High Resolution Simulations of Climate Change in the Colorado Headwaters: Water Balance

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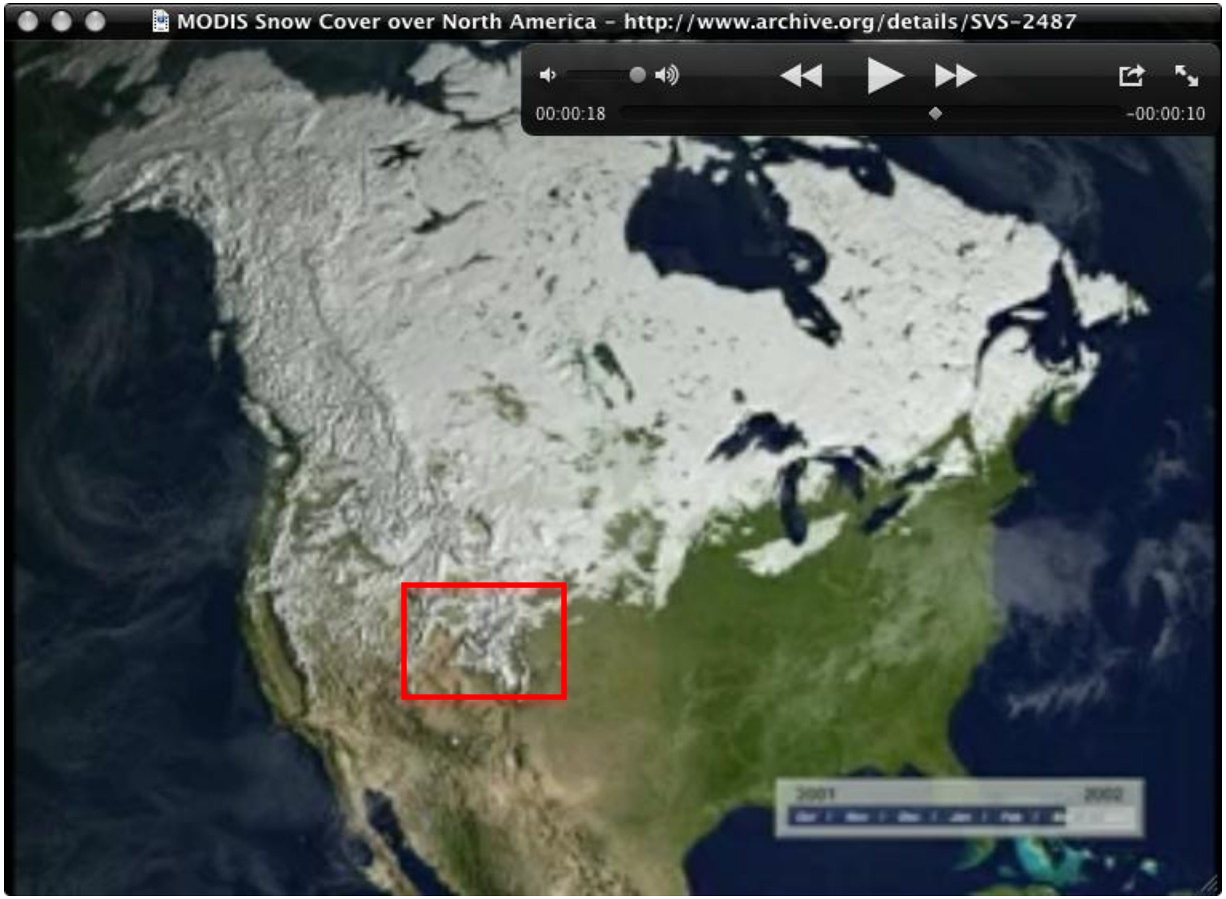
Outline of talk

- High Resolution Simulations of snowfall, snowpack and runoff over the Colorado Headwaters
- Pseudo Global Warming simulations to simulate expected changes in the water cycle due to CO_2 warming and moistening
- Budget analysis of the water cycle over the Colorado Headwaters for a current and future climate
- Conclusions

Snow cover over North America from MODIS

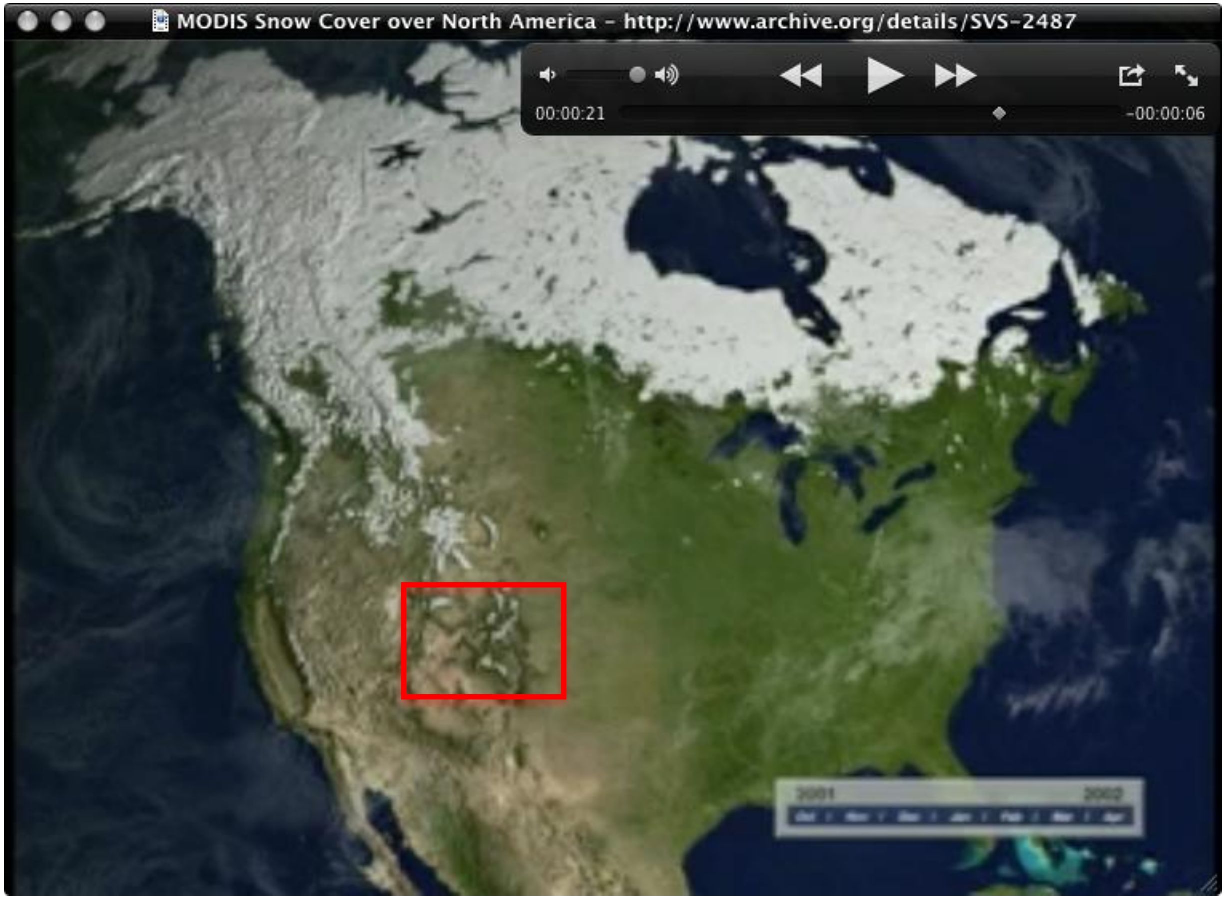
March 2002



http://www.archive.org/details/SVS-2487

Snow cover in 2001-2002 over North America from MODIS

April 2002



http://www.archive.org/details/SVS-2487

High Resolution Simulations of the Colorado Headwaters snowfall, snowpack and runoff

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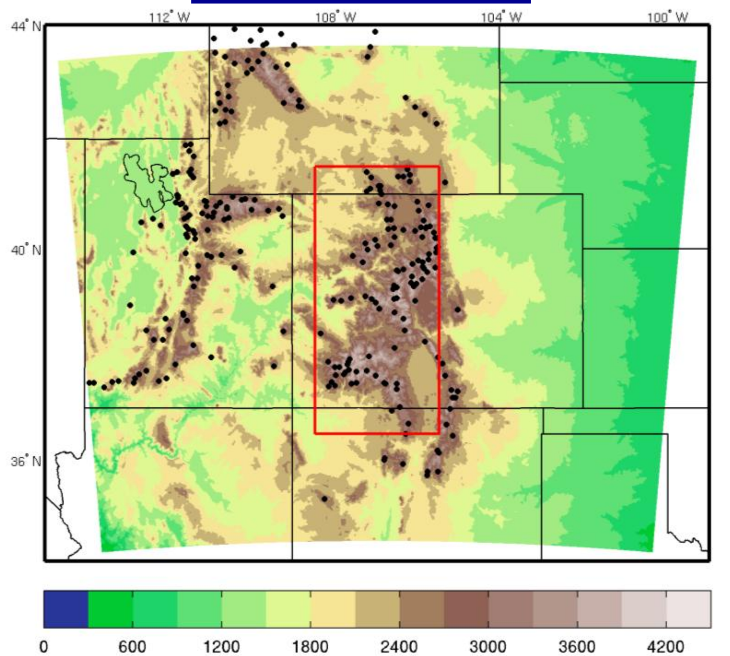
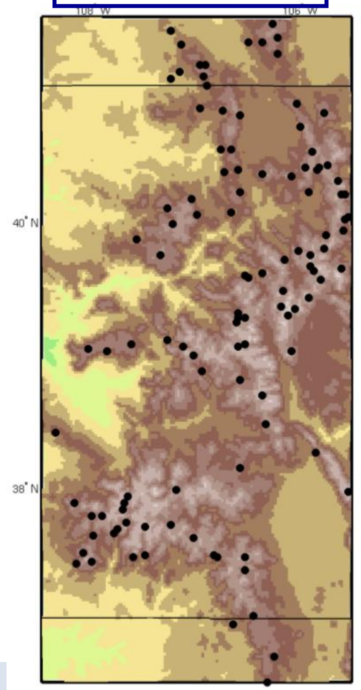
1. Perform past climate simulations using high resolution WRF model
   - Grid spacing: 4 km.
   - Continuous eight years: 2000 – 2008
2. Verified results of WRF integrations using NRCS SNOTEL data and showed that grid spacing of at least 6 km needed to faithfully reproduce the spatial pattern and amount of precipitation (Rasmussen et al. 2011, J. Climate).
3. Investigate enhancement of water cycle by adding CCSM 10 year mean temperature and moisture perturbation from 50 year future A1B simulations from AR4 runs to NARR boundary conditions

Full Domain



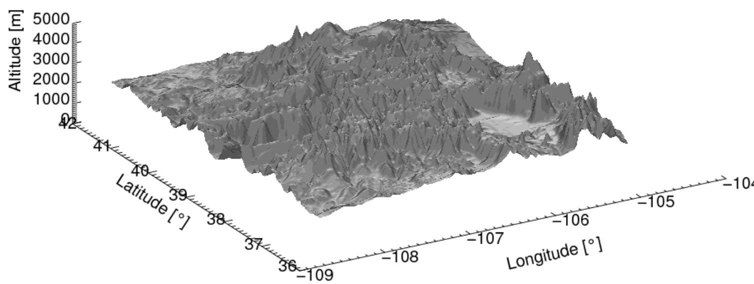
Headwaters domain



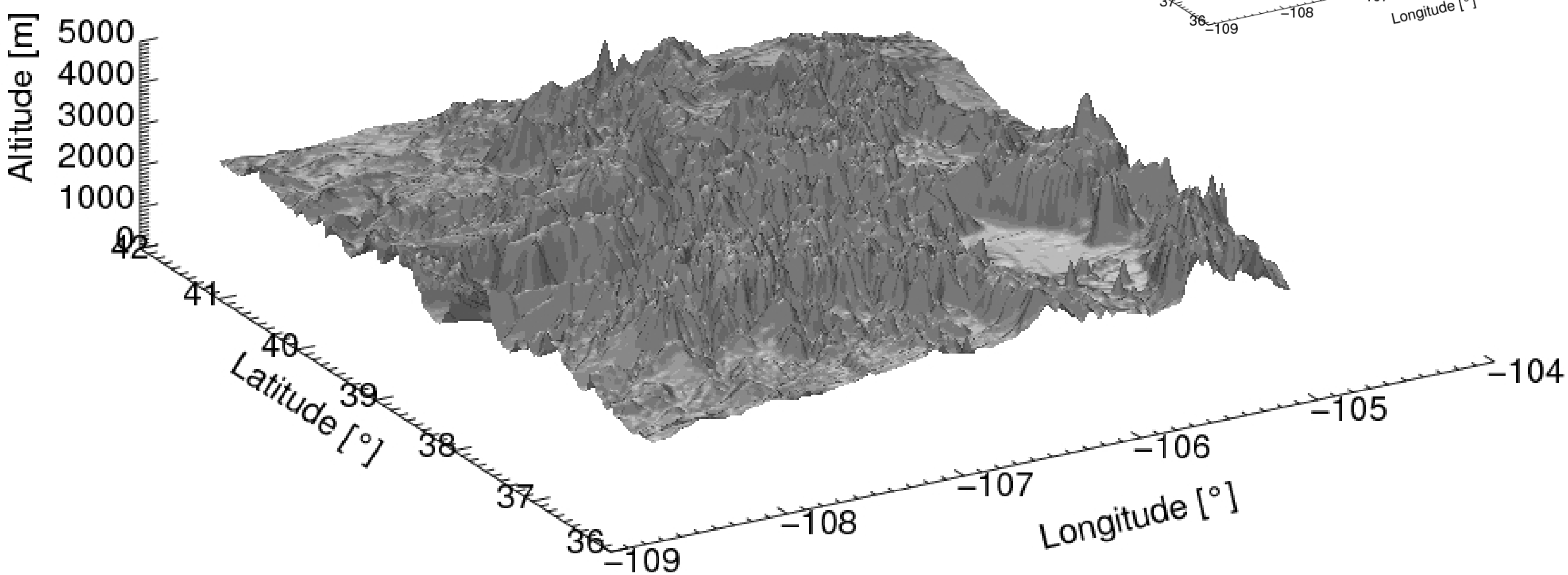
● SNOTEL sites

Value of high-res. regional model

Resolution : 2.4 km



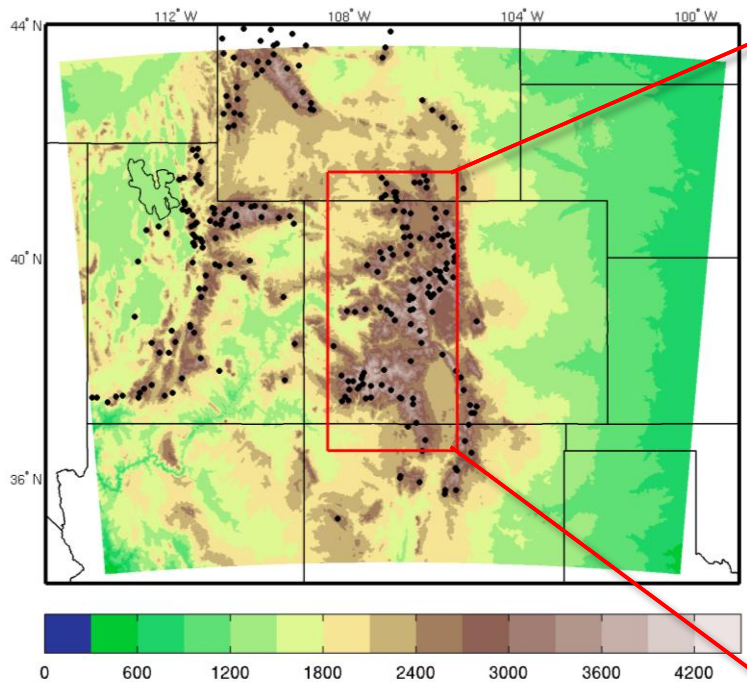
Resolution: 0.0 km



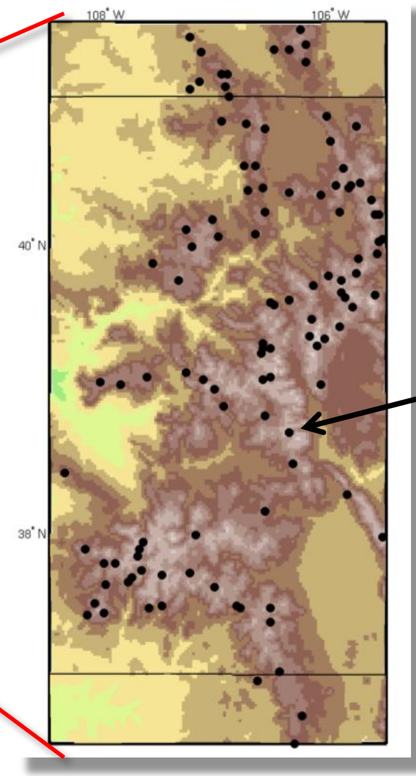
Courtesy Andy Prein

Model Verification with SNOTEL data

Full model domain



Headwaters Domain

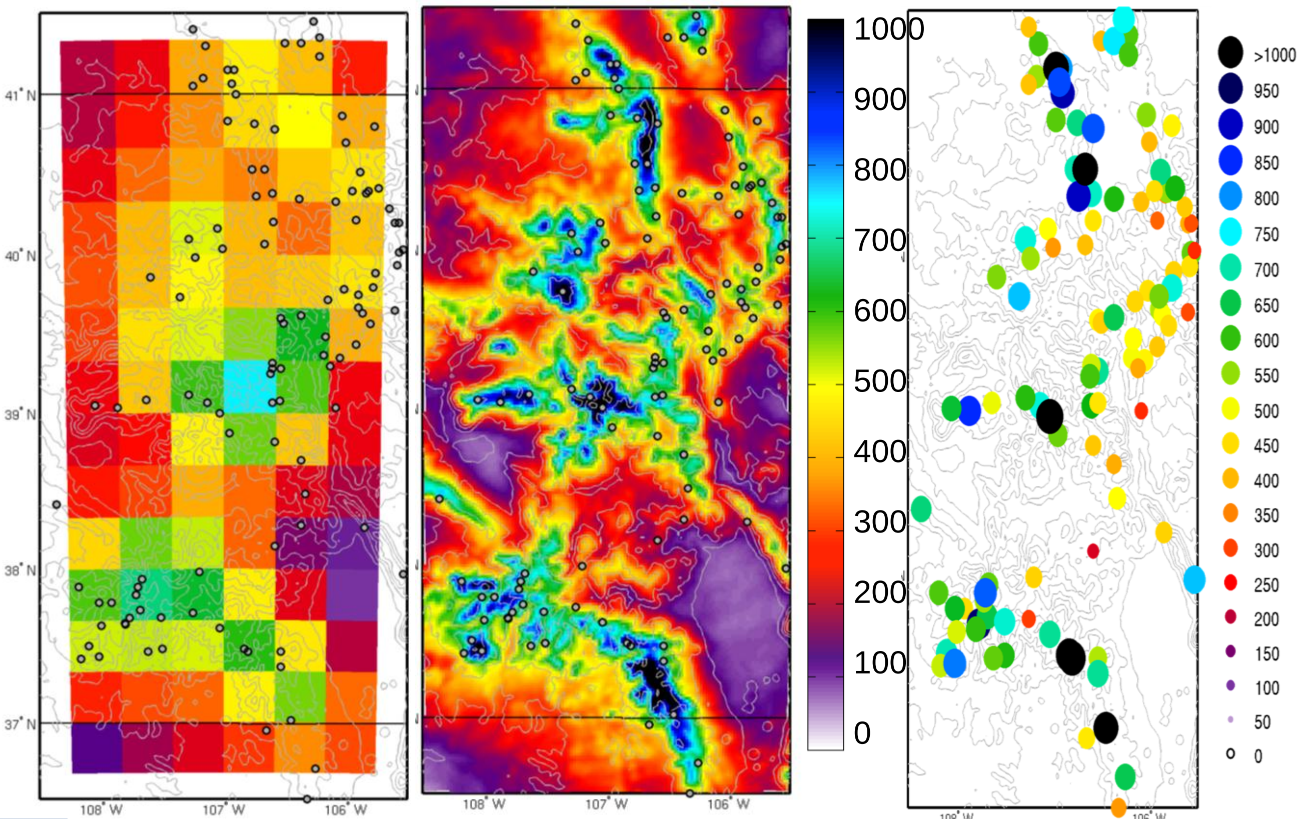


SNOTEL

- Verifications performed using 93-112 Snowpack Telemetry (SNOTEL) sites over the Headwaters domain.
  - SNOTEL typically located at elevations between 2600 and 3600 m
- Global Historical Climatology Network (GHCN) data at lower elevations for rainfall

WRF model able to reproduce the amount and spatial distribution of snowfall and snowpack over a winter season over the Colorado Headwaters at spatial resolutions less than 6 km

36 km | 2 km | SNOTEL Obs.

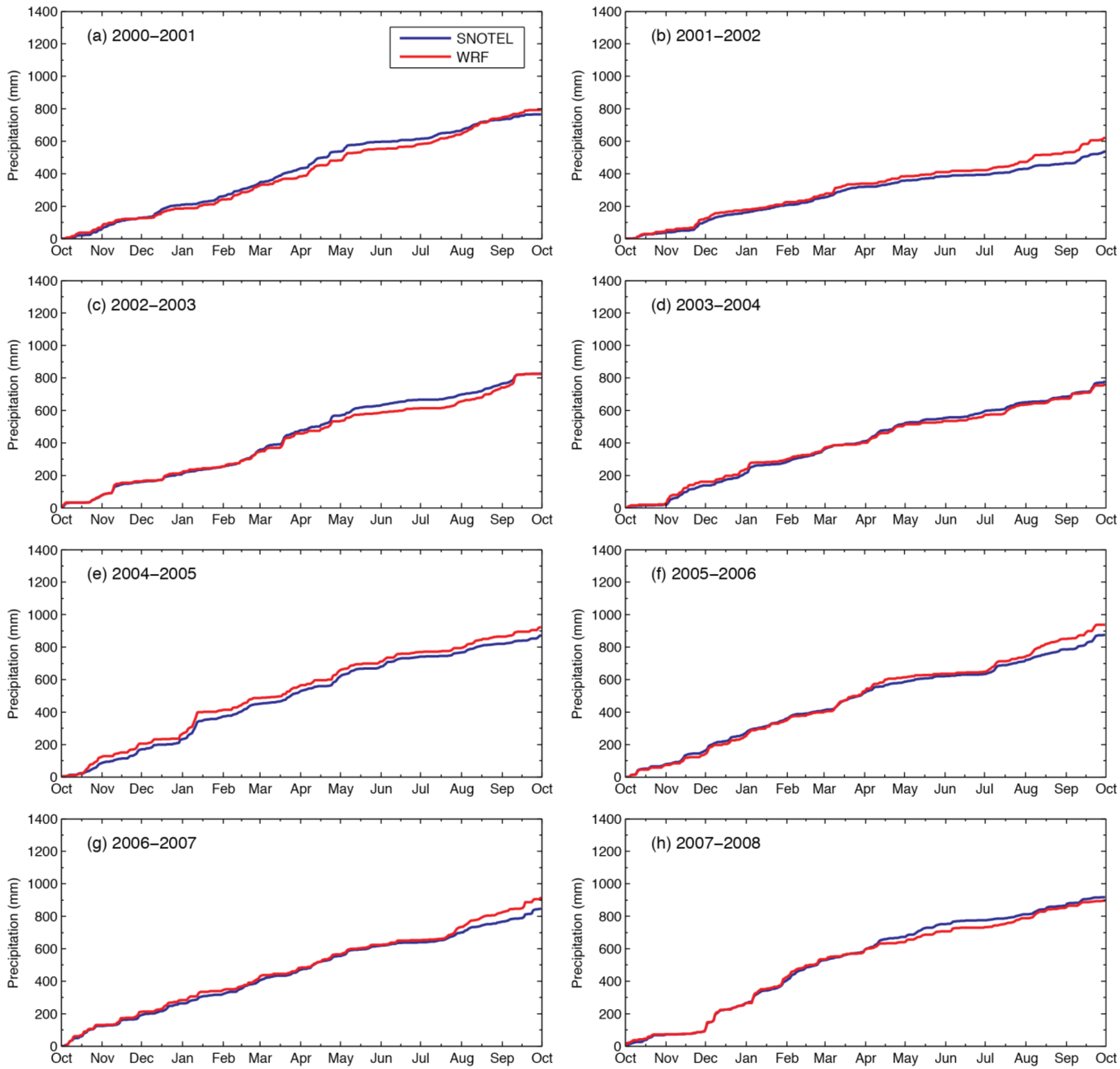


6-mo. Total Precipitation (mm) Comparison
1 Nov. 2007-1 May 2008

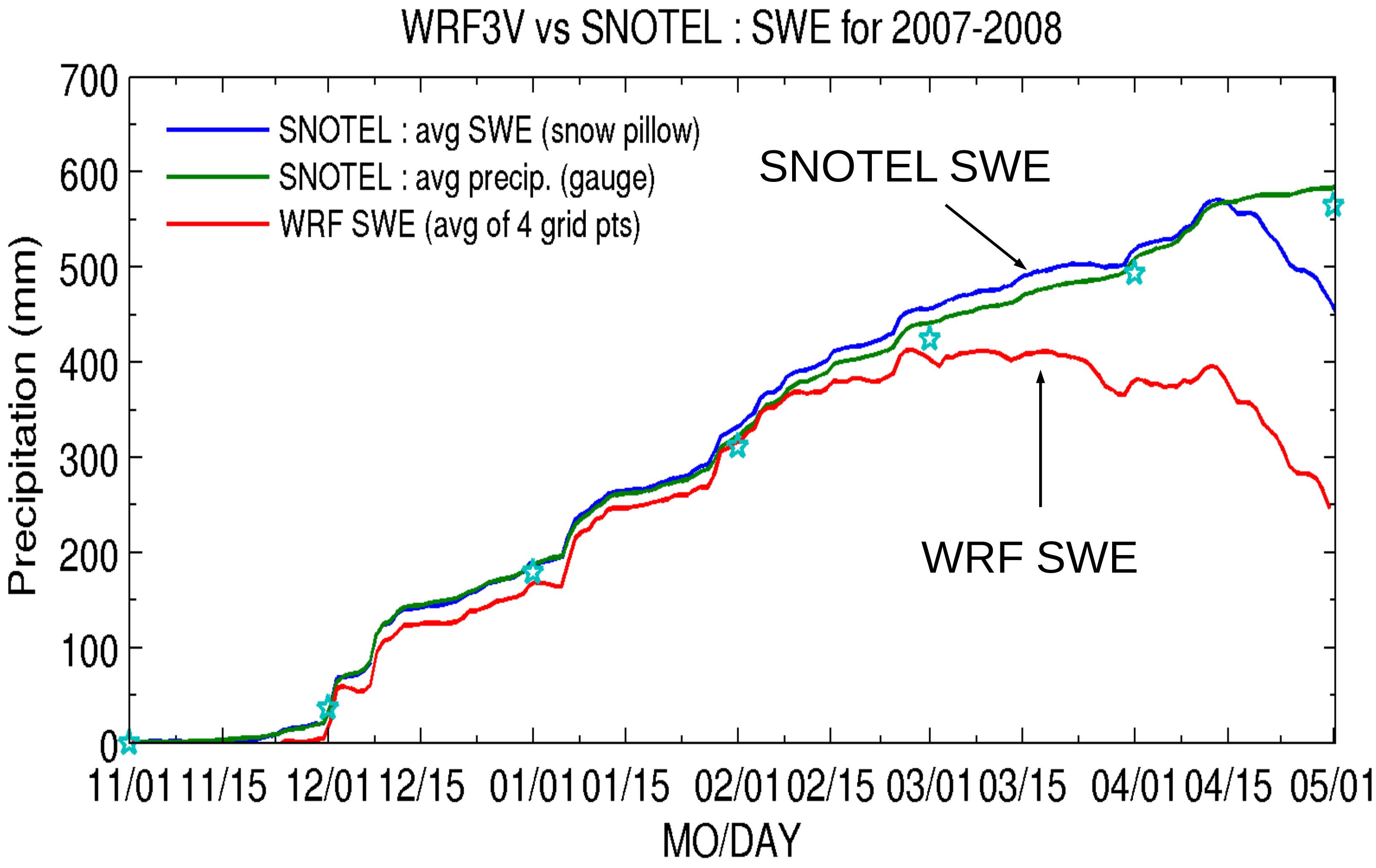
SNOTEL Precip gauge

Ikeda et al, 2010, Rasmussen et al. 2011

Annual snowfall for each of the eight years of the simulation compared to the SNOTEL data



Snow Water Equivalent from SNOTEL compared to WRF



7-year average SWE on April 1st

36 km | **12 km** | **4 km** | **OBSERVATIONS**

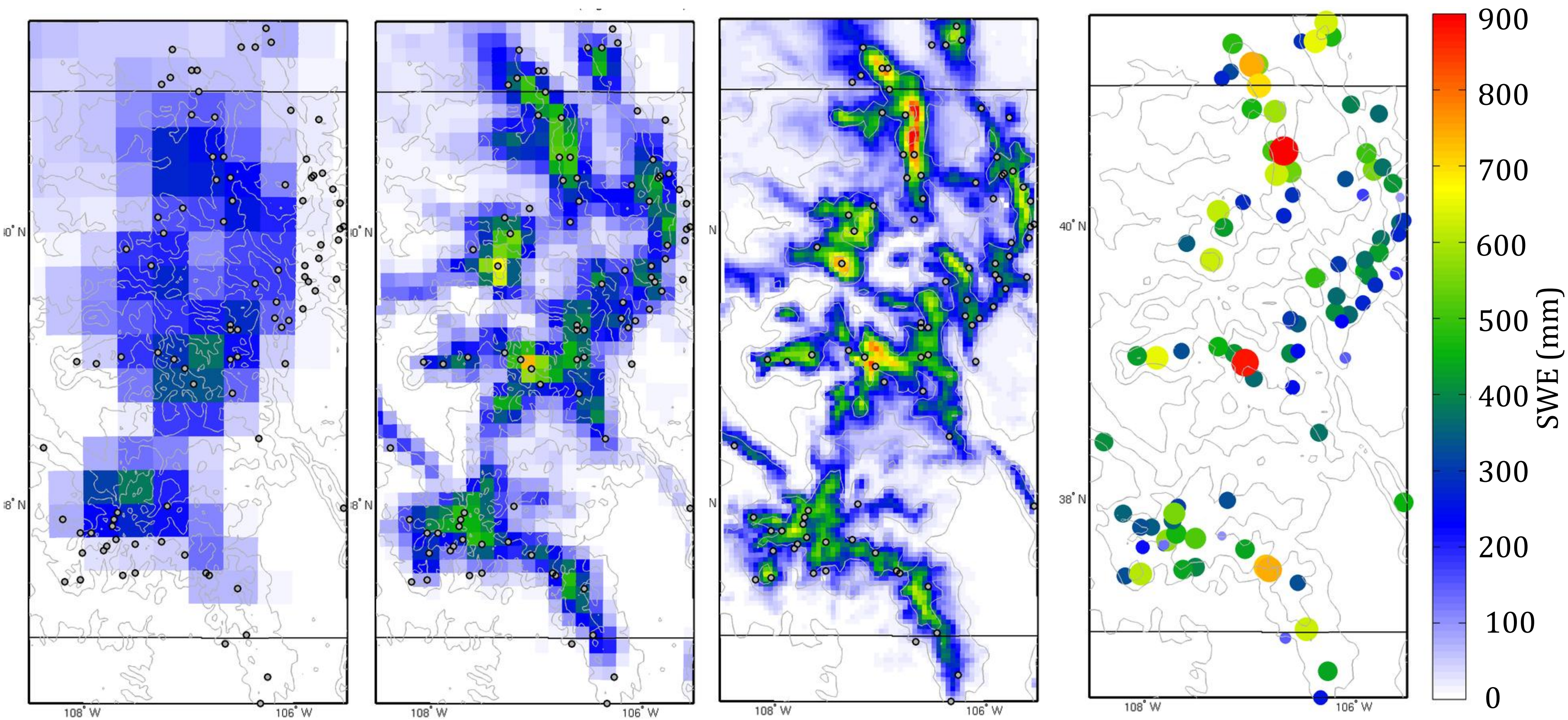


Fig. Kyoko Ikeda

7-year average SWE on June 1st

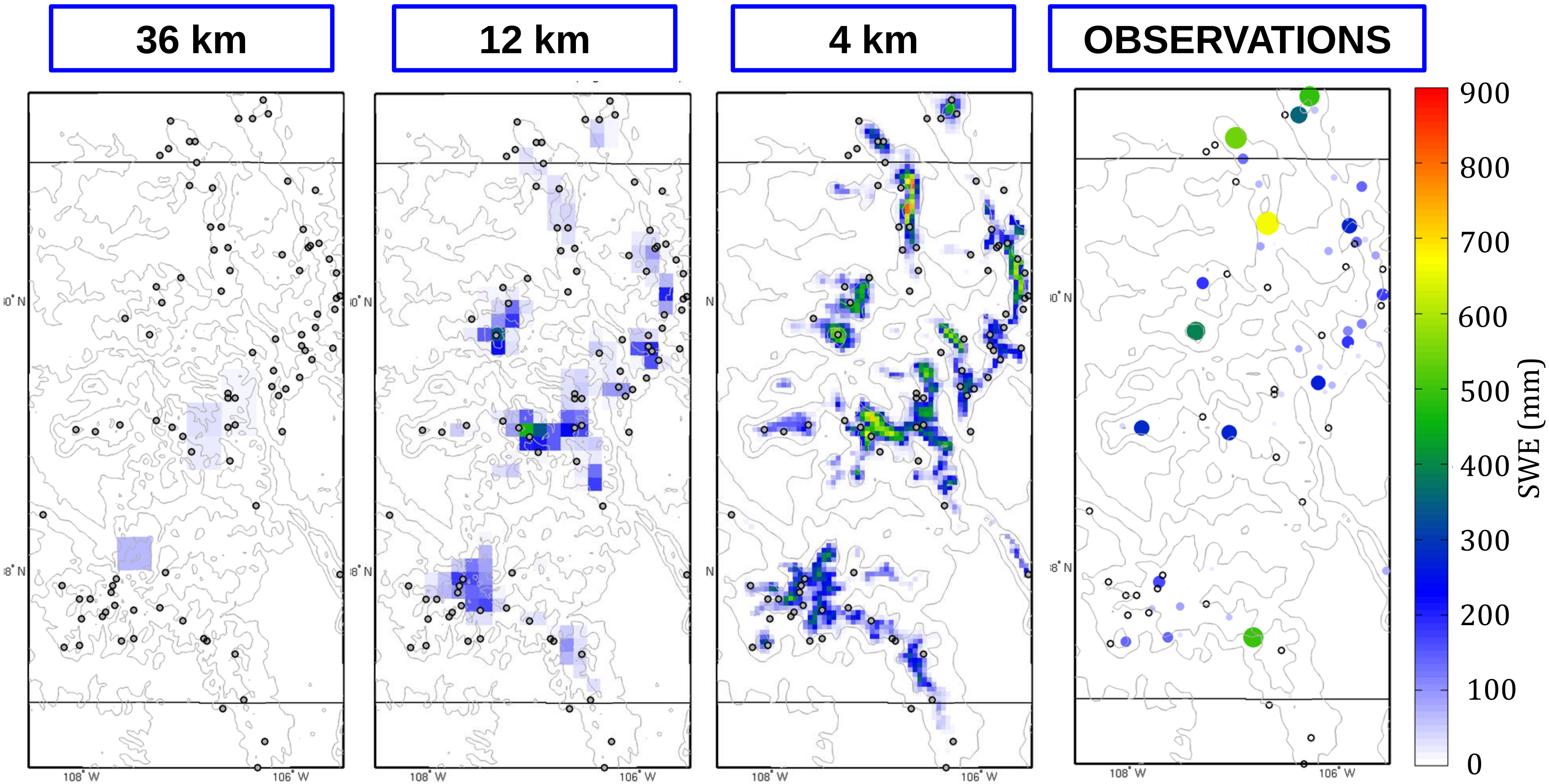


Fig. Kyoko Ikeda

WRF model simulation of Snowpack (Snow Water Equivalent) for two different model resolutions

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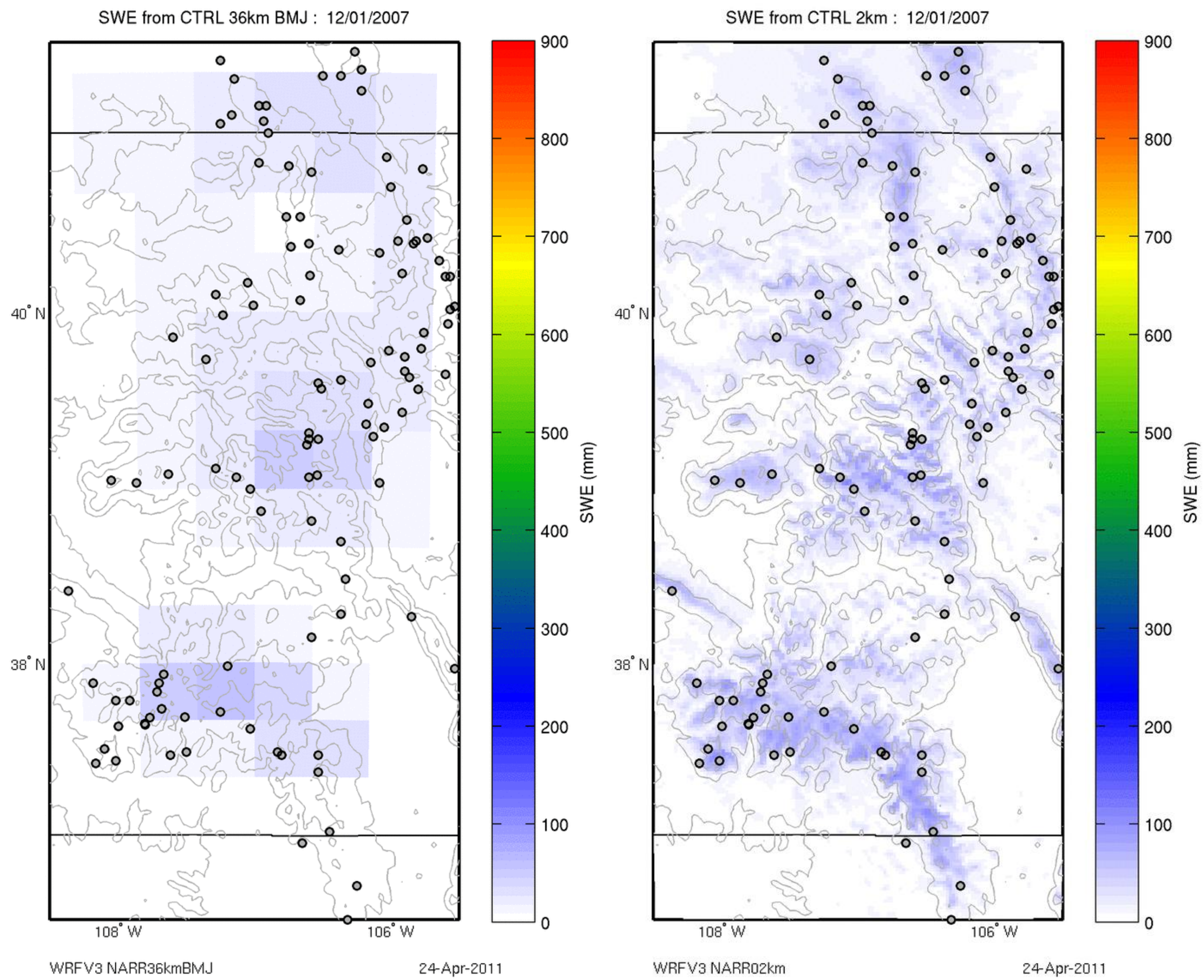
1 Dec. 2007- 1 July 2008

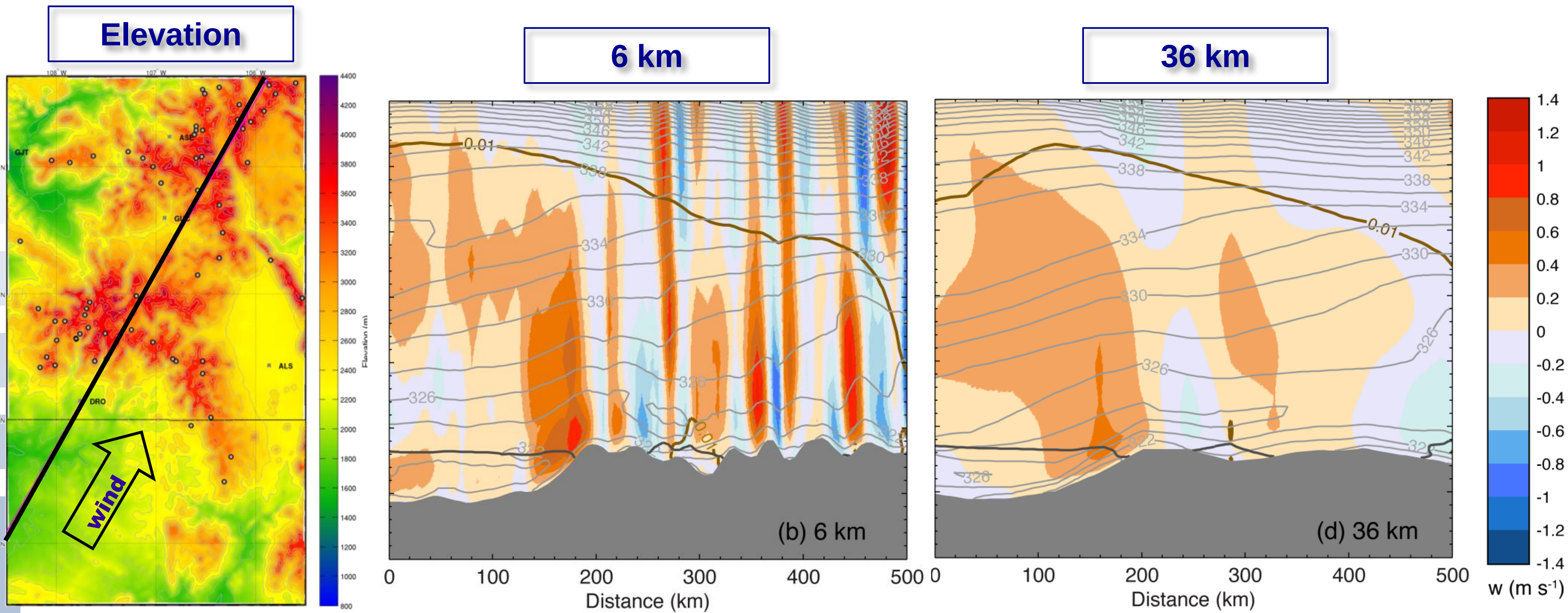
36 km resolution WRF simulation over water year shows complete loss of snowpack by April 1 and the smearing of snowpack across topographic gradients while 2 km simulation shows snowpack to last through the end of July and also produces the correct spatial pattern as compare to the 111 SNOTEL sites (black dots)

36 km | **2 km**



Model resolution impact on vertical velocity

1 December 2007 0000 UTC

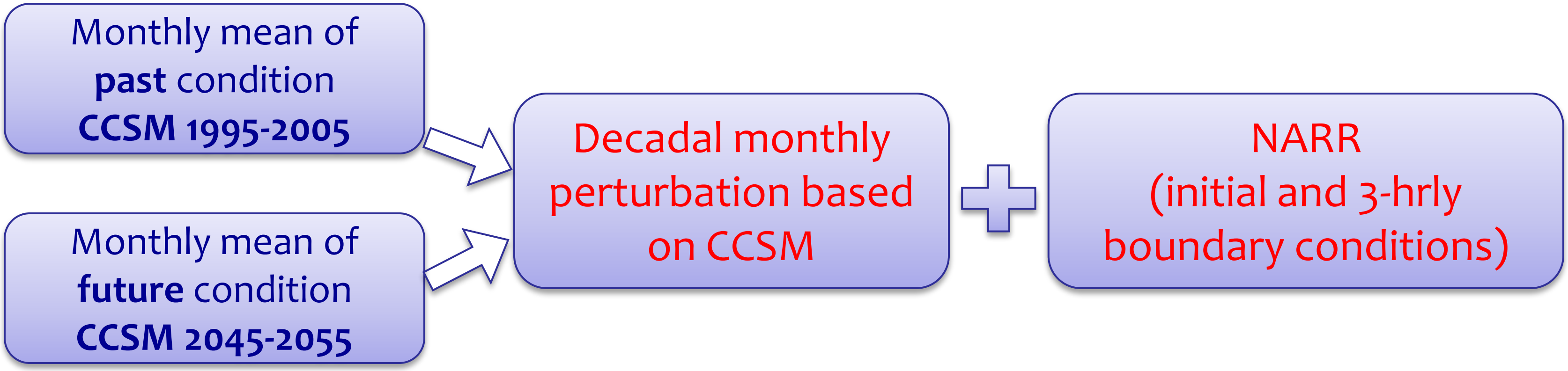


“Pseudo-Global Warming” (PGW) Methodology

Schär et al (1996), Sato et al. (2007), Hara et al. (2008), Kawase et al. (2009)

1. Calculate perturbation in 10-yr monthly mean values of **U, V**, **T**, **geopot**. **hgt**., **P_{sfc}** and **Q_v** between current and future climate periods from a Climate Global Circulation Model. (SRES-A2 from NCAR CCSM3 CCGM).

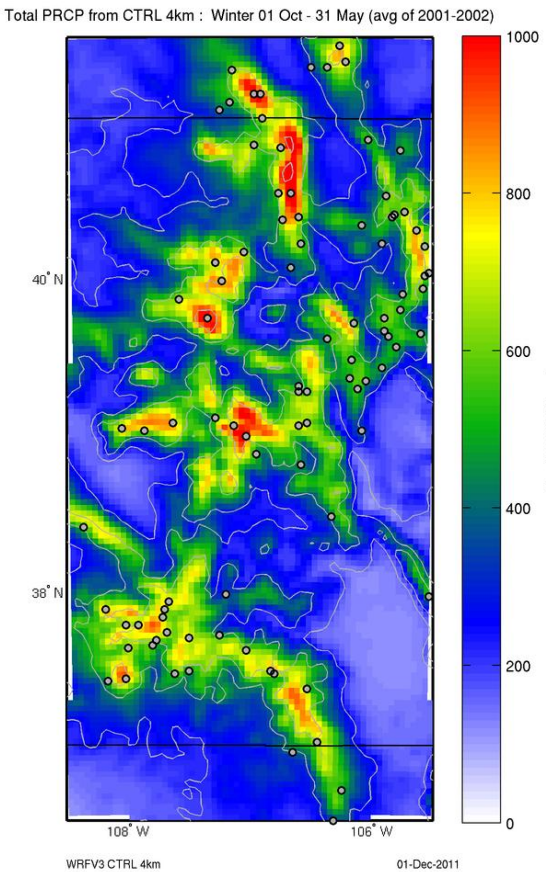
2. Add perturbation to current analyses of atmospheric conditions (North American Regional Reanalysis, 3-hrly) and extract regional model initial and lateral boundary conditions

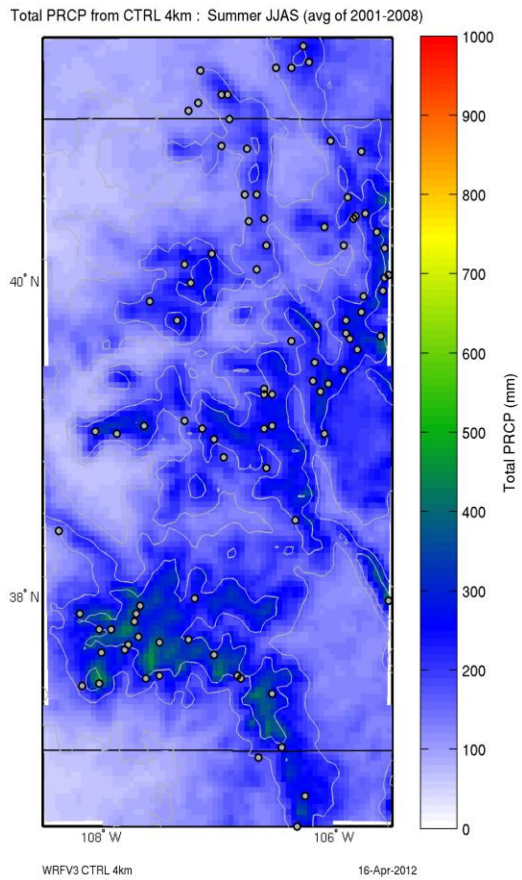


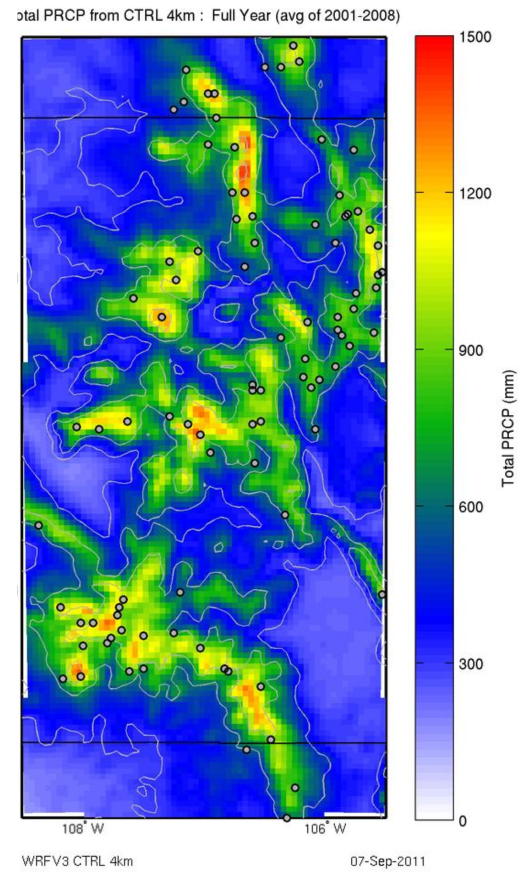
<u>Notes:</u>

- Sub-monthly phenomenon such as extra-tropical storms not captured except in their mean effect. Monthly phenomenon are, such as the Hadley Cell. No change in storm tracks, and thus transient spectra the same (i.e. same climate variability in the future except for intensification of storms within the domain)

Current Precipitation (average from 8 year simulation)

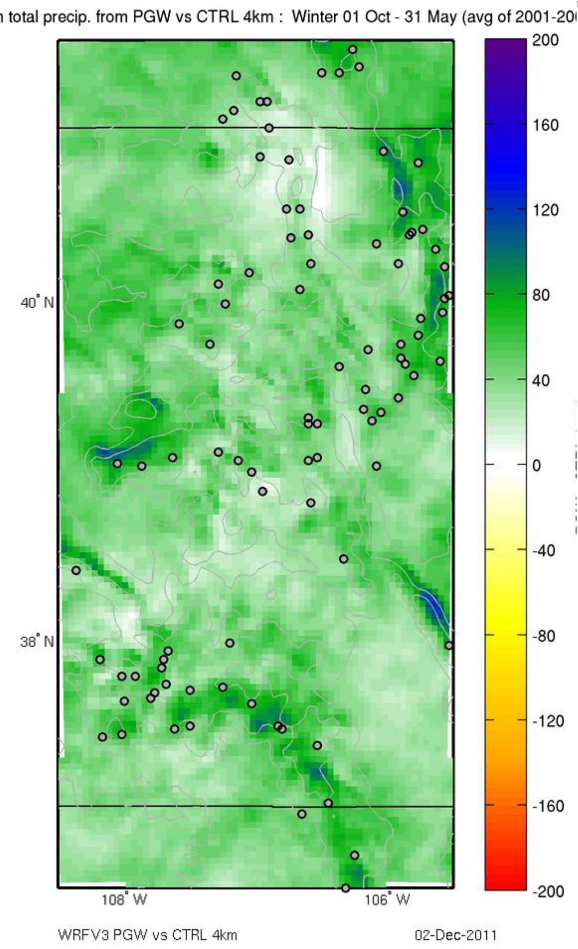




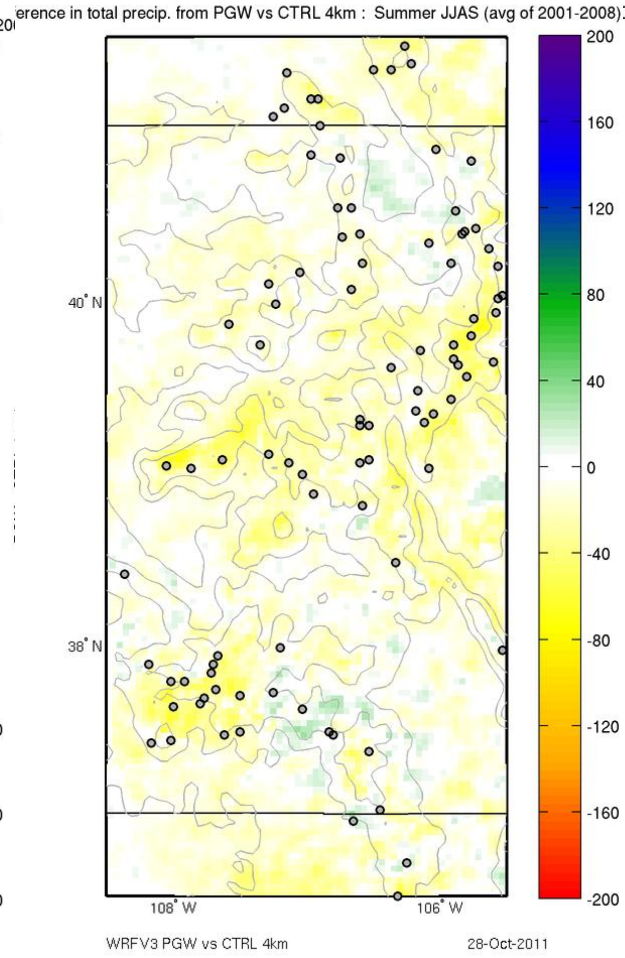


Winter **Summer** **Annual**

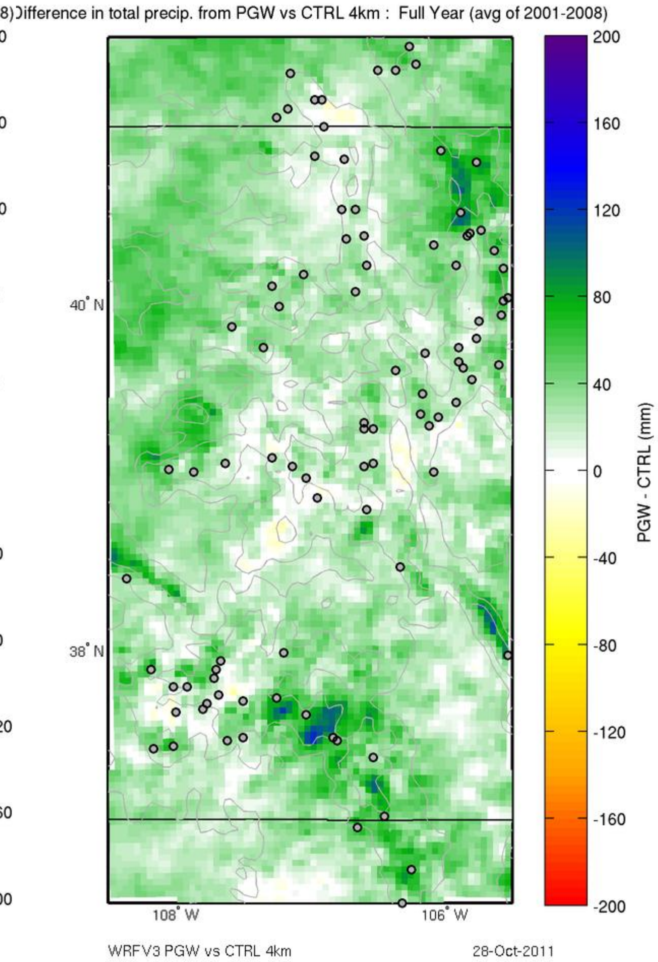
Difference in Precipitation: Future – Current (average from 8 year run)



Winter

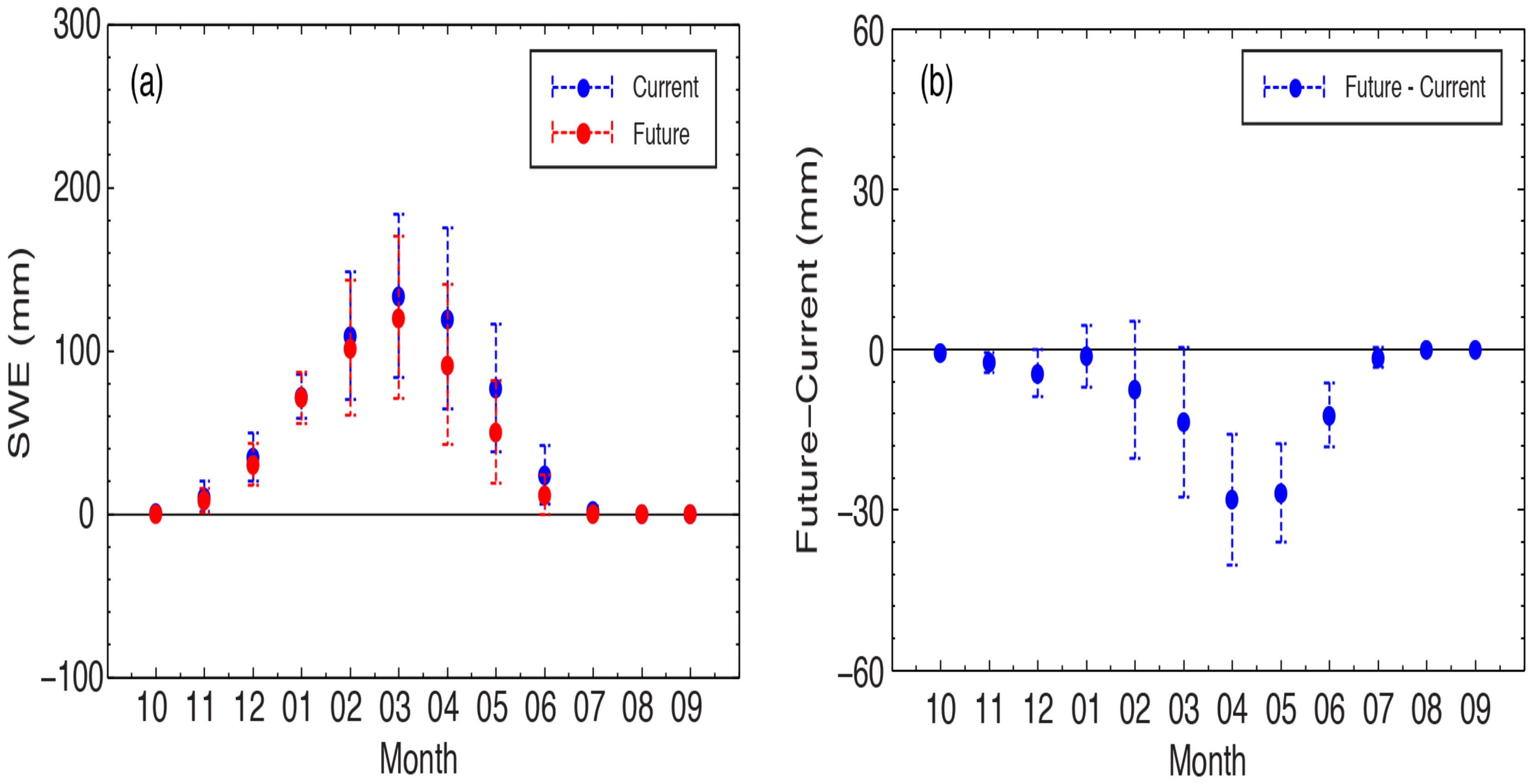


Summer

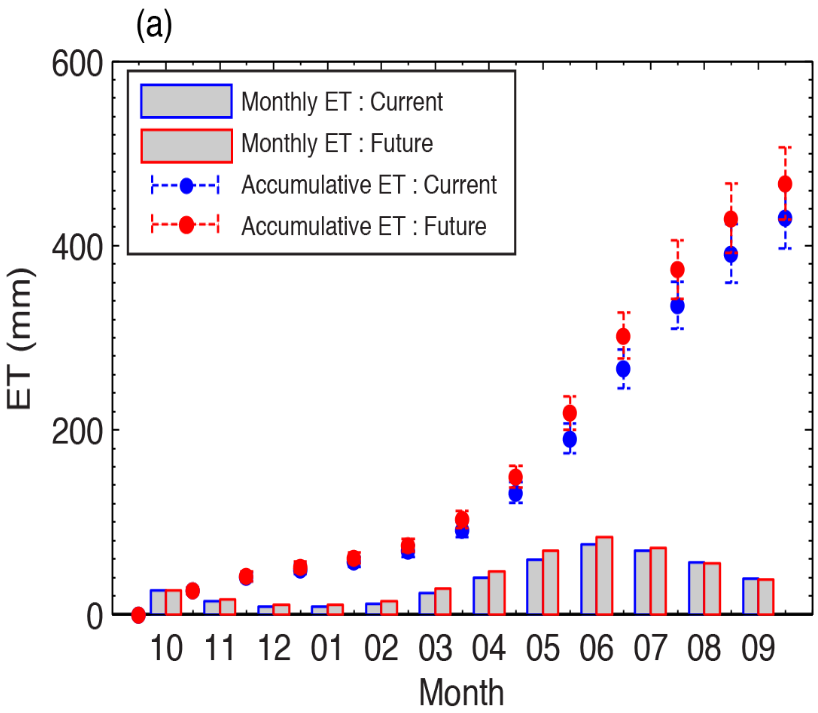


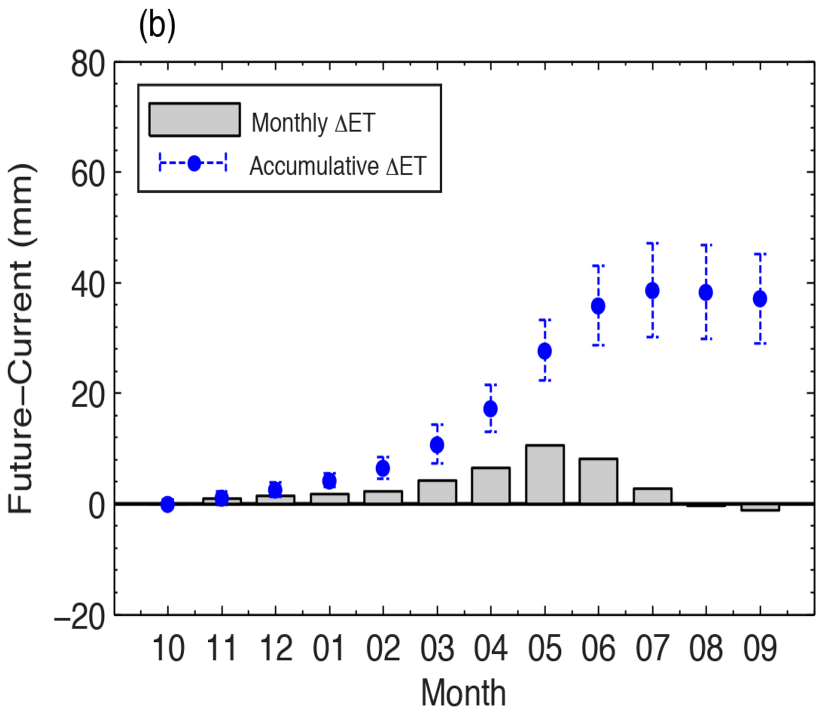
Annual

Snowpack Difference (future – current)

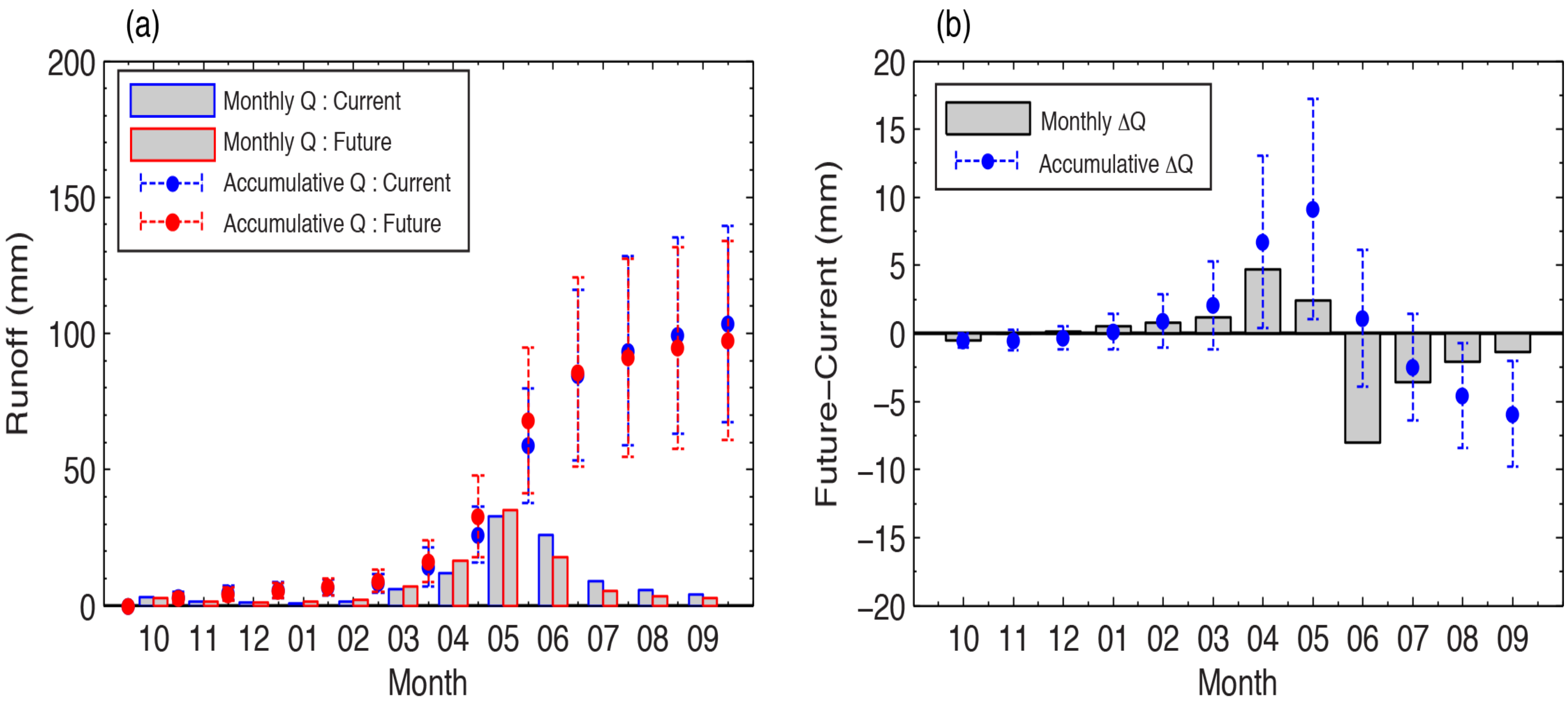


Evapotranspiration Difference (future – current)





Runoff Difference (future – current)



Changes in Snowfall, Snowcover and SWE due to climate change

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- Snowfall increases through April 1 due to moister storms.

- Snowcover decreases by 15% by April 1 due to the enhanced melting of SWE at lower elevations in a warmer climate (snow albedo effect important).

- SWE similar in the future as the present through February due to the enhanced snowfall amount at high elevations compensating for the melting of falling snow and snowpack at lower elevations.

- SWE decreases by 25% by April 1 due to the early onset of warmer temperatures in a warmer climate (snow albedo effect important).

$$1 = ET/P + Q/P$$

(annual average basis)

Q – Runoff, ET – Evapotranspiration, P - Precipitation

How does ET/P and Q/P change in the future?

Current: ET/P =0.81, Q/P =0.19

Future: ET/P = 0.83, Q/P = 0.17

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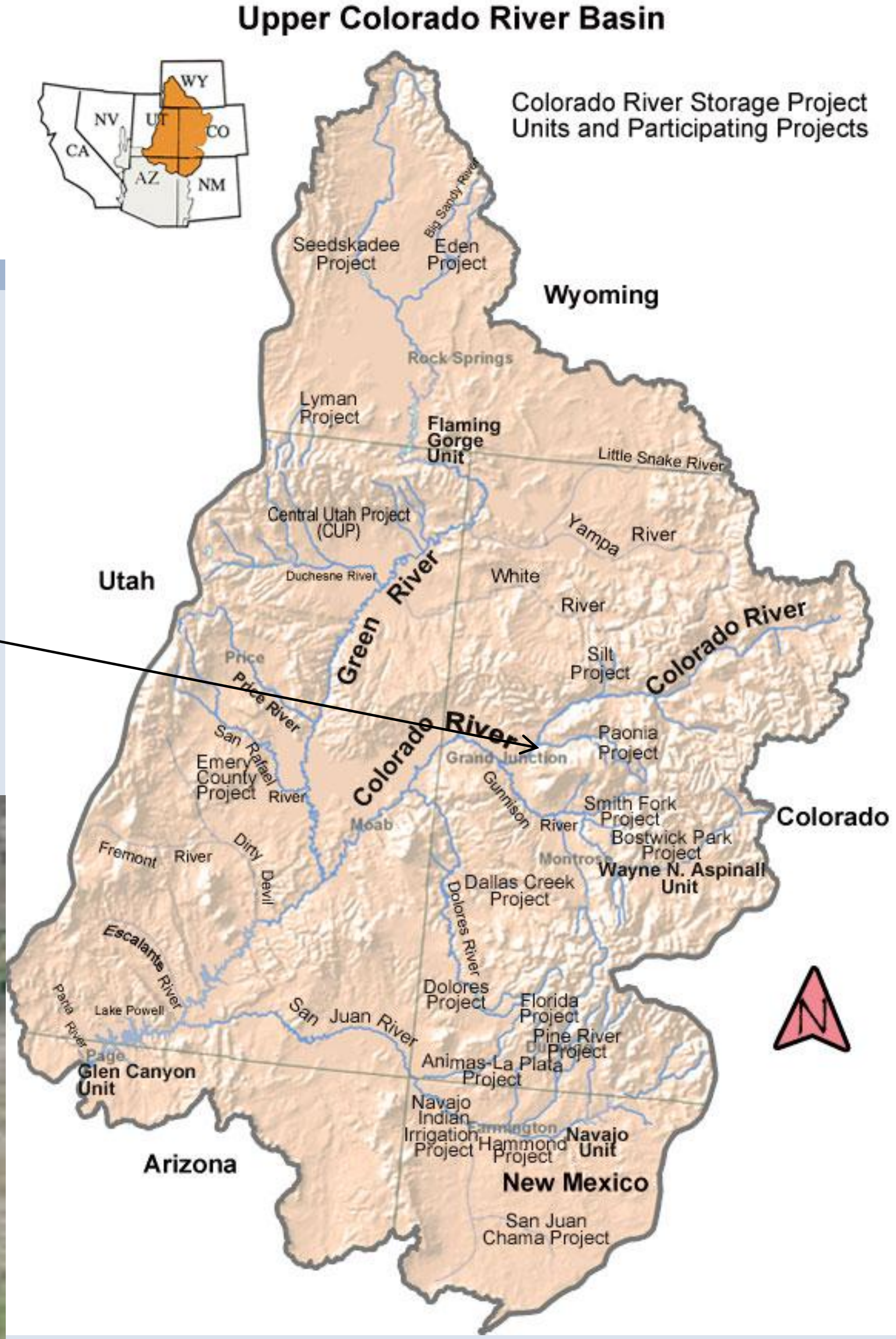
Comparison to observed streamflow

Cameo Streamgauge on the Colorado River near Grand Junction



Comparison of River Discharge Volumes: Colorado River at Cameo

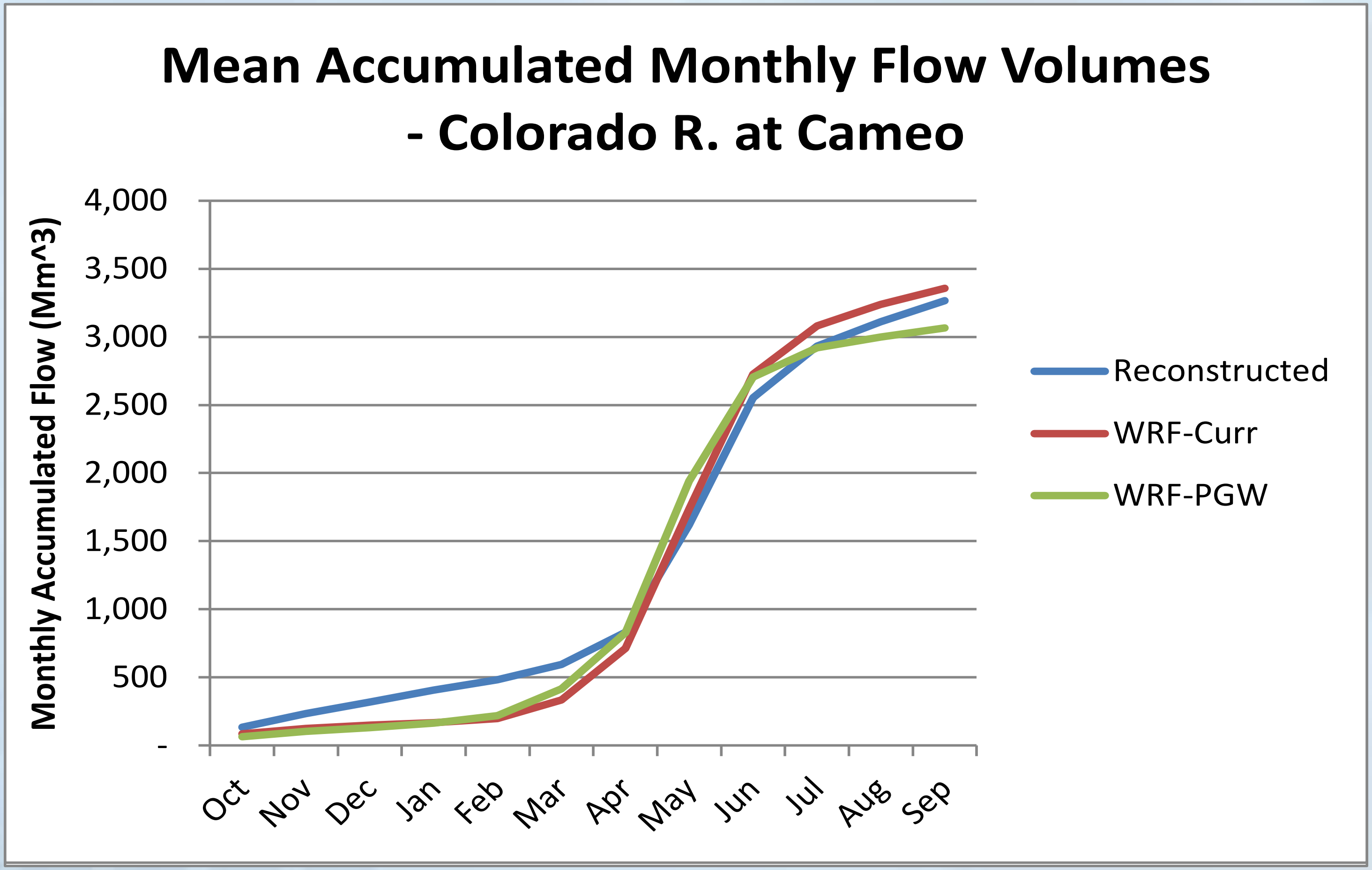


Fig. Dave Gochis

Conclusions

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- Both precipitation and evapo-transpiration increase under a warmer, moister climate.
  - Note: Summer precipitation decreases, however, yielding a smaller increase in precipitation than anticipated. Without this effect runoff might be positive.

- Evapo-transpiration increases more than precipitation, yielding a negative change in runoff.

- Future research needs to focus on reducing the uncertainty in this estimate (ET especially).