FORECAST AVERAGE RECURRENCE INTERVAL PRECIPITATION MAPS FOR THE UNITED STATES: A NEW WAY OF COMMUNICATING THE LOCATION AND MAGNITUDE OF HIGH IMPACT PRECIPITATION EVENTS

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ABSTRACT

Describing floods in terms of an Average Recurrence Internal (ARI) or "return period" (e.g. 100-year) has been used for decades to convey the rareness of flooding at stream gauges. Describing the intensity of heavy precipitation events in a similar manner has not been routinely done, but provides an equally objective perspective of extreme events. Official, gridded NOAA/NWS precipitation frequency estimates (PFEs) from documents such as NOAA Atlas 14 provide the statistical basis for translating observed or predicted precipitation at any location in the United States into an equivalent ARI between 1 and 1,000 years. Applying this concept to gridded precipitation estimates conveys how significant a particular event is relative to local climatology. This paper discusses the use of *forecast* ARI precipitation maps using Quantitative Precipitation Forecasts (QPFs) from the Weather Research Forecast (WRF) mesoscale numerical weather prediction model. Advances in the science of numerical weather prediction have significantly increased skill and resolution of QPF over the last decade, and mesoscale models such as WRF provide excellent automated forecast guidance for the one to three day forecast period, especially for strongly forced events typical of those that lead to widespread heavy rainfall. Communicating the potential for high impact precipitation events through the use of the ARI technique is a powerful way to heighten the public's awareness of impending flood potential.

1. THE ARI CONCEPT

Extreme rainfall can result in flooding and the necessity to release water from hydroelectric dams. Such events can be placed into a historical context using the concept of Average Recurrence Interval (ARI). Also referred to as the "return period", the ARI represents a current precipitation event (amount per unit time) as the average number of years (climatologically) between equivalent events for a specific location. An ARI of 100 years is the same as a 1% probability of an event occurring in any given year ("100-year event").

Rainfall frequencies have been calculated in terms of amount and period (e.g., how often 10 inches of rain may fall in a 24 hour period). These frequencies are provided in precipitation frequency atlases such as NOAA Atlas 2 and Technical Paper 40but undergoing revision at the NWS Hydrometeorological Design Studies Center (HDSC) as part of NOAA Atlas 14 (Perica et al. 2010).

Parzybok et al. (2010,2011) describes the first, real-time operational ARI product developed by METSTAT and WDT. Using WDT's gridded national quantitative precipitation estimates (QPE), current maps of ARI based on recent precipitation over the past 6 and 24 hour periods are created. These maps are made available to clients on an interactive Google™ maps interface and now make it easy for anyone to interpret the significance of recent or ongoing precipitation events anywhere in the U.S., even without knowing anything about the precipitation climatology. This product proved to be quite popular with media outlets as a "Potential Flood Index" for characterizing significant rainfall and flood events to the public (see 28 August 2011 New York Times article as an example) It should be noted that while floods are associated with heavy rain, the ARI product itself is not an indication of an equivalent flood occurrence or depth. In other words, a 100-year ARI for rainfall may or may not result in a 100-year flood event, since ARI does not account for runoff, drainage capacity, etc. However, it clearly follows that when rainfall amounts have or are expected to significantly exceed climatological normal that flooding is likely to occur. Thus, the use of ARI as a Potential Flood Index is appropriate. Figure 1 demonstrates how analyzed ARI can provide flood guidance.

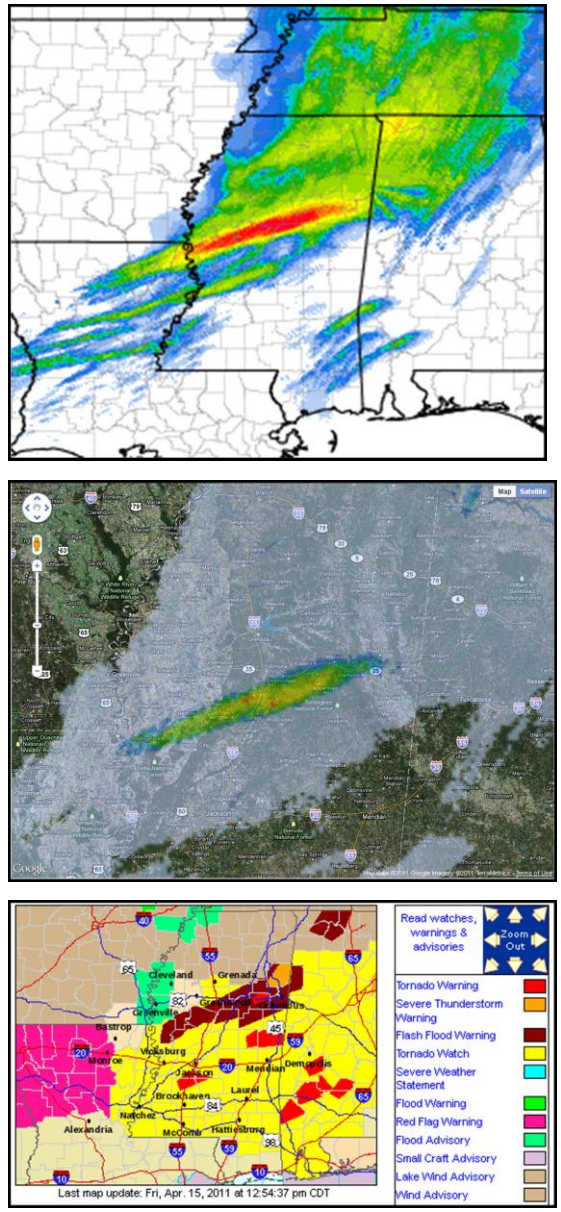

Figure 1. Example QPE (top) converted to ARI (middle) and compared to actual warnings (bottom).

2. FORECAST ARI

2.1. Motivation

If ARI derived from analyzed precipitation can more effectively communicate the significance of precipitation that has actually occurred, then it follows that it may be a useful tool for describing expected future rainfall from weather forecasts.

As computational science has advanced, so has our ability to more accurately predict the weather using automated numerical weather prediction (NWP) models, which forecast the future state of the atmosphere by integrating the equations of motion and thermodynamics forward in time from an estimated initial state. More specifically, regional *mesoscale* NWP models are much more capable now than ever before of providing useful automated precipitation forecasts because of their more sophisticated parameterizations of cloud and precipitation processes and their ability to better resolve terrain features that strongly influence local precipitation patterns.

WDT is a private sector leader in the field of operational NWP and has been providing data services and decision tools based on locally run mesoscale NWP models since its foundation. A natural extension of its product suite is to apply the ARI technique to its automated quantitative precipitation forecasts (QPF) as a means to provide more useful guidance to decision makers.

2.2. WDT's Operational NWP System

WDT has provided operational mesoscale NWP services since 2000, and has delivered numerous stand-alone NWP to international meteorological agencies (e.g., Shaw et al. 2008). For the NWP modeling system, WDT uses the Weather Research and Forecast (WRF) community modeling system; specifically, the Advanced Research WRF Version 3 (Skamarock et al. 2008). Currently, WDT produces over 200 WRF forecasts each day for a variety of applications and regions around the world.

One of the unique features of WDT's WRF implementation is the data assimilation approach, which combines the use an objective analysis system with the WRF Four Dimensional Data Assimilation (FDDA) scheme (Liu et al. 2008). The objective analysis system employed is the Local Analysis and Prediction System (LAPS) analysis, developed and maintained by the Global Systems Division of the NOAA Earth Systems Research Laboratory (Albers et al. 1996). With LAPS, WDT is able to assimilate the IR, water vapor, and visible satellite image channels from geostationary satellites as well as WDT's quality controlled three-dimensional radar mosaics. These two data sources, combined with traditional *in situ* observations, provide a more accurate initialization of the initial model moisture field through a three-dimensional cloud analysis. This technique has been shown to improve forecasts of precipitation and reduced model spin-up time (Shaw et al. 2001).

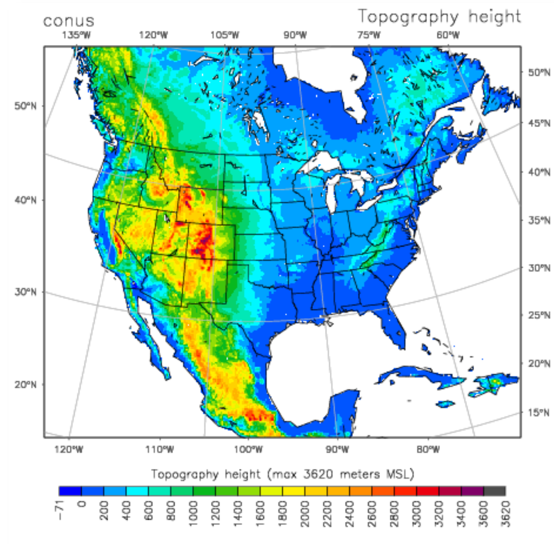

Figure 2. WDT CONUS WRF grid.

The forecast ARI product specifically uses WDT's "CONUS" WRF domain (Figure 2). This domain is updated four times per day (0300, 0900, 1500, and 2100 UTC) and provides a 5-day forecast on an 11.7 km grid. Detailed model specifications are shown in Table 1. WDT's custom post-processing provides the necessary precipitation accumulation periods and data format for input into the ARI process.

Table 1. WDT CONUS WRF configuration.

Grid Spacing	11.7 km
Microphysics	WSM-6
Convective Param.	Kain-Fritsch
PBL Scheme	YSU
LW Radiation	RRTM
SW Radiation	Dudhia
Land Surface Model	Noah
Forecast Length	120-h
Update Frequency	4 times/day

2.3. Forecast ARI Products

From each of the four daily runs of WRF, the following forecast ARI products are produced:

- 6-hour ARI values from 6-120 hours at 3-hour intervals.

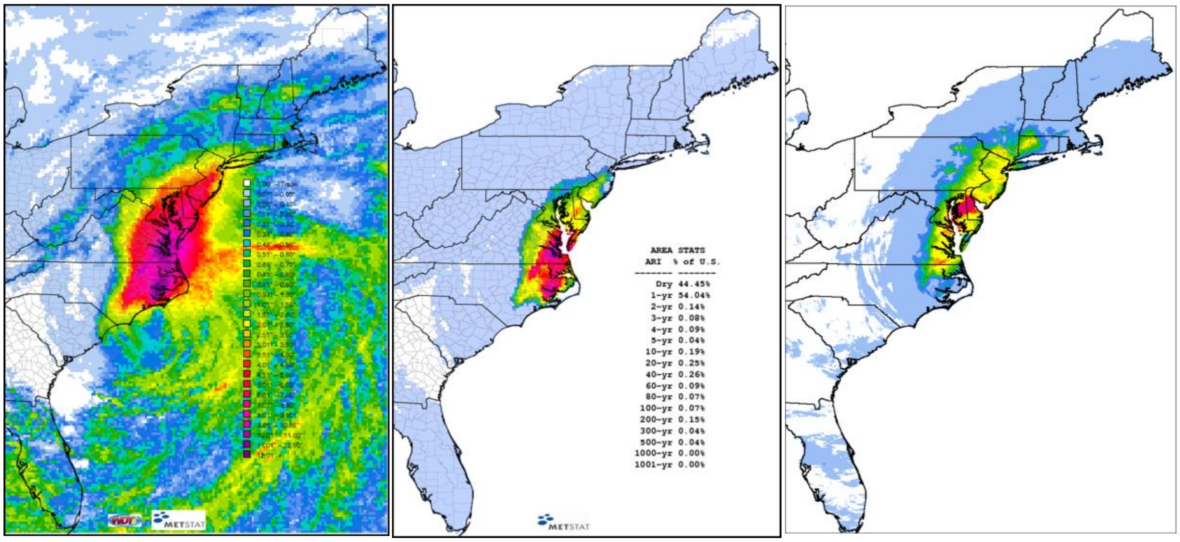

Figure 3. Example of a WRF precipitation forecast (left) converted to ARI (center) and compared to analyzed ARI (right) for Hurricane Irene. Values are for the 24-h period ending at 1200 UTC on 28 August 2011.

- 24-hour ARI values from 24-120 hours at 12-hour intervals
- Maximum 6-hour ARI value over the entire 120-h forecast period
- Maximum 24-hour ARI value over the entire 120-h forecast period

The run-maximum products make it very easy to identify areas of potential flood risk for the next five days by looking at one single map. Once areas are identified as being at risk, the individual 6 and 24-h ARI frames can be examined to gain more details about the onset and duration of the event.

Because the data are on a uniform Cartesian latitude-longitude grid, they can be easily integrated and provided in a wide variety of meteorological and GIS formats for ready display as map layers (e.g. Google).

Example forecast ARI maps are show in Figure 3. This case is from Hurricane Irene, which struck the northeast US on 27-29 August 2011 and produced significant flooding in New England region. As is typical with mesoscale NWP models running at similar resolution, there is a tendency to over-forecast the size of significant precipitation areas. However, they typically provide excellent guidance on the magnitude of the maximum precipitation amounts that can be expected in isolated areas. Thus, for the purposes of providing situational awareness of the potential for significant flooding within a 5-day outlook, this product is very promising, as it identified the magnitude and area of occurrence 48 hours in advance. Furthermore, the conversion to ARI removes the "distraction" of heavy, but not abnormal, rainfall.

3. CONCLUSIONS AND FUTURE WORK

Real-time ARIs are a promising tool for communicating anomalously heavy precipitation events in an objective fashion that allows users to quickly ascertain area of high-impact. When coupled with an appropriate NWP model, it can provide excellent guidance for flood potential for 1-5 days into the future. WDT and METSTAT will continue to improve upon the quality of the product as well as innovative uses. Current ideas under consideration for future enhancements include:

- Coupling with other NWP models (e.g., NWS NAM and GFS)
- Probabilistic guidance using ensembles

- Automated alerting products based on ARI thresholds
- Providing ARI values applicable to standard area sizes
- Provided ARI values to other meteorological elements (e.g. snow)
- Incorporating land-use coverages for better defining flooding potential

4. REFERENCES

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