Updates to NOAA Precipitation Frequency Atlases

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Abstract

The rainfall frequency atlases and technical papers published by the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) serve as de-facto national standards for rainfall intensity at specified frequencies and durations in the United States. This paper reports on progress in updating these estimates since the EWRI World Environmental and Water Resources Congress of 2006. It provides an overview of the new estimates and the methods used in their preparation as well as selected statistics. Since the 2006 Congress, NOAA has published revisions for NOAA Atlas 14 Volumes 1 through 3 covering the semiarid southwest U.S. and the Ohio River basin and surrounding states, and Puerto Rico and the U.S. Virgin Islands.

Introduction

Civil Engineers use probabilistic estimates of rainfall intensities for particular durations and locations for the design of a wide range of structures from urban storm water drainage systems to dams and spillways. More recently their use has extended beyond the realm of civil engineering to include a broad array of environmental management and analysis concerns.

Since 2003 NOAA has published updated estimates for twenty-one states or dependencies as volumes of NOAA Atlas 14. The updates are based on a variety of improvements including: use of significantly longer data records, use of a regional L-moments analysis technique (Hosking 1997), an advanced spatial interpolation and mapping procedure, and web based delivery of the final product.

This paper discusses the most recent updates and current projects. It is a follow on to a series of updates at Environmental and Water Resources Institute conferences; Bonnin (2002, 2003), Bonnin et al (2004), Lin et al (2006). Current information from the Hydrometeorological Design Studies Center can be found at www.nws.noaa.gov/ohd/hdsc.

Initial NOAA Atlas 14 Volumes

Beginning in 2003, the Hydrometeorological Design Studies Center (HDSC) located within the National Weather Service Office of Hydrologic Development published the following three volumes (Figure 1):

- NOAA Atlas 14, Volume 1: the semiarid southwest (Nevada, Utah, New Mexico, Arizona, Southeast California) in August 2003. This volume updated estimates in publication since 1964 and 1973.
- NOAA Atlas 14, Volume 2: the Ohio River basin and surrounding states (Tennessee, Kentucky, Illinois, Indiana, Ohio, Pennsylvania, New Jersey, Delaware, Maryland, Virginia, West Virginia, North and South Carolina, and Washington D.C.) in 2004. This volume updated estimates in publication since 1961, 1964, and 1977.
- NOAA Atlas 14, Volume 3, (Puerto Rico and the U.S. Virgin Islands) in 2006. This volume updated estimates in publication since 1961 and 1965.

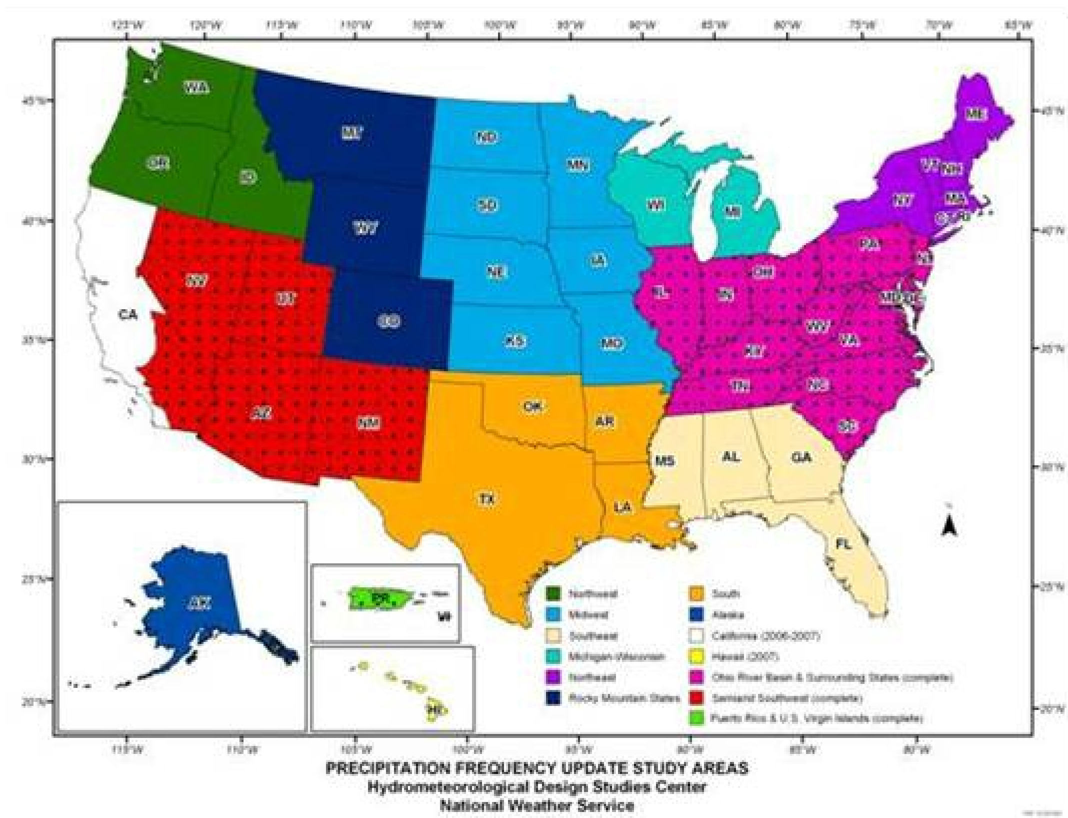

Figure 1. NOAA Atlas 14 Study Areas.

These volumes were then revised in 2006 as discussed below. In addition, HDSC is working on updating precipitation frequency estimates for Hawaii which have been in publication since 1961 and 1962 and the portion of California not included in NOAA Atlas 14 Volume 1, where estimates have been in publication since 1964 and 1973.

The work of the Hydrometeorological Design Studies Center on precipitation frequency is performed at the request of, and using funds provided by, a variety of federal, state, and local agencies. At the time of this writing we are working on agreements to update estimates for the south-east U.S. and funds are still being sought to update the remaining areas of the U.S.

Updates to NOAA Atlas 14 Volumes

In 2006, HDSC published (Bonnin et al, 2006) revisions as follows:

- NOAA Atlas 14, Volume 1, Version 4.0
- NOAA Atlas 14, Volume 2: Version 3.0
- NOAA Atlas 14, Volume 3: Version 3.0

Table 1 lists the revisions as additions or enhancements and shows which revisions have been applied to which volumes. Most of the methodologies used in the revisions were developed as part of the preparation of Volume 3 and so were already incorporated in the previous version of that volume.

Table 1. Additions, enhancements and fixes incorporated in NOAA Atlas 14.

Action	Type	Description	Vol 1	Vol 2	Vol 3	Impact on Estimates
1	Addition	Added 1-year average recurrence interval (ARI) precipitation frequency estimates	✓	✓		
2	Enhancement	Improved the computation of upper and lower confidence limits for the 24-hour duration at co-located daily and hourly stations	✓	✓		At 24-hour co-located daily and hourly stations only
3	Enhancement	Implemented new co-located and hourly-only adjustments	✓	✓		60-min quantiles at co-located stations and hourly quantiles at hourly-only stations
4	Enhancement	Implemented new inverse-distance weighting algorithm that uses true distance instead of decimal degree distances	✓	✓		Spatially interpolated grid cells for data sparse areas/durations (especially at <24hr)
5	Addition	Expanded the core study area to include the Lake Tahoe Basin in California	✓			
6	Miscellaneous Fixes	Described below	✓	✓	✓	

Explanations of additions, enhancements and fixes

1. **Added 1-year average recurrence interval (ARI) precipitation frequency estimates**
   1-year ARIs are now provided in NOAA Atlas 14. 1-year Annual Exceedance Probabilities (AEPs) cannot be theoretically defined and are not available. ARI is the average period between exceedances (at a particular location and duration) and is associated with the partial duration series (PDS). Annual exceedance probability (AEP) is the probability that a particular level of rainfall will be exceeded (once or more than once) in any particular year (at a particular location and duration) and is derived using the annual maximum series (AMS).
   The 1-year ARI cannot be directly estimated from the PDS data. However, the 1-year ARI can be indirectly estimated and converted from the AMS data by using the relationship that a 1-year ARI event is equivalent to a 1.58-year AEP event.
   The equation $T_{PDS} = [\ln(\frac{T_{AMS}}{T_{AMS}-1})]^{-1}$ (Chow et al., 1988), which is distribution free, provides a mathematical basis for converting between frequencies for the AEP and ARI events. Here, T_{AMS} and T_{PDS} stand for the frequency associated with the AMS data and the PDS data, respectively. The equation can be transformed into the following:

$$T_{AMS} = \frac{1}{1 - e^{-\frac{1}{T_{PDS}}}}$$

   From the equation T_{AMS} = 1.58-year when T_{PDS} = 1-year.

2. **Provided improved upper and lower confidence limits for the 24-hour duration at co-located daily and hourly stations**
   The 24-hour confidence limits are now obtained from analysis of the daily regions, which have a larger sample size, instead of hourly regions at co-located stations. This has decreased the band of uncertainty at most co-located stations and more accurately reflects the uncertainty associated with the quantiles, which is also derived from the daily region. The enhancements cause the band of uncertainty to be more symmetric about the mean for co-located stations. Lin (2006) discussed the asymmetry of the confidence limits.

3. **Implemented new co-located and hourly-only adjustments**
   An enhanced practical adjustment was applied to the precipitation frequency estimates at co-located daily and hourly stations that presented unique data characteristics where two or more hourly durations at the station shared the same annual maximum or had a very close values which created a very flat slope for quantiles from 5-year through 1,000-year. This coupled with different daily and hourly regional characteristics created discontinuities relative to nearby stations. The adjustment generates hourly quantiles more consistent with each other and

with daily stations given different daily and hourly regions.

4. **Implemented new inverse-distance weighting algorithm**
   Distances used in the inverse-distance weighting algorithm are now computed in meters, rather than in degrees. The revision provides a refinement to the estimates but the estimates do not exceed previously established confidence limits (although the confidence limits also change with the revision).

5. **Expanded the Volume 1 study area to include the Lake Tahoe basin in California**
   The Clinton Administration was especially concerned about the degradation of Lake Tahoe, one of America's national treasures. President Clinton asked several Secretaries (notably, the Secretaries of the Army and the Department of Interior) to personally sign an agreement to use of their agencies resources to study protection measures for Lake Tahoe. Precipitation frequency information is an important facet to this study. The U.S. Army Corps of Engineers provided funds to extend NOAA Atlas 14 Volume 1 to the entire Lake Tahoe basin. Previously the estimates were only provided in that part of the basin located within Nevada.

6. **Miscellaneous**
   - *Volume 1: Corrected daily station 04-9447, WARNER SPRINGS, CA (-116.6333, 33.2833)*
     - L-moments were mistakenly run with only 31 instead of 32 daily stations in daily region 32. This prevented the 1-day precipitation at station number 04-9447 from being properly converted from 1-day to 24-hour.
     - This caused a localized impact on the order of +12% at 100-year 24-hour.

   - *Volume 1: Corrected hourly stations in daily region 4 (northeastern Nevada). The selected best distribution is the Generalized Extreme Value (GEV), but Generalized Normal (GNO) was erroneously used during the co-located daily and hourly adjustment*
     - Seven co-located stations in daily region 4 (northeastern Nevada) had an incorrect 24-hour value because the selected distribution was GEV, but GNO was erroneously used on the daily data during the hourly co-located adjustment algorithm. The impact was minimal (<1% at 100-year 24-hour). See section 4 of the final documentation for details.

   - *Volume 1: Corrected three SNOTEL IDs: SNOTEL stations 42-0074 (TIMPANOGOS DIVIDE, UT), 42-0061 (PARLEY'S SUMMIT, UT), and 04-0010 (HEAVENLY VALLEY, CA) in daily regions 13 and 8 shared station IDs of different daily stations and hence the daily stations were not included in the spatial interpolation.*
     - Daily stations 42-0074, ALTAMONT, UT; 42-0061, ALPINE, UT; ACAMPO 5 NE, CA are now included in the spatial interpolation.

    - Impact is minimal (-3.9 to +5.1% at 100-year 24-hour) at the locations of the previously omitted daily stations in earlier versions.
- *Volume 2: Corrected 24-hour confidence limits in daily region 18 (east central Pennsylvania) - The selected best distribution is GLO, but GEV was erroneously used.*
    - Eighty-three stations in daily region 18 (east central Pennsylvania) had incorrect 24-hour confidence limits because the selected distribution was GLO but GEV was erroneously used on the daily data in the computation of the confidence limits. The quantiles themselves were correctly computed and were not affected by this change. The impact on the confidence limits was minimal (<3.5% at 100-year 24-hour).
- *Volume 3: Corrected incorrect use of preliminary means at daily-only stations*
    - This revision was necessary due to an oversight where mean annual maximums for these durations were generated at daily-only stations incorrectly using a preliminary method.
- *Volume 3: Improved adjustment of 48-hour estimates at hourly-only stations*
    - The estimates for the 48-hour duration at several hourly-only stations were adjusted to be more consistent with surrounding co-located and daily-only stations.

Cumulative Impact of Enhancements and Fixes

Volume 1 (Semiarid Southwest)

In general, the composite change on the 100-year 24-hour map (Figure 2) is small, with most areas only seeing a +/- 5% change. Likewise, most areas on the 100-year 60-minute map (Figure 3) experience a change within +/- 5%. Some areas of the 100-year 60-minute map indicate more substantial changes, particularly as a result of the hourly-only adjustment.

Volume 2 (Ohio River Basin and Surrounding States)

In general, the composite change on the 100-year 24-hour map (Figure 4) is small, with most areas seeing less than a +/- 2.5% change, primarily as a result of the new inverse distance weighting. Likewise, most areas on the 100-year 60-minute map (Figure 5) experience a change within +/- 2.5%. Slightly larger changes occurred in the confidence limits, but still most areas experienced a change within +/- 5%. Although some of the individual enhancements to the data caused larger percentage changes, the combined impacts of all enhancements lead to a relatively small change to the precipitation frequency estimates. Overall, the largest percentage changes resulted in a slight decrease in the estimate (i.e., version 3 estimates are slightly less than version 2). Most of the cumulative changes were the result of the enhanced spatial interpolation.

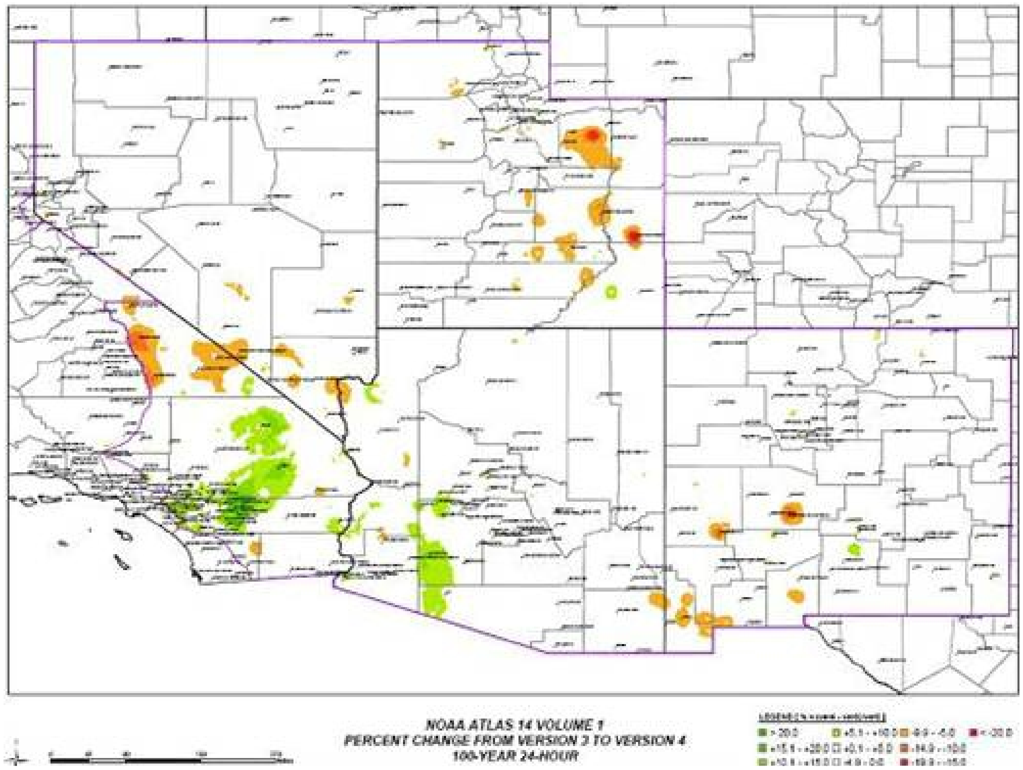

Figure 2. NOAA Atlas 14 Vol. 1 ver3 to ver4 changes, 100yr-24hr.

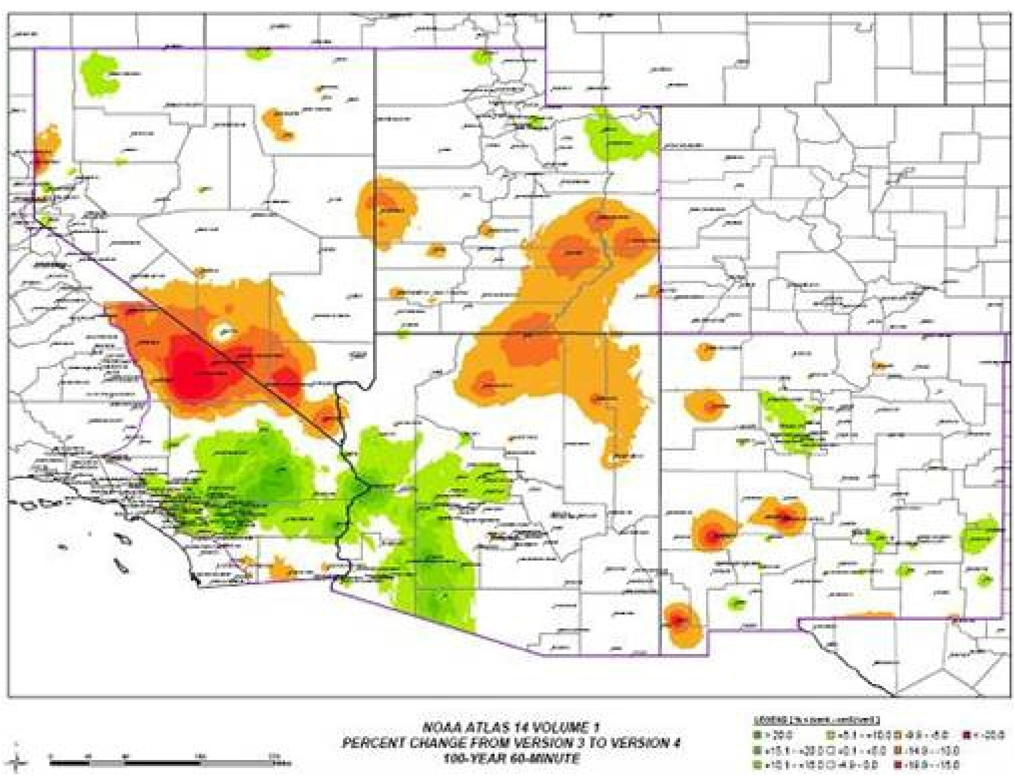

Figure 3. NOAA Atlas 14 Vol. 1 ver3 to ver4 changes, 100yr-60min.

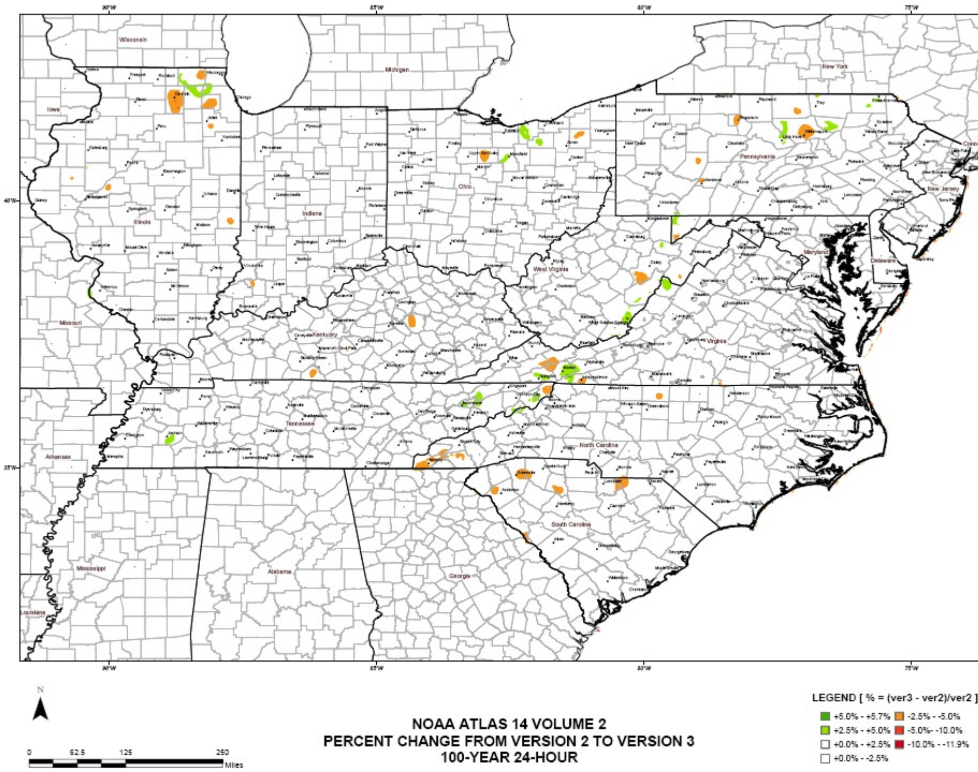

Figure 4. NOAA Atlas 14 Vol. 2 ver2 to ver3 changes, 100yr-24hr.

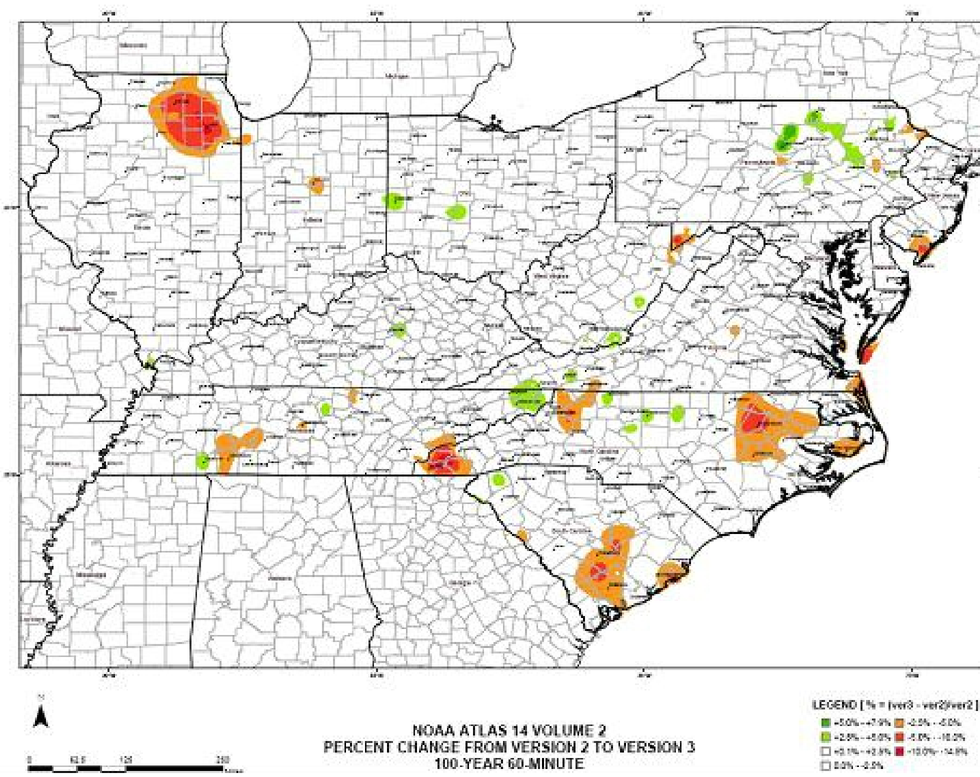

Figure 5. NOAA Atlas 14 Vol. 2 ver2 to ver3 changes, 100yr-60min.

Volume 3 (Puerto Rico and the U.S. Virgin Islands)

Although Version 3 and Version 2 are essentially the same across most of the domain, changes at the 5-minute through 12-hour durations averaged +1%, ranging from -14.2 to +9.3%. The majority of the stations showed very little change, less than 5% (Figure 6). The adjustment at the 48-hour duration at several hourly-only stations caused change less than 2% over most of the domain at the 100-year ARI. Changes are also observed through the 10-day duration as a result of the spatial interpolation process, but these changes are even smaller and more localized.

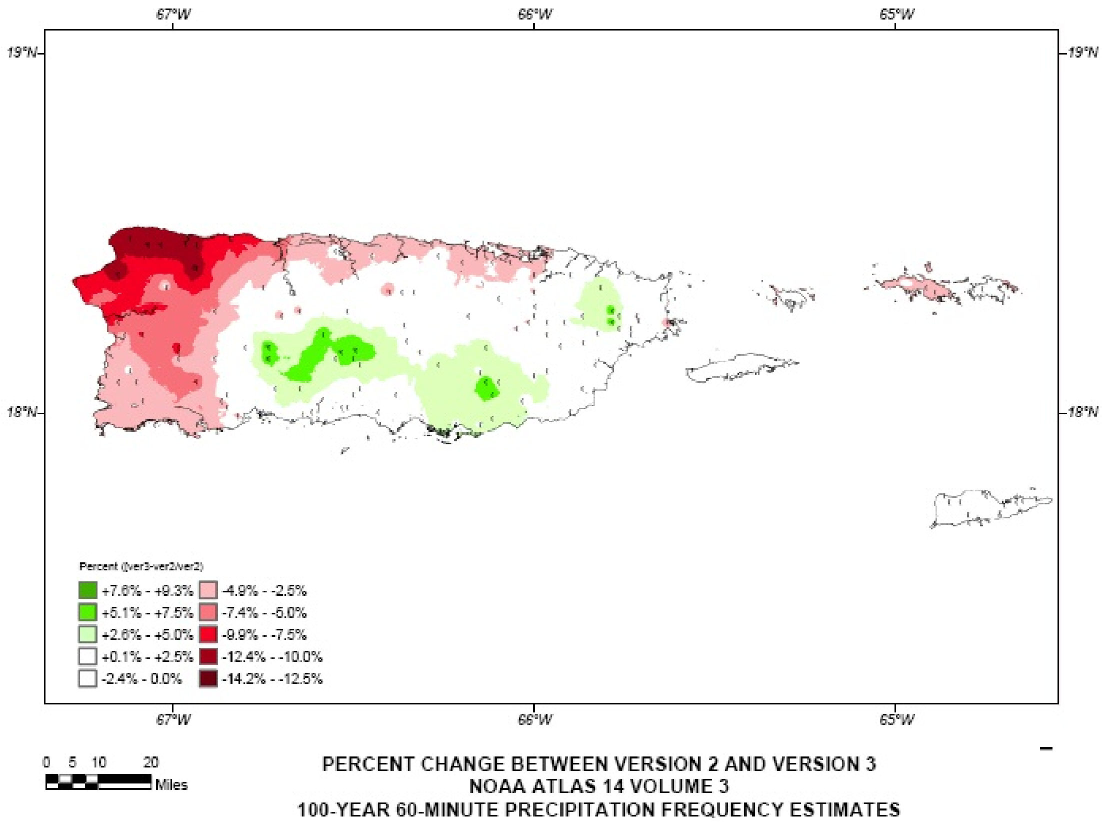

Figure 6. NOAA Atlas 14 Vol. 3 ver2 to ver3 changes, 100yr-60min.

Conclusion

Revisions to NOAA Atlas 14 Volumes 1, 2, and 3 published in 2006 provide improved precipitation frequency estimates and established more representative confidence intervals. The National Weather Service, with financial support from a variety of federal, state, and local agencies is working on new volumes for selected areas of the United States and is seeking funds to update the remaining areas.

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