EPSRC Maths Foresees Network Feasibility study report

Project title: Stochastic Modelling Approach for Future Flood Risk Modelling

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Project background: Multiple studies are now concluding that the climate change is playing a key role in the manifestation of the extreme climatic events, such as river flooding, hurricanes, cyclones, etc. For the UK, increased risk of frequent and severe flooding in the future is one of the most challenging issues. Current practice in the areas of flood risk management (FRM) mostly involves use of a single 1:N year extreme flow or rainfall design discharge (constant) or hydrograph (variable) inflow event. Yet, the devastating repeat flood inundation events over the winter of 2015/6 storms clearly demonstrated that the clustering of multiple extreme events magnify risk in a manner which cannot currently be predicted, modelled or incorporated in long-term sustainable flood risk assessments (FRA) or FRM design solutions. Given that future climate change scenarios indicate that storm and flood frequency will increase, the UKs susceptibility to storm clusters will also be magnified. Thus, this project combines stakeholder knowledge (Scottish Environment Protection Agency, SEPA) with cross-disciplinary academic expertise (statistical, river process, climate change flood modelling) to refine mathematical modeling approaches in flood risk to better consider cluster-related uncertainties in light of climate change. Specifically, the impacts of climate change on clustering of extreme river flow events has been thoroughly investigated to understand changes to the severity of flood hazard from antecedent events e.g. non-return of river baseflow, antecedent water storage of the floodplains and natural channel morphodynamics.

Project objectives: Key objectives of the project includes:

1. Develop a proficient statistical modelling framework for integrating regional climate change projections within synthetic river flow series.
2. Advance our HMM-PD modelling framework to synthesizing flow time series at finer temporal resolutions (1 hour; 15 minute) capable of robustly capturing flashy flow regimes.
3. Generate a robust, viable and constrained methodological approach for representing extreme event clusters in flood model inflow conditions.
4. Quantify the impacts of clustering of extreme events on flood hazard, accounting for future climate change.
5. Promote our methodology to flood risk management stakeholders, e.g. via Flood Modelling Guidance for Stakeholders.

Project Description:

- **Rethinking Mathematical Modelling**: EPSRCs FloodMEMORY:Multi-Event Modelling Of Risk RecoverY (EP/K013513/1) project as part of FCERM.net (EP/L000180/1) project has successfully developed a novel methodology for modeling of flood sequences (and associated risk) by integrating highly competent Hidden Markov models (HMM) with the generalized Pareto Distribution (PD). HMM models retain the overall statistical characteristics of the original flow series but reorder the magnitude, spacing and frequency of river flow. PD fitted to values over 99 percentile allows effective modelling of extreme events. HMM-PD models have been utilized to synthesize multiple time series of daily river flow [1] and have been exhaustively validated across four hydrologically distinct rivers to investigate morphological sensitivity into the flood inundation modelling [2]. Outcomes of the project were encouraging in their potential to transform how flood risk assessments are performed in the UK (and wider EU members states bound by the EU Floods Directive) by improving current understanding and model confidence for reducing future flood risks. The process-based science of FloodMEMORY drew to a close in May 2016 and the HMM-PD method has being refined for practitioner adoption via knowledge exchange secondment with SEPA (EPSRCs Impact Acceleration Award completed in autumn 2016). This feasibility project has considered three specific challenges in the approach to address practitioners confidence and UK-wide adoption of approach; it is these which underpin this proposal:

- **Climate Change Scenarios:** Our current methodology assumes stationarity of future climate by using current river gauge data; it does not incorporate climate change scenarios, nor their potential to influence cluster characteristics. To address this, the HMM-PD modeling framework has been revised to robustly integrate precipitation in the existing methodology through the implementation of STL: A seasonal-trend decomposition procedure based on Loess process [3] approach for deseasonalisation of flow and precipitation time series. Results has been presented at 2nd Rain, River and Reservoir workshop (organised at 27-31 September 2016, Heriot-Watt University Edinburgh Campus) and has been submitted as invited book chapter (Title: Stochastic modelling of flow sequences for improved fluvial flood hazard) for special volume River to Reservoir: Geoscience to Engineering to be published by Geological Society.

- **Monitored Data resolution:** To date, the HMM-PD methodology has employed Daily Mean Flow (DMF) data; this resolution likely underestimates peak flow, overestimates event interval and fails to adequately capture (non) return of river baseflow. The HMM-PD based methodology will, therefore, has been reconnoitered for synthesizing multiple flow sequences at finer temporal resolutions of 15 minute. A range of hydrologically and geographically distinct catchments has been utilised to test the methods capability for flashy hydrograph regimes.

- **Cluster Significance:** Our current statistical model generates synthetic flow sequences of up to 50 years for use as the inflow boundary of a flood model; this culminates in long model run times which are computationally and resource expensive. This project developed an alternative approach for constrain this that includes: (i) a systematic approach for defining, characterizing and extracting extreme event clusters where antecedent effects increase severity of flood hazard; a design cluster can then be used as the inflow boundary of the flood model, viably constraining run times; (ii) disaggregation of the HMM-PD flow sequence into a probability distribution of the non-return to baseflow condition between extreme events; this value informs the inflow boundary condition of the flood model, reducing uncertainty due to antecedent conditions.

- **Collaboration with SEPA:** In this research, collaboration with SEPA has greatly supported us to successfully realize our shared ambition of transforming flood risk assessment to account for cluster effects. In long term, we planned to refine the existing this methodology to provide updated inflow boundary condition data (via the published Flood Modelling Guidance for Stakeholders manual) for all Scottish rivers, for every flow gauge location. As part of this project we applied our methodology to test three rivers (Tweed, Nith and Dee) in distinct climate scenario regions of Scotland (East, West and North). These rivers are selected for their long flow records, existing hydraulic models and demonstrated hydraulic (and geomorphic) response to extreme flood clusters of winter of 2015/16. The refined HMM-PD methodology has been applied to both hydraulic-only (fixed geometry, common in current practice) and hydraulic-morphology (where the channel geometry can change over time) 1D and 2D modelling approaches; output data has been assessed for the sensitivity of flood inundation envelopes (extent, depth, velocity; i.e. hazard mapping) to clusters of extreme events.

- **Promoting Mathematical Modelling:** SEPA are the main Responsible Authority for flood risk management in Scotland and our knowledge exchange, skills training and collaboration reaches an immediate people pipeline of 100+ environmental scientists and engineers. By provision of clear guidance on modelling methodology for antecedent conditions, our work has potential to be further developed to provide direct user engagement via revised SEPA documentation on Flood Modelling Guidance for Stakeholders; this reaches 40 Responsible Authorities and over 100 environmental consultancies. Ultimately, our collaboration seeks to improve flood risk assessments for the 108,000 property owners at risk of flooding in Scotland and transcend SEPAs UK/EU network of 10,000 practitioners, policy makers and the wider academic/RD community.

Key project outcomes:

1. Developed a proficient statistical modelling framework for integrating regional climate change projections within synthetic river flow series [Figure 1].

2. Advanced our HMM-PD modelling framework to synthesizing flow time series at finer temporal resolutions (15 minute) capable of robustly capturing flashy flow regimes [Figure 2].

3. Generated a robust, viable and constrained methodological approach for representing extreme event clusters in flood model inflow conditions.

Funding secured and sought:

1. EPSRC funded project Community-scale Energy Demand Reduction in India (CEDRI) under the call UK-India Reducing Energy Demand in the Built Environment.

2. Project proposal submitted to NERC under the Newton Hydrometerological Hazard.

Future actions:

1. To quantify the impacts of clustering of extreme events on flood hazard, accounting for future climate change.
2. To promote our methodology to flood risk management stakeholders, e.g. via Flood Modelling Guidance for Stakeholders.

References:

1. Pender, D., Patidar, S., Hassan, K., Haynes, H. (2016). J. Hydraul. Eng., Vol. 142, Issue 6.
2. Pender, D., Patidar, S., Pender, G., Haynes, H. (2016). Hydrology Research, Vol. 47, no. 1, pp. 75-88.
3. Cleveland, R. B., Cleveland, W. S., McRae, J. E., and Terpenning, I. (1990). Journal of Official Statistics, 6(1):373.

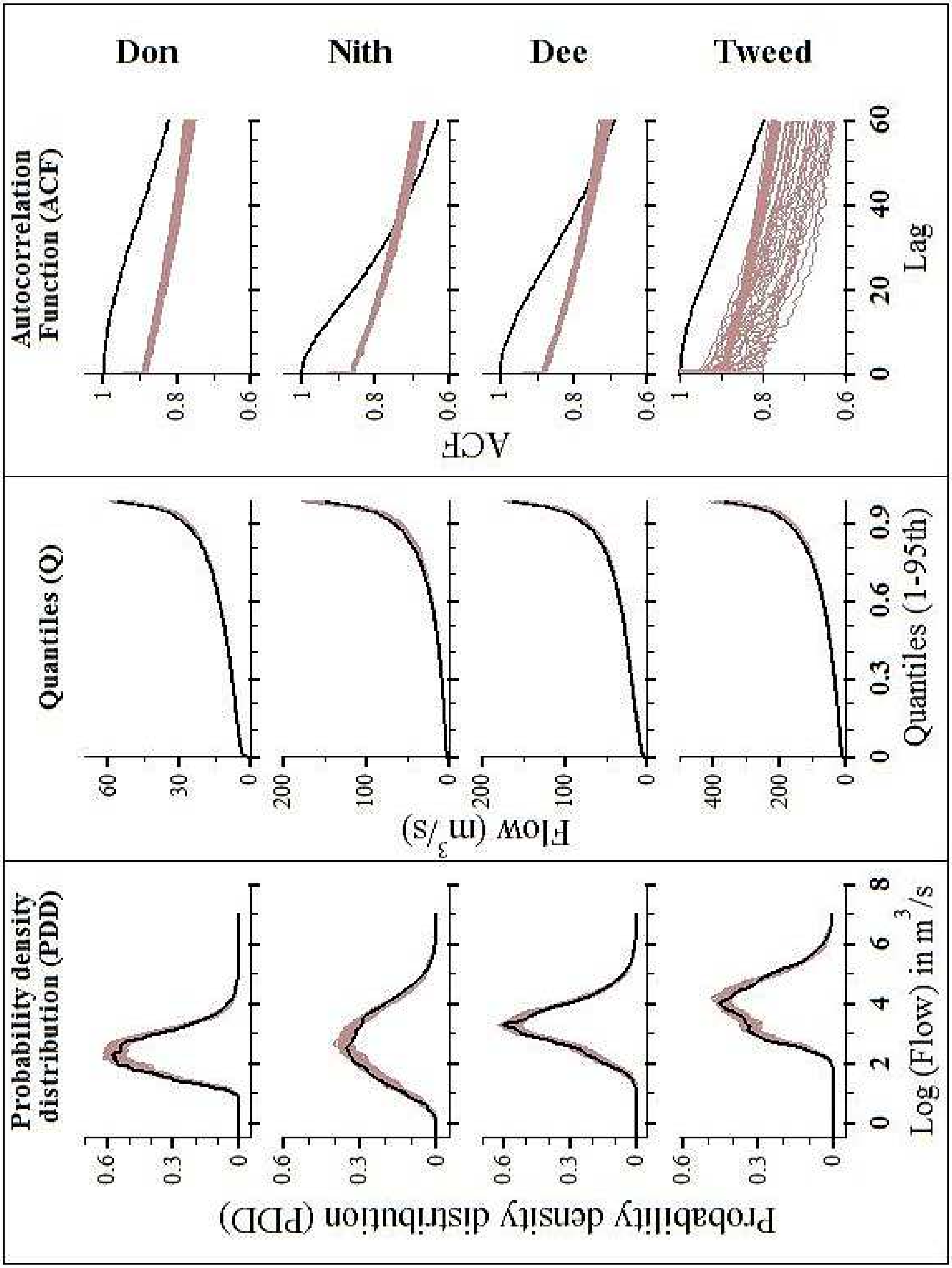

Figure 1: *Comparing Probability Density Distribution (PDD), Quantiles (from 0 to 98th percentile with a step size of 1) and Auto-Correlation Function (ACF) for the observed (solid thick black lines) and 100 synthetic streamflow profiles (solid brown (grey online) lines) generated using HMM-GP model for the case study river Don at Haughton, Nith at Friars Carse, Dee at Woodend and Tweed at Norham. Statistics are estimated for entire 15 minutely streamflow dataset available over the observation period.*

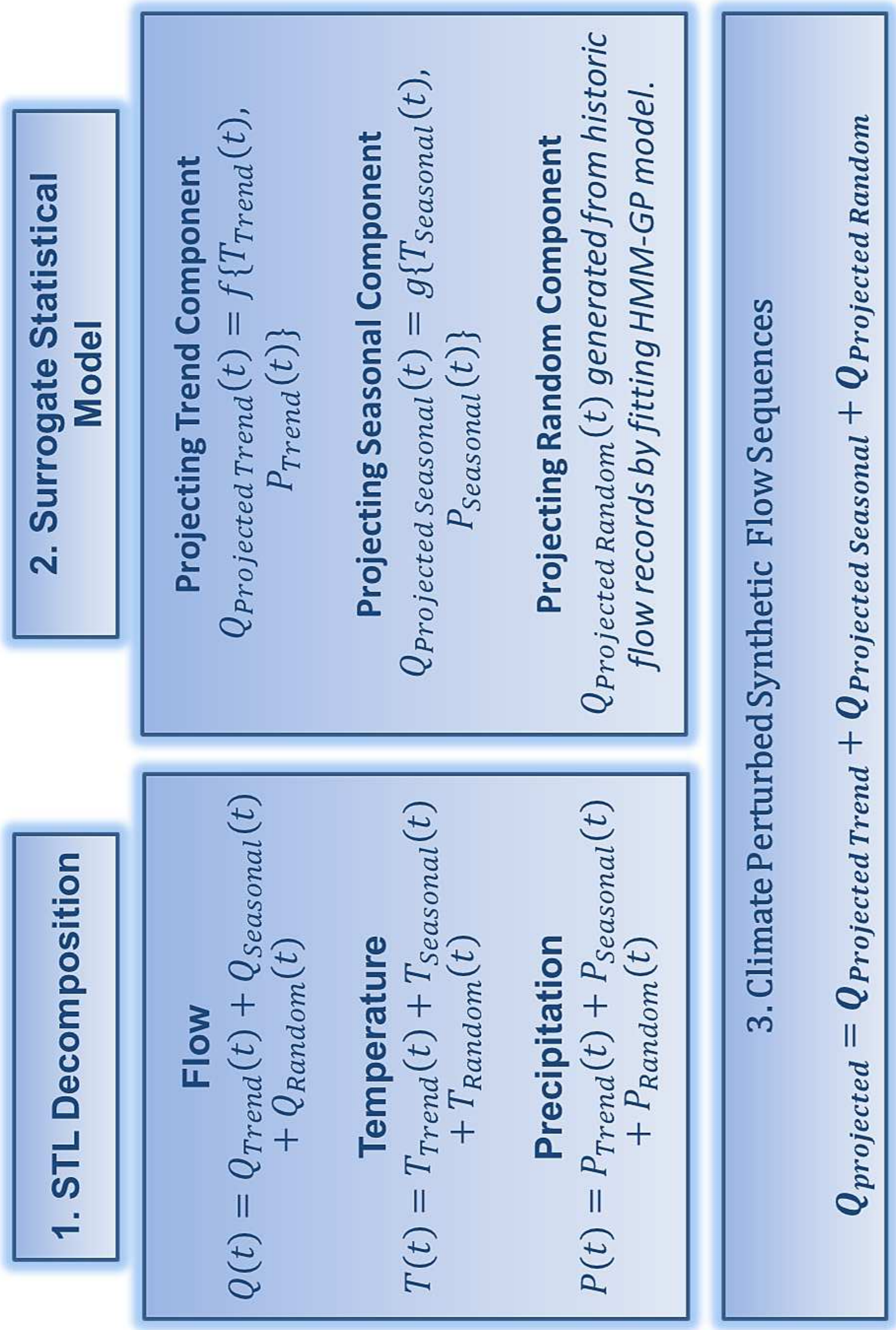

Figure 2: *Conceptual modelling framework for generating climate perturbed synthetic flow series.*