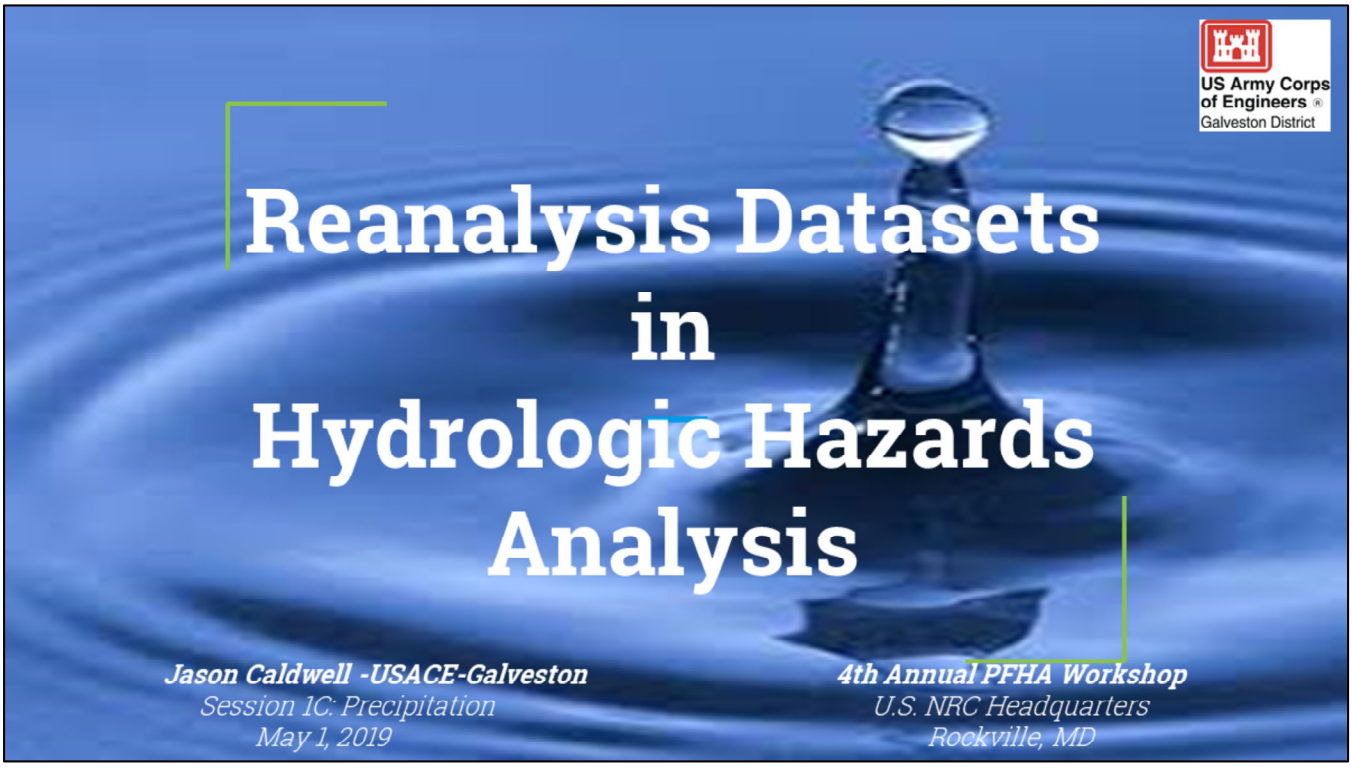
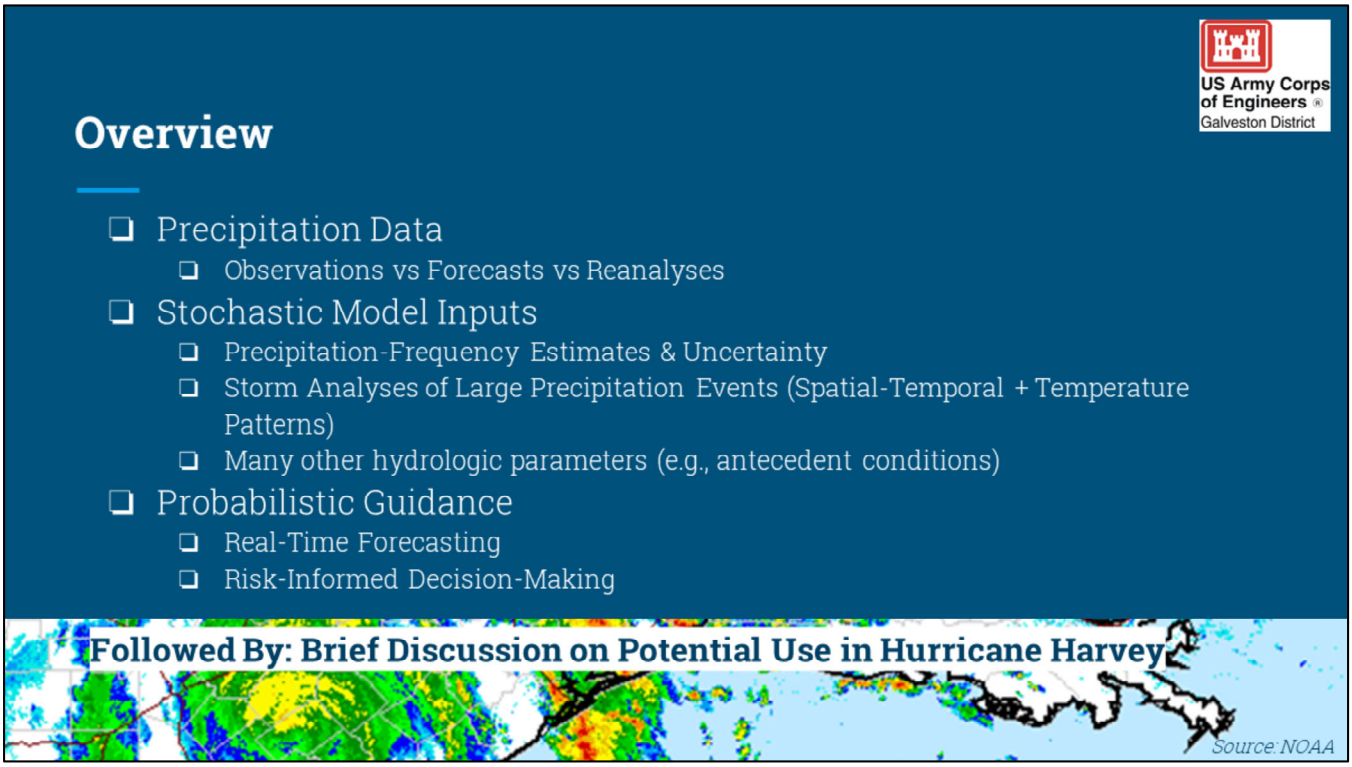


First of all, Jason would like to extend his appreciation to the NRC for the opportunity to present at this conference and sends his apologies for not being able to participate at this time due to a family health situation.

This talk is focused on the use of readily available reanalysis products, primarily meteorological in nature that are available to support hydrologic hazards analyses through model inputs for H&H models and hydrometeorological design criteria. The goal of the presentation is to describe ongoing and potential applications of reanalysis data and to spur the vision toward the future use of these data in on-the-ground application. While recently employed at the US Army Corps of Engineers, the presentation's perspective is from Jason's background across state and federal agencies and private industry.



Today – we will discuss primarily precipitation and precipitation-related datasets – either raw or post-processed and how these are used in stochastic approaches and probabilistic hazards assessments – primarily from time at Reclamation. Mel Schaefer's talk later today will elaborate on some of these items. Historically, engineers have been limited to point precipitation data and for about 15-years multisensor precip estimates (MPE); however, as time continues to march on with technological advances, so does the confidence, resolution, and availability of atmospheric data and reanalyses representative of that data.

Precipitation Data: Observations

- Station Data
  - Federal, State, Local, Private Sponsors
  - PRISM
  - Livneh et al (2016)
  - DayMet
- In Situ Measurements/Blends (QPE)
  - NWS Stage IV
  - MRMS
  - Vendor-Specific Platforms
  - CHiRPs, C-MORPH, TRMM, MSWEP, etc

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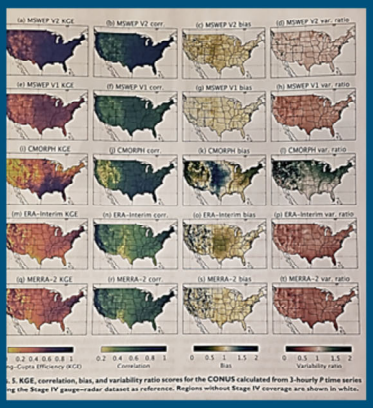

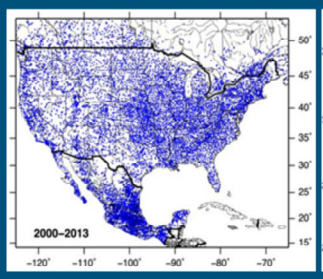

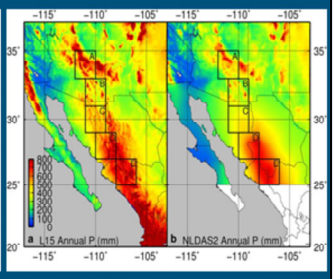

Observational data (gauges) come from a variety of sources and have been interpolated using PRISM-based technologies into historical and real-time versions of storm analysis systems. Reanalyses using these observations can also include numerical weather prediction model output constrained to these observations, which provides an opportunity to harvest additional variables of interest in the hydromet community such as moisture availability, temperatures, etc. Most recently (top image), satellite derived 3-hour precipitation estimates have been produced globally and published in the most recent Bulletin of the AMS journal. The growth in meteorological data is expected to continue to be refined and improve.

Precipitation Data: Forecasts

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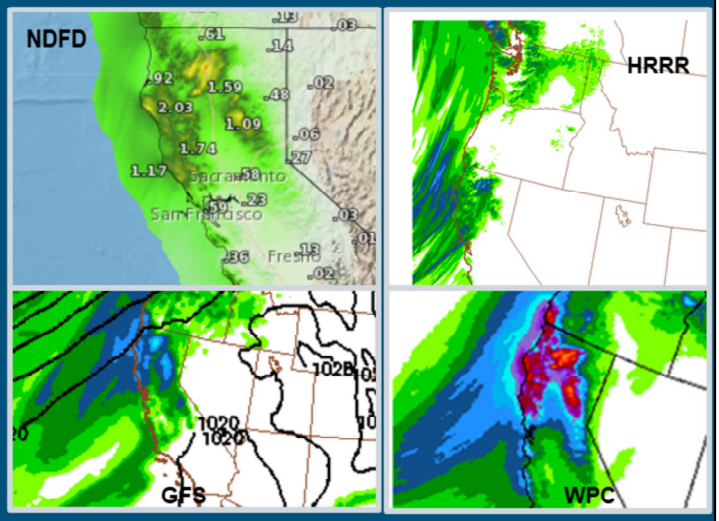
- Global Models
  - GFS/GEFS
  - ECMWF + Ensembles
  - UKMET
  - CMC
- Regional Models
  - NAM-WRF/NAEFS
  - HRRR/RUC
  - MM5 + others
- Operational Forecasts
  - Weather Prediction Center
  - National Weather Service (NDFD)
  - Weather Consultants



In addition to the historical data shown, forecast data is produced several times daily by weather models. The harvest of this data is, I would consider, at its infancy – but 1km, sub-hourly precipitation forecasts are at hand. While not the focus, necessarily, of this conference. The spatial-temporal information available can be archived to represent large events of PMP and stochastic modeling interest (i.e., annual maxima) or used for identification of areas of concern in operational decision-making processes. Private industry, and now the Weather Prediction Center, offer these products for flood monitoring.

Precipitation Data: Reanalyses

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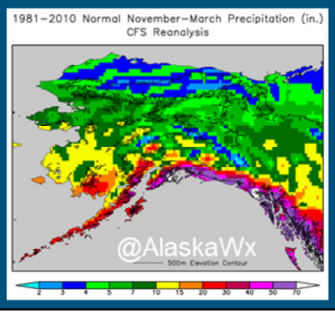
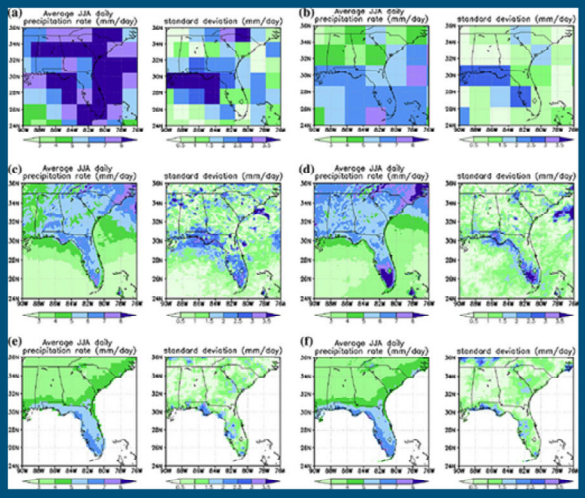
- ❑ Climate Forecast System (CFS-R)
- ❑ North American Regional (NARR)
- ❑ NCEP-NCAR (NNR)
- ❑ 20th Century Reanalysis (20C)
- ❑ European (ERA-40)
- ❑ Others





(Stefanova et al 2012)

As before, the reanalyses data continue to improve with the CFS-R data providing 1979-2014 hourly forecast fields for the entire period at approximately 12-km resolution. Others also offer 3- and 6-hour outputs – particularly useful for larger watershed and/or longer duration events – or analyzing frequency patterns of multiple events and quasi-stationary patterns – see central Texas 2019 or Midwest floods mid-1990s.

Stochastic Model Inputs: Precipitation-Frequency

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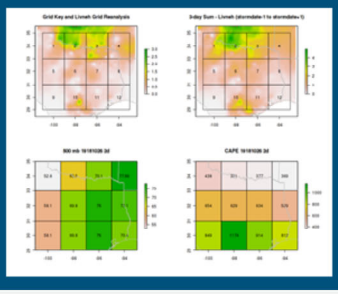
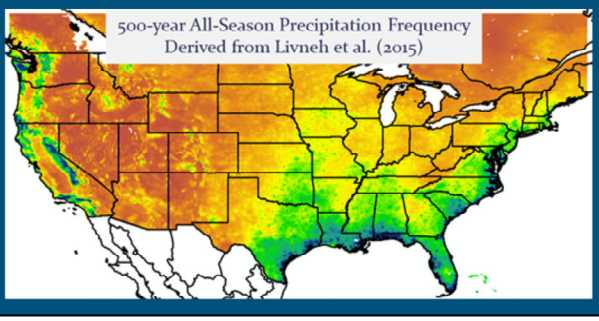
Galveston District

- Innovative & Novel Approach
  - Observational Data (e.g., Livneh, CFS-R, other)
  - Regional Approach (L-Moments) with Fixed Skew/Kurtosis
- Benefits
  - Reasonable, rapid results
  - PF Source = Storm Source
- Limitations
  - Interpolation effects
  - Scaling issues for small basins
- Next Steps
  - NWP → Enhance spatial/temporal
  - Storm Typing → Refined statistics

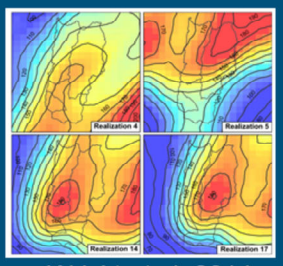




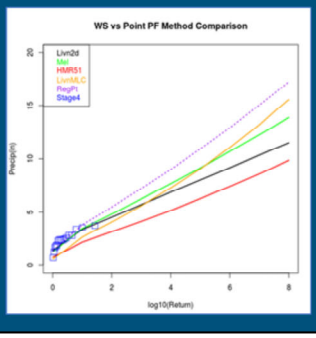
At Reclamation, initiated use of Livneh data for creating CONUS-wide precipitation-frequency analyses and continued into the private sector at MetStat. Livneh data for perspective are daily data used for VIC models under historical and future climate scenarios. I believe the information from high-resolution weather models can inform the sub-daily time steps for short-duration weather events. Furthermore, as Mel Schaefer will describe later, storm typing is the largest advancement in many years in PFA and can be applied with this coincident time series data to construct reasonable estimates quickly compared to the massive data quality procedures for more refined PFA such as NOAA14 or site-specific analyses. Limited however for the interpolation methods cause issues at the tails and in parameter selection or for small basins or short durations. With storm typing and GEV-convergence (see Mel Schaefer), better understanding of the tail behavior is underway and will soon allow this process to be further refined.

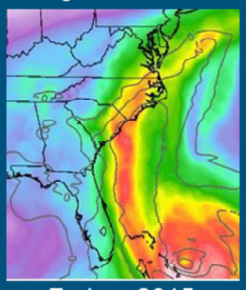
Stochastic Model Inputs: Spatial Patterns

- Storm-Specific Spatial Distribution
  - Observations vs Forecasts vs Reanalyses
- Stochastic Storm Transposition (SST)
  - Lateral + Vertical + Rotational
- Areal Reduction Factors
  - Storm-Relative vs Geographically-Fixed
- Storm Maximization
  - Model Climatology → Consistency
  - IWVT vs Dewpoint vs Precipitable Water



Wright et al, 2014





Forbes 2015

The days of the smooth isohyetal pattern are gone. And, now we have access to MPE and models that show the spatial and temporal variability of storm precipitation. We have tools like HEC MetVue, Dan Wright's SST tool online at Wisconsin, and leading examples such as TVA and CO-NM REPS projects that focused on improving ways we move/transpose storms around the country. Discoveries in ARF variability came from these and other studies showing how different thunderstorm ARF is for example relative to a large mid-latitude cyclone. Or relative to the basin orientation with respect to the general storm motion. We have a lot to learn, but the quality of meteorological data provide the ability to investigate the simplicity of elliptical storm patterns and dictated temporal patterns and their effects on hydrology and specifically AEPs. Lastly, from the PMP world, we continue to move toward understanding the moisture maximization problem – is surface dewpoint sufficient? Are we missing important considerations? Is having consistency for computation important (gauge Td, old map SST/PW, etc.)? These are industry-wide research questions we should be asking.

Stochastic Model Inputs: Temporal Patterns

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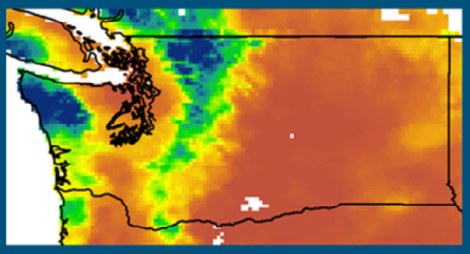
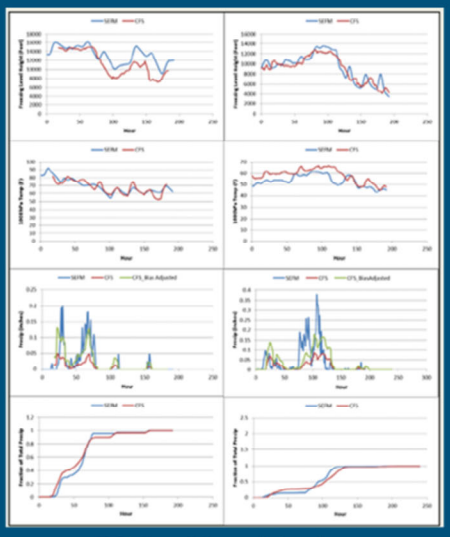
- Storm-Specific Temporal Distributions
  - Observations vs Forecasts vs Reanalyses
- Dimensionless Mass Curves
  - % of Storm Total
  - % of xx-Hour Maximum Precipitation
  - Partially mitigates magnitude/scale issues



July 1983 Storm (Livneh)

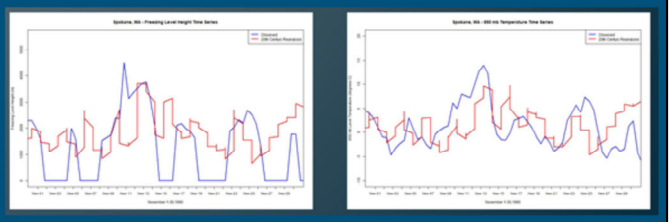


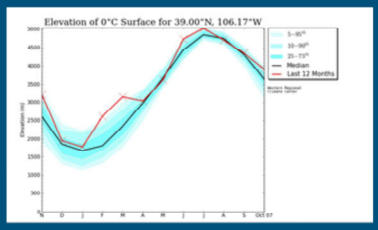
CFS-R vs Manual Analyses

Hourly observations even in todays world continue to be sparse and sub-hourly even moreso. But, past studies have shown that the disaggregation of observed data manually in a quite time consuming process of painful spreadsheets is reasonably reconstructed in normalized time series from numerical models and reanalyses.

Stochastic Model Inputs: Temperatures + Others

- Storm-Specific Temperature Profiles
  - Observations vs Forecasts vs Reanalyses
  - Snow Dynamics/Melt
- Climatological Data
  - Distributional resampling methods
  - Weather generator applications
  - Rain-snow determinations
- Deterministic Evaluations
  - Variety of Atmospheric Variables
    - Dewpoint, Precipitable Water, IWVT
    - Back-Trajectories (single vs multiple)





As we've walked through, I'm trying to focus on the items needed for hydrologic models – precipitation spatial and temporal – now on to temperatures. In southern locations, the snow-melt component is trivial and in transition areas perhaps the most difficult due to rain on snow – where hydrologic risk is a mixed bag from event-driven to seasonal pack and anomalously warm spring seasons. Shown here a few examples of seasonal variability in freezing level and times series that could be normalized to an average value for the period for scaling using these distributional properties. In the future perhaps the categorical snow, freezing rain, sleet and liquid fields from NWP reanalyses might be useful to eliminate the need for lapse rates in modeling efforts OR to establish the correct criteria for a watershed rather than assumed from location-specific literature. And not constrain ourselves to single trajectory answers for things but rather to explore the understanding of moisture for storms and what is truly the best criteria –maybe it is dewpoint, though doubted.

Risk-Informed Decision Making: Operations

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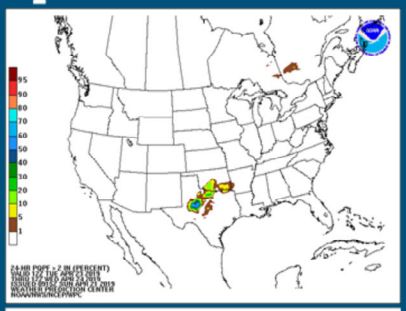
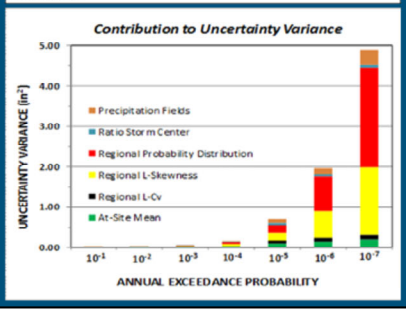
Galveston District

- Ensemble-Based Approaches
  - Statistics → Public Confusion
  - Categorical → Improved Understanding
  - PMP and/or Frequency Thresholds
- Raw + Transposed Data
  - Model-generated ensembles
  - Preferential transposition
- Hydrologic Modeling
  - Simplified Routing/Runoff (Worst-Case)
  - Stochastic Modeling (Most Likely + Uncertainty)



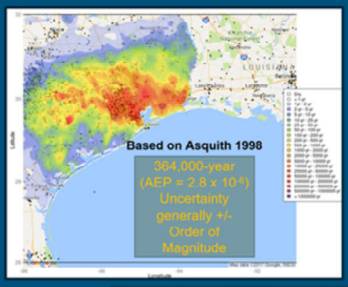


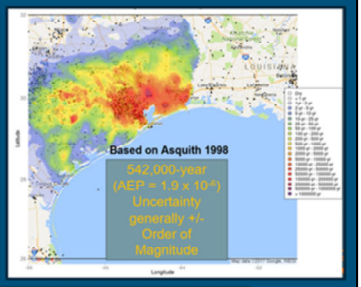
I hope by now it is clear that many components can be accessed from these data. And importantly that strides are being made to include these into tools and formats for ease of access to the larger community. Past studies for the NRC, TVA, and others elucidate this fact and the onus/responsibility lies with this group to forge a path forward. The next few slides will discuss the potential applications, some already in practice in industry and government. How do we turn these data into meaningful products.? Statistics useful from government and operators perspective but for public communication continue to be a struggle point. Placing these into categorical perspective (minor, moderate, major) or some relative amount of PMP or AEP. Probabilistic products from WPC provide a focus for where the largest precipitation amounts should occur based on ensembles – can we use this pre-storm to inform SST for H&H models? Will simple one suffice and where and why or why not? How can this be coupled with national efforts like the National Water Model? Literally the options are limitless and social scientists will need to be involved to describe. Frameworks are needed for everything from 1-D to 3-D coastal compound flood issues. Where might this feed in? This is a presentation on questions – motivating thought and future goals.

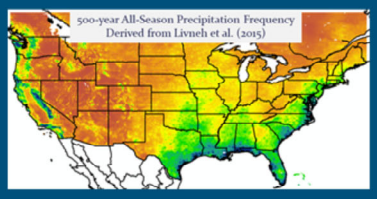
Risk-Informed Decision Making: Dam Safety

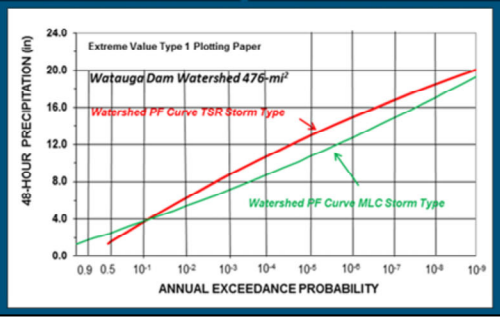
US Army Corps of Engineers
Galveston District

- Screening → Hydrologic Hazards
  - Level 1 - PMP/PMF (Low)
  - Level 2 - PF (Medium)
  - Level 3 - Full Stochastics (High)
- Precedence
  - El Vado Dam HHA
  - CO-NM Regional Extreme Precipitation Study
  - TVA Hydrologic Hazards Assessment









Dam safety – Reclamation usage – how done before. CEATI sponsored work in private industry (MetStat) for FERC Level 2 support. MetStat images give verbal credit please and to MGS Engineering.

Case Study: Hurricane Harvey - Operational Guidance

US Army Corps of Engineers
Galveston District

- Statistical Approach
  - Percentiles by Magnitude
- Categorical Assessment
  - %PMP vs ARI
- Transposition Limits/Locations
  - Storm Center - How Defined?
- Volumetric Calculations
  - Worst Case + Best Estimate w/Uncertainty

AEP = 0.10	
NA14	6.87"
MLC	5.50"
TSR	2.50" (-60%)
AEP = 0.01	
NA14	11.00"
MLC	9.00"
TSR	6.50"(-40%)
AEP = 0.001	
NA14	16.40"
MLC	12.00"
TSR	10.00"(-40%)

Estimates Only!!!

Original abstract had some focus on Harvey and with litigation ongoing adjusted some. These two slides are estimates based on plots from the Trinity River study and the net reduction may be over-estimated due to gradients in at-site means near the coast between river basins. The goal is the same – to highlight the differences that may exist and show the importance of storm typing for assessing hazards. The relative AEP of TC occurrence is small (0.30 or so – every 3rd year) which affects a much more gentle tail relative to other types. This will be important in scaling storms for stochastic models or the relative magnitude in frequency or PMP space.

US Army Corps of Engineers
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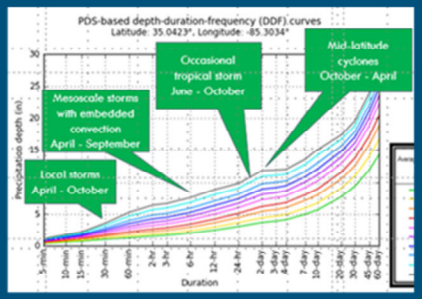
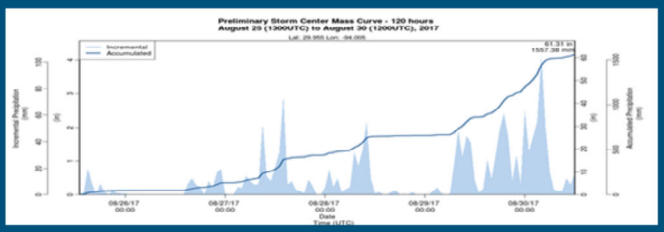
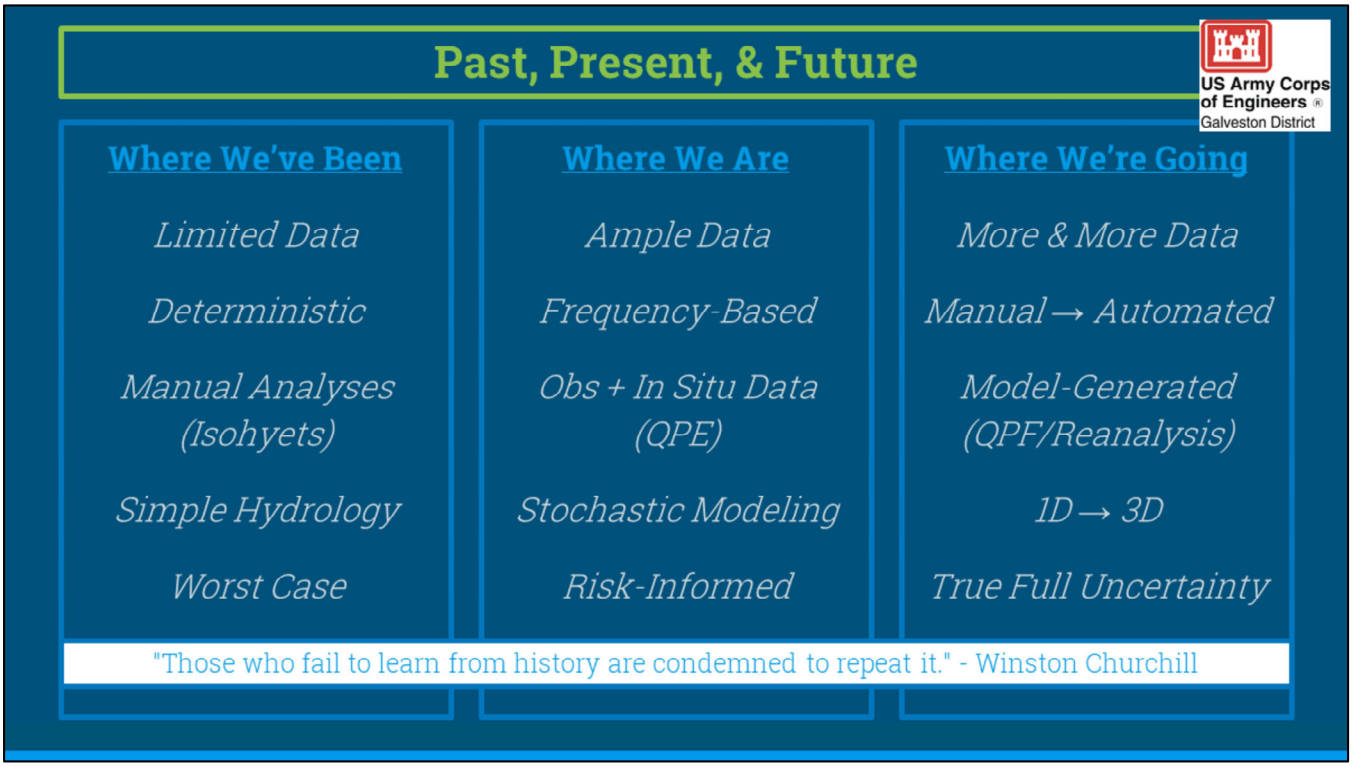
Case Study: Hurricane Harvey - Dam Safety HHA

- Precipitation-Frequency
  - All-Season vs NOAA14 vs USACE Trinity
- Storm Spatial/Temporal Characteristics
  - Depth-area-duration (DAD)
  - Mass Curves
  - Areal Reduction
- Meteorological Conditions
  - Atmospheric Moisture

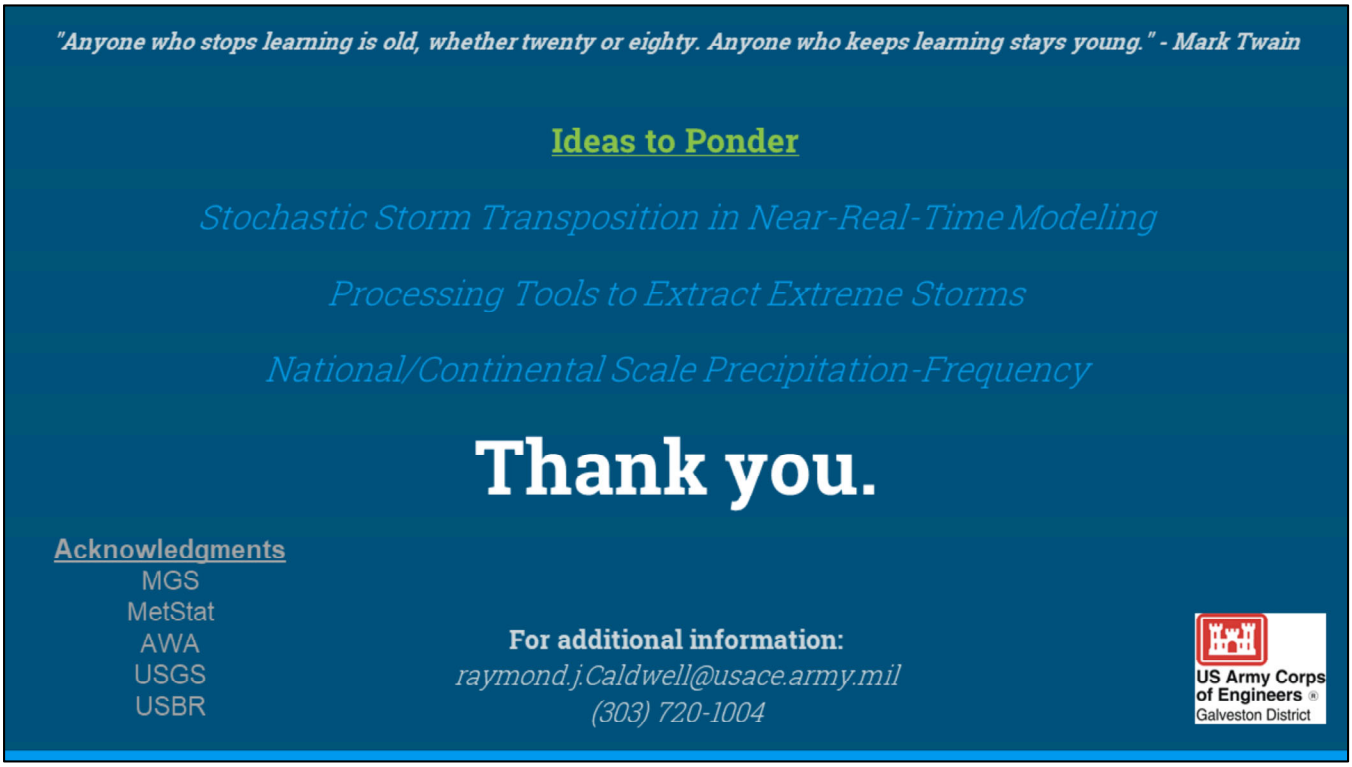




Again, just to emphasize the mixed distribution issue and describe here how you might get the plot at bottom from reanalysis. That it is likely a similar time series has occurred albeit at a different magnitude in the historical past. And, can we answer whether this is unique for a tropical storm or could a more general storm produce the same dimensionless answer. Talk about moisture source and PMP and how close Harvey was and do we really know the climate of SST and moisture when using a single value?



How to get where we are going. Where we are, where we were? Do we want to stay there? Other presentations today I believe (HDSC, Schaefer, etc) show the movement toward the right column. I am personally pleased to be here and be part of that discussion.



Finally, a few ideas to ponder in operational and storm archival (USACE Effort mentioned here and ESEWG). And, thank those at left and NRC for their contributions.