2015 COMET Outreach Program

FINAL REPORT

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Type of Project (Partners or Cooperative): Partners
Project Title: **Development of non-stationary methods for addressing climate change effects on NOAA Atlas 14 precipitation frequency estimates**
UCAR Award No.: Z16-23485
Date: 01/01/2016-08/31/2017

1. Summary of Project Objectives

1.1 Background

Since 2004, the Hydrometeorological Design Studies Center (HDSC) of the NOAA's National Water Center (NWC) has been publishing updated precipitation frequency estimates, together with supplementary information, for the United States (US) and affiliated territories. The estimates are published as volumes of the *NOAA Atlas 14, Precipitation-Frequency Atlas of the United States* in the online Precipitation Frequency Data Server (PFDS) (see, e.g., Perica et al. 2012, 2013a, b). NOAA's precipitation frequency estimates are used for a wide variety of design and planning activities at the federal, state, and local levels as well as in the private sector. For example, hydrologic and hydraulic engineers use them to design storm water-runoff facilities, to estimate the volume of detention basins and size detention-basin outlet structures, and to estimate the volume of sediment or amount of erosion caused by rainfall-runoff events. They are also used by the National Flood Insurance Program to delineate and manage urban development in floodplain areas across the US. If precipitation frequency estimates are over-estimated, that is, if the value is over-estimated, it can cause unnecessary costs to taxpayers, developers and homeowners. However, if an estimate is too low, it can cause unintended destruction of property and loss of human life.

The precipitation frequency estimates in NOAA Atlas 14 supersede the estimates published during the period from the 1950s to the 1970s. The updated estimates benefit from denser rain gauge networks with longer periods of record, the use of improved methods in statistical frequency analysis, and hybrid statistical-geographic spatial interpolation techniques and mapping. The current frequency analysis methodology used in developing the NOAA Atlas 14 estimates assumes stationarity in both the historical data used in making the estimates and in the future conditions. There is considerable speculation as to whether this assumption is appropriate.

Ultimately, precipitation frequency estimates are crucial for ensuring public safety against flooding hazards. Thus, it is imperative that estimates are accurate, reliable, and reflect our best understanding of current and future potential risk from extreme precipitation events. It has thus become necessary to fully and robustly assess the potential for incorporating the effect of climate change on precipitation frequency estimates. This means assessing the potential for incorporating non-stationarity into frequency analysis methods or even incorporating climate projections into precipitation frequency analysis. Accordingly, **the primary goal of this COMET partner project was to propose and perform a preliminary test of a new methodology for incorporating non-stationarity into the NOAA Atlas 14 estimates**.

1.2 Objectives

The objectives of this COMET project were:

- *Objective 1*: To outline, based on a comprehensive literature review, suitable and candidate state-of-the-science methodologies for non-stationary precipitation frequency analysis,
- *Objective 2*: To identify from the list in objective 1 the most suitable method(s) with respect to NOAA Atlas 14, and
- *Objective 3*: To implement and test the proposed methodology on one of the NOAA Atlas 14 project areas.

2. Project Accomplishments and Findings

The major research activities and accomplishments achieved with this COMET project are summarized next.

- A comprehensive literature review was performed which resulted in the following outcomes:
  - Identification of methods and software tools for performing non-stationarity precipitation frequency analysis; description of the different parameter estimation methods for dealing with the relevant extreme value distributions.
  - Summary of approaches for peak-over-threshold precipitation frequency analysis, which included reviewing approaches for threshold selection (non-parametric, graphical, and goodness-of-fit methods), and de-clustering techniques.
  - Summary of approaches for trend detection and analysis.
  - Identification of approaches for regional precipitation frequency analysis.
  - Summary of goodness-of-fit tests for precipitation frequency analysis.
  - Outline of current and emerging research areas.

- Selected at-site stationary precipitation frequency analysis methods were tested for both the Generalized Extreme Value (GEV) distribution and the two-parameter generalized Pareto distribution (GPD), using the US northeast project area of the NOAA Atlas 14. This research activity resulted in the following accomplishments:
  - Three different stationary models (L-moments, LM; maximum likelihood estimation, MLE; and generalized maximum likelihood estimation, GMLE) were assessed based on both simulation and observed data. The models primarily differed in the approach used for parameter estimation. We found that the different stationary models performed similarly within the typical or common range of the parameter values; some differences were observed outside the common range (e.g., MLE can outperform the other models for unusually high values of the shape parameter). We assessed and compared the models using the root-mean-squared error, density function plots, q-q plots, spatial quantile plots, and the q-score.
  - For the GMLE approach, we found that the penalization strategy has a significant effect on the value of the parameters and model performance. Hence, different penalization strategies were tested. To test and compare the penalization strategies, we used scatter plots of the shape parameter and density function plots. We found that the most reasonable strategy was to use Beta priors for the shape parameter that shrink to a non-zero value. The non-zero value can be obtained from stations with long records.

- Different at-site trend detection approaches were evaluated and compared to identify the best performing one(s). This research task accomplished the following outcomes:
  - Trend detection approaches were implemented by i) testing trends on the data and ii) testing a fitted model that accounted for trends (non-stationary model). To test trends on the precipitation data, we evaluated several versions of the Mann-Kendall trend test, and the Poisson-Wald test; while the likelihood-ratio test was used to evaluate models with trends. We found that the Poisson-Wald and the Mann-Kendall (n-excess) tests have better capabilities for identifying trends in the frequency of extreme precipitation.

- Selected at-site non-stationary precipitation frequency analysis methods were tested for both the GEV distribution and the GPD, using the US northeast project area of the NOAA Atlas 14. This research activity resulted in the following accomplishments:

- We evaluated various non-stationary models assuming different trend types (linear or fully nonlinear with spline functions) on one, several, or all the distribution parameters. For this model comparison, we used GMLE for parameter estimation.
- To compare the results from the different non-stationary models, we used the Akaike's information criterion (AIC) and Bayesian information criterion (BIC) to assess the non-stationary models with linear trends, while the q-score was used to assess the models with non-linear (spline functions) trends. We found that non-stationary models that accounted for trends only in the location (in the case of the GEV) or threshold (for the GPD) parameter tended to perform better than the models that contained trends in more than one parameter.

- The effect of pooling stations together on trend detection and parameter estimation were evaluated as an initial step towards the comprehensive evaluation of a regional non-stationary model. We found that pooling can significantly reduce the variability associated with parameter estimation and trend detection.

3. Benefits and Lessons Learned: Operational Partner Perspective

The project brought several substantive benefits to the operational partner (OP). With the completion and outcomes of this project, the capabilities of the OP to identify and implement a suitable methodology to perform non-stationary precipitation frequency analysis, based on the needs of the NOAA Atlas 14, have been tremendously expanded and facilitated. This was achieved by the comprehensive evaluation and implementation of different statistical models and methods, and the frequent interactions between the OP and university partner. The OP significantly improved its ability to make informed and critical decisions about the implementation of non-stationary methodologies with the NOAA Atlas 14. This could lead to the project having national significance by improving the extreme precipitation estimates used by engineers to design and evaluate many of our civil infrastructure.

4. Benefits and Lessons Learned: University Partner Perspective

The project resulted in several important benefits and lessons to the University partner (UP). One lesson for the UP was the increased awareness about data limitations and the need to quality control the precipitation data. Another lesson for the UP was the need to identify and agree early in the research process on a common language to ensure effective communication. Lastly, the UP became more aware and informed about the practical considerations and conditions underlying the NOAA Atlas 14 estimates. This was very valuable to the UP in order to shape the scope of the modeling work. Certainly, the funding provided by the project, the opportunity to engage graduate students, and the frequent interactions with the HDSC were critical benefits of the project to the UP. These benefits ensured the completion of the project and supported the many accomplishments listed before. We did not encounter any major problems during the project.

5. Publications and Presentations

Perica, S., S. Pavlovic, M. St. Laurent, C. Trypaluk, D. Unruh, O. Wilhite, B. Shaby, G. Bopp, and A. Mejia 2017: Improving NOAA Atlas 14 Precipitation Frequency Analysis Methods in Response to Non-Stationary Climate Conditions. EWRI's World Environmental & Water Resources Congress, in Sacramento, 21-25 May 2017.

Perica, S., S. Pavlovic, M. St. Laurent, C. Trypaluk, D. Unruh, O. Wilhite, B. Shaby, G. Bopp, and A. Mejia 2017: Impact of Non-Stationary Climate Conditions on Extreme Precipitation Frequency Estimates Needed for Engineering Design. Engineering Methods for Precipitation under a Changing Climate Workshop, Subcommittee on Hydroclimatology and Engineering Adaptation (HYDEA) of the Committee on Adaptation to a Changing Climate (CACC) of the American Society of Civil Engineers (ASCE), Reston, VA, May 30th.

6. Summary of University/Operational Partner Interactions and Roles

The OP that participated in the project were the Chief of the HDSC, Dr. Sanja Perica, and all the other members of the HDSC, including Sandra Pavlovic, Michael St. Laurent, Carl Trypaluk, Dale Unruh, and Orlan Wilhite. The HDSC members provided project guidance, reviewed and evaluated the project outcomes produced by the UP, and made the precipitation data available. The UP consisted of Dr. Ben Shaby, PhD student Gregory Bopp, and Dr. Alfonso Mejia. The UP performed all the statistical analyses and literature review, incorporated feedback from the HDSC into the analyses, and summarized major findings and recommendations. The entire project was conducted in a highly collaborative fashion with regular monthly meetings.

References

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