Improving Extreme Precipitation Estimation using Regional, High-Resolution Model-Based Methods: Part 2

NOAA/CIRES Future Efforts - Kelly Mahoney

Reclamation Complementary Efforts - Victoria Sankovich

2nd Annual Progress Meeting
30 Jan. 2014

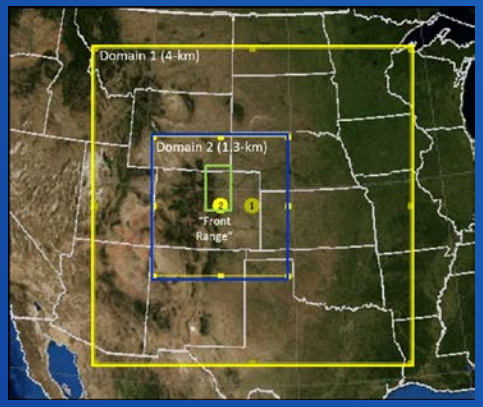
RECLAMATION

Improving extreme precipitation estimation using regional, high-resolution model-based methods: Part 2

Gap(s) Addressed

LT 2.02: Downscaled data at finer space and time resolutions
LT 2.03: Strengths and weaknesses of downscaled data and methodologies
LT 3.06: Methods for estimating extreme meteorological events in a changing climate
LT 4.03: Methods for estimating extreme hydrological events in a changing climate
LT 7.01: Uncertainties on global climate projections data

Graphic



Colorado Front Range model domain used for identification of extreme storms and extraction of ingredients-based variables in previous research

Research Question(s)

1. Is a high-resolution, model ensemble-based framework able to more realistically diagnose small-scale physical processes that generate extreme precipitation under various atmospheric conditions?
2. How might an ensemble approach aid us in understanding the envelop of uncertainty upon adjusting past storms for climate change signals?
3. What are the advantages of fully coupled atmosphere-hydrology modeling to characterize extreme hydrometeorological events in dam safety decision-making?

Collaborators/Schedule/Source of Support

- CIRES-Reclamation Cooperative Agreement and Flood Hydrology & Consequences Group
- Two year agreement beginning in Feb. 2014
- Complementary project: Coupling TREX with Stochastic Concepts and Modern Datasets

RECLAMATION

Research utility in Reclamation operations

1. Knowledge of storm events is often limited by sparse observations and lack of recent extreme storm event analyses.

2. Large uncertainty exists in estimating the intensity of historical events.

3. Past research using WRF has not been fully incorporated into FHCG operations.

4. Dynamical model framework could address longer-term need to examine storm maximization and orographic enhancement.

5. Selection and incorporation of climate change data into FHCG projects is largely unknown.

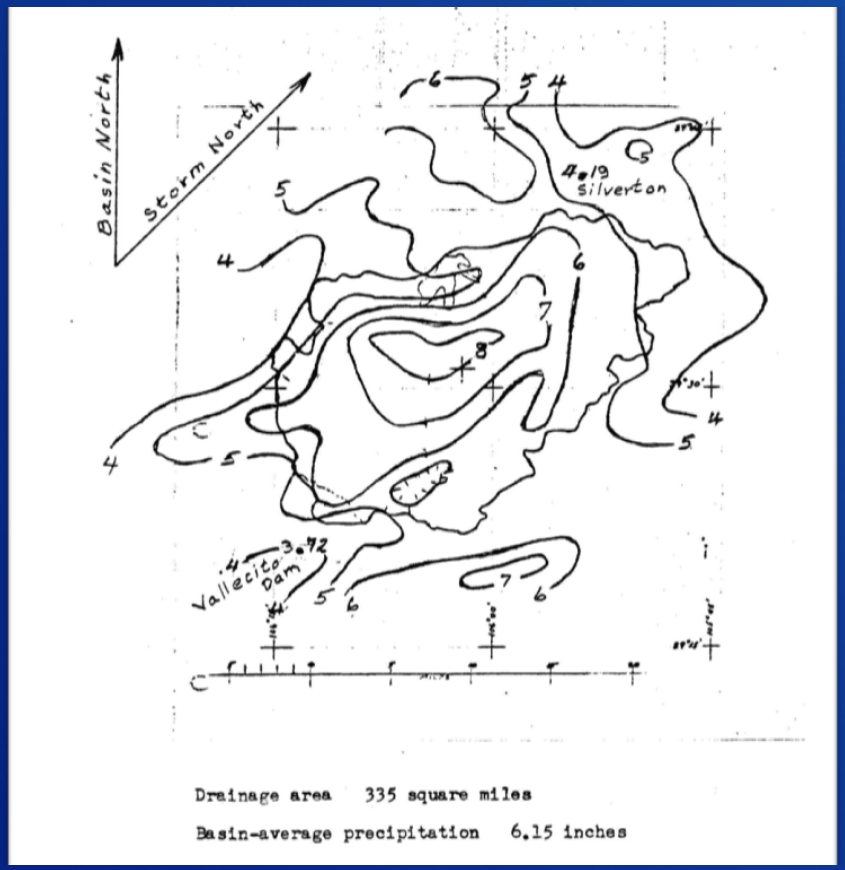
6. Gridded precipitation data for fixed events is not immediately implementable to Reclamation hydrologic modeling applications.

7. Past dynamical model-based research results have not been directly implemented into a hydrologic hazard study due to lack of infrastructure for translation of research-grade products to operations.

RECLAMATION

1. Knowledge of storm events is often limited by sparse observations and lack of recent extreme storm event analyses

Application: Storm templates for input into hydrologic models, Important to consider the largest events in the record



Example:

4-6 Sept. 1970

- Near Silverton, CO
- Temporal pattern not available
- Only two precip obs
- Isohyetals based on best guess

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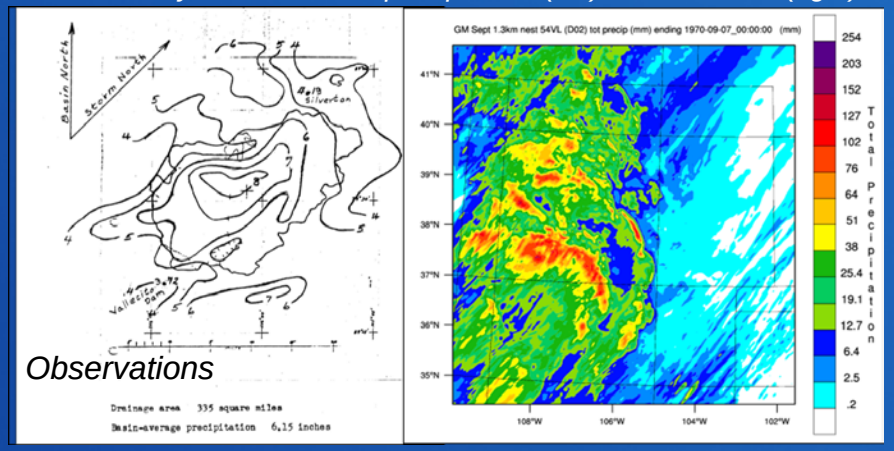
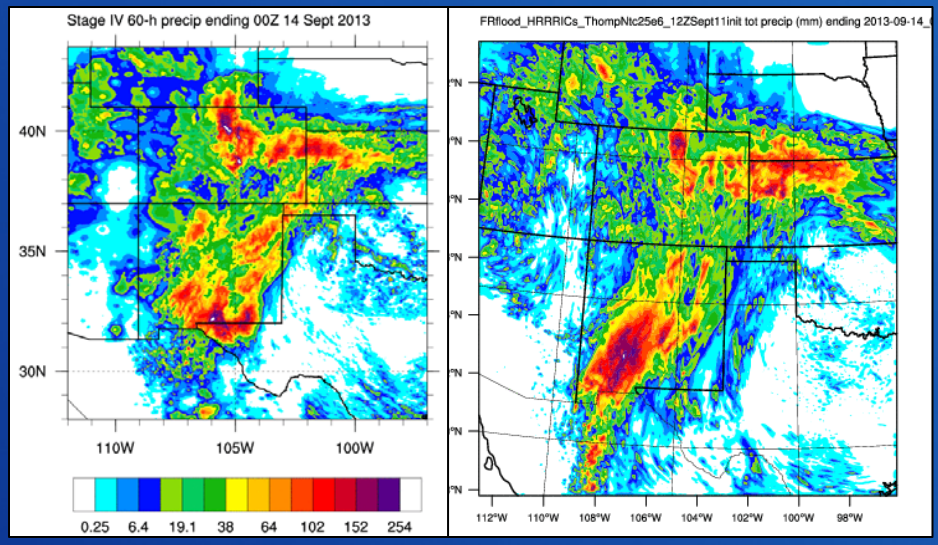
Addressed by: Dynamical Modeling

- Using a dynamical model, past cases of interest can be reproduced with continuous, high-resolution coverage in space and time.
- High-resolution, continuous coverage means that fewer approximations, transpositions, and estimations in both space and time will have to be made.
- Comparison to observations ensures consistency and validation of precipitation magnitude, timing, and distribution.

Example 1: Simulation of Sept 1970 storm in SW CO: "Observed"/analyzed storm-total precipitation (left) vs. simulation (right)



Example 2: Simulation of Sept 2013 Front Range Floods "Observed"/analyzed storm-total precipitation (left) vs. simulation (right)



RECLAMATION

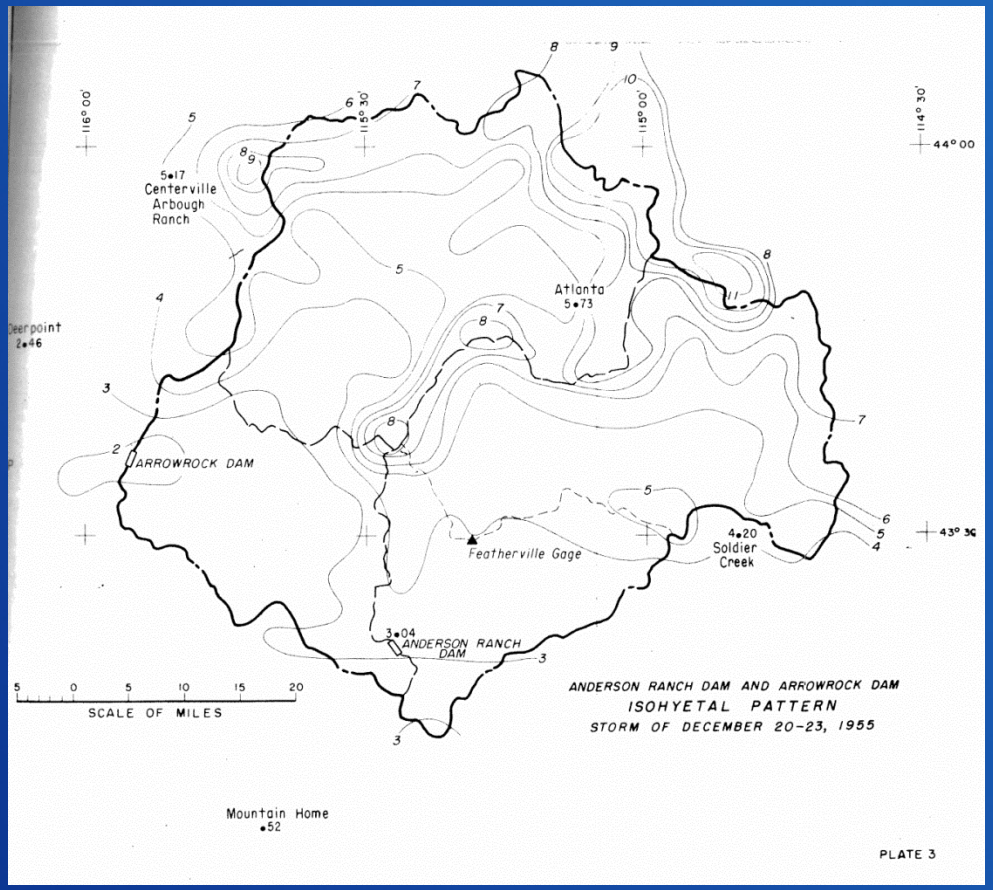
2. Large uncertainty exists in estimating the intensity of historical events

Application: Storm templates for input into hydrologic models, Large uncertainty in isohyetal patterns

Example:

20-23 Dec. 1955

- Near Anderson Ranch Dam and Arrowrock Dam, ID
- Isohyetals created using Thiessen polygons
- Contours of 8” precip noted without observations



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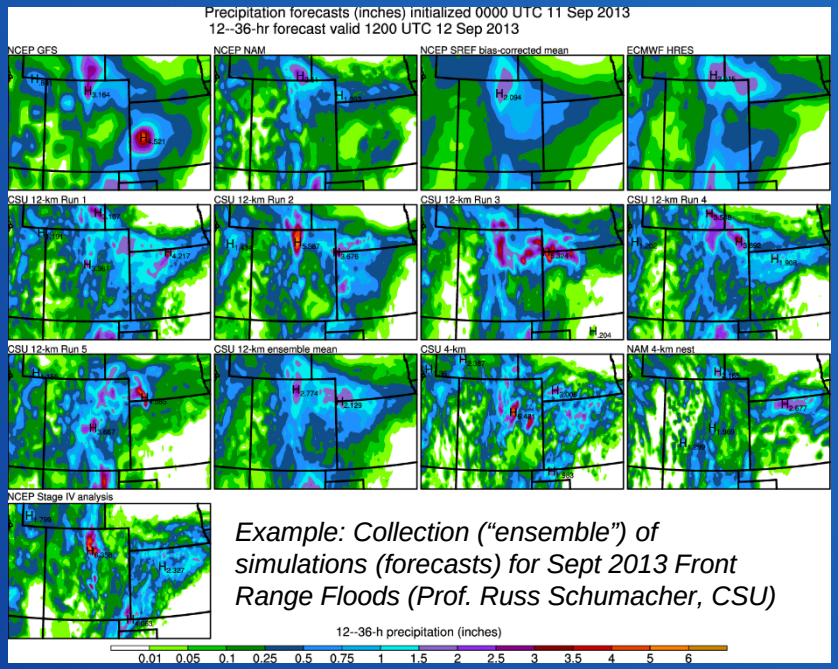
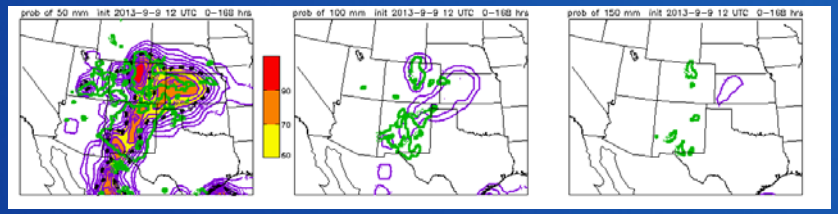
Addressed by: Ensemble-based Uncertainty Analysis

- Ensemble-based approach will allow a physically-based means of assessing a spectrum of possible event intensities for a historical event.
- Multiple permutations of a single event allows for quantification of uncertainty
- Multiple permutations of several events allows for a more representative quantitative estimate of heavy rainfall potential at the region/area/basin of interest.



Example: Collection ("ensemble") of simulations (forecasts) for Sept 2013 Front Range Floods (Prof. Russ Schumacher, CSU)



Example: Probabilistic information derived from ensemble of simulations for Sept 2013 Front Range Floods (Prof. Russ Schumacher, CSU)

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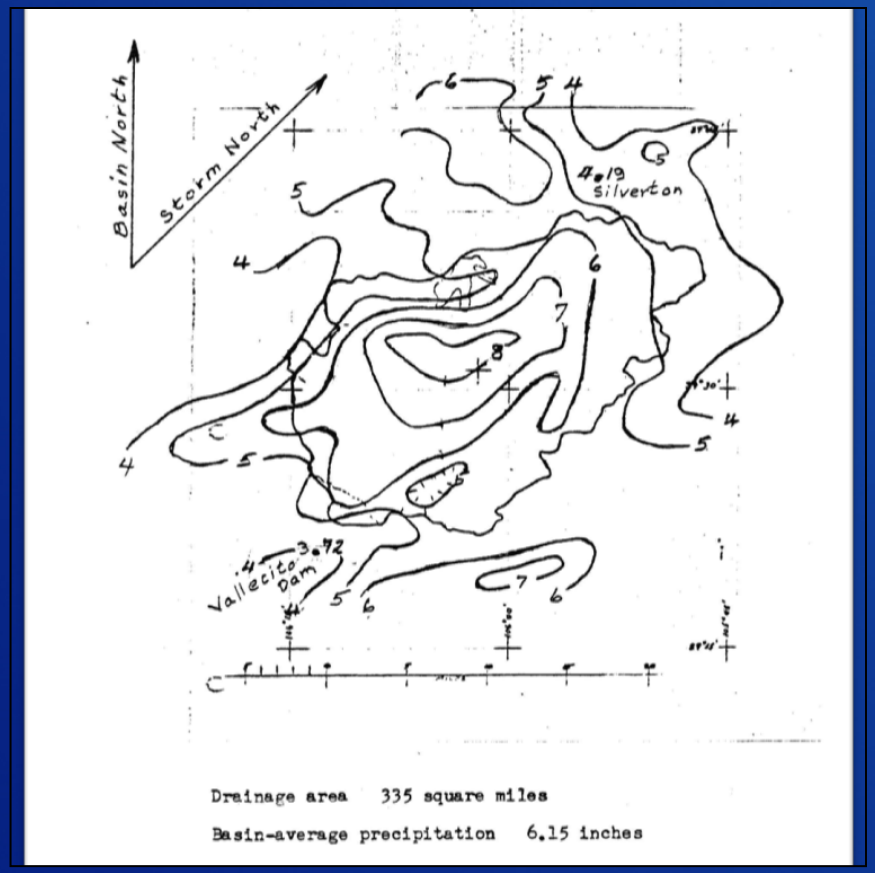
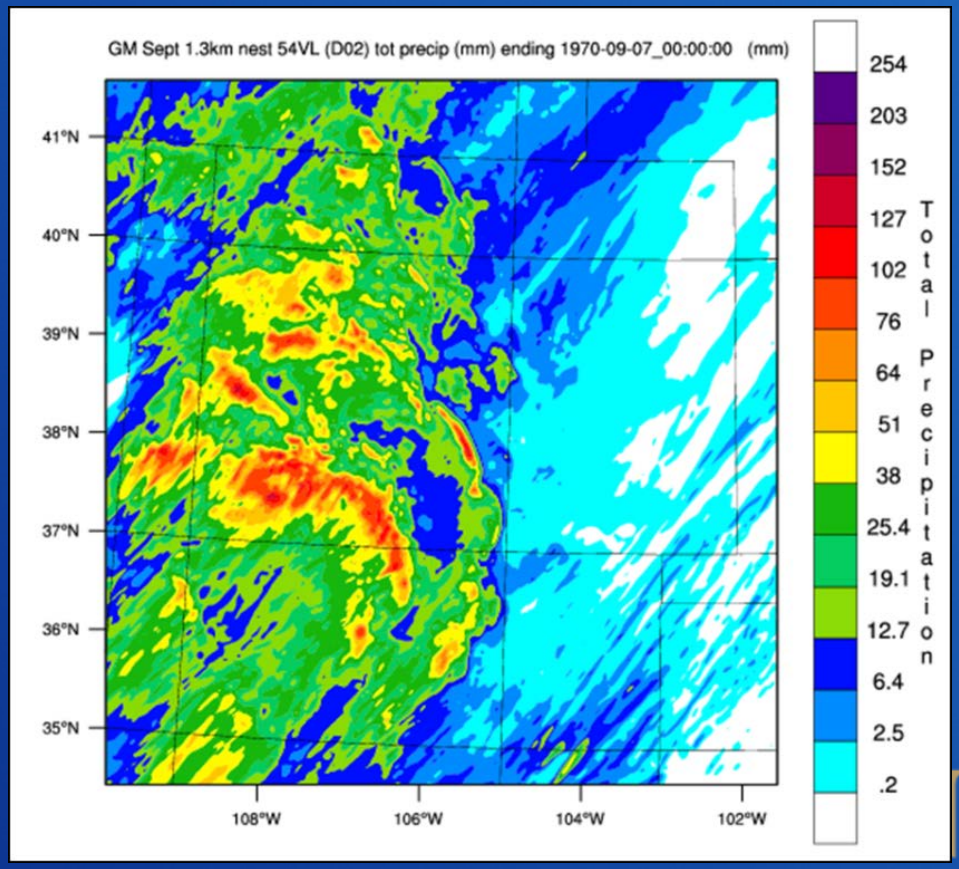
3. Past research using WRF has not been fully incorporated into FHCG operations

Application: Storm templates for input into hydrologic models, Moving towards gridded inputs

Manual precipitation analysis
4 – 6 Sept 1970



WRF Control
72-h total precipitation (mm)



Addressed by: Research-to-Operations

- Gridded model data will be supplied directly to FHCG partners, who will develop tools to be incorporated into current FHCG projects

- Faster and more efficient transfer of research products: Model simulations will be performed for the Taylor Park Dam facility in the Gunnison River Basin, CO (or a similar facility).

- Taylor Park Dam is part of the Uncompahgre Project in Colorado; FHCG has been tasked with completing a higher level hydrologic hazard study to re-estimate risks associated with flood overtopping.

- **Reclamation Complementary Efforts**
  - FY 2014: Coupling TREX with Stochastic Concepts and Modern Datasets (DSO Technology Development)
    - TREX is an event-based model that simulates flow overland flow, channel flow, and transport through river channels.
    - Fully distributed, can incorporate gridded inputs directly
    - Can be automated to run in a stochastic format
  - FY 2015: HHA using TREX with gridded inputs
    - Taylor Park Dam or similar

- The coincidence of the timing of this project and the timeline for expected research results will be ideal for fast and efficient transition of results and data to a current FHCG project.

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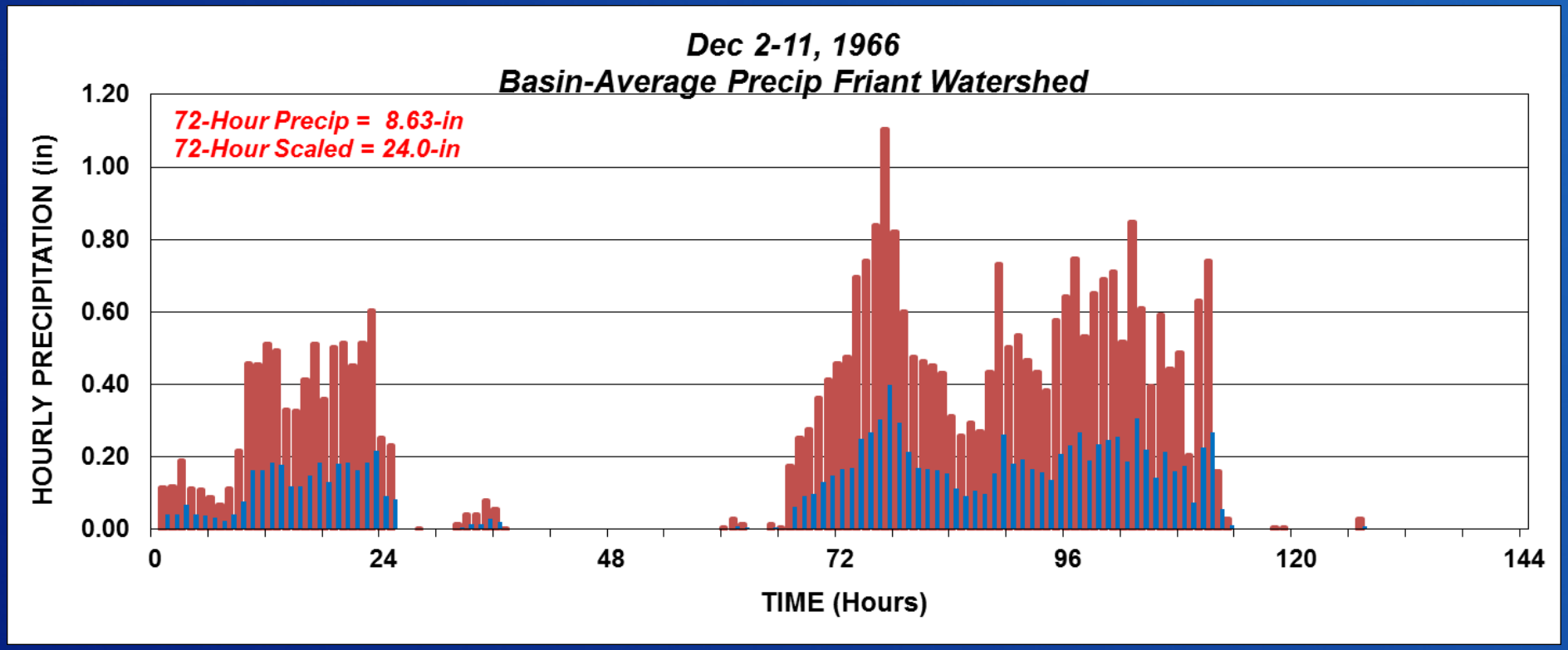
4. Dynamical model framework could address longer-term need to examine storm maximization and orographic enhancement

Application: Storm templates for input into hydrologic models,
Aid in extrapolation of storm events to several annual exceedance probabilities

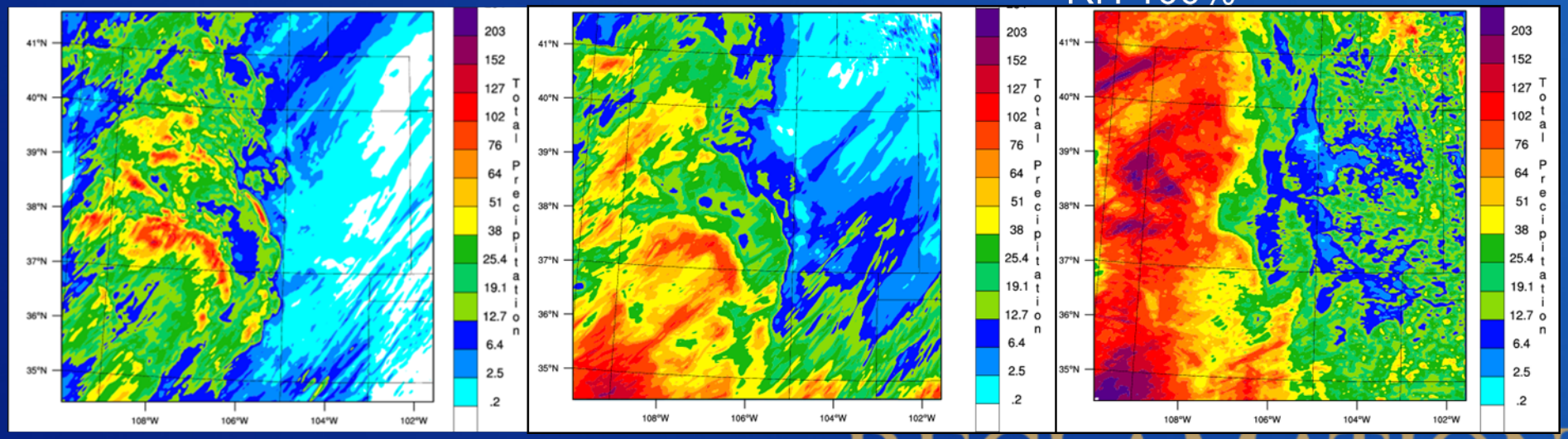


Addressed by: Exploration of Probable Maximum Precipitation Concepts

- Explore feasibility of model-based methods for FHCG implementation on a more permanent basis. Guide future FHCG decisions regarding which aspects of this type of work (e.g., running WRF and/or a hydrologic model) can ultimately be accomplished by FHCG in-house, and which may be still longer-term goals.
- Exploration of several methods of ensemble design and event selections will further inform Reclamation on what types of information and research methods may be most valuable in the process of updating and improving current extreme precipitation estimation methods.

Example: WRF-model-based moisture maximization (proof of concept)

Control | RH 1.5x | RH 100%



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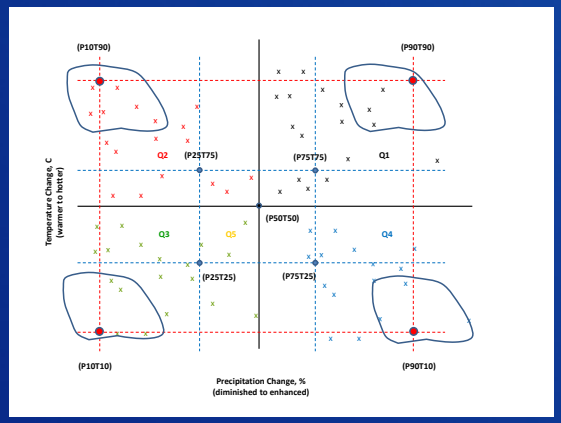
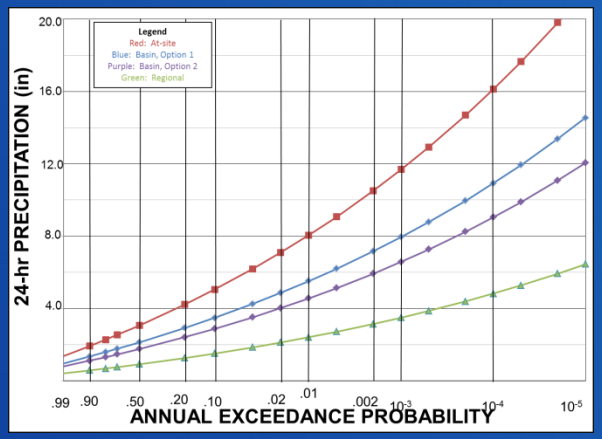
5. Selection and incorporation of climate change data into FHCG projects is largely unknown

Application: Adjust precipitation-frequency relationships and storm templates for potential future conditions

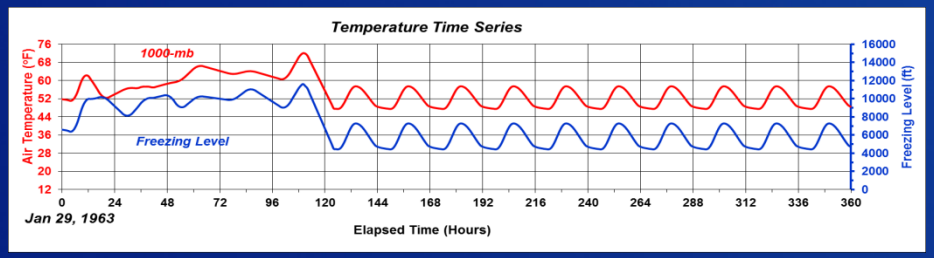
Scenarios developed from statistical downscaled methodologies



How does the precipitation-frequency relationship shift in future conditions?



Change in rain/snow freeze level?



Have not made use of dynamical models for climate change

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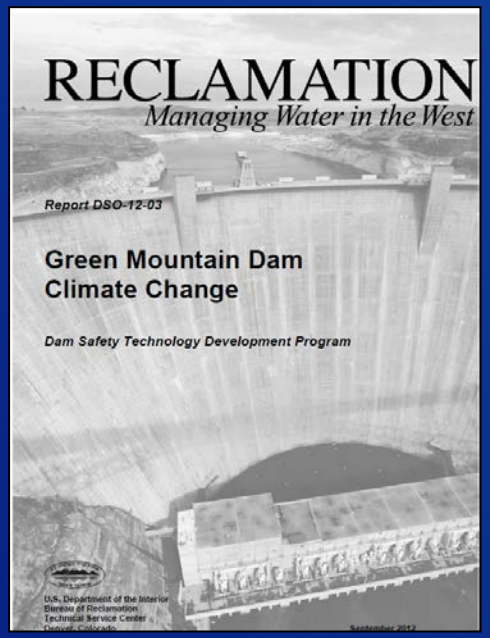
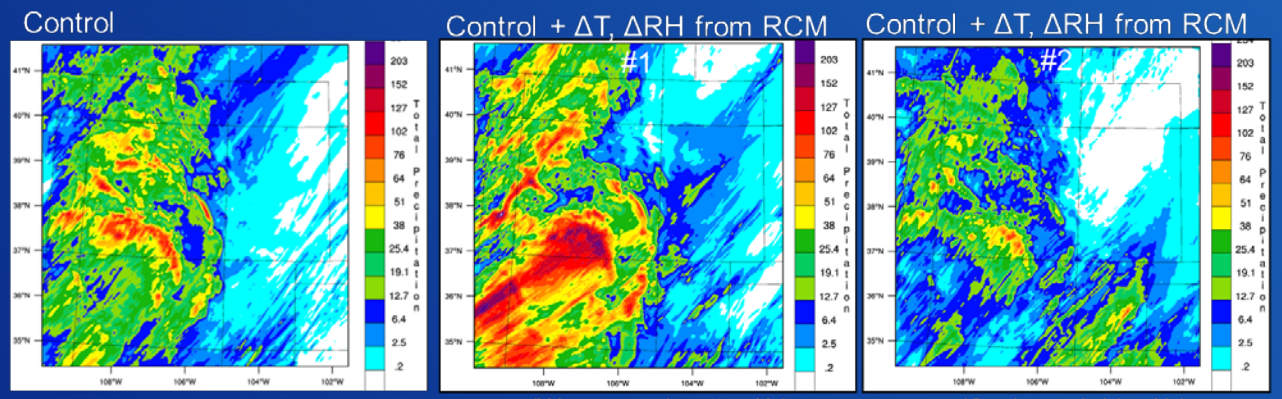
Addressed by: Climate Change Integration

- Past work already developed high-resolution dynamical downscaling capabilities for western US precipitation events, results have been described in Sankovich et al. (2012) Technical Report DSO-12-03 for Green Mountain Dam in Colorado.
- Previous work demonstrated several avenues for improvements to future studies, from improving upon both the downscaling methods themselves, to using newer and superior datasets.
- If climate change investigation is warranted at Taylor Park or any future Reclamation site of interest, such questions may be easily incorporated into the dynamical model framework proposed here.



Preliminary results:
Climate change perturbation (proof of concept)



72-h total precipitation (mm) *(Warmer and wetter Δ's)* *(Cooler and drier Δ's)*

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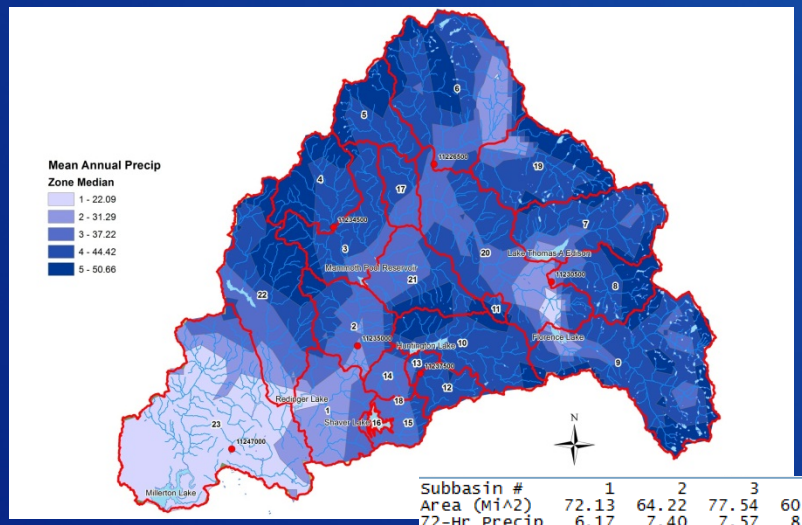
6. Gridded precipitation data for fixed events is not immediately implementable to Reclamation hydrologic modeling applications

Application: HHAs currently use semi-distributed hydrologic models



Subbasin #	1	2	3	4	5	6
Area (Mi^2)	72.13	64.22	77.54	60.79	51.21	164.87
72-Hr Precip	6.17	7.40	7.57	8.84	6.56	5.34
Hour	Dimensionless Mass Curves					
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
9	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Reclamation Complementary Effort

DSO Technology Development: Coupling TREX with Stochastic Concepts and Modern Datasets

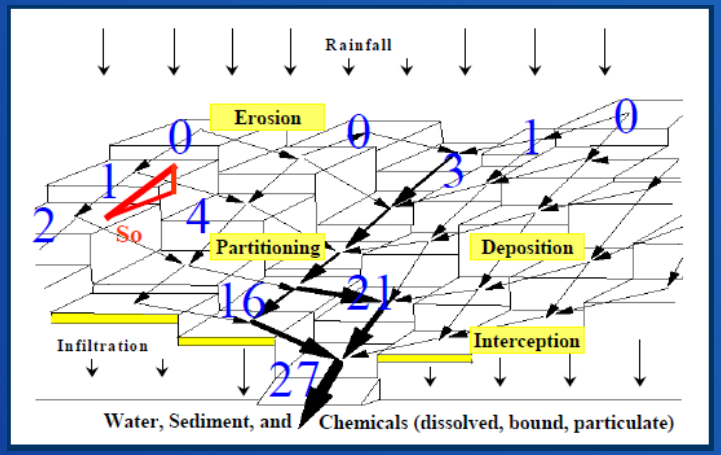


Figure courtesy of "TREX Setup and Operation"

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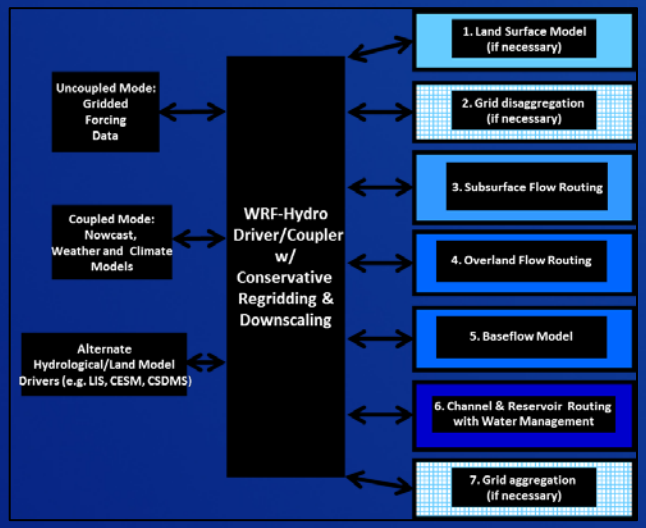
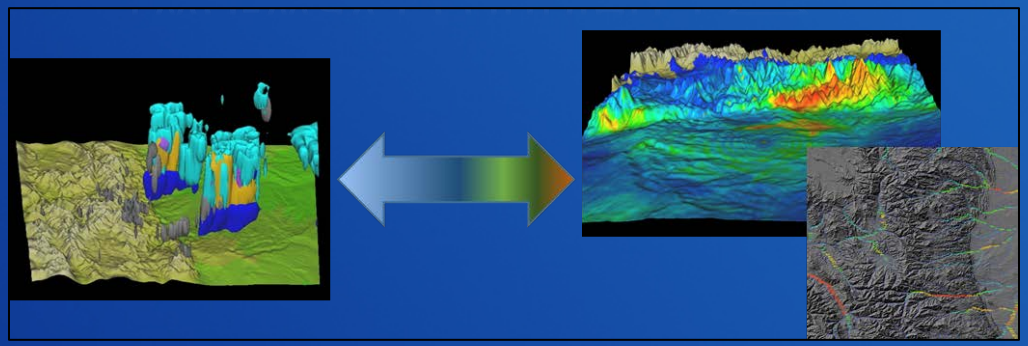
Addressed by: Coupling of Atmospheric and Hydrologic Models

- Dave Gochis (NCAR/RAL) to be funded as collaborator to explore utility of new WRF-Hydro capabilities for this project
- WRF-Hydro: A new, community-based model coupling framework designed to link multi-scale process models of the atmosphere and terrestrial hydrology
- Goals of this task:
  1. Produce model simulation output fields that may be more immediately useful to FHCG compared to precipitation amounts alone:

     e.g., spatially-distributed channel inflow amounts and rates, streamflow at specified points or at defined channel elements, overland flow, runoff, reservoir inflow rates and volumes, groundwater levels and inundation or "ponded water" depth
  2. Assess flood risk changes based on real or hypothetical changes in surface property characteristics given prescribed sets of atmospheric forcing conditions.



*WRF-Hydro: Flexible, community-based framework: works as both stand-alone hydrological modeling architecture **and** for fully-coupled hydrologic + atmospheric modeling systems.*

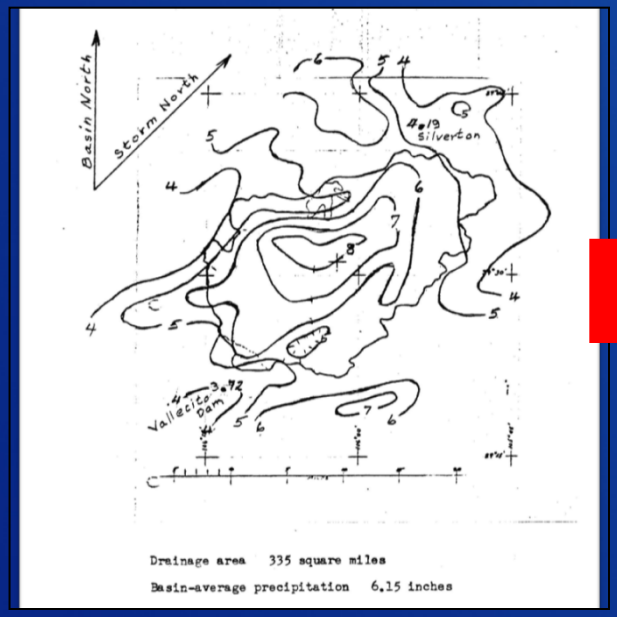


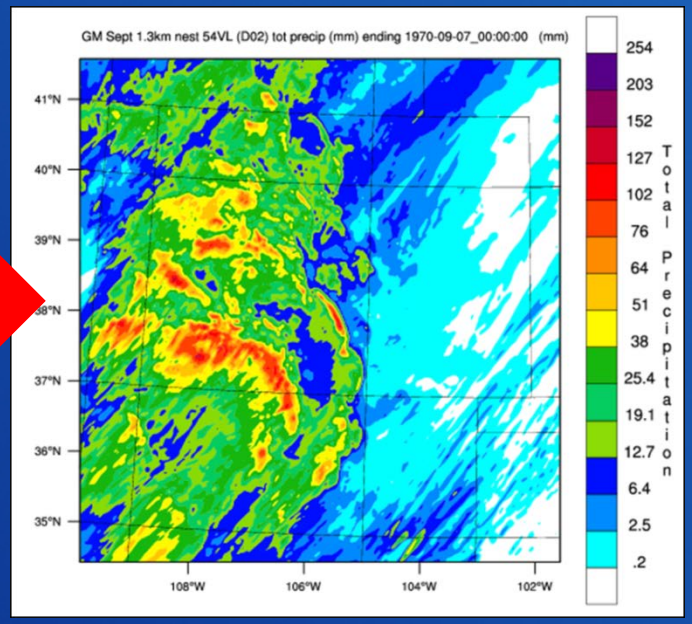
WRF-Hydro schematic of atmospheric and hydrologic coupling

RECLAMATION

7. Past dynamical model-based research results have not been directly implemented into a hydrologic hazard study due to lack of infrastructure for translation of research-grade products to operations

Application: HHAs currently use semi-distributed rainfall-runoff models, opportunity to incorporate state-of-the-science

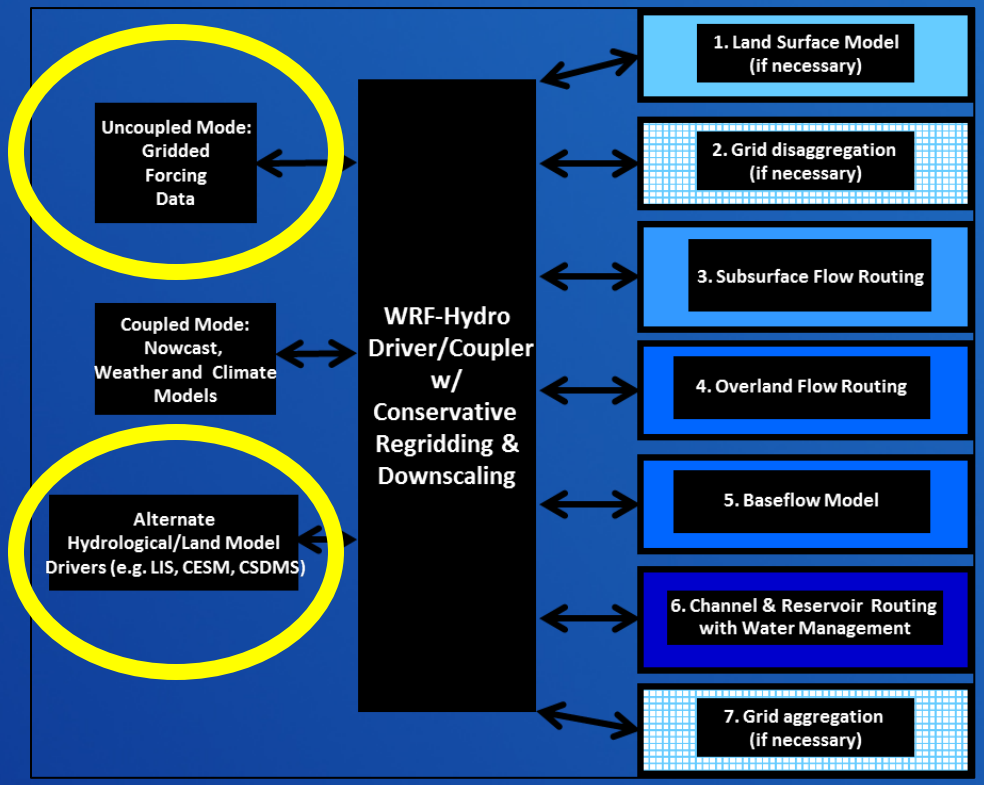




RECLAMATION

Addressed by: Sensitivity of WRF-Hydro to Input Datasets

- WRF-Hydro can be run either in a fully-coupled surface-atmosphere mode or in a 1-way mode where meteorological forcing data is prescribed.
- Many options for forcing datasets (e.g., precipitation from WRF atmospheric model, radar, satellite and networks of gauge data)
- Hydrological responses from different forcing inputs can be compared against current Reclamation hydrologic model tools and outputs.



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RECLAMATION

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Summary

1. Is a high-resolution, model ensemble-based framework able to more realistically diagnose small-scale physical processes that generate extreme precipitation under various atmospheric conditions?
2. How might an ensemble approach aid us in understanding the envelop of uncertainty upon adjusting past storms for climate change signals?
3. What are the advantages of fully coupled atmosphere-hydrology modeling to characterize extreme hydrometeorological events in dam safety decision-making?

Key Lessons Learned

- Research and operations are completed on very different time-scales.
- Implementing new research into operations is not a trivial task.

First Steps/Future Work

FY 14 Goals:

CIRES efforts:

1. Establish ensemble simulation framework using 2013 Front Range Flood or Taylor Park Event
2. Set up WRF-Hydro domain for Taylor Park, begin testing, calibration efforts

Reclamation efforts:

DSO Technology Development: Coupling TREX with Stochastic Concepts and Modern Datasets

RECLAMATION