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Effects of display design on signal detection in flash flood forecasting

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ABSTRACT

The Flooded Locations and Simulated Hydrographs (FLASH) project is a suite of tools that use weather radar-based rainfall estimates to force hydrologic models to predict flash floods in real-time. However, early evaluation of FLASH tools in a series of simulated forecasting operations, it was believed that the data aggregation and visualization methods might have contributed to forecasting a large number of false alarms. The present study addresses the question of how two alternative data aggregation and visualization methods affect signal detection of flash floods. A sample of 30 participants viewed a series of stimuli created from FLASH images and were asked to judge whether or not they predicted significant or insignificant amounts of flash flooding. Analyses revealed that choice of aggregation method did affect probability of detection. Additional visual indicators such as geographic scale of the stimuli and threat level affected the odds of interpreting the model predictions correctly as well as congruence in responses between national and local scale model outputs.

1. Introduction

In the field of weather forecasting, computational modelers are under pressure to provide actionable information to end users at increasingly local levels, pushing gridded forecasting systems to hyper-resolution scales (Wood et al., 2011; Beven et al., 2015). Although the capability to predict weather phenomena at small scales continues to develop, operational technology often limits display capacity. Large high-resolution displays have been shown to overcome data abstraction limits while enabling users to engage in exploratory data analysis (Lehmann et al., 2011). However, current operational forecasting display systems are frequently based on the multi-screen desktop setup, and meteorological visualization environments are constrained to comparatively low resolution displays.

1.1. The Flooded Locations and Simulated Hydrographs (FLASH) project

One such set of gridded forecasting products is the Flooded Locations and Simulated Hydrographs (FLASH) project. FLASH is a suite of real-time tools that use weather radar-based rainfall estimates to force hydrologic models to predict flash floods. The tools provide environmental information related to flash flood risk to professional forecasters, and the simulation models are designed to overcome several limitations of existing prediction systems (Gourley et al., 2016). The grid underlying each FLASH product covers a spatial extent of the continental United States at a horizontal resolution of 1 km. The hydrologic model calculates a return period, a measure of flash flood risk, for every cell within the grid. In hydrologic terms, a return period is the average length of time for a certain threshold of flooding to be reached (Mays, 2010). Potential FLASH users include forecasters at both the national and regional scales in the United States, including, but not limited to, National Weather Service Weather Forecast Offices (WFOs), River Forecast Centers (RFCs), and national centers. The tools are intended to assist forecasters to identify areas of dynamic flood risk across the country and, in turn, to predict specific threats.

When this work took place in 2013, the FLASH product suite was in development and experimental simulations were publicly displayed through a website. The website's visualization template was originally developed to display interactive data related to the National Mosaic and Multi-Sensor Quantitative Precipitation Estimates (NMQ) system (Zhang et al., 2011). When applied to the FLASH return period visualization, the pre-existing algorithm aggregated grid cells as the user zoomed in and out. At the finest scale, all grid cells were visible, but as a user zoomed out to the national map, an overview of the data presented aggregated sets of grid cells within each pixel. However, a design challenge emerged at this stage: when showing the map of the entire continental United States, the website platform and some

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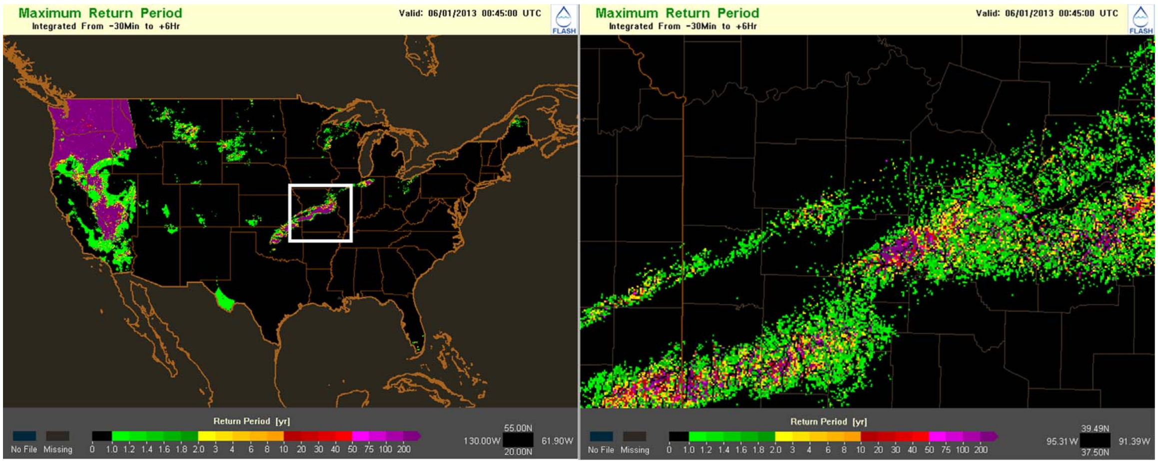

Fig. 1. The national map (on left) visualized with the original maximum-based aggregation algorithm and the associated zoomed-in local view (on right).

desktop-based display systems were not able to display each individual grid cell.

The original website displayed an overview of multiple grid cells with an aggregation algorithm to sample the maximum value out of a collection of at least 112 grid cells contained within one pixel. Predictions were displayed without any form of filtering first. In practice, while the true predicted return period values were presented when a viewer zooms in to a local level, the national view displayed an aggregated overview of the data by displaying the maximum value. An example of this phenomenon is shown in Fig. 1. At the national level, this resulted in an occlusion effect, where lower return period values were occluded by the maximum values.

1.2. Motivation

In July 2013, the Hydrometeorological Testbed at the Weather Prediction Center (HMT-WPC) hosted the first Flash Flooding and Intense Rainfall (FFaIR) experiment (Barthold et al., 2015). The purpose of the experiment was to evaluate the utility of several experimental forecast models, including FLASH, with professional forecasters and weather researchers. During the testbed, forecasters predicted heavy rainfall and flash flooding using the operational and experimental computational model outputs. Throughout these activities, the researchers observed that the information visualization affected the forecasters' ability to interpret the FLASH data. Forecasters commented that their flash flood predictions turned into false alarms more frequently in the experiment than during typical operations, which they attributed to FLASH's data aggregation algorithm. Based on these subjective comments, the researchers hypothesized that changing the aggregation algorithm would affect the rate of false alarm forecasts. In order to test this, the researchers created an alternative aggregation method which took the mean value of the grid cell predictions for a given subset (hereafter referred to as the "average-based aggregation algorithm").

The present study identified differences in terms of error rates when comparing maximum-based and average-based aggregation algorithms on the national-scale maps. This work expands upon a preliminary error rate analysis presented by Argyle et al. (2015). In addition, an analysis of response congruence was undertaken in order to determine the effects of the display condition on response accuracy across both levels of geographic scale (the national level and the zoomed-in, local level). From a design perspective, congruent decisions between levels of geographic scale are highly desirable. In FLASH, the national overview provides insight into environmental threats across the country to direct a forecaster's attention to at-risk regions. Likewise, a forecaster working at a local level may wish to examine a broader geographic region to determine potential future threats and broader environmental conditions. As such, congruent judgments between levels indicate the degree of fidelity between the abstracted overview and the individual grid cell predictions.

2. Related work

Visualization design can have a great influence on decision making and performance in weather forecasting, which largely consists of detection and identification processes (Bowden et al., 2015). Detection and identification occur rapidly and are governed by cognitive structures such as long term memory, working memory, schema, mental models, attention, feature identification, and monitoring, among others (Adams et al., 1995; Endsley, 1995, 2015; Hoffman, 2015; Wickens, 2015). In addition to these factors, success in weather forecasting has been attributed to the forecaster's ability to acquire and maintain situation awareness (Quoetone et al., 2001). As defined by Endsley (1995), situation awareness (SA) is the ability to perceive elements within a system, comprehend their significance, and project their meaning into the future in order to make a decision. Underlying the SA construct are personal factors and cognitive mechanisms, including visual information processing, cue detection, working memory, goals, preconceptions, background knowledge, and system design (Adams et al., 1995; Endsley, 1995, 2015; Hoffman, 2015).

In practice, detection is a function of factors including top-down processes, expectations, and background knowledge, aligning with Level 1 of Endsley's (1995) Model of SA, perception. Identification involves detecting an item and evaluating its fit into a categorical grouping, and it is also affected by experience and top-down processes (Endsley, 1995; Wickens and Carswell, 1997). Identification can be mapped to Level 2 of Endsley's (1995) Model of SA, or comprehension. While the third level of Endsley's (1995) Model of SA, projection, was determined to be outside the scope of the present study, future work could extend the present study's method from a detection and identification task to a projection task in which participants would have to choose whether or not a flash flood warning would be appropriate.

Detection and identification tasks can also be framed within the family of cognitive integration processes. Graph comprehension studies distinguish specific information extraction processes from information integration. In the former, a user has a goal to search and find a specific attribute in a visualization; in the latter process, a user may combine multiple attributes from a visualization in order to comprehend broader meanings and trends in the data (Ratwani et al., 2008). Due to the map-based format of many data sources used in weather forecasting, information integration is a fundamental activity for a forecaster to be able to develop SA. In example, examining a FLASH return period value assigned to a single grid cell provides much less

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