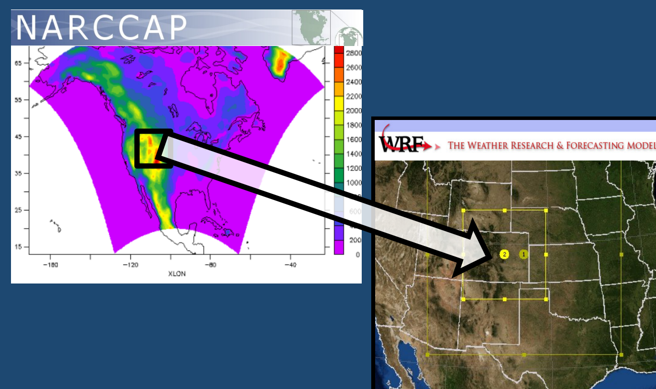
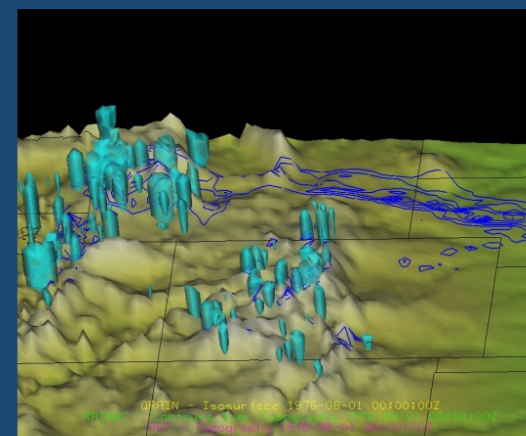
Dynamical downscaling of NARCCAP using WRF:

High-resolution simulations of extreme precipitation events in three NARCCAP climate experiments





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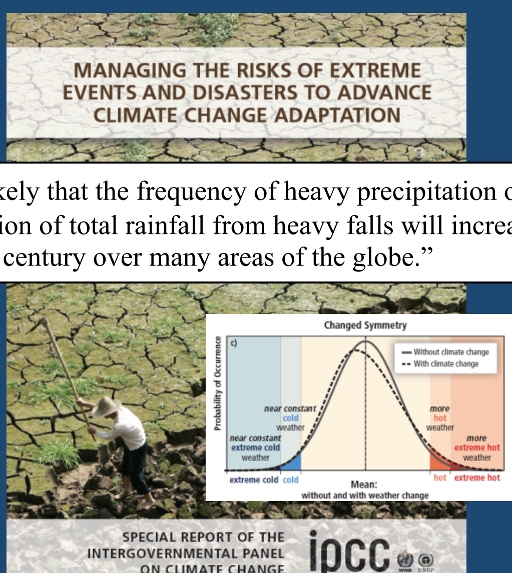
NARCCAP User's Workshop
April 11 2012

CIRES Cooperative Institute for Research in Environmental Sciences · NOAA · U.S. Department of the Interior Bureau of Reclamation

Western Water Assessment
VSP UCAR Visiting Scientist Programs · Postdocs Applying Climate Expertise Fellowship Program

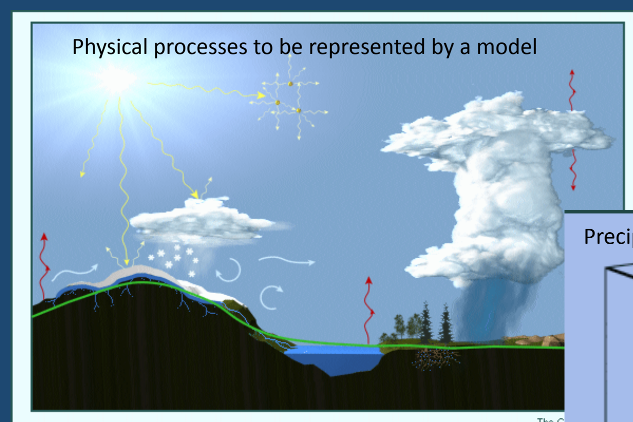
Motivation: Why downscale extreme precipitation?

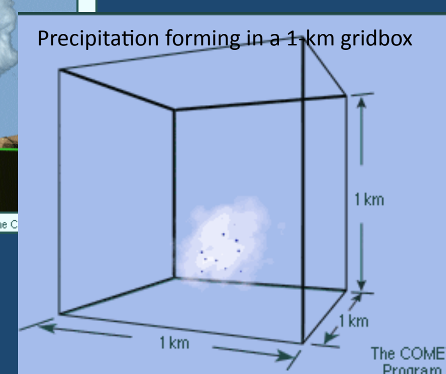
- Extreme precipitation events generally predicted to increase with warming climate…but why, when, where, and by how much?
- Global climate models not suited for simulation of extreme precipitation (resolution, parameterizations)
- Regional climate models often still too coarse, use CP schemes
- Projections, predictions most valuable at local, "weather" scales to users (public, planners) (especially in mountainous, complex terrain)



"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

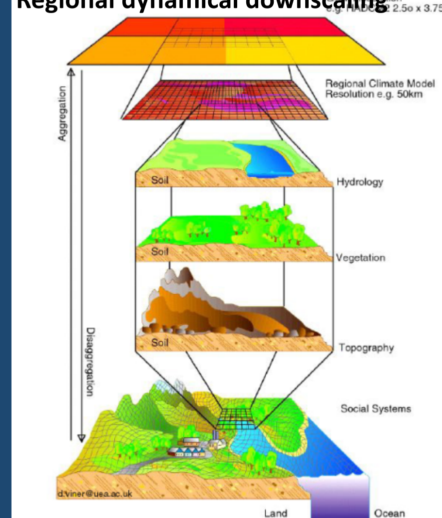
Use high-resolution dynamical downscaling to address:

1. Do elevation thresholds for storms, flooding, hail change in future scenarios?
2. Which *storm-scale physical processes* are most affected by changes in large-scale climate? (e.g., updraft strength, precipitation efficiency, entrainment?)
3. *What are the strengths, limitations of various dynamical downscaling approaches?*
    a. What is the "best" way to downscale climate extremes?
    b. Space, time scales required? Statistical significance of limited case sample size?
    c. Research- and decision-making communities:
    Improved understanding of strengths, limitations of downscaling approaches → inform selection of most appropriate approach to specific problem

Water Street (now Canyon Blvd.) in Boulder, CO during 1894 flood

Denver Public Library

Regional dynamical downscaling



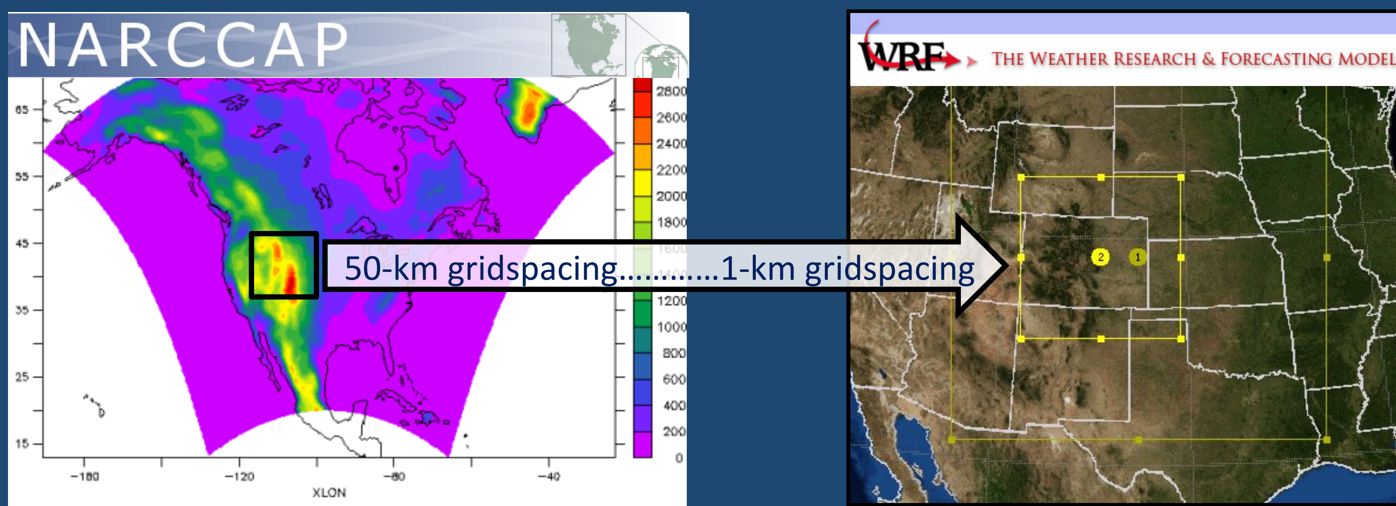
Canadian Climate Change Scenarios Network

Outline

1. Methodology
    a) 3 different approaches: Overview
    b) 1 approach; 3 different NARCCAP models
2. Results
    a) The “Good”
    b) The “Bad”
    c) The Confusing
3. Challenges & What’s next?

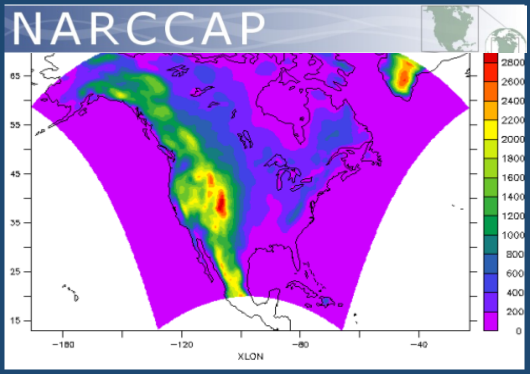
Methodology: Overview

1. Select extreme cases from regional climate model data
2. Create initial conditions for WRF simulations
3. Execute high-resolution simulations
4. Compare past, future high-resolution simulations

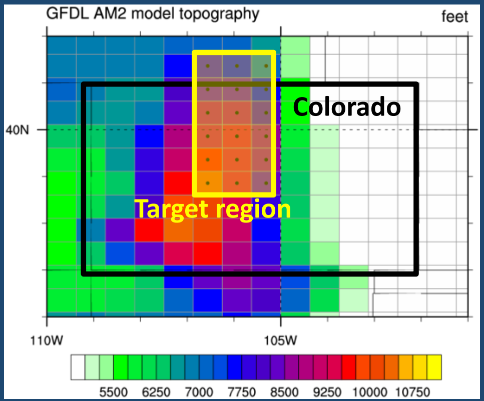


Methodology

- NARCCAP: North American Regional Climate Change Assessment Program
  - Initial, boundary conditions from 20th, 21st century AOGCM experiments
  - GFDL-timeslice, CCSM-WRF, CGCM3-RCM3

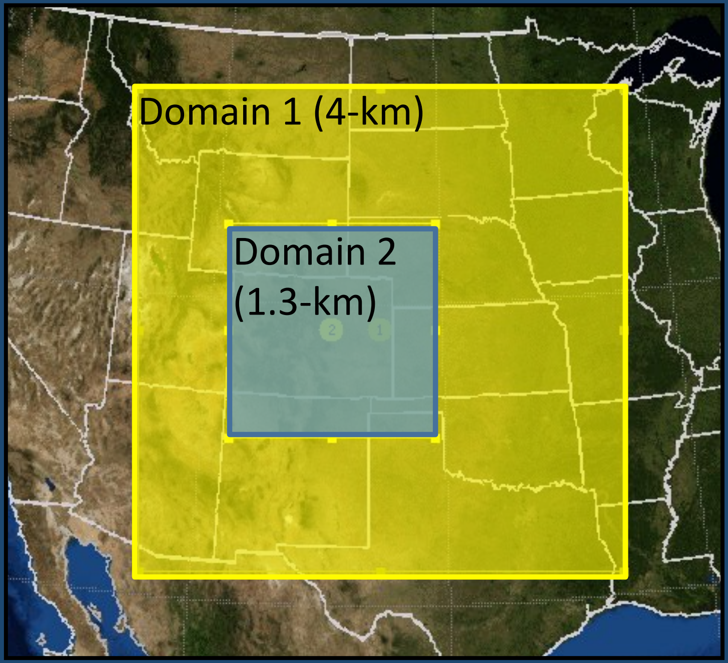


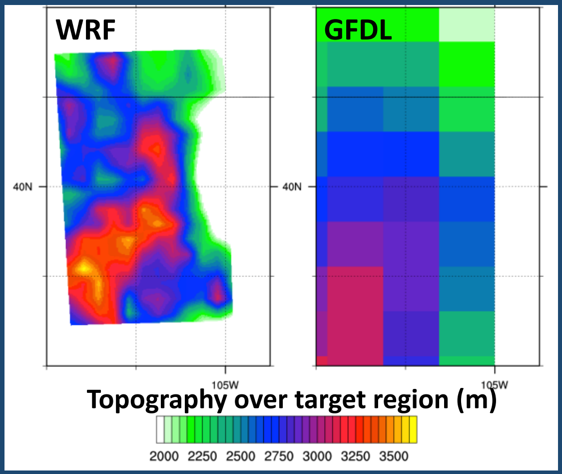
- Extreme event selection:
  1. Target region: Colorado Front Range
  2. For past (1971-2000), future (2041-2070) simulations:
     1. Sort all warm-season (June-July-August) daily precipitation values in target region
     2. 10 largest precipitation values ≈ Top 0.3% of events
     3. Limited QC, but did remove spin-up storms, obviously unrealistic cases (e.g., 10^{20} mm/day)



WRF runs: Model set-up

- WRFV3.1
  - 4km outer domain: 450x450 gridpoints
  - 1.33 km inner domain: 574x601 gridpoints
  - Hourly output for 24-h
- Parameterizations:
  - WSM6 microphysics
  - YSU Planetary Boundary Layer scheme
  - RRTM, Dudhia LW/SW radiation physics
  - Noah land surface model (4-layers)
- Initial conditions for runs shown here:
  1. GFDL – “Timeslice”
  2. CCSM-WRFG
  3. CGCM3-RCM3 (done-ish)

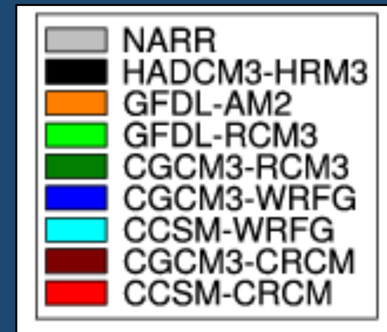


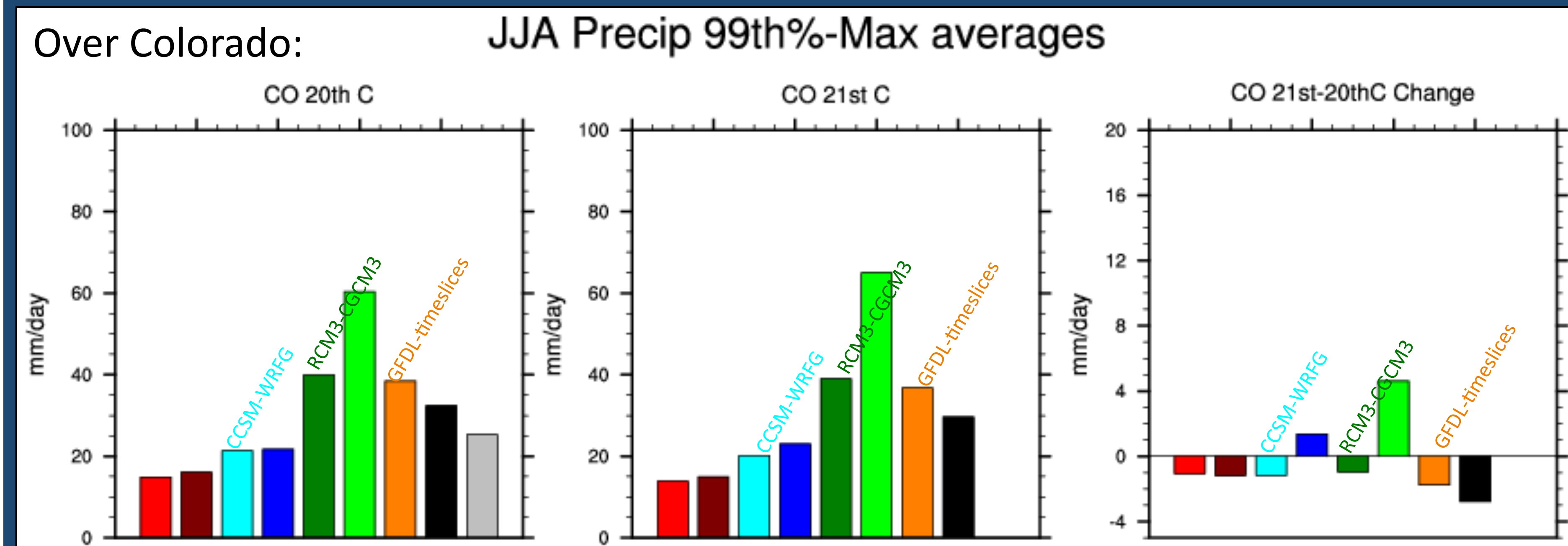


Topography over target region (m)

WRF runs: Initial conditions

- 3 NARCCAP models downscaled
  1. GFDL – "Timeslice"
  2. CCSM-WRFG
  3. CGCM3-RCM3



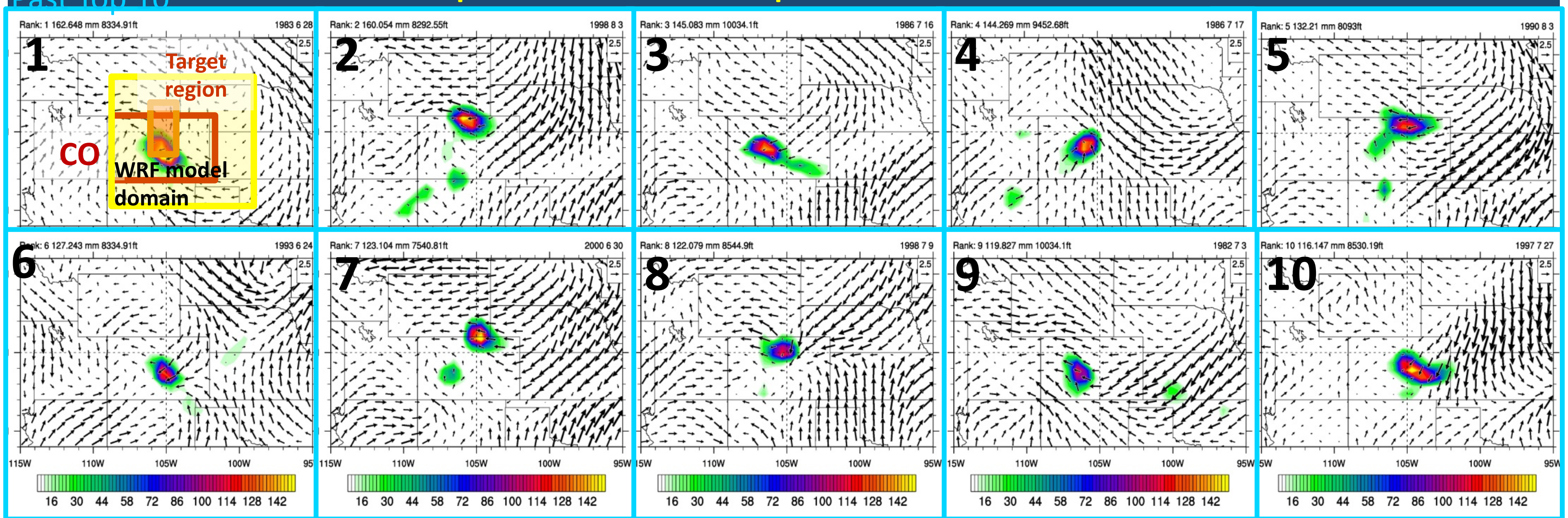


Results

1. The “Good”
2. The “Bad”
3. The Confusing

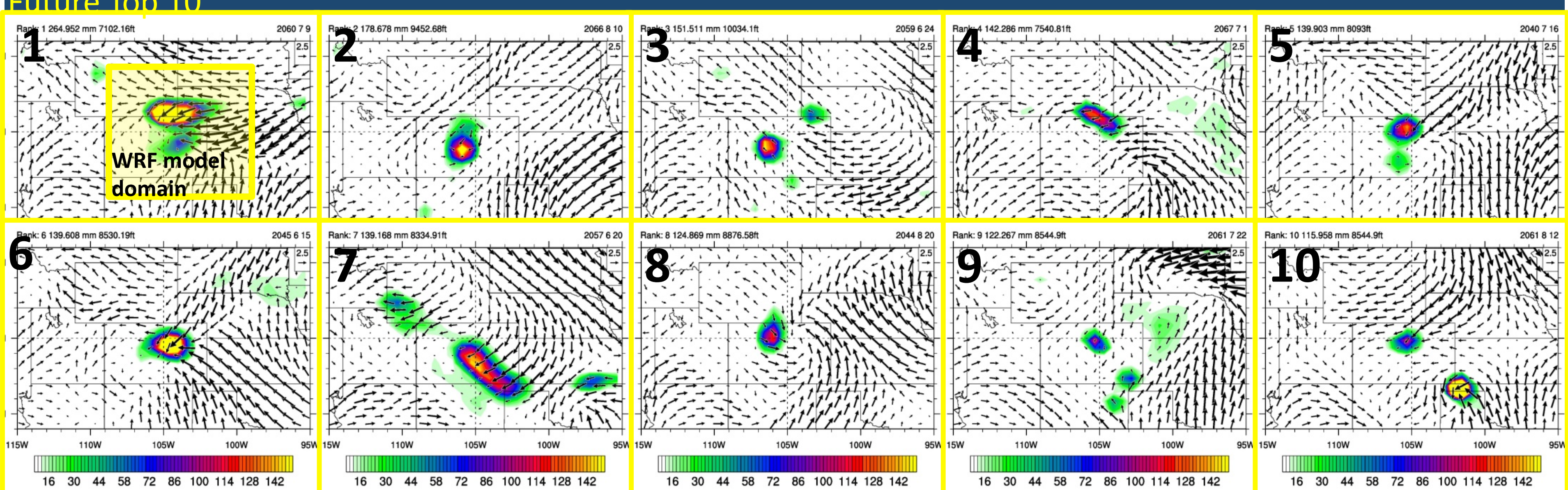
As seen at 50-km regional climate scale (GFDL-Timeslices experiment): Top 10 Past vs. Top 10 Future Events

Past Top 10

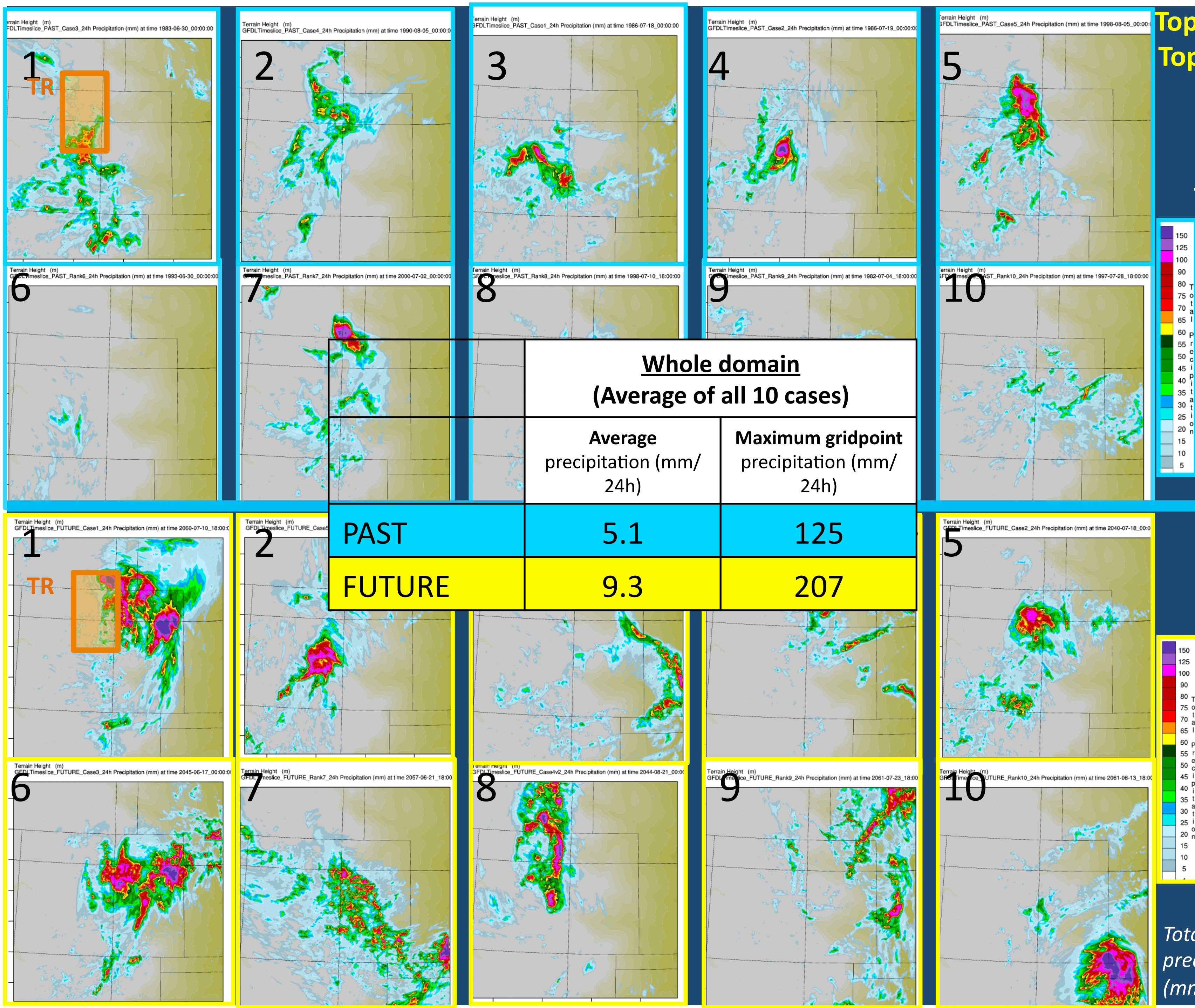


Total precipitation/24h (mm, shaded), surface winds (vectors)

Future Top 10



Top 10 Past vs. Top 10 future: WRF

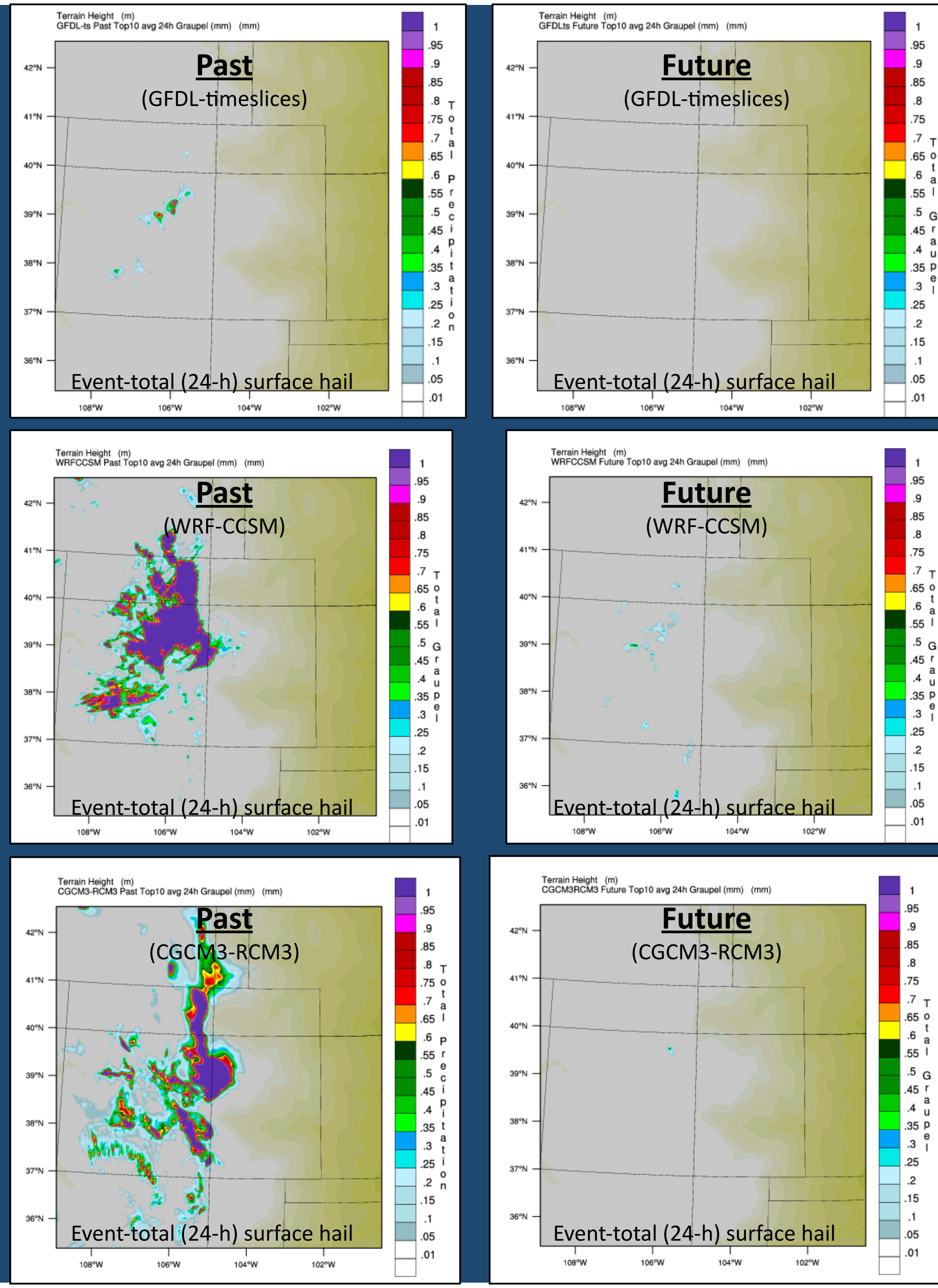


	Whole domain (Average of all 10 cases)	
	Average precipitation (mm/24h)	Maximum gridpoint precipitation (mm/24h)
PAST	5.1	125
FUTURE	9.3	207

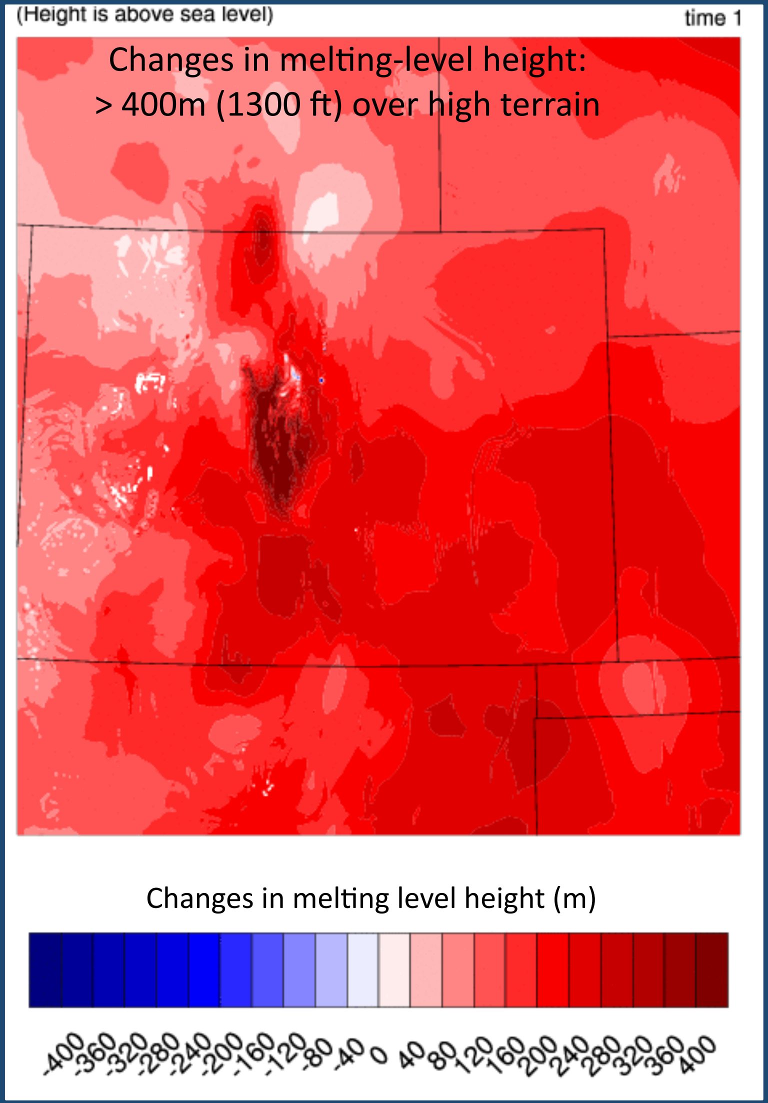
Changes in hail?

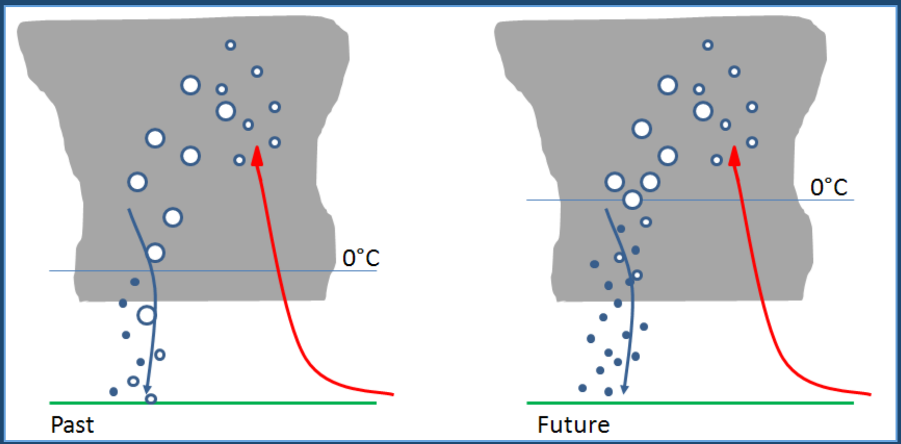
What happens to surface hail?

Average accumulated surface graupel/hail fields in Top 10 past vs. Top 10 future individual cases for 3 RCM combinations



Changes in hail?





- Height of melting level increases in future (~400 m difference) → decreases hail found at surface through increased melting

Caveats:

1. Sensitivity to model cloud physics parameterization
2. Our approach focuses on **small** (i.e., **non-damaging**) hail **at high-elevation locations**
3. Results mostly likely **not** relevant to hail-producing thunderstorms in other regions (*especially* the US Midwest/Great Plains!)

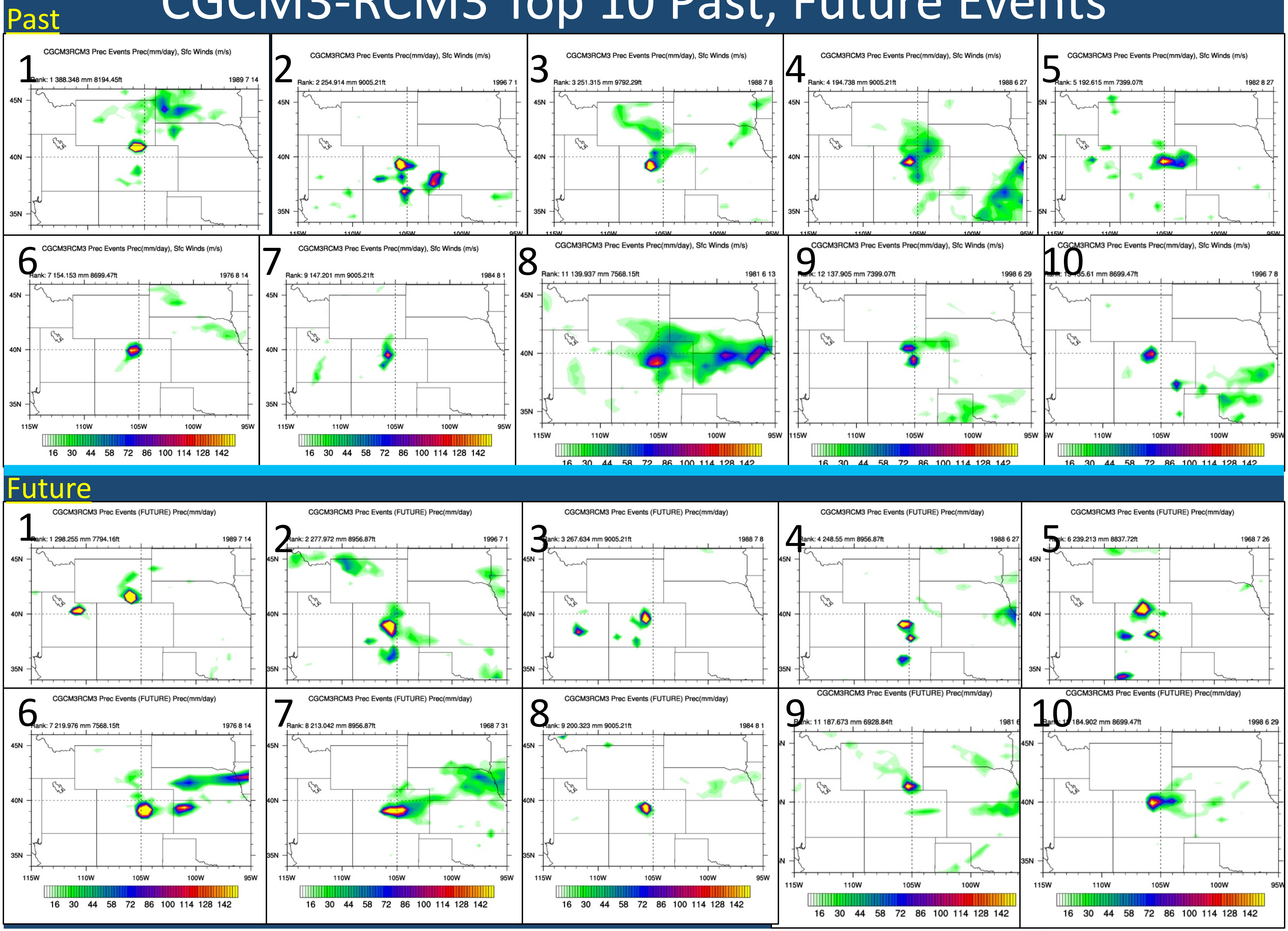
Yet: A robust change in physical process identified (we'll call it "good")!

Mahoney, K. M., M. A. Alexander, G. Thompson, J. J. Barsugli, and J. D. Scott, 2012: Changes in hail and flood risk in high-resolution simulations over Colorado's mountains. Nature Climate Change. 10 January 2012 | DOI: 10.1038/NCLIMATE1344

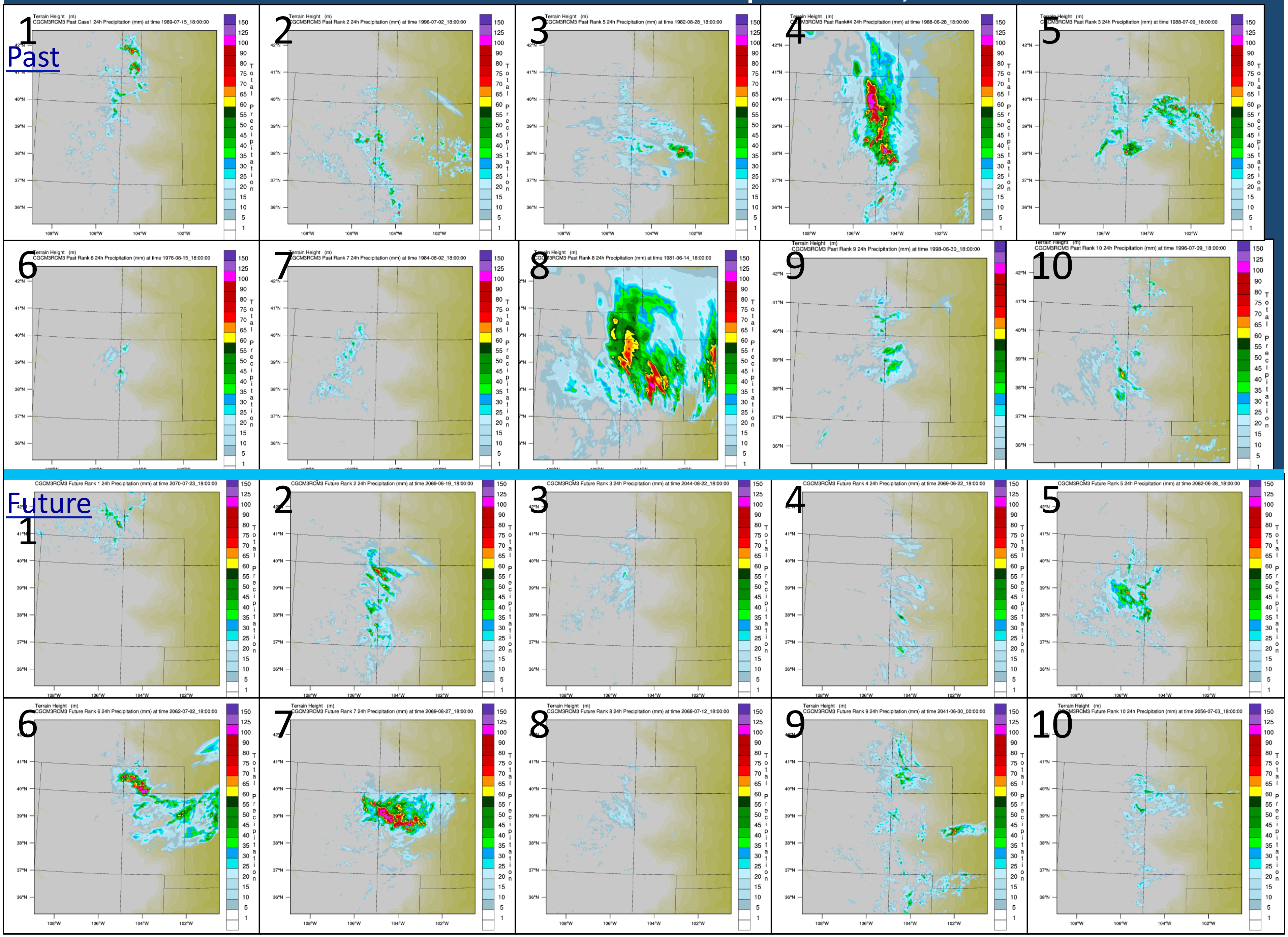
Results

1. The “Good”
2. The “Bad” → 2 examples:
    1. Too many “dud” cases (CGCM3-RCM3)
    2. Large model comparison differences
3. The Confusing

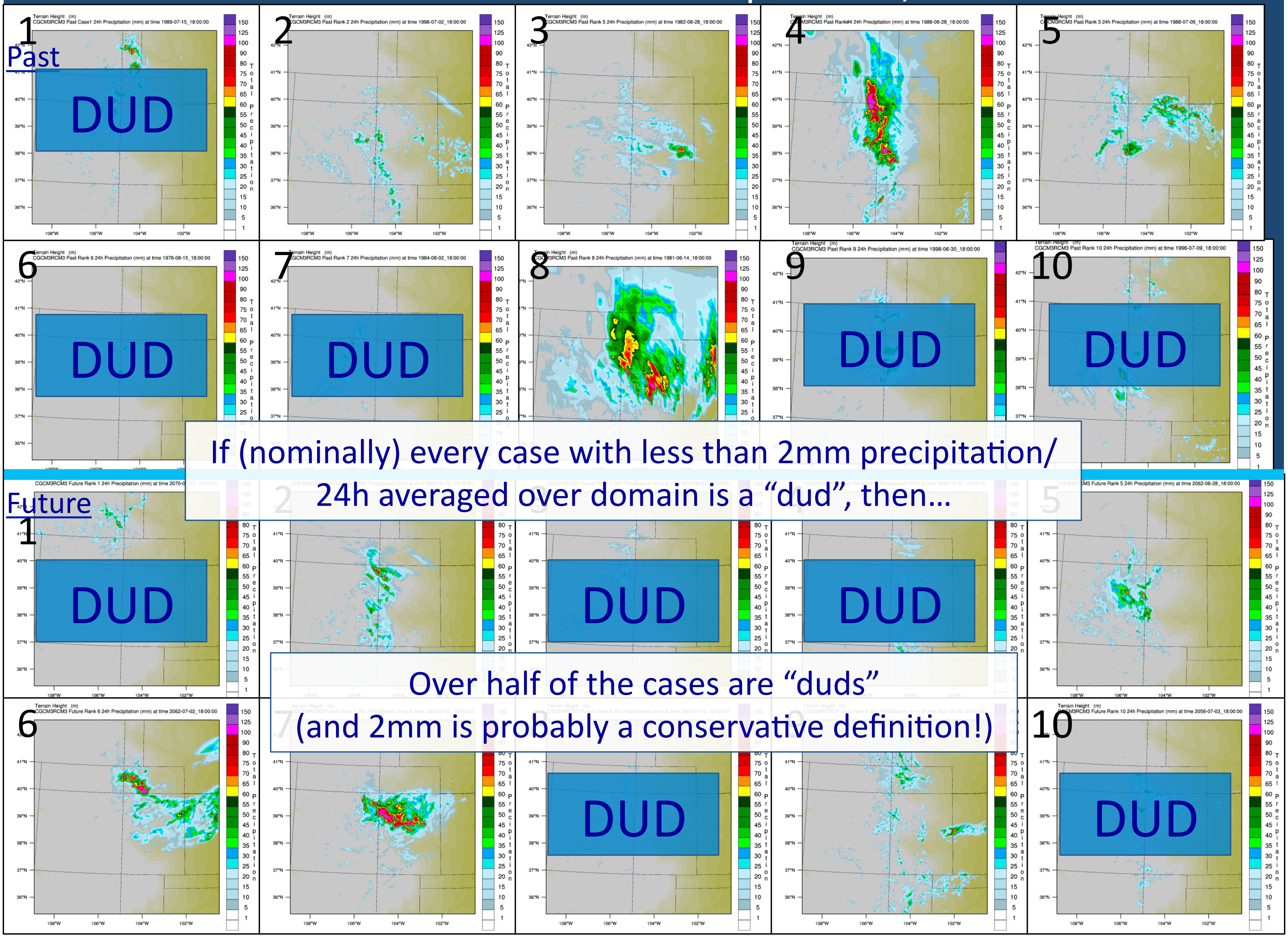
CGCM3-RCM3 Top 10 Past, Future Events



WRF-downscaled CGCM3-RCM3 Top 10 Past, Future Events



WRF-downscaled CGCM3-RCM3 Top 10 Past, Future Events



If (nominally) every case with less than 2mm precipitation/ 24h averaged over domain is a "dud", then…

Over half of the cases are "duds"
(and 2mm is probably a conservative definition!)

The ~~"Bad"~~ Reality:
3-model average and max precip comparisons

WRF 1-km Top 10 events from GFDL-ts:

GFDL-Timeslices	Whole domain (Average of all 10 cases)	
	Average precip (mm/24h)	Maximum precip (mm/24h)
PAST	5.1	125
FUT	9.3	207

Large increases from past → future

WRF 1-km Top 10 events from WRF-CCSM:

WRF-CCSM	Whole domain (Average of all 10 cases)	
	Average precip (mm/24h)	Maximum precip (mm/24h)
PAST	6.1	101
FUT	4.0	103

Small changes from past → future

WRF 1-km Top 10 events from CGCM3-RCM3:

CGCM3-RCM3	Whole domain (Average of all 10 cases)	
	Average precip (mm/24h)	Maximum precip (mm/24h)
PAST	3.9	100.7
FUT	2.1	80.1

Moderate decreases from past → future*

** So many duds, signal determined by a few (4-5) cases*

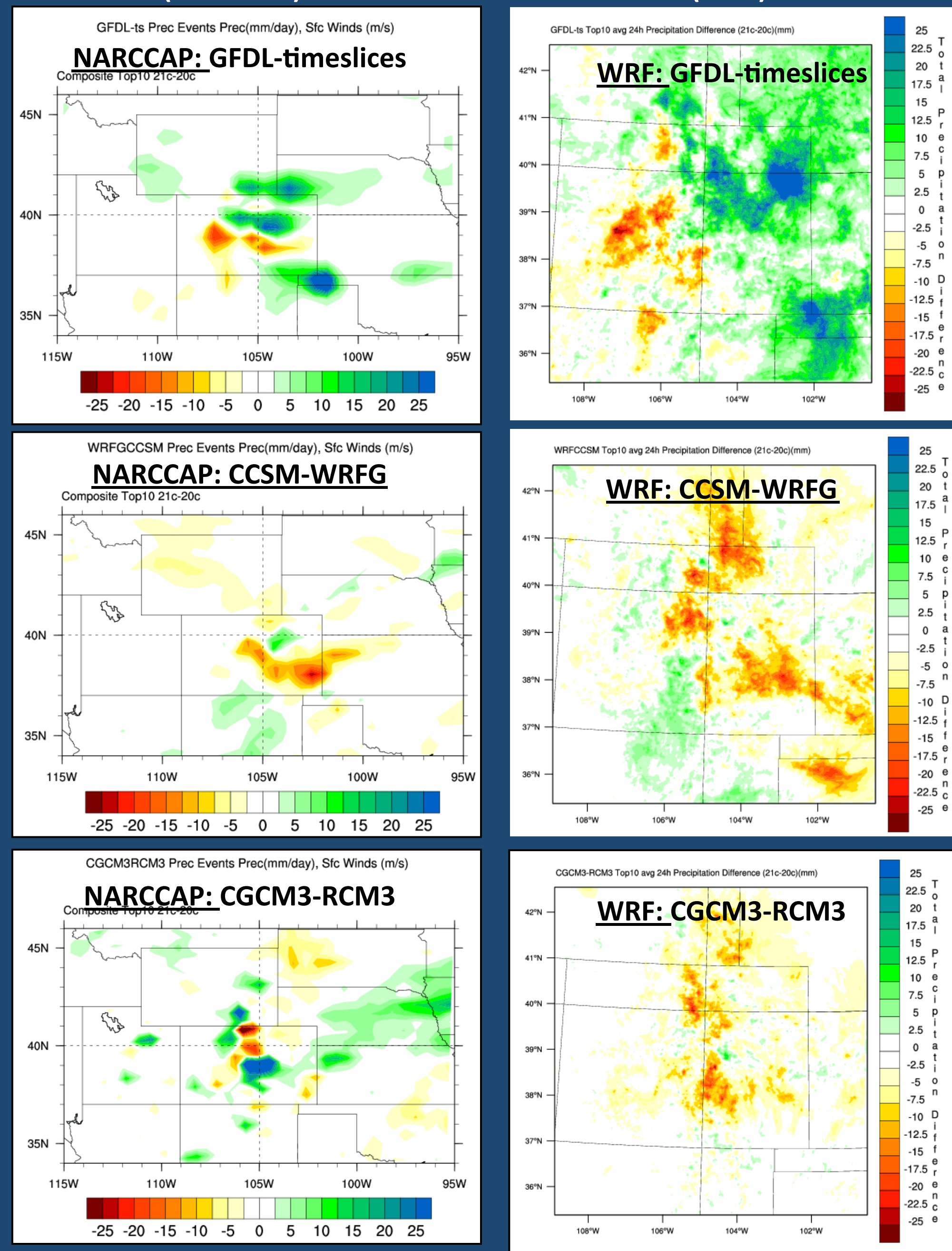
- 3 models downscaled…3 different "answers"
- While there is much more analysis that we can do here…

Has our "enhanced detail" only enhanced our number of questions?

How do NARCCAP RCM projections of extremes compare with the high-res downscaled version of the same cases?

21c – 20c Top 10 Cases Avg precip (NARCCAP)

21c – 20c Top 10 Cases Avg precip (WRF)



Results

1. The “Good”
2. The “Bad”
3. The Confusing…

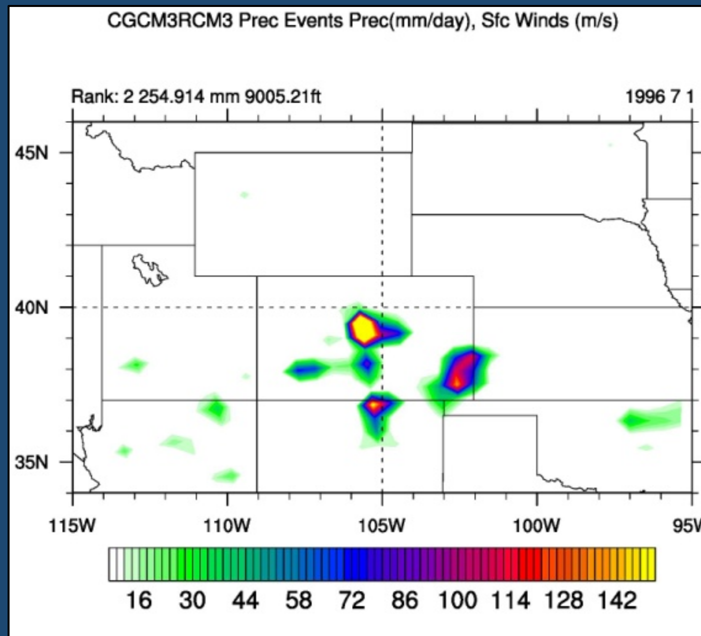
The Confusing

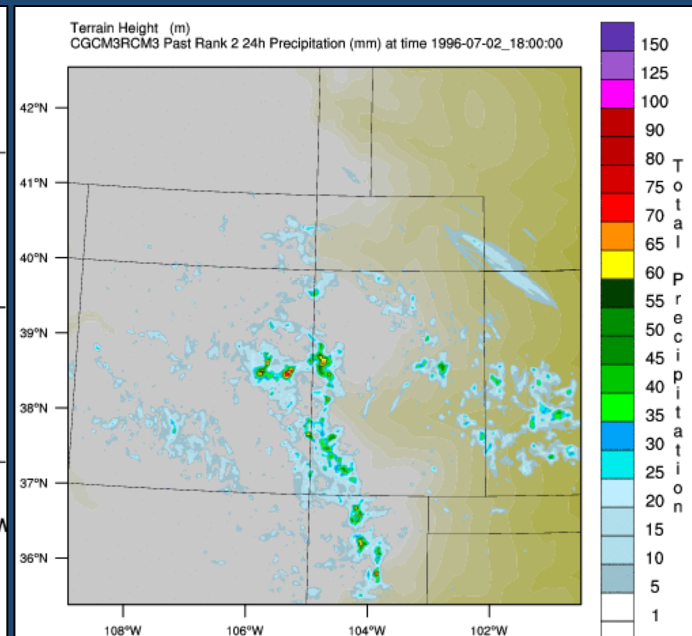
- The “duds”: What are RCM CP schemes/precipitation processes “convecting on” that high-resolution model isn’t?
- Statistical significance of results in general…but especially when significant subset of “extreme” cases in the RCM are weak in high-resolution runs?
- Example of CGCM3-RCM3 dud case:

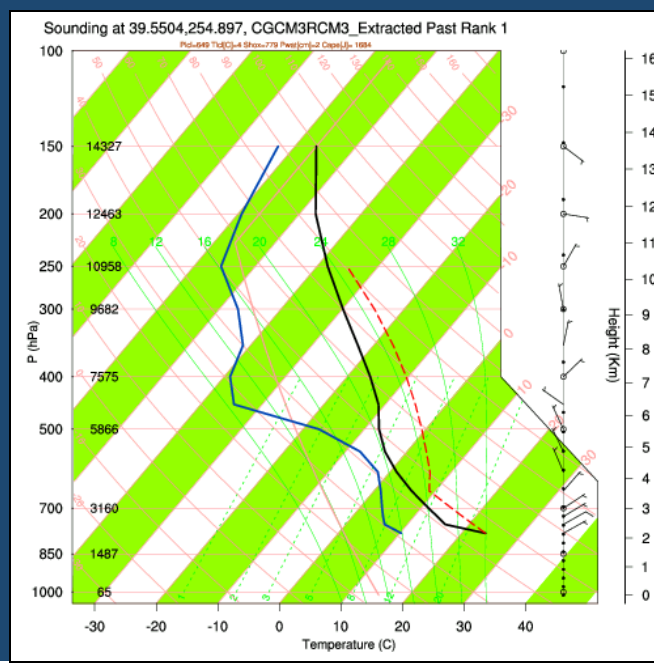
Example of “dud” case mystery

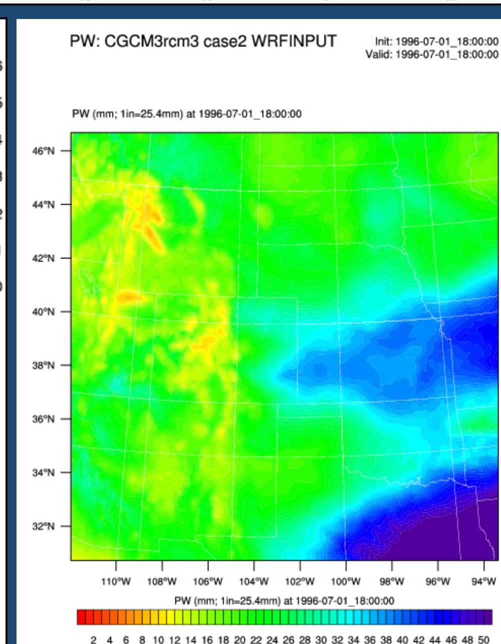
CGCM3-RCM3
Past Rank #2:

- RCM:
  255mm precip/ 24h
- WRF high-res:
  77mm max
  (but only in very small location)
- We’ve got CAPE (1500+), we’ve got moisture (PW > 25mm), we’ve got upslope flow from surface - ~700mb
- Is it a systematic problem that would be of scientific value to understand, or is it a different, inconsistent issue for each individual case?









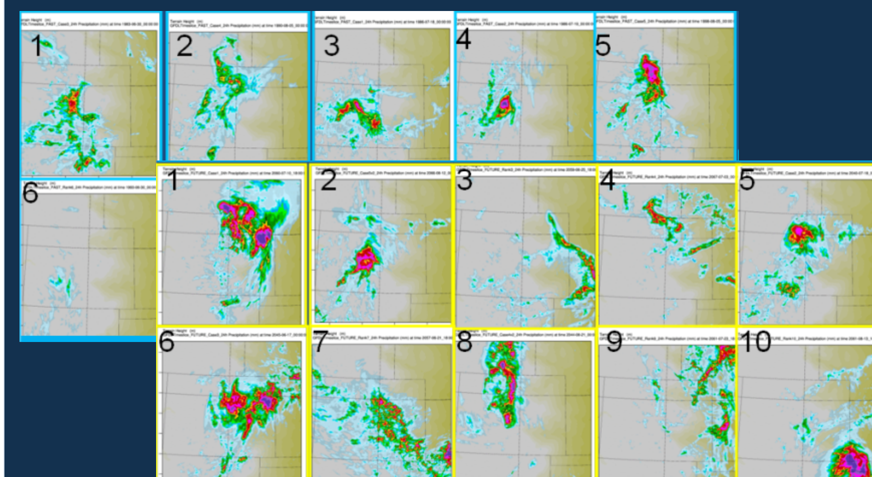
The Confusing/What's next

- Going forward, we can/should/could:
  - Investigate the underbellies of the RCM convective/gridscale precipitation production
  - Consider not choosing cases based on RCM precip, and instead focus on other environmental quantities (e.g., moisture flux, easterly/upslope flow, CAPE, etc?)
  - Reconsider methodology in general?

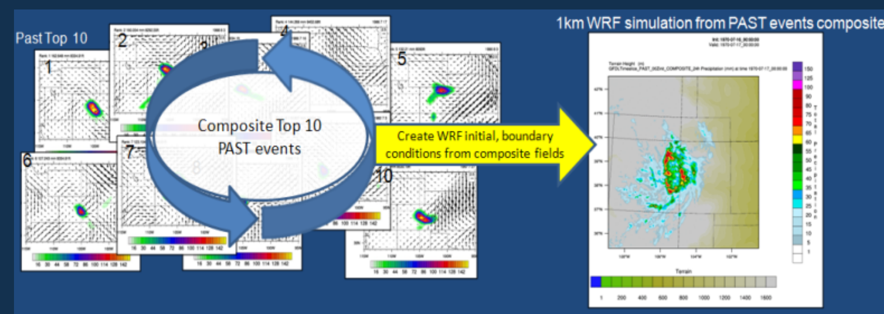
Three different downscaling methodologies (quick overview)

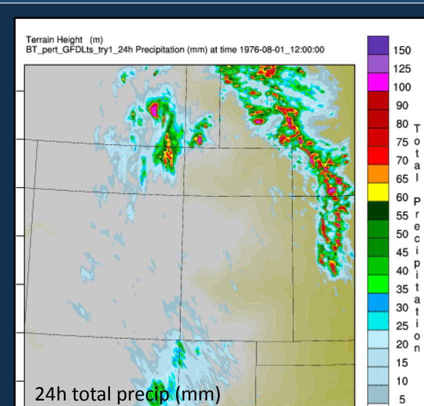
1. Individual simulations
2. Composite-initialized simulations
3. Delta method/"PGW"/climate-perturbed simulations of observed extreme event

1. Individual simulations: Comparison of top 10 past individual events vs. top 10 future individual events



2. Composite approach

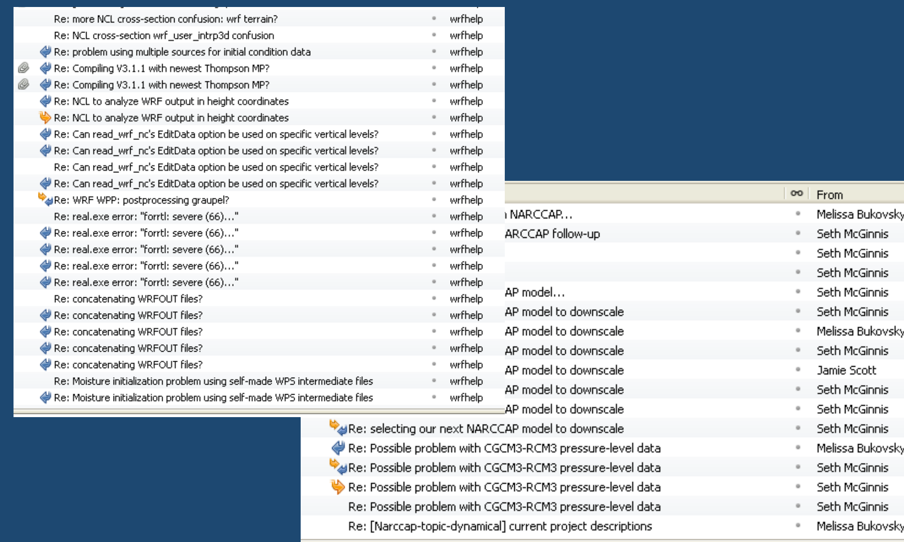


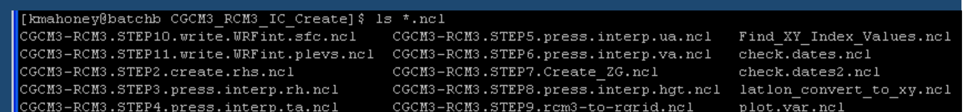


3. Big Thompson Canyon Flood in "GFDL-TS Future"

Logistical Downscaling Challenges

- NARCCAP output not designed for WRF input: construction of initial conditions complex, highly-nuanced, time-consuming
- WRF ingest of initial conditions nuanced: e.g., interpolation from RCM surface to higher-resolution surface can affect results
- Input data incongruities create challenges
  - Differences in data organization makes dynamical downscaling very challenging (e.g., different vertical coordinates, map projections, calendars, fields provided) → reinventing (13+ step) process each time
  - Data errors: "GIGO" (e.g., RCM3 zg500, WRFG SLP)
  - Unrealistic cases (spin-up storms, unphysical precipitation) throw off case selection, analysis of extremes, e.g.,
    - WRF-CCSM: has several days with 10^{20} mm of precip
    - CGCM3-RCM3 produces (very) large precip maxima – real?
- Discuss more in Topic Pod breakouts?





```
[kmahoney@batchb CGCM3_RCM3_IC_Create]$ ls *.ncl
CGCM3-RCM3.STEP10.write.WRFint.sfc.ncl    CGCM3-RCM3.STEP5.press.interp.ua.ncl    Find_XY_Index_Values.ncl
CGCM3-RCM3.STEP11.write.WRFint.plevs.ncl  CGCM3-RCM3.STEP6.press.interp.va.ncl    check.dates.ncl
CGCM3-RCM3.STEP2.create.rhs.ncl           CGCM3-RCM3.STEP7.Create_ZG.ncl          check.dates2.ncl
CGCM3-RCM3.STEP3.press.interp.rh.ncl      CGCM3-RCM3.STEP8.press.interp.hgt.ncl   latlon_convert_to_xy.ncl
CGCM3-RCM3.STEP4.press.interp.ta.ncl      CGCM3-RCM3.STEP9.rcm3-to-rgrid.ncl      plot.var.ncl
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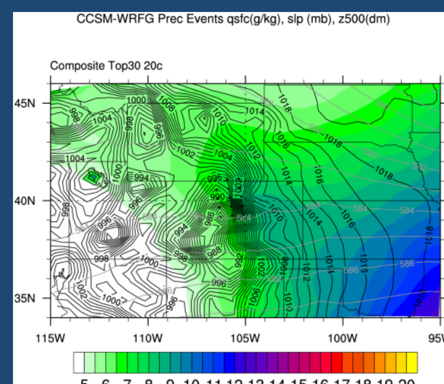
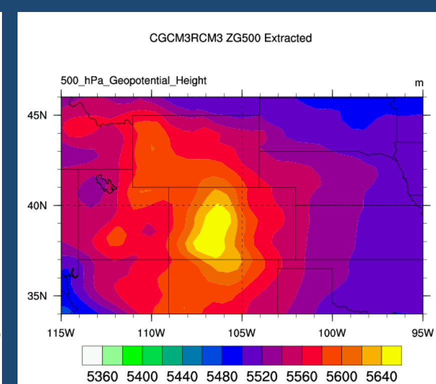




Summary

1. High-resolution simulations offer insight into past, future extreme events: spatial/temporal detail, assessment of storm-scale physical processes

   But…added complexity also yields…more complexity! (interpretation, compounding of errors, etc., …)

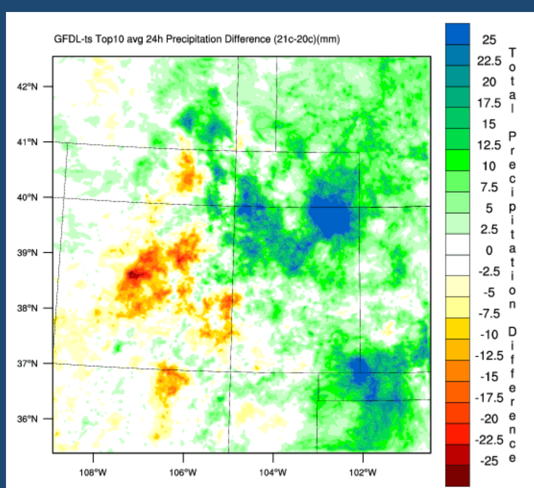
2. Preliminary results (GFDL-timeslices, WRF-CCSM) *might* suggest:
   - More or equally intense precipitation extremes in future *even when overall precipitation decreases (for the CO Front Range in 3 specific future climate experiments) (CGCM3-RCM3 cases likely too "dud"-filled to include)*
   - Potential for changes in small hail amount/hail size distribution at surface due to sub-cloud melting (all models)

3. High-resolution methodologies likely offer value for specific, carefully thought-out purposes.

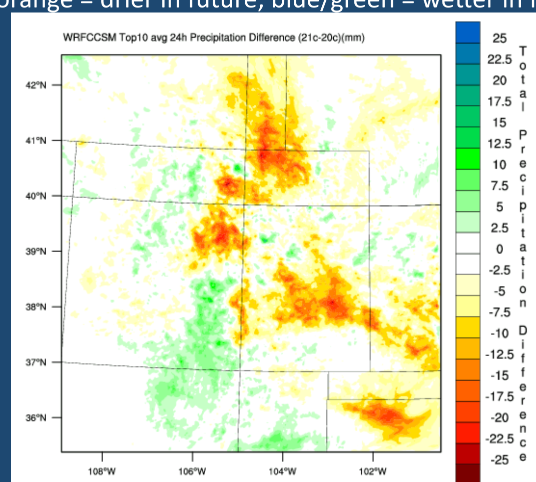
   Developmental nature of regional climate model input → limited (direct) use of downscaled simulations for certain practical (e.g., planning, decision-making) purposes…

   But for testing hypotheses, assessing physical process changes, etc., promising potential

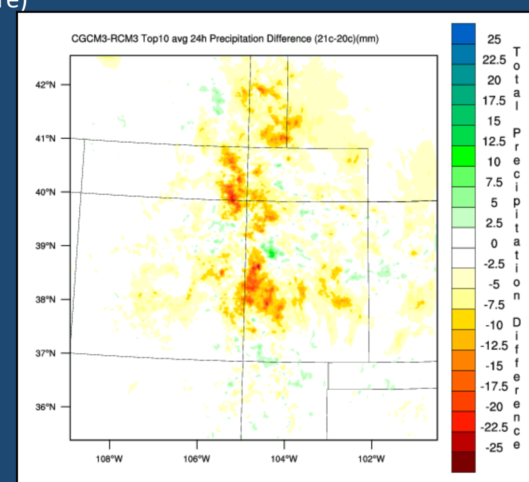
Avg difference (Future – Past) of high-res downscaled Top 10 events
(red/orange = drier in future; blue/green = wetter in future)



GFDL-Timeslice



CCSM-WRF



CGCM3-RCM3

Acknowledgments

- *US Bureau of Reclamation:*

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- Western Water Assessment (WWA)
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