New Data for Old Storms: Can New, Convection-Allowing Ensemble Simulations of Historic Storms Help Minimize Present-Day Flood Risk?

Kelly Mahoney[1], Chesley McColl[1,2], Bill Kappel[3], Douglas Hultstrand[3]

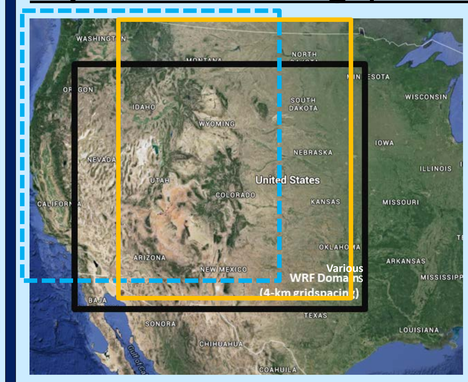
[1]NOAA Earth Systems Research Laboratory, Physical Sciences Division, [2]University of Colorado, CIRES, [3]Applied Weather Associates

The challenge

- Estimating potential extreme rainfall amounts critical for dam safety and water resources management
- "Probable maximum precipitation" (PMP): conceptual "upper limit" of precipitation
- PMP estimation relies on past storms to define historical upper bound. Many important storms are old, with sparse, incomplete, questionable observations
- Can convection-allowing weather model ensembles offer insight, provide important supplemental data for historic storms that currently determine PMP?
- Can they communicate uncertainty, indicate credibility of historic observations?
- How can model data be incorporated into existing PMP methods?

➢ Colorado, New Mexico regional study to update extreme precipitation estimates for dam safety evaluations using best available science is nearly completed. NOAA ESRL testing and prototyping dynamical model-based methods.

Experimental design, methods



Objective: Use Weather Research and Forecasting (WRF) model to simulate multiple instances of historic events by varying initial conditions

- WRF V3.7.1
- 4-km grid spacing|54 vertical levels
- Explicit convection|Thompson cloud microphysics
- YSU PBL|rev. MM5 M-O surface layer| Noah LSM| Dudhia; RRTM radiation
- 20CRv2c initial, boundary conditions
  - 1851 – 2014
  - 56-member NCEP GFS-based reanalysis using EnKF DA
  - ~200-km resolution, 28 levels
  - Compo et al. 2011, doi:10.1002/qj.776
  - http://reanalyses.org/

➢ Storms selected by Applied Weather Associates based on:
  - Importance in previous PMP values
  - Lack of observations from which to derive robust storm patterns, magnitudes
  - Uncertainty in previous analysis results

➢ 20CR ensemble members selected semi-randomly; some effort to represent maximum spread in initial conditions based on vertical velocities, moisture indicated across individual 20CR members

➢ WRF domain, simulation periods designed using existing Applied Weather Associates storm analyses

Results: The good, the bad, and the unknown

Rattlesnake, ID 1909

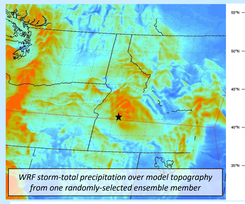
➢ Week-long series of inland-penetrating atmospheric rivers interacting with orography

➢ Four simulations offered consistency among themselves and available observations

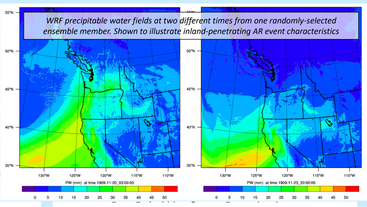
➢ Model output provided useful spatial pattern information that was applied as an improved precipitation basemap (from which PMP begins)

➢ Also helped to inform rain-snow delineation to identify regions with snow (not/less relevant to PMP)

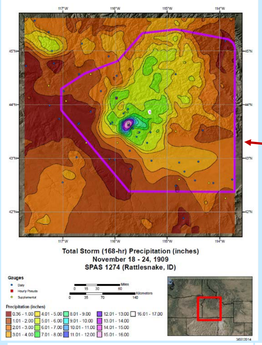
➢ Discussion of use of single simulations vs. ensemble diagnostics (spread, ensemble max)

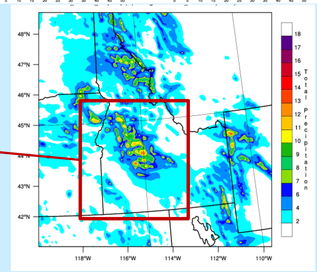


WRF storm-total precipitation over model topography from one randomly-selected ensemble member

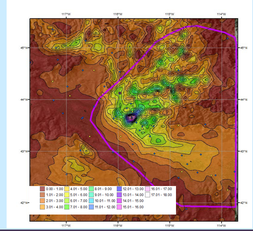


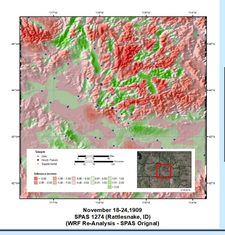
WRF precipitable water fields at two different times from one randomly-selected ensemble member. Shown to illustrate inland-penetrating AR event characteristics





Existing AWA storm-total precipitation analysis (left) vs. WRF simulation of storm-total precipitation from ensemble max values from four ensemble members (right)



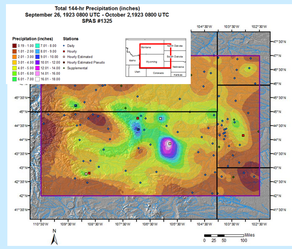


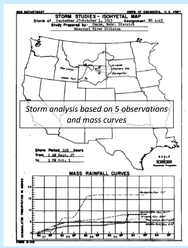
Resulting storm-total precipitation analysis after incorporating WRF model simulation data (left) and difference from original analysis (right)

Savageton, WY 1924

➢ Mid-latitude synoptic cyclone; Gulf of Mexico moisture

➢ Existing storm analysis details uses questionable observations: "…limited number of hourly and daily data near primary small storm center diminish reliability of these results…there were only 5 hourly stations…data were estimated from USACE's smoothed mass rainfall curves…"

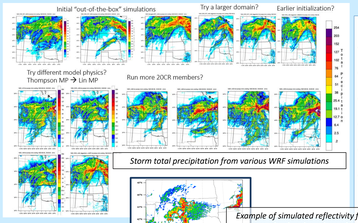




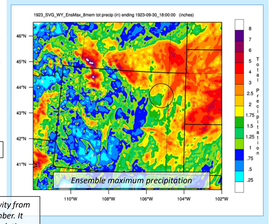
Storm analysis based on 5 observations and mass curves

➢ 14+ WRF simulations only achieve an ensemble maximum point value of ~4 inches (50mm) vs. 17.1 inches in northeastern WY

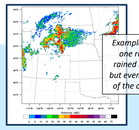
➢ AWA: "Unfortunately, the WRF reanalysis of the Savageton storm showed little skill in being able to replicate either the spatial pattern or magnitude of the storm. Therefore, the WRF reanalysis results were not used in the Savageton SPAS analysis."



Storm total precipitation from various WRF simulations

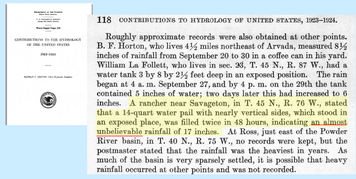


Ensemble maximum precipitation



Example of simulated reflectivity from one randomly selected member. It rained heavily at times in simulations but event totals did not equal even 25% of the currently-accepted observation

➢ Is the WRF ensemble deficient in its ability to simulate this case? Or could the 17.1 inch/108 hour observation be in error?



118 CONTRIBUTIONS TO HYDROLOGY OF UNITED STATES, 1923–1924.

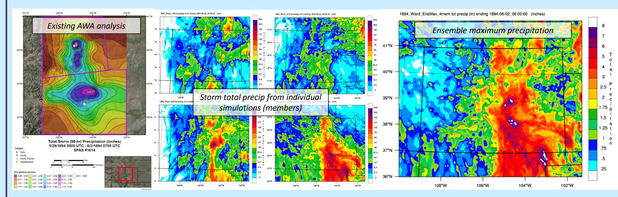
Roughly approximate records were also obtained at other points. B. F. Horton, who lives 4½ miles northeast of Arvada, measured 8½ inches of rainfall from September 20 to 30 in a coffee can in his yard. William Le Follett, who lives in sec. 26, T. 45 N., R. 87 W., had a water tank 3 by 8 by 2½ feet deep in an exposed position. The rain began at 4 a. m. September 27, and by 4 p. m. on the 29th the tank contained 5 inches of water; two days later this had increased to 6 inches. A rancher near Savageton, in T. 45 N., R. 76 W., stated that a 14-quart water pail with nearly vertical sides, which stood in an exposed place, was filled twice in 48 hours, indicating an almost unbelievable rainfall of 17 inches. At Ross, just east of the Powder River basin, in T. 40 N., R. 75 W., no records were kept, but the postmaster stated that the rainfall was the heaviest in years. As much of the basin is very sparsely settled, it is possible that heavy rainfall occurred at other points and was not recorded.

Additional cases simulated:

➢ Ward District, CO 1894

➢ Synoptic cyclone (96-hour duration), relatively good data coverage (43 stations)

➢ For Ward District, the WRF precipitation (based on maximum value of 4-member runs) were as a SPAS basemap, the WRF basemap had similar spatial pattern (slightly shifted to the southeast) and magnitude as the observed data.

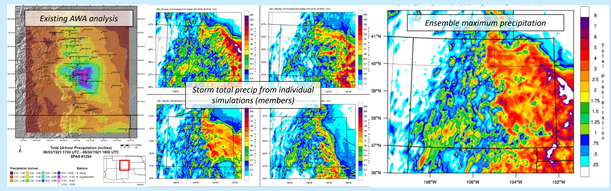


Storm total precip from individual simulations (members)

➢ Penrose, CO 1921

➢ Small-scale thunderstorm with severe lack of data. Only one station was used in the original analysis.

➢ A 4-member WRF ensemble produced spatial output similar to the original spatial analysis, the WRF storm center was shifted to the east approximately 10 miles and the magnitude was substantially less than the observed data, therefore no adjustment/basemap updates were applied.



Storm total precip from individual simulations (members)

Ensemble vs. single case considerations

- Individual simulations offer sharpest spatial, temporal detail and are relevant to actual case evolution
- Ensemble maximum grids are relevant to PMP estimation from the viewpoint of "how hard did the dynamical model think it could have rained given this overall set-up?"
- Also, ensemble spread shows variability in model solutions and gives some indication of uncertainty in robustness of simulations.

Summary & next steps

Dynamical modeling offers potential benefit to PMP estimation:

➢ Reconstruction of major historical events via numerical modeling may supplement existing storm analyses, improve spatial and temporal assumptions made with very limited observational data

➢ Utility of WRF simulations performed for this study seems proportional to role of topography in controlling rainfall spatial pattern and magnitude.

➢ More generally, dynamical models:
  - Offer continuity in space and time; data produced by solving physical equations of the atmosphere (vs. interpolation of limited observations)
  - Reduce need for many spatial, temporal, physical assumptions (e.g., storm transposition, storm templates, moisture maximization, etc.)
  - Especially important in data-sparse regions of complex (& high-elevation) topography
  - Have relatively straightforward methods for quantification of uncertainty
  - Can offer numerically-constrained/somewhat-objective methods for storm maximization, atmospheric boundary condition shifting, etc. (Ohara et al. 2011; Ishida et al. 2015; Chen and Hossain 2016, others)

➢ Dynamical modeling not a PMP improvement panacea – using dynamical models, particularly in this manner, still involves substantial subjectivity.

➢ Ongoing work will more closely examine the reliability of the Savageton, WY 1924 event, along with several other events deemed critical by Colorado and New Mexico dam safety programs.

➢ Future work will leverage new model and reanalysis technologies to be more representative of possible simulation spread and more specifically communicate uncertainty in stakeholder-relevant ways.

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