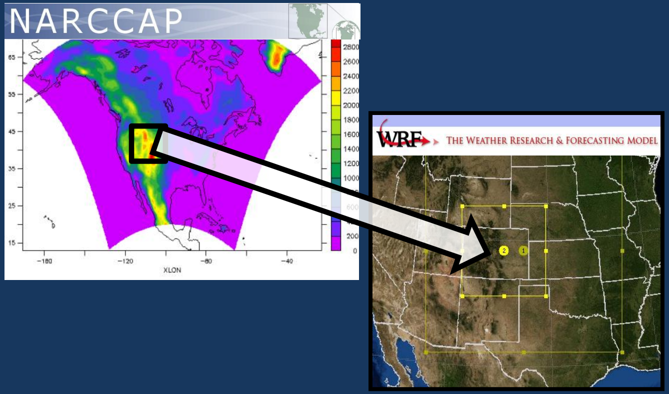
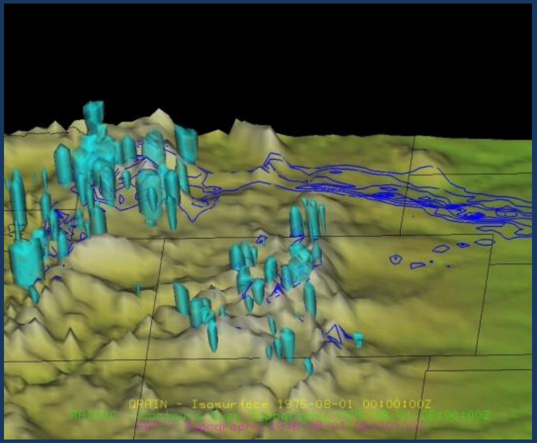
Further dynamical downscaling of NARCCAP using WRF:

High-resolution simulations of extreme precipitation events in future NARCCAP climate scenarios





Kelly Mahoney (UCAR-PACE)

Michael Alexander, Jamie Scott, Joe Barsugli

NARCCAP User's Workshop

April 8 2011

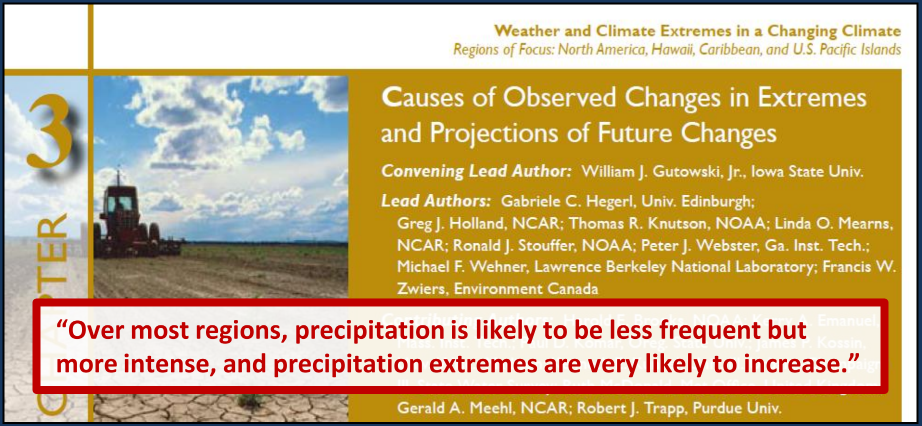
Western Water Assessment

Postdocs Applying Climate Expertise Fellowship Program

VSP UCAR Visiting Scientist Programs

Motivation: Extreme precipitation and climate change

- Extreme precipitation events generally predicted to increase*…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*



Weather and Climate Extremes in a Changing Climate

Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands

Causes of Observed Changes in Extremes and Projections of Future Changes

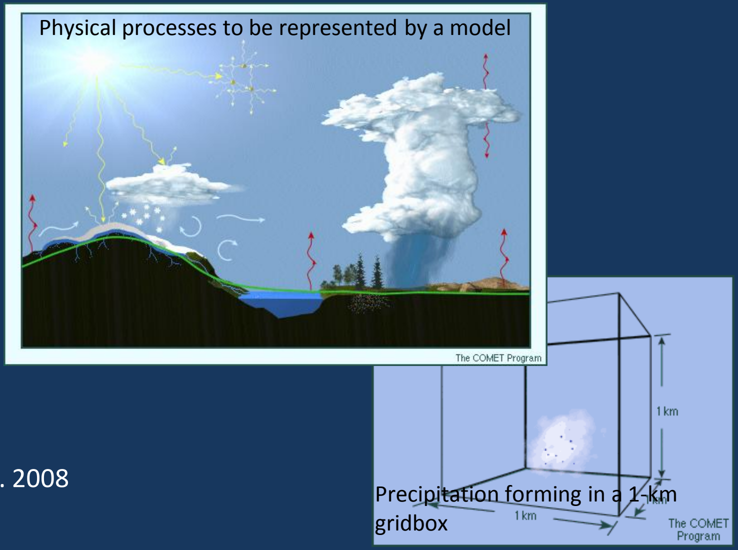
Convening Lead Author: William J. Gutowski, Jr., Iowa State Univ.

Lead Authors: Gabriele C. Hegerl, Univ. Edinburgh; Greg J. Holland, NCAR; Thomas R. Knutson, NOAA; Linda O. Mearns, NCAR; Ronald J. Stouffer, NOAA; Peter J. Webster, Ga. Inst. Tech.; Michael F. Wehner, Lawrence Berkeley National Laboratory; Francis W. Zwiers, Environment Canada

Gerald A. Meehl, NCAR; Robert J. Trapp, Purdue Univ.

"Over most regions, precipitation is likely to be less frequent but more intense, and precipitation extremes are very likely to increase."

*e.g., Frei et al. 1998; Meehl et al. 2005; IPCC 2007; Gutkowski et al. 2008; Karl et al. 2008



Physical processes to be represented by a model

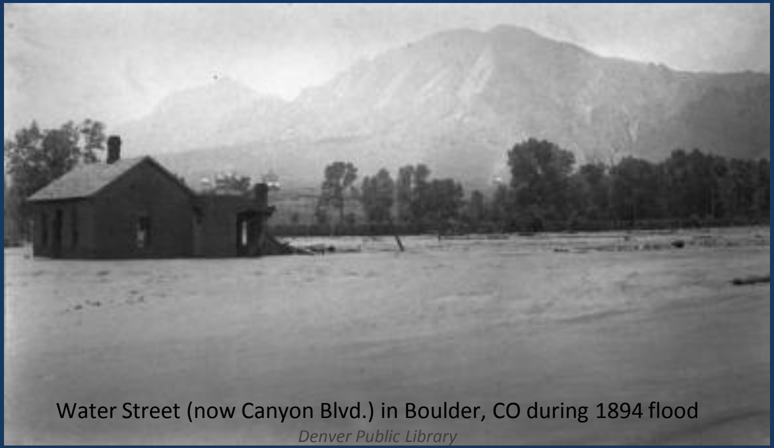
Precipitation forming in a 1-km gridbox

Research objectives

Across the Front Range of the Colorado Rocky Mountains…

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 downscaling approaches?*
    a. What is the “best” way to downscale climate extremes?
    b. Space, time scales required? Statistical vs. dynamical downscaling? Optimal approach to either?
    c. *Research- and decision-making communities:*

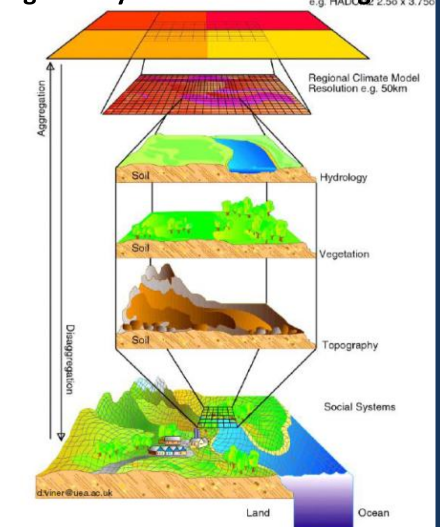
    Improved understanding of strengths, limitations of downscaling approaches → inform selection of most appropriate approach to specific problem



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

Denver Public Library

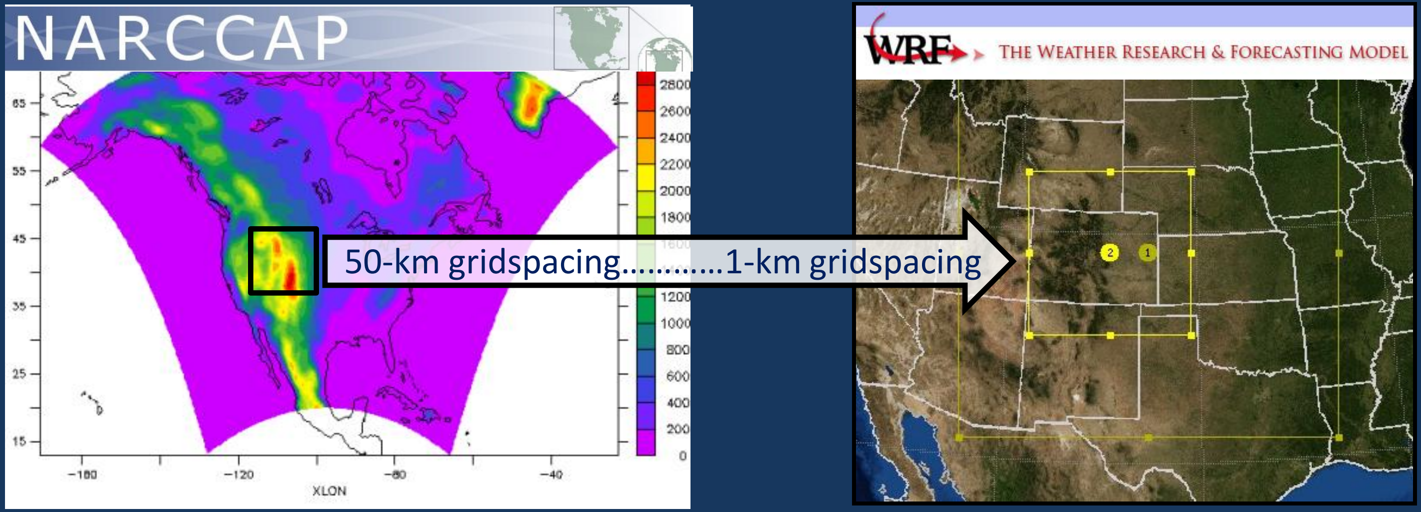
Regional dynamical downscaling



Canadian Climate Change Scenarios Network

Methodology: Overview

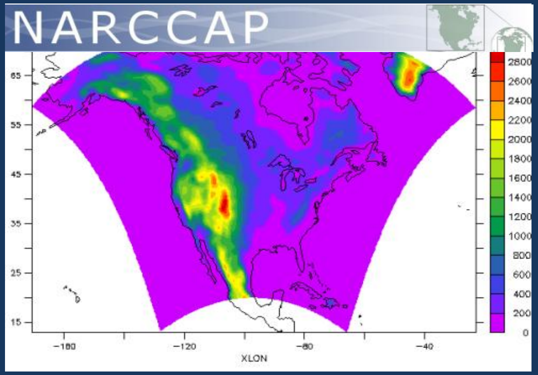
1. Select extreme cases from regional climate model data
2. Create initial conditions for WRF simulations
3. Execute high-resolution simulations
4. Compare past, future high-resolution simulations



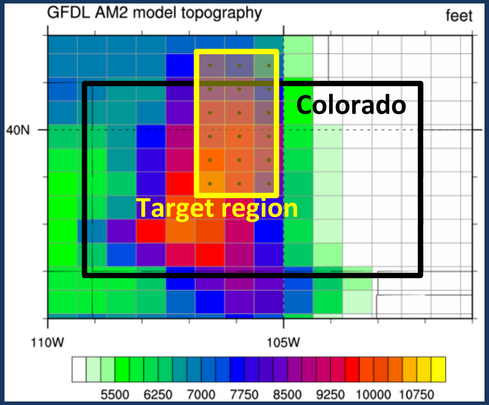
50-km gridspacing…………1-km gridspacing

Methodology

- NARCCAP: North American Regional Climate Change Assessment Program
  - Initial, boundary conditions from 20th, 21st century AOGCM experiments
  - GFDL-timeslice, WRF-CCSM used (so far)



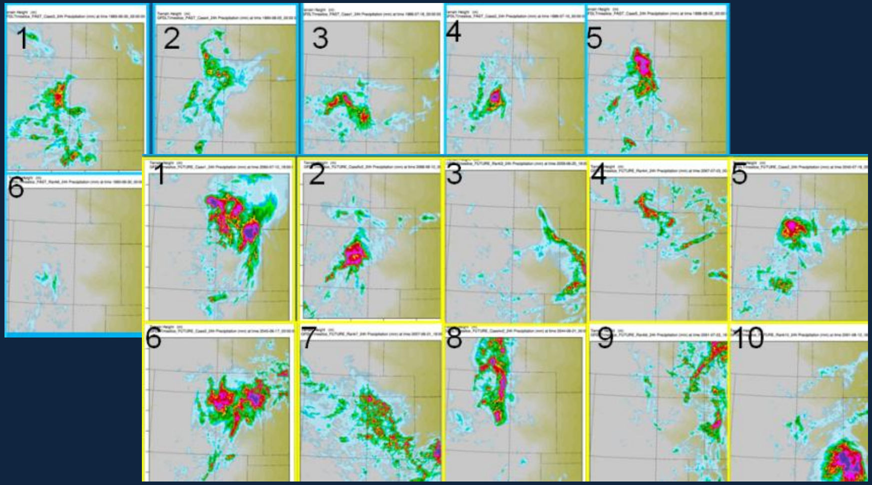
- Extreme event selection:
  1. Target region: Colorado Front Range
  2. For past (1971-2000), future (2041-2070) simulations:
     1. Sort all warm-season (June-July-August) daily precipitation values in target region
     2. 30 largest precipitation values ≈ Top 1% of events



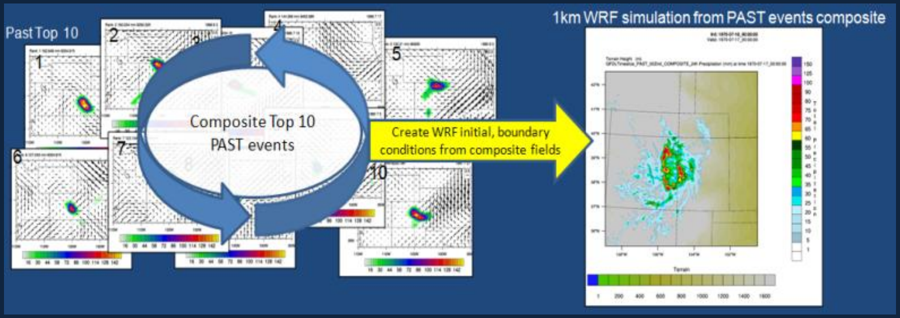
Three different downscaling methodologies (Overview)

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

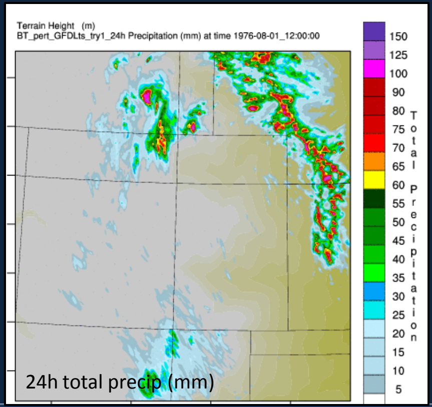
1. Individual simulations: Comparison of top 10 past individual events vs. top 10 future individual events



2. Composite approach

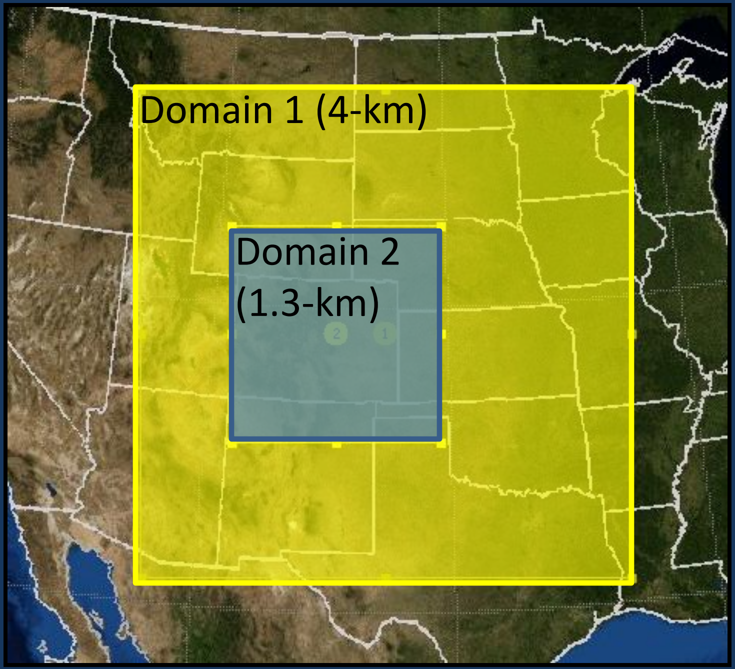


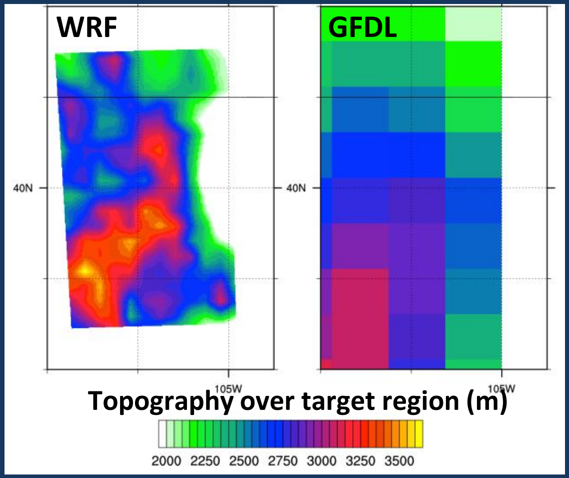
3. Big Thompson Canyon Flood in “GFDL-TS Future”



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:
  - Geophysical Fluid Dynamics Laboratory (GFDL) GCM – "Timeslice" simulations
  - GFDL AM2.1; 20C3M; SRES-A2 (Historical simulations *not* based on real events)





Topography over target region (m)

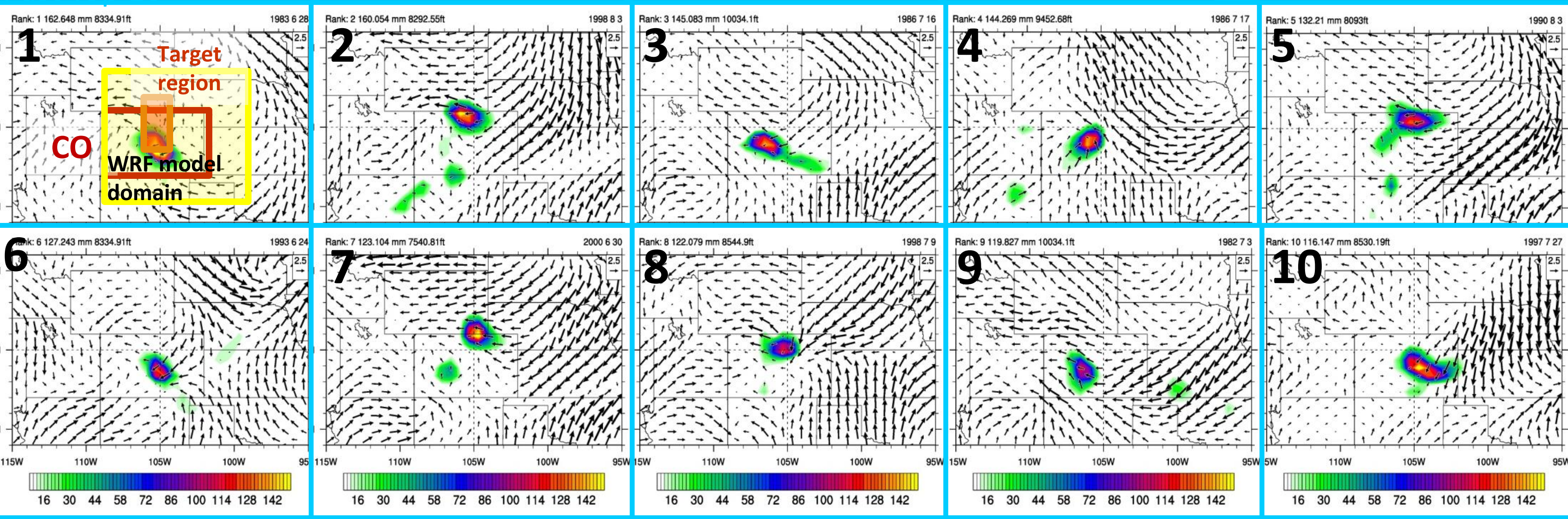
Examples of preliminary results*:

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

**Main results shown are from one NARCCAP regional climate model dataset: the GFDL-timeslices experiment…brief comparison at end*

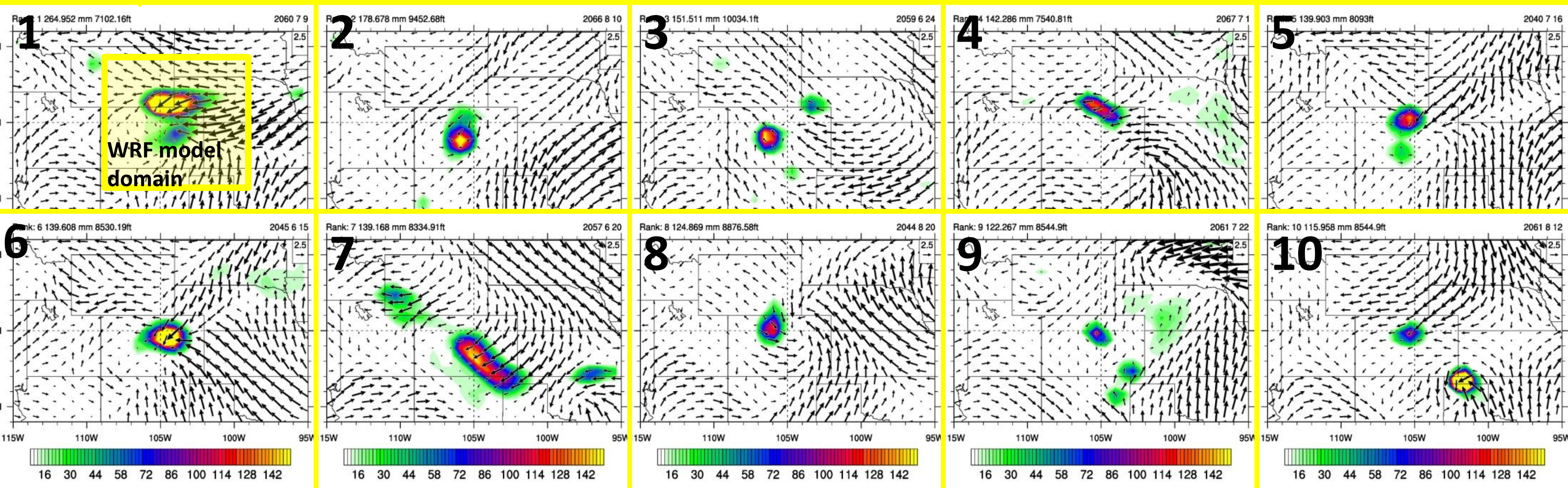
As seen at 50-km regional climate scale:
Top 10 Past vs. Top 10 Future Events

Past Top 10



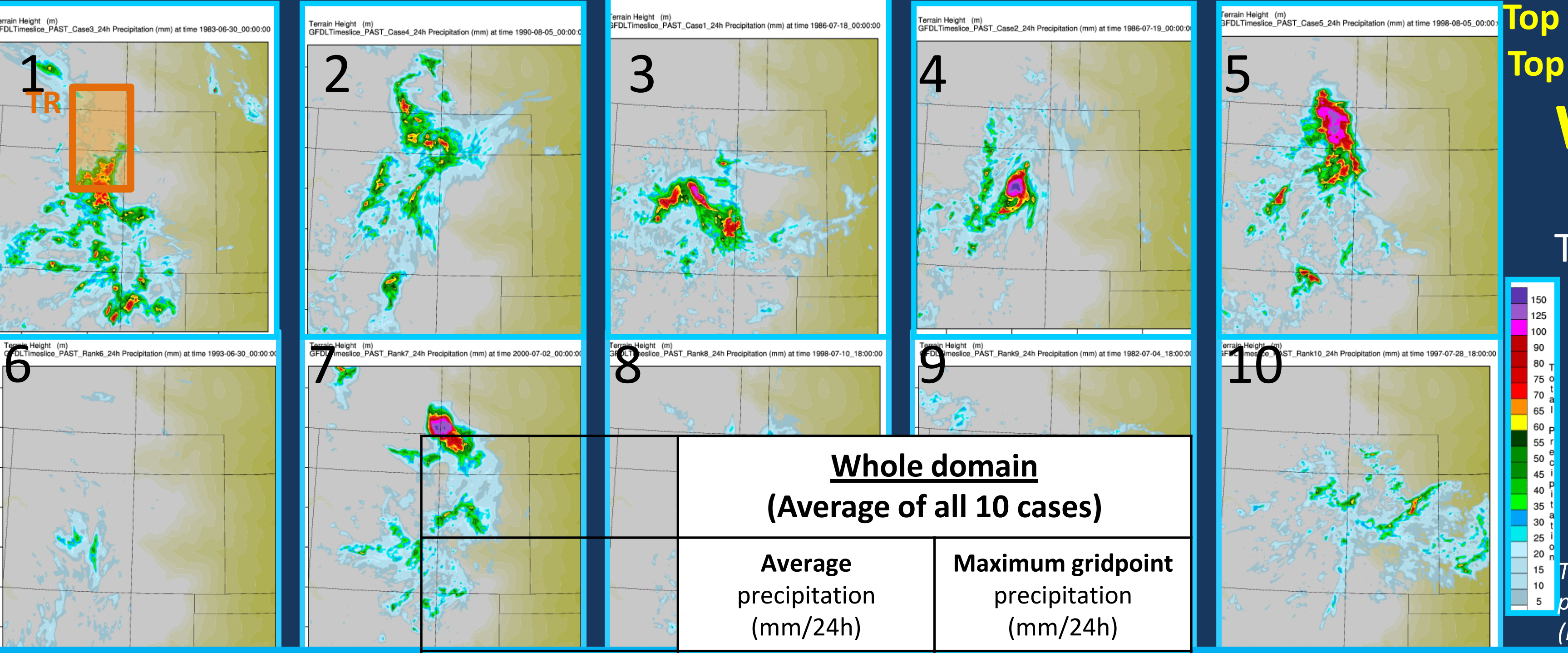
Total precipitation/24h (mm, shaded), surface winds (vectors)

Future Top 10



Top 10 Past vs. Top 10 future: WRF

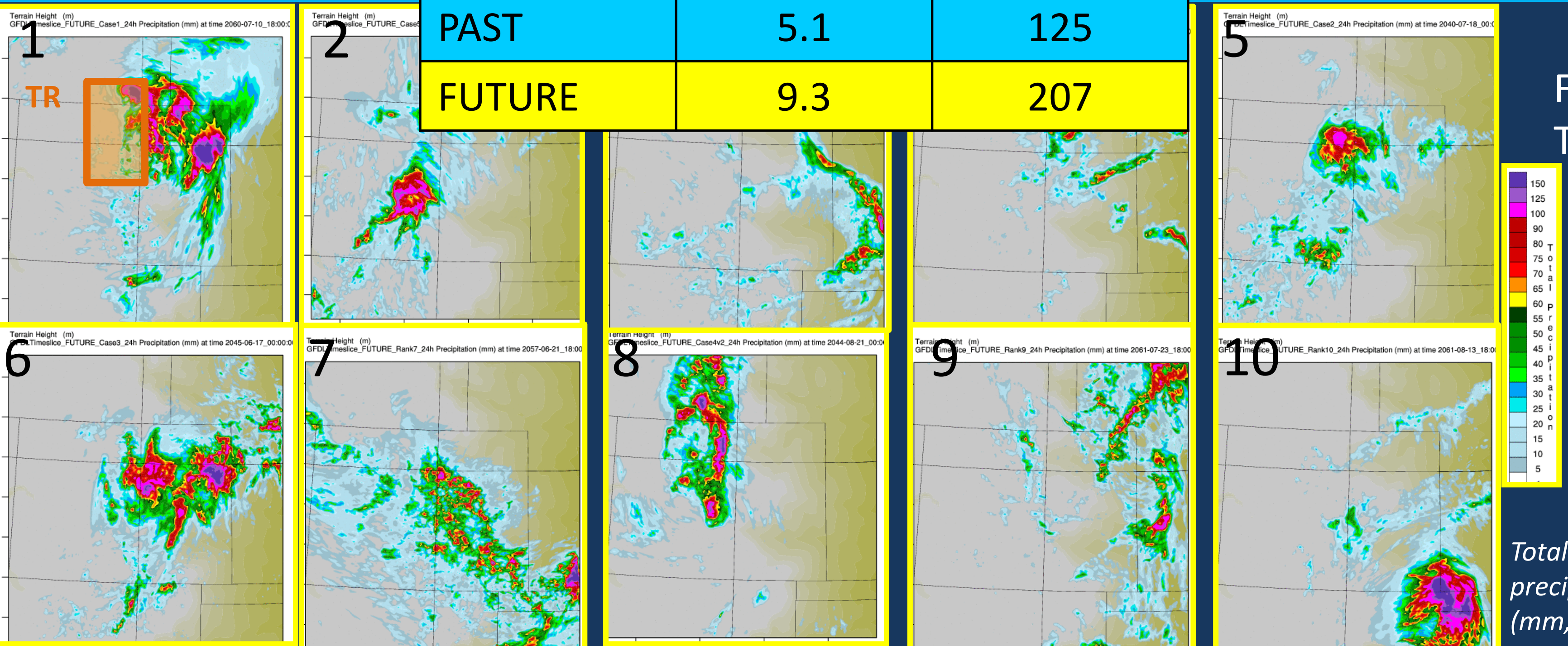
Past
Top 10



Total precipitation/24h (mm, shaded)

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

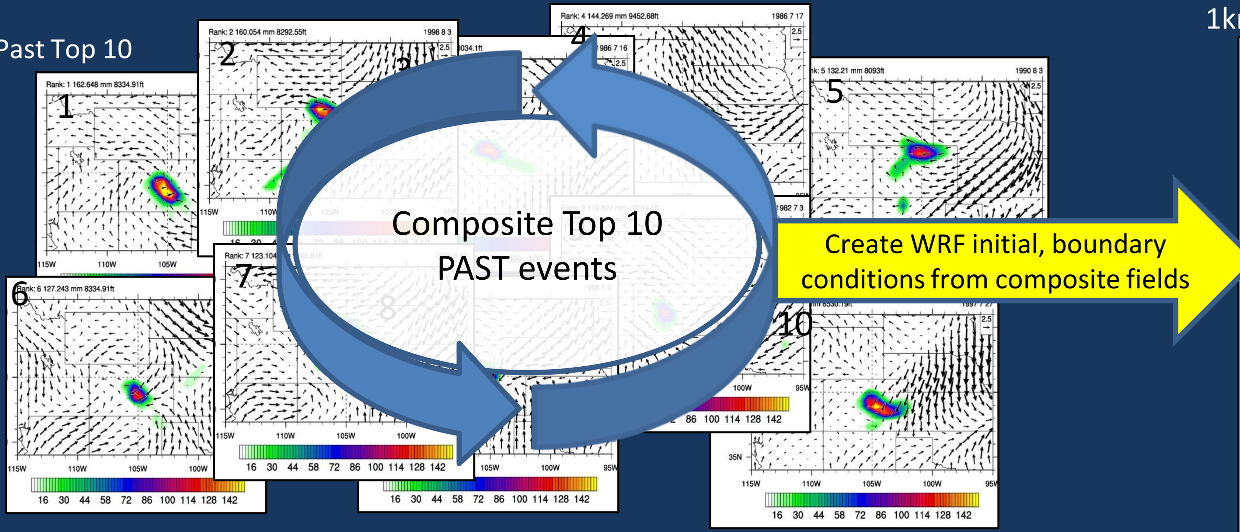
Future
Top 10



Total precipitation/24h (mm, shaded)

2. Extreme event composites as model initial conditions

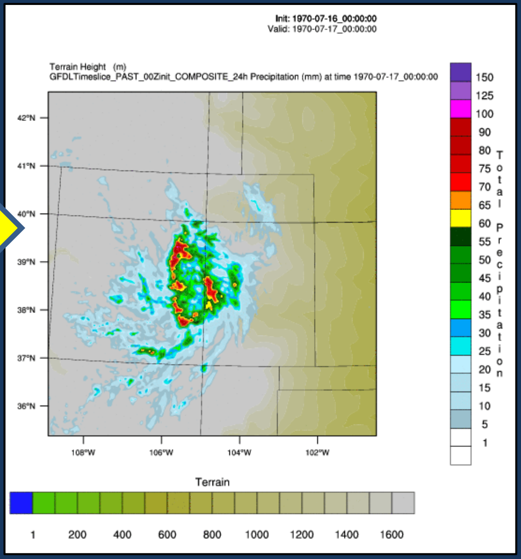
Past Top 10



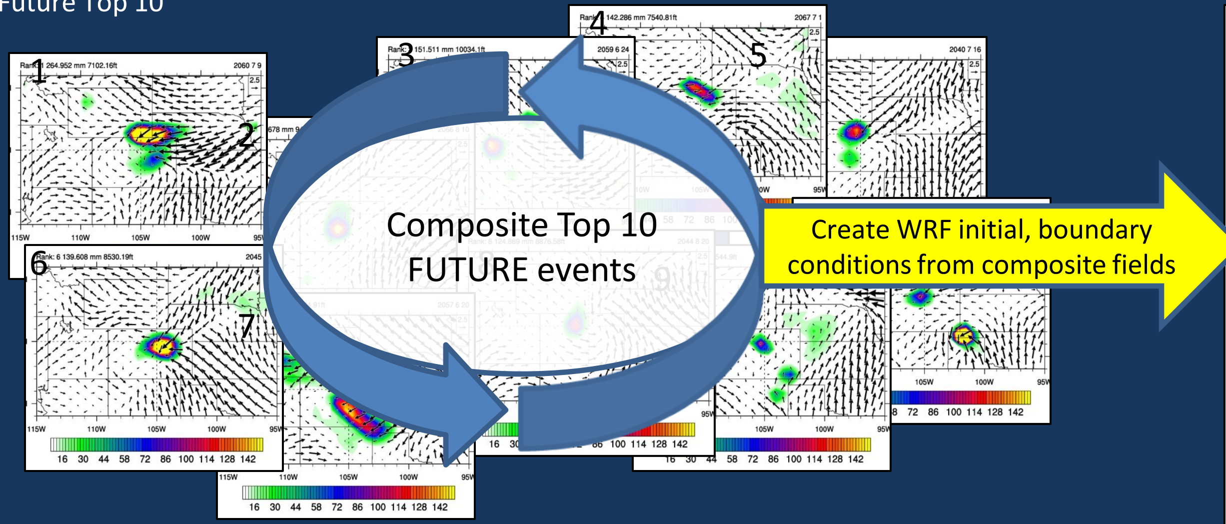
Composite Top 10
PAST events

Create WRF initial, boundary conditions from composite fields

1km WRF simulation from PAST events composite



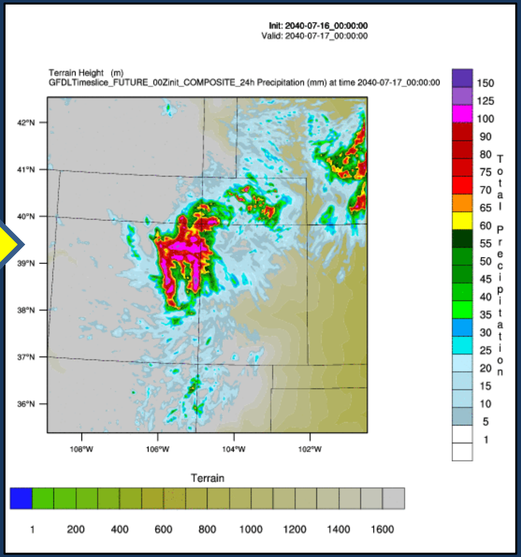
Future Top 10



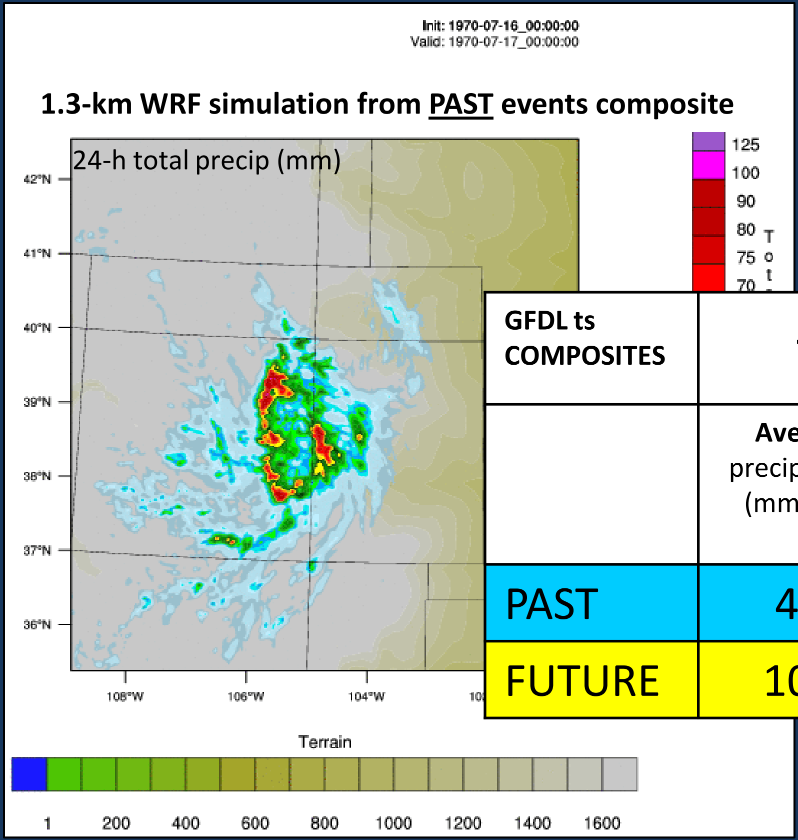
Composite Top 10
FUTURE events

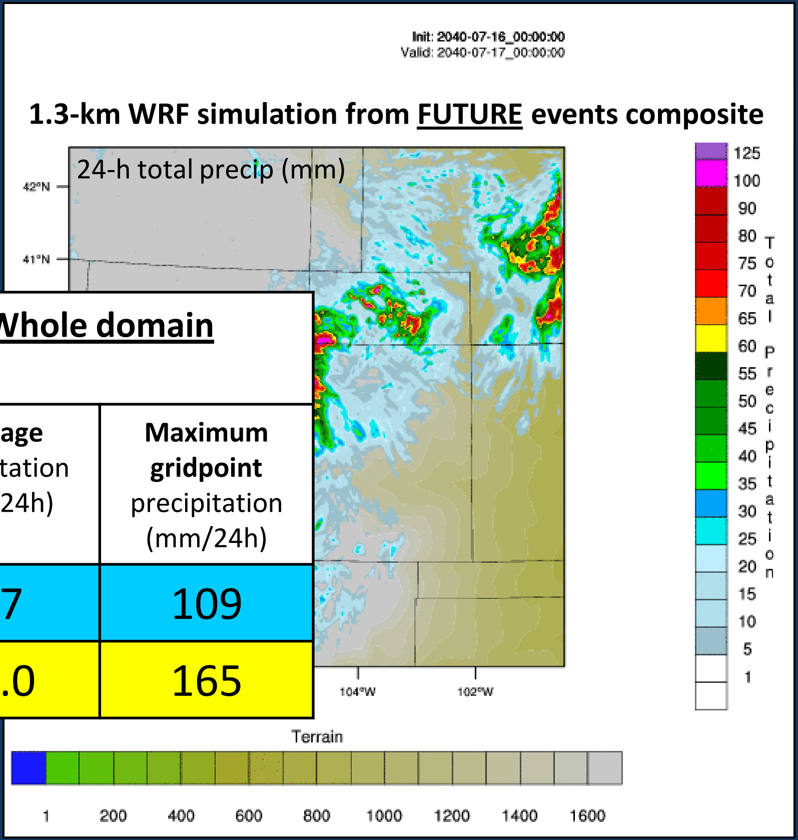
Create WRF initial, boundary conditions from composite fields

1km WRF simulation from FUTURE events composite



2. Extreme event composites as model initial conditions





GFDL ts COMPOSITES	**Whole domain**	
	Average precipitation (mm/24h)	**Maximum gridpoint** precipitation (mm/24h)
PAST	4.7	109
FUTURE	10.0	165

- Increase in future intensity, precipitation maxima; trends in composite results agree with averages of top 10 past, future individual events
- *For this particular region/driving model*, 1 composite-initialized model run yields similar qualitative results as 10 individual model runs: implications for resource-limited user groups?
- Caveat! Success of method largely dependent on signal strength in event composites (timing of extreme events, over-smoothing of initial fields may be problematic*)

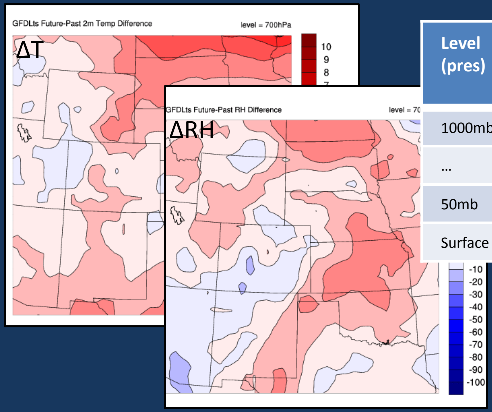
** WRF-CCSM composite runs not as successful*

3. “Climate Perturbation”/ “Pseudo-Global-Warming”/ “Delta Method” Experiment*

- *Assuming same synoptic forcing, what would an observed extreme event of the past look like with modified thermodynamics as specified by various future climate projections?*
- Using extreme event composites, difference past and future files to define “future climate anomaly” for T, RH
- Add changes to original WRF input files; run model

Using NARCCAP GFDL Composite files:

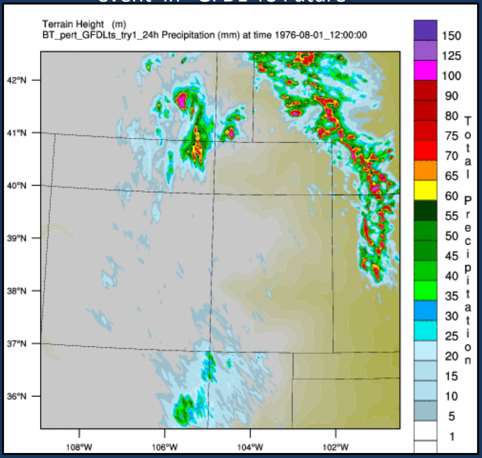
Compute ΔT_{comp}, ΔRH_{comp} between future, past at each gridpoint, vertical level



Level (pres)	ΔT (future -past)	ΔRH (future -past)
1000mb		
…		
50mb		
Surface		

Add perturbations to WRF input files; run model on perturbed data

24h total precip (mm) for Big Thompson event in “GFDL-TS Future”



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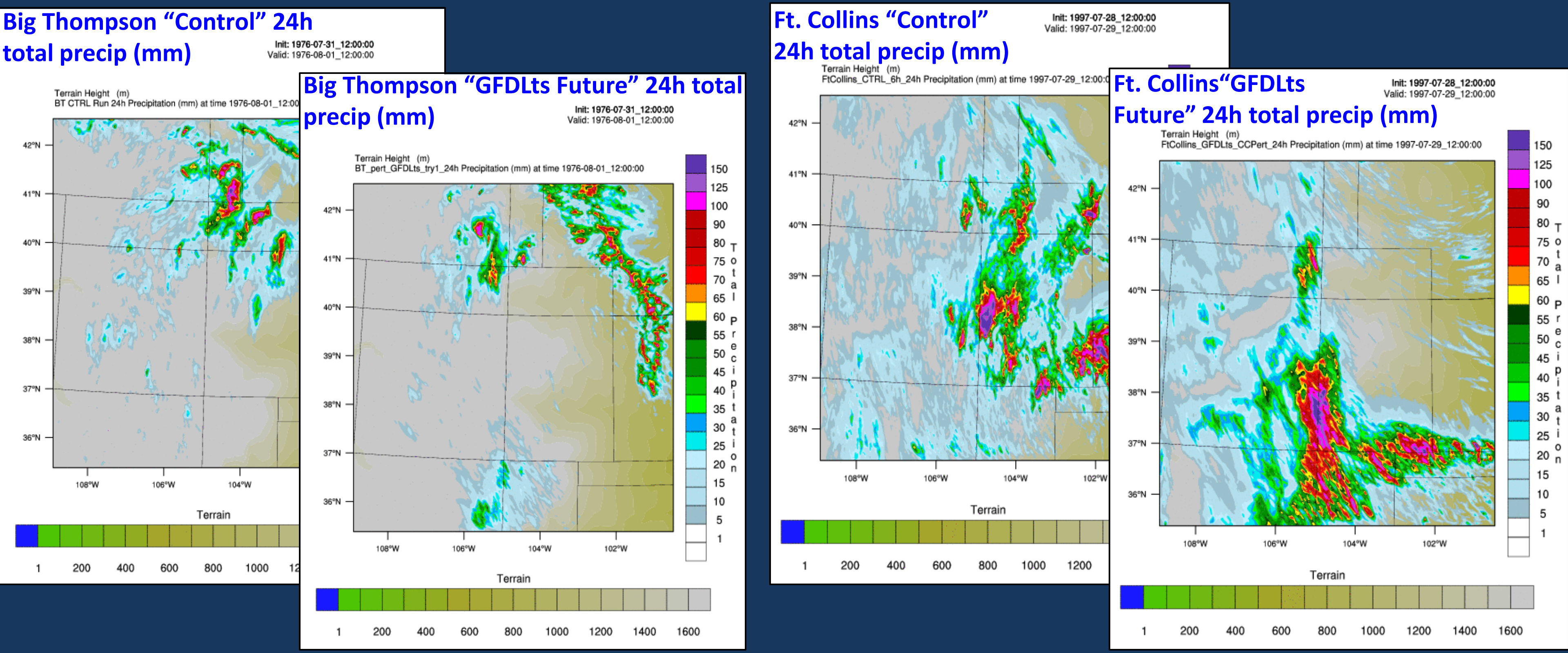
*Methodology similar to Schär et al. (1996), Hara et al. (2008), Kawase et al. (2008), Hill and Lackmann (2011), and Rasmussen et al. (2011)

Big Thompson (1976) and Fort Collins (1997) Floods: Climate Perturbed Run



Big Thompson "Control" 24h total precip (mm)

Big Thompson "GFDLts Future" 24h total precip (mm)

Ft. Collins "Control" 24h total precip (mm)

Ft. Collins"GFDLts Future" 24h total precip (mm)

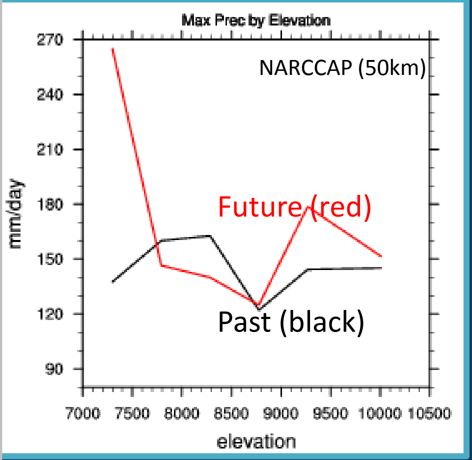
- Observed event location shifts north; magnitude of overall maxima similar
- Should "future" climate signal be derived from shifts in uniform seasonal averages, gridpoint-based shifts on "extreme-producing" days only, other?
- Proof of concept stage: value likely lies in ability to perturb environment across wide spectrum of climate change scenarios

Comparison of three approaches with 50-km NARCCAP data

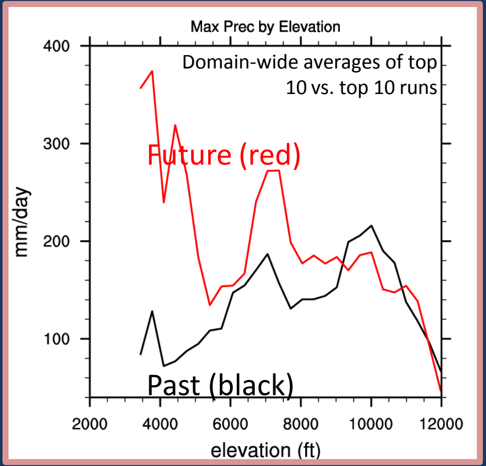
Compare 3 approaches, NARCCAP:

- How do 50-km, 1.3-km simulations compare?
- What value is being added (if any?)
- Do we see the same qualitative trends?

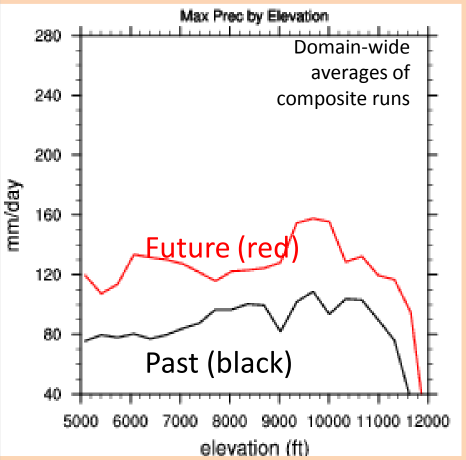
NARCCAP (50km)



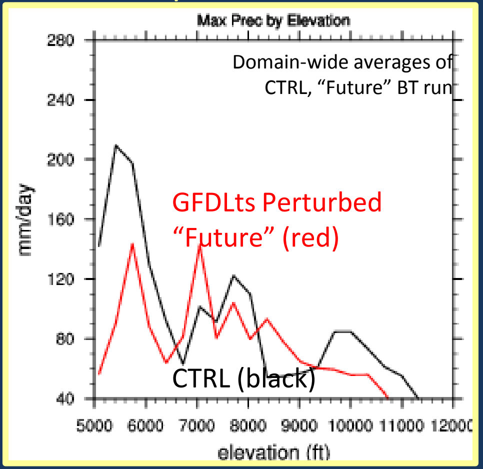
1. Individual simulations

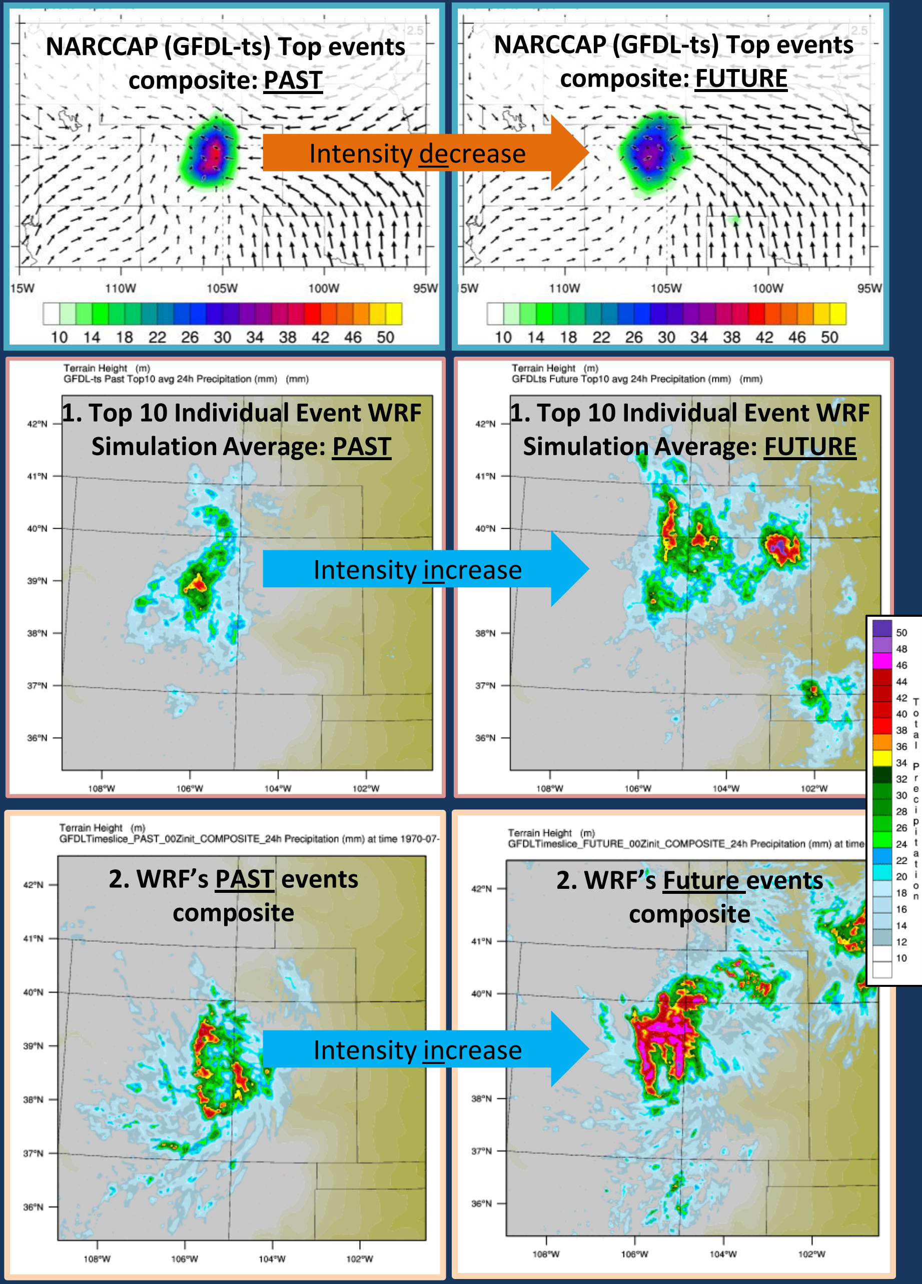


2. Composite approach



3. Climate perturbation method





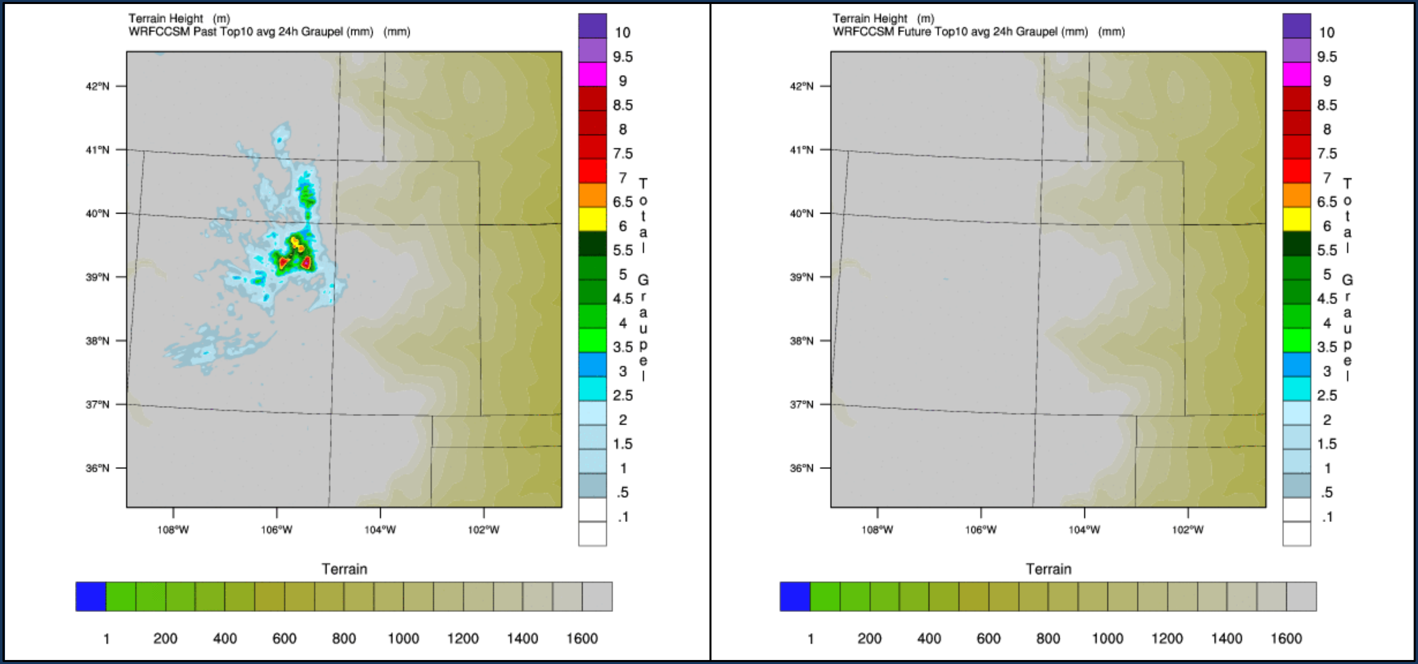
“Surprise” findings?

- What happens to surface hail?

Example of <u>average accumulated surface graupel/hail </u>fields in Top 10 past vs. Top 10 future individual cases

Event-total (24-h) hail at the surface: **<u>Past</u>**

(Average of “top 10” 1-km simulations from WRF-CCSM)



Event-total (24-h) hail at the surface: **<u>Future</u>**

(Average of “top 10” 1-km simulations from WRF-CCSM)

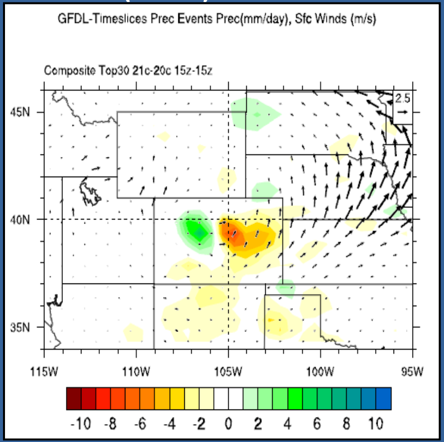
- Trend persists across *all* simulations: individual top events, composite-based, delta-method, *and* with GFDL-ts and WRF-CCSM…
- Until you change the microphysics scheme…
- *Importance of model microphysics with increased downscaling!*

Comparison of GFDL-ts, WRF-CCSM results

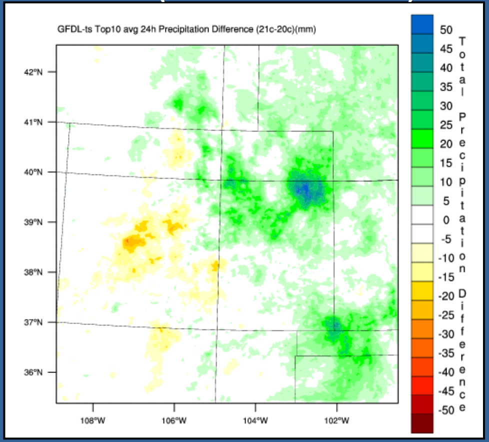
GFDL-Timeslices

Avg difference (Future – Past) of Top 10 events: **GFDL-Timeslices**
(red/orange = drier in future; blue/green = wetter in future)

NARCCAP (50 km) GFDL-Timeslice



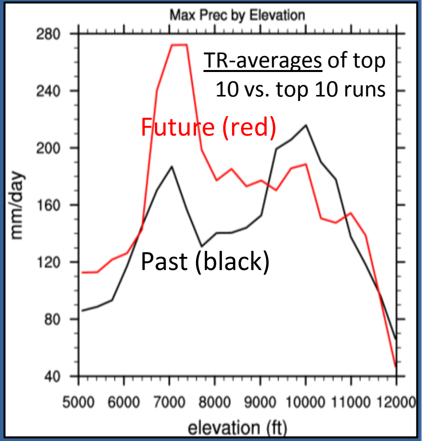
WRF-1km (from GFDL-Timeslice)



Summary by region:
WRF 1-km **<u>Top 10 events</u>** from GFDL-ts:

GFDL-Timeslices	**<u>Target Region Only</u>** (Average of all 10 cases)		**<u>Whole domain</u>** (Average of all 10 cases)	
	Average precip (mm/24h)	Max precip (mm/24h)	Average precip (mm/24h)	Max precip (mm/24h)
PAST	**16.3**	**117**	**5.1**	**125**
FUT	**18.0**	**131**	**9.3**	**207**

Elevation analysis: **<u>Max</u>** Precip
(Top 10 event averages)



<u>TR-averages</u> of top 10 vs. top 10 runs

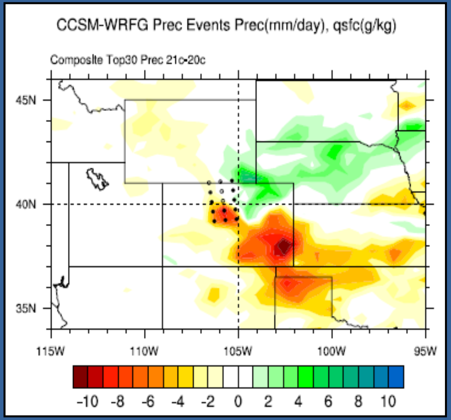
Future (red)

Past (black)

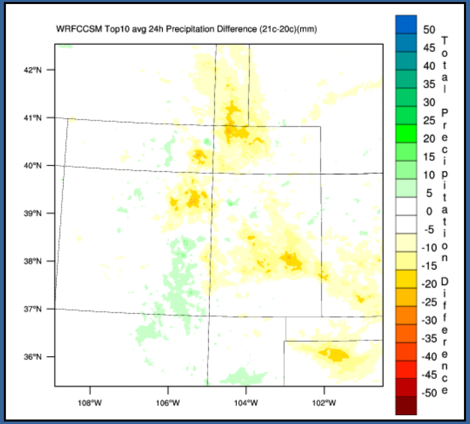
WRF-CCSM

Avg difference (Future – Past) of Top 10 events: **WRF-CCSM**
(red/orange = drier in future; blue/green = wetter in future)

NARCCAP (50 km) WRF-CCSM



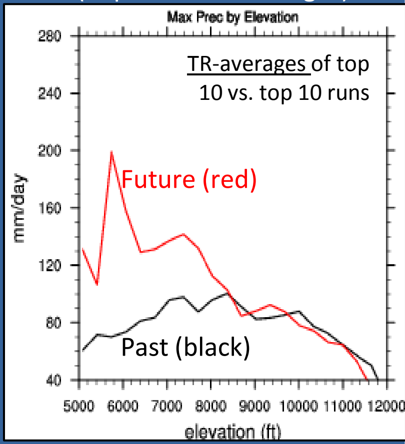
WRF-1km (from WRF-CCSM)



Summary by region:
WRF 1-km Top 10 events from WRF-CCSM:

WRF-CCSM	**<u>Target Region Only</u>** (Average of all 10 cases)		**<u>Whole domain</u>** (Average of all 10 cases)	
	Average precip (mm/24h)	Maximum precip (mm/24h)	Average precip (mm/24h)	Maximum precip (mm/24h)
PAST	**13.3**	**74**	**6.1**	**101**
FUT	**10.1**	**79**	**4.0**	**103**

Elevation analysis: **<u>Max</u>** Precip
(Top 10 event averages)



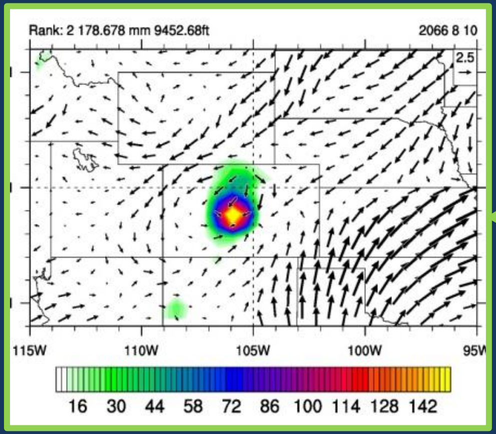
<u>TR-averages</u> of top 10 vs. top 10 runs

Future (red)

Past (black)

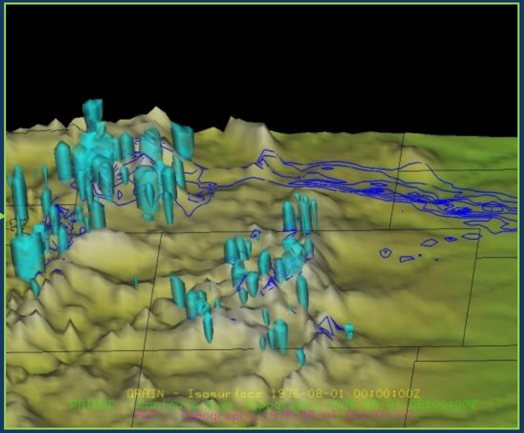
Preliminary conclusions

1. High-resolution simulations offer insight into past, future extreme events: spatial/temporal detail, assessment of storm-scale physical processes
2. Preliminary results (GFDL-timeslices, WRF-CCSM) suggest:
    - more intense precipitation extremes in future, particularly ~5000 – 9000ft (both models)
    - changes in hail amount at surface due to sub-cloud melting (both models)
    - GFDL-ts wetter overall (past and future) than WRF-CCSM
    - WRF-CCSM may have diurnal precip, QC issues: has several days with 10^{20} mm of precip reported, composites problematic
3. Value over RCM likely depends on objective (and geographic region, computing capabilities…)
    - Over whole domain, average precip amounts may be similar but spatial pattern of changes reversed in high-res vs. RCM
    - Ongoing work to establish why pattern reversal results; also differences in high- vs. low-elevation locations
4. Comparison of model methodologies underway: Composite approach may offer shortcut around individual simulations in some cases; strengths, weaknesses of all approaches to be analyzed further
5. Need (at least) one more set of NARCCAP simulations for downscaling (all methods)



50km vs. 1km?

Objective?



Acknowledgments

- *US Bureau of Reclamation:*

  Dave Raff, John England, Chuck Hennig, Levi Brekke, Victoria Sankovich, Jade Soddell, Subhrendu Gangopandyah
- UCAR/CLIVAR/PACE program
- NARCCAP Project (NCAR)
- NCAR, National Science Foundation for WRF, NCL, wrfhelp
- Unidata (UCAR) for IDV, GEMPAK
- NOAA ESRL High-Performance Computing System
- Western Water Assessment (WWA)

Contact:

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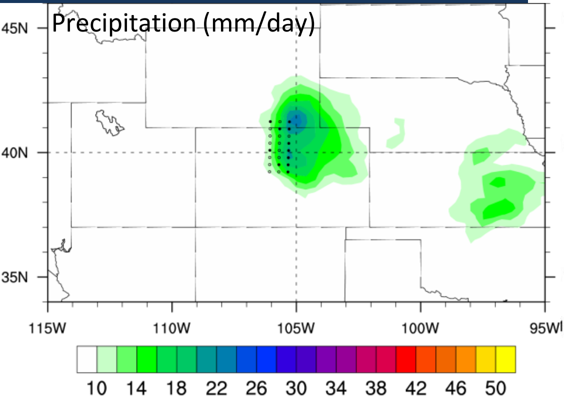
kelly.mahoney@noaa.gov

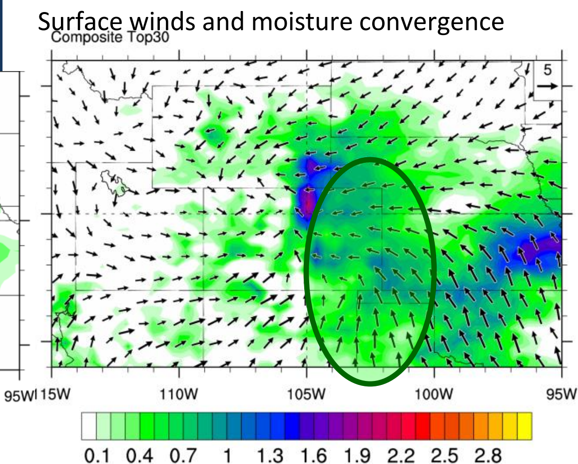
Extra slides

Case selection: Comparing NARCCAP extreme cases to extreme precipitation climatology

- Case selection quality control:

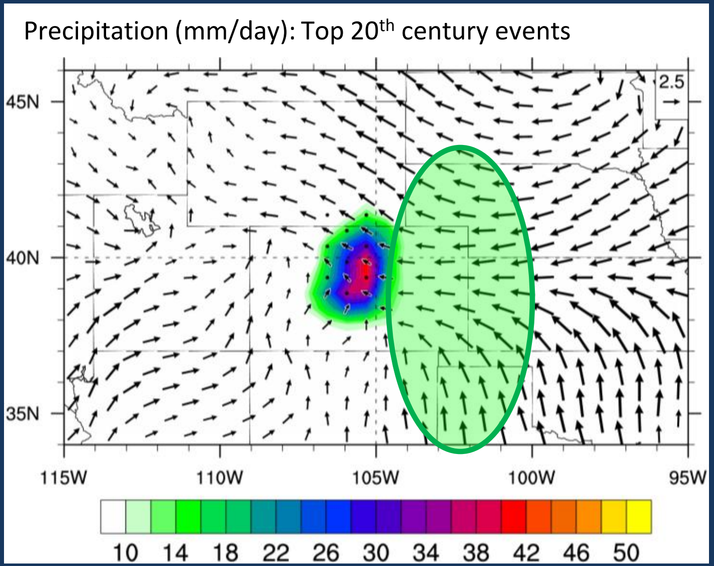
NARR Analysis
(composites of observed extreme events from 1979 - 2008)

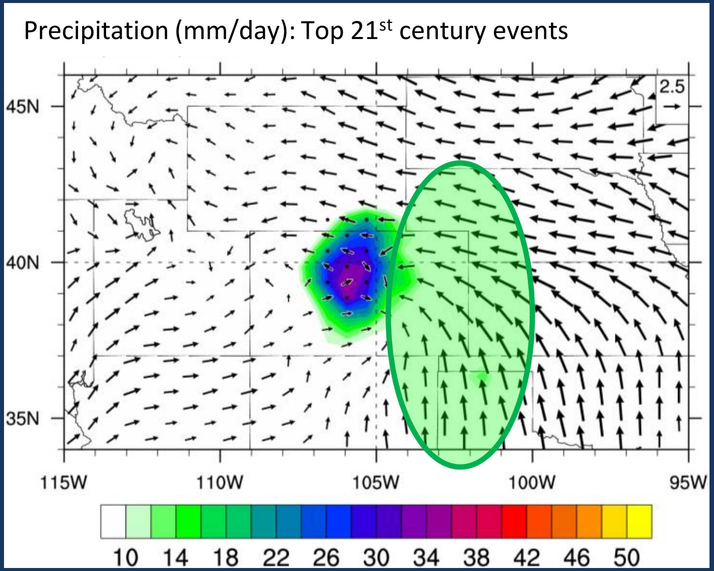




- Compare RCM's extreme event characteristics to observed extreme events (NARR)
- Moist, easterly (upslope) flow dominant weather pattern in both observations and models; large scale weather matches overall

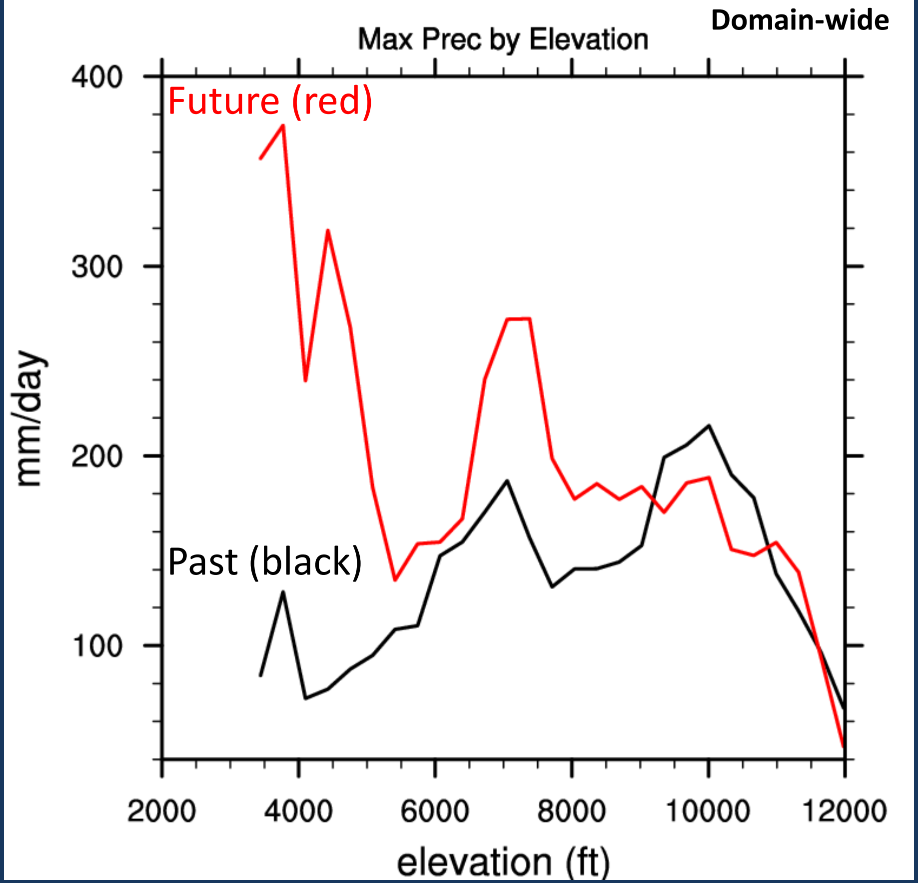
Regional climate model (GFDL) extreme event composites





Preliminary Results: Analysis of Top 10 past events vs. Top 10 future individual events

Does elevation of heaviest precipitation change from past to future?

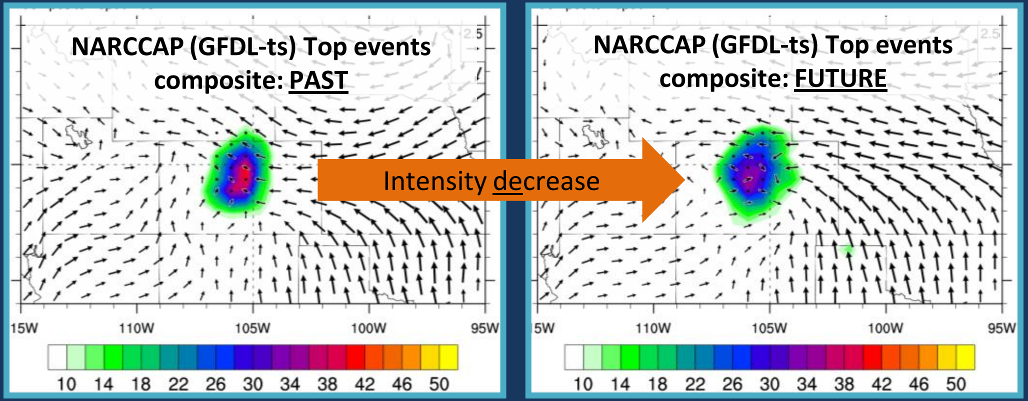


- Intense precip in future simulations increases up to 9000ft (~2700m)
- More cases, regions to be examined
- Shifts in this elevation range relevant to water resource management concerns, flood/dam safety!

Comparison of three approaches with 50-km NARCCAP data

Compare 3 approaches, NARCCAP:

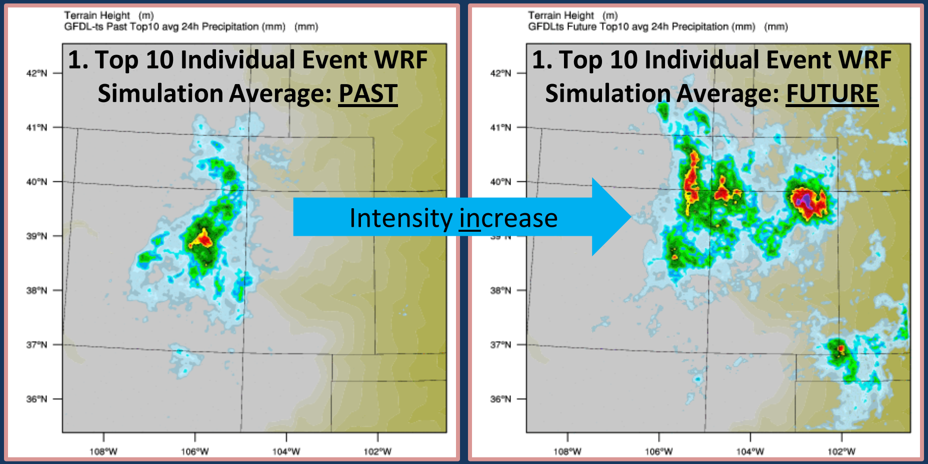
- How do 50-km, 1.3-km simulations compare?
- What value is being added (if any?)
- Do we see the same qualitative trends?



NARCCAP (GFDL-ts) Top events composite: PAST

NARCCAP (GFDL-ts) Top events composite: FUTURE

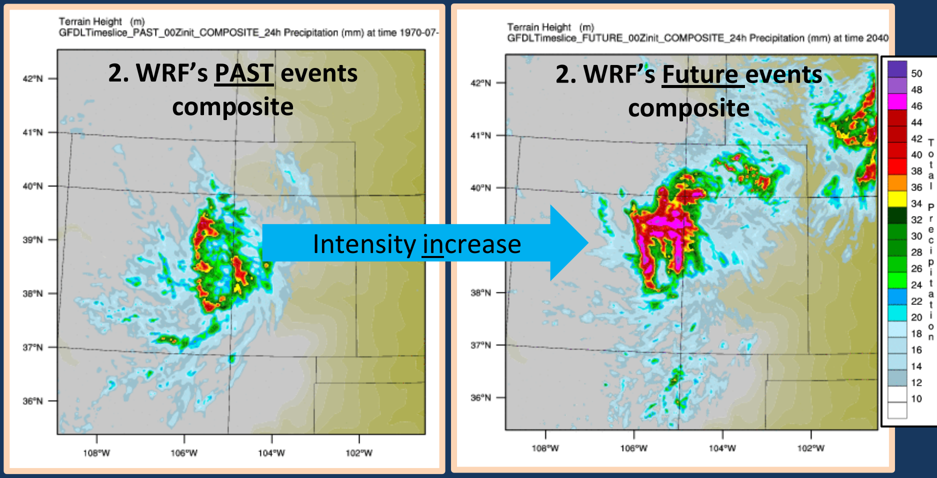
Intensity decrease



1. Top 10 Individual Event WRF Simulation Average: PAST

1. Top 10 Individual Event WRF Simulation Average: FUTURE

Intensity increase



2. WRF's PAST events composite

2. WRF's Future events composite

Intensity increase

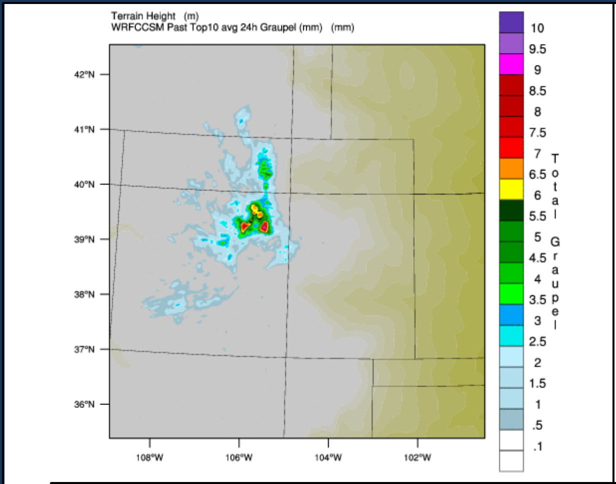
"Surprise" findings?

- What happens to surface hail?

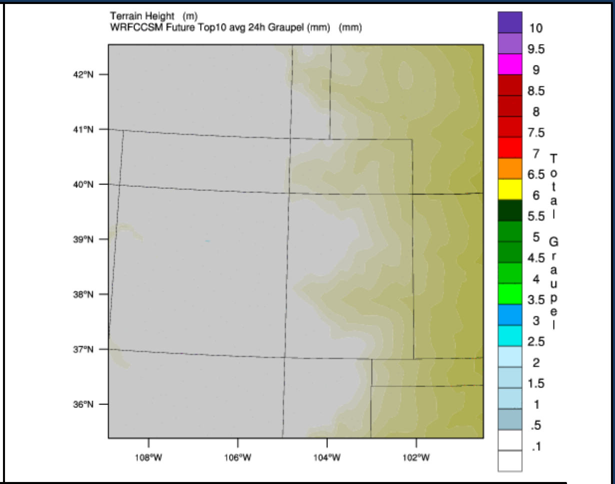
Example of <u>average accumulated surface graupel/hail </u>fields in Top 10 past vs. Top 10 future individual cases

Event-total (24-h) hail at the surface: **<u>Past</u>**

(Average of "top 10" 1-km simulations from WRF-CCSM)



Terrain Height (m)
WRFCCSM Past Top10 avg 24h Graupel (mm) (mm)

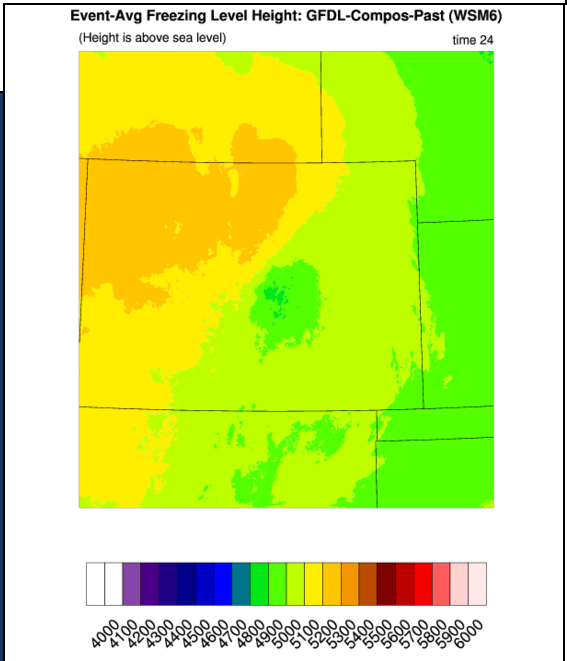


Terrain Height (m)
WRFCCSM Future Top10 avg 24h Graupel (mm) (mm)

Event-total (24-h) hail at the surface: **<u>Future</u>**

(Average of "top 10" 1-km simulations from WRF-CCSM)

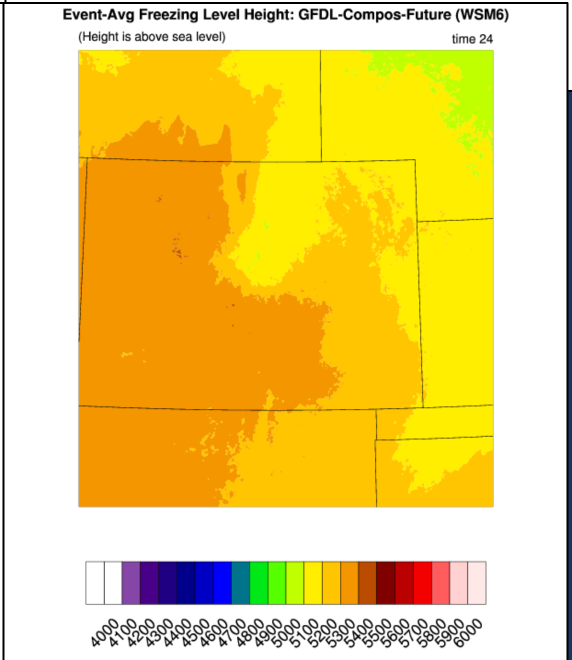
Average freezing level height: **<u>Past</u>**



Event-Avg Freezing Level Height: GFDL-Compos-Past (WSM6)

(Height is above sea level)

time 24



Event-Avg Freezing Level Height: GFDL-Compos-Future (WSM6)

(Height is above sea level)

time 24

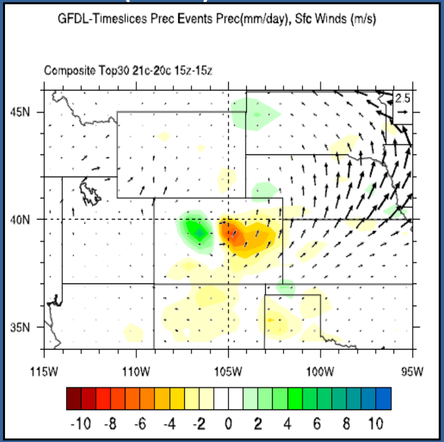
Average freezing level height: **<u>Future</u>**

Comparison of GFDL-ts, WRF-CCSM results

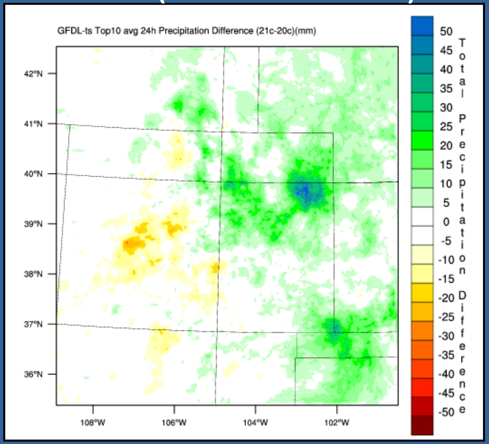
GFDL-Timeslices

Avg difference (Future – Past) of Top 10 events: **GFDL-Timeslices**
(red/orange = drier in future; blue/green = wetter in future)

NARCCAP (50 km) GFDL-Timeslice



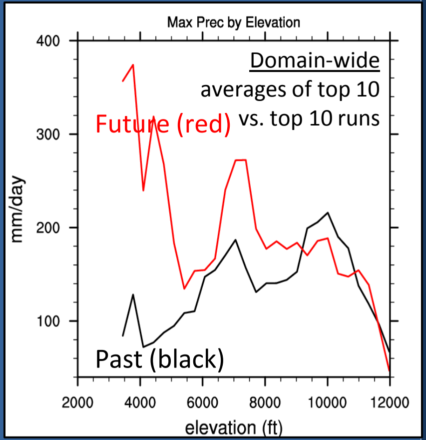
WRF-1km (from GFDL-Timeslice)



Summary by region:
WRF 1-km Top 10 events from GFDL-ts:

GFDL-Timeslices	Target Region Only (Average of all 10 cases)		Whole domain (Average of all 10 cases)	
	Average precip (mm/24h)	Max precip (mm/24h)	Average precip (mm/24h)	Max precip (mm/24h)
PAST	**16.3**	**117**	**5.1**	**125**
FUT	**18.0**	**131**	**9.3**	**207**

Elevation analysis
(Top 10 event averages)



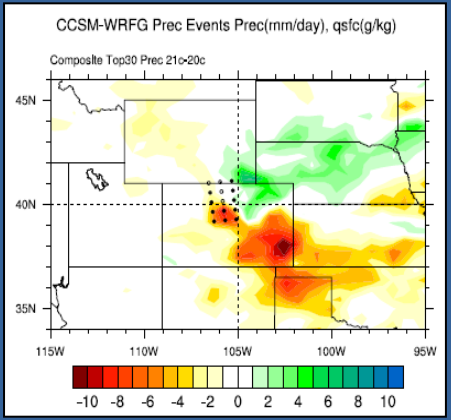
Domain-wide averages of top 10 Future (red) vs. top 10 runs

Past (black)

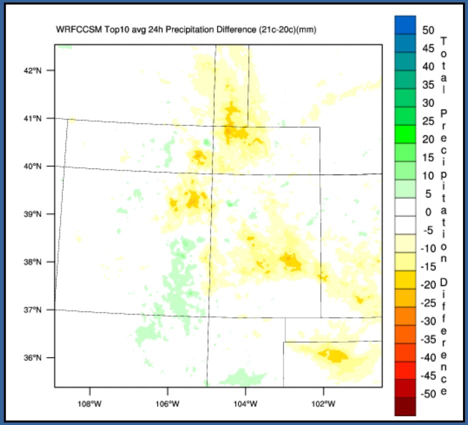
WRF-CCSM

Avg difference (Future – Past) of Top 10 events: **WRF-CCSM**
(red/orange = drier in future; blue/green = wetter in future)

NARCCAP (50 km) WRF-CCSM



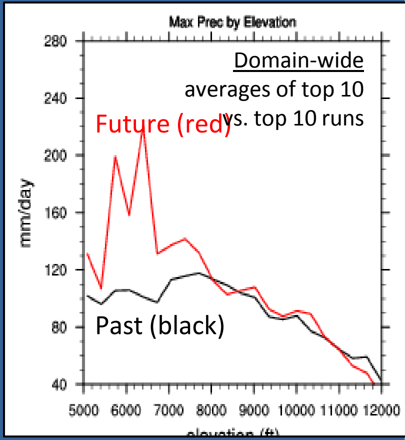
WRF-1km (from WRF-CCSM)



Summary by region:
WRF 1-km Top 10 events from WRF-CCSM:

WRF-CCSM	Target Region Only (Average of all 10 cases)		Whole domain (Average of all 10 cases)	
	Average precip (mm/24h)	Maximum precip (mm/24h)	Average precip (mm/24h)	Maximum precip (mm/24h)
PAST	**13.3**	**74**	**6.1**	**101**
FUT	**10.1**	**79**	**4.0**	**103**

Elevation analysis
(Top 10 event averages)



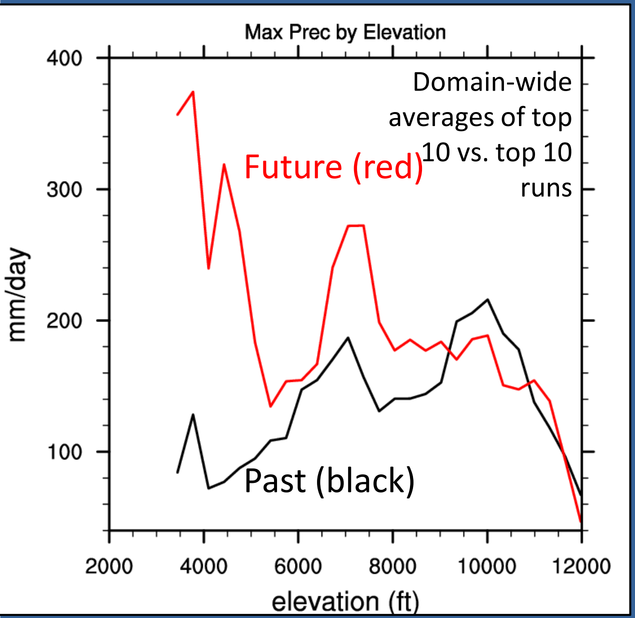
Domain-wide averages of top 10 Future (red) vs. top 10 runs

Past (black)

Comparison of three approaches with one another

1. Individual simulations: Top 10 past vs. top 10 future

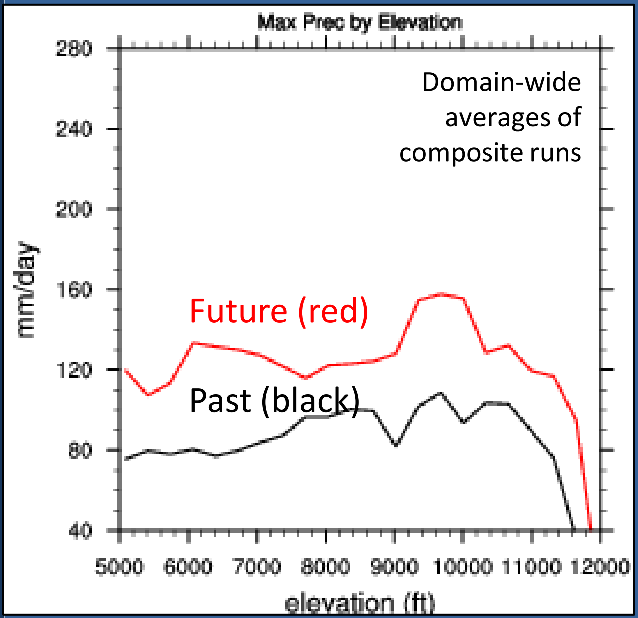
Top 10 vs. Top 10 avgs	**Whole domain (Average of all 10 cases)**	
	Average precipitation (mm/24h)	**Maximum gridpoint** precipitation (mm/24h)
PAST	5.1	125
FUTURE	9.3	207



Domain-wide averages of top 10 vs. top 10 runs

2. Composite approach

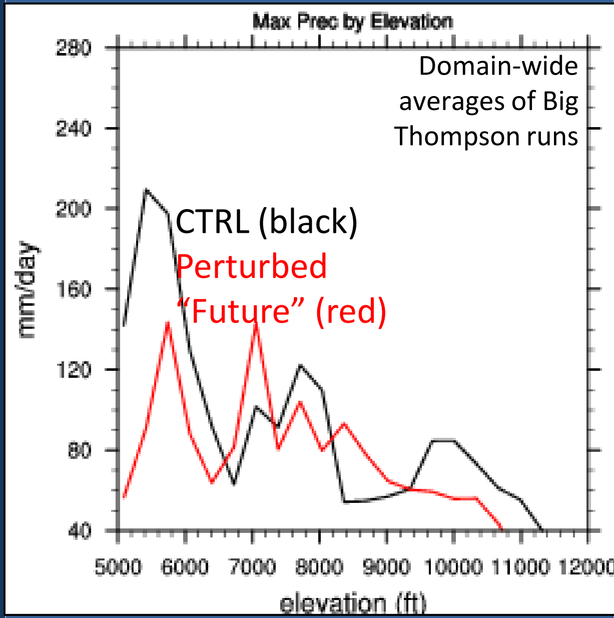
GFDL-ts COMPOSITES	**Whole domain**	
	Average precipitation (mm/24h)	**Maximum gridpoint** precipitation (mm/24h)
PAST	4.7	109
FUTURE	10.0	165



Domain-wide averages of composite runs

3. Climate perturbation/ delta method

Big Thompson experiment	**Whole domain**	
	Average precipitation (mm/24h)	**Maximum gridpoint** precipitation (mm/24h)
PAST(CTRL)	6.9	209
FUTURE	7.0	187



Domain-wide averages of Big Thompson runs

Comparison of three approaches with 50-km NARCCAP data

- Compare 3 approaches NARCCAP:
  - How does 50-km data compare to high-res WRF simulations?
  - What value is being added (if any?) in the detail?
  - Do we see the same qualitative trends?

NARCCAP (50km)

NARCCAP (50km) Top 10 vs. Top 10 avgs	**Whole domain** (Average of all 10 cases)	
	Average precipitation (mm/24h)	**Maximum gridpoint** precipitation (mm/24h)
PAST	7.8	139
FUTURE	9.6	174

1. Individual simulations

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

2. Composite approach

GFDL ts COMPOSITES	**Whole domain**	
	Average precipitation (mm/24h)	**Maximum gridpoint** precipitation (mm/24h)
PAST	4.7	109
FUTURE	10.0	165

3. Climate perturbation/ delta method

BT run	**Whole domain**	
	Average precipitation (mm/24h)	**Maximum gridpoint** precipitation (mm/24h)
PAST (CTRL)	6.9	209
FUTURE	7.0	187

Data details

- NARCCAP: North American Region Climate Change Assessment Program
  - Uses large scale forcing from 20th century and 21st century climate change (SRES A2) AOGCM experiments to force high resolution regional climate models.
  - http://www.narccap.ucar.edu/

- GFDL-AM2 (timeslice)
  - Observed SST/Sea-ice/GHG forcing for 20thC
  - Anomalous SST/Sea-ice/GHG from SRES A2 in 21stC run
  - Run atmo
    used)

Update WRF-CCSM detailsc

- WRF-CCSM

- Examine daily average (12UTC-12UTC) Precipitation from NARCCAP:
  - 20th century (1968-2000)
  - 21st century (2038-2070)
  - Warm season (June-July-August)

GFDL-ts vs. WRF-CCSM (top 10 case average): 2m-Temp

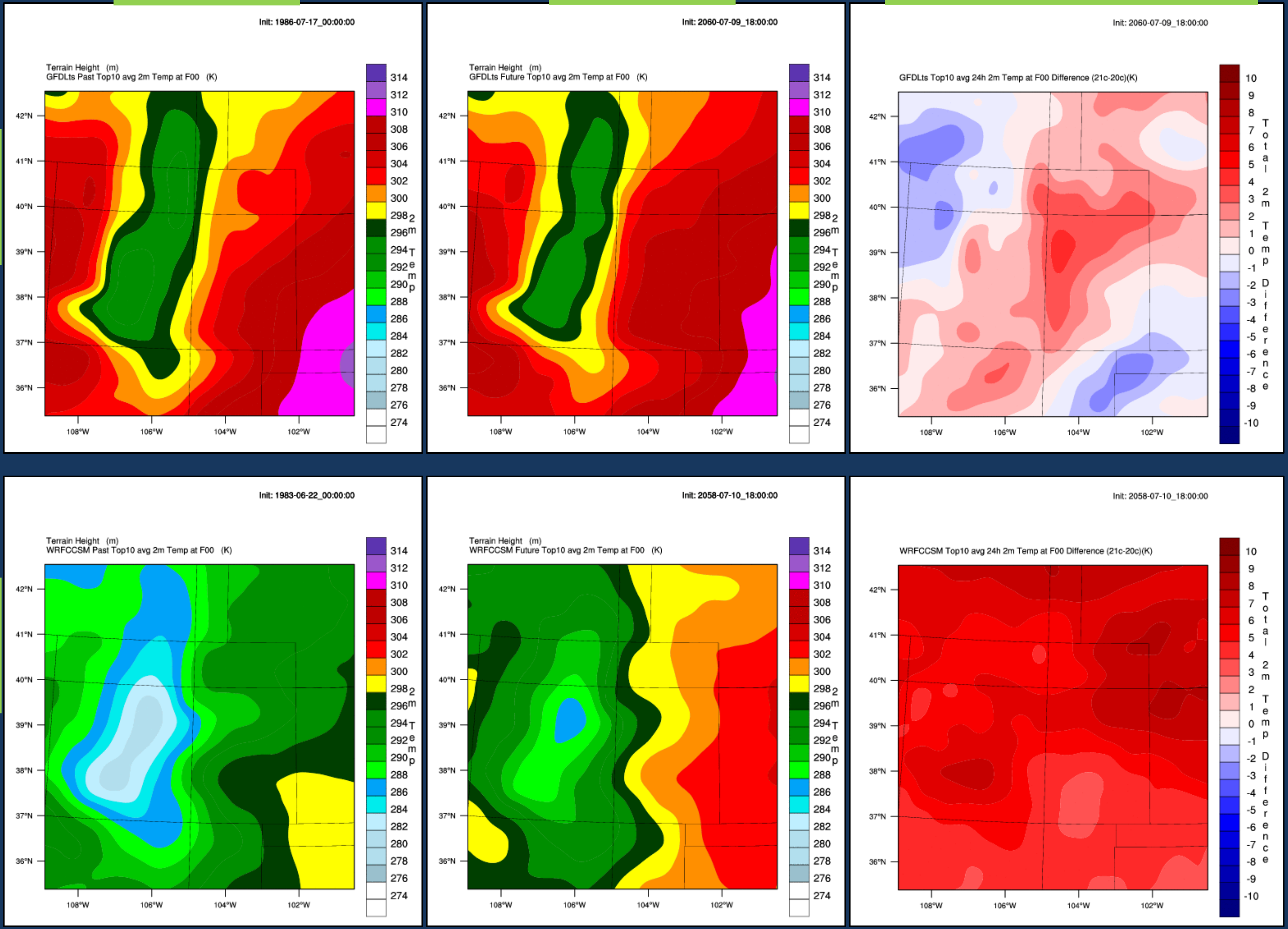
Past

Future

Difference (ΔT)

GFDL-ts

WRF-CCSM



Plot using narccap instead – make sure this isn't a WRF interpolation thing!

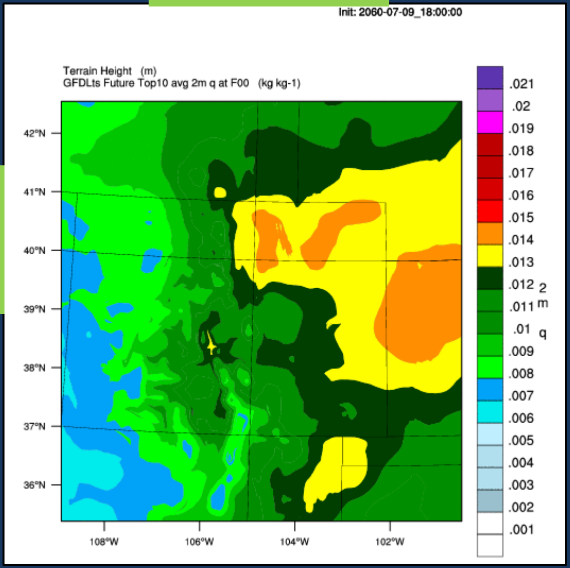
GFDL-ts vs. WRF-CCSM (top 10 case average at F00): 2m-MIXR

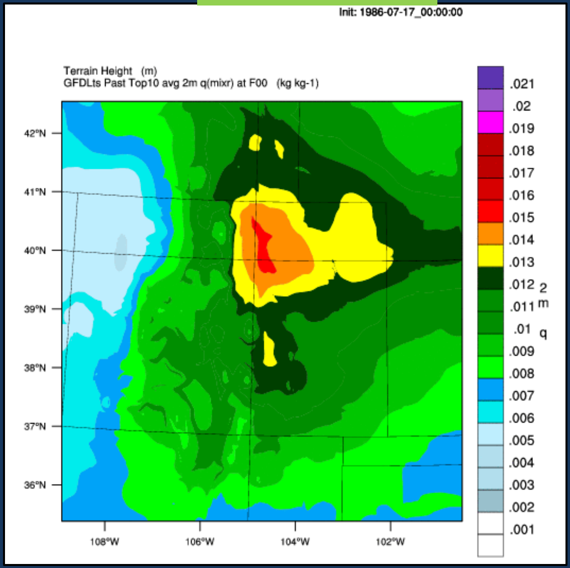
Past

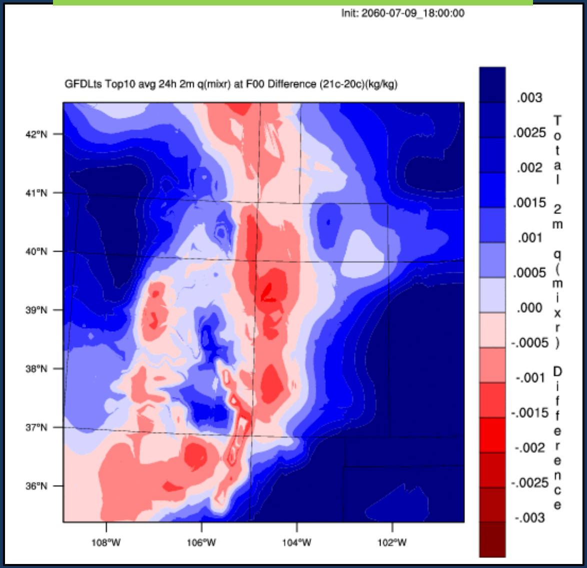
Future

Difference (ΔT)

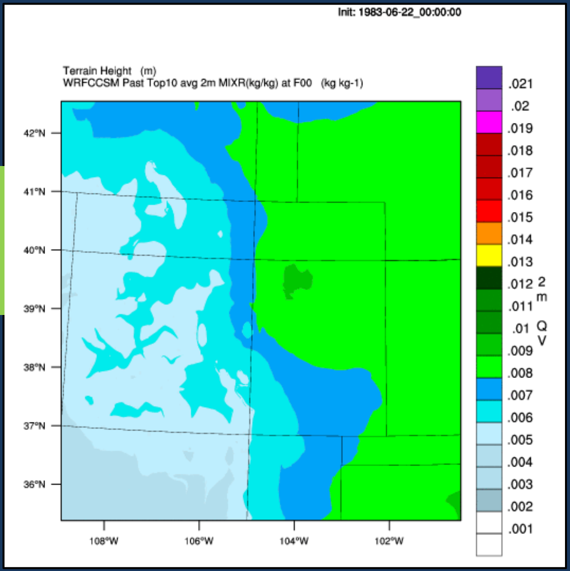
GFDL-ts

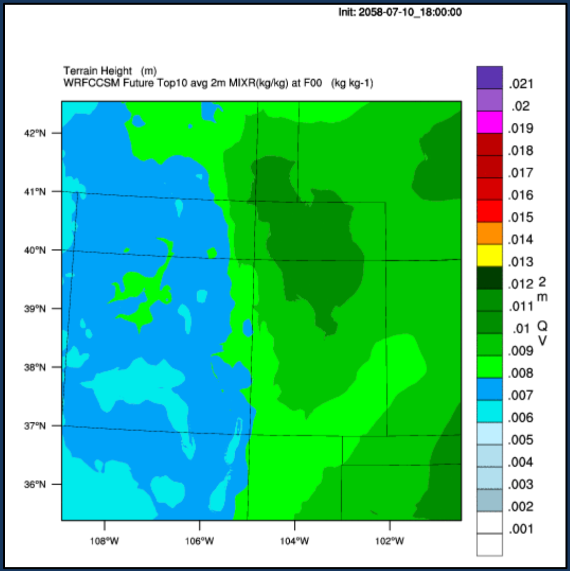


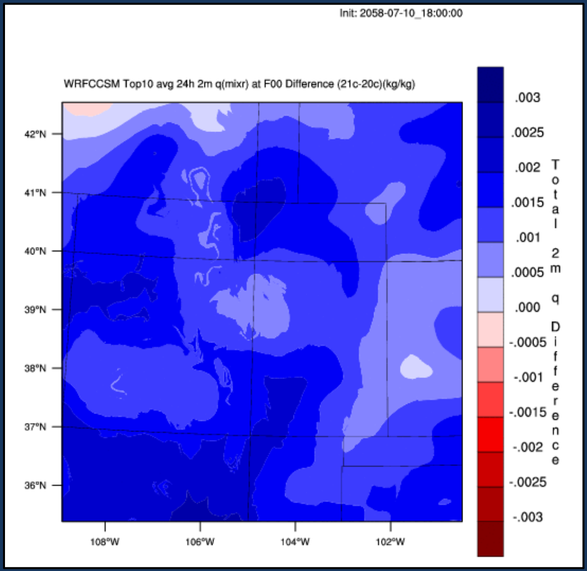




WRF-CCSM







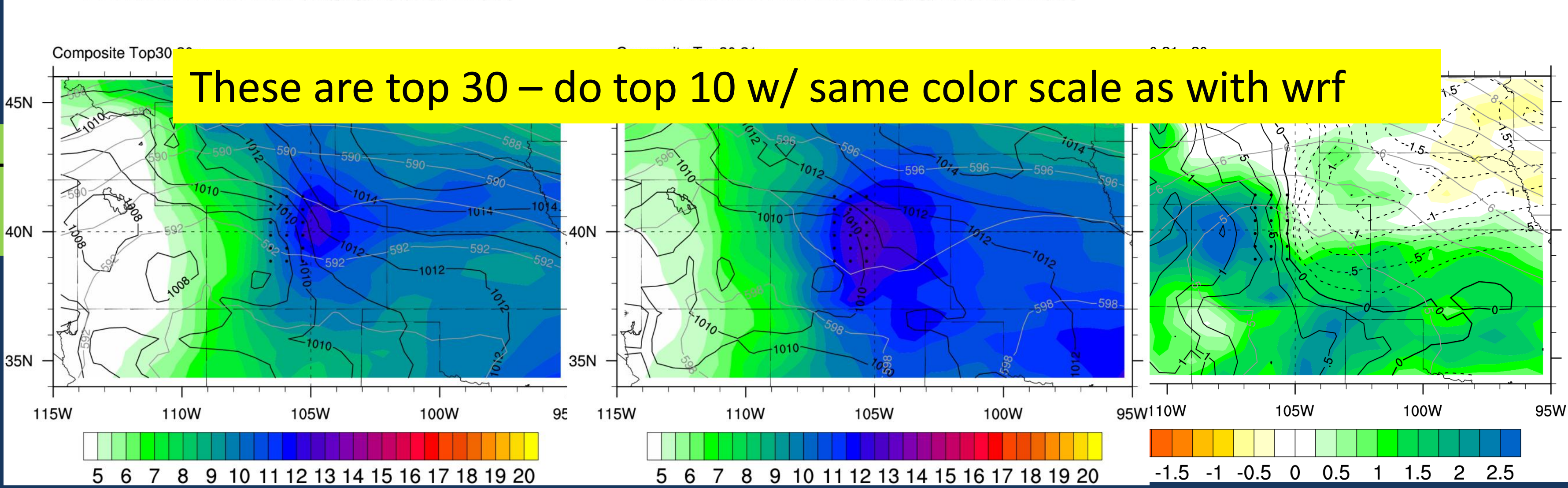
GFDL-ts vs. WRF-CCSM (top 10 case average at F00): 2m-MIXR

Past

Future

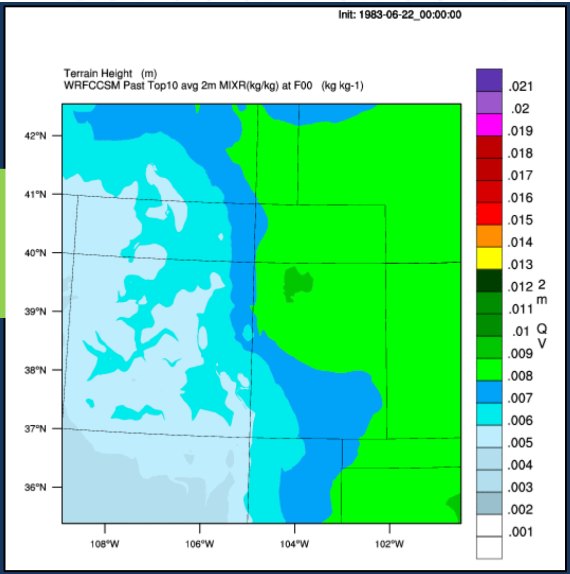
Difference (ΔT)

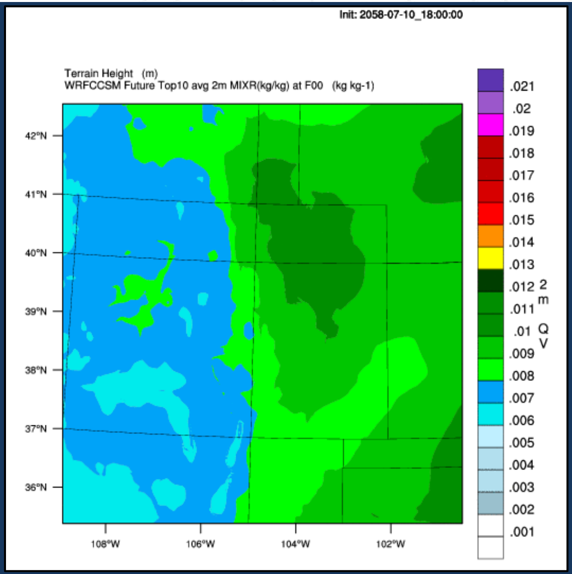
GFDL-ts

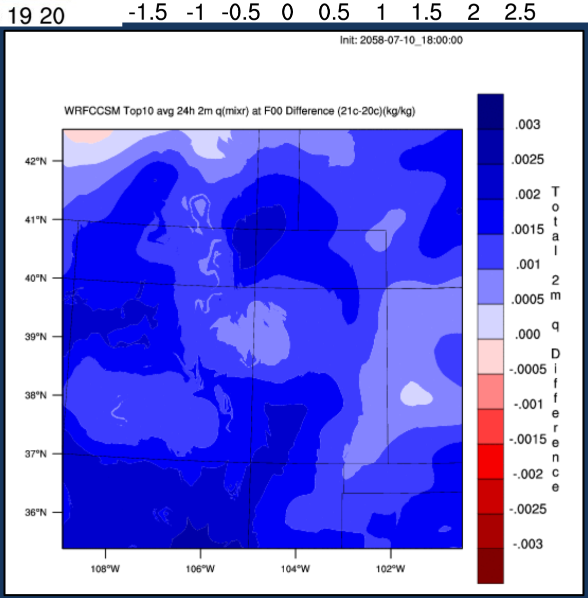


These are top 30 – do top 10 w/ same color scale as with wrf

WRF-CCSM







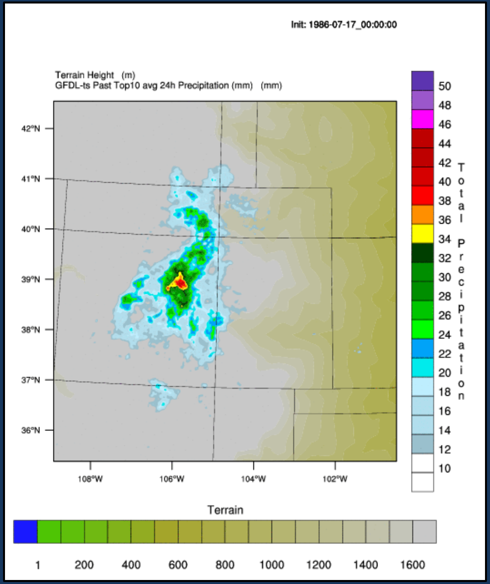
GFDL-ts vs. WRF-CCSM (top 10 case average): Precip (from WRF)

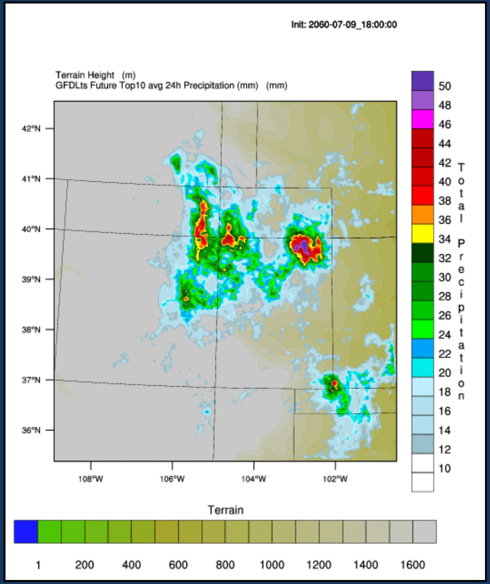
Past

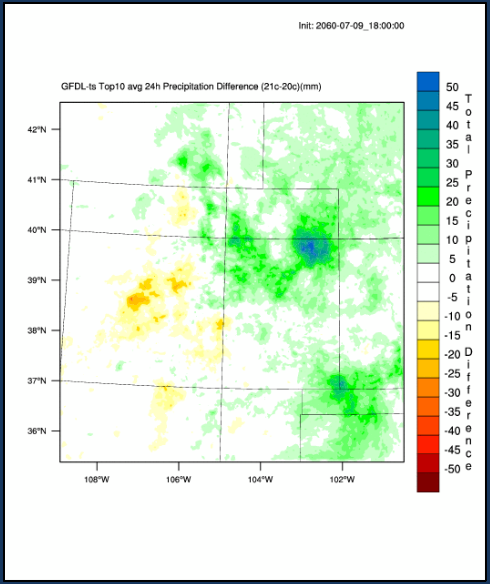
Future

Difference (ΔT)

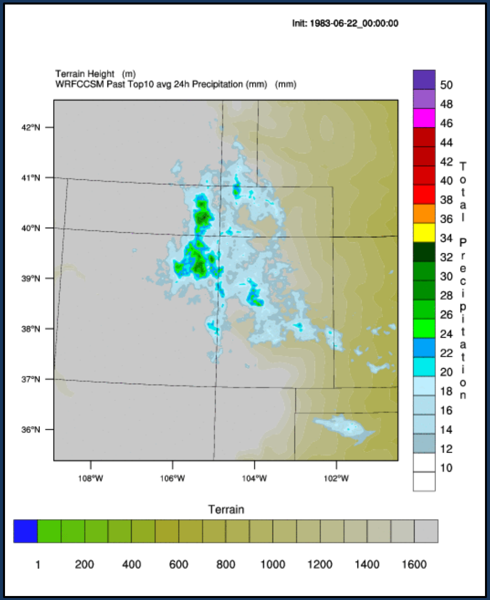
GFDL-ts

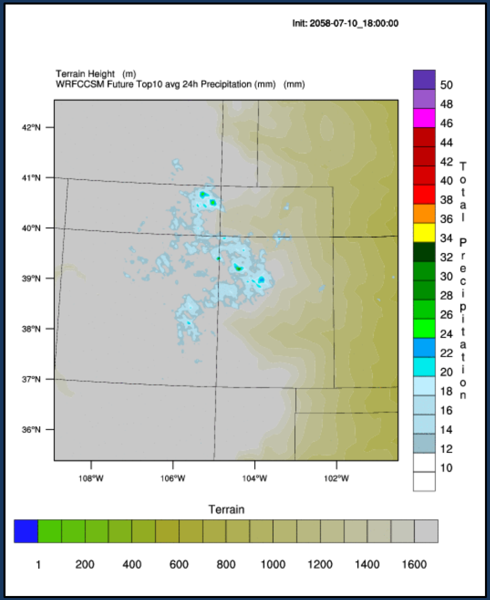


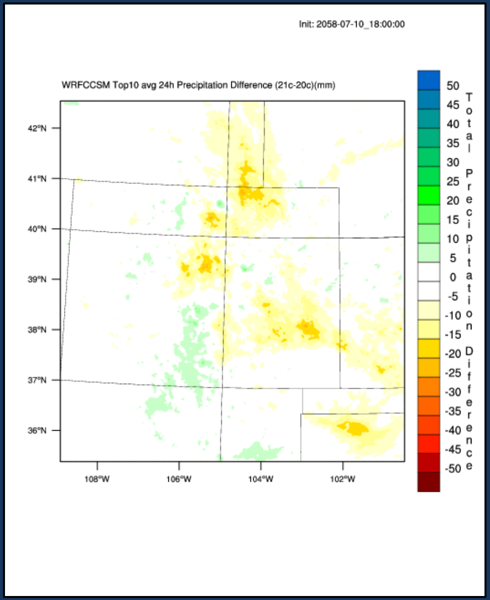




WRF-CCSM

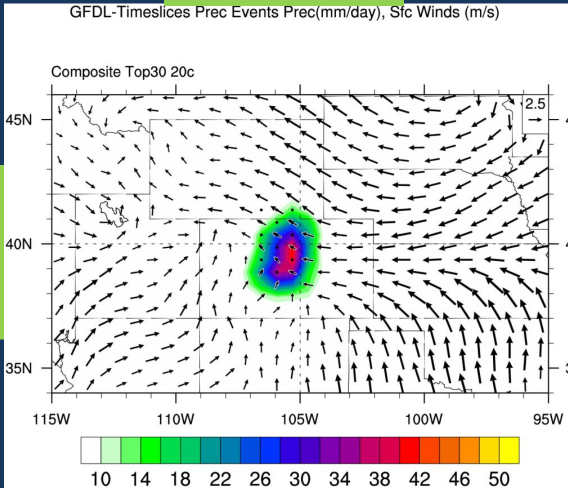




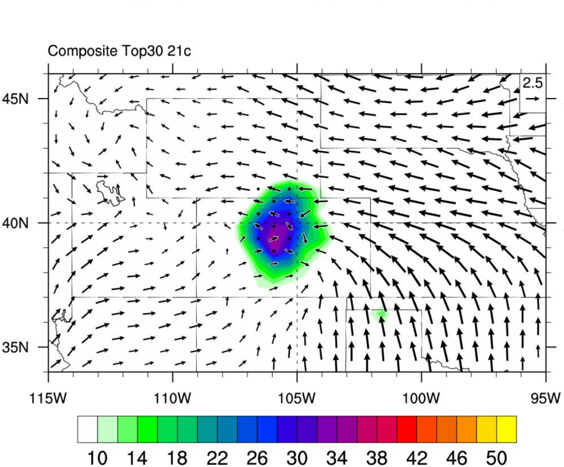


GFDL-ts vs. WRF-CCSM (top 10 case average): Precip (from NARCCAP)

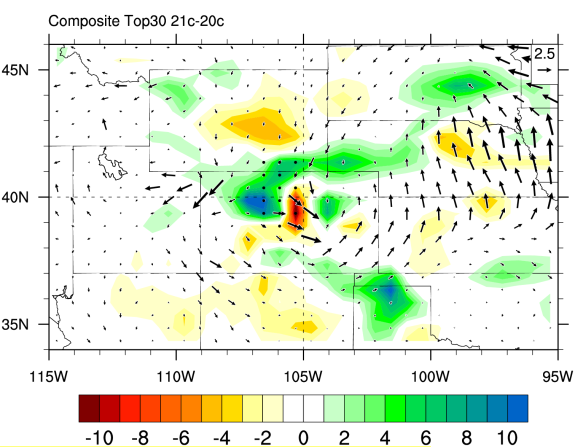
Past



Future



Difference (ΔT)



GFDL-ts

These are top 30 – do top 10 w/ same color scale as with wrf

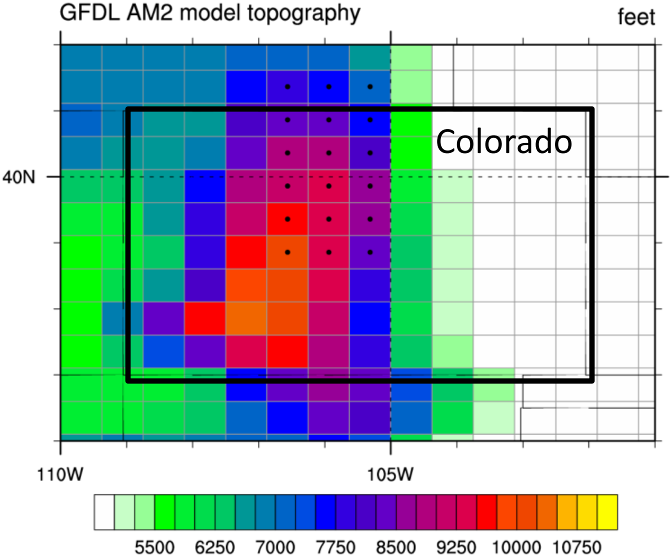
WRF-CCSM

GFDL-ts vs. WRF-CCSM (top 10 case average): Precipitable Water

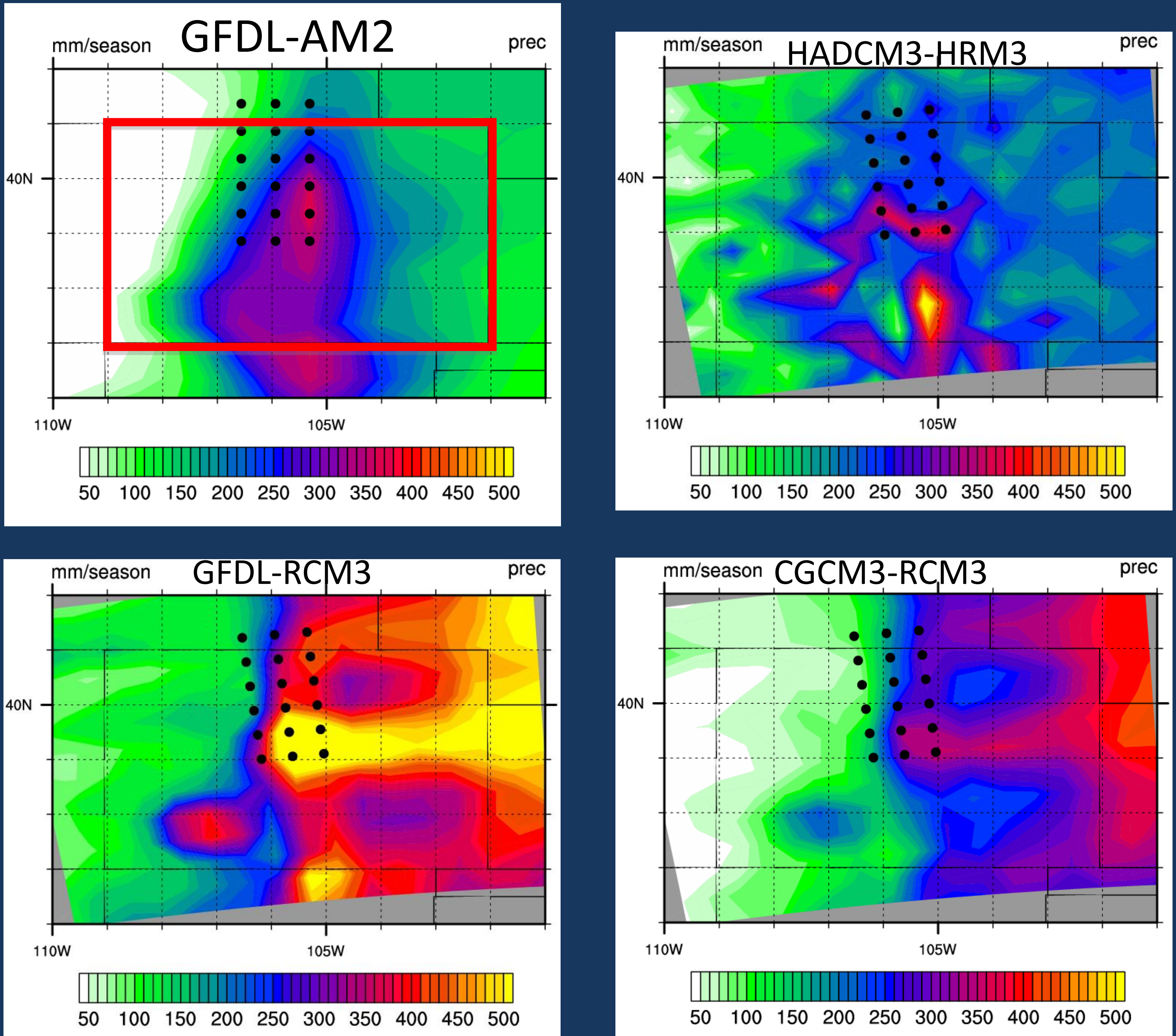
Add same thing for PW, CAPE

Targeted Composite Technique

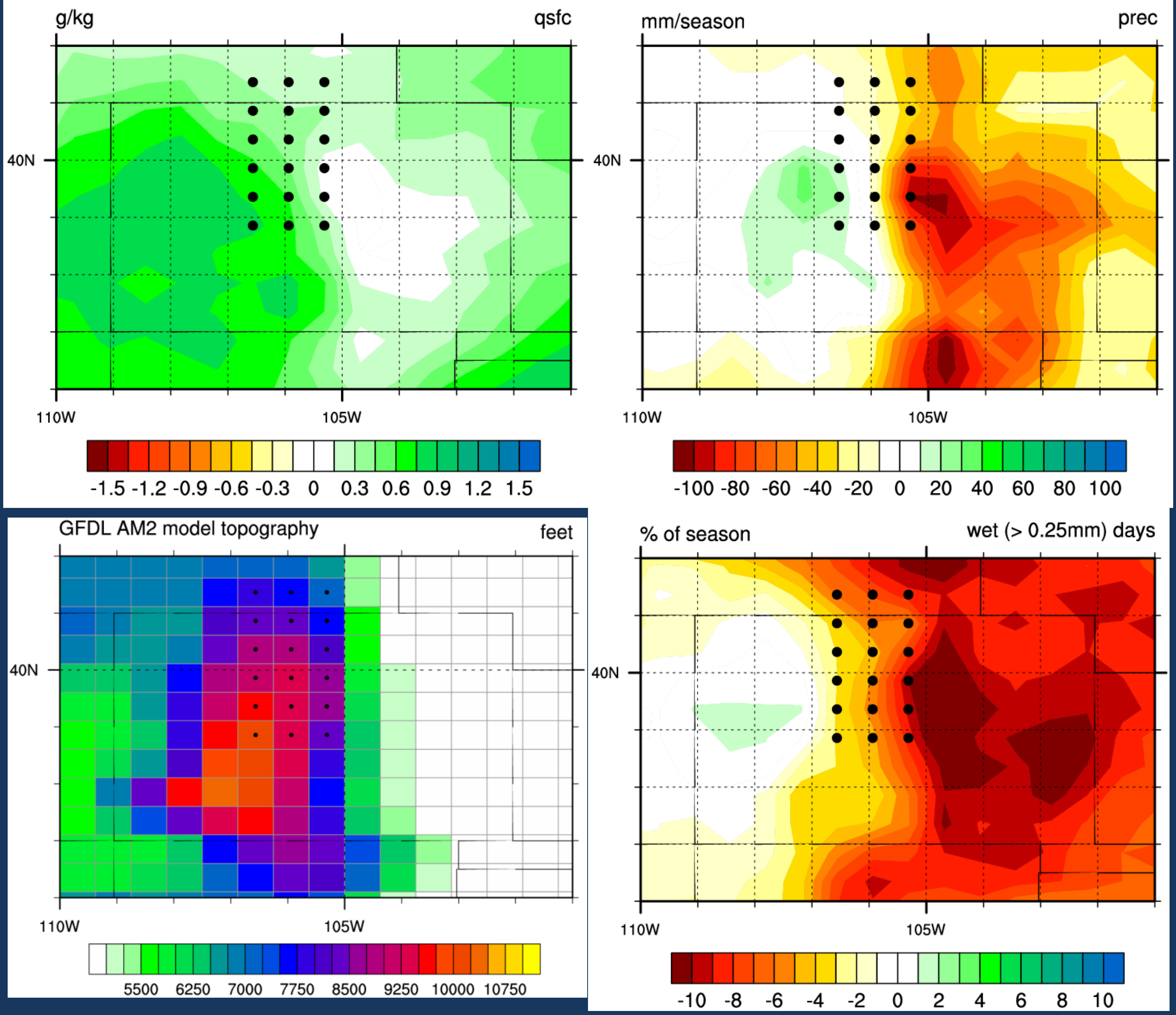
- Target region (TR): Colorado Front Range
- 38.5N-41.5N, 106.5W-105W
- Identify model grid points in TR
- Sort all Daily Prec values from JJA in TR
- Find top 30 Prec values from unique events
- Average prec, sfc hum, sfc winds and other fields (when avail) from each event

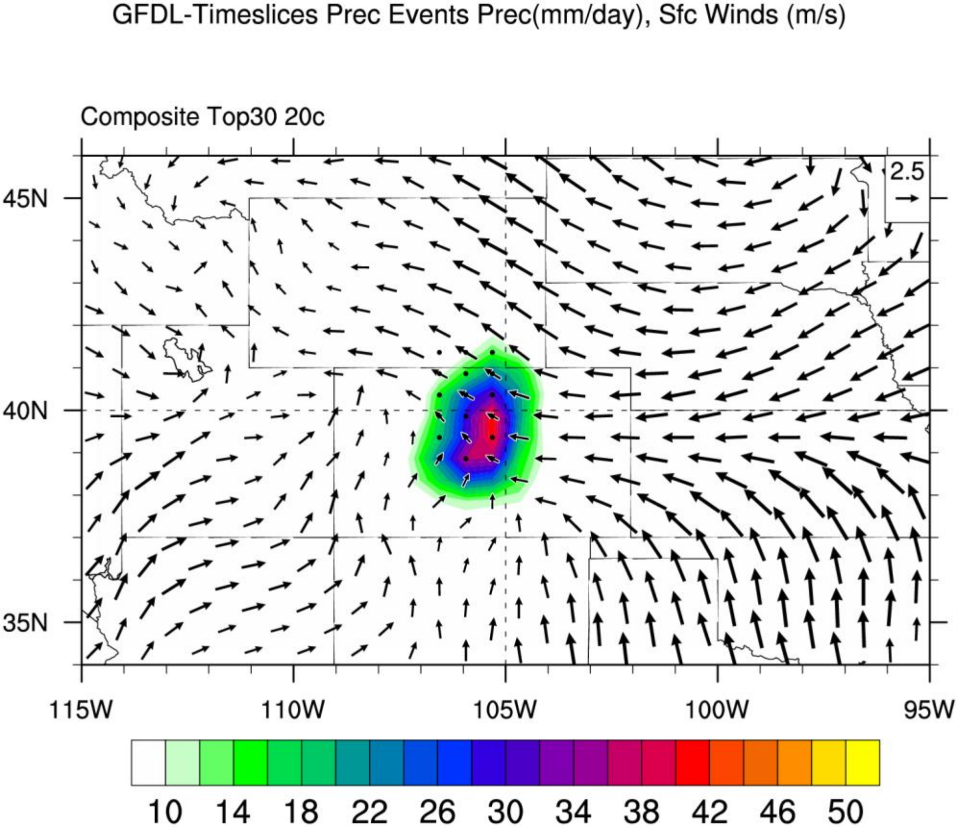


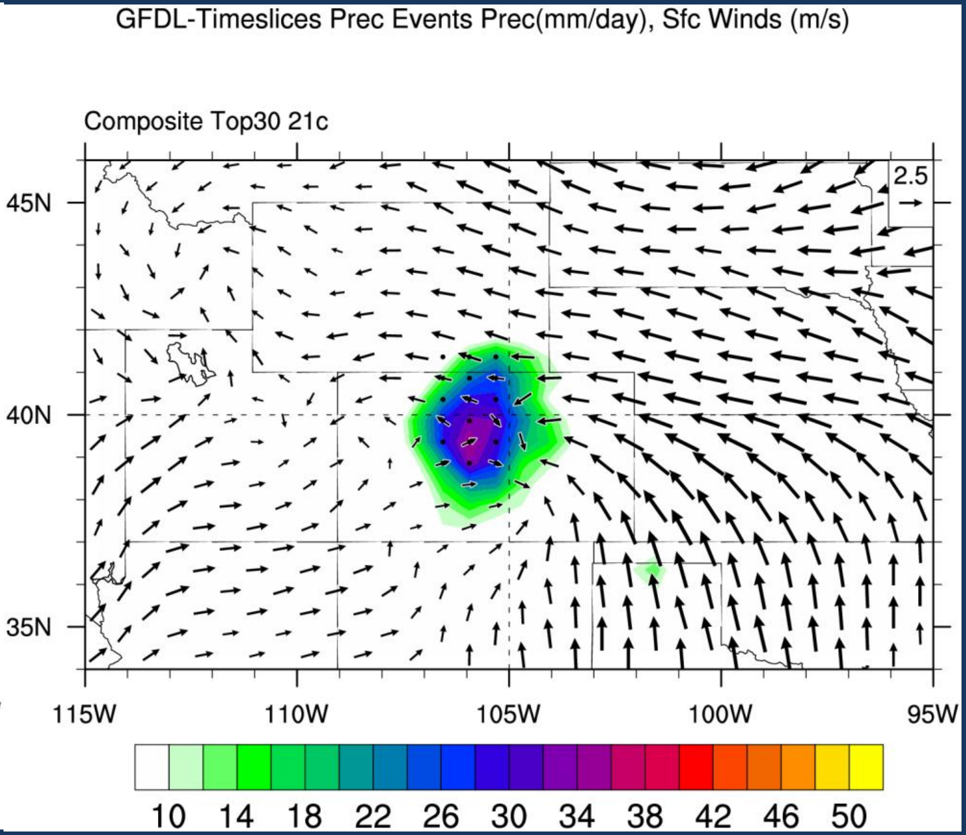
Mean Summer (JJA) Precip 1968-2000

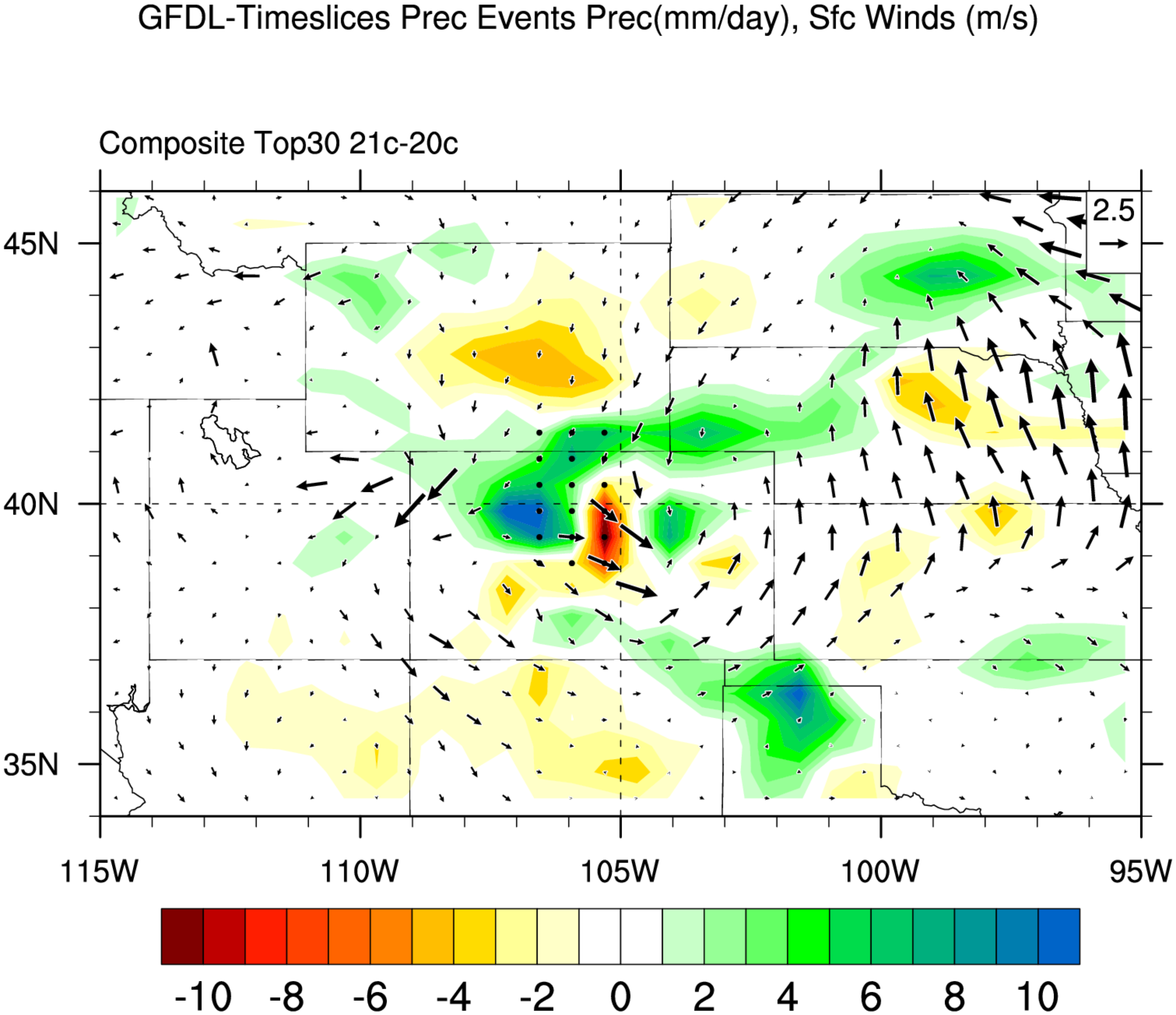


GFDL-AM2 JJA Climate change 21c-20c




GFDL-Timeslices Prec Events Prec(mm/day), Sfc Winds (m/s)
Composite Top30 20c
2.5
45N
40N
35N
115W
110W
105W
100W
95W
10
14
18
22
26
30
34
38
42
46
50


GFDL-Timeslices Prec Events Prec(mm/day), Sfc Winds (m/s)
Composite Top30 21c
2.5
45N
40N
35N
115W
110W
105W
100W
95W
10
14
18
22
26
30
34
38
42
46
50

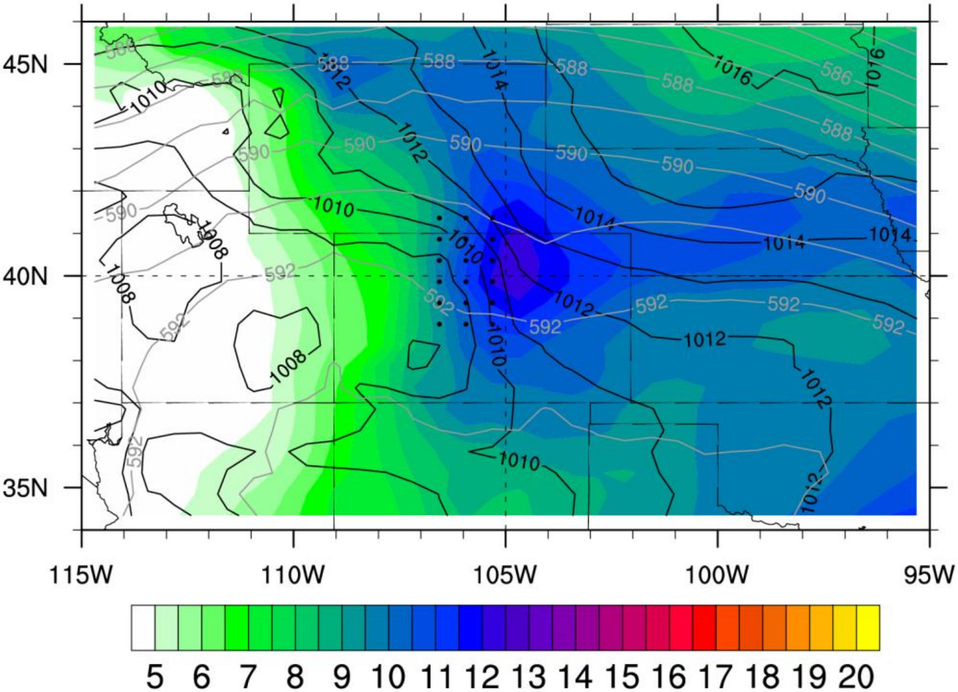


GFDL-Timeslices Prec Events Prec(mm/day), Sfc Winds (m/s)

Composite Top30 21c-20c

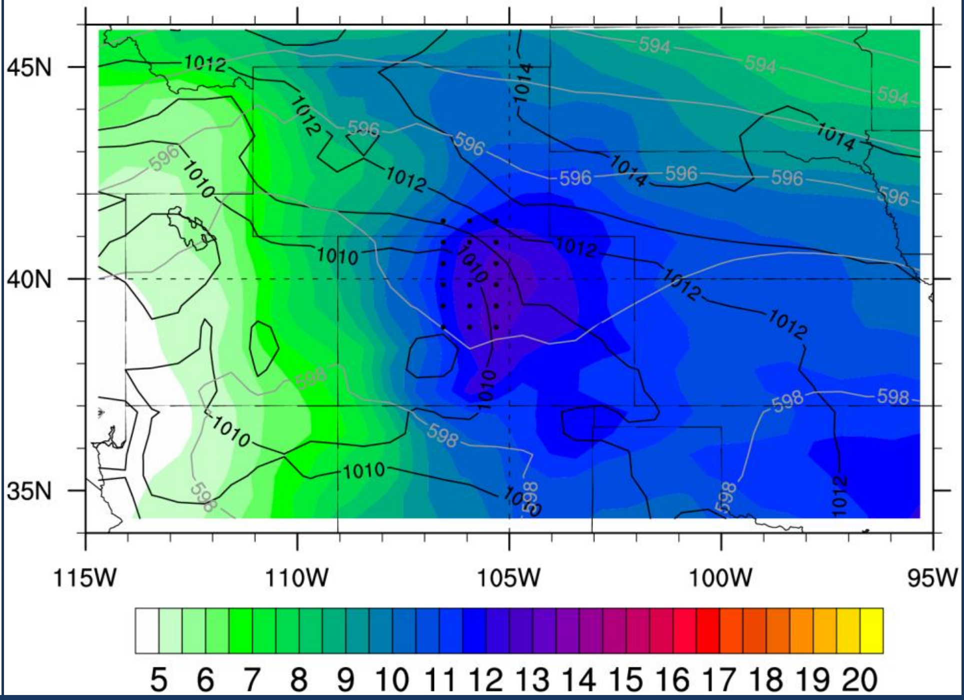
GFDL-Timeslices Prec Events qsfc(g/kg), slp (mb), z500(dm)

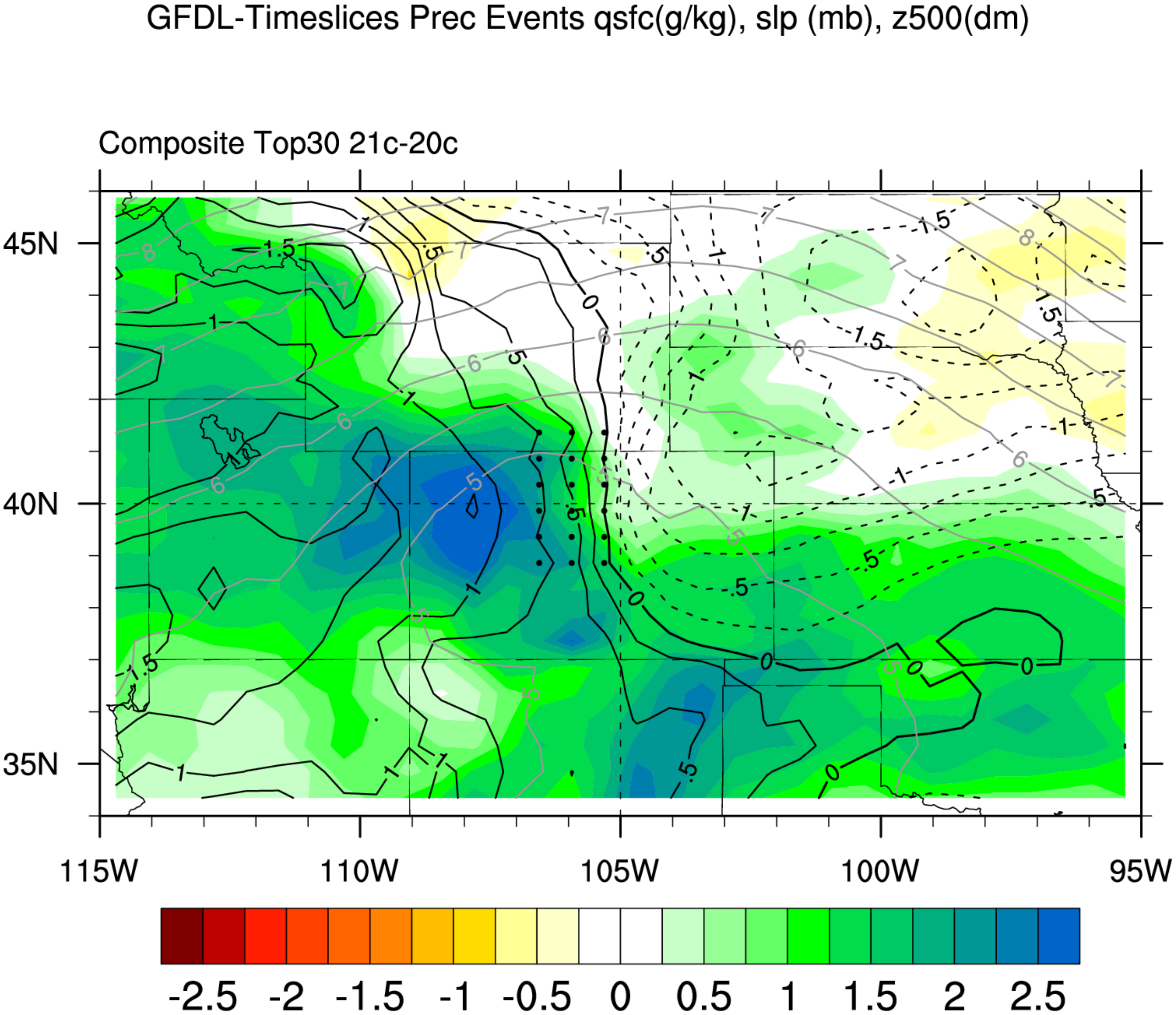
Composite Top30 20c



GFDL-Timeslices Prec Events qsfc(g/kg), slp (mb), z500(dm)

Composite Top30 21c



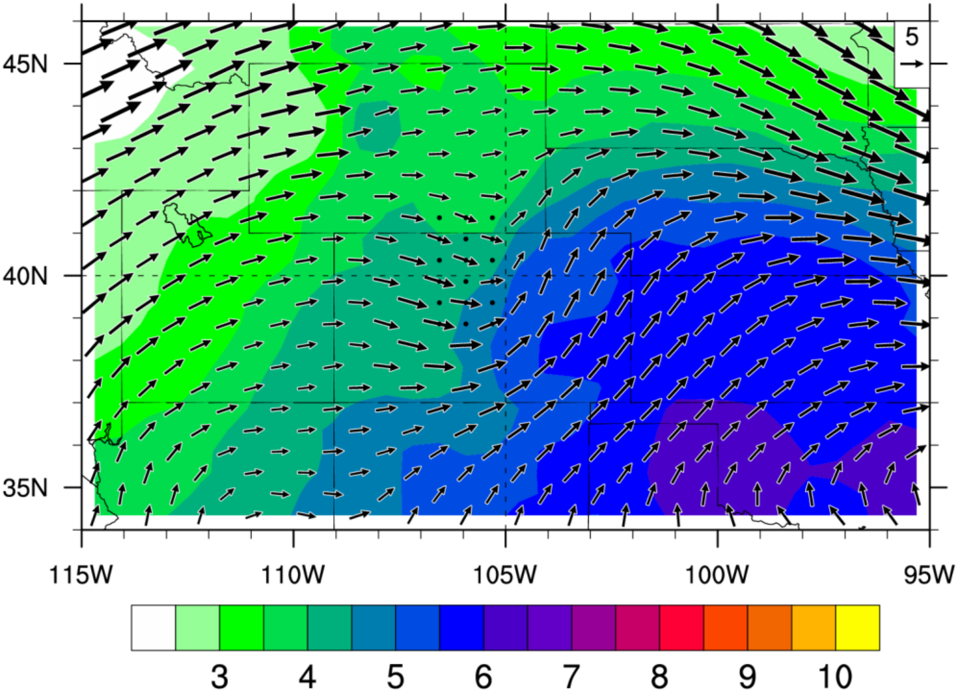


GFDL-Timeslices Prec Events qsfc(g/kg), slp (mb), z500(dm)

Composite Top30 21c-20c

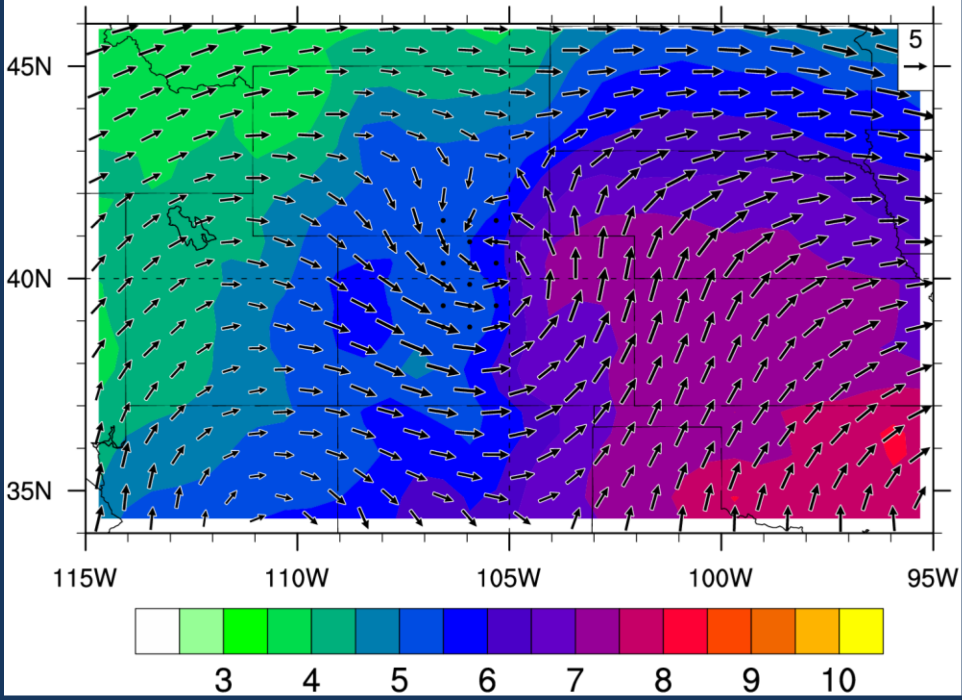
GFDL-Timeslices Prec Events q(g/kg), Winds (m/s) lower-mid troposphere

Composite Top30 20c

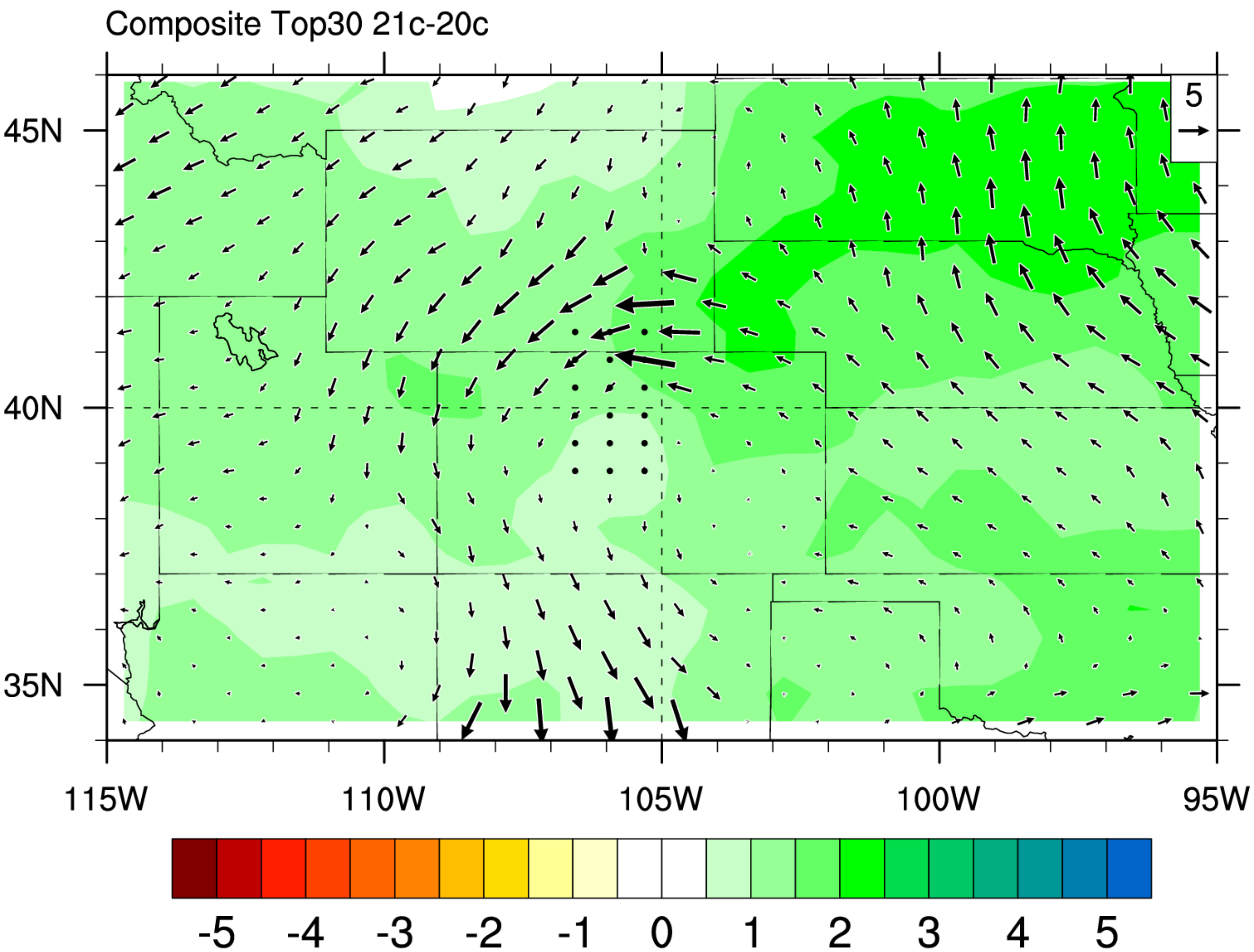


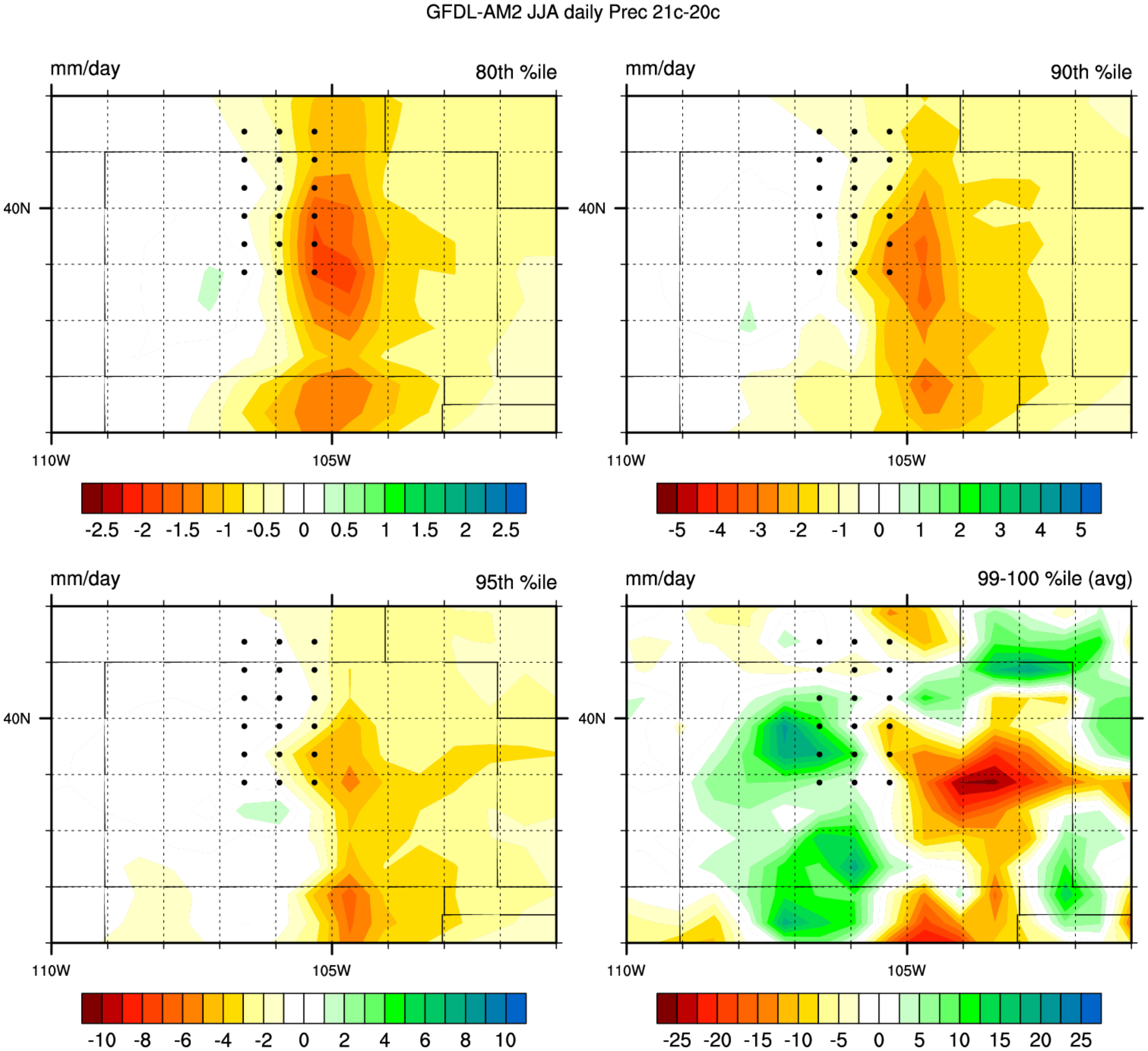
GFDL-Timeslices Prec Events q(g/kg), Winds (m/s) lower-mid troposphere

Composite Top30 21c

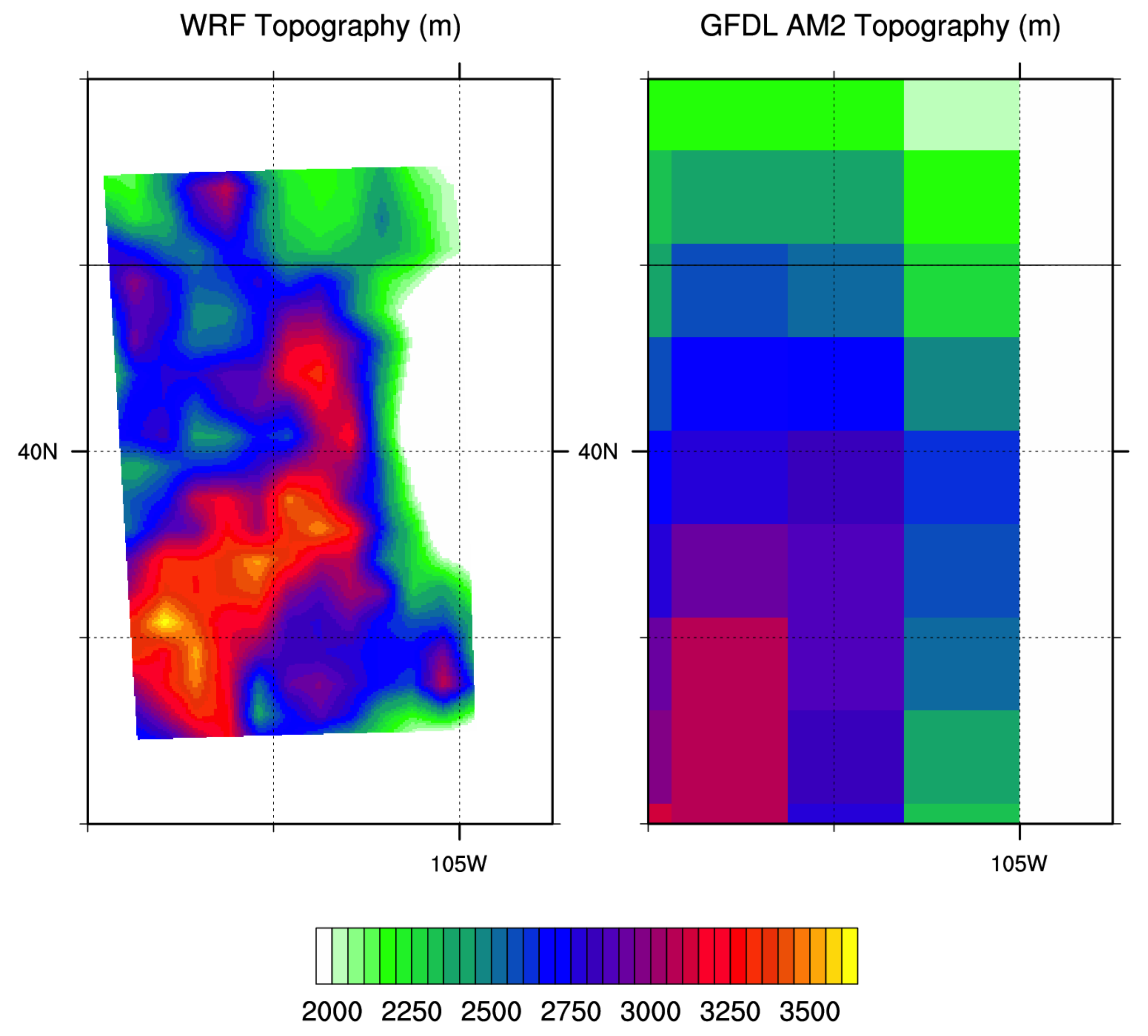


GFDL-Timeslices Prec Events q(g/kg), Winds (m/s) lower-mid troposphere




GFDL-AM2 JJA daily Prec 21c-20c
mm/day
80th %ile
40N
110W
105W
-2.5 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 2.5
mm/day
90th %ile
40N
110W
105W
-5 -4 -3 -2 -1 0 1 2 3 4 5
mm/day
95th %ile
40N
110W
105W
-10 -8 -6 -4 -2 0 2 4 6 8 10
mm/day
99-100 %ile (avg)
40N
110W
105W
-25 -20 -15 -10 -5 0 5 10 15 20 25

WRF vs. GFDL Topography

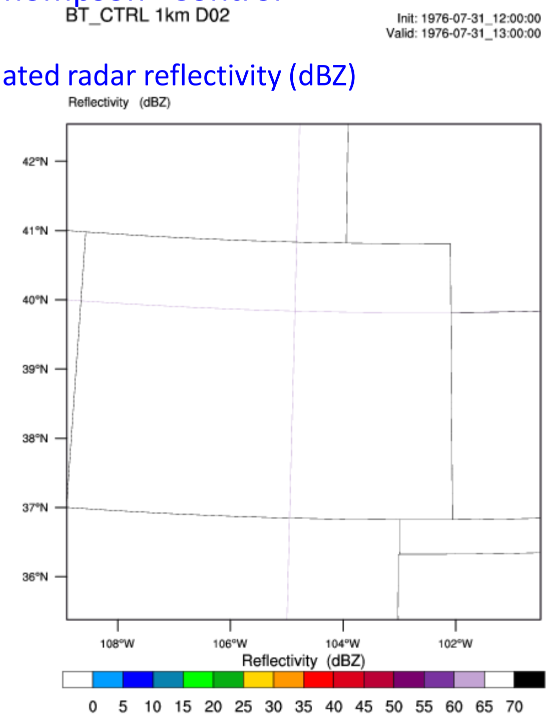


To delete

Big Thompson Climate Perturbed Run

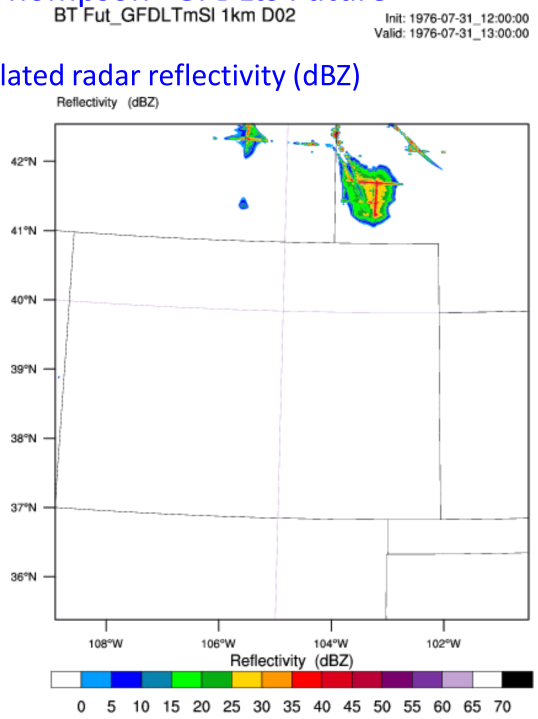
Big Thompson “Control”

Simulated radar reflectivity (dBZ)



Big Thompson “GFDLts Future”

Simulated radar reflectivity (dBZ)

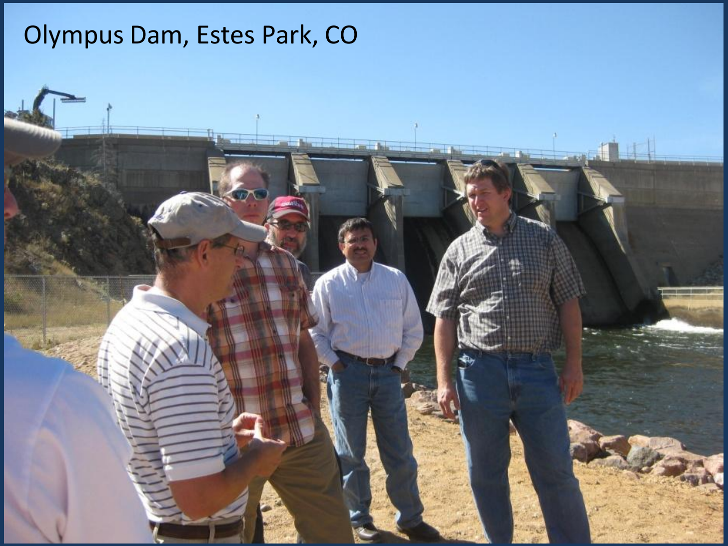


How can Reclamation use these results?

- Feedback from USBR water resources managers:
  - Want to understand elevation threshold of extreme precipitation:
    - Present precipitation-elevation thresholds?
    - Future changes?
  - Help generate future-climate scenarios for emergency preparedness exercises
  - Incorporate results into dam safety evaluations, USBR Early Warning System operations, community/risk analysis, floodplain re-mapping
- Challenges:
  - Adapting findings from atmospheric science/WRF framework to hydrologic/water management framework
  - Language/jargon, units, technology, time

Early Warning System (USBR) gauge station

Collaborative “field learning”



Olympus Dam, Estes Park, CO