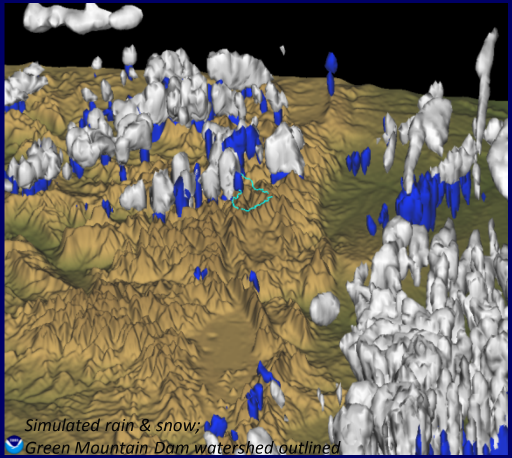
High-resolution numerical modeling as a tool to assess extreme precipitation events



Kelly Mahoney, Jason Caldwell,
Victoria Sankovich

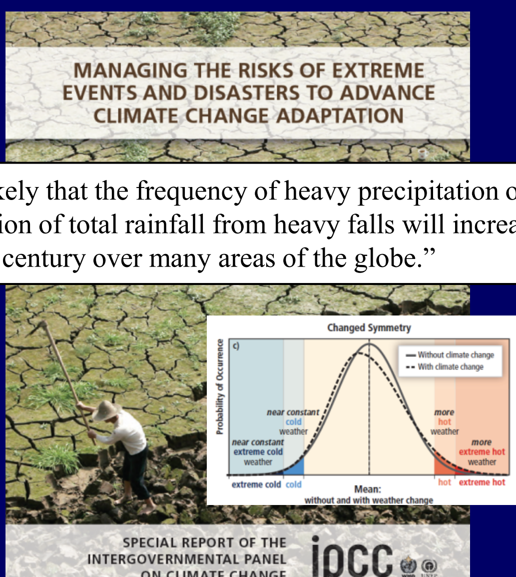
Workshop on Probabilistic Flood Hazard Assessment

Panel 3: Extreme Precipitation Events

29 Jan 2013

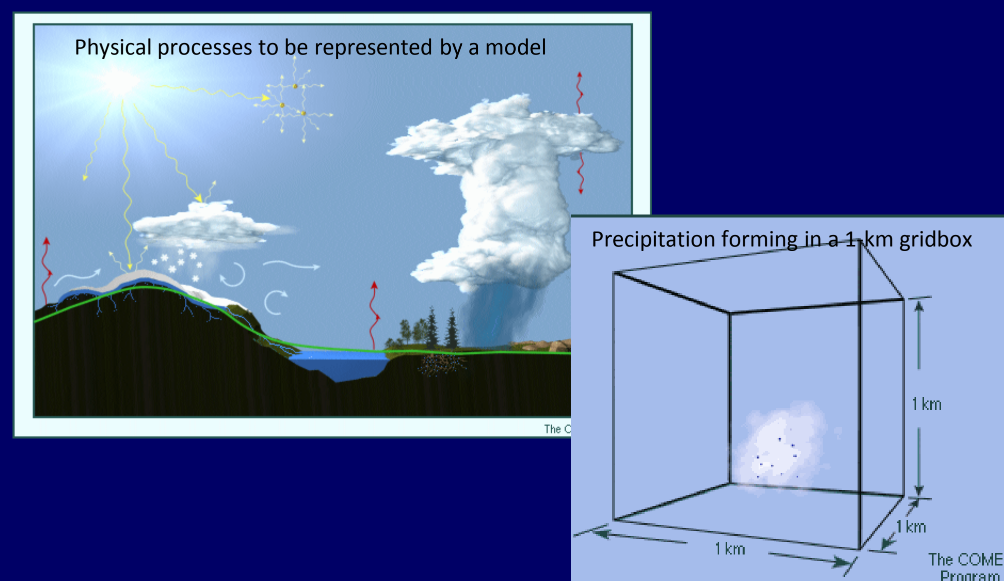
Motivation: Why downscale extreme precipitation?

- Extreme precipitation events generally predicted to increase with warming climate: Why, when, where, and by how much?
- Global climate models not suited for simulation of extreme precipitation (resolution, parameterizations)
- Regional climate models often still too coarse, use CP schemes
- Projections, predictions most valuable at local, “weather” scales to users (public, planners)



“It is likely that the frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase in the 21st century over many areas of the globe.”

IPCC (2012)

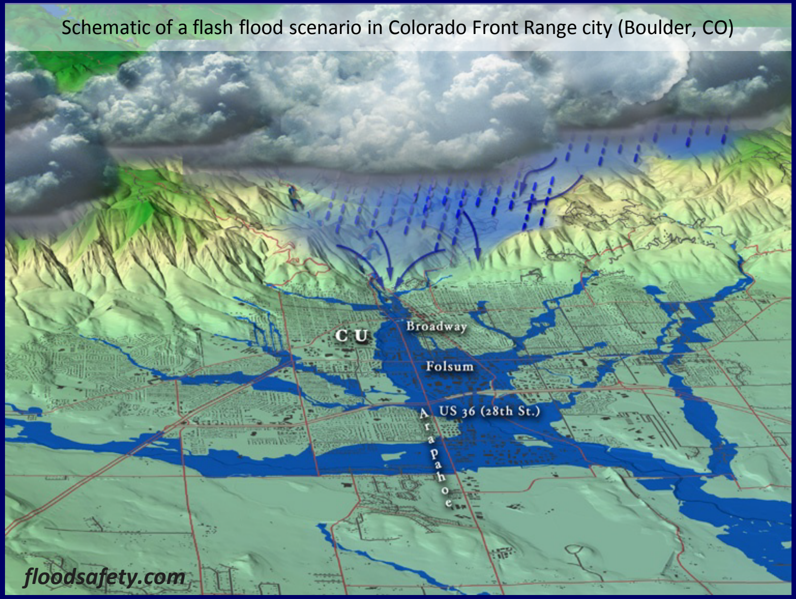


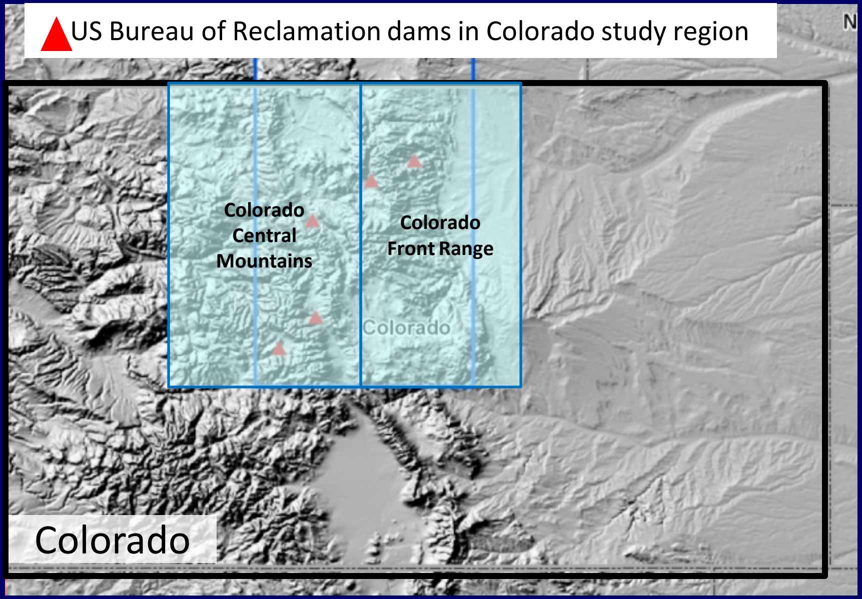
Research objectives

Address decision-making needs by exploring utility of high-resolution, event-based modeling:

1. Are current heavy/extreme precipitation estimates physically realistic (i.e., are they consistent with values produced by numerical models?)
2. Will heavy/extreme precipitation thresholds change in future due to climate change? Should current water resource management practices (e.g., dam safety, design, maintenance) be modified to account for potential effects of climate-change driven non-stationarity?

Focus is on warm-season events in Colorado Front Range & Central Mountains



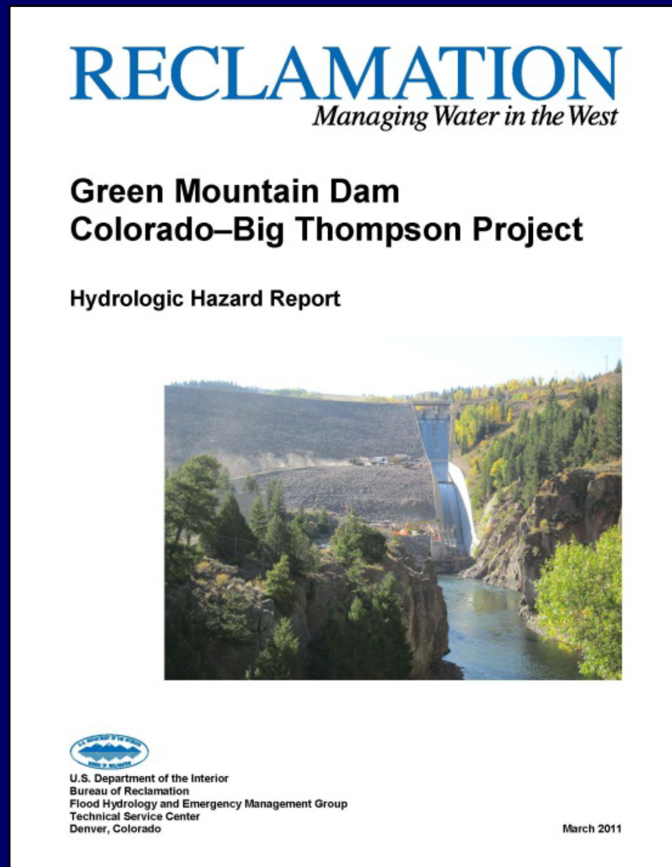


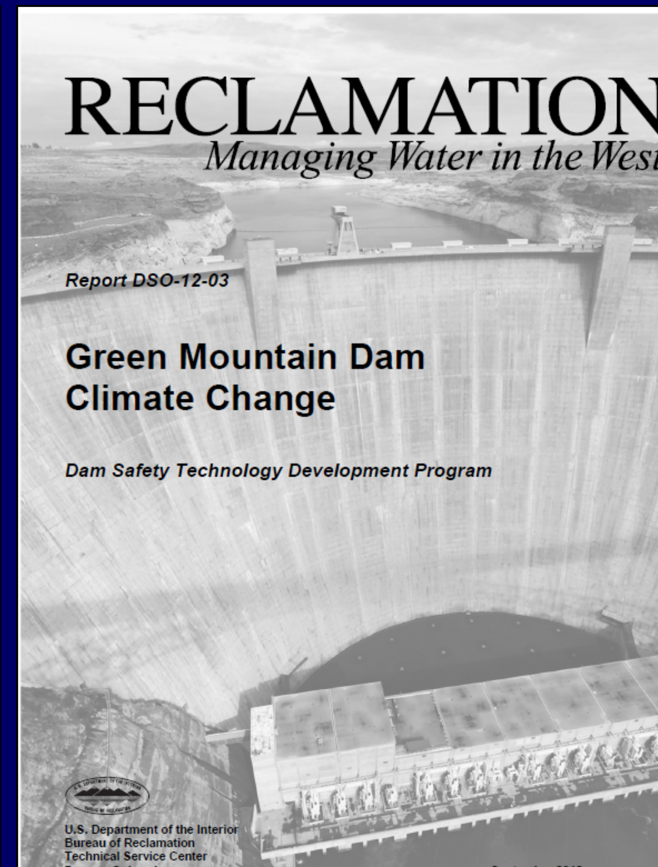
Can we use knowledge of past events and high resolution numerical model simulations to better estimate (current and future) PMP?

Example/Proof of concept study:

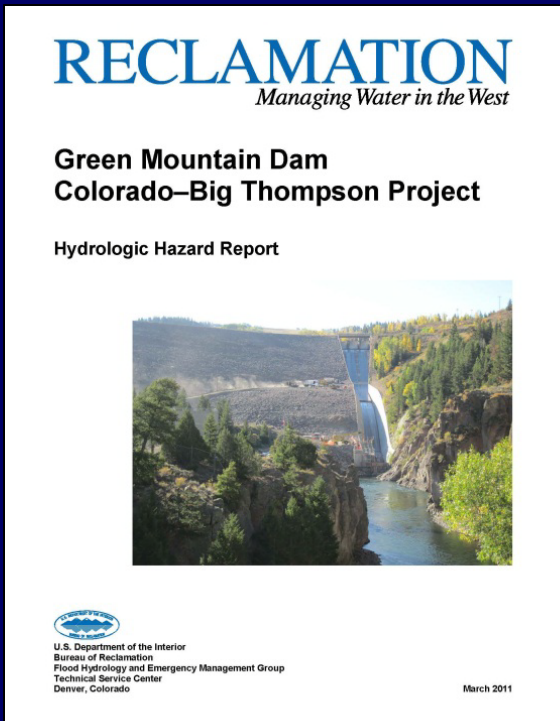
Green Mountain Dam, CO

Bureau of Reclamation Dam Safety Assessment





Water resources management and stakeholder needs: Dam safety considerations

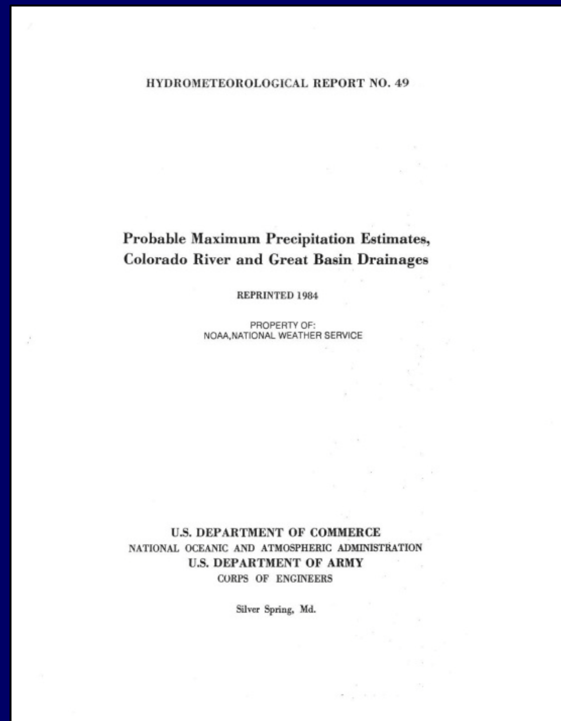

RECLAMATION
Managing Water in the West

Green Mountain Dam
Colorado–Big Thompson Project

Hydrologic Hazard Report

U.S. Department of the Interior
Bureau of Reclamation
Flood Hydrology and Emergency Management Group
Technical Service Center
Denver, Colorado

March 2011


HYDROMETEOROLOGICAL REPORT NO. 49

Probable Maximum Precipitation Estimates,
Colorado River and Great Basin Drainages

REPRINTED 1984

PROPERTY OF:
NOAA,NATIONAL WEATHER SERVICE

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF ARMY
CORPS OF ENGINEERS

Silver Spring, Md.

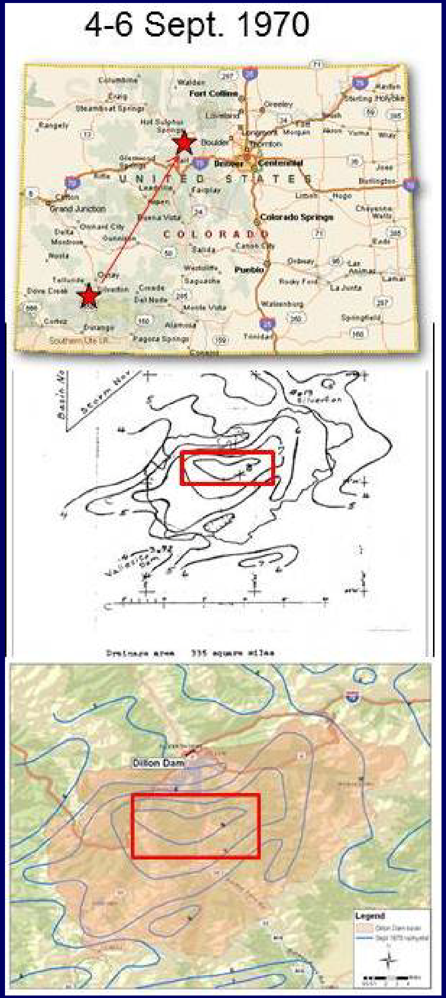
HMR 49 PMP Estimates for Green Mountain Dam	
18.58 inches	72 hours

Not seen in paleo record….is it too high?

- HMR 49 specifies probable maximum precipitation (PMP) estimates; used as (theoretical) upper limit of possible precipitation for a given location: dam safety
- Old storms used in PMP
- PMP often questionable validity in highly orographic areas
- Two main questions:
  1. Are current PMP estimates physically realistic?
  2. In potentially warmer and wetter future climates, can maximum precipitation OR precipitation frequency curves change significantly enough to alter current practices?

Probable Maximum Precipitation and Flood Frequency

- Used in dam safety assessments for:
  - Upper limit for precipitation estimates for the design and assessment of critical infrastructure (PMP)
- PMP (Probable Maximum Precipitation) involves:
  - Depth-Area-Duration Analysis
  - Storm maximization (typically moisture)
  - Storm transposition
  - Envelopment
- Can these methods be improved using a dynamical numerical model?
  - Capitalize on high spatial/temporal resolution
  - Adjust moisture/assess storm maximization concepts
  - Transpose storms (or atmospheric conditions) to new locations
  - Assess impact of climate change on future storms



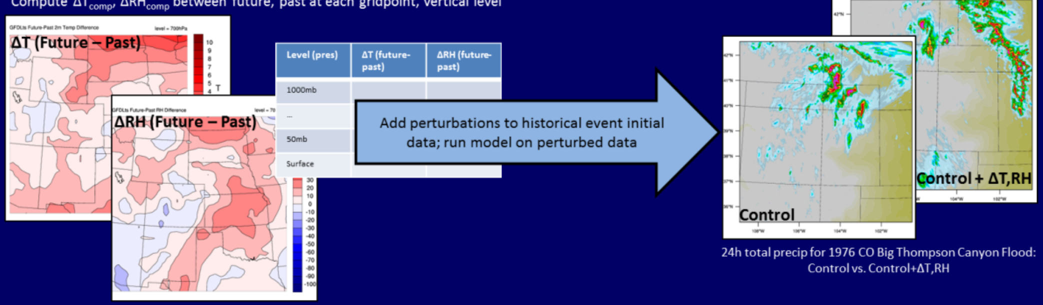
Methods: Green Mountain Dam

1. Select relevant cases from existing reports, observed record
2. Execute high-resolution control simulations
3. Perturb event to reflect potential thermodynamic perturbations indicated by climate change projections and/or to “moisture maximization”
4. Compare historical, future and control, maximized high-resolution simulations: How do amounts compare to existing PMP estimates?

Climate change experiments

Using RCM (NARCCAP) Extreme event (top 10 event) composites:

Compute ΔT_{comp}, ΔRH_{comp} between future, past at each gridpoint, vertical level



24h total precip for 1976 CO Big Thompson Canyon Flood: Control vs. Control+ΔT,RH

Moisture maximization:

Start with original initial conditions, then alter moisture fields, e.g.,

1. Increase RH by 50% (RH1.5x);
2. Set RH = 100% at initial and boundary times (RH100)

Similar event-based methods: Lackmann (2013), Ohara et al. (2011)

Can we use knowledge of past events + high resolution numerical model simulations to better estimate (current and future) PMP?

Historical precedent: Design Storm Study for Dillon Dam (Bertle, 1982)

Dillon Dam located 25 miles upstream of Green Mountain Dam

Storms of record used in Dillon Dam study:

Date	Center
1-3 June 1943	Glenwood Springs, CO
17-18 May 1944	East of Steamboat Springs, CO
7-8 June 1964	Spillover from Glacier Park, MT
5-7 Oct. 1970	Northeast of Steamboat Spring, CO
4-6 Oct. 1911	Gladstone, CO
1 Aug. 1968	Blanding-Monticello, UT
4-6 Sept. 1970	Bug Point, UT
4-6 Sept. 1970	South of Silverton, CO
3 Aug. 1924	Mesa Verde National Park, CO
27 July 1937	Leadville, CO
16 Aug. 1968	Morgan, UT

From Dillon Dam design storm study:
"None of the storms analyzed support the severity of the HMR 49 curve"

Estimates for Dillon Dam	
7.97 inches	48 hours

Can we use knowledge of past events + high resolution numerical model simulations to better estimate (current and future) PMP?

Date	Center
1-3 June 1943	Glenwood Springs, CO
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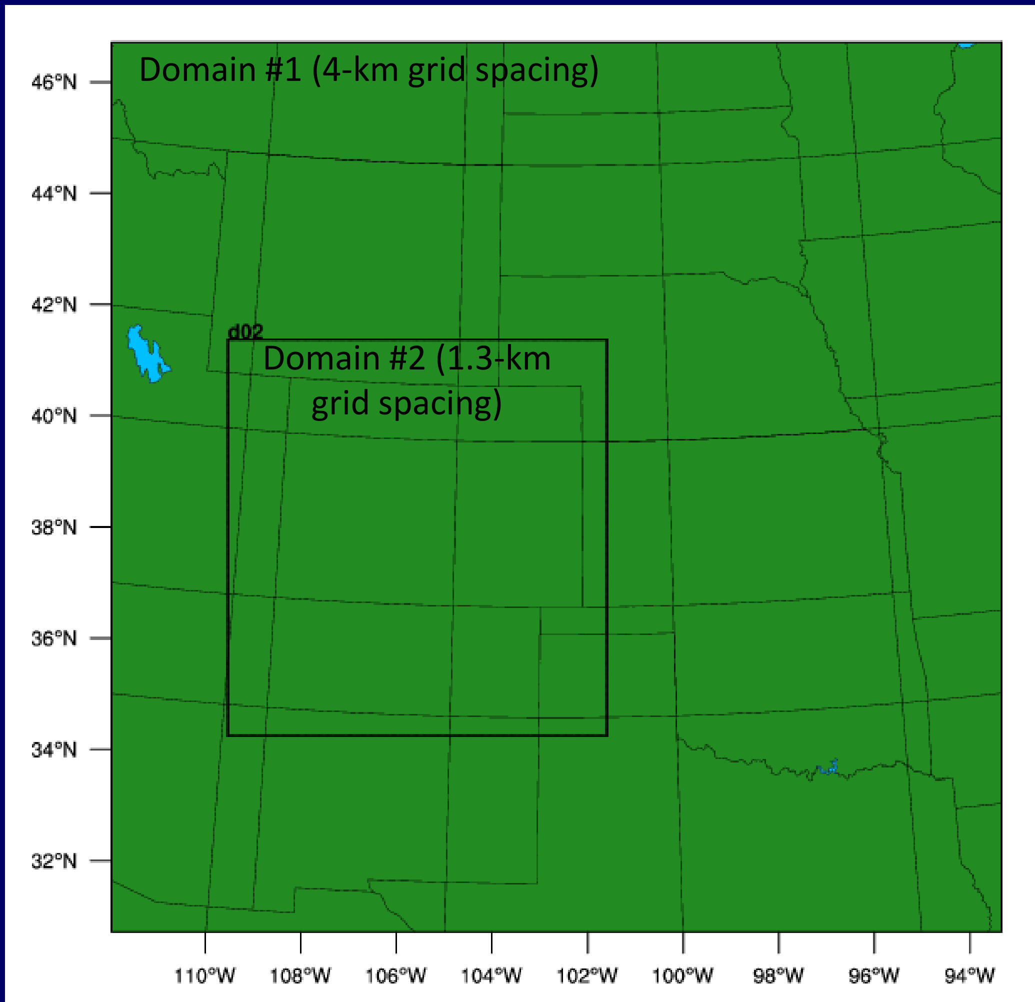
16 Aug. 1968	Morgan, UT

- Case selection based on existing reports, historical assessments not always optimal…
- First cut: 4 – 6 Sept 1970:

  8 inch/3day maximum in southwest CO*
- (Storm totals were transposed from SW CO to Green Mountain Dam for study; we will model/ study storm in-situ)

** Based on bucket surveys, hand-drawn maps*

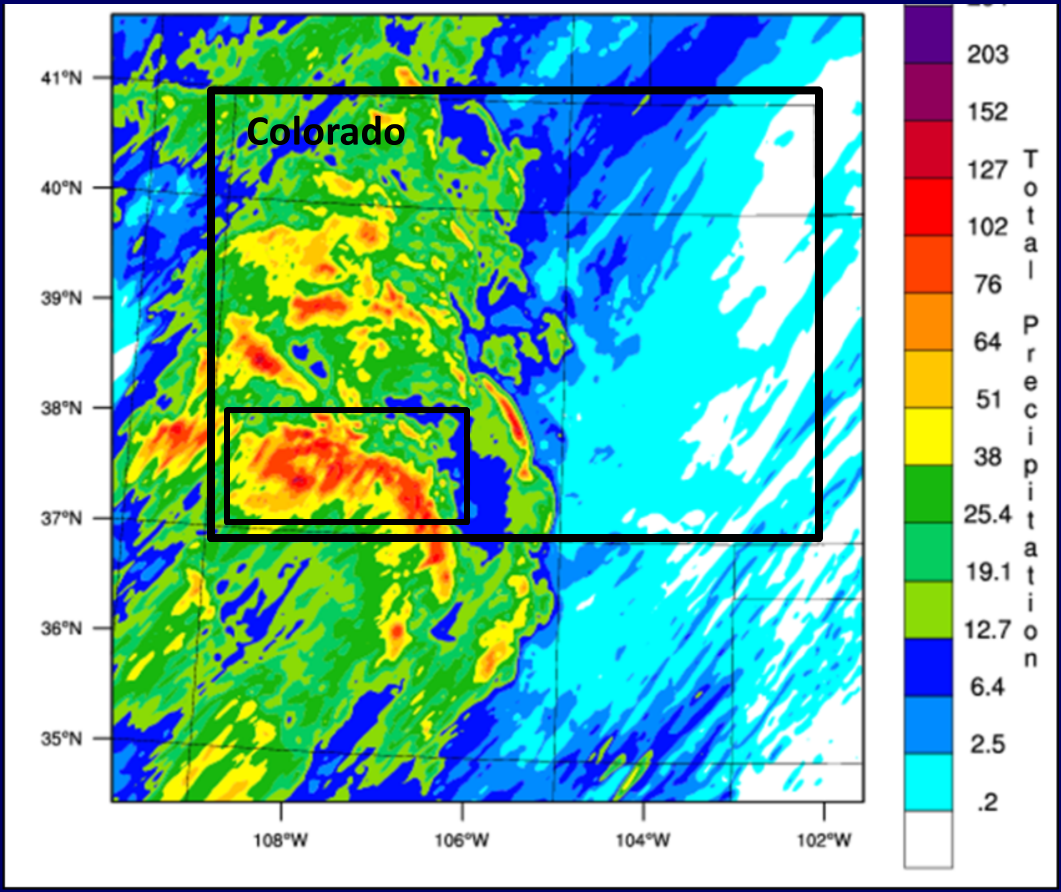
Weather Research & Forecasting (WRF) model set-up



Model Version	WRF (ARW) Version 3.3.1
Duration	72 hours; output frequency: 1-hour
Grid	1.3-km grid spacing (within a 4-km outer nest)
	574 x 601 gridpoint domain (outer domain 450 x 450)
	54 vertical levels
Physics	Explicit convection (no cumulus parameterization)
	Thompson microphysics
	YSU planetary boundary layer (PBL) scheme
	NOAH land-surface model, Monin-Obukhov surface layer physics
	Dudhia, RRTM radiation physics
Initial Conditions	NCEP/NCAR Reanalysis Project (NNRP) dataset (Kalnay et al., 1996)

- Control simulations
- Moisture maximization
- Climate change perturbation

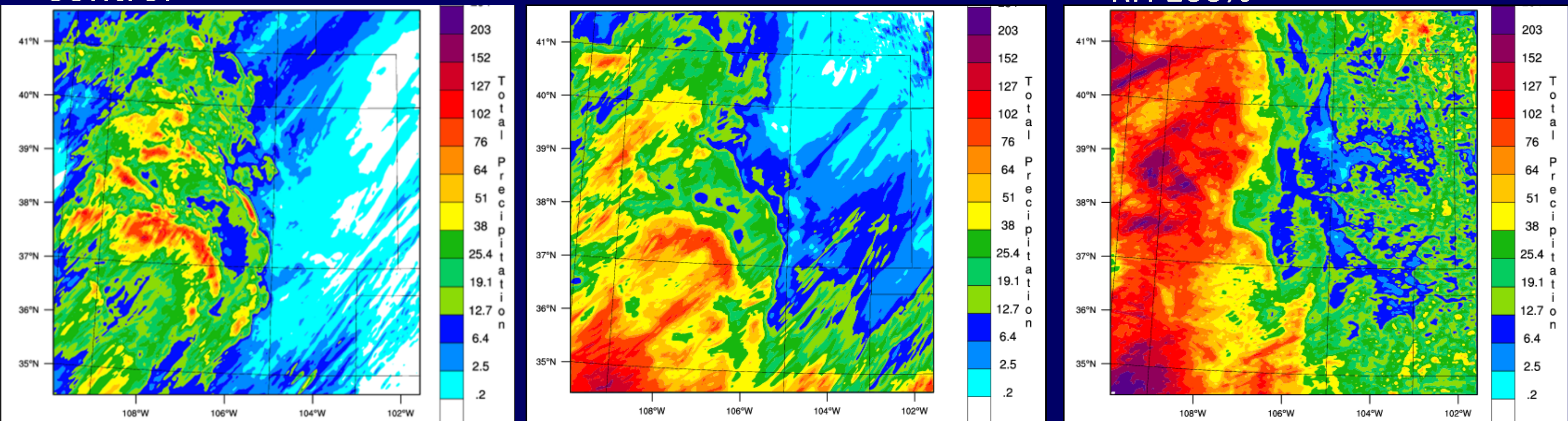
Green Mountain Dam:
Control Simulation for 4 – 6 Sept 1970 event



- Control simulation produced precipitation maximum of 6+ inches in approximate region where 8-inch maximum was reported
- Considerable uncertainty in observed amounts

Preliminary results:
Moisture maximization (proof of concept)

Control | RH 1.5x | RH 100%



72-h total precipitation (mm)

Moisture maximization:

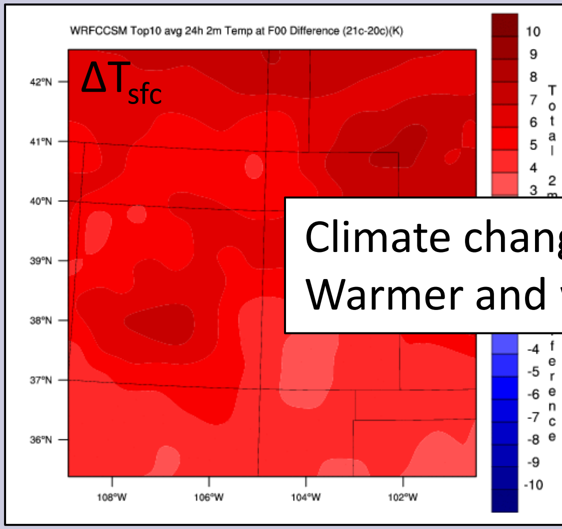
- Qualitative results unsurprising…More moisture → larger rainfall totals
- Quantitative, percentage differences, spatial distribution of changes of interest
- If method is deemed worth pursuing, will require an ensemble of cases, storm types, and moisture perturbation methods to make results robust

Preliminary results:
Climate change perturbation (proof of concept)

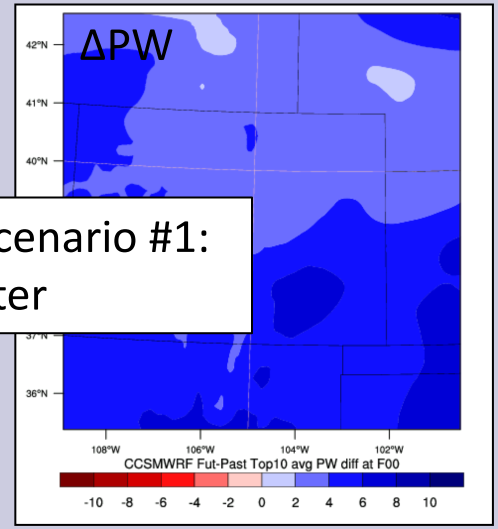
ΔT_{sfc}(fut-past) from RCM #1 (WRF+CCSM)

Red = warming

Climate change from model #1



Climate change scenario #1:
Warmer and wetter



ΔPW(fut-past) from CW-model

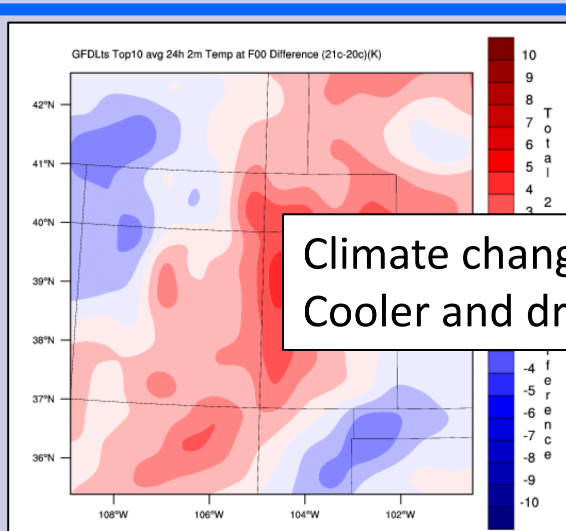
PW: precipitable water

Blue = moistening

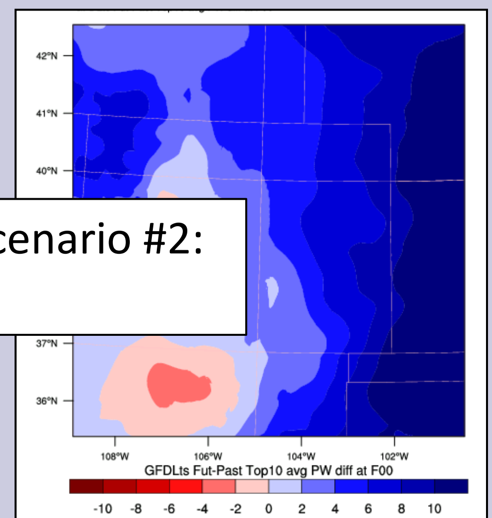
ΔT_{sfc}(fut-past) from RCM#2 (GFDL-ts)

Red = warming
Blue = cooling

Climate change from model #2



Climate change scenario #2:
Cooler and drier

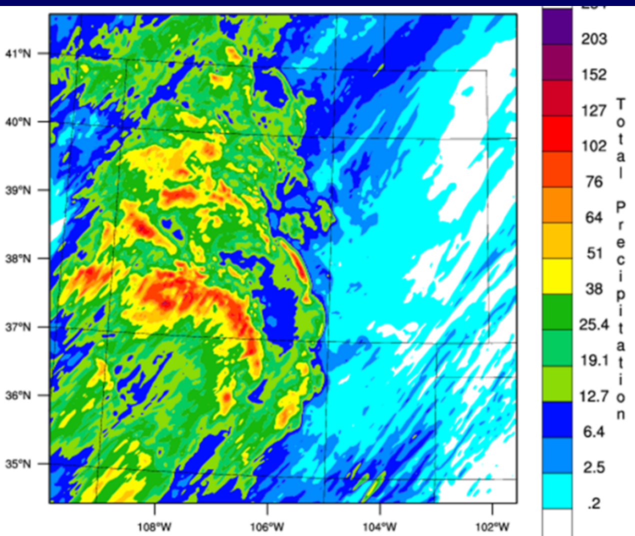


ΔPW(fut-past) from GT-model

Red = drying
Blue = moistening

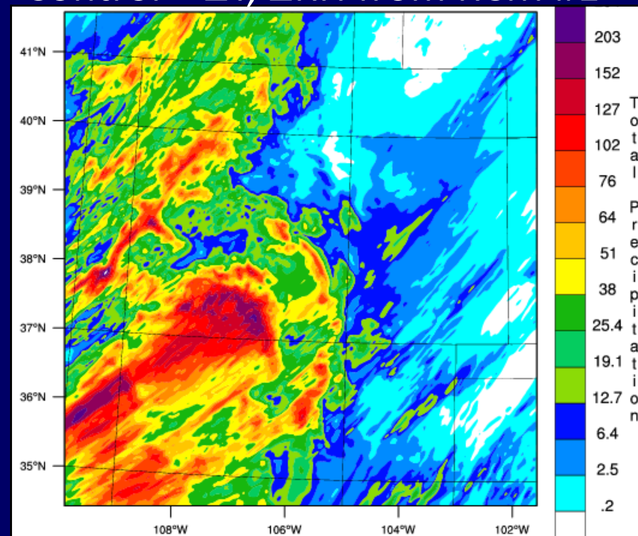
Preliminary results:
Climate change perturbation (proof of concept)

Control



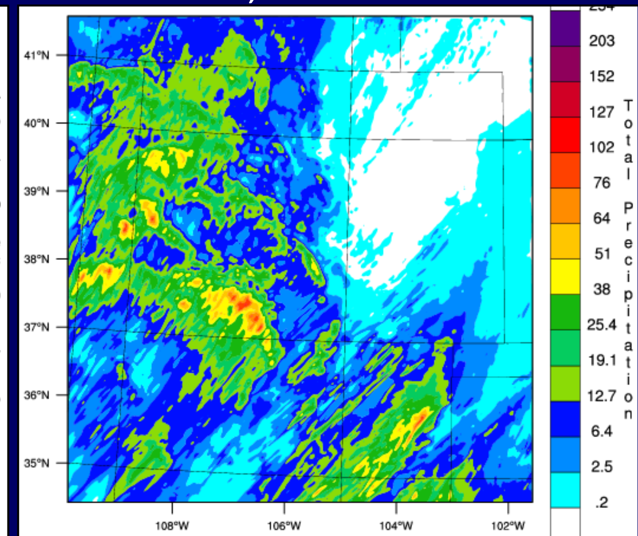
72-h total precipitation (mm)

Control + ΔT, ΔRH from RCM #1



(Warmer and wetter Δ's)

Control + ΔT, ΔRH from RCM #2

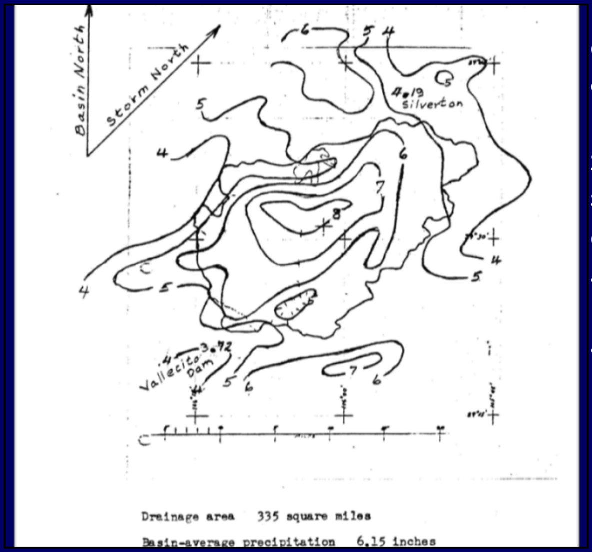


(Cooler and drier Δ's)

- Qualitative results again unsurprising:
  - Warmer, wetter Δ's → larger rainfall totals
  - Cooler, drier Δ's → smaller rainfall totals
- Percentage differences, spatial distribution of changes of greater interest: are event totals (historical and "future") close to or greater than existing PMP estimates?
- If method deemed worth pursuing, will require an ensemble of cases, storm types, and climate change signals (Δ's) to make results robust

Summary and next steps

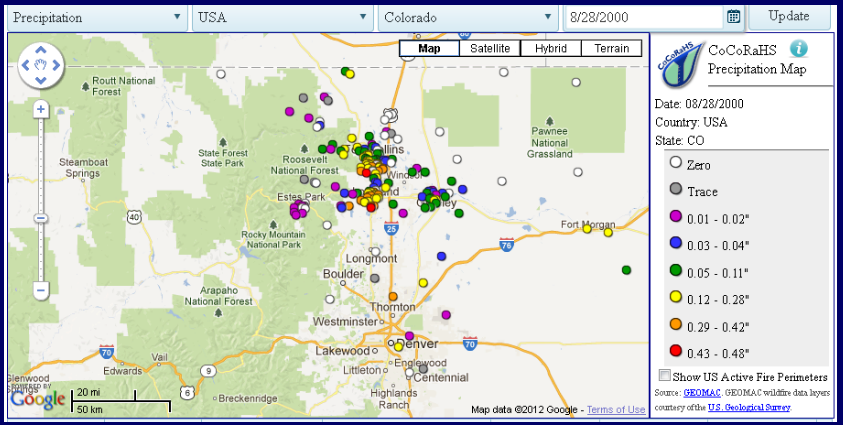
1. Utility demonstrated in improved spatial, temporal information of observed cases; potential for testing moisture maximization and climate change hypotheses.
2. What are “representative” climate change signals for extreme precipitation in this region?
   - Simulate additional event types, using additional climate change signatures/deltas, moisture perturbation methods
   - Use more recent cases (NARR, GDCN, CoCoRaHS): improved event selection, model validation
3. Expand perturbations to be dynamical; incorporate effects of potential storm track shifts.
4. Connect results to surface hydrology and specific metrics used in previous USBR reports such as basin-average precipitation totals, temporal distribution over 24-, 48-, and 72-h intervals, and specific fields (e.g., surface dewpoint) used in PMPs
5. How many future scenarios, event types required for study to be representative “enough”? Explore feasibility of an larger ensemble-based approach.



Challenge of old cases/analyses:

Isohyetal pattern of September 1970 storm

Only observations available; unknown how storm was analyzed



Example of more contemporary case/observations: 28 July 2000; CoCoRaHS

Acknowledgments

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