Planned Improvements for NOAA Atlas 14 Process and Products

- **Presenter: Sanja Perica**

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U.S. NRC Probabilistic Flood Hazard Assessment (PFHA) Research Workshop, 19 February 2020

What is NOAA Atlas 14?

- Since early 2000s HDSC has been updating precipitation frequency estimates for various parts of the United States and affiliated territories. Updated estimates with relevant supplementary information are published in NOAA Atlas 14 “Precipitation-Frequency Atlas of the United States.”

- Atlas 14 supersedes NOAA publications HYDRO35, TP40, TP49 and Atlas 2 published in 1950s to 1970s.

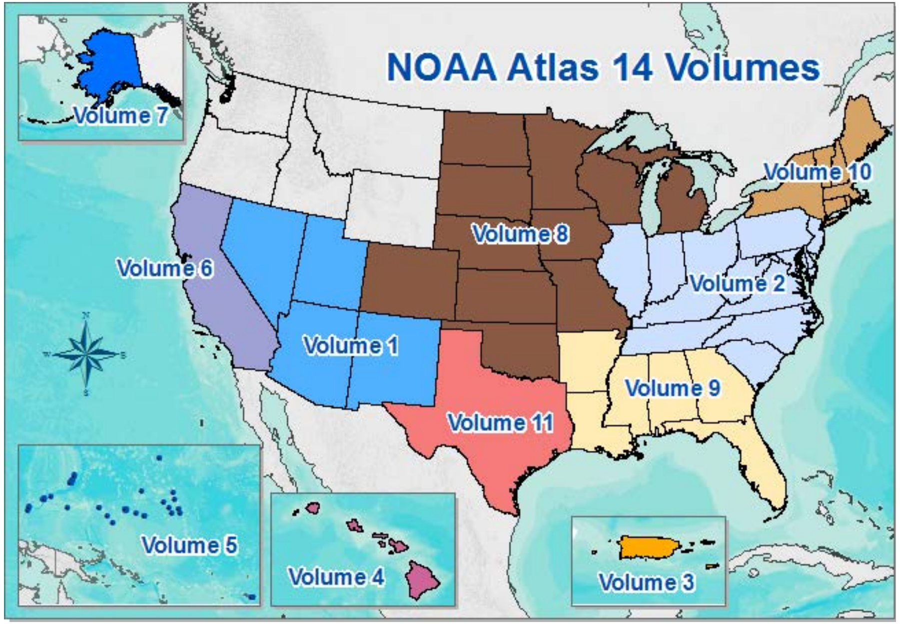
- Funding model dictates that Atlas 14 updates are done in stages based on state boundaries.

  2004: Vols 1 & 2 (19 states)
  …
  2013: Vols 8 & 9 (17 states)

  2015: Vol 10 (7 states)

  2018: Vol 11 (TX)

  ????: Vol 12 (ID, MT, OR, WA, WY).



What are Precipitation Frequency Estimates?

- **Precipitation Frequency Estimate (at a given location)**:
  Precipitation **D**epth (or **I**ntensity) for a specific **D**uration that has a certain **F**requency of occurring.

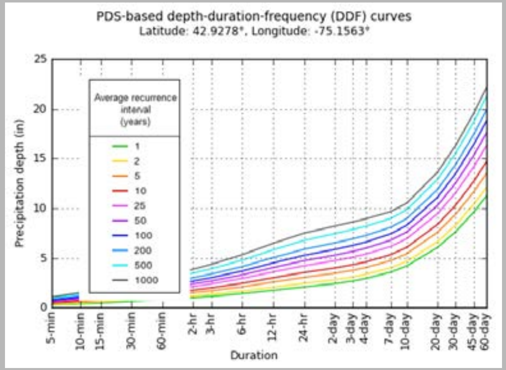
- **Frequency:**

Annual Exceedance Probability ("1-in-N event")

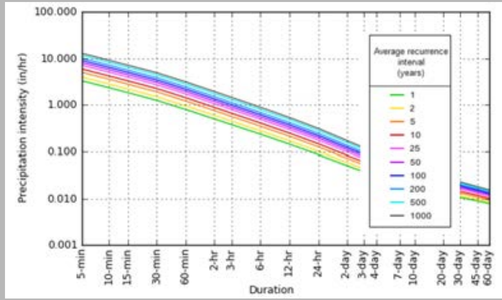
- Probability associated with exceeding a given amount of precipitation for a specified duration at least once in any given year.
- Ex. AEP of 1-in-100 equates to a 1% chance of the amount being exceeded at least once in any year.

Average Recurrence Interval, Return Period ("N-year event")

- Average time between precipitation events exceeding particular magnitude for a specified duration.
- Ex. 100-year amount on average occurs every 100 years.



Depth-Duration-Frequency (DDF) Curves



Intensity-Duration-Frequency (IDF) Curves

Where are Atlas 14 Estimates Used?

- ❑ NWS uses for monitoring observed/ forecasted rain to indicate flooding threats.

- ❑ Widely used to estimate severity of historic events.

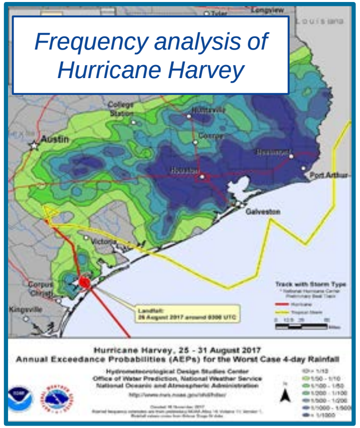
Forbes The Rainfall In Texas Is Changing And Here Is Proof

USA TODAY

Ellicott City rainstorm confirmed as 1-in-1,000 event — the second in two years

- ❑ HDSC analyzes severity of **selected** events

Frequency analysis of Hurricane Harvey



http://www.nws.noaa.gov/oh/hdsc/aep_storm_analysis/index.htm

- ❑ Estimates serve as the de-facto standards for designing, building and operating infrastructure to withstand the forces of heavy precipitation and floods.

- ❑ Selection of design criteria are governed by cities, municipalities, local or state governments and generally **depends on acceptable risk of failure.**

Highway culverts	
Low traffic	5–10
Intermediate traffic	10–25
High traffic	50–100
Highway bridges	
Secondary system	10–50
Primary system	50–100
Farm drainage	
Culverts	5–50
Ditches	5–50
Urban drainage	
Storm sewers in small cities	2–25
Storm sewers in large cities	25–50
Airfields	
Low traffic	5–10
Intermediate traffic	10–25
High traffic	50–100
Levees	
On farms	2–50
Around cities	50–200
Dams with no likelihood of	

Generalized design criteria for water-control structures.
From Chow, "Applied Hydrology"

Why Is It Important for Regulatory Authorities to Reference Most Recent Estimates?

- ❑ Over-estimated precipitation frequency estimates can cause unnecessary cost to taxpayers or developers; under-estimated can result in destruction of property and loss of human life.
- ❑ Atlas 14 supersedes NOAA publications from 1950s to 1970s. New estimates are superior in terms of accuracy, reliability, and resolution.

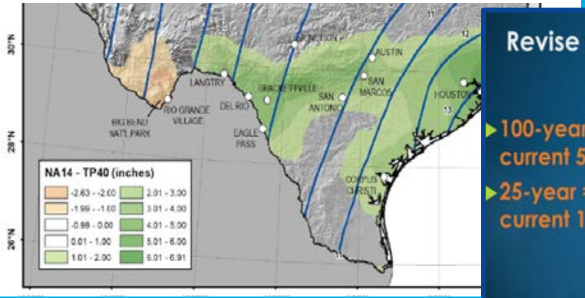
Example from Volume 11 (TX)
City of Austin analysis (NA14 vs TP40)*:

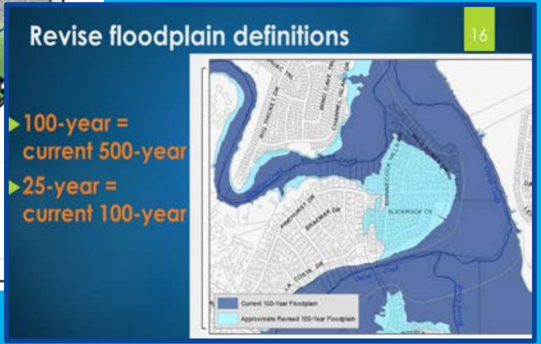
500-year floodplain is now 100-year floodplain

100-year floodplain increased ~25%

number of buildings in floodplain increased from ~3700 to ~6500

Atlas 14 – TP40
100-year 24-hour estimates.





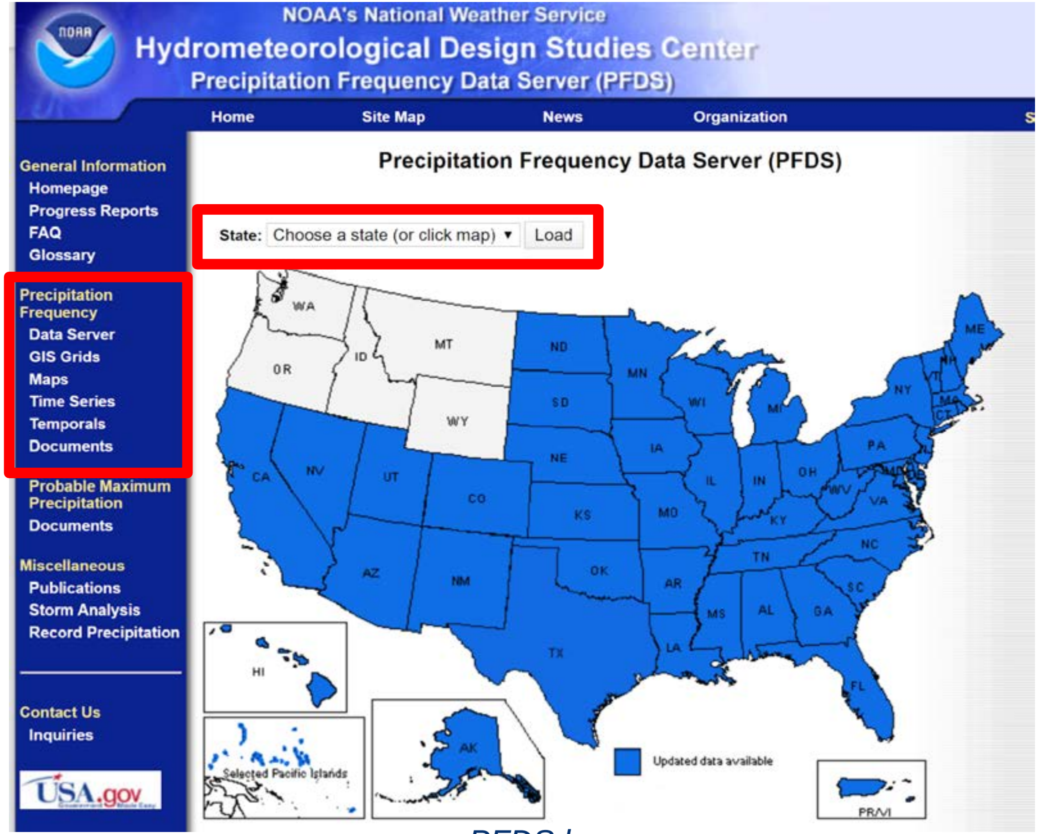
**Analysis does not include Colorado River floodplain*
Source: http://www.austintexas.gov/edims/document.cfm?id=302092

Where to Find Atlas 14 Estimates?

- NOAA Atlas 14 products can be downloaded from **Precipitation Frequency Data Server (PFDS)** hdsc.nws.noaa.gov/hdsc/pfds/index.html

- **Estimates for a specific location** can be retrieved by clicking on appropriate state on the map or selecting the state name from the drop-down menu

- **Estimates applicable across states in each volume** Can be retrieved from side menu under "Precipitation Frequency" tag

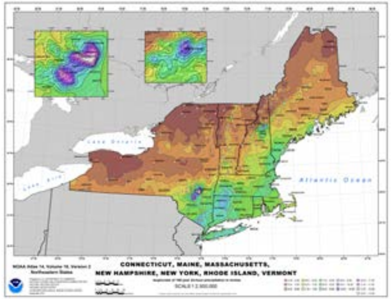


PFDS homepage

Atlas 14 Products

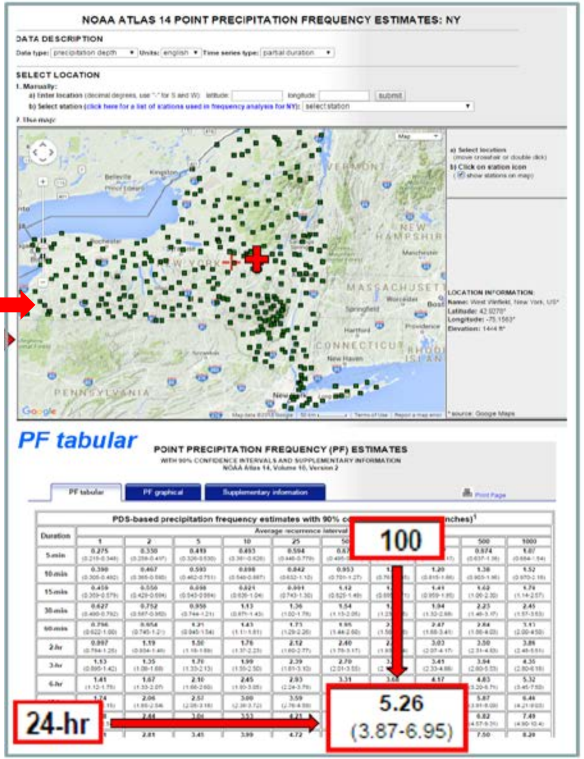
Whole project area

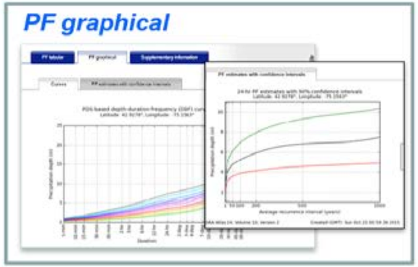
- GIS Grids. 30 arc sec grids of AMS-based and PDS-based estimates with 5% and 95% confidence limits for 5-min to 60-day durations and average recurrence intervals up to 1,000 years
- PF Maps. Cartographic maps for selected durations and ARI

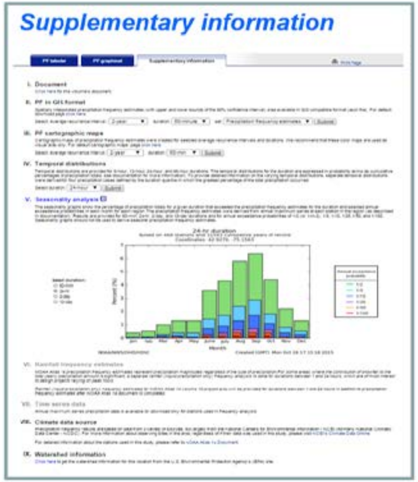


- Time Series
- Temporals
- Documents

Selected location

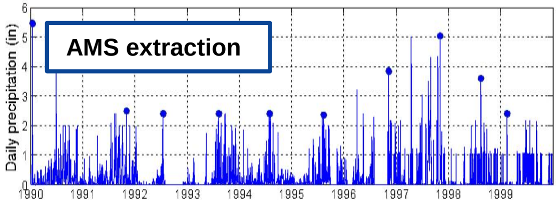




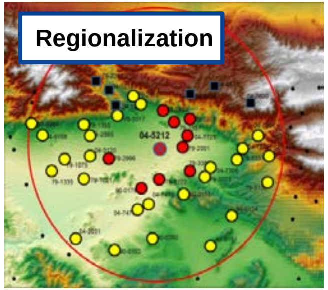


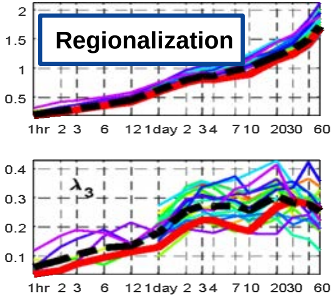
How are the Estimates Calculated?

1. **Data collection, Annual Maximum Series (AMS) extraction and QC**
   - Data collection, digitization, formatting
   - Examination of geospatial data and station cleanup
   - AMS extraction for 17 durations and quality control



2. **At-station DDF/IDF curves**
   - Regionalization
   - Derivation of estimates and confidence limits, consistency checks

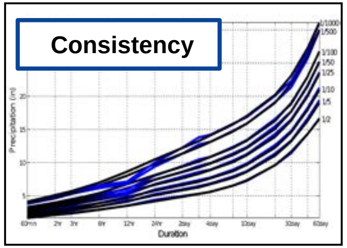


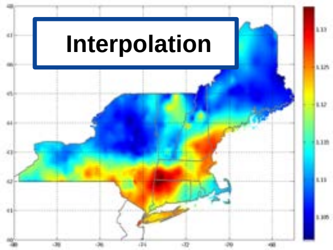


3. **Interpolation to 30 arc-sec grid**
   - PRISM statistical-geographic approach

4. **Peer review**
   - Funding agencies, HDSC list-server subscribers, others

5. **Revision** (back to steps 1 to 3)





6. **Supplementary information**
   - Documentation, confidence intervals, cartographic maps, etc.

7. **Web publication**

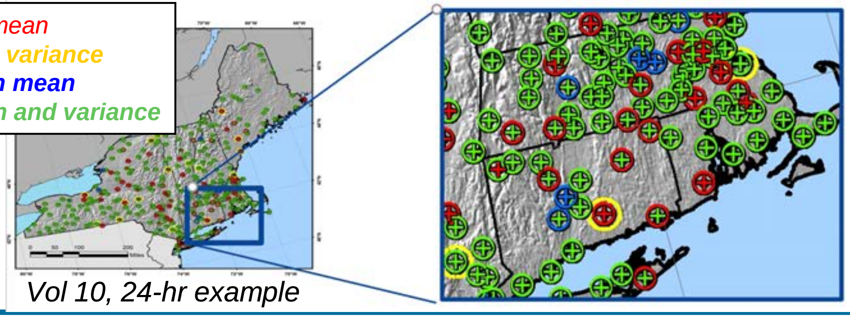
NA14 Stationary Process – Testing Stationarity Assumption

Stationarity is dead – whither water management?" (Milly et al. 2008)

REGIONAL ANALYSIS:
H_0 : no correlation in regional normalized AMS regressed against time (5% level)

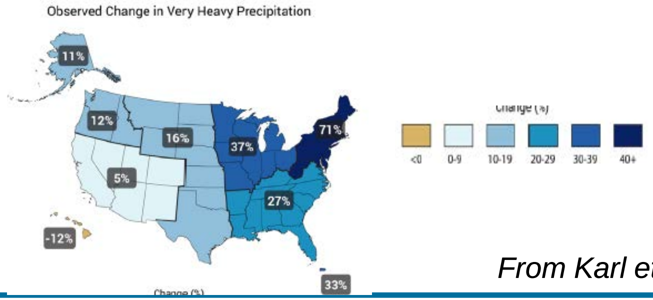
AT-STATION ANALYSIS:
Parametric and non-parametric tests

positive trend in mean
positive trend in variance
negative trend in mean
no trend in mean and variance



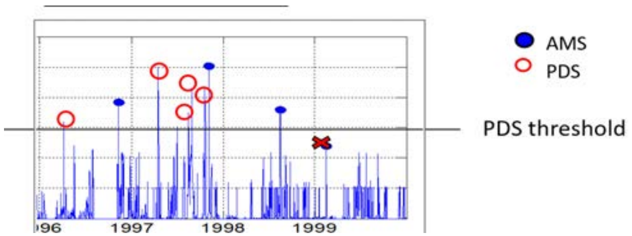
Vol 10, 24-hr example

Climate research indicates positive trends in frequency and magnitude of extreme events.



From Karl et al., 2009

So, why don't we detect consistent trends in NA14?
Inadequate tests? Data?



Development of Non-Stationary NA14 Approach

- ❑ **Current approach:**
  Stationary regional frequency analysis approach based on Generalized Extreme Value (GEV) distribution with parameters calculated from L-moment statistics from AMS (AMS assumed stationary).

- ❑ **Goal:**
  To develop scientifically defensible non-stationary "NA14 method" that will be applicable across the whole US and valuable for engineering design.

- ❑ **Non-stationary method to be used for future NA14 updates:**
  - Main modifications/enhancements to current NA14 method
    - ✓ Added new tests for trend detection
    - ✓ Partial Duration Series (PDS)-based Generalized Pareto Distribution (GPD) model replaced AMS-based GEV model
    - ✓ (Generalized) Maximum Likelihood replaced L-moment distribution parameterization approach
    - ✓ Distribution parameterization enabled to vary in time with a wide range of non-linear relationships
    - ✓ Framework flexible to allow for estimating future conditions using different approaches (next slide)

Work done in collaboration with Penn State University (Shaby, Mejia, Bopp).

Development of Non-Stationary NA14 Approach.
Estimating Future Precipitation Frequency Estimates (PFE)

❑ Extrapolation using historical trends

- Nonstationary model fitted to observational data; distribution parameterization modeled as function of time

For example, for the location parameter – μ:

- $\mu(t) = \mu_0$
- $\mu(t) = \mu_0 + a\,t$;
- $\mu(t) = \mu_0 + a_1\,t + a_2 t^2 + \ldots$
- $\mu(t) = \exp(a_1 + a_2 t)$
- μ(t) = any non-linear function of t; including sine fns

❑ Using outputs from (downscaled) climate models

a) Quasi-stationary "delta" method

- PFEs are estimated for several non-overlapping periods; stationarity is assumed within each period

b) Climate model outputs used directly as covariates for modeling distribution parameterization

For example:

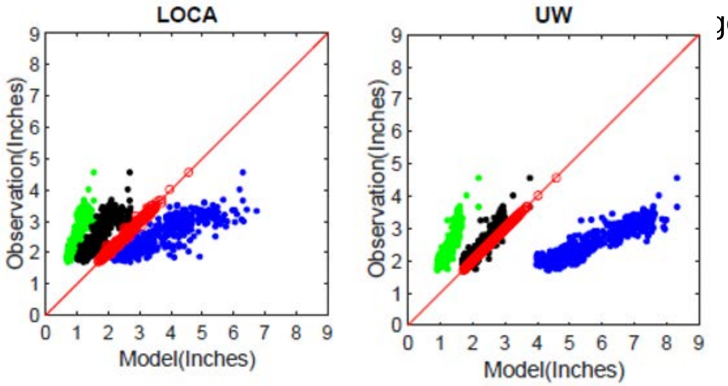
$\mu(t) = a + b * CMIP5$

CMIP5 represents value from CMIP5 (downscaled) data chosen to be covariate

Development of Non-Stationary NA14 Approach.
Inclusion of Future Climate Projections

- *Work done in collaboration with University of Illinois at Urbana-Champaign (Markus, Angel, Grady) and University of Wisconsin-Madison (Shu, Wang, Lorenz)*

- **Evaluation of downscaled CMIP5 model data sets:**
  - Period of evaluation: 1960-2005
  - Models evaluated:
    - Statistically downscaled: LOCA (32 models); BCCAv2 (20),
      UWPD – University of Wisconsin Probabilistic Downscaling (24 models, >300 realizations)
    - Dynamically downscaled: NA-CORDEX (6)
  - Compared: various modeled and observed extreme precipitatio ... ges, AMS & PDS climatology, AMS, corresponding PF estimates)
  - LOCA and UWPD retained for further analysis.



Example. Scatterplot of 1960-2005 mean AMS calculated based on station observed data and modeled data (green: lowest values, black: medians; red: closest values to observations; blue: highest values).

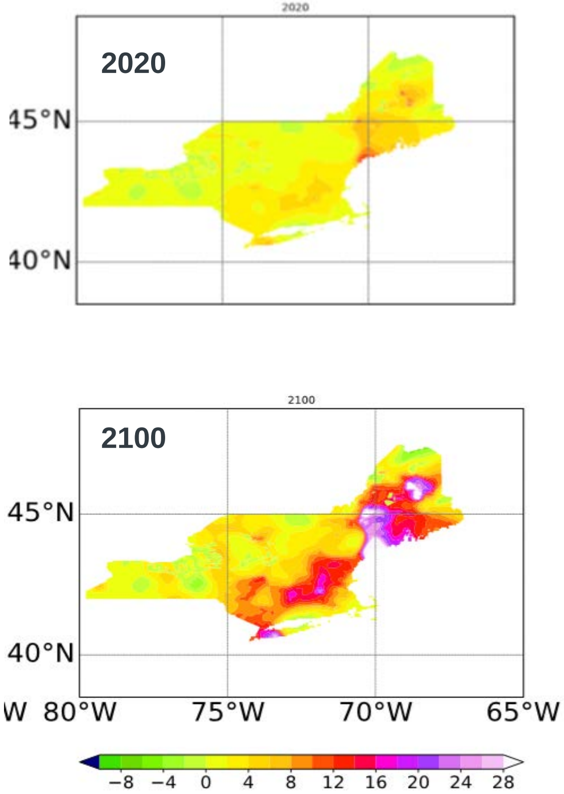
Development of Non-Stationary NA14 Approach. Inclusion of Future Climate Projections

❑ Considered:

- RCP4.5 and RCP8.5 emission scenarios.
- LOCA and UWPD downscaled CMIP5 datasets.

❑ Main findings:

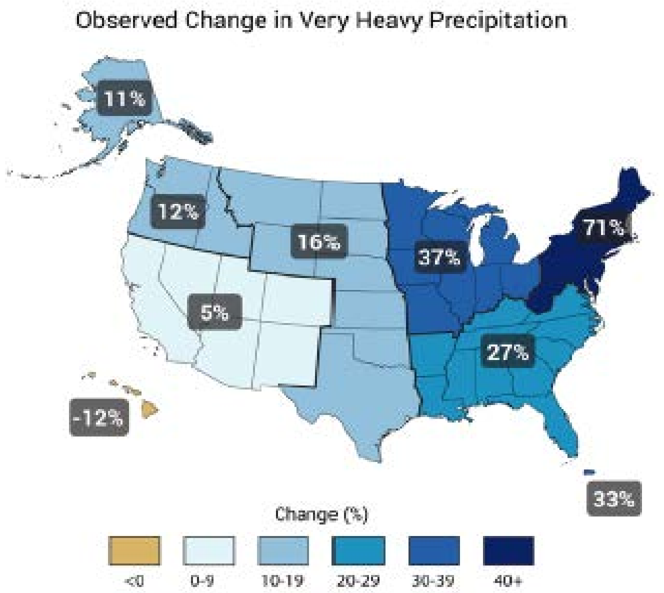
- Extrapolation of historical trends into future is usually not advisable.
- PF estimates for Volume 10 area will generally continue increasing, regardless of emission scenario or model used.
- There are considerable differences in projections depending on what dataset and what model are used.
- Projected PF spatial patterns are also quite dissimilar among different models/datasets.
- Uncertainties are significant; probabilistic approaches may be necessary.



Projected increases in % for 100-year 1-day estimates for years 2020 and 2100 under RCP4.5 scenario based on LOCA data and Delta method.

Addressing Climate Change – Some Considerations

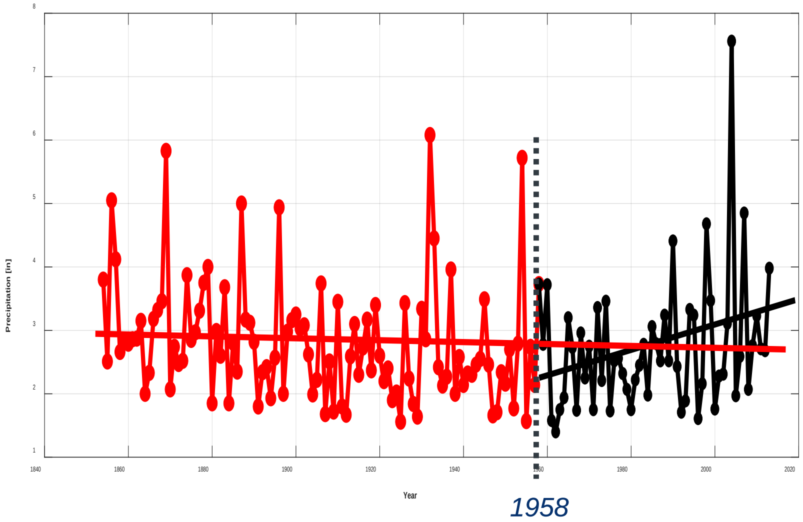
- Extrapolating historical trends. How far back to go in the analysis?



Percent increases in the amount of precipitation falling in very heavy events (defined as the heaviest 1% of all daily events) from 1958 to 2012 for each region (from Karl et al., 2009)

Amherst, MA
1-day AMS

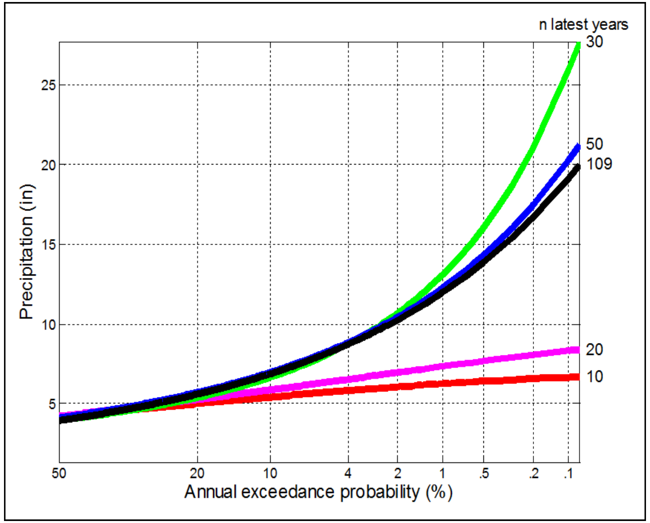
1958 – 2012 positive trend
1854 – 2012 negative trend



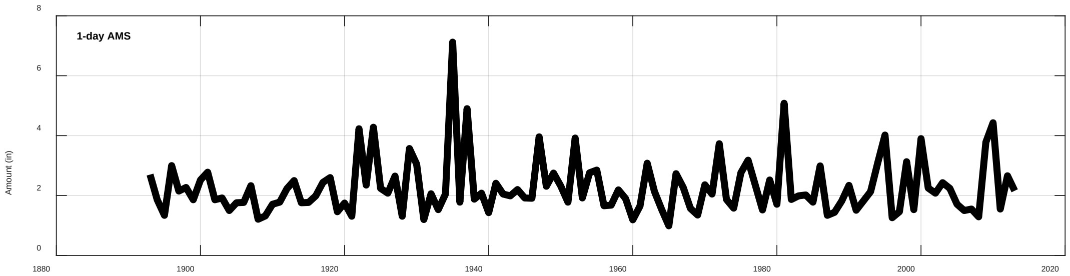
Addressing Climate Change – Some Considerations

- Is 30-year long record adequate for frequency analysis?

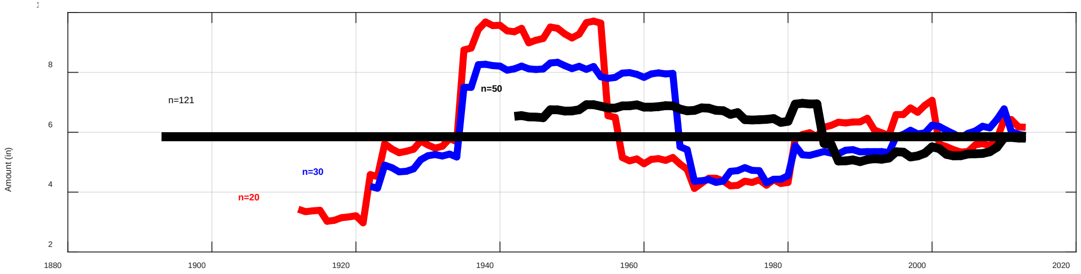
Effect of sample size on estimates



Amherst, NY



100-year estimates from 20-, 30- and 50 years of data over time.



Ensuring Accurate Assessment of Non-Stationary Climate Effects on Estimates

❑ Effects of methodology selection

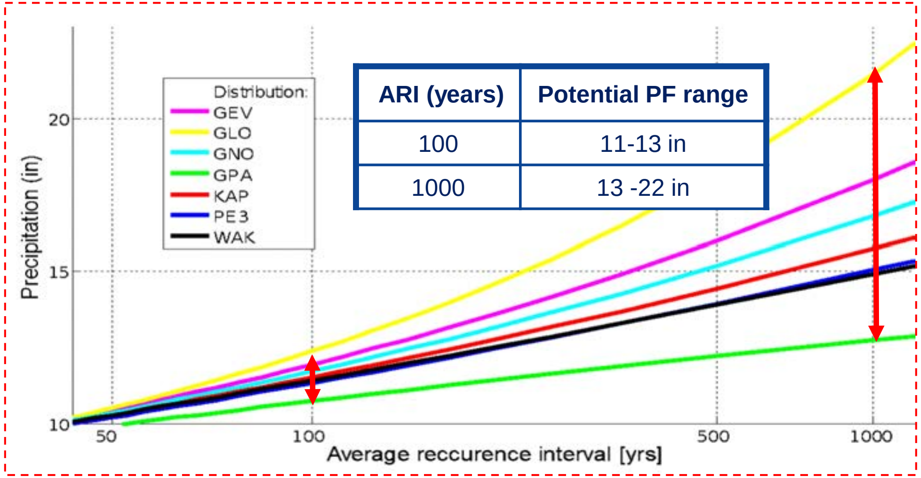
Example 1. Parameterization

24-hour 100-year estimates for BARRANQUITAS, PR station

- stationary NA14 (L-moments) vs. Non-stationary NA14 (MLE, μ(t)): 15.4 vs 20.7 in (34% increase)
- stationary NA14 (L-moments) vs. Stationary NA14 (MLE): 15.4 vs 19.9 in (29% increase)

Example 2. Distribution selection

- All distributions provide acceptable fit to data based on statistical tests.
- 13 inches of rain could be 1000-year or 100-year event (or anything in-between) depending on what distribution is selected.



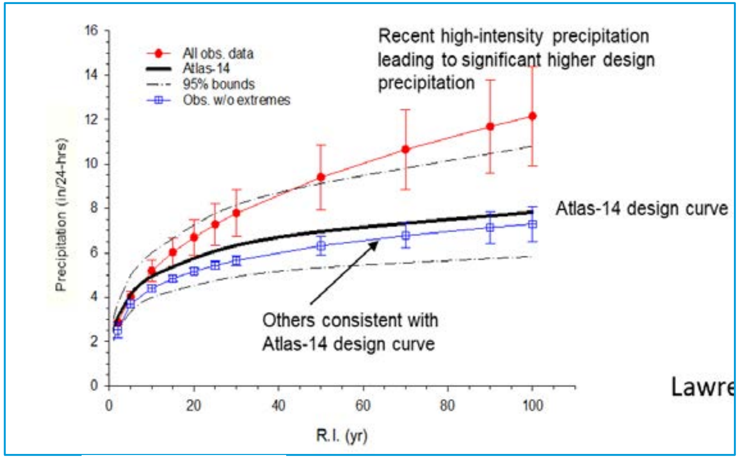
ARI (years)	Potential PF range
100	11-13 in
1000	13 -22 in

Ensuring Accurate Assessment of Non-Stationary Climate Effects on Estimates

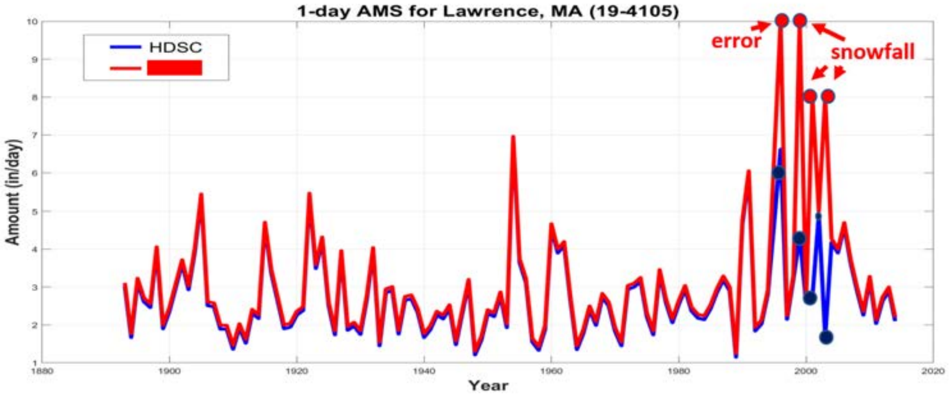
- Data issues

Example 1. External review of stationary NA14 estimates

24-hour estimates for Lawrence, MA station (from Volume 10)



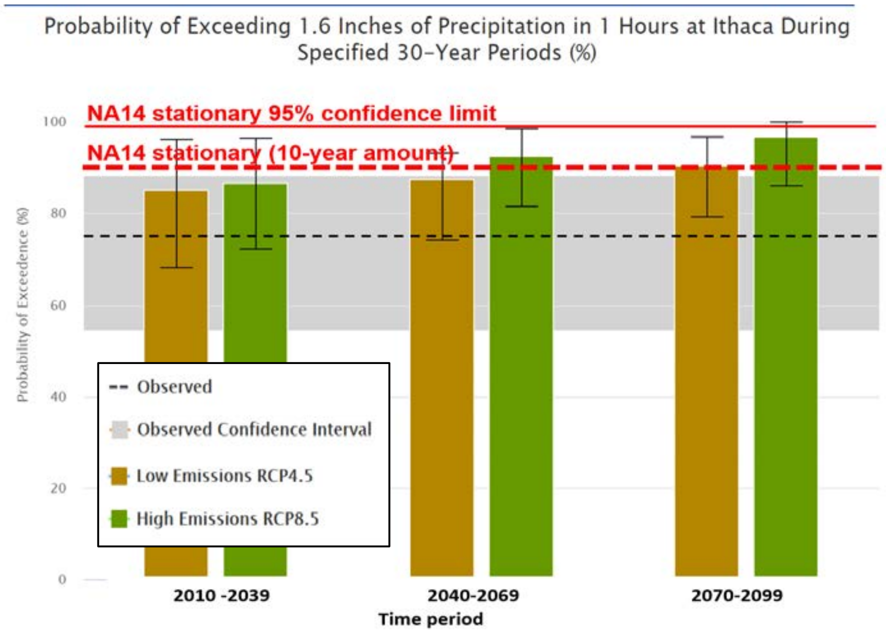
Source:



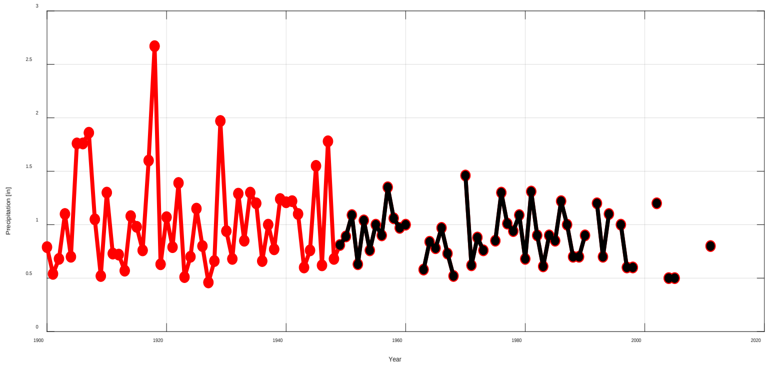
Increase in PFs almost entirely due to data errors.

Accurate Assessment of Non-Stationary Climate Effects on Estimates

- Data issues



Cornell University, Northeast Regional Climate Center (NRCC)
web-based IDF projection tool: http://ny-idf-projections.nrcc.cornell.edu/

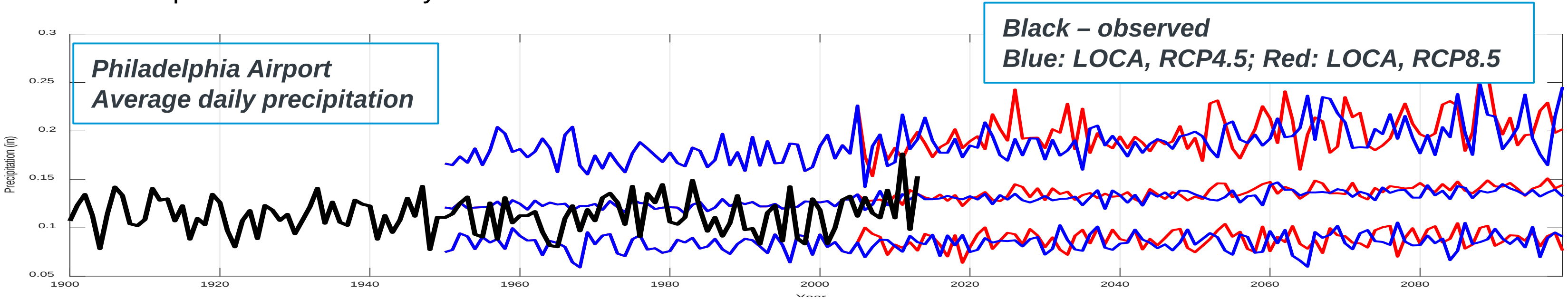


Ithaca, NY
49 years of additional hourly data digitized for NA14

Stationary NA14 estimates higher than most of projected estimates.

Addressing Climate Change – Some Considerations

- **Design standards will have to change under non-stationarity!**
  - Return period (ARI, AEP) risk and other reliability measures will have to explicitly account for a length of planning period (e.g., design life level, Rootzen and Katz, 2013).
  - Probabilistic approaches will have to replace current deterministic approaches if climate projections are considered. Quantification of predictive uncertainty of future conditions has to be considered.



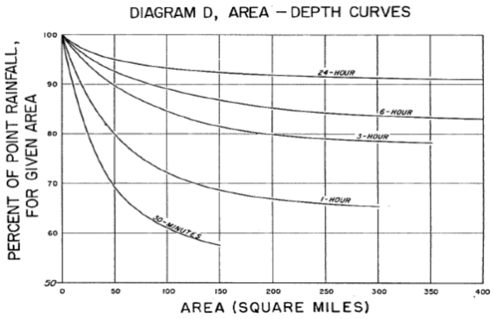
- **Effects of non-stationarity need to be accurately evaluated.**
- **Error contribution of stationarity assumption has to be evaluated relative to other sources of error.**

"Stationarity is dead – whither water management?" (Milly et al. 2008)
"Stationarity: wanted dead or alive?" (Lins and Cohn 2011)
"Comment on the announced death of stationarity" (Matalas 2012)
"Negligent killing of scientific concepts: the stationary case" (Koutsoyiannis and Montanari 2014)
"Modeling and mitigating natural hazards: Stationarity is immortal!" (Montanari and Koutsoyiannis 2014)
"Stationarity is undead: uncertainty dominates the distribution of extremes" (Serinaldi and Kilsby 2015)
"Stationarity should always remain the default assumption…" (Salas et al. 2017)

Atlas 14 Proposed Upgrades and Updates - Additional Products

❑ Areal Precipitation Frequency Estimates

- BACKGROUND: Atlas 14 estimates are point estimates. ARFs are used to convert point precipitation to average precipitation over a watershed. Many ARF methods have been proposed, but Weather Bureau's ARF curves from 1958 are still commonly used.
- PROPOSED: Develop location, duration and ARI specific ARF curves for states with NA14 coverage. Design PFDS web tool to delineate a watershed for a selected location and provide corresponding areal precipitation frequency estimates.



Weather Bureau's ARF curves (1958)

❑ Atlas 14 Design Storm

- BACKGROUND: Atlas 14 provides precipitation frequency estimates for a given duration, but designers often need information on how precipitation is distributed in time and not just the total amount.
- PROPOSED: Develop Atlas 14 design storm product with guidance on how to use the product.

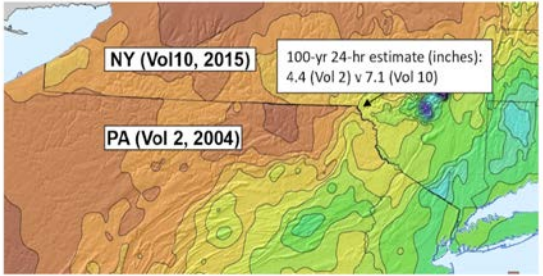
❑ Confidence Intervals

- BACKGROUND: Atlas 14 provides only bounds of 90% confidence interval.
- PROPOSED: Development of confidence intervals of variable width.

Atlas 14 Proposed Upgrades and Updates - Funding Approach

❑ Current

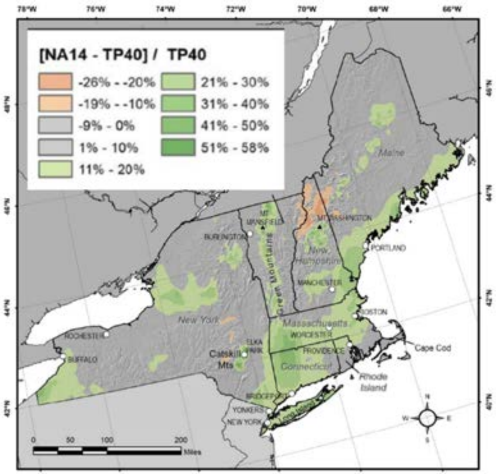
- Estimates are updated in Volumes as funding becomes available.
- Approach results in discontinuities at volumes’ boundaries and creates issues for users that typically consider watershed (and not state-based) boundaries.



❑ Proposed

- Estimates should be updated on a regular cycle of ~10 years to take advantage of more stations with longer records, addition of most recent data in the analysis and use of modern methods.
- Boundary issues could be avoided by updating all states simultaneously.

Having a continuous and sustainable funding approach will be a small investment that would result in significant return and benefits for infrastructure design in the U.S.



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