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Sensitivity of Hydrologic Impacts Assessment to the Downscaling Methodology and Spatial Resolution

Team: Roy Rasmussen, Martyn Clark, Levi Brekke, Jeff Arnold, Changhai Liu, Kyoko Ikeda, Ethan Gutmann, Tom Pruitt, David Gochis, Naoki Mizukami, Pablo Mendoza, and Balaji Rajagopalan.

NCAR

NSF

Background

- **We have multiple methods for translating climate projections into hydrologic impacts; downscaling is typically involved.**
  - Dynamical vs. Non-Dynamical methods
  - Both types methods have supported planning activities.
- **We have two goals when choosing a downscaling method.**
  - Represent physics as well as possible → dynamical?
  - Represent many available climate projections → non-dynamical?
- **We have access to multiple types of hydrologic models and evaluation methods to translate downscaled climate into runoff.**
- **Science question: How do methodological choices (downscaling methods, hydrologic models) affect the portrayal of climate impacts?**

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Objectives

- **Overall objective: Determine the extent to which the portrayal of climate impacts depends on methodological choices**
  - Understand why different methods produce different results
  - Provide guidance on the suitability of different methods to provide state-of-the-art intelligence for water resources planning.

- **Specific science questions include:**
  - Is the portrayal of hydrologic impacts under climate change dependent on the chosen downscaling method (i.e. dynamical downscaling using regional climate simulation versus non-dynamical downscaling using statistical or empirical methods)?
  - At what space and time scales does impacts portrayal begin to be sensitive to methods class, and for what types of hydrologic metrics?
  - How do the responses to these questions vary with the spatial resolution of dynamical downscaling and the adequacy of process representation in atmospheric and hydrologic models?

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Outline

- **WRF simulations at multiple spatial scales, with impacts on the water balance (Roy)**
- **Inter-comparison of statistical and dynamical downscaling methods (Ethan)**
- **Sensitivity of portrayal of climate change impacts on hydrology to methodological choices (Martyn)**
  - Forcing data
  - Model parameters/structure
- **Summary / next steps**

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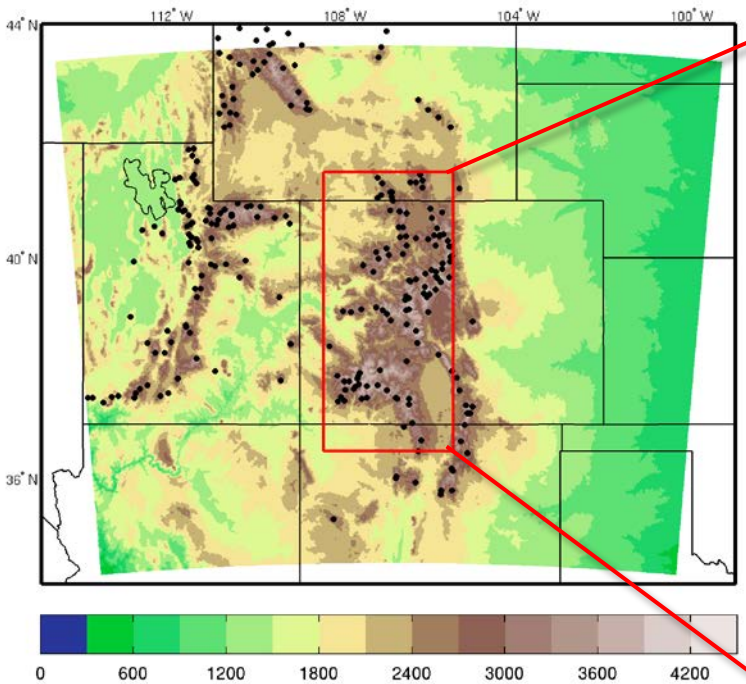
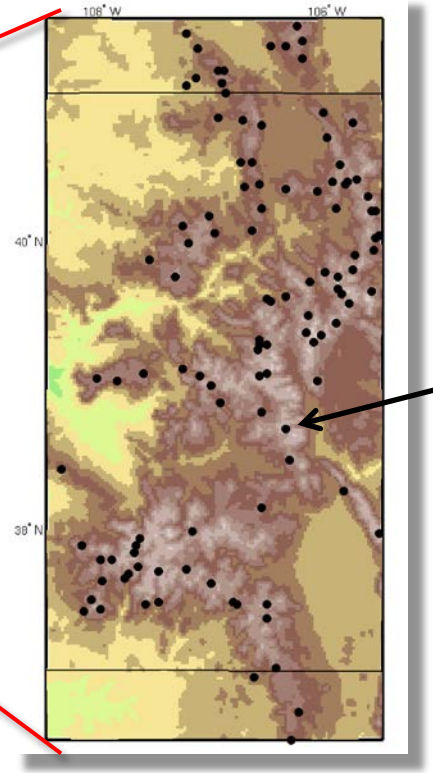
Domain: Colorado Headwaters

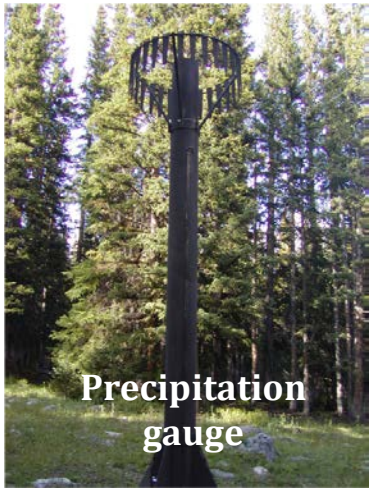
Full model domain



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

Fig. Kyoko Ikeda

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Mean difference in monthly precipitation between WRF and SNOTEL from 8-year climatology data

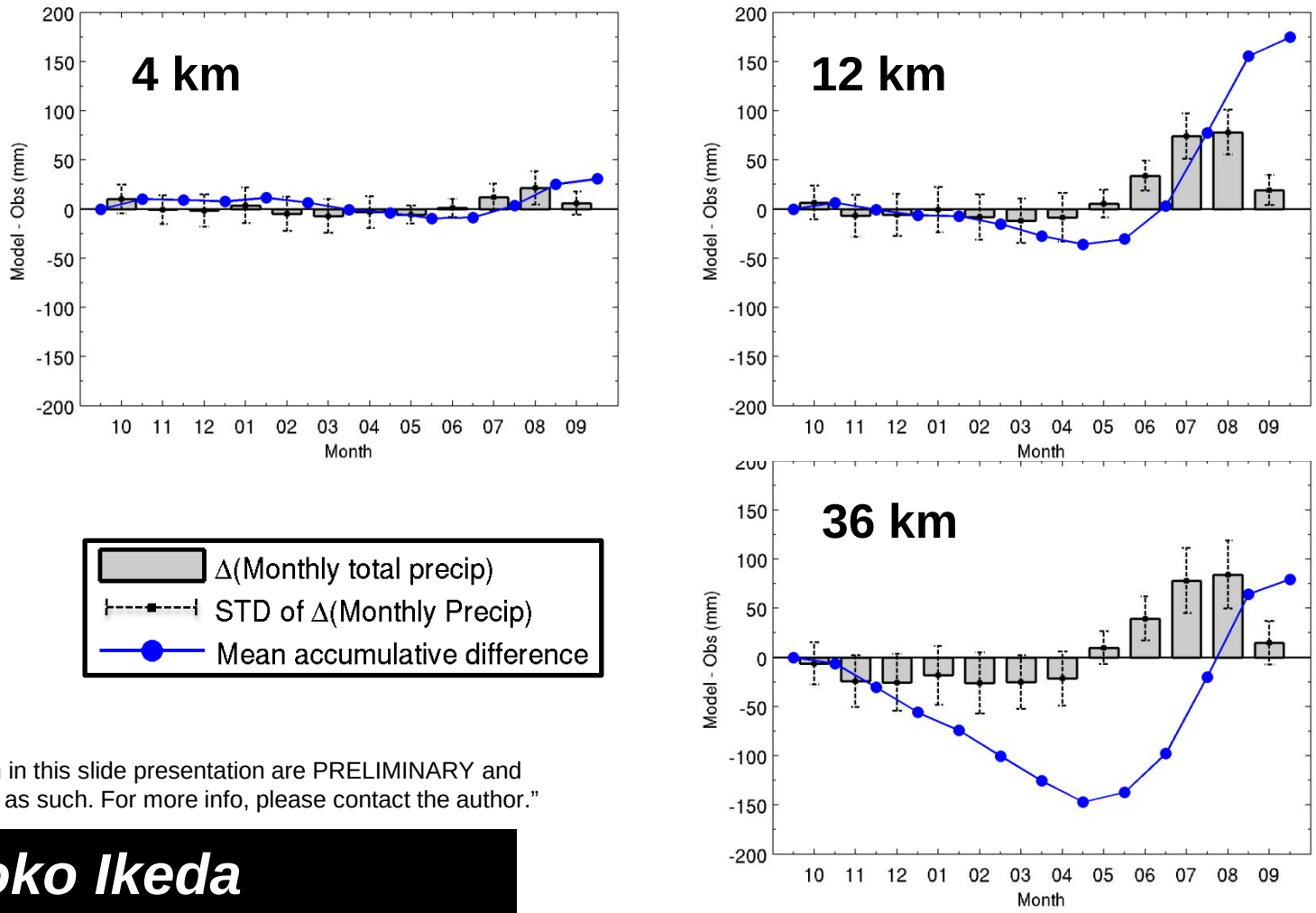

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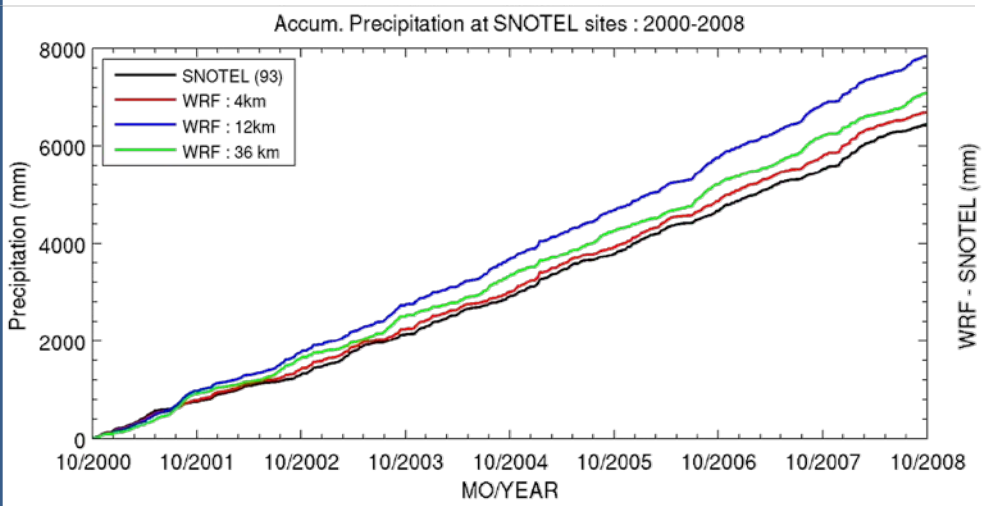
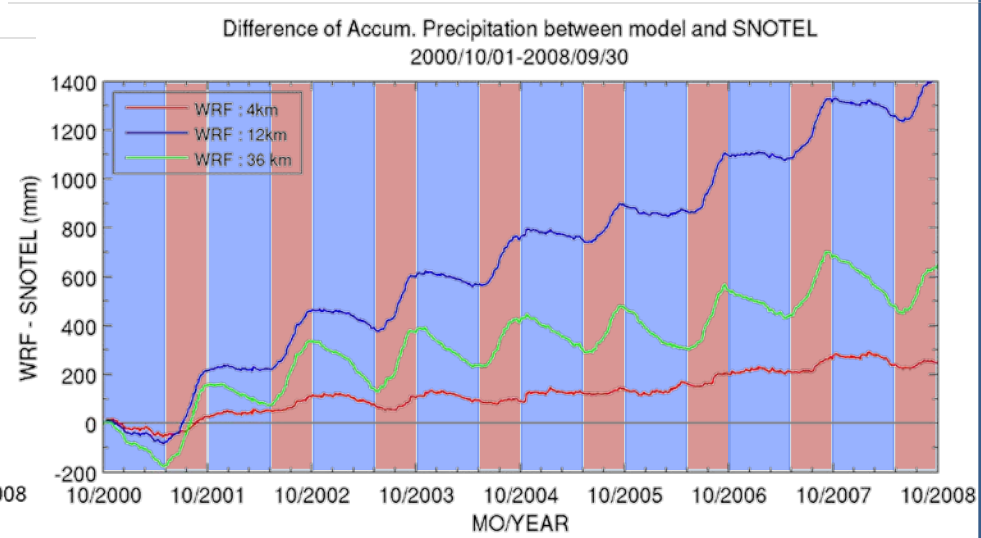
Fig. Kyoko Ikeda

Sensitivity to model grid resolution: Precipitation from the 8-year Current Climate Simulation





Percent model bias in annual total and 8-yr total precipitation [Model – Obs] / Obs*100

	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	8 years
4 km	3.4	15.4	-0.4	-2.0	5.4	7.3	8.1	-2.3	**3.9**
12 km	28.0	45.1	16.7	20.4	14.5	23.6	26.9	9.2	**21.9**
36 km	20.2	32.6	4.6	5.9	5.3	8.4	16.7	-4.2	**10.1**

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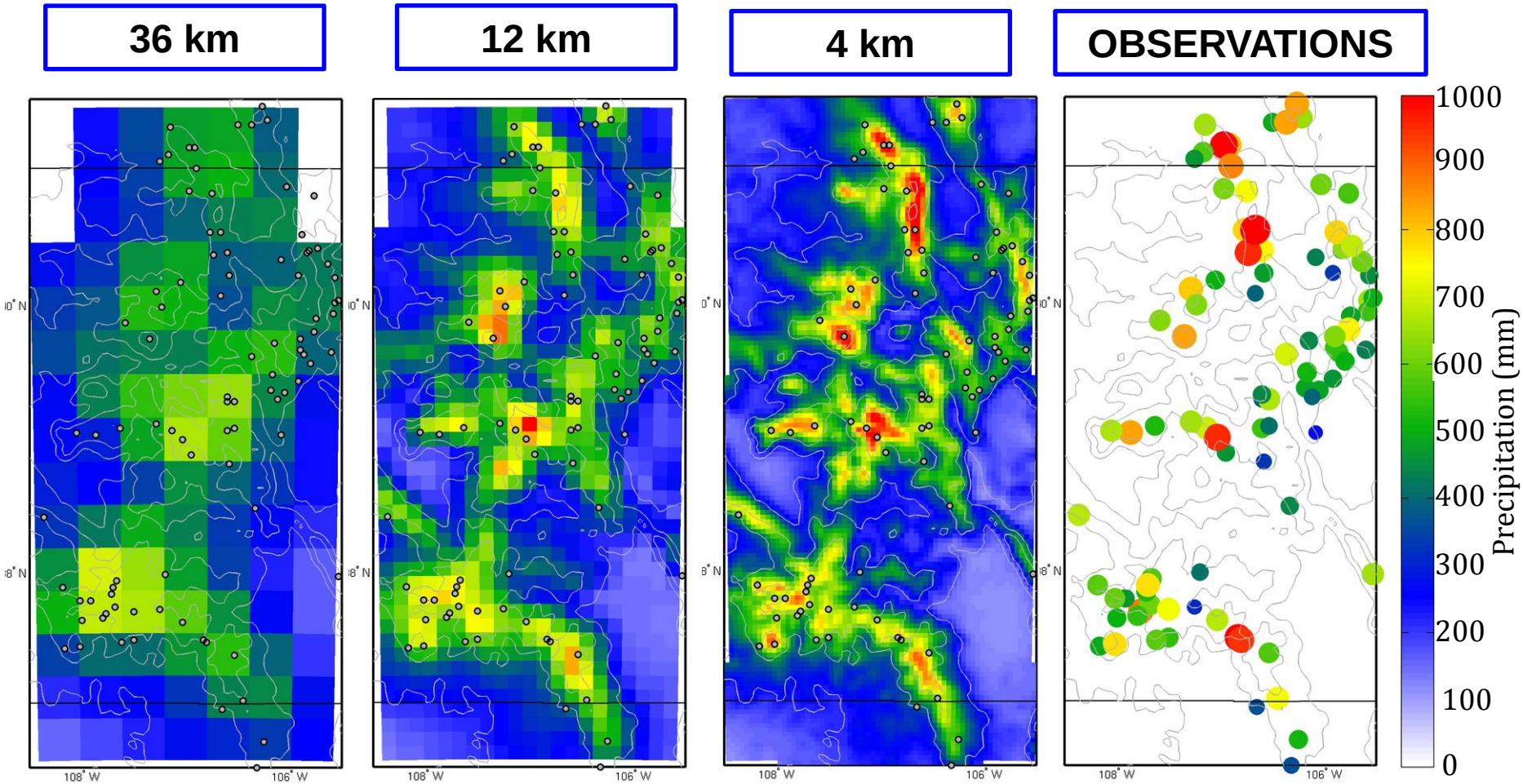
7-year average cool-season precipitation :
1 October – 31 May



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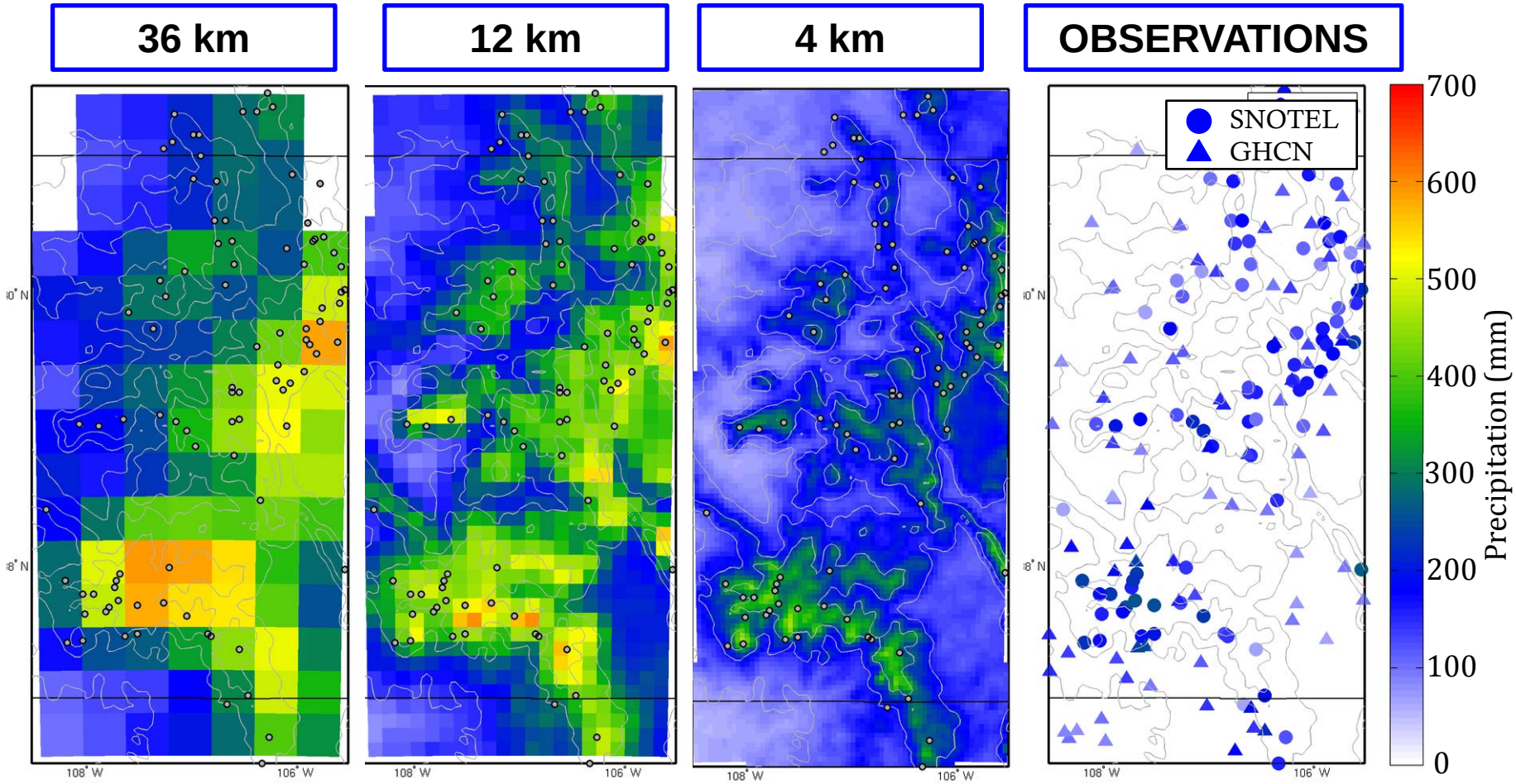
7-year average warm-season precipitation:
1 June – 30 September



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SWE from WRF@4km, 36km and SNOTEL

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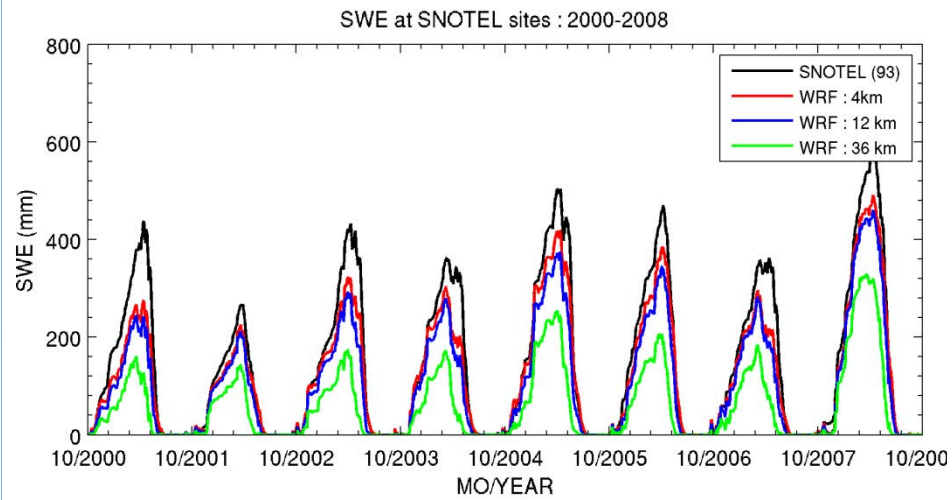
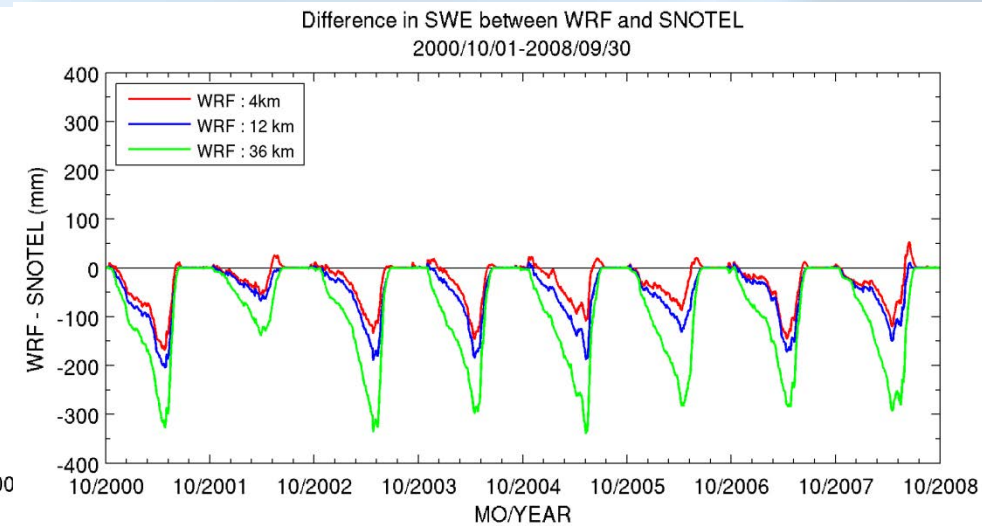




Percent difference in average peak SWE

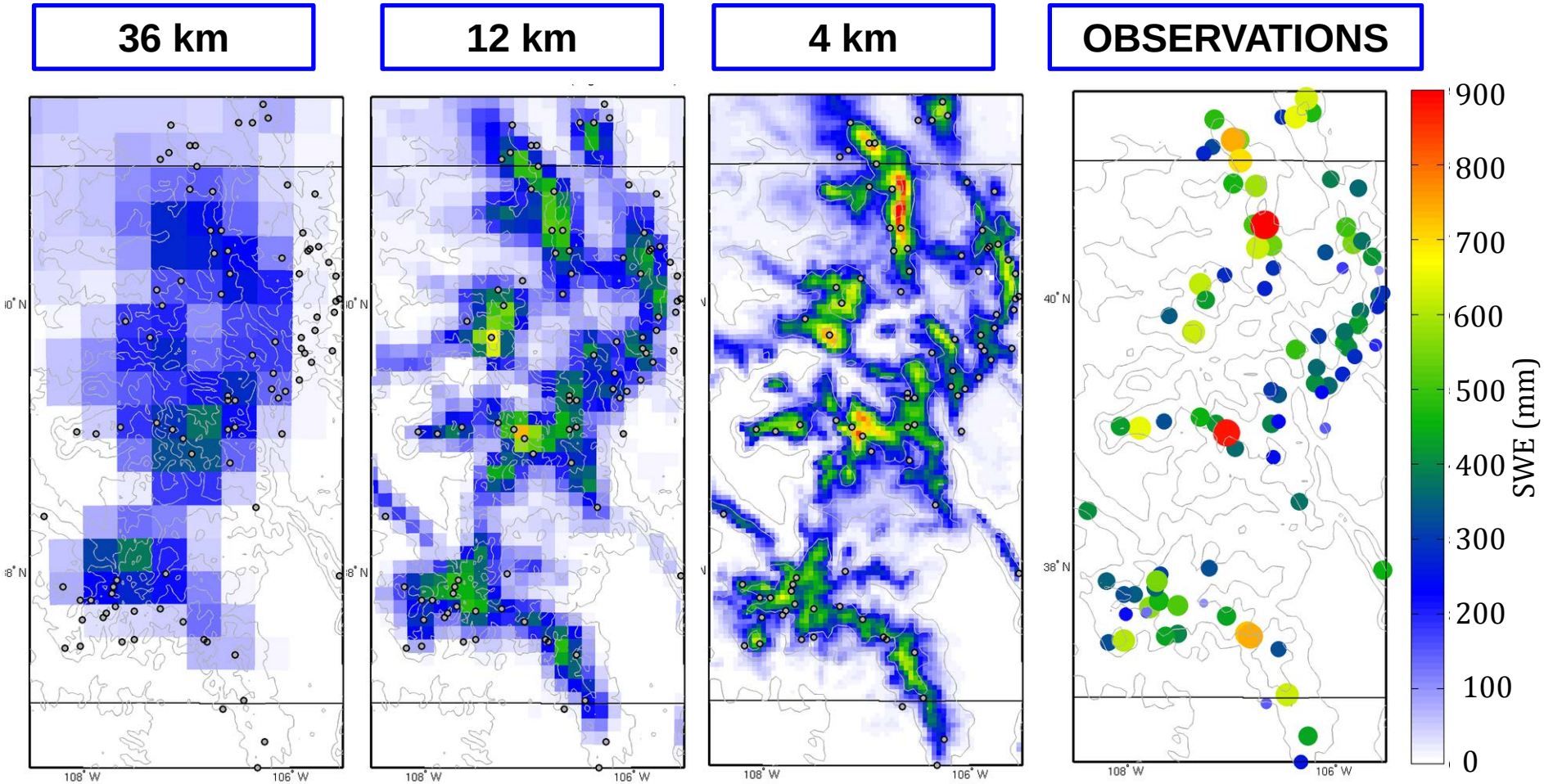
[Model – Obs] / Obs*100

	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08
4 km	-34.5	-18.8	-27.7	-23.2	-19.5	-18.0	-25.2	-19.5
12 km	-42.4	-23.9	-36.3	-31.1	-28.6	-26.8	-30.5	-24.3
36 km	-65.0	-47.9	-61.7	-58.2	-51.4	-55.3	-55.9	-45.4

Median Peak SWE date: Mod – Obs (days)

	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08
4 km	-5	-8	-12	-3	-5	-2	-9	-2
12 km	-10	-8	-17	-7	-6	-5	-10	-3
36 km	-29	-10	-26	-36	-12	-9	-43	-12

7-year average SWE on April 1st



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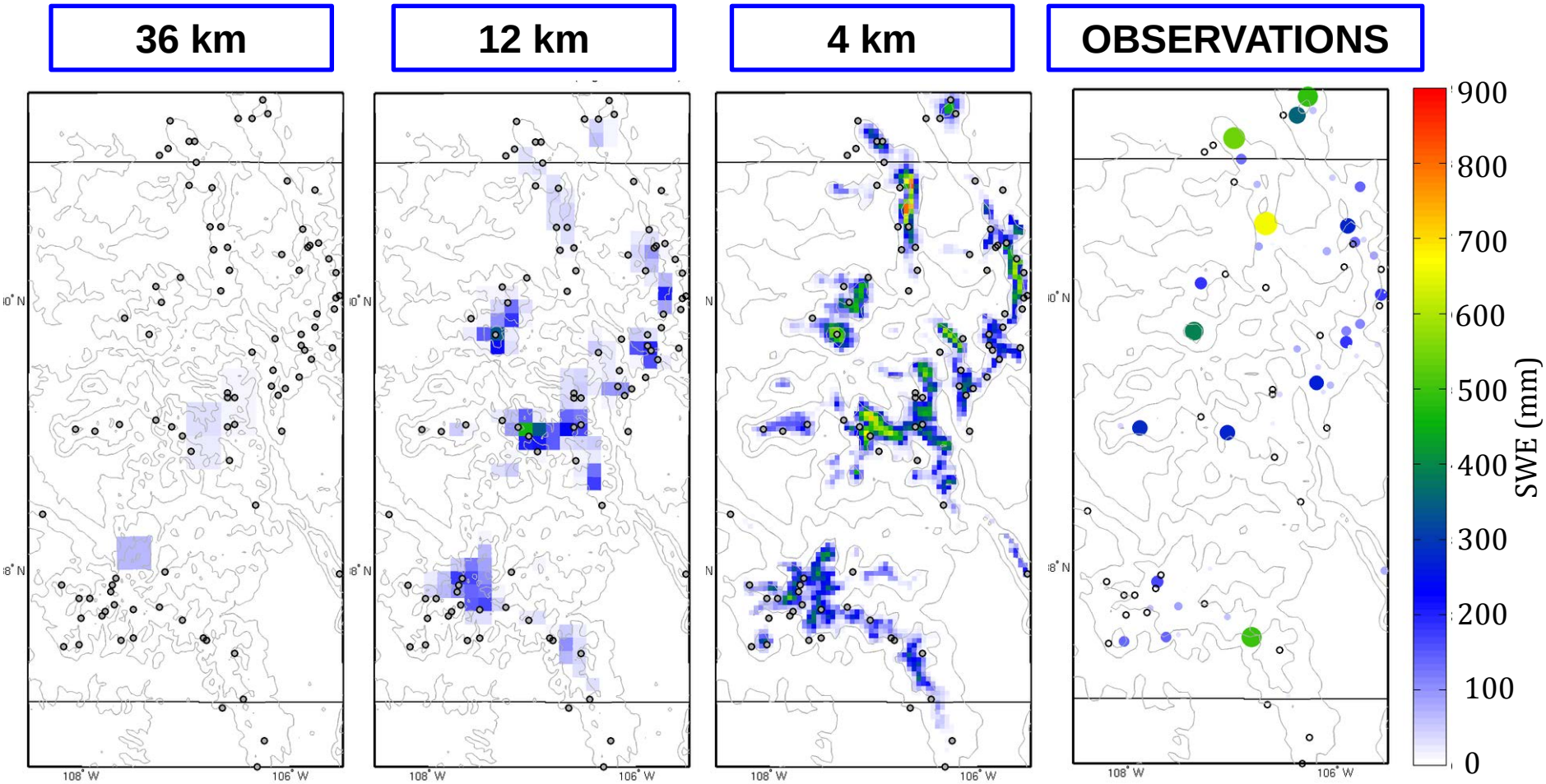
7-year average SWE on June 1st



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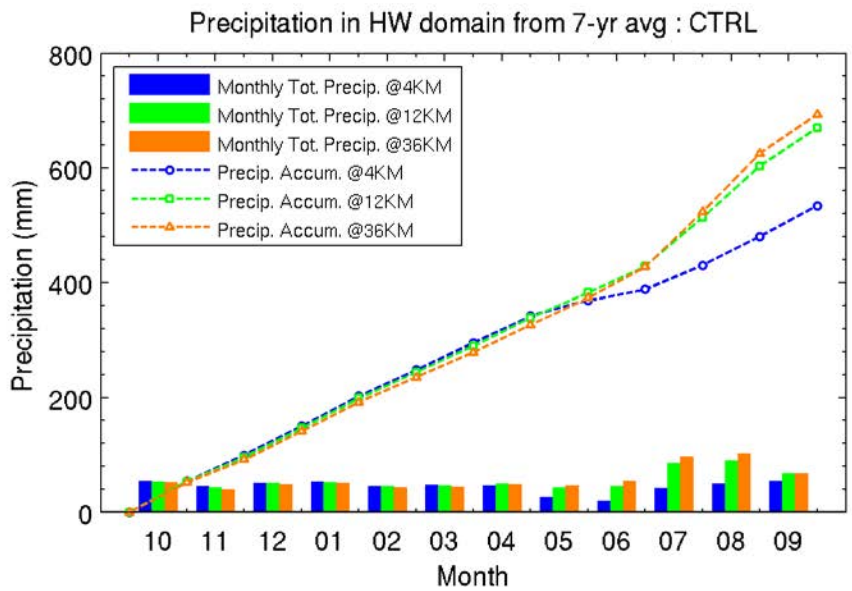

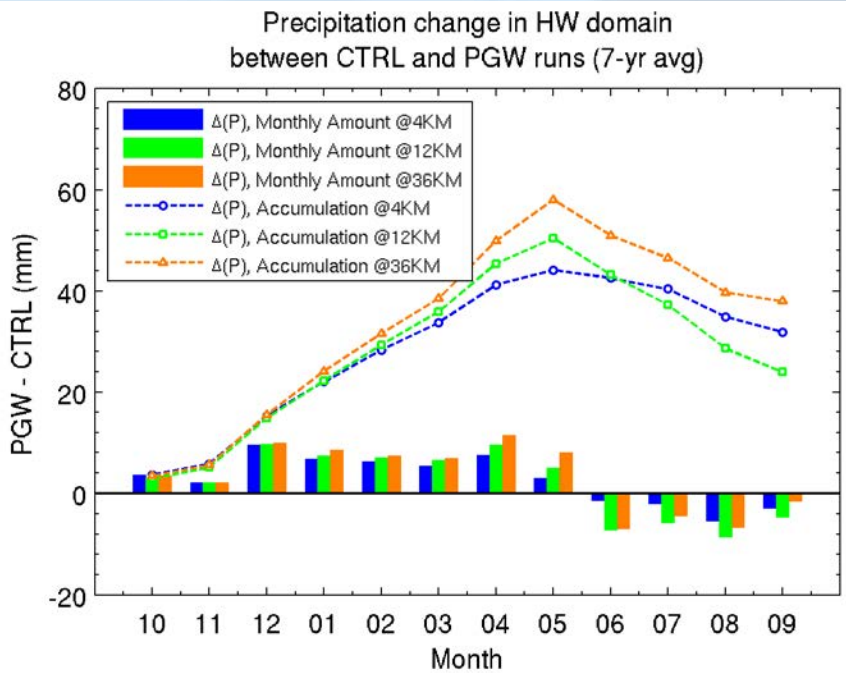

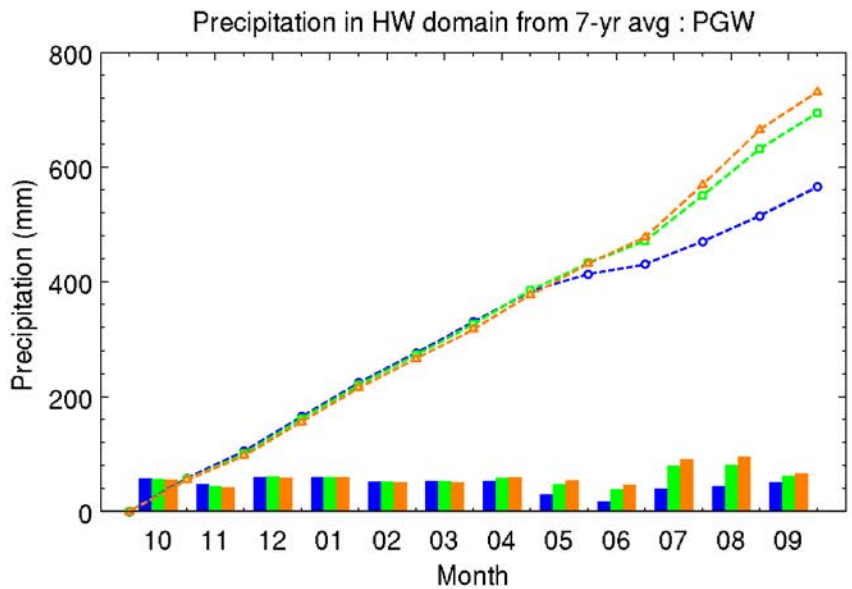

1. Accumulation amount is essentially the same among the three model resolutions during cool season (Oct-May).
2. The precip. accumulation during cool season is the same for all three resolutions because details of ridges and valleys in the coarser models are washed out which leads to more (less) precip in the valleys (mountain peaks) in the coarser models than the 4 km model. i.e., precipitation is redistributed.
3. Beginning in June, the 12 and 36 km models produce much more rain than the 4 km because of the cumulus parameterization.
4. Change signal in the future climate is similar in all three models. More precip. in winter (10-15%). Less in summer (~10%).

Fig. Kyoko Ikeda

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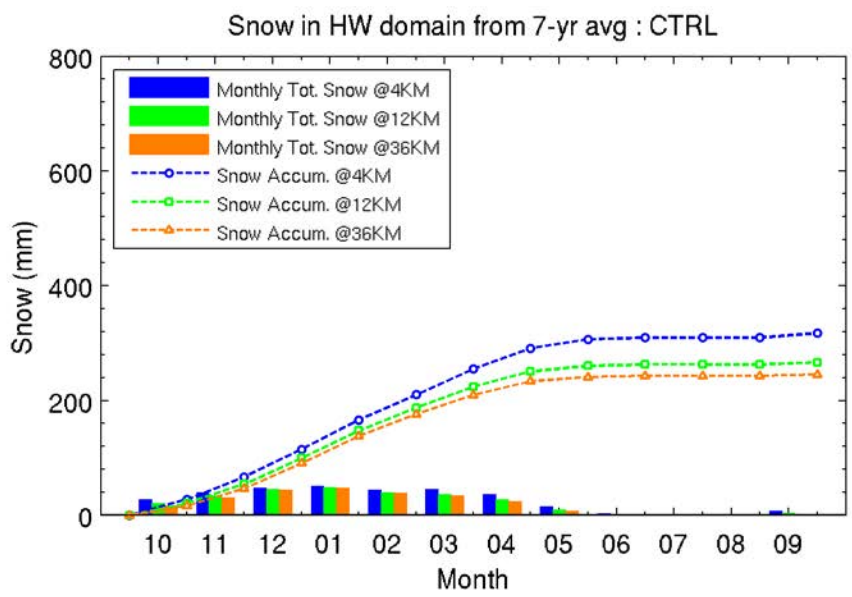

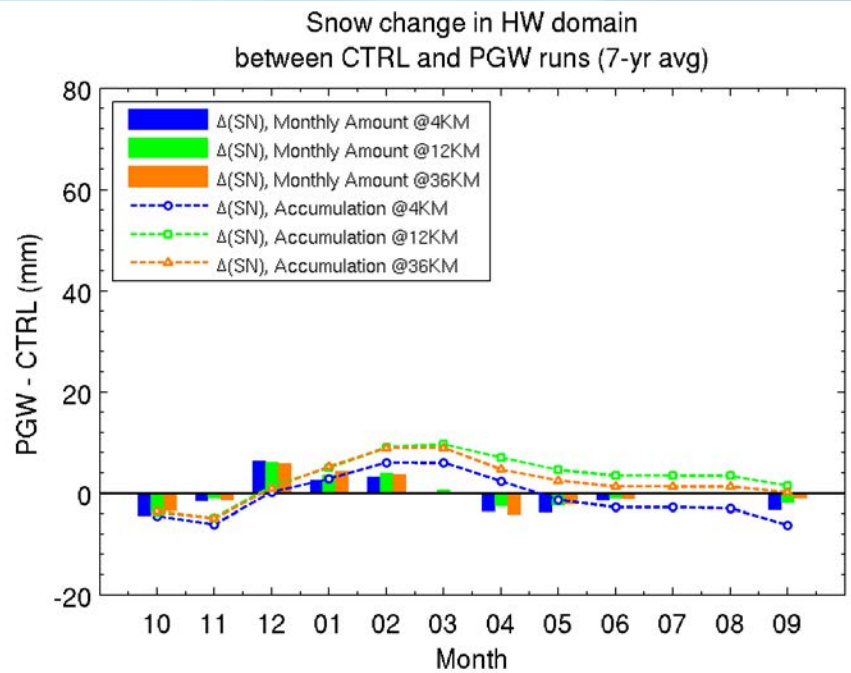

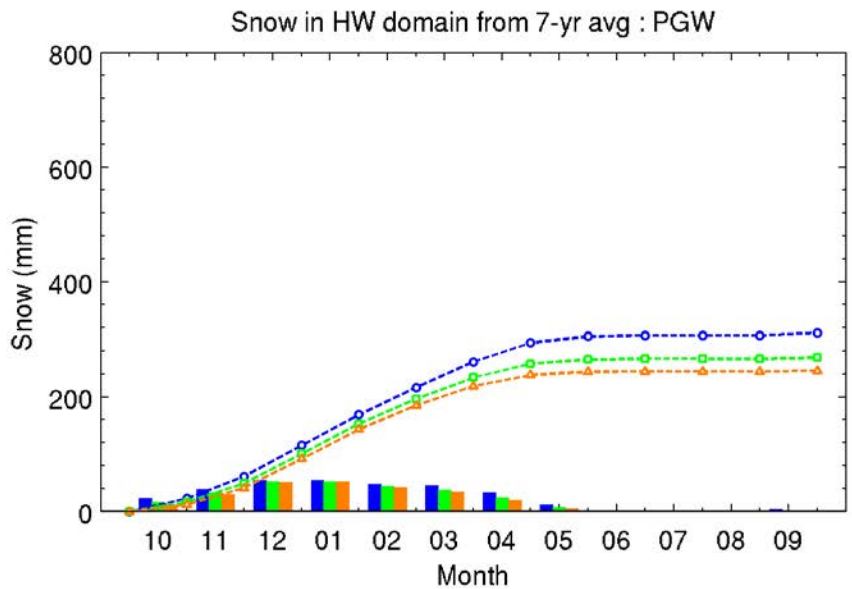

1. Consistent with our earlier findings using the 2 km, 6-month simulation data (HW2008), change in snowfall amount is only a small portion of the total change in annual precipitation.
2. Among the three models, the 4 km model produced more snow than coarser models. This came from snow at high elevations represented in the 4 km run. (see e.g., spatial distribution maps)

SNOW

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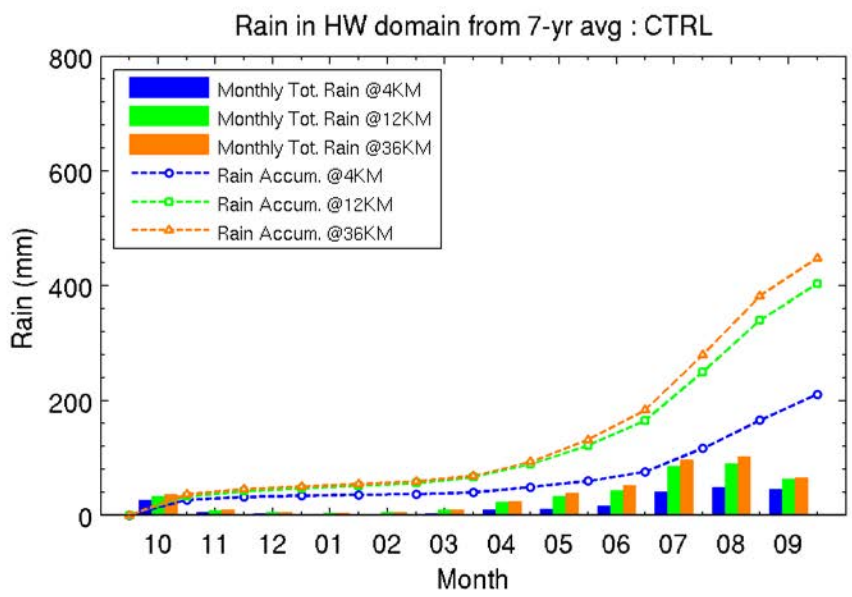

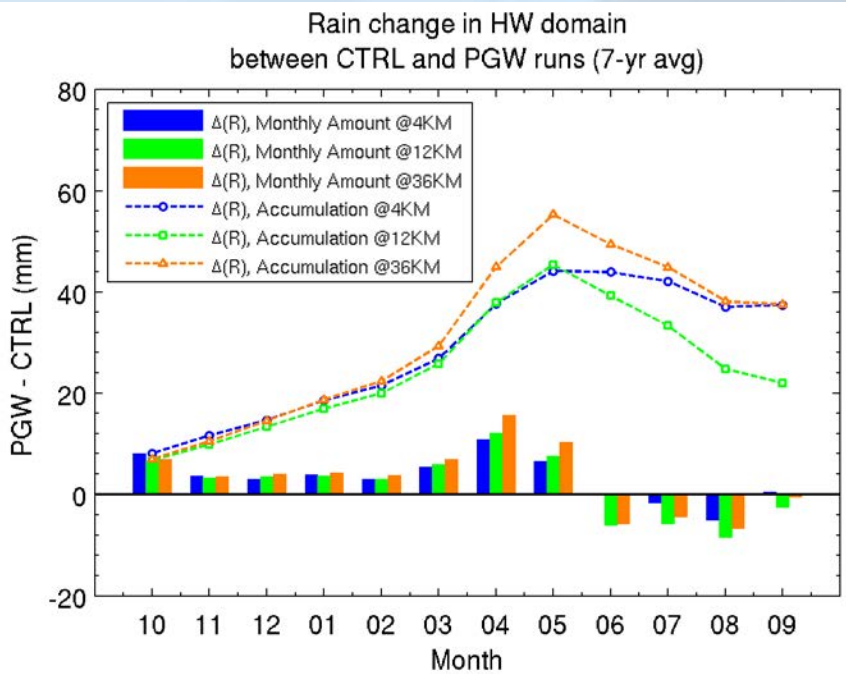

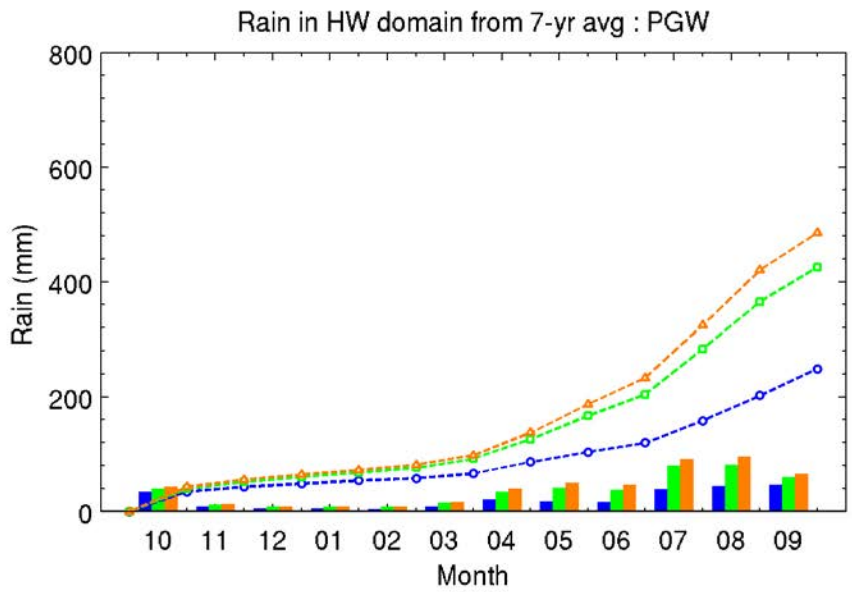

1. Most of the change in future precipitation over the full year is due to an increase in rain in cold season. Increase in rain during cold season simply from the rain-snow line at higher elevation.
2. Amount of rain accumulation during cold season is similar among the three resolutions. Strictly speaking, there is a little more rain for coarser runs.

RAIN

Fig. Kyoko Ikeda

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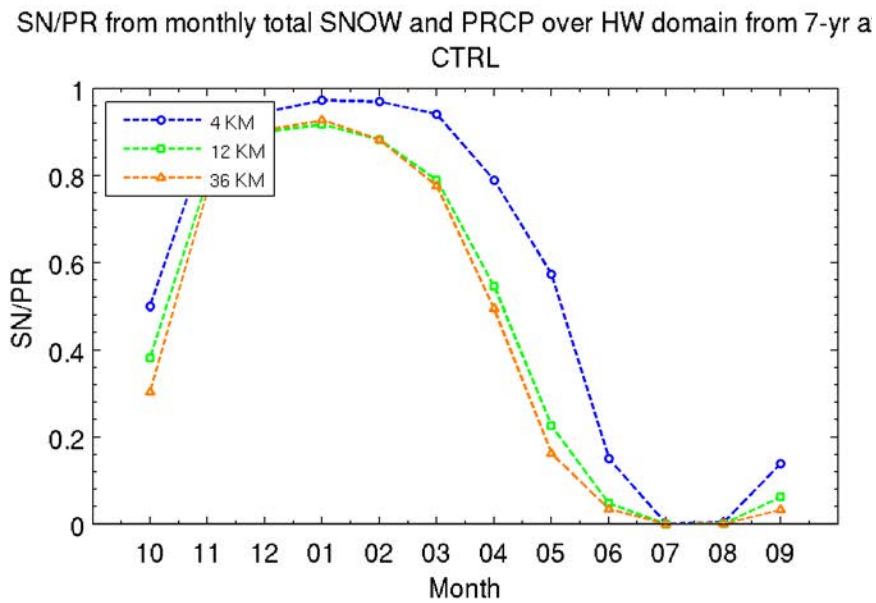

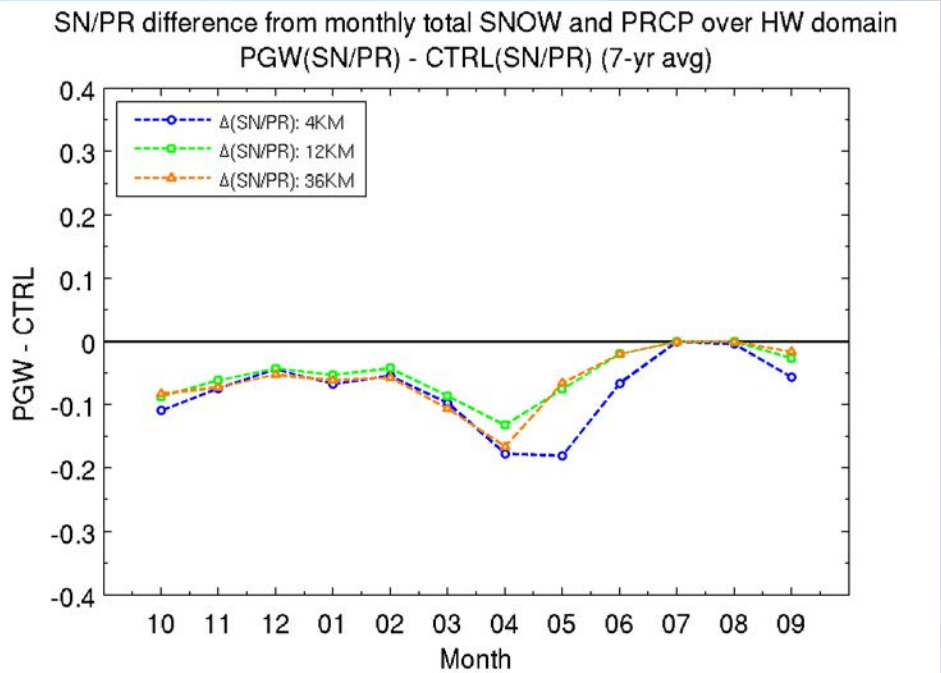

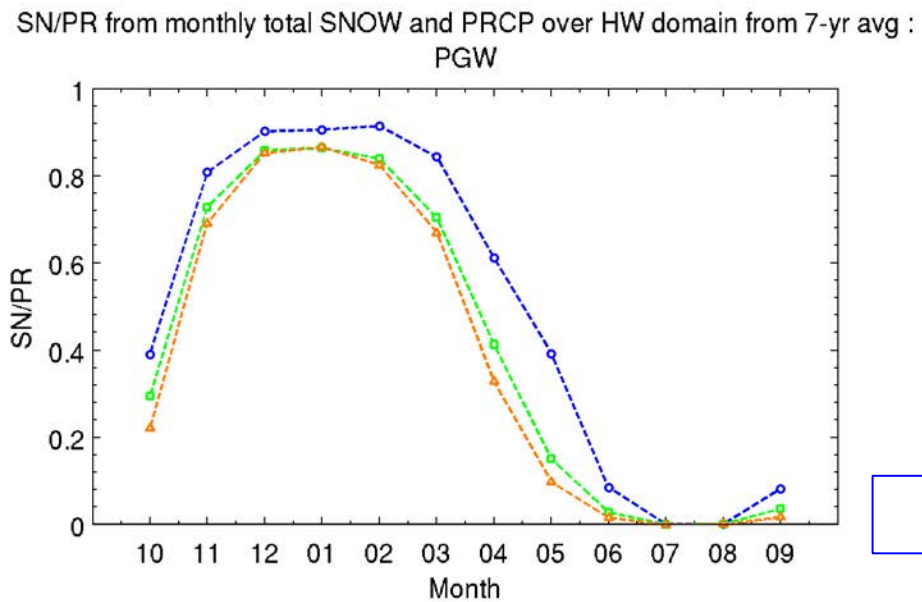

1. Interestingly, the change in snow fraction in the future climate during cold season is the same for all resolutions. However, it is different from early Spring to early Summer. This will contribute to a different hydrologic response in climate change.
2. As expected, snow fraction is less in the coarser resolution models compared with the 4 km run—also an important factor influencing the water cycle changes in the future climate.

SNOW FRACTION = SNOW / (RAIN + SNOW)

Fig. Kyoko Ikeda

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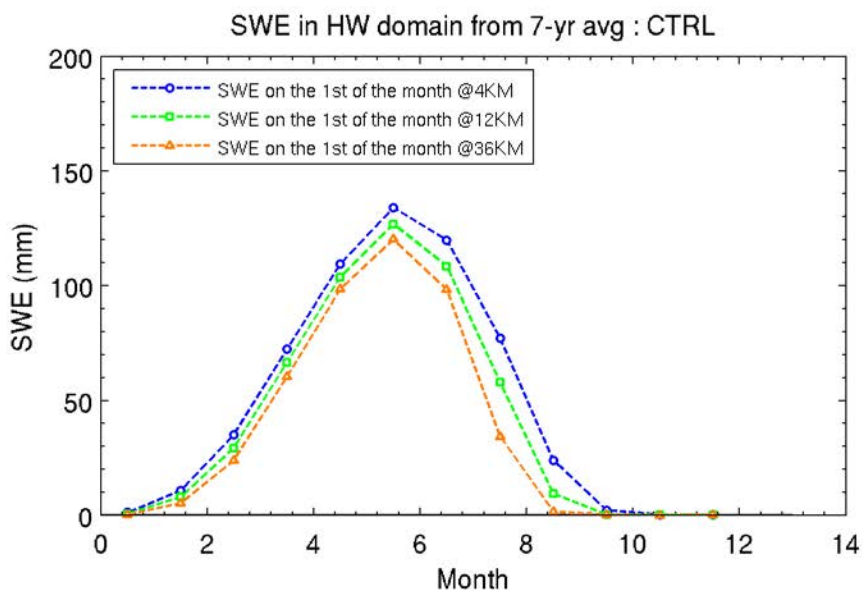

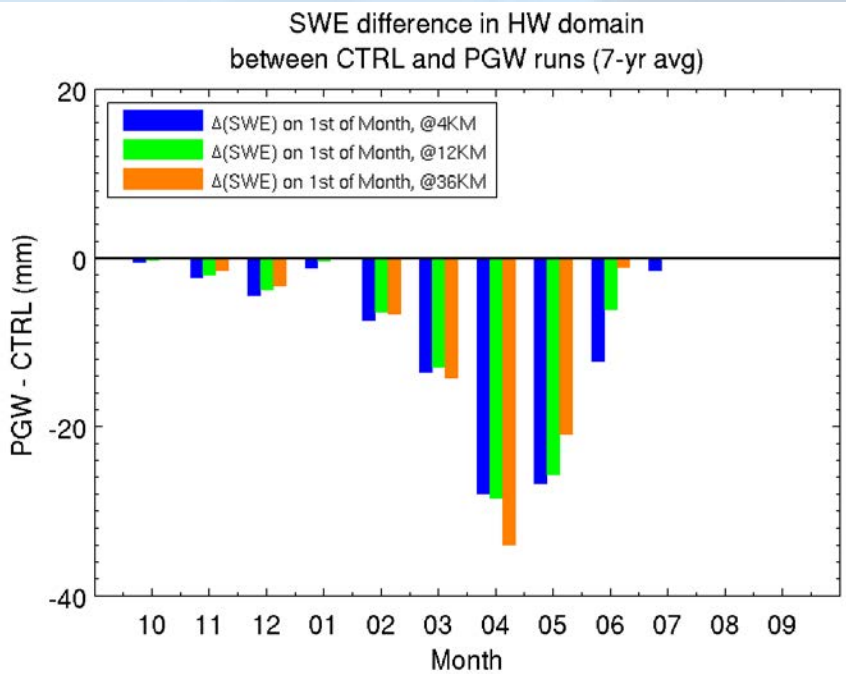

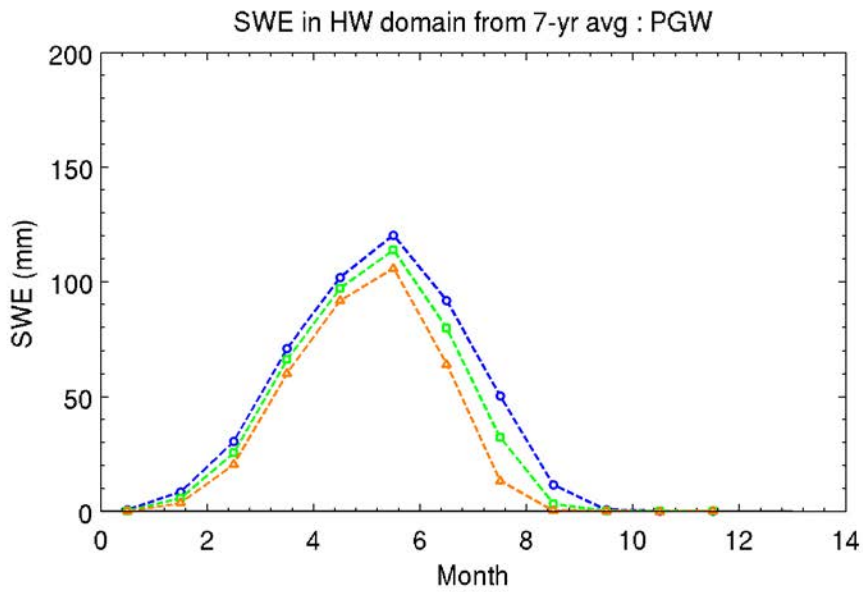

1. The peak difference in SWE in the future climate occurs in Apr. in all simulations. The magnitude is the largest with the 36 km run (by ~5 mm).
2. As expected, less SWE in coarser model runs because of underestimating snowfall at high elevations in the model. Lower mountain peaks also means warmer temperature at these heights.

SWE

Fig. Kyoko Ikeda

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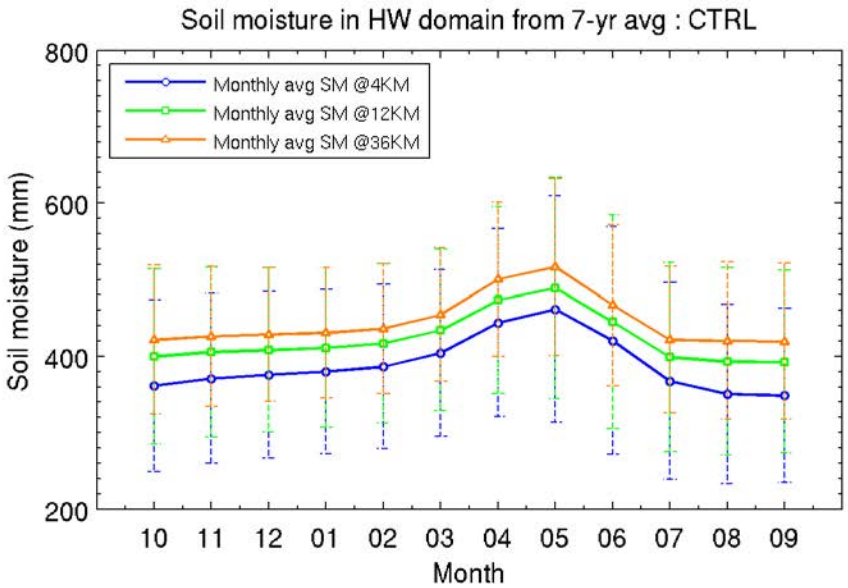

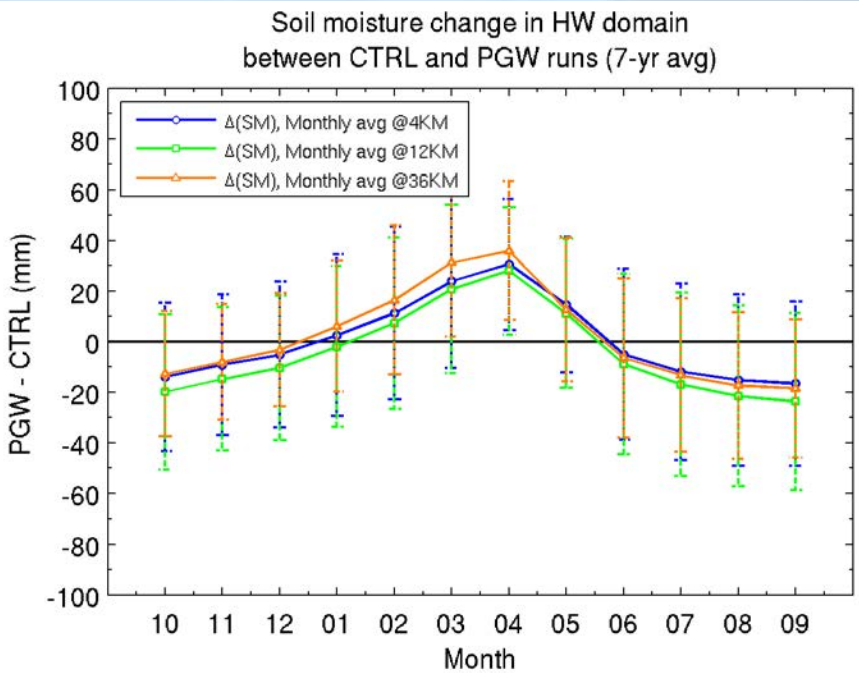

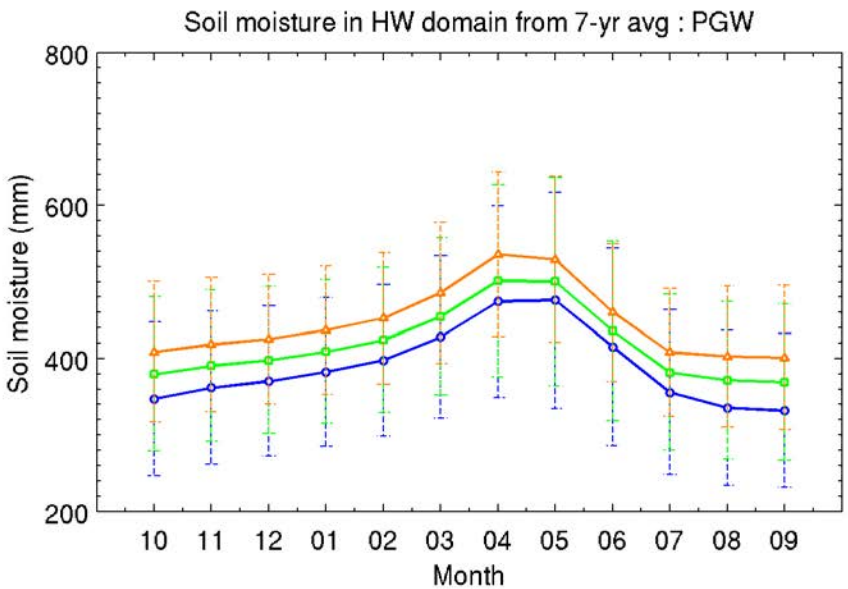

1. The response signature to warmer climate is the same among all three resolutions.

MONTHLY AVERAGE SOIL MOISTURE

Fig. Kyoko Ikeda

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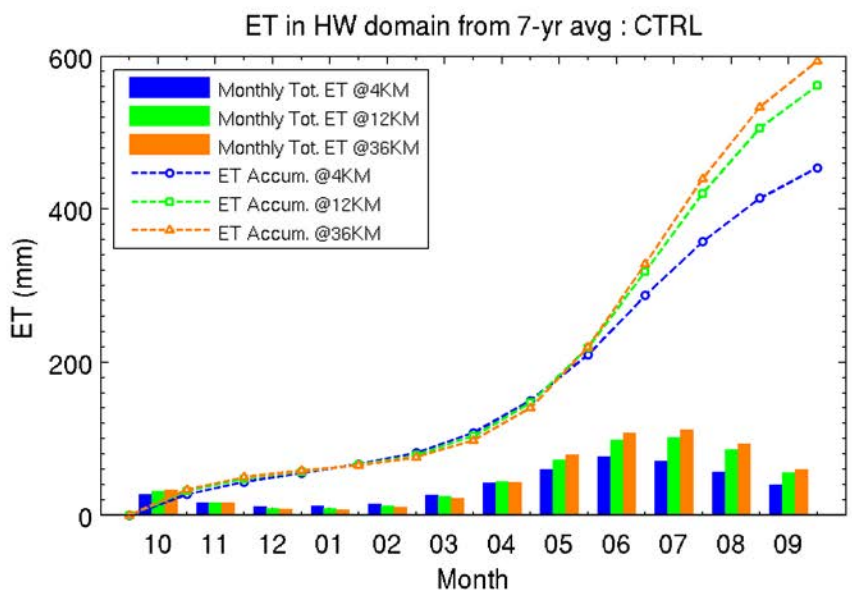
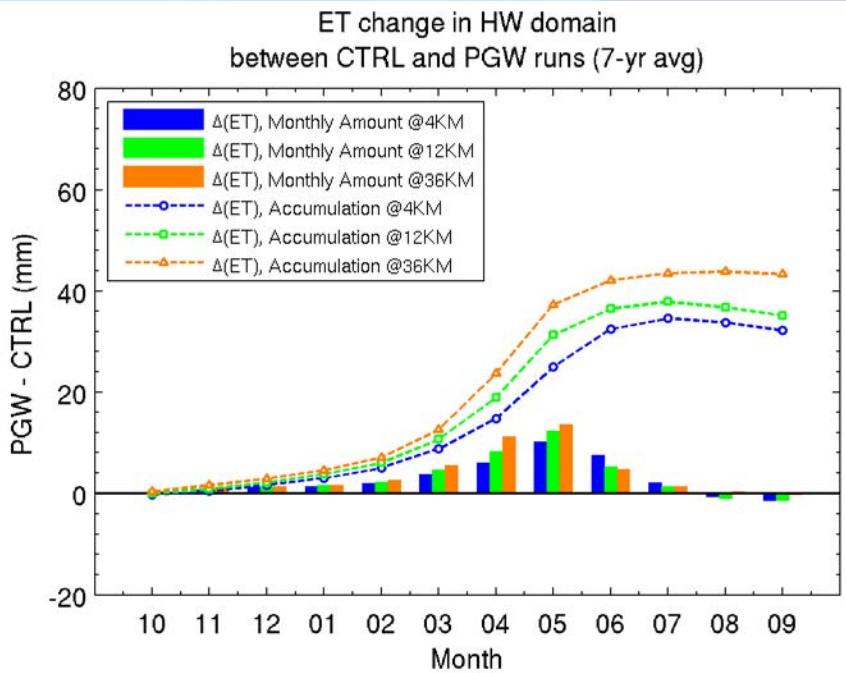
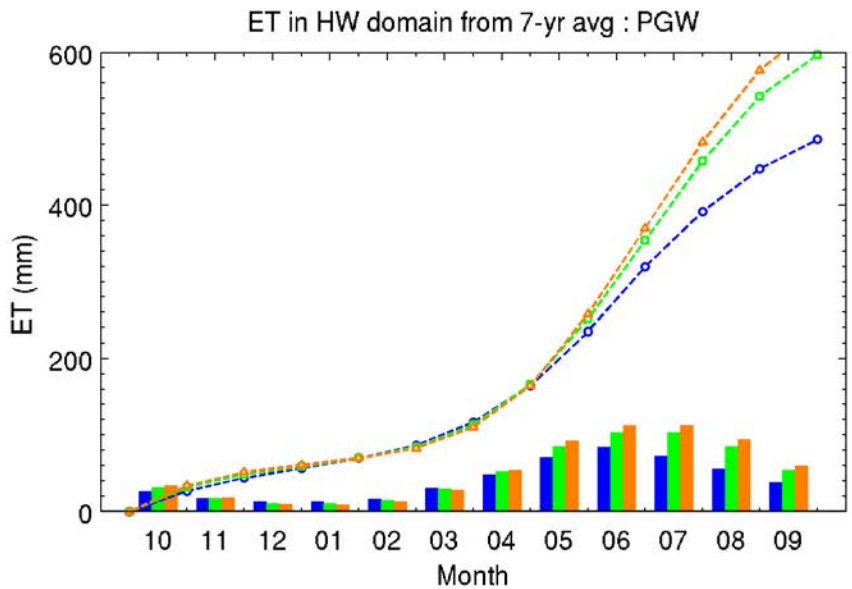


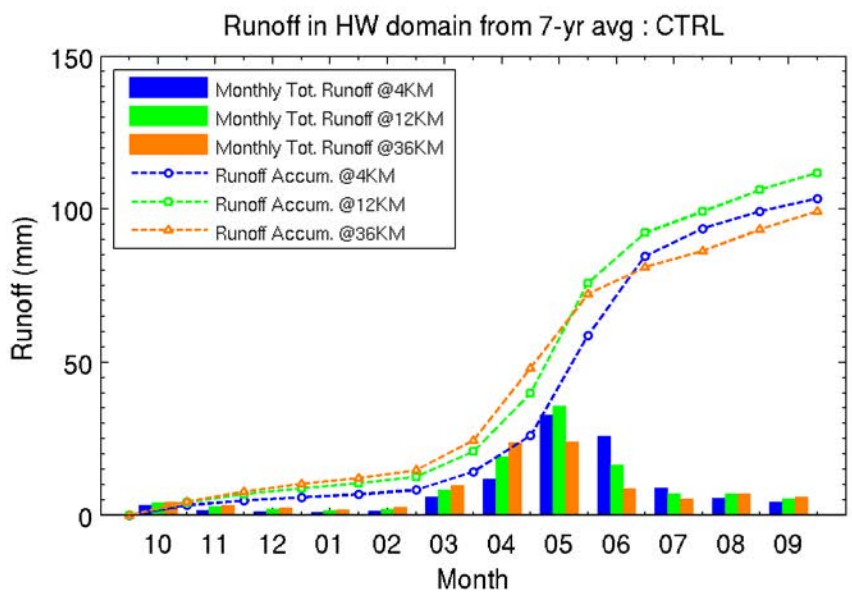


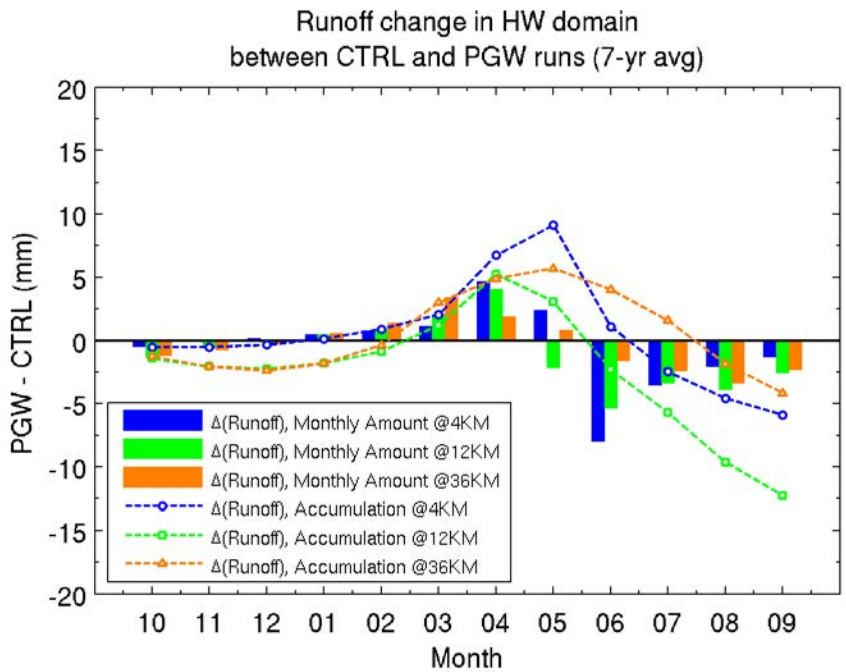


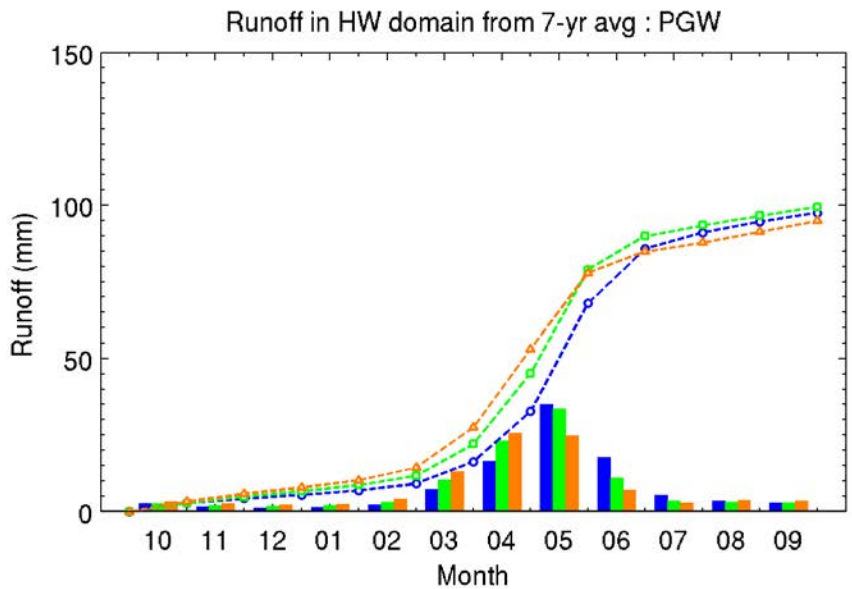
1. Signs on the future change in ET are the same among all three resolutions. The response from the warmer climate simulation is larger in the 12 and 36 km runs compared with the 4 km run.
2. Time series of ET shows that ET accumulation is essentially the same during cold season. This is probably related to the similar precipitation accumulation during cold season and domain *average* temperature is similar in the three runs.
3. ET rapidly increases in early Summer in the 12 and 36 km runs because much more rainfall are produced in these coarser models compared with the 4 km model.

EVAPOTRANSPIRATION

Fig. Kyoko Ikeda







1. Signs on the change are the same in all three models except in May.
2. More runoff during cold season in the 12 and 36 km runs compared to the 4 km run due to more rain and less snow in these coarser model runs.
3. The 4-km run produces more runoff during Spring. More SWE that lasts longer at high elevations due to colder temperature in the 4-km model.

RUNOFF

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Fig. Kyoko Ikeda

Comparison of River Discharge Volumes: Colorado River at Cameo

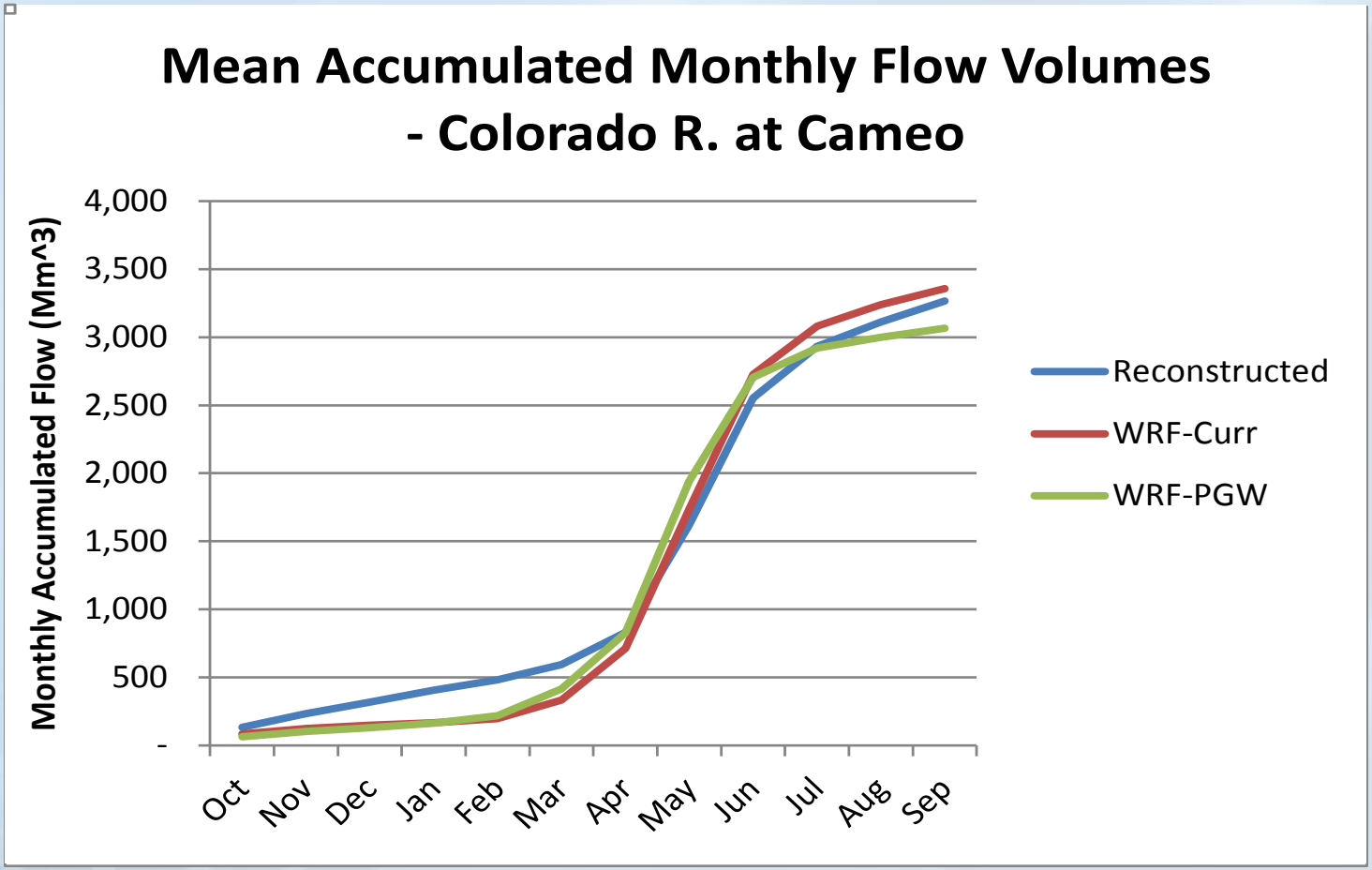

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Fig. Dave Gochis

Outline

- **WRF simulations at multiple spatial scales, with impacts on the water balance (Roy)**
- **Inter-comparison of statistical and dynamical downscaling methods (Ethan)**
- **Sensitivity of portrayal of climate change impacts on hydrology to methodological choices (Martyn)**
  - Forcing data
  - Model parameters/structure
- **Summary / next steps**

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Statistical Downscaling Overview

Comparing Downscaling products from combinations of:

- Driving Model : NARR, NCEP
- Downscaling Method:CA, SD, SDmonthly, SAR
- Bias Correction: BC or not
- Resolution: 4km, 12km

For each of 3 variables: Tmin, Tmax, Precip

For each of 4 experiments:

- Standard:
  - CONUS domain, training period:1979-1999
- e0: Spatial Subset
  - headwaters domain, training period: 1979-1999
- e1: Verification time period
  - headwaters domain, training period: 2000-2008
- e: "Climate Change"
  - headwaters domain, training period: "most different years" 79-99
  - (also "Hot", "Cold", "Dry", "Wet" experiments)

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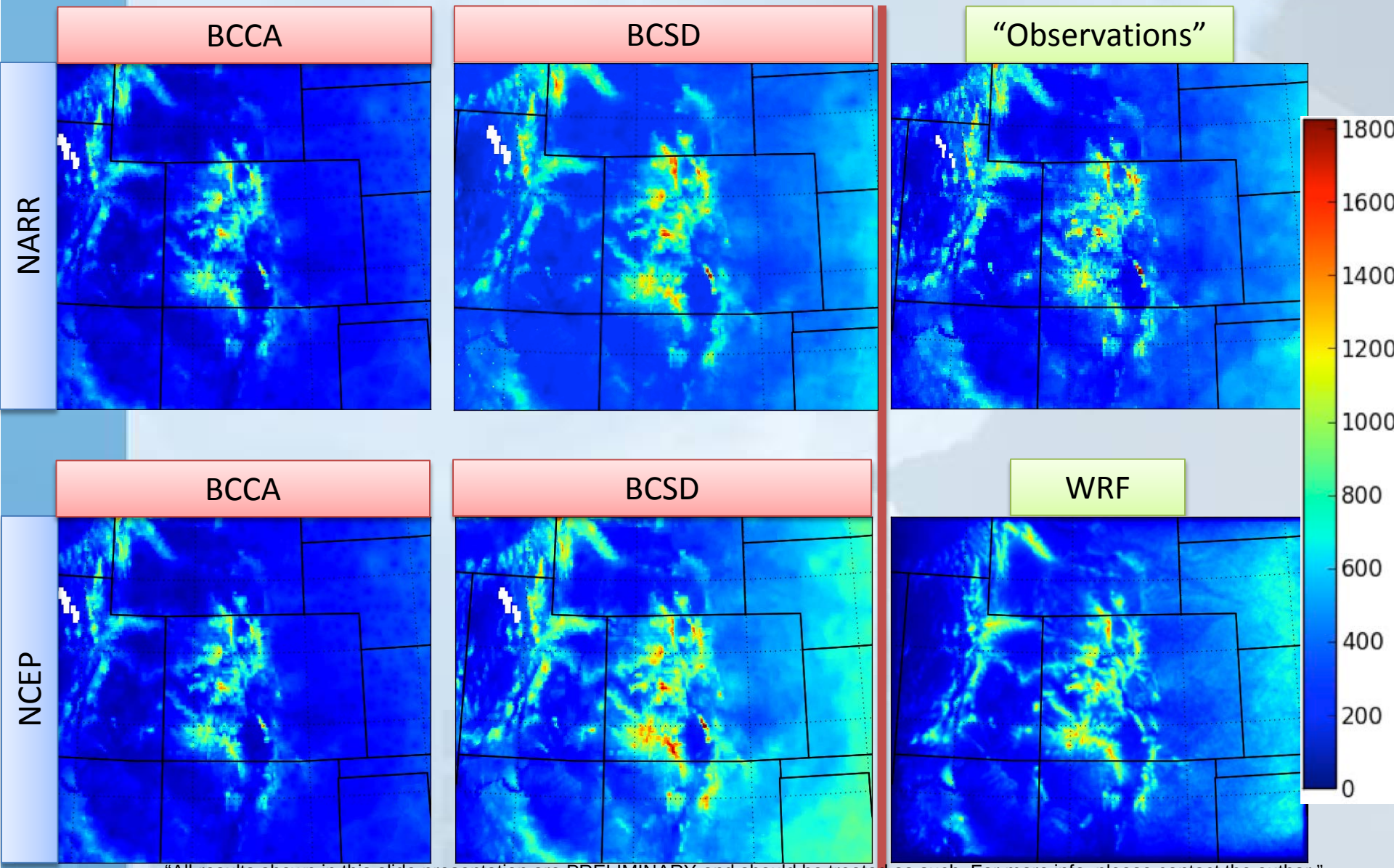
Mean Annual Precipitation



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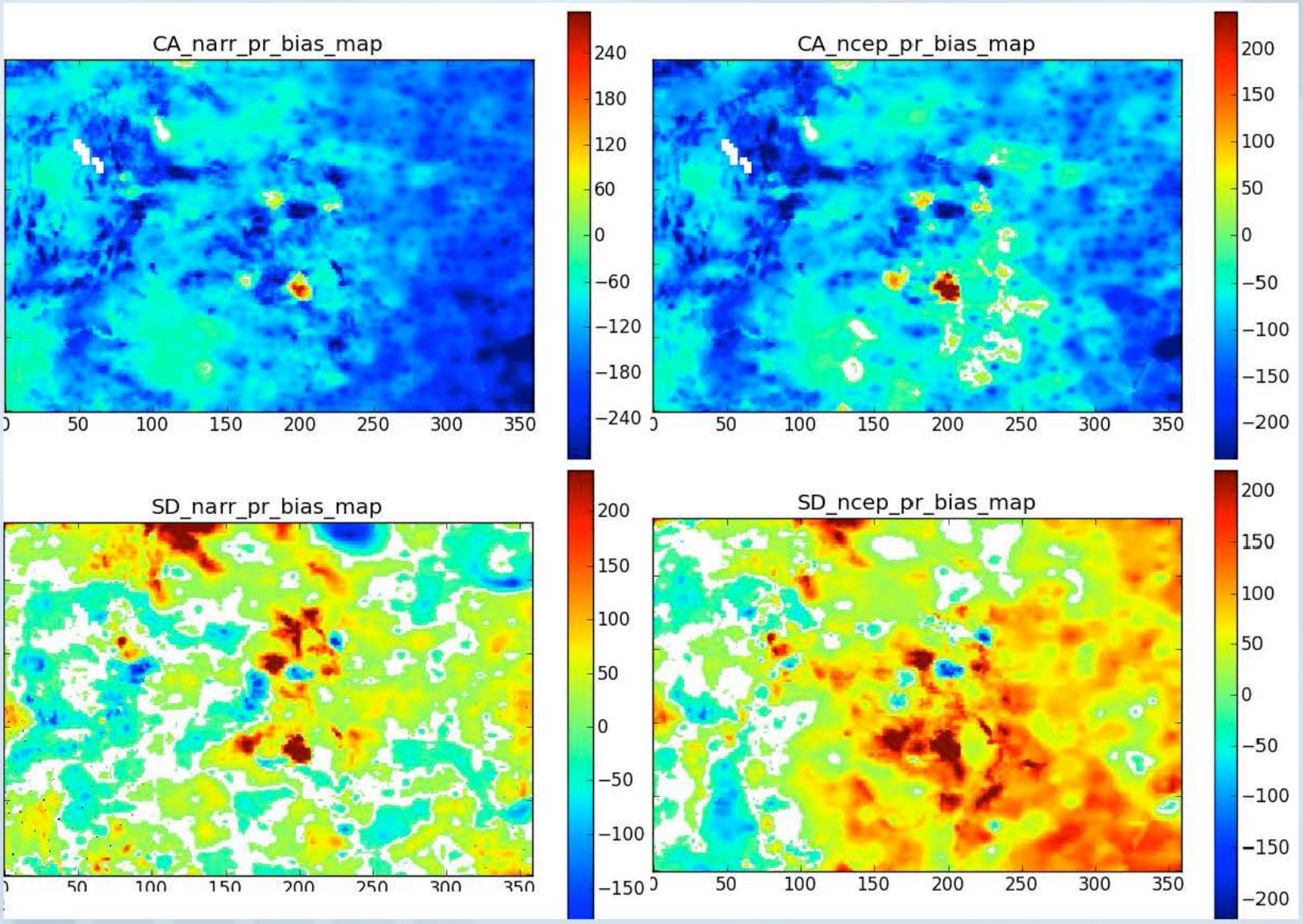
Biases in Precipitation



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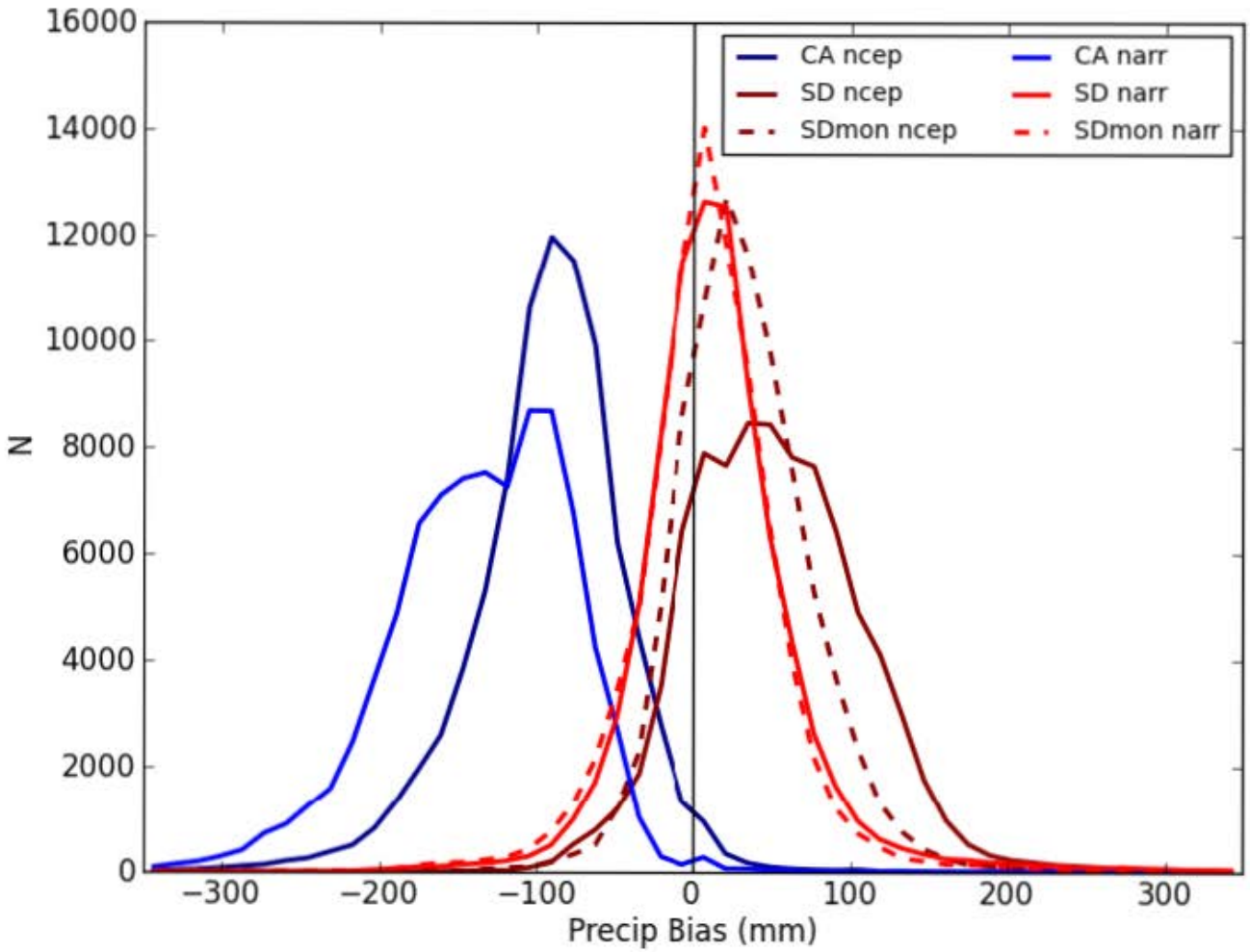
Biases in Precipitation



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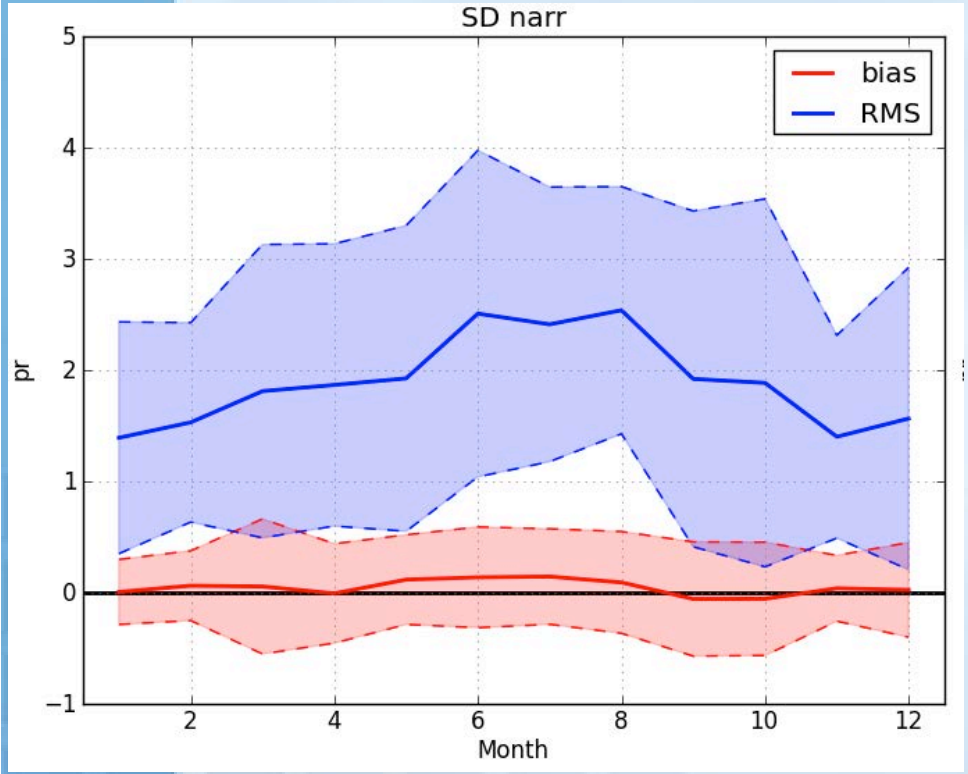
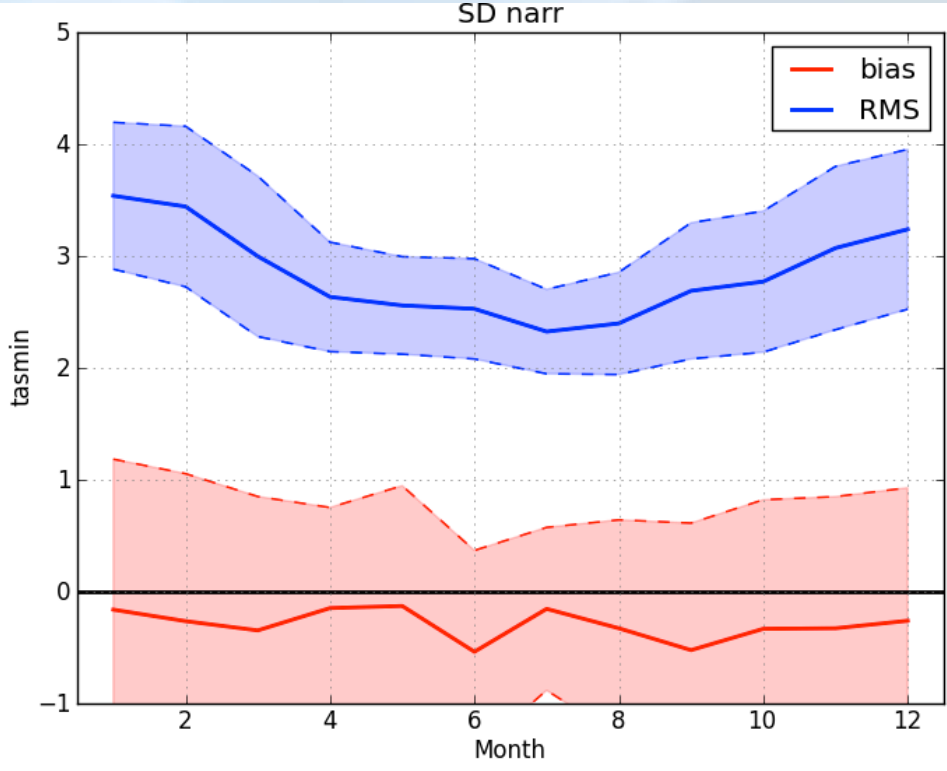
Seasonality of errors

Precipitation has larger errors in the summer

Temperature has larger errors in the winter





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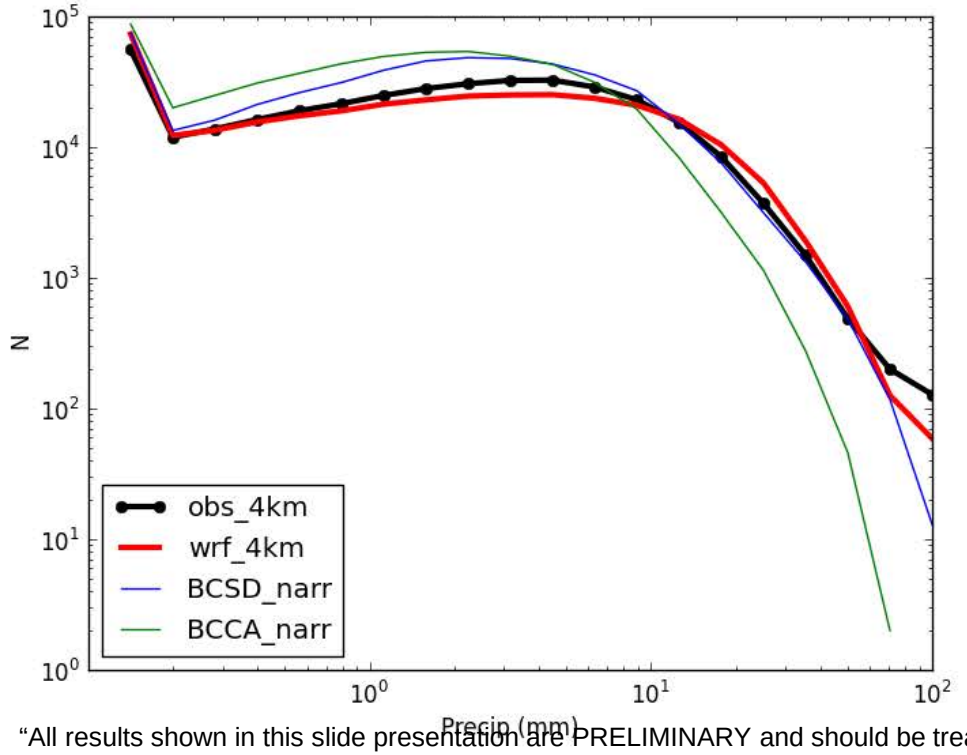
Precipitation Histograms

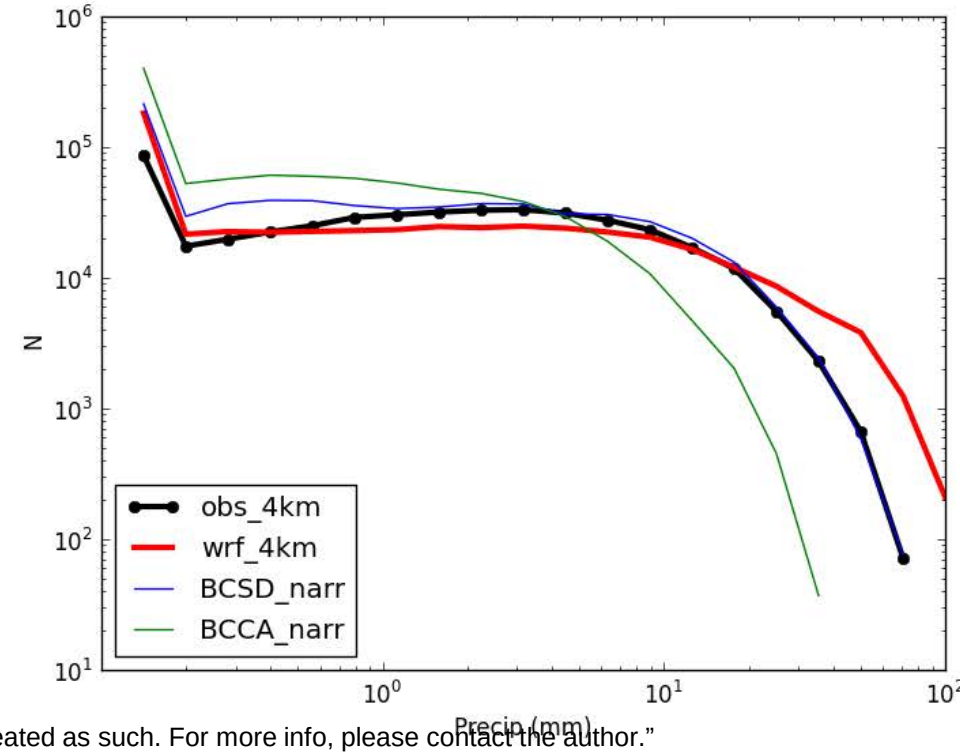
BCCA has too much drizzle especially in the plains

BCSD is better still too much light precipitation

Mountains



Plains



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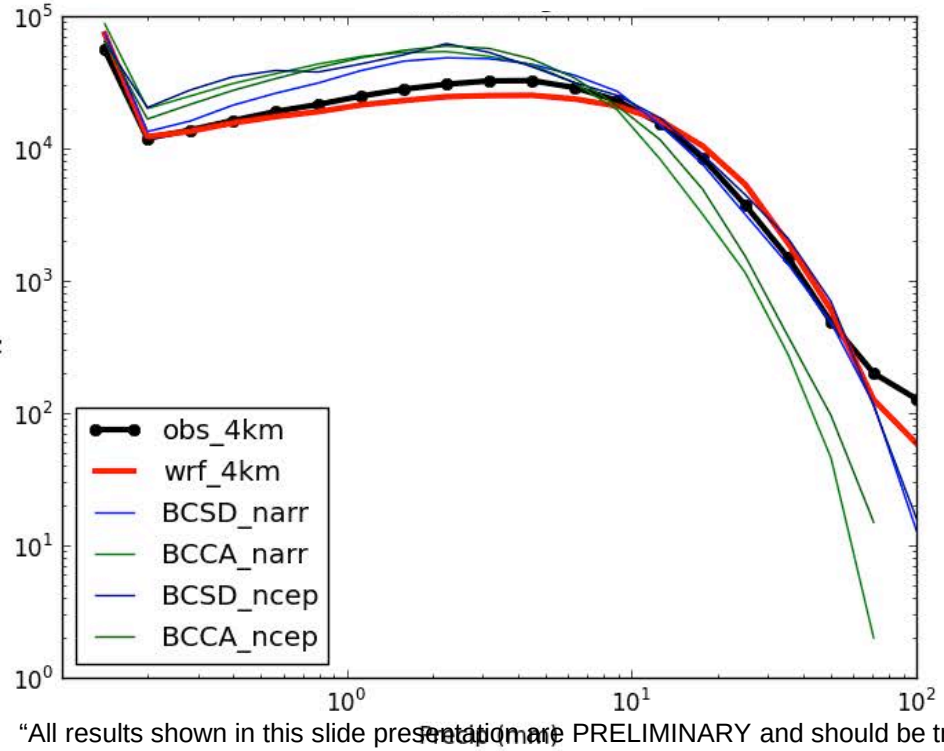
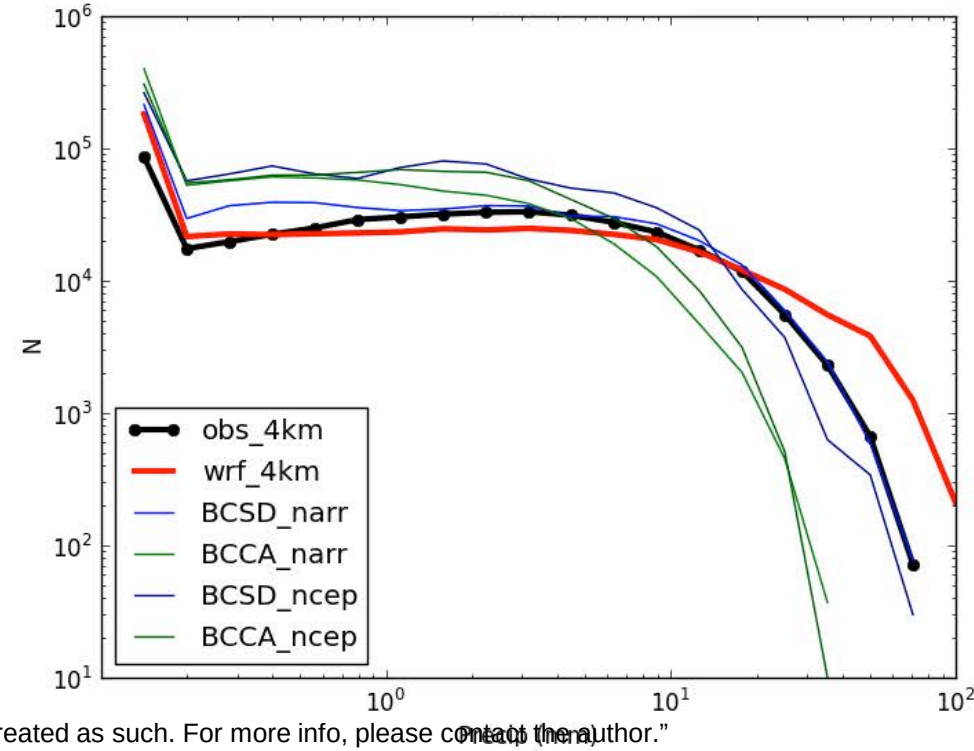
Precipitation Histograms

NCEP forcing is worse, especially over the plains (too much drizzle)

Mountains



Plains



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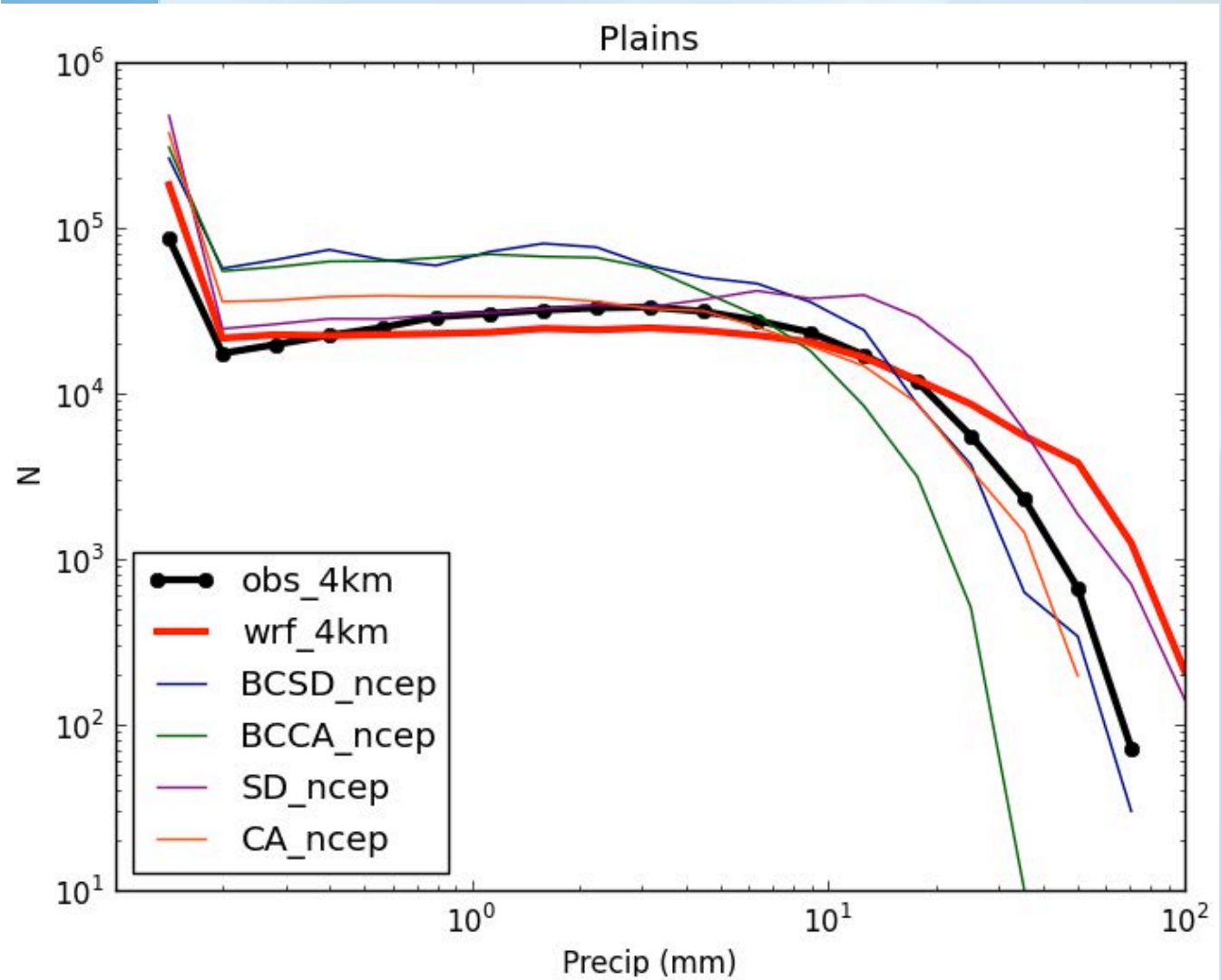
Precipitation Histograms



Bias Correction

Important for SD

Not as important for CA

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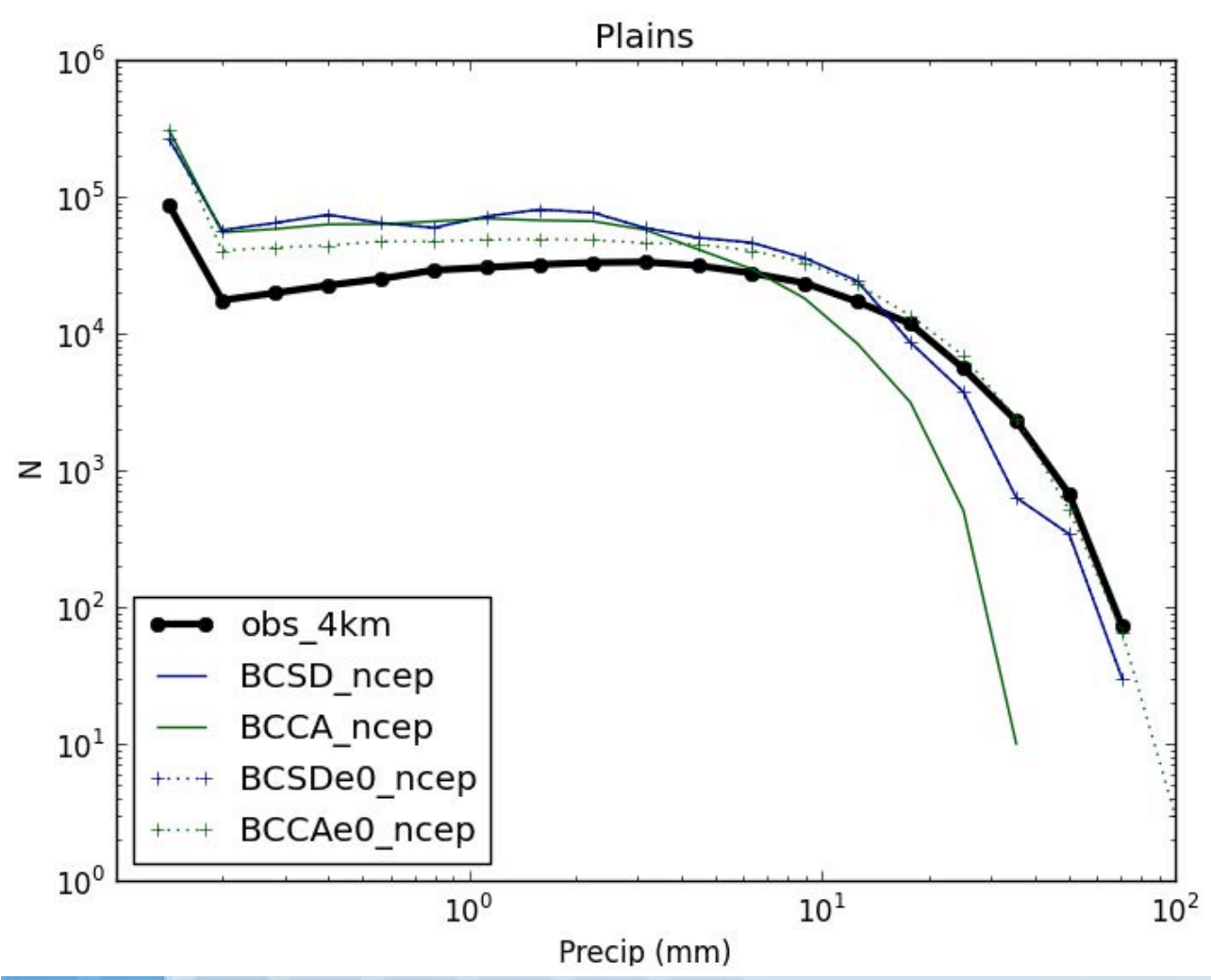
Precipitation Histograms



EXPERIMENT e0

Training region has a large impact on CA method

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Inter-annual Variability

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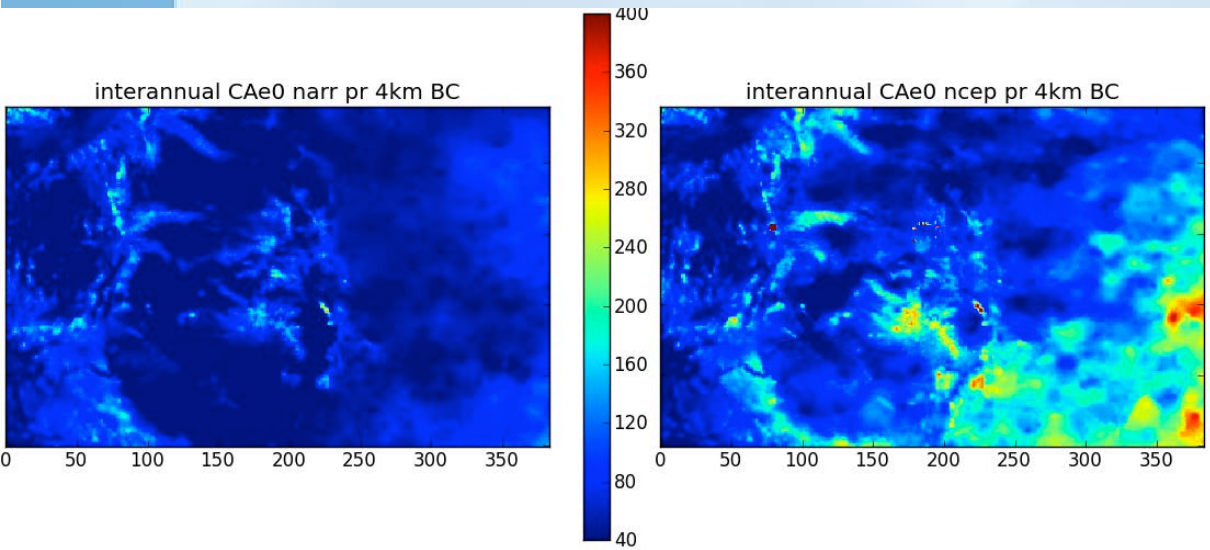
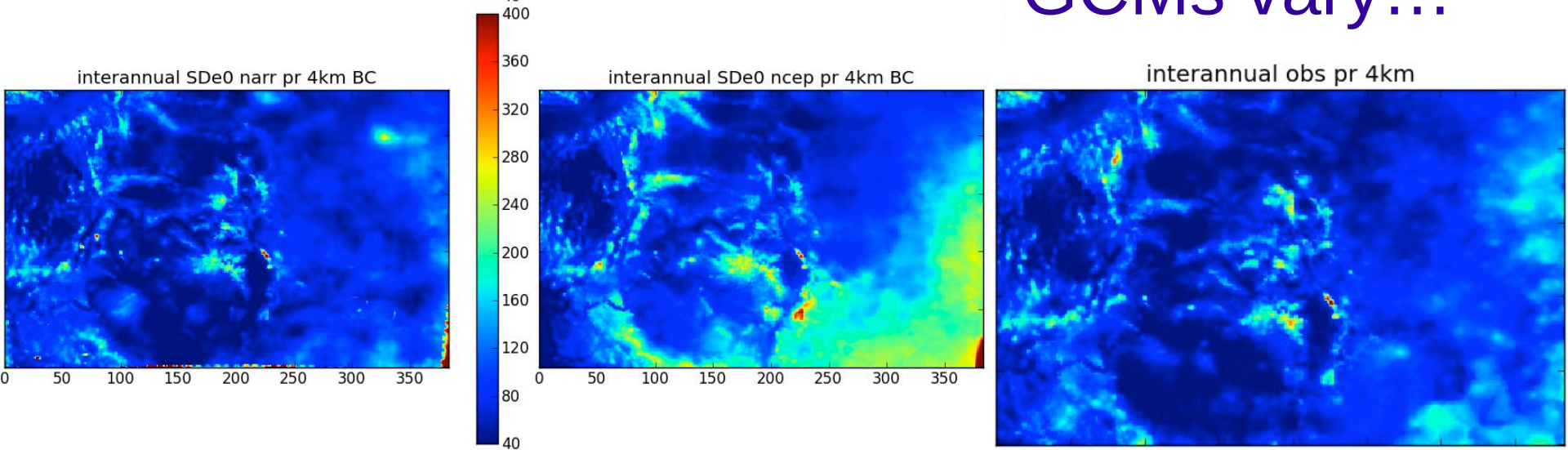


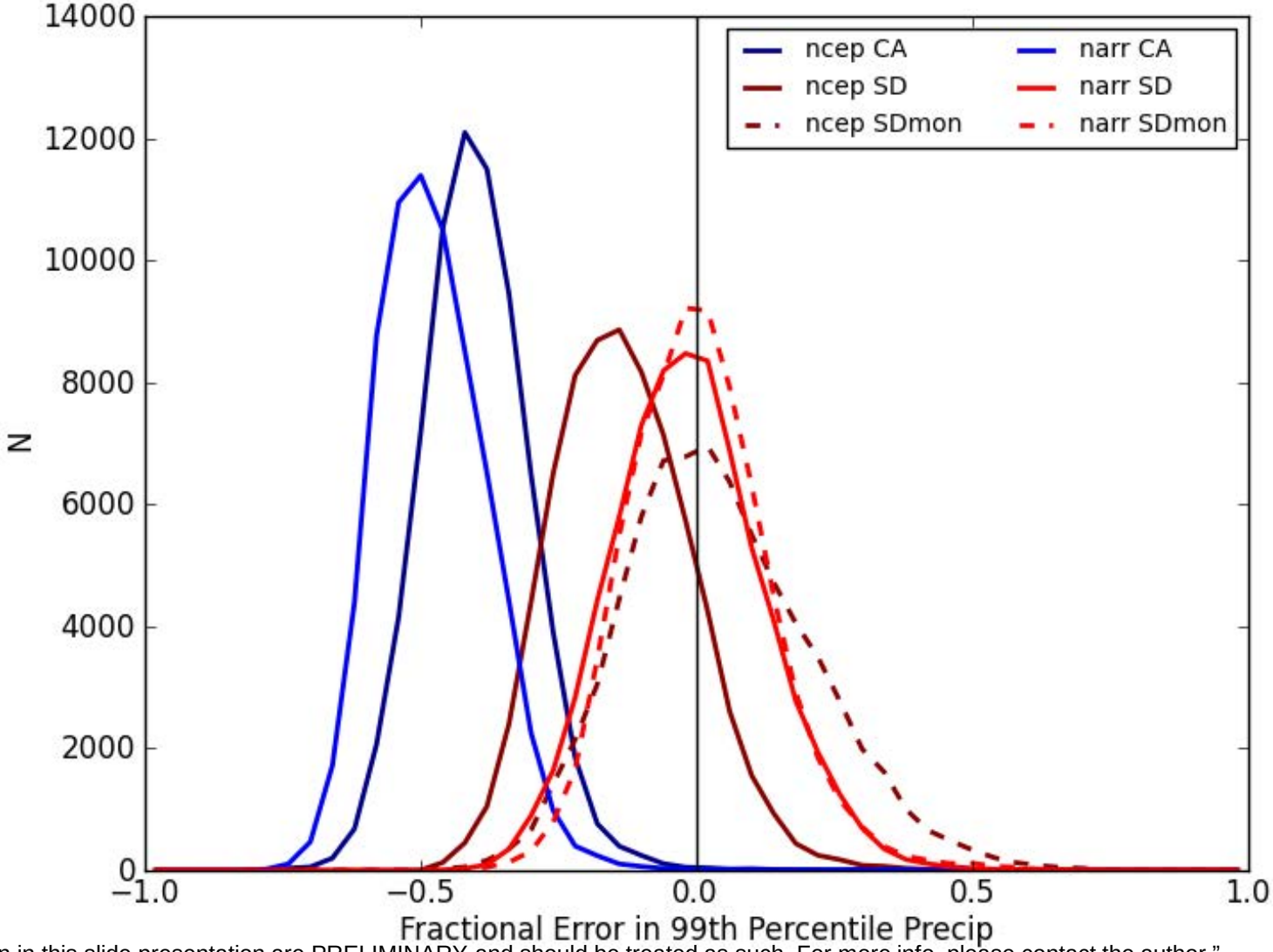


NCEP exhibits strong inter-annual variability

GCMs vary…

"Extremes" (99th percentile)

Error = (downscaled - obs) / obs



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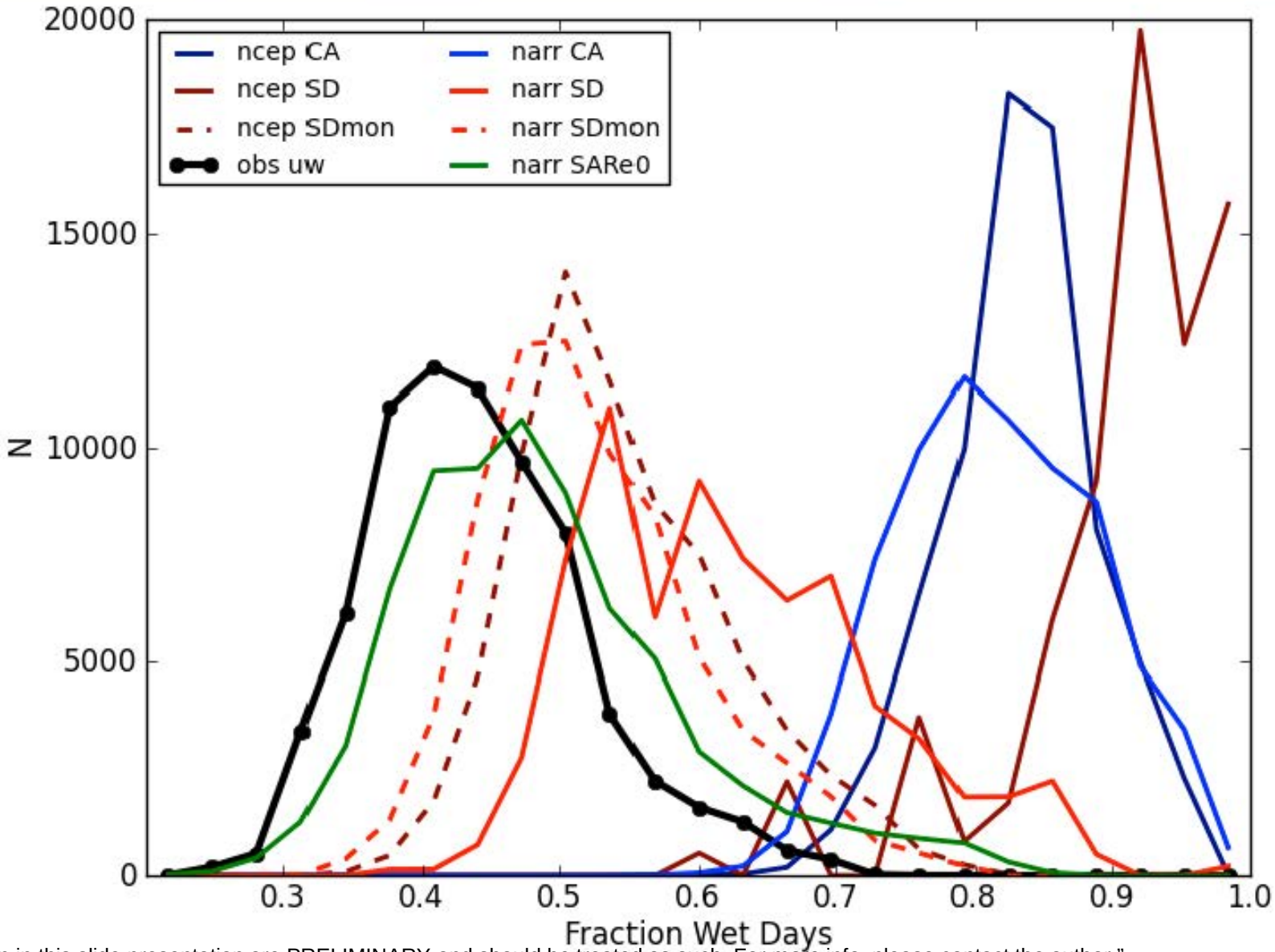
Fraction of days with precip.



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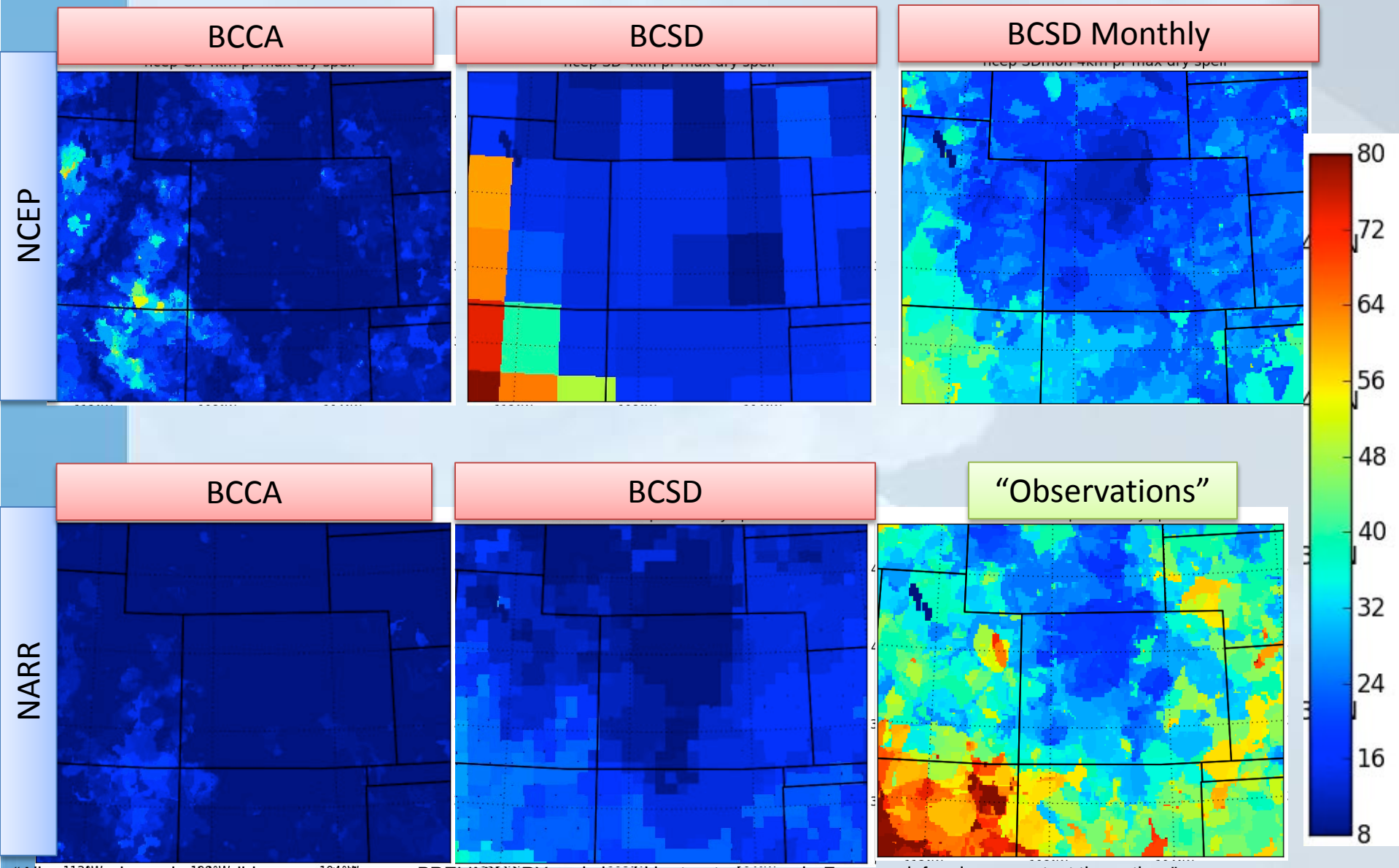
Maximum Dry Spell (n days without precip)



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Statistical Downscaling Summary

- All methods are OK at predicting means (CA biased low)
- CA methods have too much drizzel
- SD methods have reasonable statistical distributions
- SD and CA methods fail to reproduce temporal statistics (e.g. dry spell length) (SD monthly does better)
- All methods over estimate the number of wet days. (SAR and monthly do better)
- All methods have large errors in 99th percentiles, CA is biased low.
- Bias Correction more important for SD than CA methods
- 4km and 12km results are similar (differences are in the "observations" not the methods at this resolution)
- All methods inherit inter-annual variability from the parent model.
- Climate change sensitivity experiments suggest that all methods are relatively insensitive to climate change

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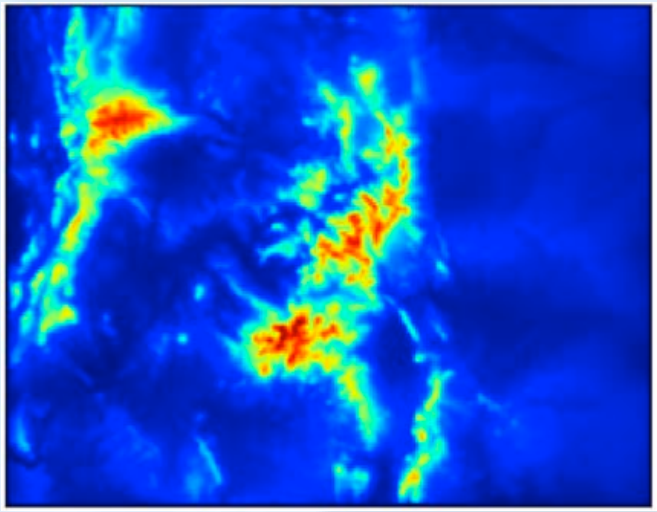
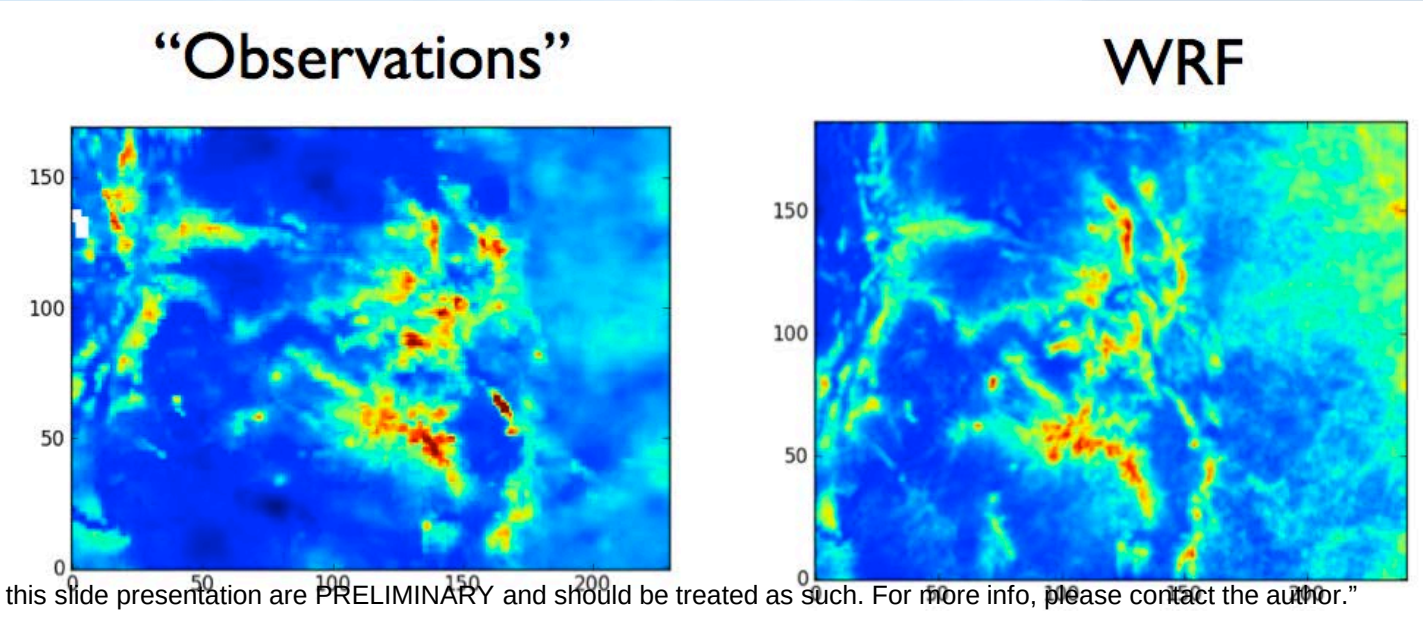
Hybrid statistical-dynamical approach

- Early results promising for precipitation totals, temporal patterns, and statistics even without statistical post-processing





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Future downscaling work

- Further examination of downscaling products (e.g. covariance of variables?)
- Possible improvements to (e.g.) inter-annual variation in statistical methods
- Refine hybrid pseudo-dynamical model

- Evaluating the impact on hydrology models…

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Outline

- **WRF simulations at multiple spatial scales, with impacts on the water balance (Roy)**
- **Inter-comparison of statistical and dynamical downscaling methods (Ethan)**
- **Sensitivity of portrayal of climate change impacts on hydrology to methodological choices (Martyn)**
  - Forcing data
  - Model parameters/structure
- **Summary / next steps**

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Hydrologic sensitivity to climate variability/change

How does choice of forcing dataset affect climate sensitivity?

Background: *Methodological choices (e.g. model and forcing) impact climate change impact assessments*.
Objective: *Examine how choice of forcing datasets affect hydrologic sensitivity to climate variability?*

Forcing Data:

- VIC Forcing (University of Washington: 1/8th degree)
  - computes SW, LW, humidity with empirical equation using precipitation and temperature
- NLDAS (NCEP: 1/8th degree)
  - Derived based on NARR data (SW-bias correction with GOES radiation product, Temperature and Humidity- correction based on elevation)

Model:

Community Land Model 4.0

Naoki Mizukami

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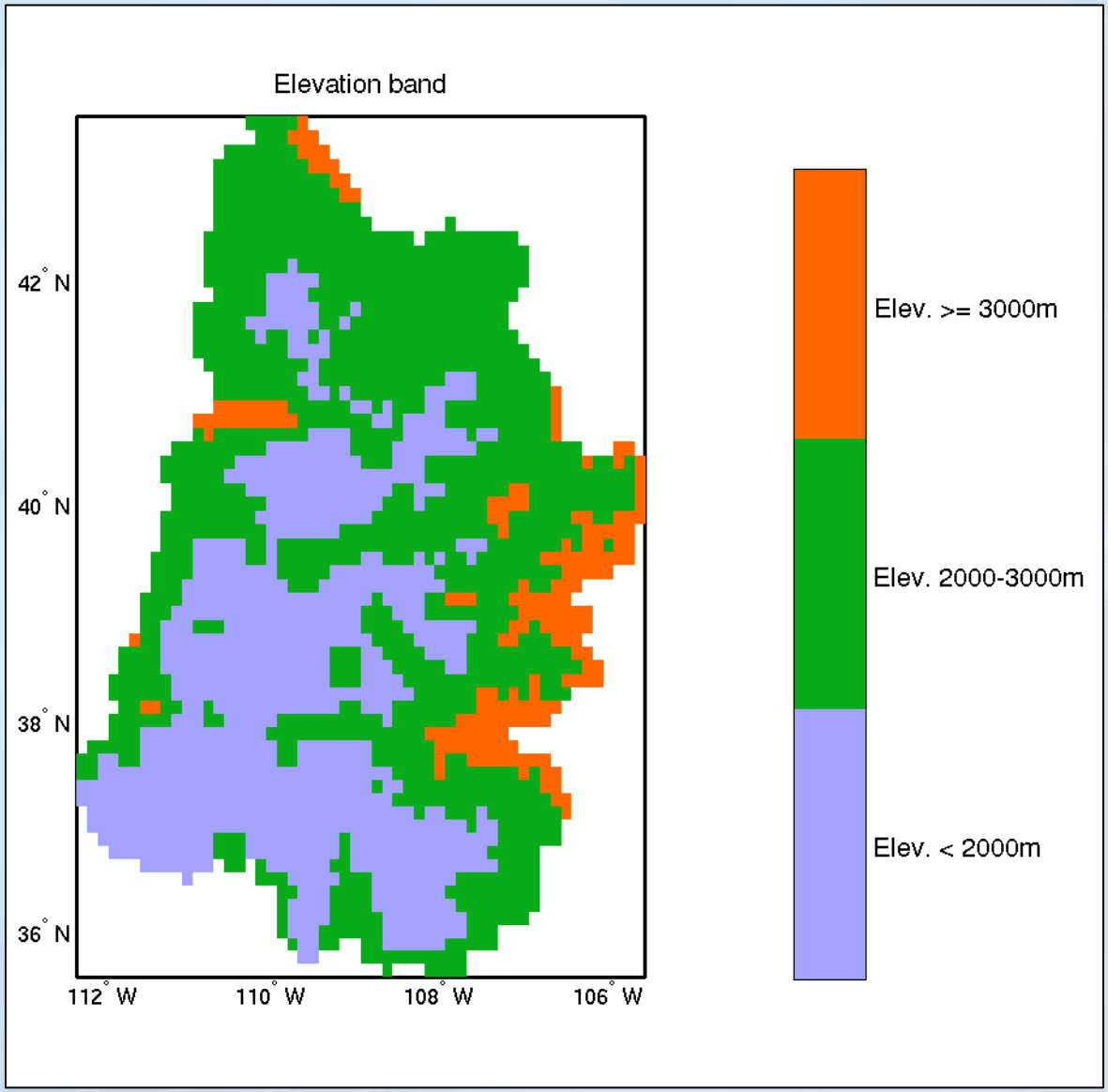
Analysis over the Colorado River basin, for elevation bands



Number of grid boxes (3520)

Low elevation band - 1398

Mid elevation band - 1878

High elevation band - 244

Fig. Naoki Mizukami

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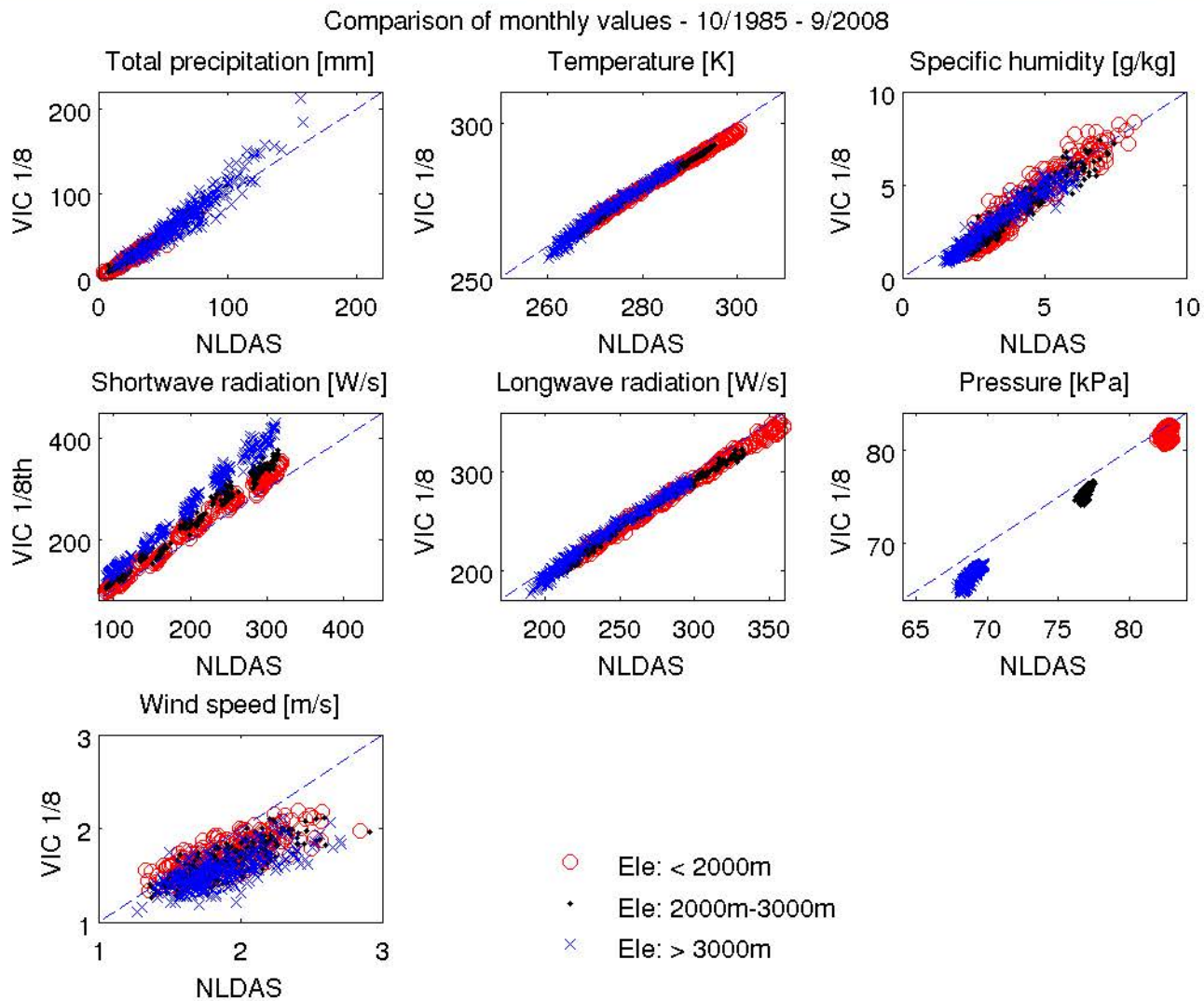
Forcing comparison NLDAS vs. VIC

Elevation band average over upper Colorado River Basin



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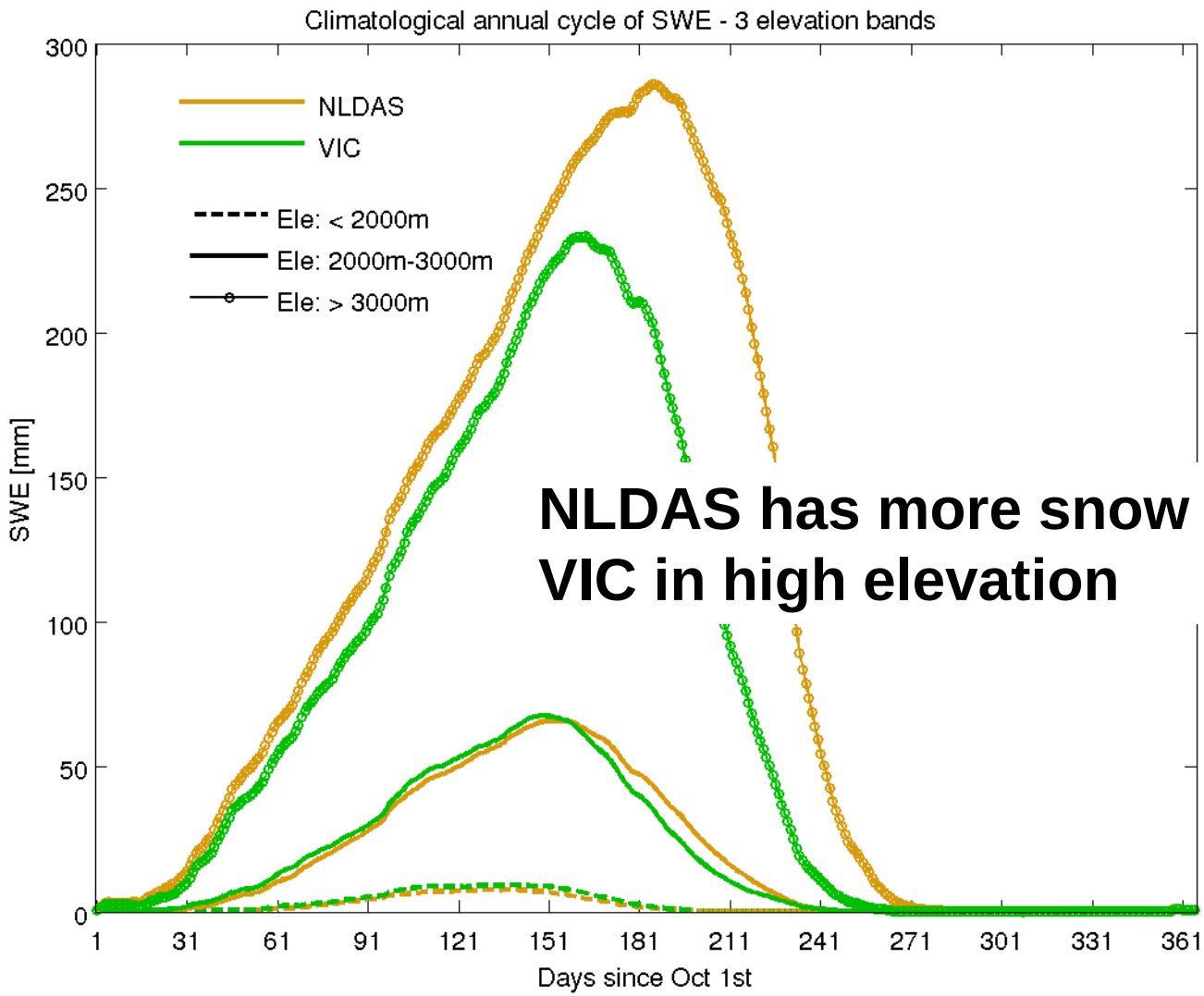
Climatological annual cycle- SWE



NLDAS has more snow than VIC in high elevation

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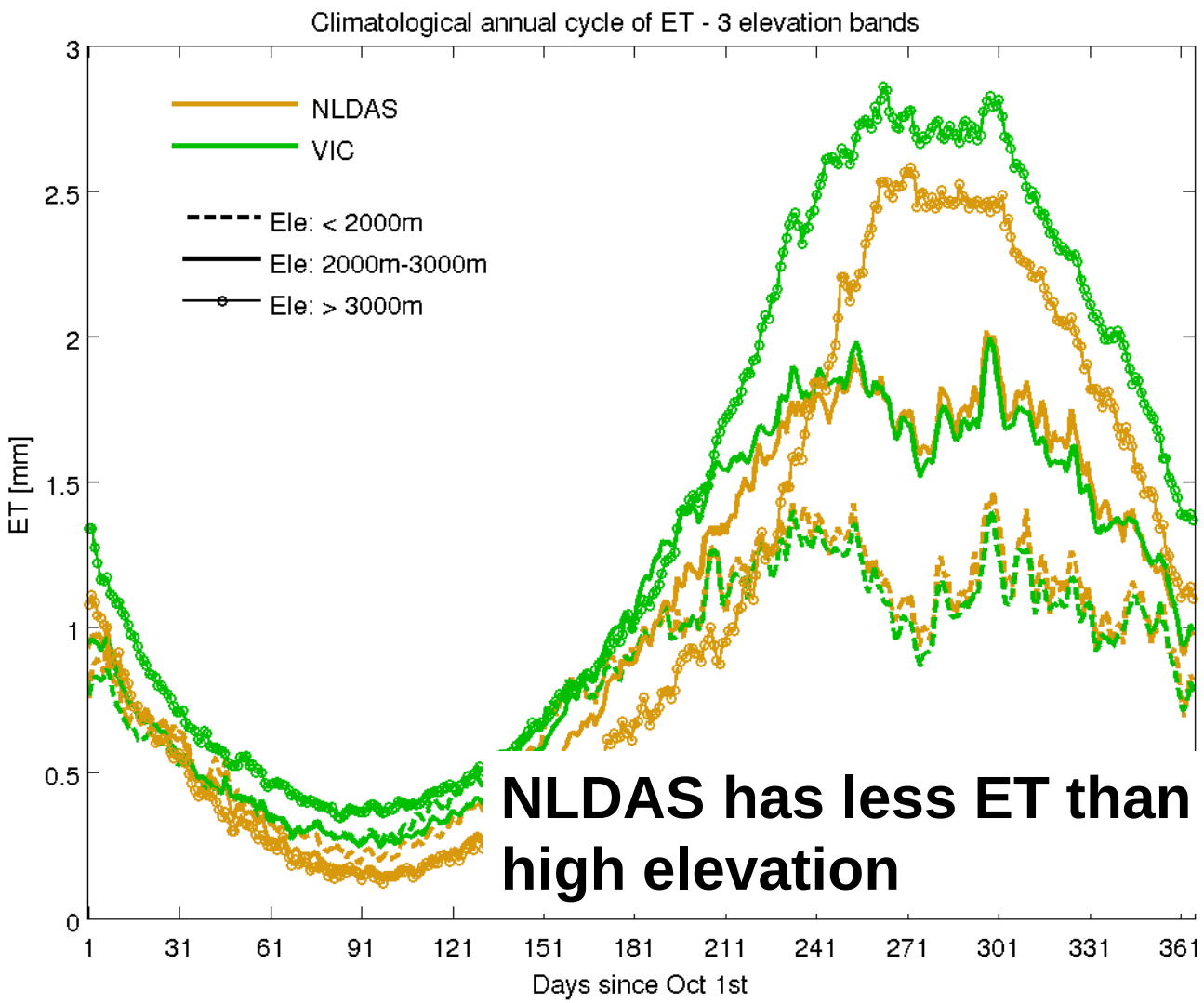
Climatological annual cycle- ET



NLDAS has less ET than VIC in high elevation

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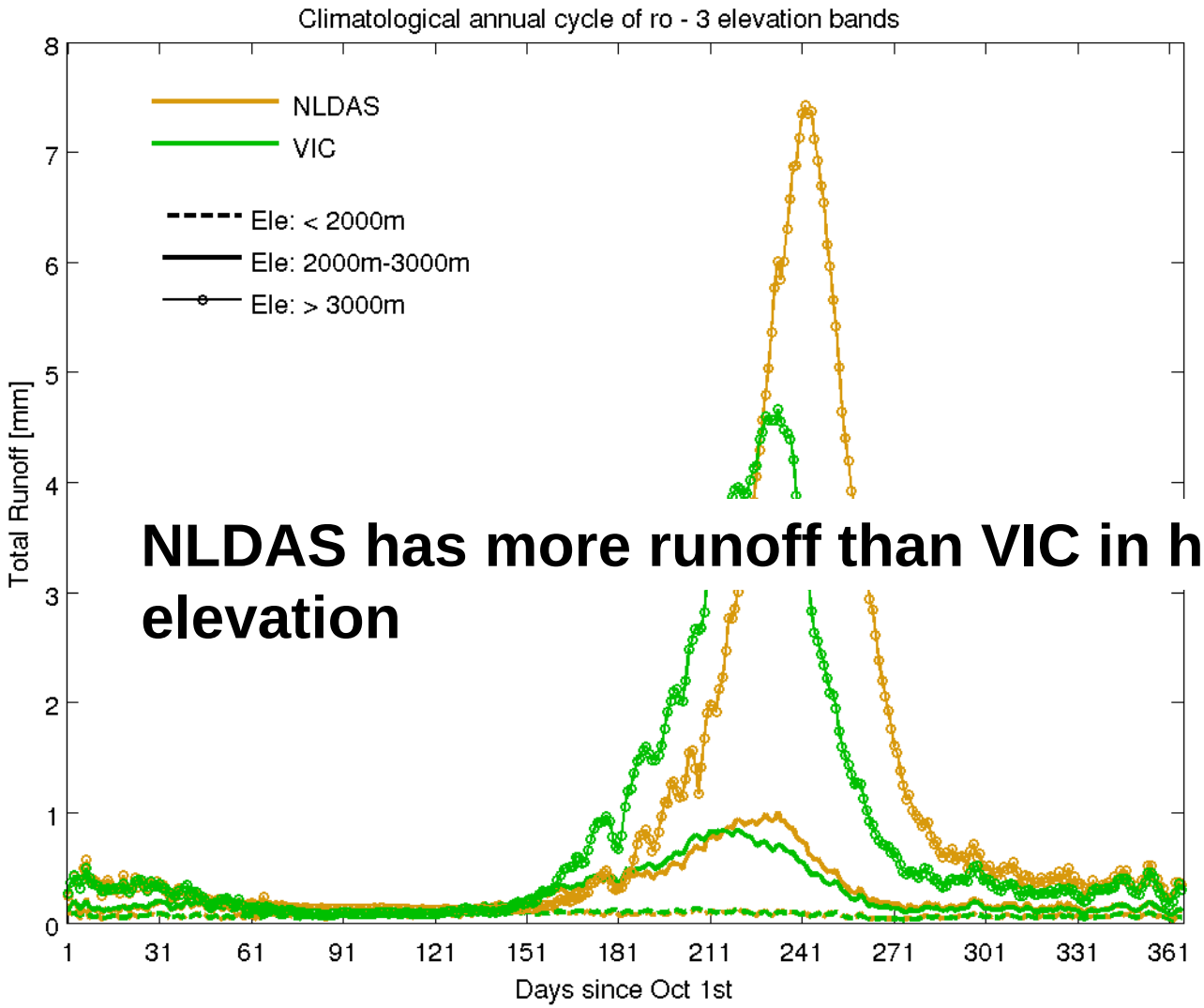
Climatological annual cycle- Runoff



NLDAS has more runoff than VIC in high elevation

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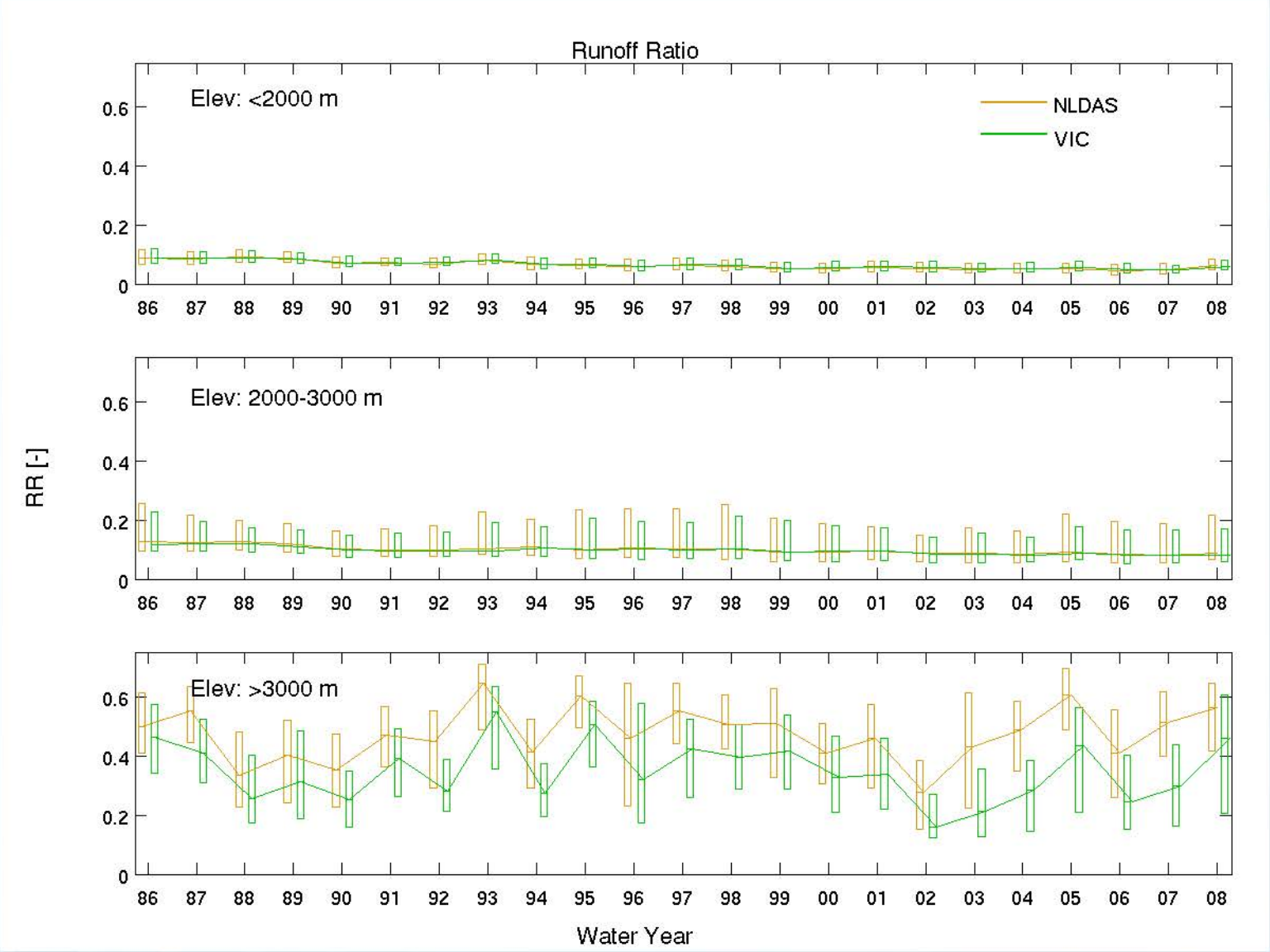
Time series of runoff ratio



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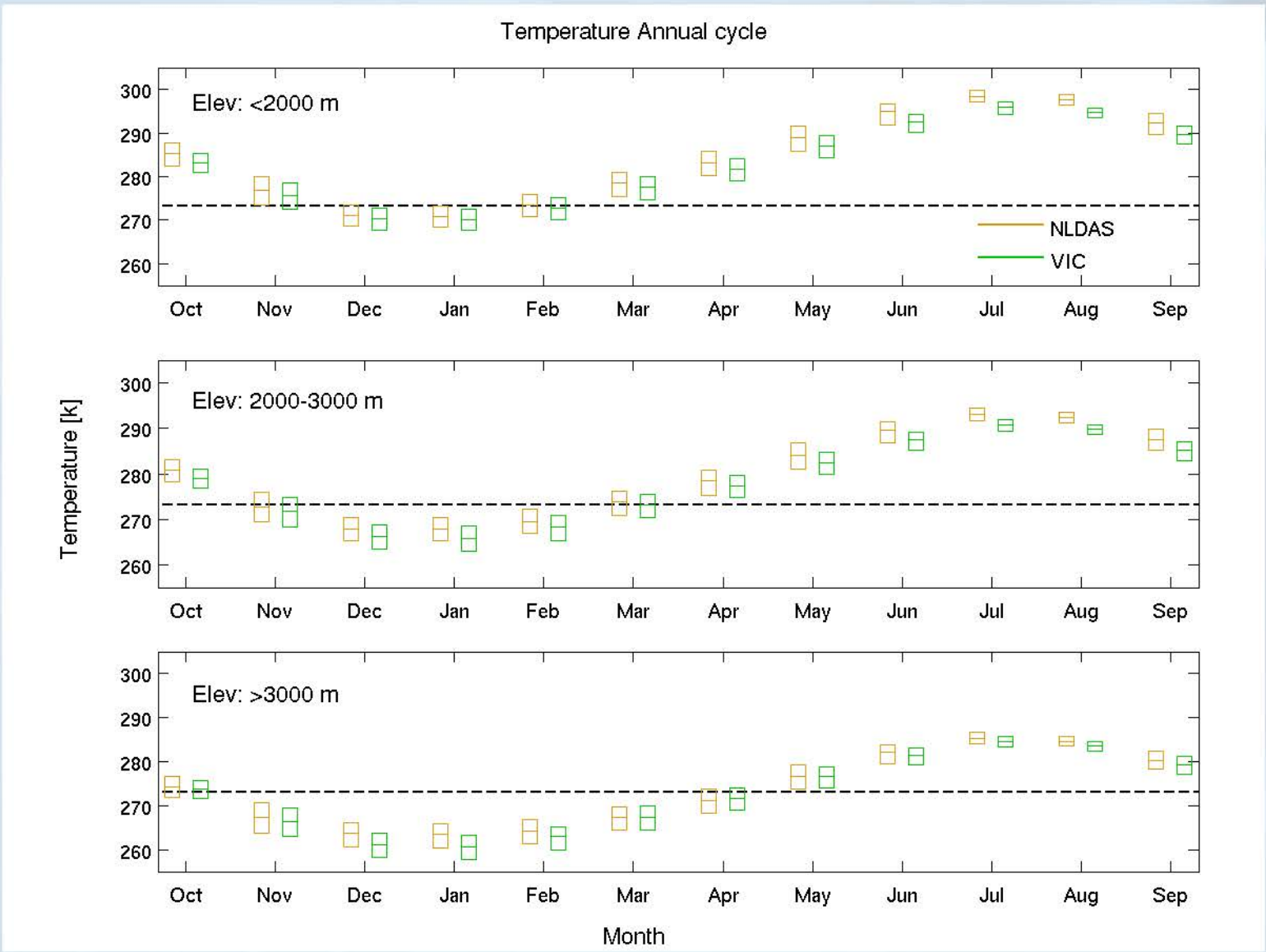
Temperature – Climatological annual cycle



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Daily maximum temperature – Climatological annual cycle

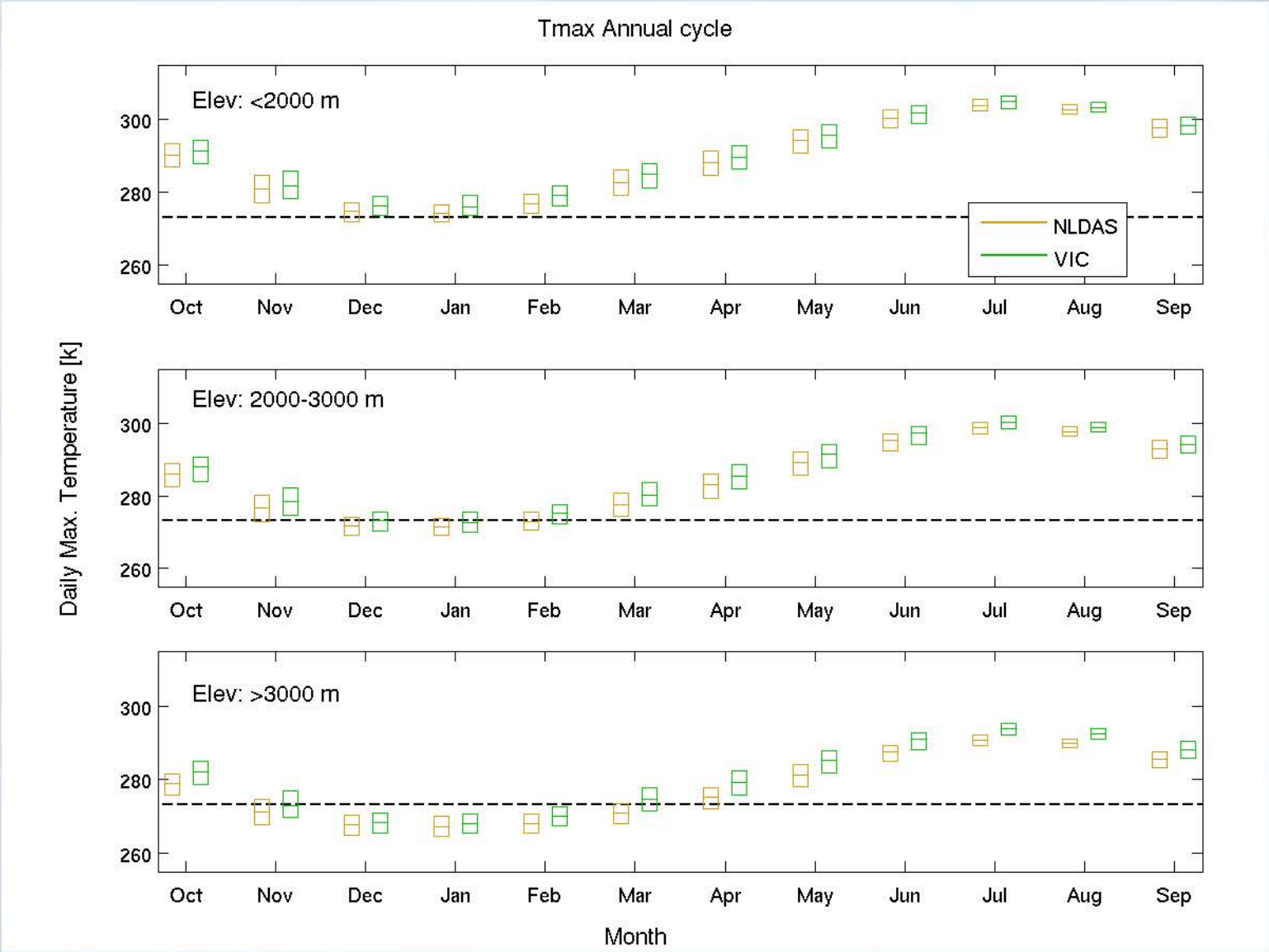

Fig. Naoki Mizukami

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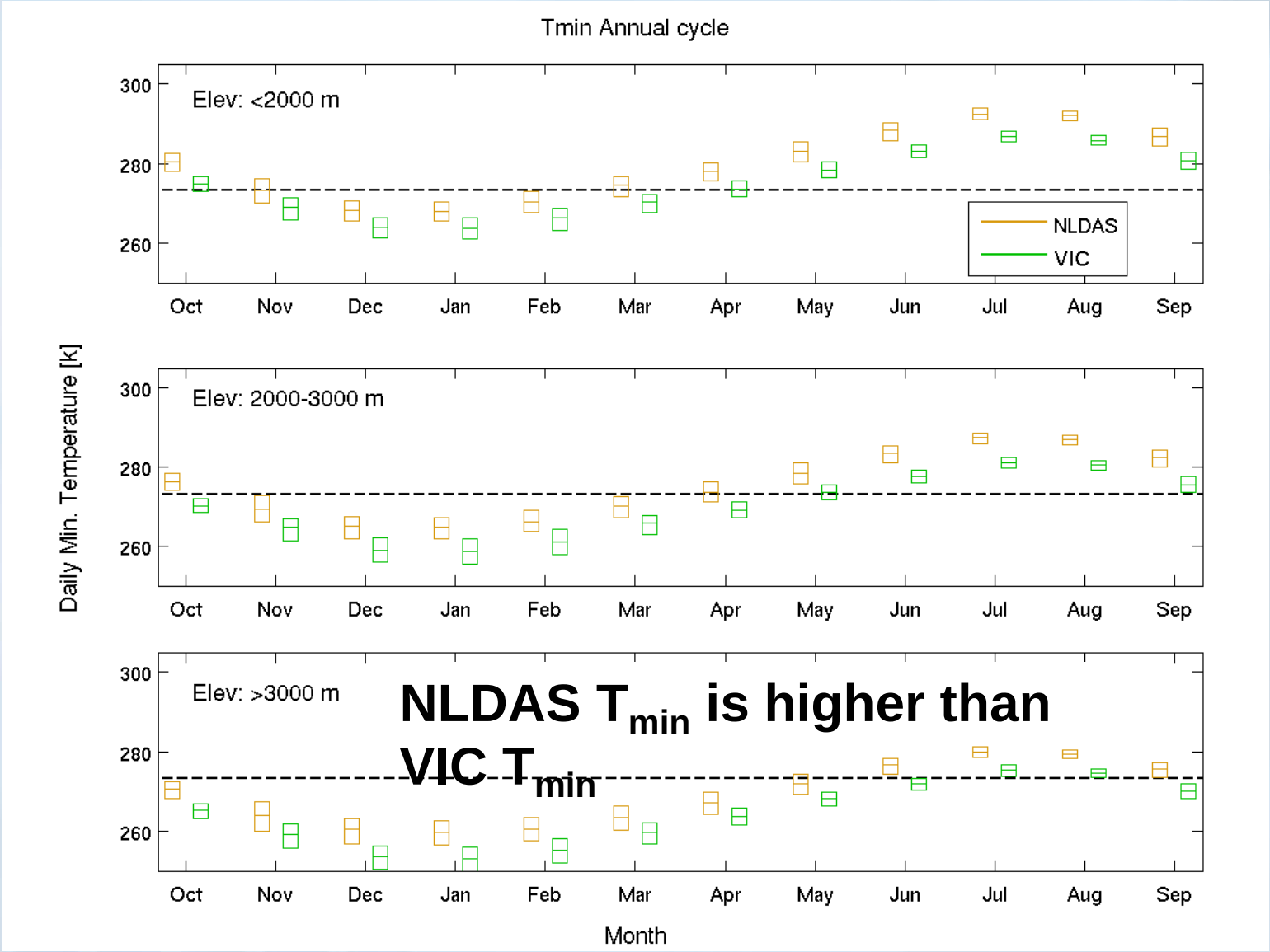
Daily minimum temperature – Climatological annual cycle



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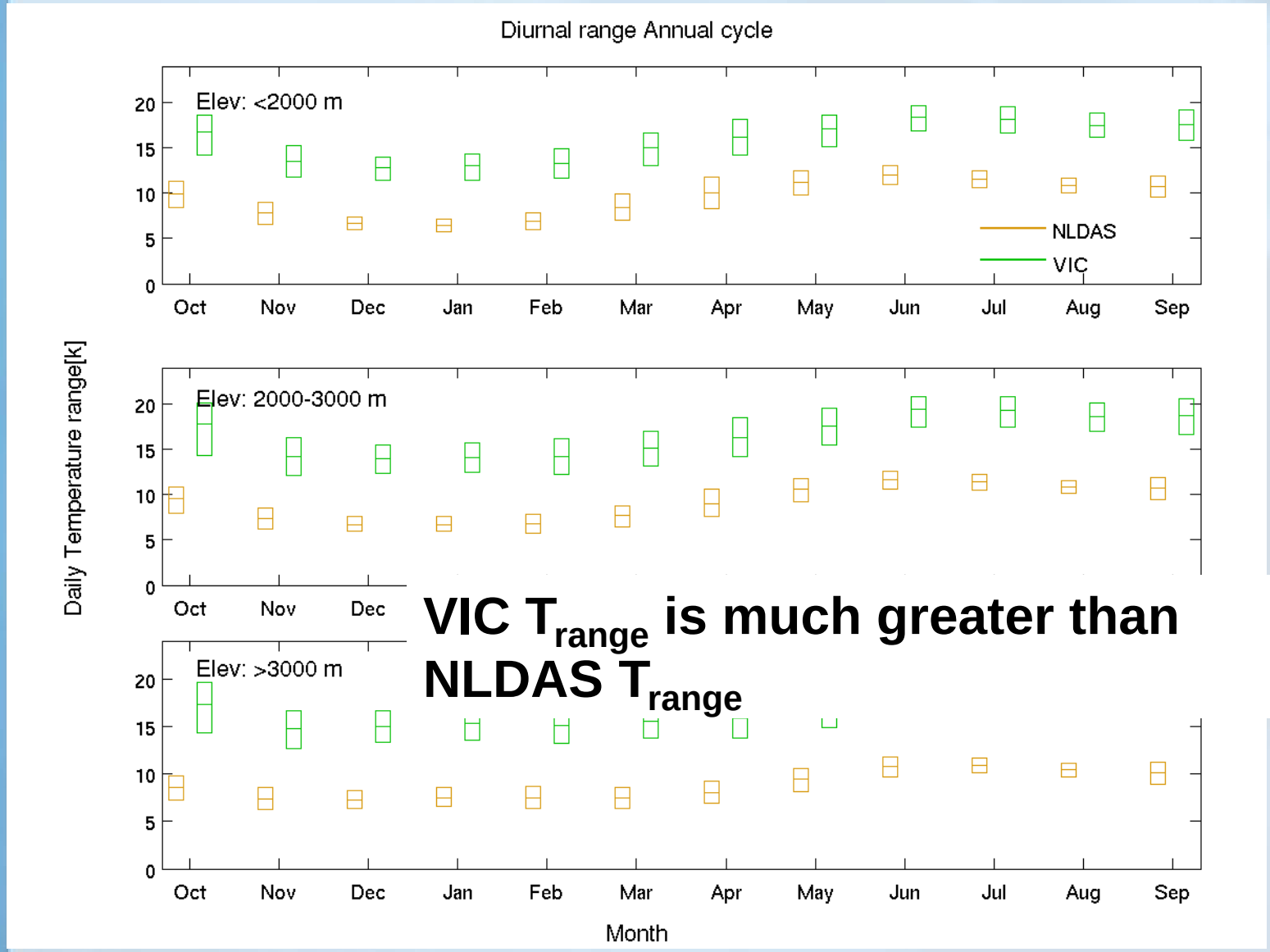
Diurnal temperature range – Climatological annual cycle



VIC T_{range} is much greater than NLDAS T_{range}

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Wet days – Climatological annual cycle

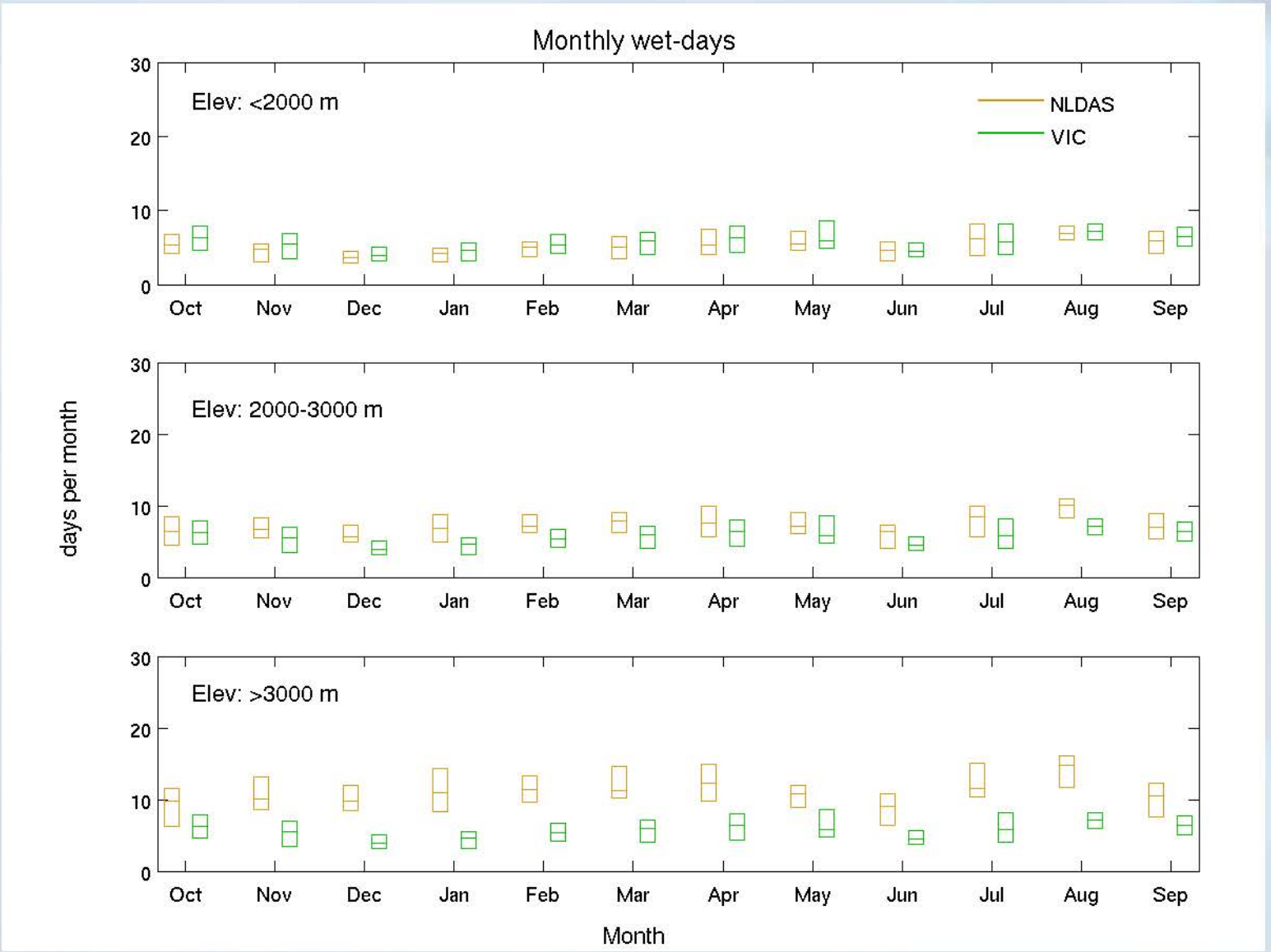

Fig. Naoki Mizukami

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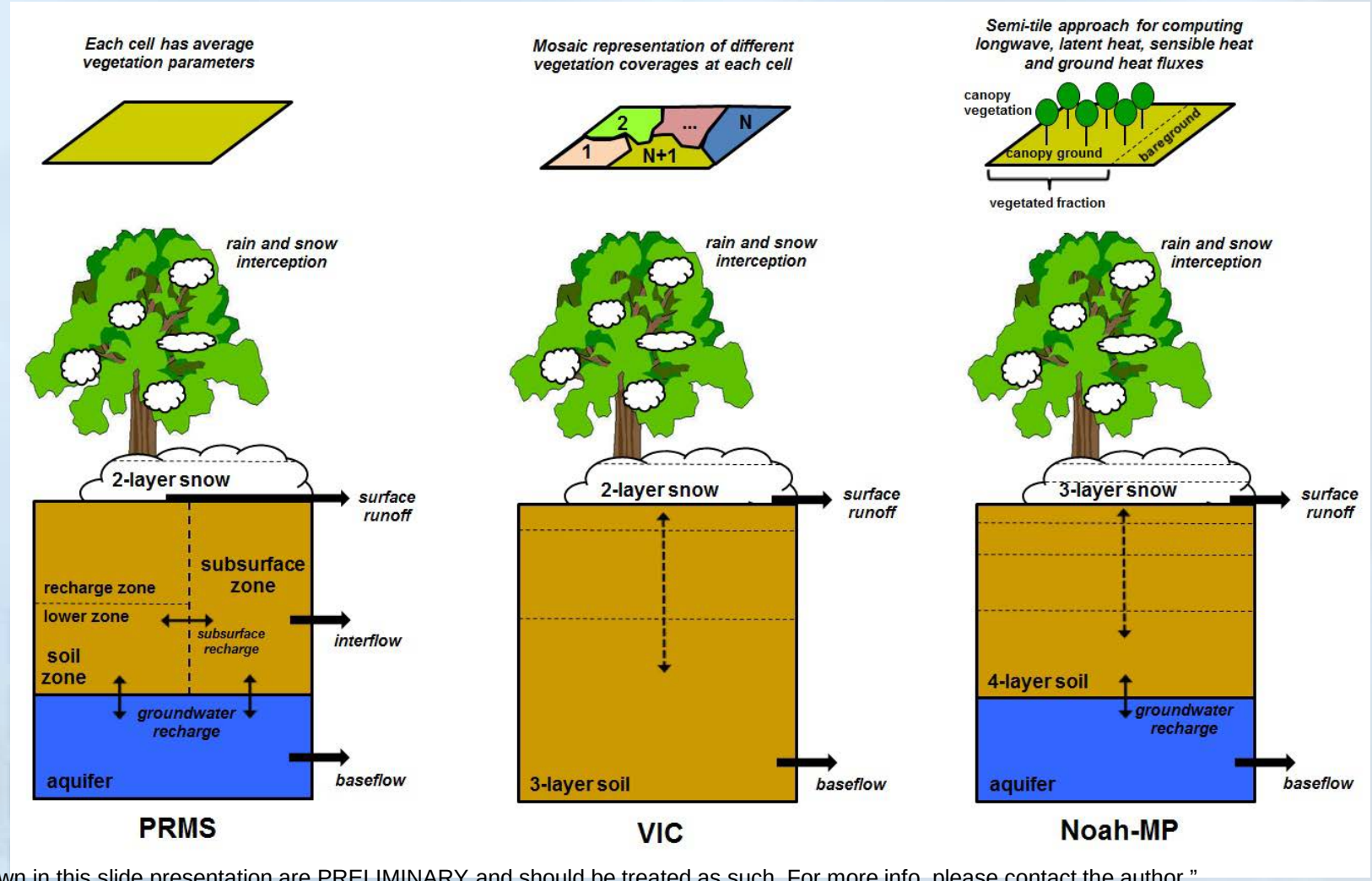
Hydrologic sensitivity to climate variability/change

Pablo Mendoza

How does choice of model structure and parameters affect climate sensitivity?



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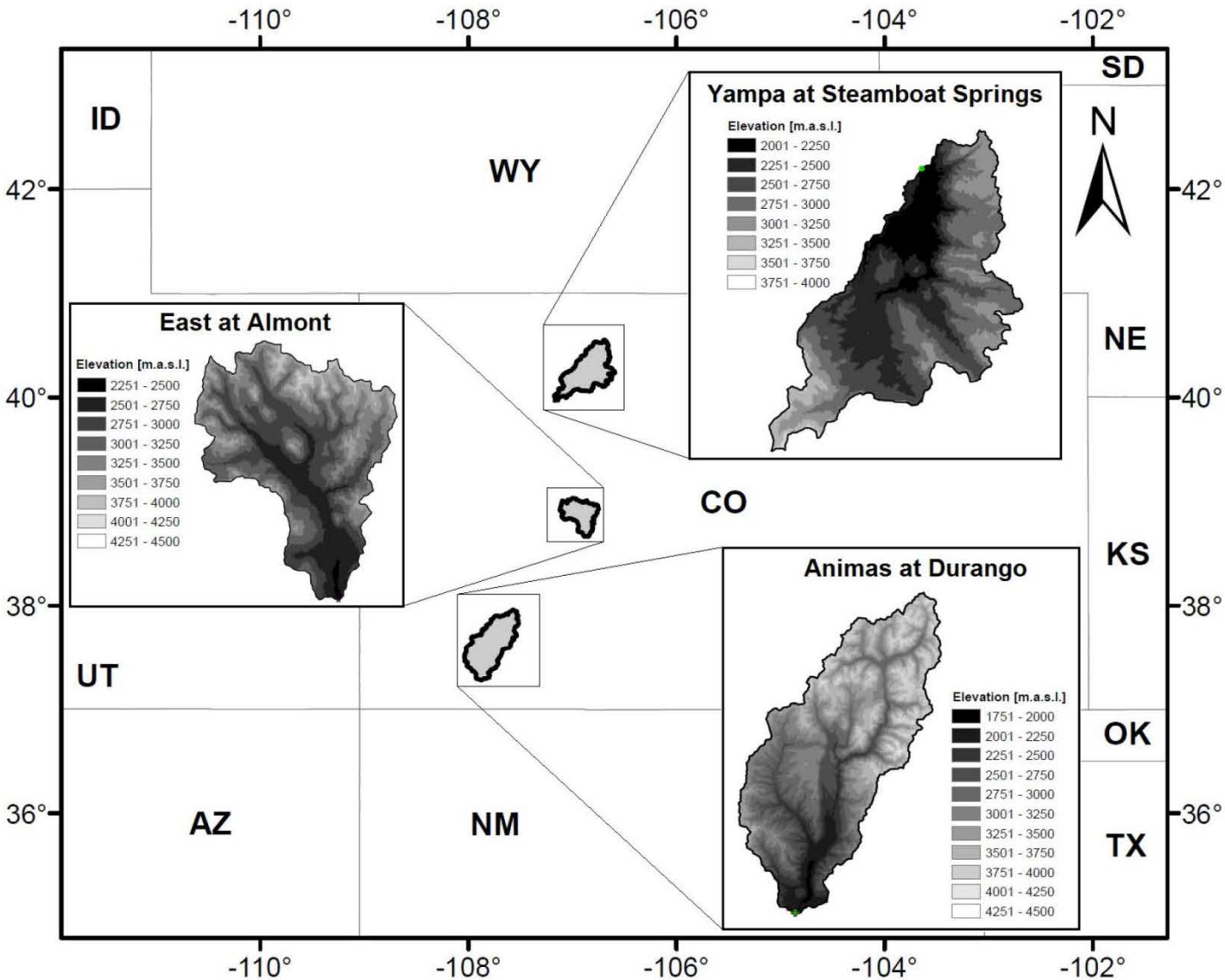
Basins of interest for the study



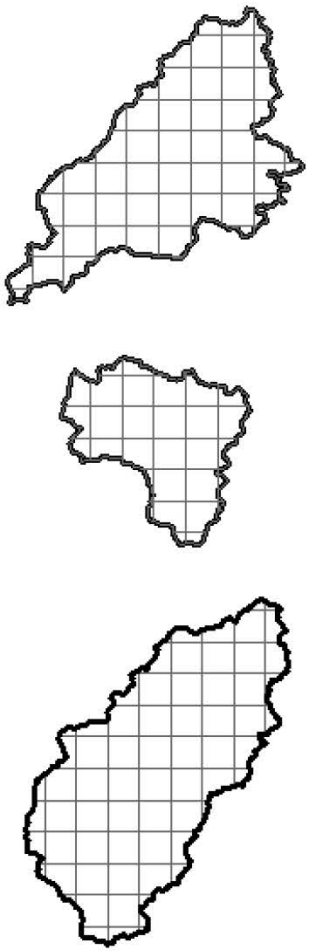


Fig. Pablo Mendoza

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Evaluation of model structures

Fig. Pablo Mendoza

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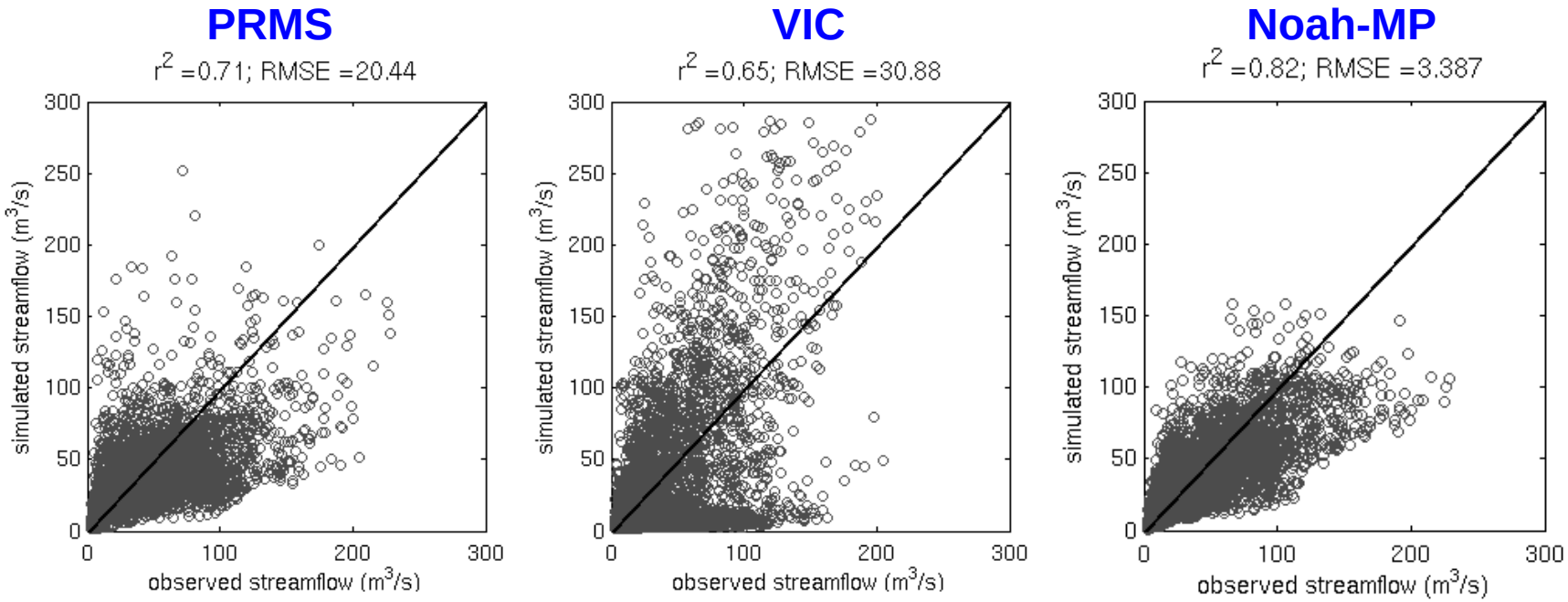
- Simulation period: Oct/1980 – Sep/2008.
- Time step: 24 hours for PRMS and VIC, 1 hr for Noah-MP
- Forcing dataset: **N**orth American **L**and **D**ata **A**ssimilation **S**ystem (NLDAS).
- Forcing interpolation: nearest neighbor.
- Additional info: DEM (100 m resolution), Soils (STATSGO), and land cover
- Spatial resolution: 1/16º for all models (**69 grid cells**)

Simulated vs. observed daily streamflow (Animas at Durango)



Model time step: 24 h

Model Time step: 24 h (water balance mode)

Model time step: 1 h

Evaluation of model structures

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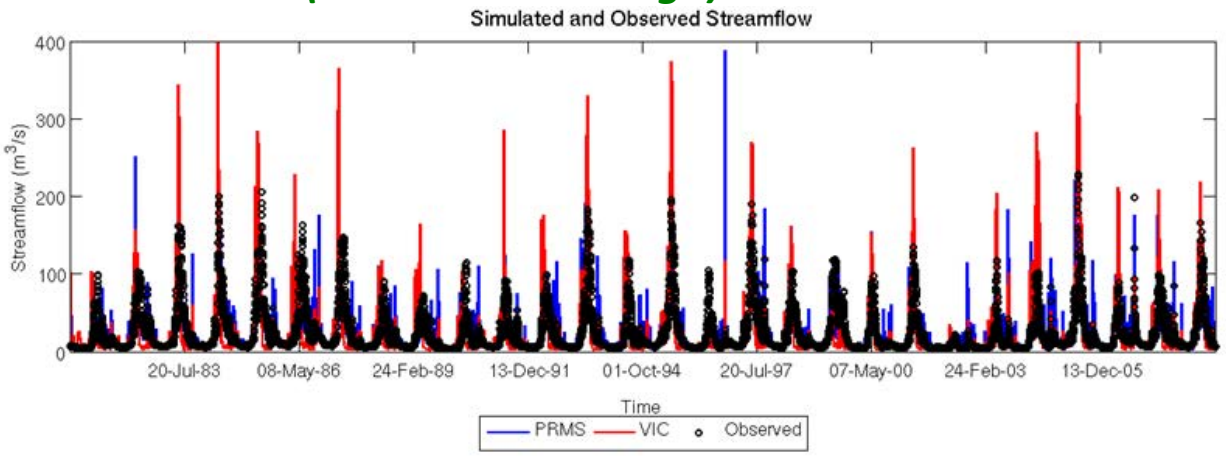
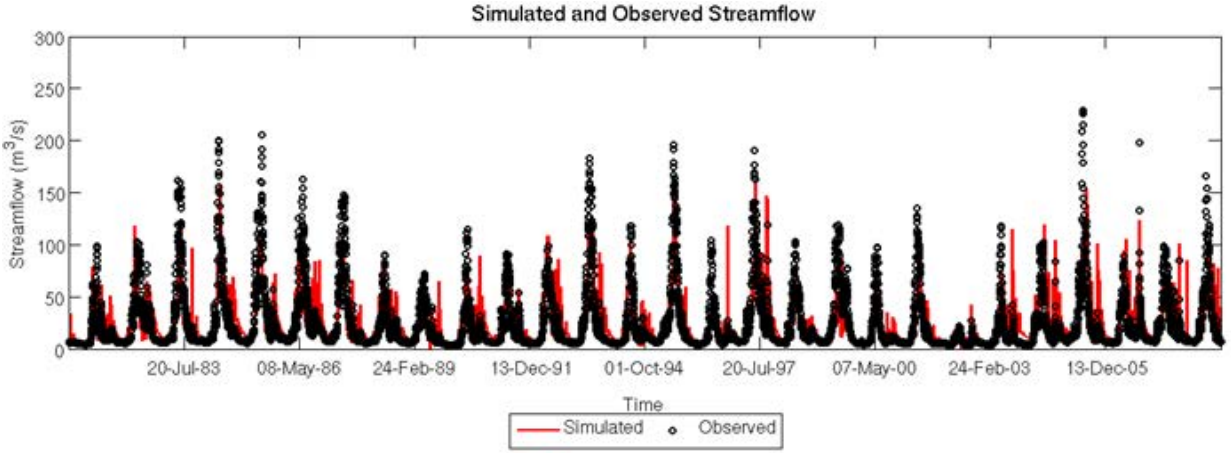
PRMS and VIC (Animas at Durango)…



…and Noah-MP (Animas at Durango)



- Preliminary results at Animas show the potential of uncalibrated LSMs with a very detailed process representation as NoahMP.
- Overall water balance and base flow better represented by Noah-MP, followed by PRMS.

Current and **future** tasks:

- **Switching forcing** data to WRF (Oct/2000 – Sep/2008).
- **Expanding** to East and Yampa River Basins.
- **Climate change analysis** using perturbed climate for the same period 2000-2008.
- **Parameter perturbation** analysis… are **parameters** more important than differences in **model structures**?

Fig. Pablo Mendoza

Outline

- **WRF simulations at multiple spatial scales, with impacts on the water balance (Roy)**
- **Inter-comparison of statistical and dynamical downscaling methods (Ethan)**
- **Sensitivity of portrayal of climate change impacts on hydrology to methodological choices (Martyn)**
  - Forcing data
  - Model parameters/structure
- **Summary / next steps**

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Summary of progress

- **WRF simulations**
  - 4-km, 12-km and 36-km completed (both current and PGW)
  - Compensatory seasonal effects, with overall reduction in runoff
  - Hydrologic impacts depend on horizontal resolution of the WRF model
- **Statistical downscaling**
  - Demonstrated varying skill of different statistical downscaling methods, especially for quantities such as wet days and extremes
  - New hybrid downscaling method developed
- **Hydrologic modeling**
  - Interesting sensitivities to choice of forcing dataset
  - Analysis of model structural issues underway

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