paper is a 2.15km2 urban catchment, located at the southeast of Paris region. The model used is Multi-Hydro, which is a fully distributed and physically based model developed at the Ecole des Ponts ParisTech. It is an interacting core between open source software packages, each of them representing a portion of the water cycle in urban environment. The spatial resolution up to 1m is chosen by the user and is easily changeable. The distribution of imperviousness through scales is analyzed with the help of fractal tools; results confirm the scale dependency previously mentioned with a break at roughly 100m, scale after which it becomes difficult to represent in a correct way the heterogeneity of the catchment in hydrological models.

For modelling purposes, 10 X band high-resolution rainfall events are used, the data was spatially aggregated 6 times to 1km2 resolution and temporally 3 times to 10min. For each event, 28 spatio-temporal combinations were then simulated using MultiHydro model at different resolutions (10m, 5m and 2m), results show a high sensitivity of MultiHydro model to rainfall variability, which increases further when increasing the model resolution. The study pointed also to the fact that high-resolution modelling is still a big challenge, and efforts have to be made to deal with the high computation times noticed (from 30min at 10m to 24h at 2m to simulate 8h event).

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MULTIFRACTAL COMPARISON OF TWO RADAR PRODUCTS

ABDELLAH ICHIBA, UNIVERSITE PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU, AND CONSEIL GENERAL DU VAL-DE-MARNE, DIRECTION DES SERVICES DE L'ENVIRONNEMENT ET DE L'ASSAINISSEMENT (DSEA), ICHIBA.ABDELLAH@LEESU.ENPC.FR
AUGUSTE GIRES, UNIVERSITE PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU
IOULIA TCHIGUIRINSKAIA, UNIVERSITE PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU
DANIEL SCHERTZER, UNIVERSITE PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU
PHILIPPE BOMPARD, CONSEIL GENERAL DU VAL-DE-MARNE, DIRECTION DES SERVICES DE L'ENVIRONNEMENT ET DE L'ASSAINISSEMENT (DSEA)

Distributed rainfall data provided by weather radars are widely used in hydrology and increasingly used in urban hydrology. However radar validation and comparison still commonly rely on standard scores such as the Nash-Sutcliffe coefficient, correlations, Quadratic Errors and other second order statistics which do not enable to grasp the underlying spatio-temporal structure of the studied rainfall fields. In this paper, a new innovative comparison method of rainfall radar products has been developed. This new method relies on the Universal Multifractal framework and enables the comparison of products' structures by comparing their scaling behavior and the distribution in both space and time of their Universal Multifractal parameters α and C1.

The two products are Météo France radar data and RHEA product. Both products uses raw data from the same C-band radar but do not rely on the same QPE algorithms (one uses dual polarization capabilities and not the other) and do not use the same rain gauge network in the adjustment phase. The comparison has been performed using five rainfall events that occurred in 2010, 2011 and 2013.

In a first step we compare each radar product to a network of 27 rain gauges disturbed over a 245 Km2 area. The rain gauges are operated by the DSEA of the Val de Marne County, the local authority in charge of urban drainage. To achieve this, standard scores at various resolutions (5min, 15min, 30min and 1h) are computed. It appears that Rain gauges are better correlated with Météo France radar product than CALAMAR field.

In a second step both spatial (on 2D maps) and temporal (on 1D time series for each pixel) multifractal analysis are performed and UM parameters computed. Multifractal comparison method reveals significant differences between the two products parameters α and C1 in term of temporal evolution and less significant in spatial distribution, results have been discussed with the help of some field characteristics especially the rainfall rate and the percentage of zeros values.

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EFFECTIVE USE OF SHORT RANGE WEATHER FORECASTING IN SEWER NETWORK OPERATIONS

MR ARSHAN IQBAL, UNIVERSITY OF EXETER, AAII201@EXETER.AC.UK
DR GUANGTAO FU, UNIVERSITY OF EXETER, G.FU@EXETER.AC.UK
PROF DAVID BUTLER, UNIVERSITY OF EXETER, D.BUTLER@EXETER.AC.UK

A number of studies have used sewer models to produce output of various sewer variables from rainfall forecast data, known as Quantitative Precipitation Forecasts (QPF), as a way to indicate the likelihood of surcharges that would result in sewer flooding. However, more focus is needed around the identification of peak flows and to accurately predict these in various regions of the sewer network in the area of interest, which identifies the requirement to combine several sources of radar QPF/QPE data.

Therefore, a research project is set up with Northumbrian Water, United Kingdom to investigate the various uses of short range radar QPF data to supporting short term decisions in reducing the risk of sewer flooding. The purpose of this abstract is to introduce the project background, goals and intended outcomes as well as to describe various aspects of the methodology that will help accomplish these outcomes.

The important steps to be taken include developing a set of rainfall forecast data that will be tested in the EPA SWMM model as well as sourcing specific asset/customer data that can be used to make flood forecasts more specific. Then using the selected models, various catchment designs will be used to study specific output variables such as flow, discharge, water depth of different regions of the sewer network from the forecast data in a series of 'sensitivity' experiments. Furthermore, the mapping of the forecasts to specific interventions that tackle sewer floods will be modelled. It is expected that the results will provide a more accurate means to use short range weather forecast data by the WSP's operations team to give them the confidence to introduce the necessary interventions that are specific, resourceful and efficient in execution to reduce the risk of damage from a sewer flood or to prevent the event from occurring.

THE DEVELOPMENT AND MAINTENANCE OF MCS BY SST VARIATION EFFECTS OVER THE YELLOW SEA, KOREA

YUNHEE KANG, DEPARTMENT OF ENVIRONMENTAL ATMOSPHERIC SCIENCES, PUKYONG NATIONAL UNIVERSITY, BUSAN, KOREA, YUNI3545@PKNU.AC.KR
DONG-IN LEE, DEPARTMENT OF ENVIRONMENTAL ATMOSPHERIC SCIENCES, PUKYONG NATIONAL UNIVERSITY, BUSAN, KOREA, LEEDI@PKNU.AC.KR
JONG-HOON JEONG, FORECAST RESEARCH DIVISION, NATIONAL INSTITUTE OF METEOROLOGICAL RESEARCH, SEOUL, KOREA, JEONGJH737@KOREA.KR

Heavy rainfall causes serious disasters such as flash floods and landslides that occur in a small area for a short time. To reduce damage of human life and property, it is important to understand the characteristics, structure and formation of mesoscale convective system (MCS). The heavy rainfall-producing MCS from Yellow Sea to land was investigated using observations and numerical simulation. The Sea Surface Temperature (SST) value higher than the annual mean plays a role in development of MCS and mid-latitude heavy rainfall events. The aim of the study is to examine impact of SST on the development and maintenance of MCS and understand the physical mechanisms of heavy rainfall event.

The linear-MCS developed from Yellow Sea to Gunsan area that lead to heavy rainfall with accumulated rainfall more than 400 mm. We performed CReSS (Cloud-Resolving Storm Simulator, suboki and Sakakibara, 2002) model of Nagoya University to investigate the reason of effects of SST variation on MCS over ocean. The control experiment (CNTL) is successfully simulated with reproduceing linear MCS and rainfall pattern compared with observation. The latent heat flux from the sea surface appears strongly and it is associated with sea-atmosphere interactions. In sensitive experiment of 1 ºC decreasing SST (RSST), the simulated linear MCS was weak and latent heat flux was rapidly reduced. The higher SST value than annual mean contributed to formation and development of linear MCSs from Yellow sea to land.

SENSORS AND CITIZENS PREPARING URBAN ENVIRONMENTS FOR EXTREME WEATHER

W. KOOLE, TU DELFT, DEPARTMENT OF CIVIL ENGINEERING AND GEOSCIENCES, W.KOOLE@TUDELFT.NL
R. UIJLENHOET, WAGENINGEN UR, DEPARTMENT OF ENVIRONMENTAL SCIENCES, REMKO.UIJLENHOET@WUR.NL
R.H.J. SIPS, IBM BENELUX, CENTER FOR ADVANCED STUDIES, RJSIPS@NL.IBM.COM
A. OVEREEM, WAGENINGEN UR, DEPARTMENT OF ENVIRONMENTAL SCIENCES, AART.OVEREEM@WUR.NL
M.B. VAN RIEMSDIJK, TU DELFT, DEPARTMENT OF INTELLIGENT SYSTEMS, M.B.VANRIEMSDIJK@TUDELFT.NL
J.A.E. TEN VELDHUIS, TU DELFT, DEPARTMENT OF CIVIL ENGINEERING AND GEOSCIENCES, J.A.E.TENVELDHUIS@TUDELFT.NL

On 28 July, a cloudburst hit Amsterdam, pouring 90 mm of rainfall over the city with intense rainfall peaks of up to 150 mm/h (Amsterdam Rainproof, 2014). Sewer and drainage systems were unable to cope with this amount of water and flooding occurred at many locations. This example illustrates the disruptive effects that intense storms can have on urban societies, the economy and infrastructure.

Extreme rainfall is expected to occur more often in the future as a result of climate change. To be able to react to this, urban water managers need to accurately know vulnerable spots in the city, as well as the potential impact to society. Currently, detailed information about rainfall intensities in cities, and effects of intense storm events on urban societies is lacking.

Innovative sensing techniques will be utilised, based on routinely collected data and existing infrastructure, such as rainfall estimation from microwave links, low-cost acoustic rainfall sensors on umbrellas and lamp posts and sensors in drainage pipes for water level observation (e.g. Overeem et al., 2013). These will be combined with Social Sensing; information provided by citizens in an active way through smartphone apps and in a passive way by information retrieval from social media posts (Twitter, Flickr etc.) (Gaitan et al., 2014).

In an initial deployment in the city of Amsterdam, we aim to derive 2 main results: (1) results from high resolution hydrodynamic modelling fuelled by the input from Innovative sensing, (2) results from Social sensing experiments using a prototype smartphone app.

The central storage and analysis of data will enable us to (1) develop robust machine learning to accurately derive results from Social Sensing, using the Innovative Sensing as ground truth and (2) analyse the minimum amount of existing infrastructure needed for deployment in an arbitrary urban environment.

EMPIRICAL SPACE-TIME SCALING ANALYSIS OF MACROWEATHER PRECIPITATION PRODUCTS FROM MONTHLY TO CENTENNIAL SCALES

ISABEL DE LIMA, DEPARTMENT OF CIVIL ENGINEERING, UNIVERSITY OF COIMBRA, COIMBRA, PORTUGAL, IPLIMA@UC.PT, AND INSTITUTE OF MARINE RESEARCH (IMAR) AND MARINE AND ENVIRONMENTAL SCIENCES CENTRE (MARE), PORTUGAL
SHAUN LOVEJOY, PHYSICS DEPARTMENT, MCGILL UNIVERSITY, MONTREAL, CANADA, LOVEJOY@PHYSICS.MCGILL.CA

Scaling studies of atmospheric fields have shown the existence of an intermediate ("macroweather") regime between the familiar weather and climate regimes, over the range of time scales from about 10 days to decadal, centennial scales. These regimes qualitatively, quantitatively alternate in the way precipitation fluctuations vary with scale.

We systematically study macroweather precipitation space-time variability and the outer scale limit of temporal scaling using three centennial, global scale precipitation products (one instrument based, one reanalysis based, one satellite and gauge based) over wide ranges of time and space scales. The spatial, temporal and joint space-time statistics are analysed using spectra and Haar fluctuations. We also examine long station data, in a regional context. From the space-time scaling properties of precipitation, we quantify the agreement (and lack of agreement) of the precipitation products as a function of space and time scale. We expect that this mismatch in scales also extends to other precipitation products.

In the macroweather regime, fluctuations decrease while anthropogenic effects increase with time scale; our approach determines the time scale at which the anthropogenic signal can be detected above the natural variability noise. The critical scale is about 20 - 40 yrs (depending on the product, on the spatial scale). This explains why the usual approaches using decadal trends are not statistically significant: the period is too short. We discuss using the CO_2 radiative forcing as a surrogate for all the anthropogenic effects, which ascribes a statistically significant increasing trend in global rain rate; however, the effect is not trivial at smaller scales.

Overall, this work contributes to clarify a basic problem in hydro-climatology, which is to measure trends at decadal and longer scales and to distinguish anthropogenic and natural variability in precipitation records, and to quantify both as functions of scale.

ANALYSE STATISTIQUE DE LA PLUVIOMETRIE JOURNALIERE MAXIMALE AU BASSIN VERSANT DE L'EXTREME NORD TUNISIEN

M. MATHLOUTHI, LABORATOIRE DE RECHERCHE EN SCIENCES ET TECHNOLOGIES DE L'EAU A L'INAT, TUNIS, TUNISIE, MAJID_MATHLOUTHI@YAHOO.FR
F. LEBDIF, INSTITUT NATIONAL AGRONOMIQUE DE TUNISIE (INAT), UNIVERSITE DE CARTHAGE, TUNISIE

L'étude de la pluviométrie dans un bassin versant ou une région porte, non seulement sur la pluie moyenne et sa distribution spatiale et temporaire, mais aussi sur la pluie journalière maximale. Cette caractéristique journalière maximale est un élément important pour l'évaluation des débits des cours d'eau d'une façon directe ou indirecte. On utilise une approche statistique pour généraliser la pluie journalière maximale pour le bassin versant de l'extrême nord Tunisien, ajuster les lois statistiques appropriées et estimer les périodes de retour des valeurs extrêmes. Pour plus de précision relative à l'approche statistique, plusieurs modèles d'ajustement ont été utilisés. Le choix des stations s'est fait selon l'étendue des séries de données et la continuité des observations. L'analyse a montré que parmi les lois étudiées, la loi Log-normale est celle qui s'ajuste le mieux selon les critères statistiques. Ces critères portent sur l'aspect de la courbe théorique, le test de X2 et la comparaison des critères d'information Bayésien et d'Akaike. La loi de Kritsky et Menkel est aussi la première loi d'ajustement pour certaines stations. Pour une période de retour centennale, un maximum de pluie qui dépasse les 200 mm dans la région de l'extrême nord ouest du pays peut être obtenu.

SPECTRAL ANALYSIS OF THE TURBULENT BOUNDARY LAYER (TBL) IN URBAN LAKE, DURING EXTREME WEATHER EVENTS

Y. MEZEMATE, UNIVERSITY PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU, YACINE.MEZEMATE@ENCP.FR
G.FITTON, UNIVERSITY PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU
I. TCHIGUIRINSKAIA, UNIVERSITY PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU
D. SCHERTZER, UNIVERSITY PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU
C. BONHOMME, UNIVERSITY PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU
F. SOULIGNAC, UNIVERSITY PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU
B.J. LEMAIRE, UNIVERSITY PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU
B. VINCON LEITE, UNIVERSITY PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU

In the event of heavy rainfall, large amounts of storm water will carry roof runoff pollutants into urban lakes. This kind of discharge not only changes the dynamics of the lake (i.e. the mixing processes that occur) but also complicates ones ability to predict pollutant concentrations. Being able to quantify these changes in pollutant during and after extreme weather events is important for water quality management.

In this study the impact of extreme weather events on urban water bodies is investigated. For that, we set-up an Acoustic Doppler Current Profiler (ADCP) next to a storm water discharge point at the bottom of a shallow urban lake in Creteil, a region in Paris.

The positioning of the ADCP, in a stable, stratified lake, with a strong turbulent flow occurring close to the surface has given us a unique situation in which a turbulent bounded-layer can be analysed. Vertical profiles measured in the atmospheric boundary-layer are typically intrusive due to the requirement of masts and other complex measuring structures. Moreover atmospheric profilers are normally coarsely spaced in the vertical.

To analyse the TBL dynamics we look only at the scaling properties of the velocity field. If the velocity is scaling the log-log plot of the energy spectra will be linear in wavenumber (or frequency). The slope of the log-log plot of the spectra gives the spectral scaling exponent. Performing the analysis we find a spectral exponent close to -1. Dimensional arguments suggest that this exponent occurs when the energy flux becomes dependent on the friction velocity instead of the length scale; likely a result of the strong inflow during extreme rainfall events. The ADCP data allows us to observe a smooth transition from a free stream turbulent regime (-5/3) to a bounded-turbulent exponent (-1) through depth.

This kind of analysis suggests the possibility for a general scaling model of the TBL that can be used to predict the mixing of pollutants during and after extreme weather events.

ENHANCING HIGH-RESOLUTION STORM CELL TRACKING: A MULTI-THRESHOLD TITAN ALGORITHM IN SYNERGY WITH OPTICAL FLOW TECHNIQUE

CARLOS MUÑOZ-LÓPEZ, KU LEUVEN, CIVIL ENGINEERING, HYDRAULICS SECTION, LEUVEN, BELGIUM, CARLOS.MUNOZLOPEZ@BWK.KULEUVEN.BE
LI-PEN WANG, KU LEUVEN, CIVIL ENGINEERING, HYDRAULICS SECTION, LEUVEN, BELGIUM, LIPEN.WANG@BWK.KULEUVEN.BE
PATRICK WILLEMS, KU LEUVEN, CIVIL ENGINEERING, HYDRAULICS SECTION, LEUVEN, BELGIUM, PATRICK.WILLEMS@BWK.KULEUVEN.BE

TITAN (Thunderstorm Identification, Tracking, Analysis, and Nowcasting) is an object-based storm tracking algorithm, which was developed for convective rain cell tracking (Dixon and Wiener, 1993). However, due to the single-threshold setting, TITAN was found to be unable to well identify adjacent storm cell clusters. In addition, its tracking algorithm was developed based upon an overlapping technique (which compares the overlapped area of storm cells between successive radar images), and this technique has proven to be less effective for capturing fast-moving storms and for high spatial-resolution rainfall data.

To improve the applicability of the original TITAN to high-resolution rainfall data processing, two treatments have been incorporated in this work. First, based upon the hierarchical threshold segmentation (HTS) method (Peak and Tag, 1993), a multi-threshold technique was developed to better identify and isolate rainfall cells at small scales. Second, the optical flow technique, which is a field-based storm cell tracker, was employed to provide the initial estimate of the storm cell movement. The high-resolution (~500 m / 5 min) C-band radar data provided by the Royal Meteorological Institute of Belgium were used to test the proposed work. Preliminary results showed that the enhanced TITAN algorithm can better handle high-resolution storm details, and the improvement is particularly evident in avoiding faulty tracking between decaying and new born storm cells. This provides a great basis for future applications, where high-resolution rainfall estimates are critical; e.g., stochastic spatial-temporal rainfall modelling and nowcasting for urban hydrology.

PROPAGATION OF UNCERTAINTIES IN RAINFALL AND SURFACE MODEL STRUCTURE TO URBAN FLOOD SIMULATION AND FORECASTING RESULTS

DAMIAN MURLA, KU LEUVEN, BELGIUM. DAMIAN.MURLATUYLS@BWK.KULEUVEN.BE
LORIS FORESTI, RMI, BELGIUM. LOFOREST@METEO.BE
LI-PEN WANG, KU LEUVEN, BELGIUM. LIPEN.WANG@BWK.KULEUVEN.BE
VICTOR NTEGEKA, KU LEUVEN, BELGIUM. VICTOR.NTEGEKA@BWK.KULEUVEN.BE
MAARTEN REYNIERS, RMI, BELGIUM. MAARTEN.REYNIERS@METEO.BE
LAURENT DELOBBE, RMI, BELGIUM. LAURENT.DELOBBE@METEO.BE
PATRICK WILLEMS, KU LEUVEN, BELGIUM. PATRICK.WILLEMS@BWK.KULEUVEN.BE

Hydraulic models have increasingly been used for quantifying the impacts of urban floods, in support of urban water management, but also on the basis real-time flood forecasting and warning. Hydrodynamic 1D (sewer) - 2D (surface) dual-drainage models have shown to be effective tools for the simulation of urban floods. The reliability of such tools depends on different types of uncertainties. The uncertainty in the rainfall inputs is most often the most dominant one, but also the uncertainty in the hydraulic model structure may be of importance. In this study, a rainfall nowcasting model coupled with a urban hydraulic model was used to quantify the uncertainty associated with the hydraulic model structure. The nowcasting model used was the Short Term Ensemble Prediction System (STEPS), originally co-developed by the UK Met Office and Australian Bureau of Meteorology and further customised by the Royal Meteorological Institute of Belgium (denoted STEPS-BE). It provides high-resolution (1 km/5 min) rainfall nowcast ensembles with a 2 hour lead time. The hydraulic model consists of a 1D sewer network and an innovative 'nested' 2D surface model. The surface components are categorised into three groups and each group is modelled using triangular meshes at different resolutions; these include streets (3.75-15m2), high flood hazard areas (12.5-50m2) and low flood hazard areas (75-300m2). Five historical storm events passing over a flood-prone catchment (649 ha) in Ghent (Belgium) during 2013 and 2014 were selected as case study. Results demonstrate that the structuring of the urban surface network has important impacts on the urban flood simulation and forecasting results. This suggests that there is a need to consider not only rainfall input uncertainties but also to correctly identify, quantify and propagate the additional sources of uncertainty such as the model structure uncertainty in order to provide complete uncertainty information to flood risk managers.

OPEN-SOURCE STOCHASTIC RAINFALL GENERATOR FOR HIGH-RESOLUTION PRECIPITATION SIMULATION

TERO NIEMI, AALTO UNIVERSITY SCHOOL OF ENGINEERING, FINLAND, TERO.NIEMI@AALTO.FI
TEEMU KOKKONEN, AALTO UNIVERSITY SCHOOL OF ENGINEERING, FINLAND, TEEMU.KOKKONEN@AALTO.FI

Urban areas are sensitive to both spatial and temporal distribution of rainfall, and often the requirements for the data resolution are higher than what the operational precipitation measurement networks can provide.

An open-source stochastic rainfall generator is being developed at Aalto University to provide ensemble simulations of realistic precipitation events for the needs of hydrological assessments. The model has a modular structure describing the main components of a precipitation event; time series for the mean areal rainfall, field spatial structure including anisotropy, temporal evolution of fields according to dynamic scaling, and field advection. The modular structure enables easy adaptation of the model to a variety of storm events as well as adding extensions to the model. The scaling behaviour of rainfall will be exploited to generate precipitation fields at the desired resolution. High resolution weather radar data is available from Helsinki Metropolitan region to test the assumption of scaling between the 'source scale' (operational radar data at resolution of 1 km^2 in space and 5 min in time) and the 'target scale' needed for urban high-impact weather assessments (in the order of few hectares and few minutes).

The model will be utilized to produce design events for urban hydrological studies. Future plans also include short term nowcasts of precipitation and runoff. The near future precipitation fields are constructed by randomly perturbing the advection velocities inferred from past observations and continuously replacing the small precipitation structures with structures based on stochastic noise. Large structures having longer lifetimes are replaced at a slower pace. Runoff nowcasts are produced by feeding the nowcasted precipitation ensembles through an urban hydrodynamic model.

SURFACE WATER FLOOD WARNINGS IN ENGLAND: OVERVIEW, ASSESSMENT AND RECOMMENDATIONS BASED ON SURVEY RESPONSES AND WORKSHOPS

SUSANA OCHOA-RODRÍGUEZ, IMPERIAL COLLEGE LONDON, UNITED KINGDOM, S.OCHOA-RODRIGUEZ@IMPERIAL.AC.UK
LI-PEN WANG, KU LEUVEN, BELGIUM
ANDY JOHNSTON, LOCAL GOVERNMENT INFORMATION UNIT/LOCAL GOVERNMENT FLOOD FORUM, UNITED KINGDOM
CHRISTIAN ONOF, IMPERIAL COLLEGE LONDON, UNITED KINGDOM

Following extensive surface water flooding (SWF) in England in summer 2007, rapid progress has been made in improving the forecasting, warning and management of this type of flooding. A rainfall threshold based Extreme Rainfall Alert (ERA) service was launched in 2009 and superseded in 2011 by the Surface Water Flood Risk Assessment (SWFRA). Through survey responses from local authorities (LAs) and the outcome of workshops with a range of flood professionals, this work examines the understanding, benefits, limitations, and ways to improve the current SWF warning service. In general, the warning services are perceived as useful by district and county LAs, although their understanding of the rationale behind these alerts, including the difference between likelihood and risk, is low. The majority of LAs do take action upon receipt of the SWFRA alerts, with the type of response varying according to the risk level and lead time (the top 3 combinations of probability and lead time at which the greatest response would be possible are 60 % probability - 2 h lead time, 80 % probability – 1 h lead time, and 80% probability – 0.5 h lead time). Moreover, the LAs' reactiveness appears to have increased over the years and as SWFRA superseded ERA. This is a positive and encouraging development towards increased resilience to SWF. The main drawback of the current service is its broad spatial resolution. Flood professionals believe that, despite improvements, the service provided by the FFC will continue to be a national service and it is unlikely that it can ever deal with the fine detail of local urban areas. Alternatives for providing localised SWF forecasts and warnings were analysed and a two-tier national-local approach, with pre-simulated scenario-based local SWF forecasting and warning systems, was deemed most appropriate by flood professionals, given current monetary, human and technological resources.

EVALUATION OF THE MET OFFICE SUPER-RESOLUTION C-BAND RADAR RAINFALL PRODUCT OVER THE GREATER LONDON AREA

SUSANA OCHOA-RODRÍGUEZ, IMPERIAL COLLEGE LONDON, UNITED KINGDOM, S.OCHOA-RODRIGUEZ@IMPERIAL.AC.UK
CAROLINE SANDFORD, MET OFFICE, UNITED KINGDOM
KATIE NORMAN, MET OFFICE, UNITED KINGDOM
LI-PEN WANG, KU LEUVEN, BELGIUM
SHARON JEWELL, MET OFFICE, UNITED KINGDOM
MARIA AKERBOOM, IMPERIAL COLLEGE LONDON, UNITED KINGDOM, AND TU DELFT, NETHERLANDS
CHRISTIAN ONOF, IMPERIAL COLLEGE LONDON, UNITED KINGDOM

Urban catchments are characterised by high spatial variability and fast runoff processes and are therefore very sensitive to the spatial and temporal variability of precipitation. Consequently, high resolution precipitation estimates are required in order to properly represent urban runoff processes. As part of the RainGain project and with the purpose of meeting the stringent requirements of urban hydrological applications, a high spatial resolution (100 m / 5 min) radar rainfall product has been developed and trialled over the Greater London Area. Quantitative precipitation estimates (QPEs) were generated using data from two operational dual polarisation C band radars operating in "short-pulse" mode with a pulse length of 0.5 microseconds (or 75 m) and half power beam width of 1 degree. QPEs from each radar were interpolated onto a 100 m resolution grid every 5 minutes, and the use of advection and rain-gauge merging techniques to improve rainfall accumulation estimates was investigated.

The quality and added value of these high resolution QPEs for urban hydrological applications is evaluated using as case study 6 storm events observed in a small urban catchment in North East London for which dense rain gauge and sewer flow records, as well as a recently-calibrated high-resolution urban drainage model were available. Results show that the high-resolution radar product performs well in terms of accuracy and captures the small-scale structure of rainfall fields. When comparing the use of higher spatial resolution radar QPEs (at 100 m / 5 min resolution) and the 1 km / 5 min operational Met Office radar QPEs as input for urban hydrological modelling, improvements are only tangible in the case of highly spatially variable storms. Further work is required to better understand the interaction and dependence between rainfall input and the resolution of hydrological models.

COMPARISON OF MULTIFRACTAL PARAMETERS OBTAINED FROM THE ANALYSIS OF WEATHER RADAR DATA IN BRAZIL, JAPAN AND FRANCE

IGOR DA SILVA ROCHA PAZ, ÉCOLE DES PONTS PARISTECH – LEESU, FRANCE, IGOR.DA-SILVA-ROCHA-PAZ@ENPC.FR
GEORGE FITTON, ÉCOLE DES PONTS PARISTECH – LEESU, FRANCE, GEORGE.FITTON@LEESU.ENPC.FR
AUGUSTE GIRES, ÉCOLE DES PONTS PARISTECH – LEESU, FRANCE, AUGUSTE.GIRES@LEESU.ENPC.FR
IOULIA TCHIGUIRINSKAIA, ÉCOLE DES PONTS PARISTECH – LEESU, FRANCE, IOULIA.TCHIGUIRINSKAIA@ENPC.FR
DANIEL SCHERTZER, ÉCOLE DES PONTS PARISTECH – LEESU, FRANCE, DANIEL.SCHERTZER@ENPC.FR

Quantifying rainfall heterogeneity at different scales of time and space, with the help of X-band radar data to improve flood-forecasting methods, is the focal point of our research during three upcoming years.

The weather radars are the only measuring devices that provide estimates of rainfall in time and space, while the uncertainty in rainfall field forecasts remains the main source of uncertainties for flood forecasts. The long spin-up time of weather forecast models actually prevents them to deliver short term rainfall forecasts. Our work aims to further contribute to the development of stochastic multifractal forecasts. This approach has merged from the successive developments of continuous in scale multifractal cascade models, scaling anisotropy between space and time and causality. These models have the advantage to have a very limited number of parameters that can be either theoretically or empirically determined. Overall, the multifractals resulting from the continuous cascades are defined by only three robust parameters α, C_1 and H that have a straightforward physical significance. In this work, we particularly address the question of regional variability of these multifractal parameters.

Using standard multiscale techniques, such as the (functional) box counting, spectral analysis and (double) trace moments, and the SERQUAL procedure, we have analyzed several rainfall radar data from three countries: Brazil, France and Japan. The obtained results allow us to discuss:

- the question of rainfall data quality and the corresponding scaling behaviour;
- the physical significance of the multifractal parameters in the context of their regional variability;
- the question of the time-space anisotropy due to the difference between the temporal and spatial scaling moment functions;
- the range of space-time scales that would be most pertinent for the future flood-forecast modelling, being based on multifractal rainfall forecasts.

SEMI-DISTRIBUTED VS. FULLY-DISTRIBUTED URBAN STORMWATER MODELS

RUI DANIEL PINA, IMPERIAL COLLEGE LONDON, UK., R.PINA13@IMPERIAL.AC.UK
SUSANA OCHOA, IMPERIAL COLLEGE LONDON, UK., S.OCHOA-RODRIGUEZ@IMPERIAL.AC.UK
NUNO E. SIMÕES, MARE, DEPARTMENT OF CIVIL ENGINEERING, UNIVERSITY OF COIMBRA, PORTUGAL, NUNOCS@DEC.UC.PT
ANA MIJIC, IMPERIAL COLLEGE LONDON, UK., ANA.MIJIC@IMPERIAL.AC.UK
ALFEU SÁ MARQUES, MARE, DEPARTMENT OF CIVIL ENGINEERING, UNIVERSITY OF COIMBRA, PORTUGAL, JASM@DEC.UC.PT
CEDO MAKSIMOVIC, IMPERIAL COLLEGE LONDON, UK., C.MAKSIMOVIC@IMPERIAL.AC.UK

Urban stormwater models are important tools for flood prediction. Their main input is rainfall data and the resolution of both data and models should be in agreement and detailed enough to capture flooding events. Fully distributed (FD) urban stormwater models are generally more detailed than the commonly used semi-distributed (SD) models. SD models are based on sub-catchments units through which rainfall is applied to the model and at which runoff volumes are estimated. In FD models, the runoff volumes are estimated and applied directly on every element of a two-dimensional (2D) model of the overland surface. FD models are theoretically more realistic and physically-based than SD models. In this work a comparison is presented of SD and FD models based on two case studies: Zona Central catchment in Coimbra, Portugal, and Cranbrook catchment in London, UK. For the Zona Central case study, modelling results of flooding events were compared with photographic records and for the Cranbrook case study modelling results were compared against water depth and flow records in sewers. The results suggest that FD models are more sensitive to surface storage, defined by the 2D overland mesh, leading to underestimate floodplains and require higher detail of the sewer network in order to yield accurate results. In applications when high-resolution data are not available, the use of SD models could be a better choice.

VARIABILITY OF THE DROP SIZE DISTRIBUTION AT RADAR PIXEL SCALE

TIMOTHY H. RAUPACH, LTE, ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE, SWITZERLAND, TIM.RAUPACH@EPFL.CH
ALEXIS BERNE, LTE, ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE, SWITZERLAND, ALEXIS.BERNE@EPFL.CH

The raindrop size distribution (DSD), which characterises the microstructure of rainfall, is often assumed to be constant over space and time. Take for example the case in which a weather radar measures a single reflectivity (Z) value over a volume of interest. To convert this value to rain rate R, a Z-R relationship must be assumed. The parameters of this relationship are usually estimated using DSDs measured at a the point scale, which do not account for the full variability of the DSD across the volume.

We investigate the sub-grid variability of the DSD for two typical spatial scales: a 2x2 km^2 region corresponding to a typical numerical weather prediction (NWP) model pixel, and a 5x5 km^2 region corresponding to the ground footprint of the Global Precipitation Measurement (GPM) space-borne weather radar. We use data from a network of fifteen disdrometers deployed in Ardeche, France (instruments and data provided by LTE, EPFL and LTHE, Grenoble). Over these typical scales, we perform interpolation of the measured DSD using a novel geostatistical technique that allows us to estimate the non-parametric DSD at unmeasured locations. We thus produce a dense grid of estimated DSDs from a set of point locations.

We quantify the error that is introduced by assuming that the DSD at one point represents the DSD over the entire pixel. We do so for drop concentrations themselves, for bulk rainfall variables, and for the parameters of the commonly used Gamma DSD model. Further, we investigate and quantify the variability of the Z-R relationship over these typical pixel sizes, and quantify the effect of this variability on estimates of rain rates based on radar reflectivity measurements. As expected, the larger typical pixel displays more variability. The DSD is shown to exhibit significant variability over even these relatively small scales.

DUAL-POLARIMETRIC X-BAND WEATHER RADAR: STORM OBSERVATION AND ACCURATE RAINFALL ESTIMATION

RICARDO REINOSO-RONDINEL, DEPARTMENT OF GEOSCIENCE AND REMOTE SENSING, DELFT UNIVERSITY OF TECHNOLOGY, DELFT, NETHERLANDS, R.R.REINOSORONDINEL@TUDELFT.NL
HERMAN RUSSCHENBERG, DEPARTMENT OF GEOSCIENCE AND REMOTE SENSING, DELFT UNIVERSITY OF TECHNOLOGY, DELFT, NETHERLANDS, H.W.J.RUSSCHENBERG@TUDELFT.NL

Weather observations are conventionally performed by single-polarimetric C-band weather radars with temporal and spatial resolutions of 5 min and 1 km, respectively. However, in recent years, weather radars have been upgraded from single to dual-polarimetric for improved weather measurements. For example, the dual-polarimetric capabilities might lead to more accurate rainfall estimation than that of single-polarimetric. Still, these spatial and temporal resolutions might be undesirable for the detection of localized heavy rainfall which is usually required to model fast rainfall-runoff processes in urbanized areas. Moreover, small but threatening patterns associated with severe weather might be unseen. In this work, a dual-polarimetric X-band weather radar, IDRA hereafter, located in the Netherlands (NL) is used to observe and derive physical processes and obtain accurate rainfall estimation of storms, at high temporal and spatial resolutions. Observations of multiple storms by IDRA were compared with those of the operational C-band radars of the NL. High resolutions observations were able to capture essential patterns, such as the hook-like echo, associated with non-supercell storms which were difficult to detect by the C-band radars. In this work, rainfall estimation was based on the specific differential phase (Kdp), for moderate and convective storms. In addition, an advanced method to estimate Kdp from pure rain at X-band frequencies is proposed. To analyse the impact of resolution quality on the variability of rainfall intensities, estimates of rainfall intensities by IDRA were used to simulate rainfall intensities at coarse resolutions. Preliminary results have shown significant variability in rainfall intensities when the spatial resolution was decreased from 100 m to 250, 500, and 1000 m. It is foreseen that weather surveillance performed by dual-polarimetric X-band radars would lead to early detection of crucial storm patterns and improve the quality of radar-based rainfall estimation as recommended by both, weather-forecast and urban-hydrology communities.

SOURCES OF UNCERTAINTY IN RAINFALL MAPS FROM CELLULAR COMMUNICATION NETWORKS

MANUEL FELIPE RIOS GAONA, HYDROLOGY AND QUANTITATIVE WATER MANAGEMENT GROUP, WAGENINGEN UNIVERSITY, THE NETHERLANDS, MANUEL.RIOSGAONA@WUR.NL
AART OVEREEM, HYDROLOGY AND QUANTITATIVE WATER MANAGEMENT GROUP, WAGENINGEN UNIVERSITY, THE NETHERLANDS, AND ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE, AART.OVEREEM@KNMI.NL
HIDDE LEIJNSE, ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE, HIDDE.LEIJNSE@KNMI.NL
REMKO UIJLENHOET, HYDROLOGY AND QUANTITATIVE WATER MANAGEMENT GROUP, WAGENINGEN UNIVERSITY, THE NETHERLANDS, REMKO.UIJLENHOET@WUR.NL

Accurate measurements of rainfall are important in many hydrological applications, for instance, flash-flood early-warning systems, hydraulic structures design, weather forecasting, and climate modelling. Rainfall intensities can be retrieved from (commercial) microwave link networks. Whenever possible, link networks measure and store the decrease in power of the electromagnetic signal at regular intervals. The decrease in power is largely due to the attenuation by raindrops along the link paths. This technique is now a potential alternative to fulfill the current demands for rainfall measurements at high spatiotemporal resolutions.

Rainfall maps from microwave link networks have recently been introduced at city- and country-wide scales. Despite their potential in rainfall estimation at high spatiotemporal resolutions, the uncertainties present in these rainfall maps are not yet fully comprehended. Here, we identify and quantify the sources of uncertainty present in interpolated rainfall maps from link rainfall depths. In order to disentangle these sources of uncertainty, we classified them into two categories: (1) those associated with the individual microwave link measurements, i.e., the physics involved in the measurements such as wet antenna attenuation, sampling interval of measurements, wet/dry period classification, drop size distribution (DSD), and multi-path propagation; (2) those associated with mapping, i.e., the combined effect of the interpolation methodology, the spatial density of the network, and the availability of link measurements.

We computed ~ 3500 rainfall maps from real and simulated link rainfall depths for 12 days for the land surface of The Netherlands. These rainfall maps were compared against quality-controlled gauge-adjusted radar rainfall fields (assumed to be the ground truth). Thus, we were able to not only identify and quantify the sources of uncertainty in such rainfall maps, but also to test the actual and optimal performance of one commercial microwave network from one of the cellular providers in The Netherlands.

MULTIFRACTAL RADAR METEOROLOGY: BEYOND THE SCALAR CASE

DANIEL SCHERTZER, ECOLE DES PONTS PARISTECH, DANIEL.SCHERTZER@ENPC.FR;
IOULIA TCHIGUIRINSKAIA, ECOLE DES PONTS PARISTECH, IOULIA.TCHIGUIRINSKAIA@ENPC.FR

Radar meteorology has been inspiring for the development of multifractals because it enabled to work on a 3D+1 field, as well as a fruitful domain of applications, e.g. data analysis, inversion of the radar reflectivity into the rain rate, inter comparisons between radars and radars vs. raingages, predictability and stochastic forecasts. However, most of these developments were focused on the rain rate that is a scalar valued field. It was furthermore considered as a direct result of a unique cascade process, whereas the initial argument was to consider it as a by-product of coupled cascades of the velocity and the water content. Although there were some arguments in favor of such a simplification, the later might be the source of several discrepancies with empirical data.

Fortunately, recent advances in multifractal modeling allows to come back to the initial and ambitious project to take into account the complex interactions between several fields, including the velocity field that can be estimated with the help of the doppler capacity of meteorological radar, although limited to rainy fractions of the space.

We therefore present a wide class of vector-valued multifractal processes whose generators are Lévy stable on Clifford algebra. Both properties ensure important universality properties, e.g. these processes are robust and defined with the help of a limited number of relevant, meaningful parameters.

RAINFALL SENSING AND BUSINESS OPPORTUNITIES WITH SMART SYSTEMS & FRACTAL IN-SITU NETWORKS: WHY THE X-BAND RADARS MAKE THE DIFFERENCE ?

IOULIA TCHIGUIRINSKAIA, ECOLE DES PONTS PARISTECH, IOULIA.TCHIGUIRINSKAIA@ENPC.FR;
DANIEL SCHERTZER, ECOLE DES PONTS PARISTECH, DANIEL.SCHERTZER@ENPC.FR;
AUGUSTE GIRES, ECOLE DES PONTS PARISTECH, AUGUSTE.GIRES@LEESU.ENPC.FR;
BRUNO TISSERAND, VEOLIA ENVIRONMENT RESEARCH AND INNOVATION, BRUNO.TISSERAND@VEOLIA.COM;
THOMAS THOUVENOT, VEOLIA ENVIRONMENT RESEARCH AND INNOVATION, THOMAS.THOUVENOT@VEOLIA.COM;
LAURENT MONIER, VEOLIA ENVIRONMENT RESEARCH AND INNOVATION, LAURENT.MONIER@VEOLIA.COM

Space remote sensing has been playing a prominent role in monitoring climate and the water cycle across a large number of scales. Nonetheless, the revisit time (a few hours) and space resolution (a few kilometers) are too coarse for a lot of hydrologic applications, especially those in urban or semi-urban areas that concentrate most population and assets. Therefore the deployment of new ground sensors is crucially needed to achieve an integrated system of observations across a wider range of scales.

For decades (C and S-band) networks of ground weather radars have gradually been set up for remote sensing precipitation measurement. Recent advancements in dual-polarization techniques have dramatically enhanced the X-band radar performances. They enable accurate quantitative precipitation estimates at unmatched space and time resolutions for hydro-meteorological applications. They eliminate radar calibration, yet required for low-cost X-band radars, along with associated sources of uncertainty. Ongoing experiments CASA and TOMACS in metropolitan areas of respectively Dallas Fort Worth (Texas, USA) and Tokyo (Japan) are illustrative cases of X-band dual-pol radar networks. Even though it is a high-potential technology, its application-driven development faces barriers to overcome in Europe. Rain gauges continue to be used along with modern devices (disdrometers) for point precipitation measurement.

Inhomogeneous distributions of rain gauging networks lead to only a partial information on the rainfall fields. In another words, the statistics of measured rainfall is strongly biased by the fractality of the measuring networks. This fractality needs to be properly taken in to account to retrieve the original properties of 2-D rainfall fields (Tchiguirinskaia et al., 2004). When the fractal dimension of the networks is too low, the 2-D rainfall retrieval remain out of the reach, i.e., without any alternative to radar rainfall measurements. In turn, such a critical fractal dimension opens new possibilities not only for optimisation of rainfall measurement networks, but also for an original way to evaluate the effective costs of reliable rainfall measurements,- a first step towards a business model for integrated precipitation-oriented products and services. In particular we demonstrate that whereas they are economically competitive in-situ networks with respect to the S-band radars, this is no longer the case for X-band radars. We believe that this result has far reaching consequences in the monitoring of the water cycle.

WAGENINGEN URBAN RAINFALL EXPERIMENT 2014 (WUREX14): EXPERIMENTAL SETUP AND PRELIMINARY RESULTS

THOMAS C. VAN LETH, WAGENINGEN UNIVERSITY, TOMMY.VANLETH@WUR.NL
REMKO UIJLENHOET, WAGENINGEN UNIVERSITY REMKO.UIJLENHOET@WUR.NL
AART OVEREEM, WAGENINGEN UNIVERSITY/ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE, AART.OVEREEM@KNMI.NL
HIDDE LEIJNSE, ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE, HIDDE.LEIJNSE@KNMI.NL
PIETER HAZENBERG, WAGENINGEN UNIVERSITY, PIETER.HAZENBERG@WUR.NL

Microwave links from cellular communication networks have been shown to be able to provide valuable information concerning the space-time variability of rainfall. In particular over urban areas, where network densities are generally high, they have the potential to complement existing dedicated infrastructure to measure rainfall (gauges, radars). In addition, microwave links provide a great opportunity for ground-based rainfall measurement for those land surface areas of the world where gauges and radars are generally lacking. Such information is not only crucial for water management and agriculture, but also for instance for ground validation of space-borne rainfall estimates such as those provided by the GPM (Global Precipitation Measurement) mission.

WURex14 is dedicated to address several errors and uncertainties associated with such quantitative precipitation estimates in detail. The core of the experiment is provided by three co-located microwave links installed between two major buildings on the Wageningen University campus, approximately 2 km apart: a 38 GHz commercial microwave link, provided by T-Mobile NL, and 26 GHz and 38 GHz (dual-polarization) research microwave links from RAL. Transmitting and receiving antennas have been attached to masts installed on the roofs of the two buildings, about 30 m above the ground. This setup has been complemented with a Scintec infrared Large-Aperture Scintillometer, installed over the same path, as well as 5 Parsivel optical disdrometers and an automated rain gauge positioned at several locations along the path. Temporal sampling of the received signals was performed at a rate of 20 Hz. The setup is being monitored by time-lapse cameras to assess the state of the antennas as well as the atmosphere. Finally, data is available from the KNMI weather radars and an automated weather station situated just outside Wageningen.

We report on the preliminary results from this experiment, collected during the summer, fall and spring of 2014/2015.

STUDY OF GREEN ROOF PERFORMANCES IN STORMWATER MANAGEMENT REGARDING SPATIAL DISTRIBUTION OF PRECIPITATION

PIERRE-ANTOINE VERSINI, UNIVERSITE PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU, PIERRE-ANTOINE.VERSINI@LEESU.ENPC.FR
AUGUSTE GIRES, UNIVERSITE PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU, AUGUSTE.GIRES@LEESU.ENPC.FR
IOULIA TCHINGUIRINSKAIA, UNIVERSITE PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU, IOULIA.TCHIGUIRINSKAIA@ENPC.FR
DANIEL SCHERTZER, UNIVERSITE PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU, DANIEL.SCHERTZER@ENPC.FR

In order to study the hydrological impact of green roofs at the basin scale (compatible with operational issues), a modelling scheme has been developed. It is based on the Multi-Hydro distributed rainfall-runoff model where a specific module dedicated to simulate green roof behaviour has recently been added. It enables to analyse the impact of the spatial variability of precipitation and land use, and especially the precise location of green roof.

Multi-Hydro has been applied on a highly urbanized basin located close to Paris (Loup, 0.5 km2). 20% of its area is occupied by buildings dedicated to industrial activities where it has been assumed that green roof can be implemented. In order to test the impact of spatial variability of precipitation, an ensemble of 50 realistic downscaled rainfall fields with a resolution of 10 m in space was generated from Radar data by using multifractals technics. This methodology has been applied on several rainfall events differentiated by their intensities and durations.

The reduction of the hydrological response (peak and volume runoff) reaches more than 60% for the more common event. Spatial variability of rainfall fields slightly influences the basin response: variation of about +/-8% regarding the average response. Results obtained for more intense events are less pronounced (reduction of about 20%). The use of green roof seems also to mitigate the effects of a rainfall event characterized by a return period lower than 10 years.

QUALITY AND IMPACT ASSESSMENT OF COMMUNICATION ON HYDROLOGY FOR RESILIENT CITIES

ROSA VICARI, UNIVERSITE PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU,
ROSA.VICARI@ENPC.FR
DANIEL SCHERTZER, UNIVERSITE PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU,
DANIEL.SCHERTZER@ENPC.FR
JEAN-CLAUDE DEUTSCH, UNIVERSITE PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU,
JCD@ENPC.FR
REGIS MOILLERON, UNIVERSITE PARIS-EST, ECOLE DES PONTS PARISTECH, LEESU,
REGIS.MOILLERON@ENPC.FR

The quality of communication in the field of science has become more and more challenging due to the fact that the role of traditional mediators (e.g. well reputed newspapers or broadcasters, science museums), that used to be considered quality guarantors, has now become marginal. Furthermore, there is presumably a deficit in terms of research and reflection on objective tools to assess the quality and impact of communication activities.

This research aims to understand how communication strategies, addressed to the general public, can optimise the impact of research findings in hydrology for resilient cities. The research will greatly benefit from the development of automated analysis of unstructured Big Data that allows the exploration of huge amounts of digital communication data: blogs, social networks postings, public speeches, press releases, publications, articles... Furthermore, these techniques facilitate the crossing of socio-economic and physical environmental data and possibly lead to the identification of existing correlations.

Case studies correspond to those of several research projects under the umbrella of the Chair "Hydrology for resilient cities" aimed to develop and test new solutions in urban hydrology that will contribute to the resilience of our cities to extreme weather. This research was initiated in the framework of the Interreg IVB project RAINGAIN and pursued in the project Blue Green Dream of the EU KIC Climate and in worldwide collaborations (e.g. TOMACS). These projects involve awareness raising and capacity building activities aimed to stimulate cooperation between scientists, professionals (e.g. water managers, urban planners) and beneficiaries (e.g. concerned citizens, policy makers).

TEMPORAL INTERPOLATION OF RADAR RAINFALL IMAGES: PERFORMANCE ASSESSMENT ACROSS SPATIAL SCALES

LI-PEN WANG, KU LEUVEN, LEUVEN, BELGIUM, LIPEN.WANG@BWK.KULEUVEN.BE
SUSANA OCHOA-RODRIGUEZ, IMPERIAL COLLEGE LONDON, UNITED KINGDOM, S.OCHOARODRIGUEZ@ IMPERIAL.AC.UK
MARIA AKERBOOM, DELFT UNIVERSITY OF TECHNOLOGY, DELFT, NETHERLANDS, MARIA.AKERBOOM14@IMPERIAL.AC.UK
PATRICK WILLEMS, KU LEUVEN, BELGIUM, PATRICK.WILLEMS@BWK.KULEUVEN.BE
CHRISTIAN ONOF, IMPERIAL COLLEGE LONDON, UNITED KINGDOM, C.ONOF@IMPERIAL.AC.UK

Radar quantitative precipitation estimates (QPEs) are playing an increasingly important role in urban hydrology due to their better description of the spatial and temporal characteristics of rainfall. However, the operational radar QPE products provided by national weather services (typically at 1 km / 5-10 min resolution) still fail to meet the stringent resolution requirements of urban hydrological applications. While the spatial and temporal resolution of rainfall inputs are strongly related, recent studies suggest that the latter generally constitutes a more critical factor and that temporal resolutions of ~1-2 min are required for urban hydrological applications, while spatial resolutions of ~1 km appear to be sufficient. Traditional strategies for obtaining higher temporal-resolution radar QPEs include changes in radar scanning strategies and stochastic downscaling. However, the former is not always possible, due to hardware limitations, and the latter results in impractical large ensembles. In this work a temporal interpolation method, based upon the multi-scale variational optical flow technique, is proposed to generate high temporal-resolution radar QPEs..

The proposed method was used to generate radar QPEs at 1-min temporal resolutions from UK Met Office C-band radar QPEs originally at 5-min temporal resolution and varying spatial resolutions of 1 km, 500 m and 100 m. The performance of the temporally-interpolated radar QPEs, across a range of spatial resolutions, was assessed through comparison against local rain gauge records and through hydrological verification using as case study 3 storm events observed in a small urban catchment (~865 ha) in London for which dense rain gauge and sewer flow records, as well as a recently-calibrated high-resolution urban drainage model were available. Results show that the temporally-interpolated rainfall estimates can better reproduce the small-scale dynamics of the storm events, leading to improved reproduction of urban runoff. Improvements are particularly evident for QPEs of higher spatial resolution.

CLIMATE CHANGE AS A DRIVER FOR PARADIGM CHANGE IN URBAN WATER MANAGEMENT

PATRICK WILLEMS, KU LEUVEN, DEPT. CIVIL ENGINEERING, HYDRAULICS DIVISION, LEUVEN, BELGIUM, PATRICK.WILLEMS@BWK.KULEUVEN.BE

Cities are becoming increasingly vulnerable to flooding because of rapid urbanization, installation of complex infrastructure, and changes in the precipitation patterns caused by anthropogenic climate change. This is partly because of decreasing volumetric rainfall trends in many parts of the world, which might have severe effects on reservoir yields and operational practices. In addition, more frequent and more severe intensity rainfall events can cause substantial urban inundation problems.

For many cities in the world, future projections of climate change impacts on extreme short-duration rain showers and urban drainage show significant increases in the frequency of sewer surcharge, flooding and overflow spills. At the same time, due to the difficulties and uncertainties in climate change impact modelling and analysis on the urban scales, caution must be exercised when interpreting climate change scenarios. These uncertainties can however not be used as an argument for not taking determined actions. Instead, uncertainties should be accounted for and flexible and sustainable solutions aimed at.

Interestingly, climate change serves as a driver for changes in urban drainage paradigm. An adaptive approach has to be established that both provides inherent flexibility and reversibility and also avoids closing off options. In addition to these flexible management strategies, urban flood forecasting and warning systems should be installed, but also this is quite challenging. Moreover, co-optimizing urban drainage infrastructure with other objectives as well as active learning and involvement will become ever more important to keep our cities liveable in the future.

DECADAL VARIATION IN RAINDROP SIZE DISTRIBUTIONS IN BUSAN, KOREA

CHEOL-HWAN YOU, ATMOSPHERIC ENVIRONMENTAL RESEARCH INSTITUTE, PUKYONG NATIONAL UNIVERSITY, KOREA, YOUCH@PKNU.AC.K
DONG-IN LEE, ATMOSPHERIC ENVIRONMENTAL RESEARCH INSTITUTE, PUKYONG NATIONAL UNIVERSITY, KOREA, LEEDI@PKNU.AC.K
SUNG-HO SUH, ATMOSPHERIC ENVIRONMENTAL RESEARCH INSTITUTE, PUKYONG NATIONAL UNIVERSITY, KOREA, ENVATM@PKNU.AC.KR
JUNG-TAE LEE, ATMOSPHERIC ENVIRONMENTAL RESEARCH INSTITUTE, PUKYONG NATIONAL UNIVERSITY, KOREA, JTLEE87@PKNU.AC.KR
HYEON-JOON KIM, ATMOSPHERIC ENVIRONMENTAL RESEARCH INSTITUTE, PUKYONG NATIONAL UNIVERSITY, KOREA, HYEONJOON5@PKNU.AC.KR
DONG-JIN KIM, RADAR OPERATION DIVISION, WEATHER RADAR CENTER, KOREA METEOROLOGICAL ADMINISTRATION, SEOUL, KOREA, KDJ1105@KOREA.KR

This paper investigated the variability of raindrop size distributions (DSDs) in Busan, Korea, using data from two different disdrometers: a precipitation occurrence sensor system (POSS) and a particle size velocity (Parsivel) optical disdrometer. DSDs were simulated using a gamma distribution model to assess the inter-comparability of these two techniques. The two disdrometers, which have different bin widths, yielded a maximum difference in mean drop diameter (Dm) of 0.144 mm, and an average difference of 0.033 mm during the simulations, suggesting that DSDs obtained from the POSS and Parsivel systems can be compared directly, without interpolation. Annual rainfall amount was higher in 2012 than in 2002, as were the annually averaged Dm (which was 0.1 mm greater in 2012) and the frequency of convective rain. The Dm of convective and stratiform rain was larger in 2002 than in 2012. The parameters of the gamma-fitted DSDs changed concomitantly with Dm; e.g., the intercept (Nw) exhibited an inverse trend. Severe rainfall (greater than 20 mm h−1) occurred more frequently and with a larger Dm in 2012. The Dm associated with medium (5 < R < 10 mm h−1) and strong (10 < R < 20 mm h−1) rates of rainfall was larger in 2002 than in 2012. The values of Dm from July, August, and December 2012 were much greater than from other months when compared with 2002. During spring and autumn, there were no significant changes in Dm and Nw when comparing 2002 with 2012. Larger raindrops contributed to the higher rain rates that were observed in the morning during 2012, whereas relatively smaller raindrops dominated in the afternoon. These results suggest that the increase in raindrop size that has been observed in Busan may continue in the future; however, more research will be required if we are to fully understand this phenomenon. Rainfall variables are highly dependent on drop size and so should be recalculated using the newest DSDs to allow more accurate polarimetric radar rainfall estimation.

EXCUSED

A REVIEW ON X-BAND RADAR FOR QUANTITATIVE PRECIPITATION ESTIMATE

MASAYUKI MAKI, KAGOSHIMA UNIVERSITY, MAKI@RDC.KAGOSHIMA-U.AC.JP

Development of X-band weather radar from the end of World War II to the present is reviewed. It has been believed for long time that X-band wavelength was not adequate for QPE, however, this changed drastically after differential phase shift measurements became practical. The sensitivity of differential phase shift to rain rate at X-band wavelength is higher than that that of C- and S-band wavelength. Its smaller size compared to C- and S-band radars and its high spatiotemporal resolution has accelerated its use as a gap-filling radar and a networked radar in urban areas. Multidisciplinary projects are ongoing in Japan, the US, and Europe, with the aim of developing more effective information from X-band polarimetric radar networks. The products from these experiments provide the variety of information required by end-users, which cannot otherwise be attained from the nation-wide radar network.

STATISTICAL DOWNSCALING OF DAILY RAINFALL PROCESS AT AN UNGAGED SITE

VAN-THANH-VAN NGUYEN, MCGILL UNIVERSITY, DEPARTMENT OF CIVIL ENGINEERING AND APPLIED MECHANICS, MONTREAL, QUEBEC, CANADA, VAN.TV.NGUYEN@MCGILL.CA
MYEONG-HO YEO, MCGILL UNIVERSITY, DEPARTMENT OF CIVIL ENGINEERING AND APPLIED MECHANICS, MONTREAL, QUEBEC, CANADA

Climate change has been recognized as having a profound impact on the hydrologic cycle and Global Climate Models (GCMs) have been extensively used for assessing this impact. However, outputs from these models are at resolutions that are too coarse and hence not suitable for hydrological impact studies at a local scale. Downscaling methods have been thus proposed for establishing the linkages between the large-scale climate variables given by GCMs and the observed characteristics of hydrologic variables at a local site. These downscaling methods, however, are not suitable for dealing with cases where the hydrologic data at the location of interest are limited (a partially-gauged site) or not available (an ungauged site). The downscaling of a hydrologic process such as the daily precipitation for such cases remains still a crucial challenge for water resources planning and management in practice. Therefore, the present study proposes a statistical downscaling (SD) approach to establishing accurately the linkages between the climate variables given by GCM outputs and the "estimated" daily precipitation characteristics at a location of interest where the precipitation data are limited or unavailable. More specifically, the suggested SD procedure is based on a combination of two components: (i) a regional stochastic method for reconstructing the unmeasured daily precipitation series at the ungauged site; and (ii) a SD model for describing the linkage between the constructed daily precipitation series and the climatic predictors given by GCM outputs. The feasibility and accuracy of the proposed SD procedure was assessed based on the NCEP re-analysis and observed daily precipitation data available at two raingages in Korea with different climatic conditions (Seoul and Busan stations). Results of this assessment have indicated that the proposed procedure could provide comparable results as those given by the downscaling using real observed precipitation data at the same local site.

June 8, 2015

Block 1 Chairs: Geoff Austin, Daniel Schertzer	09:00 - 09:10	Préteux	Préteux	ENPC	Welcome by the ENPC Research Director	(10 min)
	09:10 - 09:30	ten Veldhuis	ten Veldhuis	RainGain / TU Delft	Welcome and project overview by the RainGain coordinator	(20 min)
	09:30 - 09:45	Barbaresco	Barbaresco	Thalès	Ultra-Fast & High Resolution Rainfall measurement for Airport Runway Excursion with Solid-State Electronic Scanning Radar	Oral (15 min)
	09:45 - 10:00	Knapp	Knapp	University of Massachusetts	Alternative Business Model Hypotheses for Widespread deployment of X Band Radars	Oral (15 min)
	10:00 - 10:30	Russchenberg	Russchenberg	TU Delft	Radar rainfall studies: of raindrop shapes and showers	Invited (30 min)
Block 2 Chairs: Remko Uijlenhoet, Susana Ochoa Rodrigue	11:00 - 11:30	Willems	Willems	RainGain / KU Leuven	RainGain WP2 Overview : Fine-scale rainfall data acquisition and prediction	Invited (30 min)
	11:30 - 12:00	Lee	Lee	Pukyong National University	Development of high resolution spatio-temporal radar data using a network of operational polarimetric X-band radars	Invited (30 min)
	12:00 - 12:15	Antonini	Antonini	Consorzio LAMMA, Toscana	A regional X-band radar network	Oral (15 min)
	12:15 - 12:30	Schmitt	Schmitt	Deutscher Wetterdienst (DWD)	The German Radar Precipitation Climatology and its Application Possibilities	Oral (15 min)

Block 3 Chairs: Dong In Lee, Katharina Lengfeld	14:00 - 14:30	Zhang	Austin	Met service Singapore / Auckland University	The impact of high resolution initialization of NWP models on their ability to make short term quantitative precipitation estimates	Invited (30 min)
	14:30 - 14:45	Caumont	Caumont	Météo-France	Weather radar data assimilation for high-resolution quantitative precipitation forecasting at Météo-France: Status and plans	Oral (15 min)
	14:45 - 15:00	Mosthaf	Mosthaf	Universität Stuttgart	Stochastic gridded multi-site simulation of hourly rainfall	Oral (15 min)
	15:00 - 15:15	Akrour	Akrour	LATMOS, UVSQ	Generation of 2D rain maps with realistic properties: methodology and results.	Oral (15 min)
	15:15 - 15:45	Lovejoy	Lovejoy	McGill University,	Space-time weather and macroweather precipitation models	Invited (30 min)
Block 4 Chairs: Marie-Claire ten Veldhuis, Eric Knapp	16:15 - 16:45	Maksimovic	Maksimovic	RainGain / IC London	RainGain WP3 Overview : Modelling and prediction of urban pluvial flood	Invited (30 min)
	16:45 - 17:00	Ochoa - Rodriguez	Ochoa - Rodriguez	RainGain / IC London	Spatio-temporal rainfall input resolution requirements for urban drainage modelling: a multi-catchment investigation	Oral (15 min)
	17:00 - 17:15	Grum	Grum	Kruger	Radars and Weather Nowcasts Adding Value to Wastewater Management	Oral (15 min)
	17:15 - 17:30	Moreau	Moreau	Novimet	Accurate measurement of precipitation by X-band radar: Hydrological Applications in the Maritime Alps	Oral (15 min)
	17:30 - 17:45	Li	Li	Univ Hamburg	2D hydrodynamics of Pearl River Estuary using D-Flow Flexible Mesh	Oral (15 min)
	17:45 - 18:00	Poulard	Poulard	Irstea	From rainfall fields to flood hazard and flood risk: advantages of (semi-) continuous simulation	Oral (15 min)

June 9, 2015

Block 5 Chairs: Johan Van Assel, Auguste Gires	09:00 - 09:30	ten Veldhuis	ten Veldhuis	RainGain / TU Delft	RainGain WP4 Overview : Implementation of rainfall data and flood modelling into urban water management	Invited (30 min)
	09:30 - 09-45	Kramer	Kramer	Institute for Technical and Scientific Hydrology Ltd., Hanover,	Real time radar data correction for operational sewer management in the City of Hamburg	Oral (15 min)
	09:45 - 10:00	Thorndahl	Thorndahl	Aalborg University, Denmark	Towards real-time modelling of drainage systems with radar rainfall inputs	Oral (15 min)
	10:00 - 10:15	Sutherland - Stacey	Sutherland - Stacey	WeatherRadar.co.nz / Auckland University	High resolution radar observations from a mobile radar X-Band radar in support of urban waste water infrastructure.	Oral (15 min)
	10:15 - 10:45	Moore	Moore	CEH, UK	Distributed flood forecasting from countrywide to urban scales	Invited (30 min)
Block 6 Chairs: Robert Moore, Ioulia Tchiguirinskaia	11:15 - 11:45	Overeem	Uijlenhoet	Wagenigen Univ. / KNMI	Urban rainfall estimation in Rotterdam employing commercial microwave links	Invited (30 min)
	11:45 - 12:00	Lengfeld	Lengfeld	Univ Hamburg / Centre de Recerca Aplicada en Hidrometeorologia, Spain,	Urban High-Resolution Precipitation Product for rainfall-runoff simulations: Combining C-Band and Local X-Band Radar Data	Oral (15 min)
	12:00 - 12:15	Norman	Norman	UK Met Office	High resolution rainfall products from the UK weather radar network.	Oral (15 min)
	12:15 - 12:45	Nakatani	Nakatani	NIED, Japan	Introduction of Tokyo Metropolitan Area Convection Study for Extreme Weather Resilient Cities (TOMACS)	Invited (30 min)

Radar Inauguration

14:00-14:10 Opening: Gilles Robin, vice-director of Ecole des Ponts ParisTech

14:10-14:30 Challenges pointed out by the conference: Philippe Courtier (Ministry of Ecology, Sustainable Development and Energy)

14:30-16:00 Roundtable "Institutions", moderator Jean-Marie Potier (LCI TV)

16:20-17:50 Roundtable "Industries", moderator Jean-Marie Potier (LCI TV)

17:50-18:30 Inauguration and press briefing

18:30-19:30 Reception and Orchestra Solistes de France